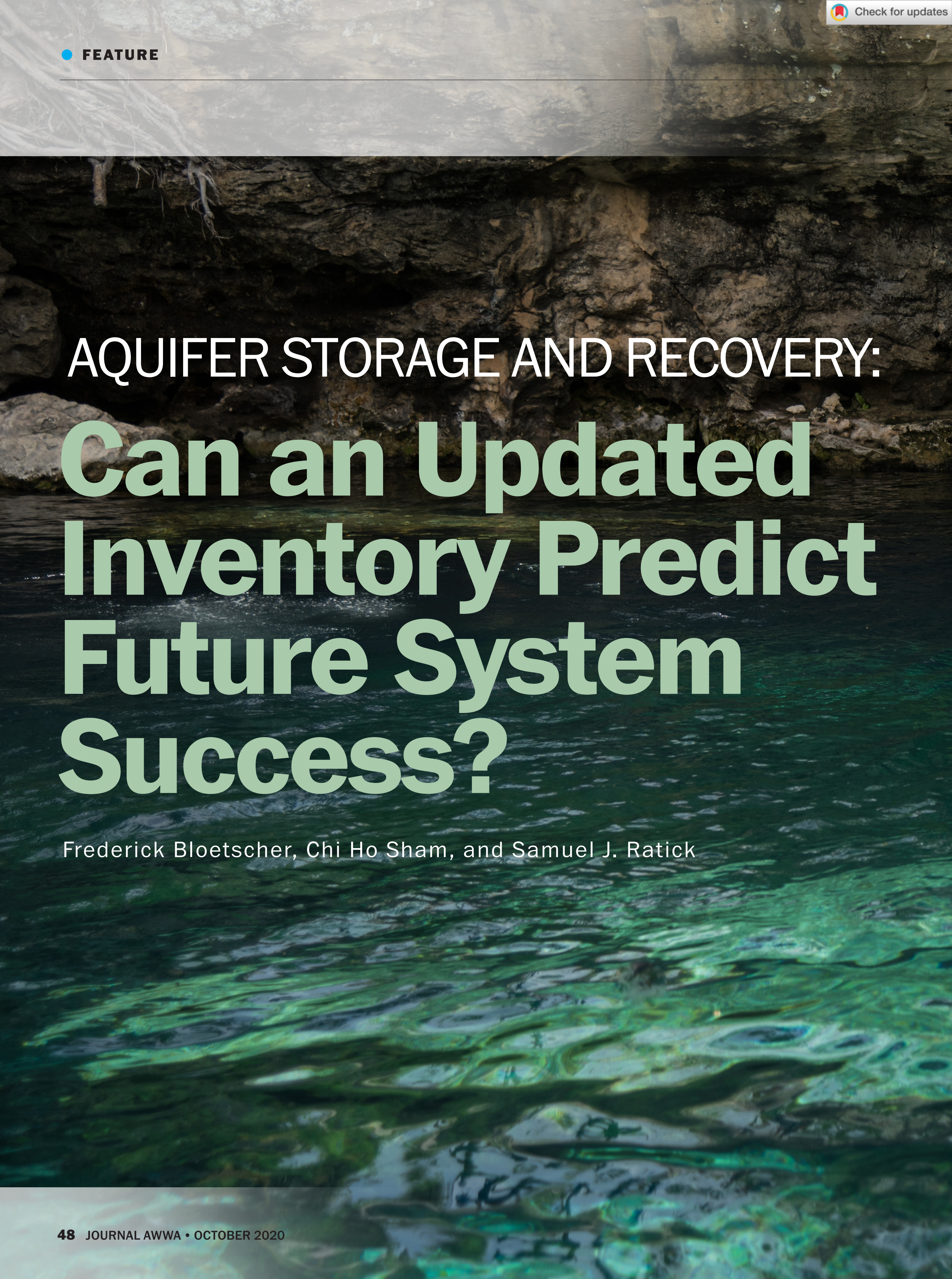
