Innovative Concepts to Meet Irrigation Demands

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The City of Naples has an above average irrigation demand. In fact, the City's reclaimed water system is incapable of meeting the irrigation demands without supplemental flow. Pres-ently, the City uses all of its reclaimed water to meet irrigation demands with the deficit supplied with potable water. This is a concern to both the City and the South Florida Water Management District (District) since potable per capita usage is higher than desired. Average reclaimed water production over a 10-year period was 6.72 million gallons per day (mgd) which is about 4 mgd short of the irrigation demands.

To address this challenge, the City of Naples has embarked on an integrated water re-sources plan that includes use of the Aquifer Storage and Recovery (ASR) concept to alleviate the potable water demands. Increasing wet weather storage and using available excess water will enable the City to meet irrigation demands, and reduce unwanted discharges to environmentally sensitive areas. In addition, this project will significantly defer expansion of the existing water treatment facilities.

This element of the overall alternative water supply program consists of development of an underground storage system that includes ASR wells, monitor wells, and appurtenances. The ASR system, which will use both reclaimed water and canal surface water, is a critical compo-nent of the City's integrated water supply plan. One ASR well, identified as ASR-1, has been constructed as part of Phase 1. The second phase included construction and testing of a second ASR well (ASR-2) and two monitor wells. Monitor Well No. 1 (MW-1) is a dedicated storage zone monitor well as requested by the Florida Department of Environmental Protection (FDEP), while Monitor Well No. 2 (MW-2) is designed to monitor the first permeable zone near the 10,000 mg/L total dissolved solids (TDS) interface.

This initiative is being implemented in conjunction with regulators to ensure permit com-pliance. The City's alternative water supply plan consists of a strategy that includes close coor-dination with the Big Cypress Basin and the District, as well as the FDEP.

The City of Naples was issued Water Use Permit (WUP) No. 11-00017-W on June 12, 2003, which expired on June 12, 2008. A renewal WUP application was prepared and submitted to the District in June 2008. A key component of the WUP is the implementation of an alterna-tive water supply program to assist with reduction of potable water consumption. The proposed alternative water supply program consists of developing an ASR system that utilizes both re-claimed water and excess surface water. The District accepted the City's water supply strategy and issued a 20-year WUP on June 21, 2010. The WUP expires on June 23, 2030.

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Existing Facilities

Located on the coast in southwest Florida, the City of Naples has unique water resources challenges and opportunities. Figure 1 shows the location of the City's limits. The City of Naples owns and operates a water treatment plant and an advanced wastewater treatment plant (WWTP), or water reclamation facility. The location of the 30 mgd water treatment plant and the 10 mgd water reclamation facility is illustrated in Figure 2.

Understanding the challenges facing a coastal community begins with recognition of de-mands and available resources. The City's water treatment facility has produced approximately 17.33 mgd of potable water to meet system demands for the 10-year period extending from Jan. 1, 2000, through Dec. 31, 2009 (see Figure 3). As noted in Figure 4, production has been fairly consistent on an annual basis throughout this period, with a slight decrease observed in 2008 and 2009, probably due to water conservation and expansion of the

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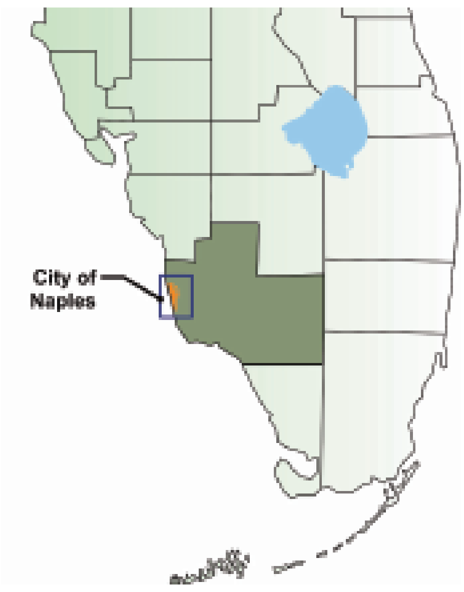

