Aquifer Storage and Recovery for Management And Supply of Water to Meet Recreational Irrigation Demands

Robert G. Maliva, W. Kirk Martin, and Thomas M. Missimer

Robert G. Maliva, Ph.D., P.G., is a senior hydrogeologist with CDM; W. Kirk Martin, P.G., is an associate with CDM; and Thomas M. Missimer, Ph.D., P.G., is a vice president with CDM. The authors work at the firm's Fort Myers office.

Aquifer Storage and Recovery (ASR) technology is being recognized increasingly as a cost-effective technology for managing water resources, particularly in areas such as Florida that have a pronounced seasonality of peak water demand and availability. ASR also has great potential to improve the management of irrigation-water resources by non-public water users, such as golf courses.

ASR is the underground storage of water during periods of excess supply for later recovery during periods when demand exceeds available supply. The vast majority of ASR systems in operation or currently in the permitting process in Florida are operated by municipalities or water utilities. The water in current ASR systems is stored mostly for eventual use in potable-water systems or, less commonly, in reclaimed-water systems.

For large-quantity water users in the private sector, such as golf-course developments, ASR can provide a drought-proof water supply. The more effective management of water resources by larger users benefits other users of freshwater aquifers by making more freshwater available during times of shortage. Groundwater-to-groundwater ASR systems are particularly attractive for private recreational facilities because they can use existing water supply and distribution infrastructure and have minimal or no treatment requirements.

Groundwater-to-Groundwater ASR

Groundwater-to-groundwater ASR is the withdrawal of freshwater from one aquifer and its storage in a brackish-water aquifer, typically at a greater depth. A fundamental, but often not fully appreciated, hydrologic reality in Florida is that most real or perceived water problems are due to drawdowns that are a dynamic response to well withdrawals, as opposed to long-term depletion of aquifers. Since the aquifers of Florida are not being mined, such as is occurring in many western states, the drawdowns are reversible. Once pumping is reduced or curtailed, water levels (heads) quickly rebound.

Shifting groundwater withdrawals from the dry season to the wet season in groundwater-to-groundwater ASR systems thus provides a definite hydrologic benefit by reducing freshwater withdrawals during periods when the aquifer is under greatest stress.

The great practical advantage of groundwater-to-groundwater ASR systems is that they take advantage of the natural filtration that occurs as water infiltrates into and flows through an aquifer. For aquifers that are not under the direct influence of surface water, the recovered water should be free of pathogens and should meet primary and most secondary drinking-water standards. Untreated shallow groundwater in Florida may not meet the color and iron secondary drinking-water standards, for which a Florida Department of Environmental Protection (FDEP) water-quality criteria exemption would be required. If the production wells are properly constructed and developed, sediment production will be very low and clogging should not occur. The recharge water for a well-designed groundwater-to-groundwater ASR system would require no treatment.

The groundwater-to-groundwater ASR strategy also has a low potential for adverse fluid-rock and fluid-mixing reactions that have resulted in elevated concentrations of arsenic and radionuclides (Arthur et al., 2001, 2002; Williams et al., 2002) and deterioration of well performance in some Florida ASR systems. Potential source and storage aquifers in Florida are in carbonate rocks, with a few possible exceptions (e.g., Sand and Gravel Aquifer in the Florida Panhandle). The recharge and native storage-zone waters will thus tend to be chemically similar in their saturation state with respect to carbonate mineral and their redox potential.

Both the recharge and storage-zone waters will generally be at saturation with respect to calcite, which minimizes the potential for leaching of the host rock. The recharge and storage-zone waters will also be reducing, which minimizes the potential for adverse redox reactions, such as the oxidation of pyrite to release arsenic.

ASR for Golf Course Irrigation

Currently the standard practice for supplying irrigation water to a golf course involves using multiple sources of water to minimize the impacts to any one source and supplementing the freshwater sources with a blend of brackish water that maintains a quality suitable for use on turf grass. Although designed to meet irrigation needs with minimal environmental impacts, the current practice has significant limitations. Peak irrigation demands occur during periods of low rainfall when aquifers and sensitive environmental systems are most vulnerable and competition for available water supplies is high.

