Statistical Analyses of Successes and Failures of Aquifer Storage & Recovery Systems in the U.S.

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Introduction

- The concept of Aquifer Storage and Recovery (ASR) has been applied in the U.S. since the late 1940s with limited development occurred until the 1990s.
- Common applications are the injection of potable or raw surface water into an aquifer with the intention to provide future withdrawal for augmentation of water supplies later.
Regulatory requirements

- Federal underground injection control – Class V wells
- State zones of discharge or mixing zone – allow exceedance of groundwater standards for some distance from the well
- Water rights and allocations
- Use of reclaimed water
- Use of impaired water
Introduction

States with ASR-specific Statutes or Rules

- States with comprehensive ASR statutes/rules
- States with ASR statutes/rules for water rights only
- States with ASR (operational or pilot) with statutes/rules under development
- States with ASR (operational or pilot) but no ASR statutes/rules
- States without ASR, with statute prohibiting ASR
Introduction

1985 – ASR Projects in 3 states
1995 – ASR Projects in 8 states
2001 – ASR Projects in 15 states
2010 – ASR Projects in 27 states
Introduction

- A survey was conducted in 2013 for the development of an American Water Works Association (AWWA) manual of practice on ASR (M63) – published in 2015
- The survey identified 204 ASR sites (with over 700 wells) in the U.S. for which data were collected
Data Collection Effort

Data elements:

- Well sites and status
  - State
  - Date the program was initiated or first well drilled
  - Stage of development/status – study, testing, operational, or abandoned
  - Number of wells drilled
  - Number of abandoned wells
  - Number of ASR wells onsite to accommodate design capacity
  - Number of abandoned wells or wells no longer in service
Data Collection Effort

- Data elements:
  - Operation status
    - Source of water – ground, surface, reclaimed, or industrial
    - Use of recovered water – irrigation, potable water supply, raw water supply, or surface water augmentation
    - Number of storage cycle (estimated; indicative of age)
    - Injection rate for individual well
    - Withdrawal rate for individual well
    - Inject and withdrawal ratio (calculated)
    - Peak flow (measure of total available capacity)
    - Total water stored (measure of storage)
    - Operational issues
Data Collection Effort

- **Data elements:**
  - **Well characteristics**
    - Depth of well casing below the surface
    - Depth of well borehole
    - Casing diameter
    - Presence of tubing and/or packer
    - Casing material – steel, PVC, fiberglass, stainless steel
Data Collection Effort

- Data elements:
  - Injection zone
    - Formation – limestone, sand, sandstone, basalt, or alluvial
    - Transmissivity
    - Total dissolved solids of water in injection formation
    - Type of confinement – clay, dolomite, silt, shale, sandstone, basalt, or none
    - Number of monitoring wells
In addition to M63, two articles were published

Initial Data Update

- Since 2013, limited tracking of the status of some of the ASR system development efforts
  - Limited updates of Florida data in 2016 and 2018
  - Led to another article:
At the 2019 GWPC UIC Conference, statistics and data analysis results were presented – leading to productive discussion on the state of ASR activities post-2013.
2019 Data Update Effort

Post-2013 updates

- Georgia decided not to permit ASR systems
- Texas included ASR in water resources portfolio
- Florida & EPA entered into an agreement to address arsenic in recovered water
- Washington undertook a feasibility study
- Cheyenne, WY ceased pursuing its ASR project
- Army Corps of Engineers completed 2 test projects for the South Florida Water Management District
- Utah continues to evaluate ASR and surface reservoirs in high growth areas of the state
2019 Data Update Effort

- Dataset updated through the Fall of 2019
- 29 new sites added
- Large increase in Texas – study mode (no new wells)
- Many inactive sites and wells
- A net decline in active sites (74 to 68)
Current Effort

- 2013 data (204 ASR sites)
- 2019 data (29 new sites)
Current Effort

- **Summary**
  - Florida - #1 in ASR sites, followed by California & Texas
  - Texas – highest increase, primarily in study mode
Current Effort