Figure 1 – City of Naples

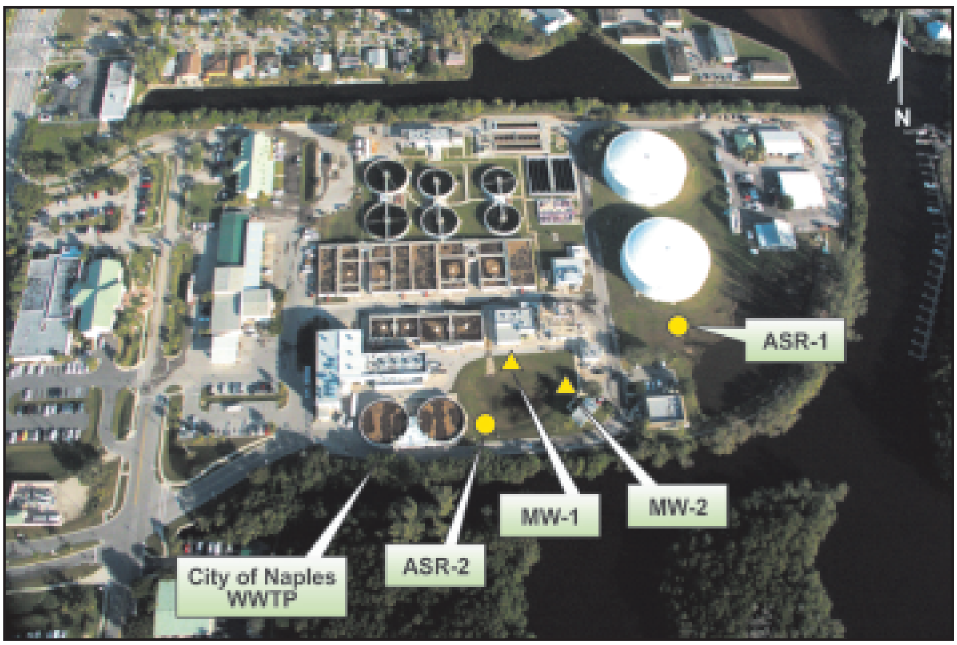

Figure 2 – City of Naples Water Recla

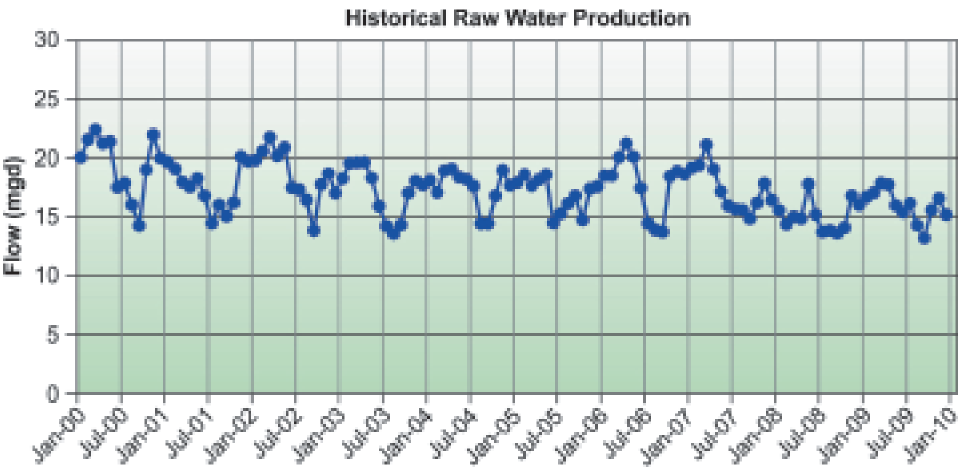

Figure 3 – Historical Water Production

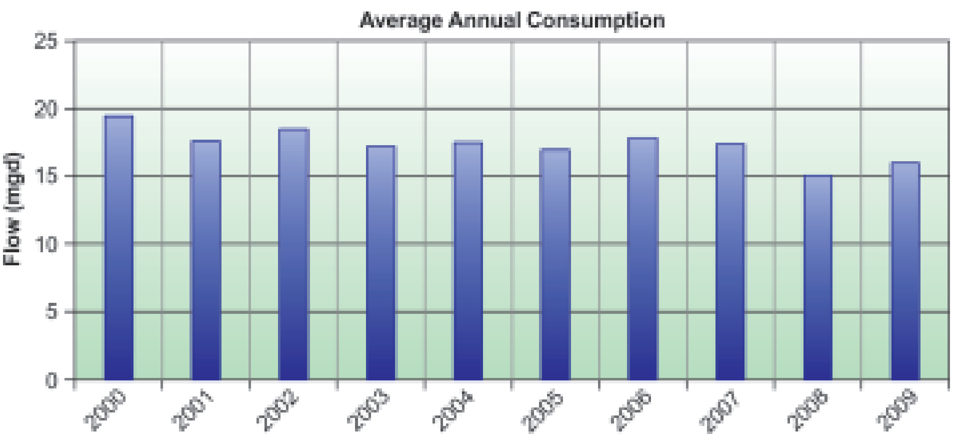

Figure 4 – Historical Average Annual Water Consumption

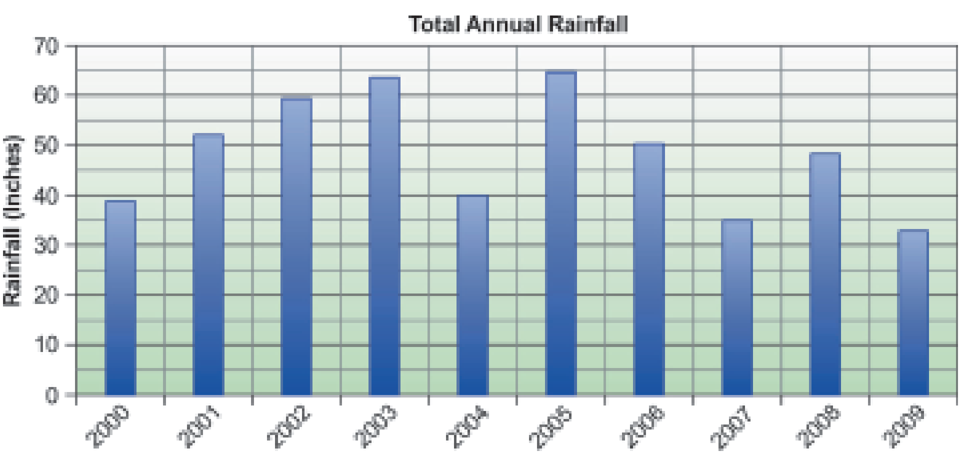

Figure 5 – Historical Average Annual Rainfall

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City's reuse facility. Historical consumption was also compared with historical average annual rainfall (see Figure 5) to evaluate the effect of rainfall to usage on an annual basis. The comparison does not indicate good correlation between water consumption and rainfall as evident in 2004, which was a very dry year, yet water usage was not exceptionally high.

An evaluation of historical data was also performed on a historical monthly basis. Figure 6 shows that historical consumption was highest during the period extending from February through March, which corresponds to the dry season as indicated in Figure 7. The monthly com-parison shows excellent correlation between consumption and rainfall. The wet season, as typical in south Florida, appears to extend from June through October based on the period reviewed.

Total wastewater flows produced by the City's water reclamation facility are shown in Figure 8, along with flows discharged to tide. As with the water production, wastewater flows are fairly consistent, with a slight decrease observed from 2007 to date. An average of 6.72 mgd of reclaimed water has been produced for the referenced period. Since the City has above aver-age irrigation demands, the majority of wastewater flow (i.e., reclaimed water) is used to meet those demands. However, during the wet season, the City has to discharge excess reclaimed wa-ter to tide as supply exceeds demands (discharge to tide is shown in red in Figure 8). Trends on a monthly average are presented in Figure 9, which show that the additional discharge to tide typi-cally occurs during the peak of the rainy season previously discussed. On average, 1.48 mgd of reclaimed water is wasted to tide due to lack of viable storage. The amount of reuse, which aver-ages around 5.39 mgd, is slightly less than the total reclaimed water production due to lack of wet weather storage. Hence, the excess flows (i.e., reuse water), which are presently discharged to tide during wet weather conditions, are lost as a resource to meet irrigation needs. As illus-trated in Figure 10, the City has aggressively expanded its reclaimed water distribution infra-structure to maximize reuse opportunities.