Irrigation-water supply is an ideal application of ASR technology in Florida because of the pronounced seasonality of irrigation-water demand. **Figure 1** illustrates the annual average rainfall, evapotranspiration, and irrigation requirement for turf grass in Fort Myers. The data are from the South Florida Water Management District (SFWMD) modified Blaney-Criddle method spreadsheet.

Rainfall exceeds turf grass consumption of

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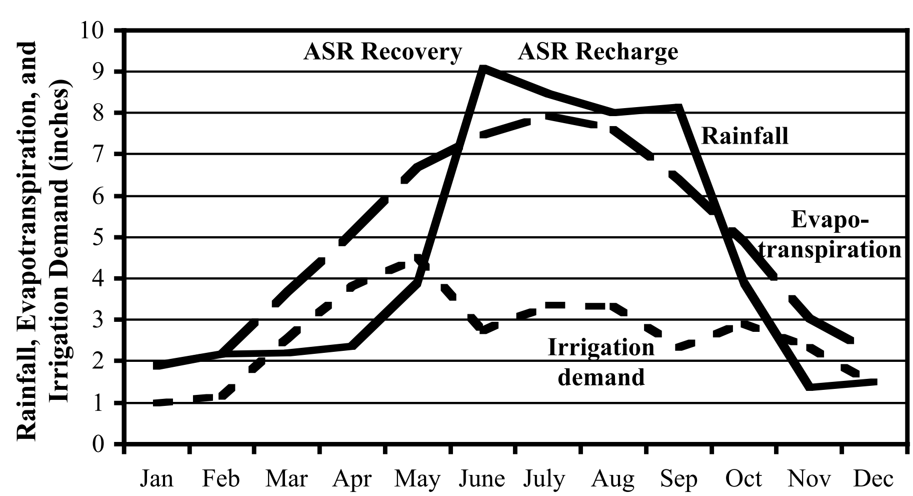

Figure 1: Average monthly rainfall, evaporation, and irrigation demand for turf grass in Fort Myers

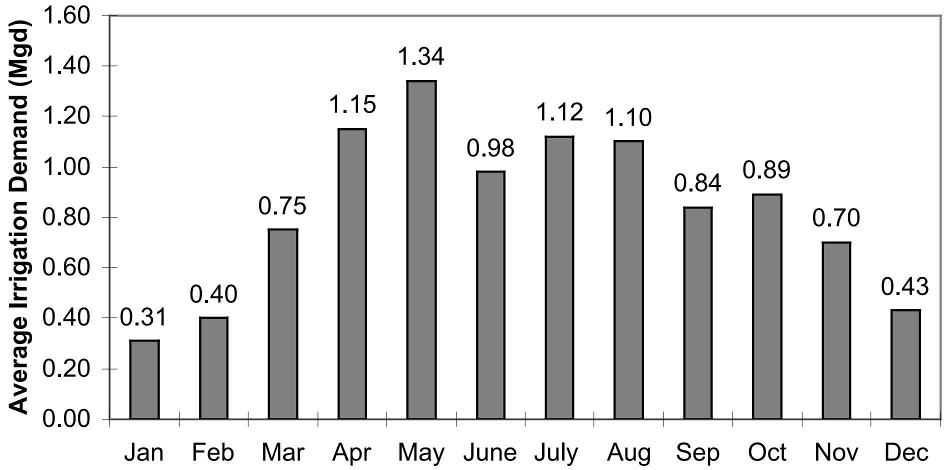

Figure 2: Average daily irrigation demand for 240 acres of turf grass in Fort Myers (two-in-10 drought year, solid-set sprinkler irrigation)

Continued from page 36

water (evapotranspiration) during the months of June through September, which is the preferred period for recharging an ASR system. The maximum rainfall deficiency and irrigation demand occur from March through May, which is the main recovery period for an ASR system.

Figure 2 shows the irrigation-water requirements for a hypothetical two-golf-course development with a total irrigated area of 240 acres. The data are for the Fort Myers area in a two-in-10 drought year. The average daily water requirement using solid-set sprinklers is 0.84 million gallons per day (MGD), whereas the maximum-month (May) average daily demand is 1.34 MGD.