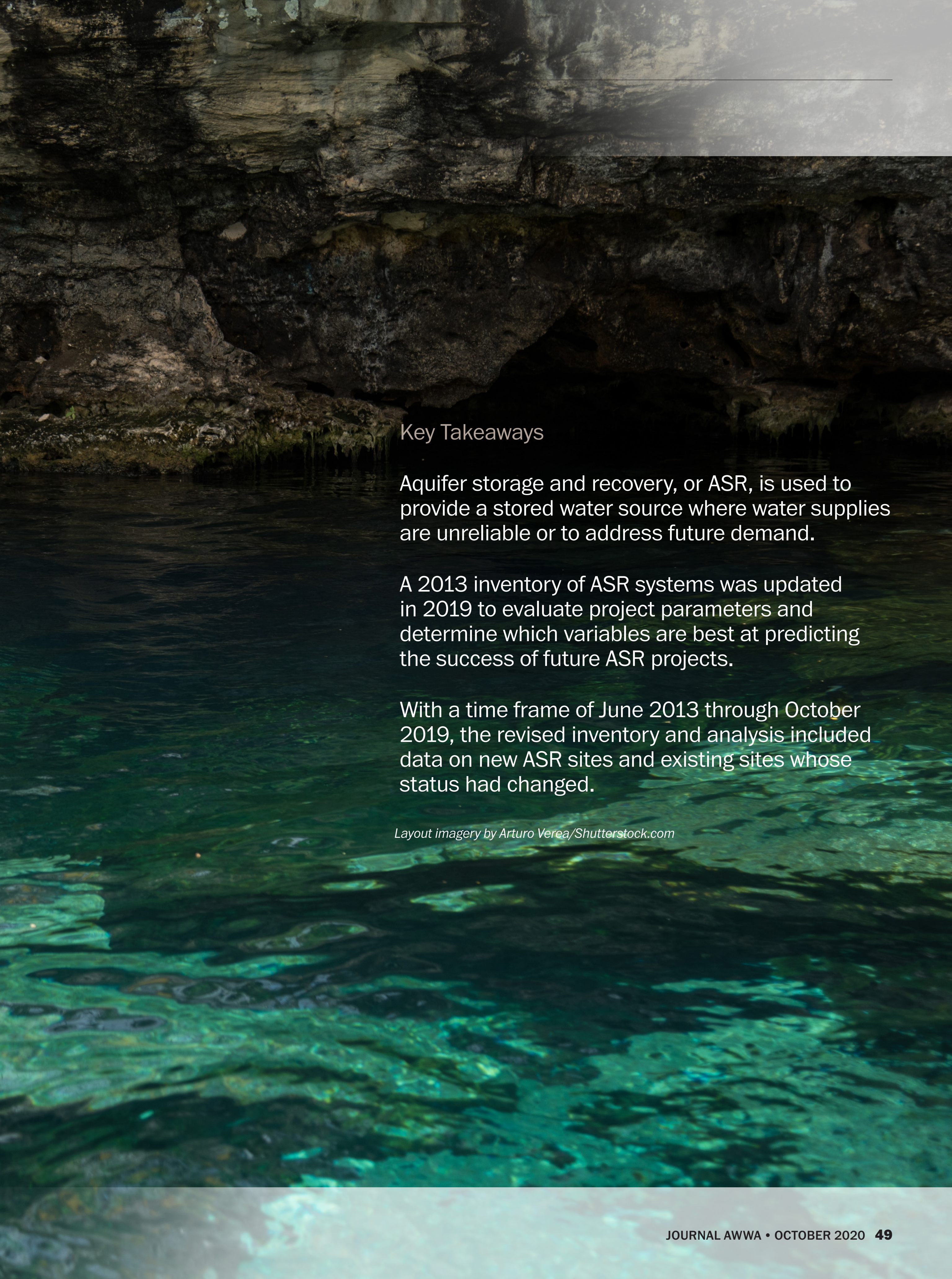