The City's reclaimed water system is incapable of meeting the irrigation demands without supplemental flow, although the area receives approximately 48.48 inches of rainfall on an annual basis. Irrigation demands have been reported to be as high as 70 percent of the total water production. For this evaluation, a value of 60 percent of the total water demand was assumed. Hence, the estimated irrigation demand is 17.33 mgd x 0.60 = 10.40 mgd. Since the available reclaimed water is only 6.72 mgd,

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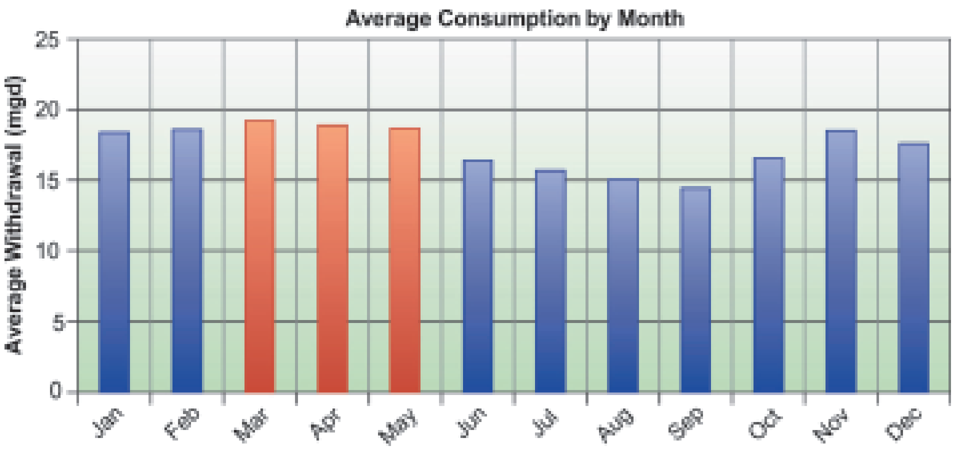

Figure 6 – Average Monthly Water Consumption

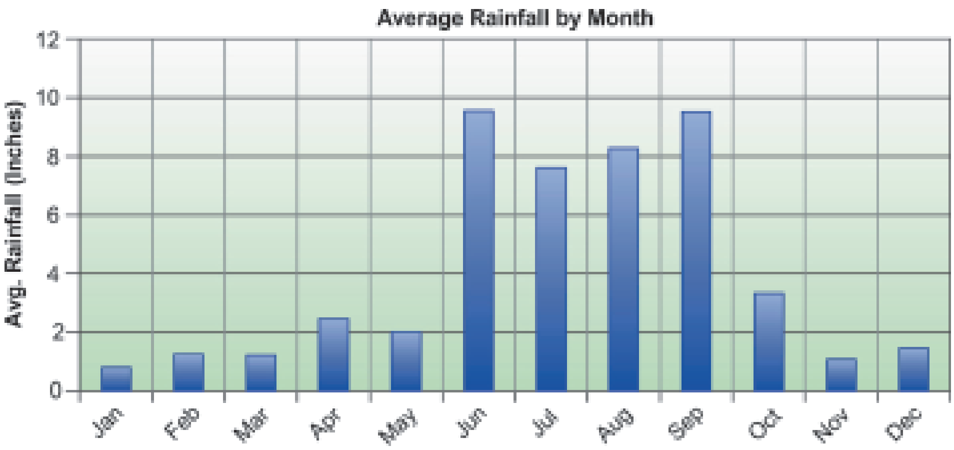

Figure 7 – Average Monthly Rainfall in Inches for the City of Naples

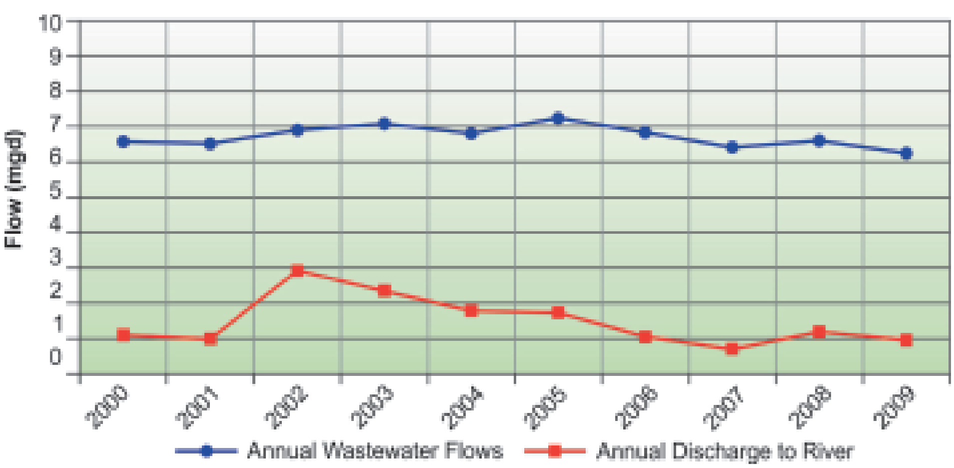

Figure 8 – Historical Average Annual Wastewater Flows Compared with Annual Discharge to Tide

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a deficit of 10.40 mgd – 6.72 mgd = 3.68 mgd exists. This deficit has been historically met with potable water, resulting in excessively high potable water demands on a per capita basis. It is estimated that approximately 5 mgd of water is needed during the months of March through May to meet seasonal irrigation demands.