An ASR system for this two-golf-course development could be designed either to meet peaks in demand or for the entire dry-season (November through May) water demand, depending upon the needs of the golf-course operator. SFWMD impact evaluations for water-use permits are usually based on maximum-month water-use rates.

Installation of an ASR system to reduce maximum-month (dry-season) withdrawals from freshwater aquifers may allow for a water-use permit (WUP) to be obtained for the entire development in areas where a WUP might not otherwise be issued because of high existing permitted-water use. In the case of the 240-acre golf-course complex in the Fort Myers area, maximum-month use could be reduced from an average daily rate of 1.34 MGD to 0.84 MGD with the installation of a 0.5-MGD ASR system.

Under current SFWMD rules (Chapter 40E-21.275 (d) (e)), water from ASR systems is exempt from water restrictions during water emergencies. Installing an ASR system would allow a golf-course operator to maintain a normal water schedule during water emergencies, thus drought proofing the golf course. ASR systems used to provide for drought proofing must be designed to meet the full maximum-month water requirements.

ASR used for irrigation can have higher recovery efficiencies than potable-water systems because higher salinities are acceptable for recovered water than for potable water, which must meet primary and secondary drinking-water standards. The primary drinking-water standard for chloride, for example is 250 mg/L. Water with higher chloride concentrations, even exceeding 500 mg/L, may be used to irrigate turf grass, especially for short periods of time. Also, the mixing of the ASR water with storage-lake water can produce a blend of water with less than 250 mg/L chloride.

Hydrogeological Considerations

ASR does not work everywhere. The successful implementation of a groundwater-to-groundwater ASR system requires the presence of a permittable source of fresh groundwater and a brackish-water aquifer with suitable water quality and hydraulic properties to serve as a storage zone. To facilitate eventual high-recovery efficiencies, chloride concentration (as a proxy for salinity) should preferably be in the 250 to 2,000 mg/L range and ideally less than 1,000 mg/L. Aquifer transmissivity should be high enough (typically greater than 10,000 ft2/day) to allow for acceptable well yield (≥ 0.5 MGD), but not so high as to result in excessive migration and mixing of injected water.

In Southwest Florida, the lower Hawthorn Aquifer and some aquifers within the intermediate (Hawthorn) aquifer system are the preferred targets for ASR storage zones. Elsewhere in South and Central Florida, transmissive intervals within the upper Floridan Aquifer are potential storage zones. The hydrogeology of a potential irrigation-water ASR system in central Lee County is summarized in **Figure 3** to provide an example of the hydrogeology of groundwater-to-groundwater ASR systems.

Both the Water Table and Sandstone aquifers contain freshwater that is suitable as a recharge-water source. The Sandstone Aquifer is the preferred source because it is a confined aquifer; therefore, contamination from surficial activities is not a concern. The Sandstone Aquifer meets all drinking-water standards except for color. The storage zone would be the underlying lower Hawthorn Aquifer, which contains mildly brackish water (chloride concentration is 750 mg/L).

In the example illustrated in Figure 3, fresh groundwater would be pumped directly from the Sandstone Aquifer and/or the Water Table Aquifer into the lower Hawthorn Aquifer without any treatment. During recovery periods, the ASR well would flow under artesian pressure to a golf-course storage pond. Ideally, the ASR system would be installed within the irrigation wellfield to minimize piping requirements and facilitate the integration of the ASR system into the existing or planned irrigation system.

Regulatory Issues

Irrigation ASR systems must be permitted with both the local water management district and the FDEP Underground Injection Control (UIC) Division. The SFWMD response to ASR for golf-course irrigation has generally been very favorable. Reduction of dry-season withdrawals of fresh groundwater by large users clearly benefits the resource and other users.

The operator of the system should have sufficient technical sophistication to handle the operational, monitoring, and permitting requirements of ASR systems. It is undesirable, for example, for an ASR system to be an integral part of an irrigation system that will be handed over to a homeowners association that does not have the technical expertise or inclination to properly manage it.