AQUIFER STORAGE AND RECOVERY:

Can an Updated Inventory Predict Future System Success?

Frederick Bloetscher, Chi Ho Sham, and Samuel J. Ratick



Key Takeaways

Aquifer storage and recovery, or ASR, is used to provide a stored water source where water supplies are unreliable or to address future demand.

A 2013 inventory of ASR systems was updated in 2019 to evaluate project parameters and determine which variables are best at predicting the success of future ASR projects.

With a time frame of June 2013 through October 2019, the revised inventory and analysis included data on new ASR sites and existing sites whose status had changed.

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A common water management practice is for treated or treatable water to be pumped below ground and stored to preserve and protect current water resources, prepare for future droughts, recharge wellfields, and store water for use at a later time to sustain development (AWWA 2015). Aquifer storage and recovery (ASR) is one approach to groundwater recharge that is generally accepted as viable for managing both potable and nonpotable water supplies in areas with unreliable supplies and water shortage (AWWA 2015, Bloetscher et al. 2014a, 2014b; Pyne 1995). ASR systems pump water, treated or not, down a well into an aquifer, and the water in that aquifer is recovered later from the same well for some intended purpose. ASR as defined here excludes other types of managed aquifer recharge programs such as infiltration basins, spreader basins, trenches, and other means to recharge aquifers from the surface. By leveraging unused treatment plant capacity to treat excess or available water and store it in an aquifer for later withdrawal, ASR programs can

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augment future water supplies, which can help utilities avoid the need to build in extra water treatment capacity (AWWA 2015, 2014; Bloetscher et al. 2014a, 2014b).

In 2013, a data set on ASR systems in the United States was collected from the US Environmental Protection Agency (USEPA) and state environmental agencies. In addition, data were compiled from literature and through telephone interviews with specific water utilities. This effort yielded 204 sites that included more than 700 wells, with the most sites found in Florida (54), followed by California (28) and New Jersey (19). The ASR projects in this inventory used water sources that included raw surface water (64%), groundwater (21%), and reclaimed wastewater (14%). Storage periods ranged from months to years depending on the goal, which included storing water to meet the next high-demand period, supplementing supply during an emergency such as a severe drought, and providing water during an interruption of supplies resulting from equipment breakdown. Approximately 37% of the ASR sites were considered operational, while 25% of the sites were not active (Bloetscher et al. 2014b), with the rest in various stages of testing (26%) or feasibility studies (12%).

This article updates, to the extent possible, data and analysis from the 2013 survey of ASR sites in the United States with data from ASR systems that have been initiated since June 2013 through October 2019. The goal of this article is to use the updated ASR data set to reveal insights into the criteria associated with the development of ASR systems and to highlight those characteristics that might lead to a higher rate of success for new sites.

Review of ASR Databases

We reviewed current and publicly available USEPA, state, and regional regulatory databases with respect to ASR systems; our aim was to identify changes in the ASR inventory since 2013. We focused on new sites and those for which the status had changed (through October 2019). Several findings resulted from this effort:

- Georgia had decided not to permit ASR systems.
- The Texas State Water Plan included ASR as part of the water resources portfolio (at a total of 1% of total water use), which has spawned 20 proposed ASR project sites for investigation over the next 10 years.
- Florida and USEPA entered into an agreement to address arsenic in recovered water from ASR systems in limestone formations, which may have fostered renewed interest in ASR in Florida.
- Washington has conducted ASR feasibility studies in all aquifers in the state, while Cheyenne, Wyo., has ceased pursuing its ASR project.
- Two projects undertaken by the US Army Corps of Engineers for the South Florida Water Management District completed testing, with no further activities.
- Utah continues to evaluate ASR and surface reservoirs in high-growth areas of the state, and surface reservoirs are chosen most frequently.

Some of the "new" systems had data available in the literature, but most were in the study stage. For our study, a larger initial set of data was selected on the basis of data availability and working knowledge of ASR programs, with the intention of accounting for operational issues, construction approaches, and local differences.