To address the irrigation storage, the City has initiated an ASR program which consists of constructing ASR wells to provide storage of excess reclaimed water when demands are less than production. In addition, the City is moving forward with using excess surface water from the nearby Golden Gate Canal, which is presently being discharged to tide. At present, the excess surface water discharge from the Golden Gate Canal that is lost to tide has been an unused and unrecoverable resource. Use of untreated surface water from the Golden Gate Canal will make up the short-fall left by reclaimed water.

The combination of reclaimed water and surface water will provide the City with a hybrid ASR system that optimizes use of alternative water resources as replacement water to meet irri-gation demands. This concept will not only conserve resources presently lost to tide, but signifi-cant reduce potable water consumption. The District/Big Cypress Basin and the FDEP are very receptive to this approach and actively participating in this project.

Solution

Additional storage is needed to optimize use of reclaimed water for irrigation. In addition, conveyance and storage facilities are needed to capture excess surface water from the Golden Gate Canal for beneficial use (i.e., irrigation). Without storage, valuable fresh water re-sources are discharged and lost to tide.

An assessment of feasible options led the City to pursue use of the ASR concept by develop-ing a storage zone on the existing WWTP site. Permitting conditions were discussed with FDEP and the District, and a plan was initiated to construct and test ASR wells, including monitor wells. The ASR plan was developed based on the following assumptions:

Recharge volumes and rates – Based on the information previously discussed, the fol-low-ing design assumptions were made:

- Target recharge period is from June through October (~150 days)
- Recovery rates will be 1 to 1.4 mgd (i.e., 700 to 1,000 gpm)
- Estimated recharge water quality is 575 to 725 mg/L total dissolved solids (TDS)

Storage period(s) – The anticipated storage period based on review of records from 2000 through 2009 occurs from November through February, or approximately 120 days. It should be noted that any available water from the City's reclaimed water system and/or the Golden Gate Canal will be recharged and stored during this period. A minimal trickling recharge flow will be maintained when ASR wells are inactive.

Recovery volumes and rates – Based on the information above, the following design as-sumptions were made:

- Target recharge period is from March through May (~90 days)
- Recovery rates will be approximately 1 mgd to 1.4 mgd (i.e., 700 to 1,000 gpm) per well

Storage horizon – The City's ASR system will use a storage horizon below the potential un-derground source of drinking water (USDW) to facilitate permitting. Such a zone appears to exist at the WWTP site; however, recovery efficiencies may be reduced due to the saline na-ture of the native water and the characteristics of the formations (i.e., overlying confinement and storage zone hydraulic conductivity). Based on data collected at the ASR test well, a storage horizon from approximately 1,080 to 1,350 feet has been selected. This zone contains water with a TDS concentration greater than 25,000 mg/L. Selection of a storage zone below the USDW appeared to be the most feasible zone from a permitting perspective based on dis-cussions with the FDEP, knowing that recovery efficiency may suffer.

