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

Chi Ho Sham, Ph.D., Eastern Research Group, Inc., Lexington, MA
Fred Bloetscher, Ph.D., Florida Atlantic University, Boca Raton, FL
Samuel Ratick, Ph.D., Clark University, Worcester, MA

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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.
Introduction

- 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
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
Initial Data Analyses

- 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:
2019 Data Update Effort

- 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
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>
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<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>
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<th>B</th>
<th>S.E</th>
<th>Sig.</th>
<th>Exp(B)</th>
</tr>
</thead>
<tbody>
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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
Chi Ho Sham, Ph.D.
VP and Chief Scientist
Eastern Research Group
110 Hartwell Ave., #1
Lexington, MA 02421
Phone: 781-674-7358
E-mail: ChiHo.Sham@erg.com