There have been many changes in drilling technologies and subsurface condition assessments over the past 40 years, so especially for some earlier ASR systems, there were inconsistencies or missing parts in the data set. For this study, ASR sites with incomplete data were not used in associated statistical analyses. After removing sites with incomplete or questionable project data, 127 sites were included in the analysis. Linear regression and logistic regression models were run on the complete data set, using XLSTAT software for the linear regression and SPSS for the logistic regression, to help determine which variables may lead to the success or failure of an ASR. Within the limits of our data and the model, our goal was to estimate likelihood of successful future ASR projects given sufficient background information. (Contact us for details of the status of ASR programs.)

Analyzing the 2019 ASR Inventory

The updated database added 29 new sites to the previous inventory of ASR sites in the United States. The state with the most ASR sites is still Florida (Figure 1), with California and Texas next in line, and no new states were added. The greatest increase of ASR projects has been in Texas, although many of these are in study mode—i.e., no wells have been drilled yet—so the amount of new data was limited. The presence of ASR sites is not necessarily an indicator of the future of ASR projects; taking Florida as an example, more than half its sites are inactive or have wells that are no longer used as a result of recovery issues; metals were a previous concern, and while an agreement was reached with USEPA to resolve these issues, some Florida programs have not restarted.

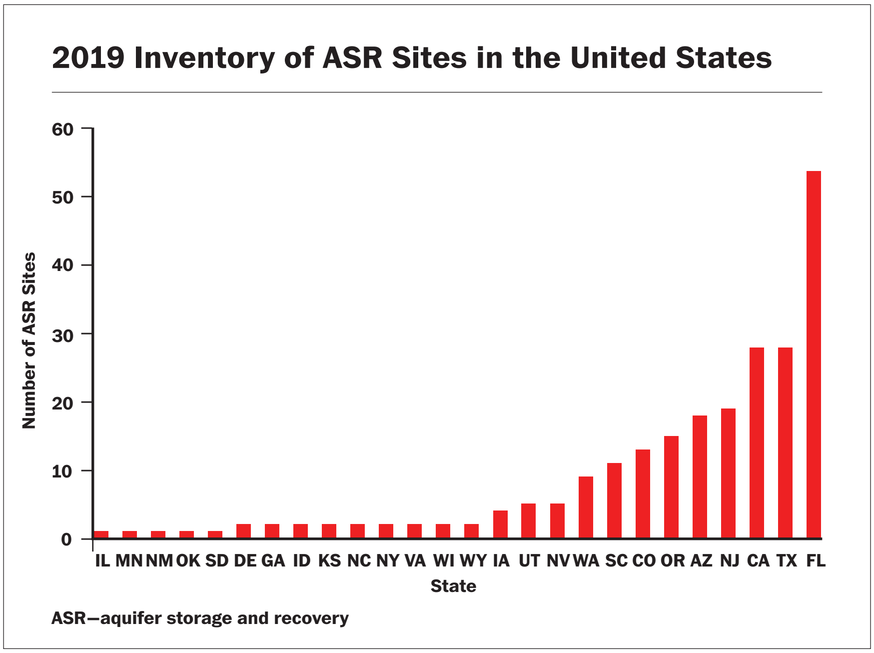

Figure 1

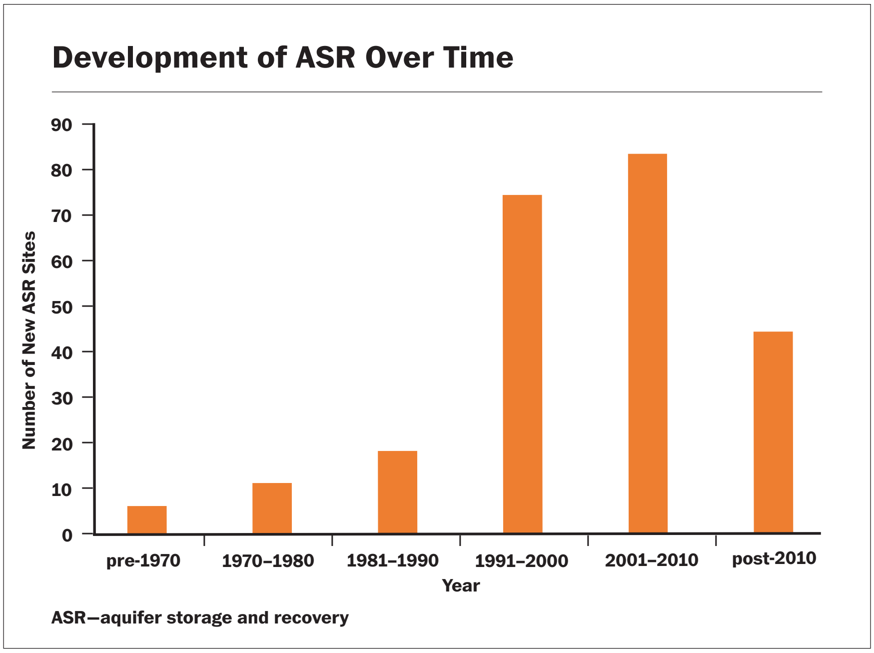

Figure 2

In California, many sites lack reliable water sources and are therefore inactive. At one point, the Metropolitan Water District of Southern California was going to deliver surface water supplies to ASR sites in the Los Angeles area, but changes to water supply reservoirs under then-governor Jerry Brown altered this effort. In the current data set, approximately 29% of ASR sites nationally were considered operational, while 33% of the sites were inactive. The remaining 38% are in test and study modes (including most of the new Texas sites).