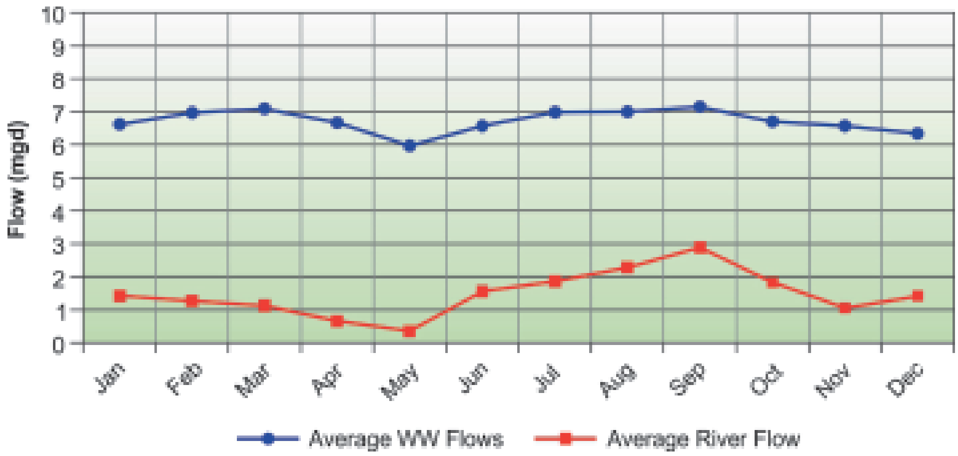

Figure 9 – Average Monthly Wastewater Flows Compared with Annual Discharge to Tide

Water quality constraints – The end user of the recovered water, as well as regulations, will determine the upper limits for acceptable water quality.

Monitoring – A monitoring system consisting of a dedicated storage zone monitor well and a shallow monitor well were required by the FDEP. The dedicated storage zone monitor well will assist in monitoring movement within the storage horizon, while the shallow monitor well will assist in monitoring overlying potential sources of raw water supply, albeit brack-ish.

Initial plans include recovery of stored water to the filtration system for chlorination and filtering prior to delivery. Recovered waters will be blended with reclaimed water during fil-tration and stored in existing

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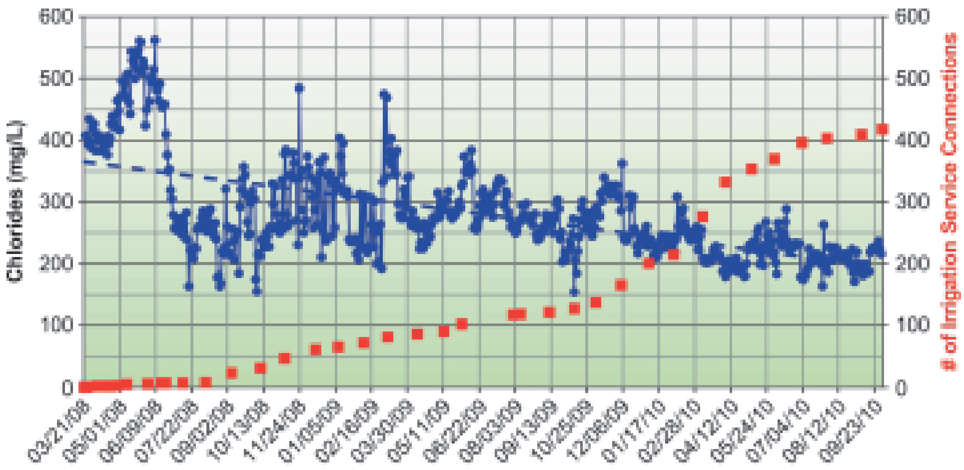

Figure 10 – Reuse Program

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aboveground storage tanks. The existing reclaimed water distri-bution pump station would be used for delivery of stored water. If data demonstrates the re-covered water is acceptable for direct blending, the City would request permission to recover directly from the ASR wells into the aboveground storage tanks, then disinfect and distribute the water via the existing reclaimed water distribution pump station.

One additional issue considered during design was well spacing. For ASR systems, proximity of wells is desired to optimize recovery efficiencies. An overlap of injected fluids between wells, especially in horizons with poor water quality, appears to be the preferred mode of operation for multi-well systems. Therefore, the ASR wells were designed in

Table 1
Well Construction Details

Well	Final Casing		Total Well Depth (feet)
	Diameter (inches)	Depth (feet)	
ASR-1	24	1080	1350
ASR-2	24	1080	1350
MW-1	6-⅝	1080	1350
MW-1	6-⅝	670	740

close proximity taking into ac-count the physical constraints of the site.

Testing

A detailed testing program was designed to collect specific information needed to evaluate the efficiency of ASR below the USDW. An exploratory well was originally constructed on the site which provided preliminary information on the underground conditions. Unfortunately, the exploratory well was designed to investigate potential storage zones above the USDW. A phased approach was developed to allow go/no-go check points during project implementation. The first phase included construction and testing of ASR Well No. 1 (ASR-1). This well in-cluded a pilot-hole to a depth of 1,500 feet to allow assessment of hydrogeologic conditions. Testing included extensive geophysical logging, straddle packer testing, and step drawdown test-ing. An important objective was the preliminary identification of the USDW.