- **Summary**
  - Source of water – dominated by surface water
Current Effort

- **Summary**
  - Reported use of the recovered water

![Bar chart showing the use of recovered water](chart.png)
Current Effort

- **Summary**
  - Challenges encountered

- **Clogging**
  - Mechanical
  - Chemical
  - Biological

- **Water Quality**
  - Leaching
  - Disinfection byproducts
  - Carbon dioxide

- **Low recovery and expectation**
2019 Data Analysis

- Use of linear regression and logistic regression
  - Identify variables likely to predict success of an ASR site
  - Missing data is still a challenge
  - Only include Active and Inactive sites (i.e., study and test sites are excluded)
2019 Data Analysis

- **Linear regression**
  - Dependent variable – status of ASR site
  - Independent variables – weights
  - Correct prediction – 79%

- **Positive influence**
  - Number of active wells
  - Water supply
  - Sand/Sandstone and basalt formation

- **Negative influence**
  - Number of wells
  - Low number of cycles
  - Use of water
  - Limestone and carbonate formations
2019 Data Analysis

Linear Regression Variable Weight (full dataset)

Status of ASR program / Standardized coefficients
(95% conf. interval)
2019 Data Analysis

- Logistic regression
  - Dependent variable – status of ASR site (binary)
  - Independent variables – odd ratios
  - Correct prediction – 96%

- Increasing the odds of success
  - Number of active wells
  - Water supply
  - Number of cycles
2019 Data Analysis

Logistic Regression Results - All Variables. Highlighted and Bolded Variables Contribute to ASR Success

<table>
<thead>
<tr>
<th>Variables</th>
<th>B</th>
<th>S.E</th>
<th>Sig.</th>
<th>Exp(B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Est_Start_Date</td>
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<td>0.121</td>
<td>0.803</td>
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</table>
2019 Data Analysis

Logistic Curve (full dataset)
2019 Data Analysis

- Remove variables that are intrinsic to the success of a project
  - Number of active wells
  - Number of injection/withdrawal cycles
2019 Data Analysis

- Linear regression (reduced dataset)
  - Dependent variable – status of ASR site
  - Independent variables – weights
  - Correct prediction – 66%

- Positive influence
  - Water supply
  - Injection formation – except limestone and carbonate

- Negative influence
  - Use of water
  - Injection Formation – limestone and carbonate
2019 Data Analysis

Linear Regression Variable Weight (reduced dataset)
2019 Data Analysis

- Logistic regression
  - Dependent variable – status of ASR site (binary)
  - Independent variables – odd ratios
  - Correct prediction – 63%

  - Increasing the odds of success
    - Water supply
    - Injection formation – except limestone
    - Injection / Withdrawal ratio
2019 Data Analysis

Logistic Regression Results - Reduced Dataset. Highlighted and Bolded Variables Contribute to ASR Success

<table>
<thead>
<tr>
<th>Variables</th>
<th>B</th>
<th>S.E.</th>
<th>Sig.</th>
<th>Exp(B)</th>
</tr>
</thead>
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</table>
2019 Data Analysis

Logistic Curve (reduced dataset)
Observations

- **Data Gaps:**
  - Although data on ASR projects were available, much were missing (e.g., drill logs, water quality, injection zone properties, and others), especially for older wells.
  - Study sites generally have limited geologic data and no test well data so predicting success is difficult.
  - The lack of a centralized system for permitting makes data requirements high variable.
Observations

- These are 233 sites
- ASR projects have been with us for over 40 years, with over 200 sites in 27 states (at least investigated)
- There were 68 ASR systems in operation
- ASR systems encountered challenges such as clogging, metal leaching, and low recovery rate
- ASR should be in the toolbox for water systems to address water availability challenges
- Success of ASR project is not guaranteed but careful planning and forward thinking can help
Questions?

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