In the aggregate, there were fewer active sites in 2019 compared with those in 2013, and part of this can be explained by test or study efforts that were discontinued (e.g., South Florida Water Management District and Cheyenne). The change has reduced the number of active sites from 74 in 2013 to 68 in 2019. Figure 2 shows that growth in the number of new sites initiated since 2010 has slowed compared with previous decades. In part, issues with water supply, regulations, and weather/droughts have all affected decisions to evaluate and invest in ASR projects.

The majority of sites are storing surface water (64%), and virtually all the new sites propose to use surface water; groundwater (21%) and reclaimed water (14%) make up the balance of what is stored using ASR projects in the United States. Likewise, use of withdrawn water is primarily for raw (untreated) and direct public water supplies as opposed to other uses, including irrigation, reuse, canal recharge, industrial, and firefighting. All of the new ASR sites propose raw water for treatment for indirect or direct potable use.

ASR wells often face challenges, which for this study included high arsenic levels, clogging, recovery, water supply reliability, and lack of demand. The challenges have not significantly changed as new wells have been installed. In some cases, the lack of water demand or the absence of water sources has led to inactivity of ASR projects; several of these projects could be restarted if conditions change.

> **In the end, an area's geological formation may be the most useful parameter to predict future ASR success, but further study is required.**

Figure 3 shows the most likely ASR well diameter is less than 15 inches, with 15–20 inches being the second most common size. The casings continue to be primarily steel (Figure 4). The casing depths are mostly less than 750 feet from land surface (Figure 5), and the main storage units are limestone and alluvial formations (Figure 6). Because so many systems are in test, study, or inactive stages, it's