Information collected during construction and testing of ASR-1 was invaluable. The data identified the location of the USDW around 760 feet below land surface, and more importantly, below the lower most source of raw water supply in the region (i.e., the Lower Hawthorn, which contains brackish water). Another key finding was the identification of a moderately transmis-sive storage zone between 1,080 and 1,350 feet below land surface. The data collected at ASR-1 provided characteristics compatible with storage of fresh water in a saline environment (i.e., presence of a potential storage zone and existence of confinement between the storage zone and the USDW). Based on these findings, the City elected to proceed with Phase 2, which included construction of a second ASR well (ASR-2) and construction of monitor wells.

The second ASR well was used to confirm the presence of the targeted storage zone and to allow for further assessment of confinement by coring and additional straddle packer testing. The location of the USDW was also verified. Two monitor wells were constructed during Phase 2. Monitor Well No. 1 (MW-1) was constructed by converting the existing exploratory well into a dedicated storage zone monitor well. The FDEP required construction of a second monitor well (MW-2) to monitor the first permeable zone at or near the USDW. Construction details of the ASR and monitor wells are summarized in Table 1.

A comparison of data collected was reviewed to evaluate the underground conditions en-countered. Figure 11 shows a combined gamma ray log from ASR-1, ASR-2, and MW-1, along with the hydrogeology en-

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countered. The location of the USDW was estimated based on straddle packer testing and geophysical logging. Figure 12 presents the log-derived water quality from ASR-1, ASR-2, and MW-1. As seen in the Figure 12, the location of the 10,000 mg/L TDS ap-pears to occur between depths of 760 and 780 below land surface. These findings were critical as they provided reasonable assurance that separation existed between the targeted storage zone and the USDW. Flow log data also indicated that the targeted storage zone would accept recharge water at reasonable injection rates with specific capacities estimated to range from 70 to124 gpm/ft at a pumping rate of 700 gpm.

Conclusions

Development of the storage zone began in the spring of 2011. Conclusions from the construction and testing conducted to date are as follows:

- The 10,000 mg/L total dissolved solids interface was estimated to occur somewhere be-tween the depths of approximately 760 to 780 feet below land surface based on informa-tion collected via geophysical logging and straddle packer tests. The 10,000 mg/L total dissolved solids interface is the base of potential USDW. This depth is important as FDEP has separate criteria for regulating ASR systems completed below the USDW.
- A potential storage zone was identified to exist between depths of 1,080 and 1,350 feet below land surface. This zone has been targeted as a potential storage horizon as it con-tains water with total dissolved solids greater than 10,000 mg/L and there appears to be adequate confinement present between the targeted top of the potential storage zone and the USDW.
- The storage zone has adequate hydraulic conductivity to allow injection and recovery at rates from 700 gpm (~1 mgd) to possibly 1,400 gpm (~2 mgd) based on results of the step drawdown testing.
- The storage zone contains water with a total dissolved solids concentration over 25,000 mg/L.