Groundwater-to-groundwater ASR systems under FDEP rules are classified as Class V, Group 7 injection wells. FDEP rules and policies for ASR systems distinguish between potable-water and non-potable-water ASR systems, with potable water being defined as water that passes through a permitted drinking-water treatment facility. Groundwater-to-groundwater ASR systems are thus lumped together with other non-potable-water ASR systems, such as reclaimed-water and surface-water systems, even though the recharge water used in groundwater-to-groundwater ASR systems may be potable in the sense that it is fit for human consumption.

The regulatory distinction between potable and non-potable water is significant in that it affects the cost of ASR implementation. Potable-water ASR systems are less tightly regulated because there are few public health and environmental concerns over the underground injection of treated drinking water. Potable-water ASR systems, for example, do not require an operation permit (F.A.C. 62-528.640 (1.c.) or monitoring

(F.A.C. 62-528.615 1.a.2). Current FDEP UIC rules and policies do not recognize the inherent low environmental concern over the injection of high-quality groundwater into underlying aquifers containing low-quality water.

Most shallow groundwater in Florida naturally does not meet the secondary drinking-water standard for color and often for iron. Secondary drinking-water standards are based on aesthetic considerations rather than health concerns. A water-quality criteria exemption (WQCE) is required for underground injection of liquids that do not meet a secondary drinking-water standard. The requirement for a WQCE is a demonstration that granting the exemption is in the public interest and poses no public-health risk. Obtaining a WQCE for a groundwater-to-groundwater ASR system is not problematic, since the water-resource management benefits of ASR are in the public interest.

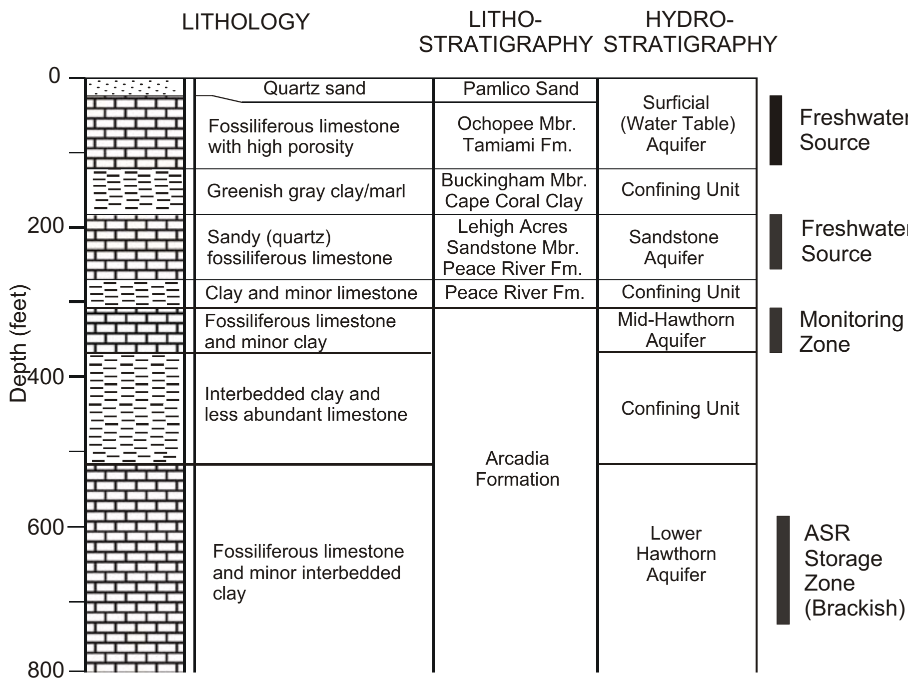

Figure 3: Hydrogeology of a potential irrigation-water ASR site in central Lee County

Economic Considerations

The demand for irrigation ASR is price sensitive. The benefits of the ASR system to the golf-course owner must exceed the cost to permit, construct, test, and operate the system. The cost of the ASR system must also compare favorably to other non-conventional irrigation-water source options, such as reverse-osmosis desalination.