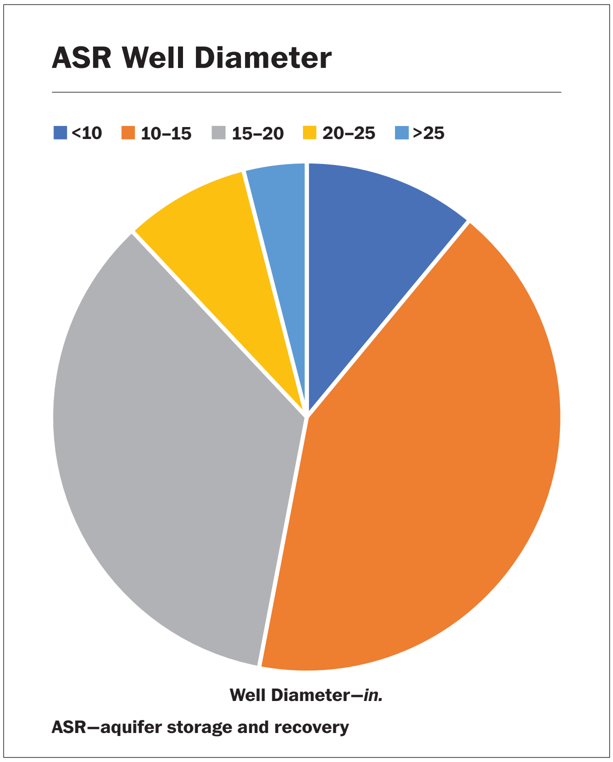

Figure 3

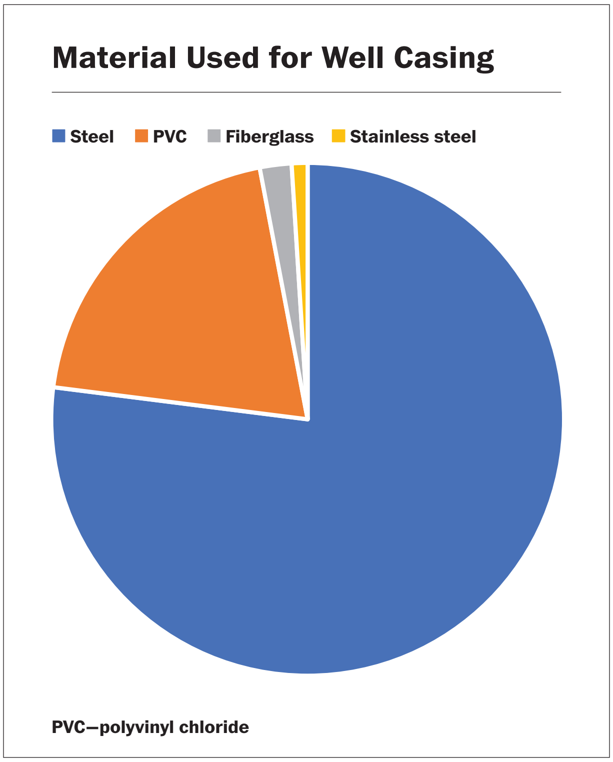

Figure 4

not surprising that more than half the systems have had fewer than 10 cycles (Figure 7).

The largest ASR project stored more than 10 billion gallons, but the majority (73%) were less than 1 billion gallons, and the second-largest group (15%) stored between 1 billion and 2 billion gallons.

The injection and withdrawal rates tend to be around 1 mgd, a threshold that suggests high-volume ASR wells are not achievable. From the current database, 40% of injection rates were less than 1.0 mgd and 36% were in the range of 1.0–1.5 mgd. Likewise, 31% of withdrawal rates were less than 1.0 mgd and 26% were in the range of 1.0–1.5 mgd. Most injection/withdrawal ratios are less than 1.25 (see Figure 8).

Estimating Future Success—or Not

As shown in Bloetscher (2018), when ASR wells were grouped into US regions, significant correlations existed:

- Sand and sandstone formations in the East
- Unconfined alluvial formations in the West/Southwest
- Confined limestone formations in Florida
- Storage of reclaimed water for irrigation

However, these are general attributes of these regions and are not useful for predicting success at the local level. Using other data fields, a linear regression model was developed to provide preliminary estimates for ASR project success. The resulting model provided good predictions of success or failure, but it included many redundant factors indicative of success (e.g., number of wells, injection/withdrawal cycles, water stored). Independent variables—number of active wells and water supply sources—contributed to predicting success (with positive coefficients). Attributes or variables that indicated project failure included low number of cycles (<20), limestone formations, and use of water.

A linear regression coefficient matrix, which identified the number of sites that were correctly classified and those that were not, yielded a correct prediction 79% of the time. Variables that had a strong influence on increasing the odds of success were the number of wells and number of active wells (which makes sense since that's what is being tested for); water supply (all sources); number of cycles; injection formation; and injection capacity (measured in million gallons per day).