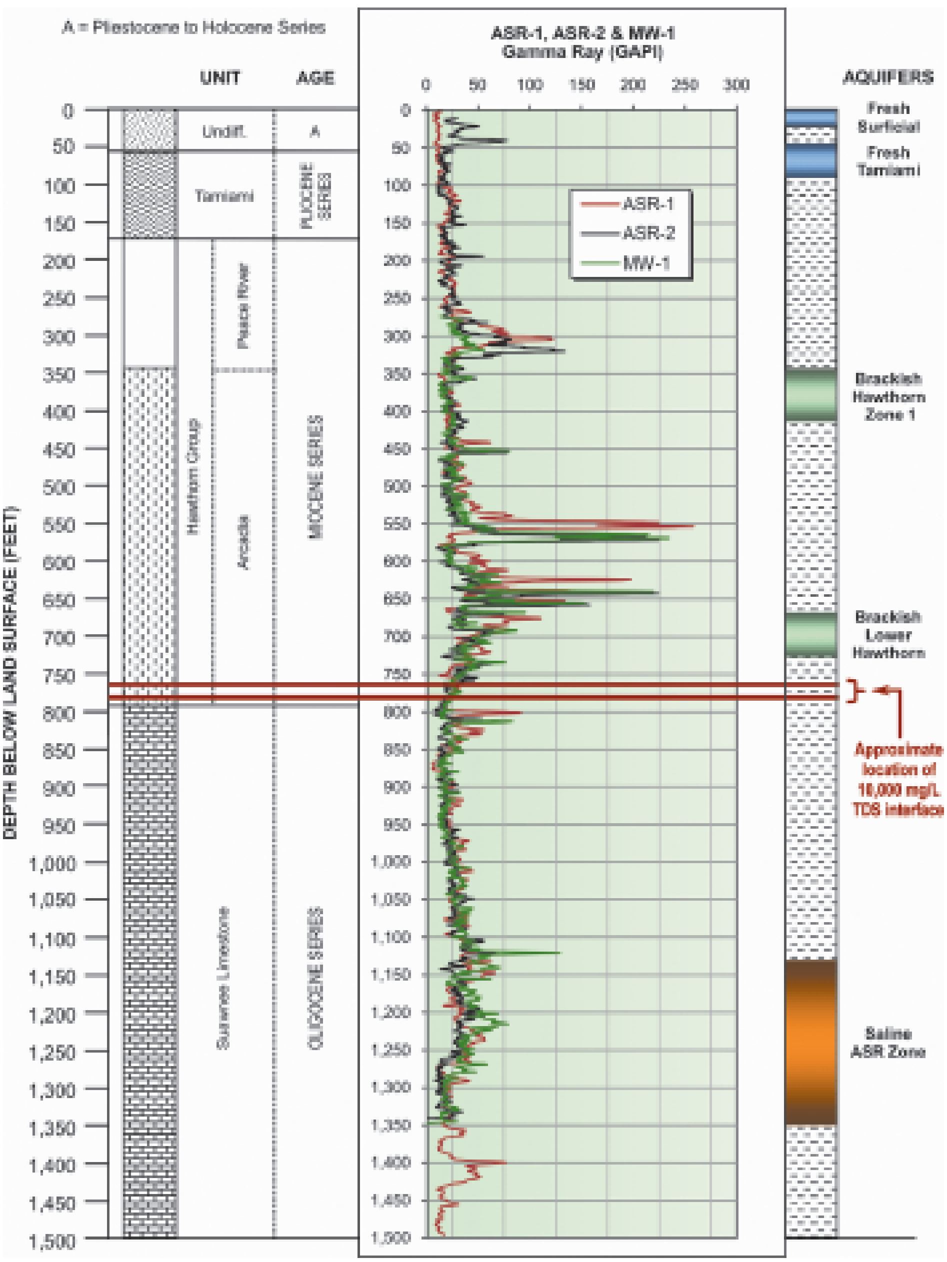

Figure 11 – Generalized Hydrogeologic Section from ASR and Monitor Wells

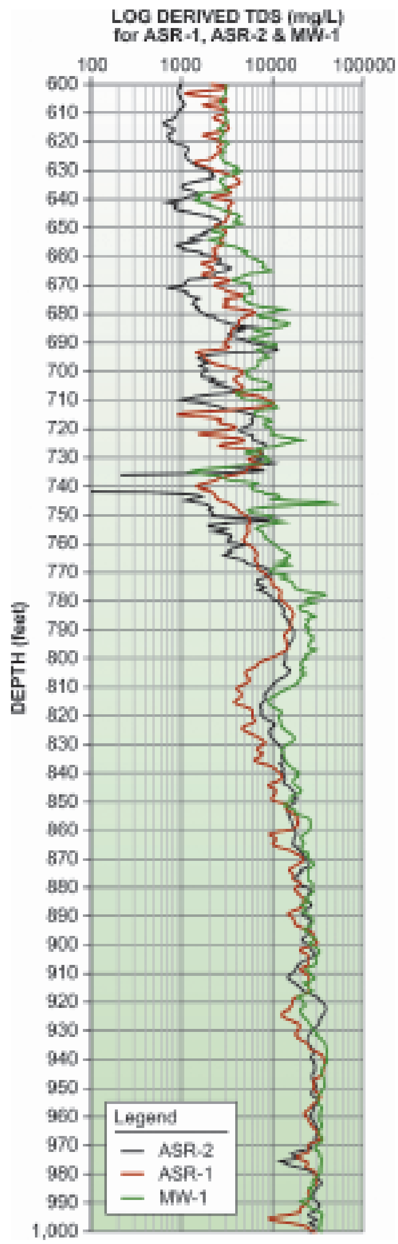

Figure 12 – Location of the 10,000 mg/L TDS