An additional cost-benefit factor that must be considered is the potential that the ASR system may not work or meet expectations because of site-specific hydrogeologic conditions. The risk of failure unfortunately has often been downplayed or ignored in marketing ASR systems. The risks associated with the initial testing can be ameliorated if the ASR well or initial test well can be converted into a brackish water-supply well where tests show that the ASR program is likely to be unsuccessful. Brackish water is used to supplement freshwater during peaks in irrigation-water demand in many golf-course developments.

The approximate cost for implementing a one-well ASR system with a target capacity of 1 MGD is summarized in **Table 1**. The main cost for ASR systems is well construction. In addition to the ASR recharge and recovery well, two monitor wells must typically be constructed in the storage zone and in a transmissive interval above the storage zone. Well-construction costs vary largely according to the depth of the storage zone and the diameter of the well.

Permitting costs will also vary, depending on whether or not a WQCE is required and the number of parameters for which a WQCE is needed. Pre-operational water-quality testing will include, based on recent permitting experiences, six rounds of analyses of the source water for the full primary and secondary drinking-water standards, radionuclides, and microbiological parameters (total and fecal coliforms, Enterococci, Giardia, Cryptosporidium).

It is assumed that water can be delivered at adequate pressure for injection to the ASR well under pressure from the production-well pumps. A pump may or may not be needed for the ASR well, depending on artesian flow rates, if present. Typically, golf-course irrigation wells discharge to a storage pond in which high-capacity pumps are installed to allow for high-volume irrigation. Not included in Table 1 are the costs of piping to the ASR well and advance telemetry (e.g., SCADA) beyond basic data loggers.

The total cost of an ASR system, as estimated in Table 1, is not at risk when an ASR strategy is pursued. The plans for ASR projects should incorporate "go/no-go" decision points at which the feasibility of successful ASR implementation is evaluated. Sufficient data may be obtained after the installation of a test well (to be converted into the storage-zone monitor well) to make a more informed evaluation of ASR feasibility at a site.

A significant part of the costs in Table 1 is due to the additional FDEP well construction and monitoring requirement because the recharge water is considered non-potable. For example, the requirement that the ASR well pass a pressure test more than doubled well construction costs quoted from drillers because of the additional effort and risk.

Although ASR is more expensive than a purely extractive irrigation-water supply system, it is often still cost effective in locations where a conventional freshwater supply is not fully permittable. The cost to install a reverse-osmosis desalination system, including brackish-water supply wells and a concentrate disposal system, is at least twice the cost

Continued on page 40

Table 1: Estimate Costs to design, permit, construct, and operationally test a one-well ASR system (in $1,000s)

No.	Item	Cost
1	Design and permitting (professional services and permit fees)	30 – 70
2	Pre-operational test water quality testing	40 - 50
3	ASR and monitor well construction (includes supervision and FDEP reporting)	120 – 220
4	Operational cycle testing (includes monitoring and reporting)	80 – 120
5	Well completion report, operation testing report, miscellaneous professional services	40 – 60
	Total	310 – 520

Continued from page 39
of an ASR system of the same capacity.

Implementing Irrigation ASR

CDM has either conducted feasibility studies or is actively permitting irrigation ASR systems for three golf course developments in South Florida. Considerable interest has been expressed in irrigation ASR by large developers, who are taking a somewhat conservative wait-and-see approach as far as implementation. Work will likely be initiated at other developments once it is demonstrated that the system can be permitted successfully and can be constructed cost-effectively.

The implementation of groundwater-to-groundwater ASR for irrigation would benefit from monitoring and construction requirements commensurate with the high quality of the injected water, which would reduce costs and make the technology more attractive. It is therefore important to establish a successful early track record for the technology.

Conclusions

Irrigation ASR using a groundwater-to-groundwater approach offers a win-win scenario in which golf-course developments and other large irrigation-water users can ensure a reliable water supply while also making more water available to other freshwater aquifer users during the dry season and water emergencies. The groundwater-to-groundwater approach is attractive because it can use existing irrigation production wells for a water source and the recharge water usually will require no treatment prior to injection.

The degree of ASR implementation is cost sensitive, with the cost to construct and operate a system depending to a large degree on regulatory requirements. Nevertheless, ASR under the current regulatory environment may still be cost effective in locations where a conventional water source is not available or permittable and/or the drought-proofing benefits of ASR are of particular value.

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