All other variables—except start date, number of wells, and depth of wells, which had little or no effect—reduced the odds of ASR success. (Contact us for model-specific details.)

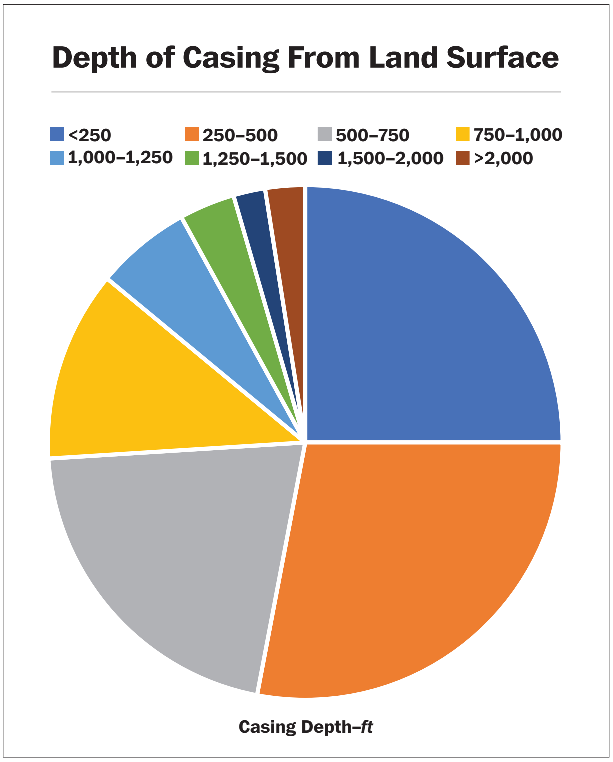

Figure 5

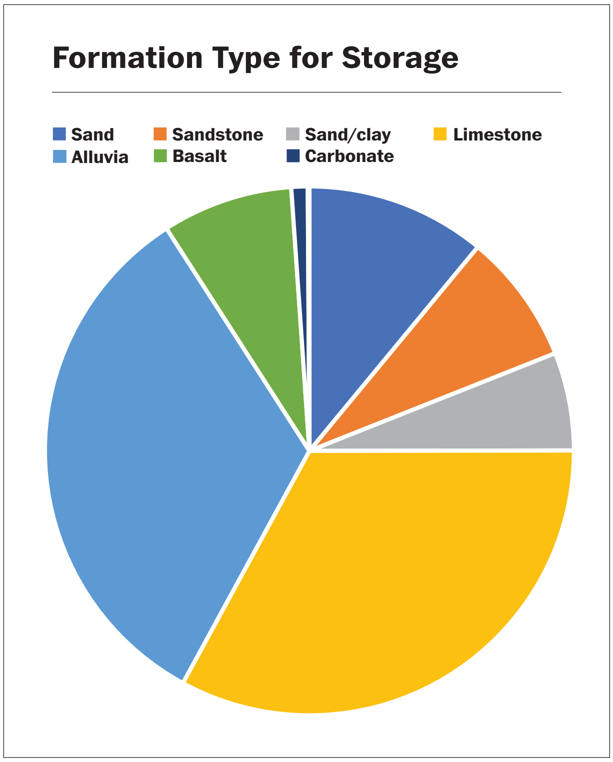

Figure 6

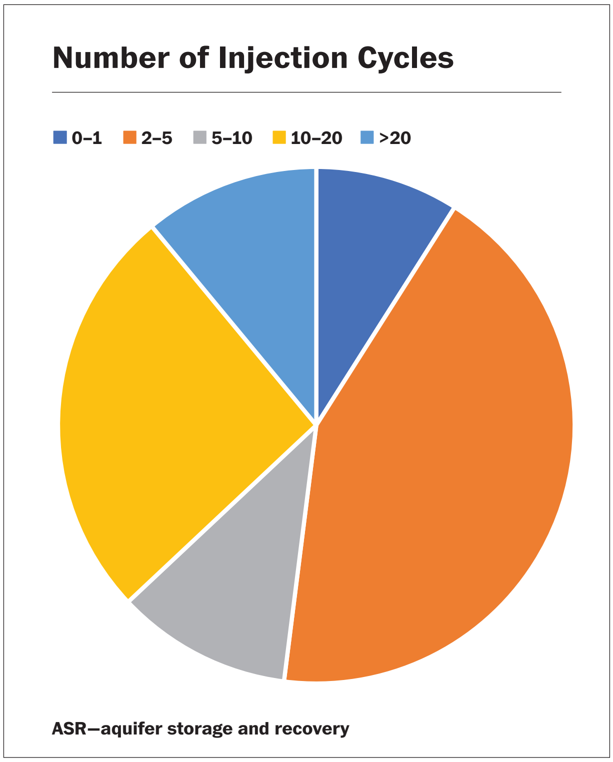

Figure 7

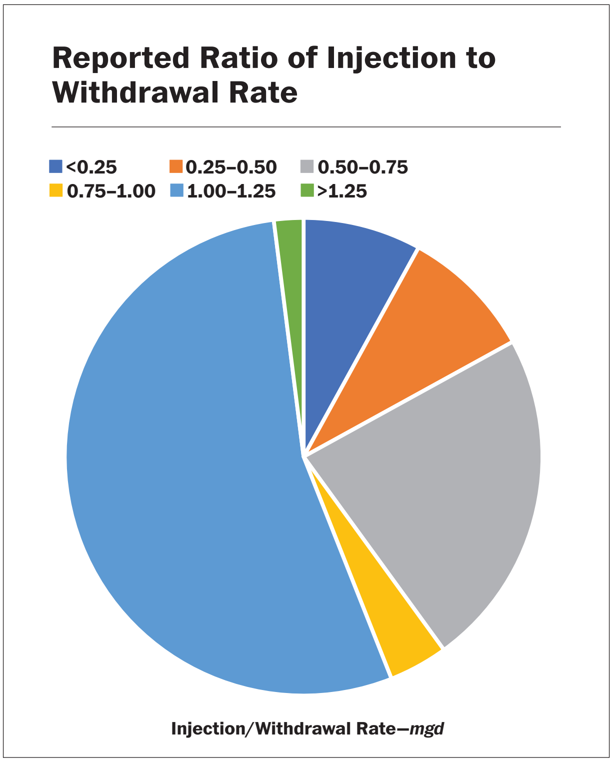

Figure 8

> **The presence of ASR sites is not necessarily an indicator of the future of ASR projects.**

Some variables, such as the number of wells, storage cycles, and amount of water stored, are inherently measures of ASR success, so these data aren't valuable in predicting success at sites with no injection data. Therefore, to determine the influence of the other variables in the analysis, variables that correlate highly with successful projects were removed: influence of number of wells, storage cycles, and amount of water stored. The remaining variables in the model showed that positive influence was exerted by water supply and injection formations, except limestone. Negative influence was found in two variables: use of water and injection formation (limestone). Using this approach, the model predicted the correct status 64.8% of the time.

A logistic regression model was run using the reduced variable set; injection capacity, withdrawal capacity, and ratio of planned pumping in or out had slight positive effects on the odds of success. Estimated start date and well depth did not have any effect on the odds of success. All other variables reduced the odds of ASR success (i.e., uses for the water, limestone and carbonate formations). The logistic model correctly predicted the ASR site status 68% of the time. Both the linear regression and the logistic regression were close in this case, but only as an initial estimate of ASR project success. The use of binary variables is typical of logistic regression and may be a reason the answers are close.

Of the 233 total ASR sites in the updated US inventory, 127 collected sufficient data to evaluate their success or failure. In the end, an area's geological formation may be the most useful parameter to predict future ASR success, but further study is required. Data on well construction are not indicative of success because well construction accounts for the subsurface formations onsite. Information on water quality in the formation and confinement layers was missing for many ASR sites, but both are likely to have predictive value for ASR project success. As more utilities across North America explore ASR and more projects come online, it is hoped that more complete information will improve our ability to predict where ASR systems will find success.

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