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

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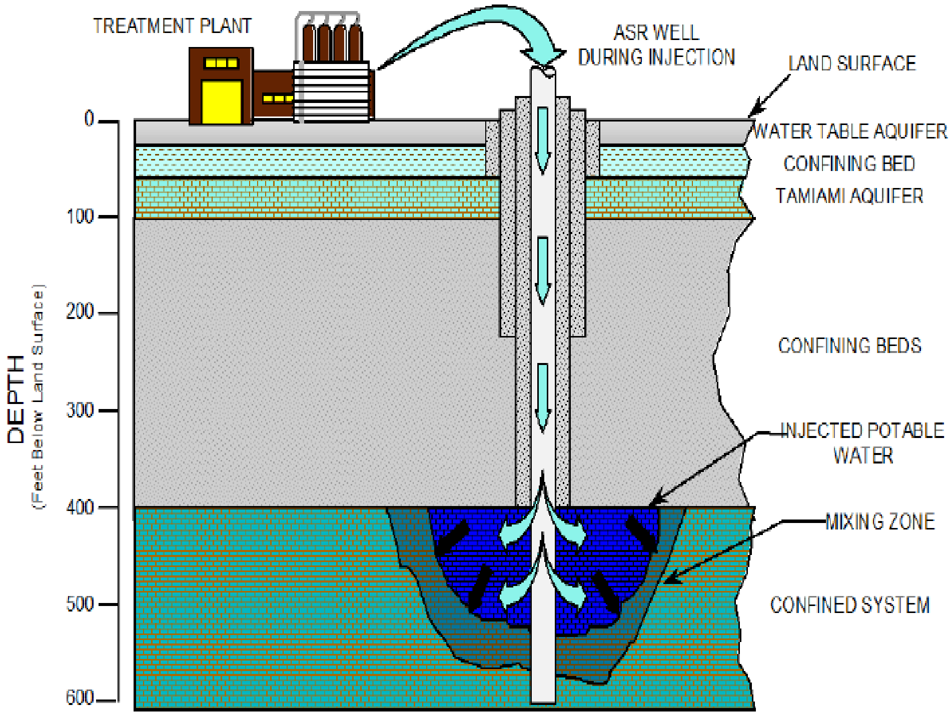
Introduction

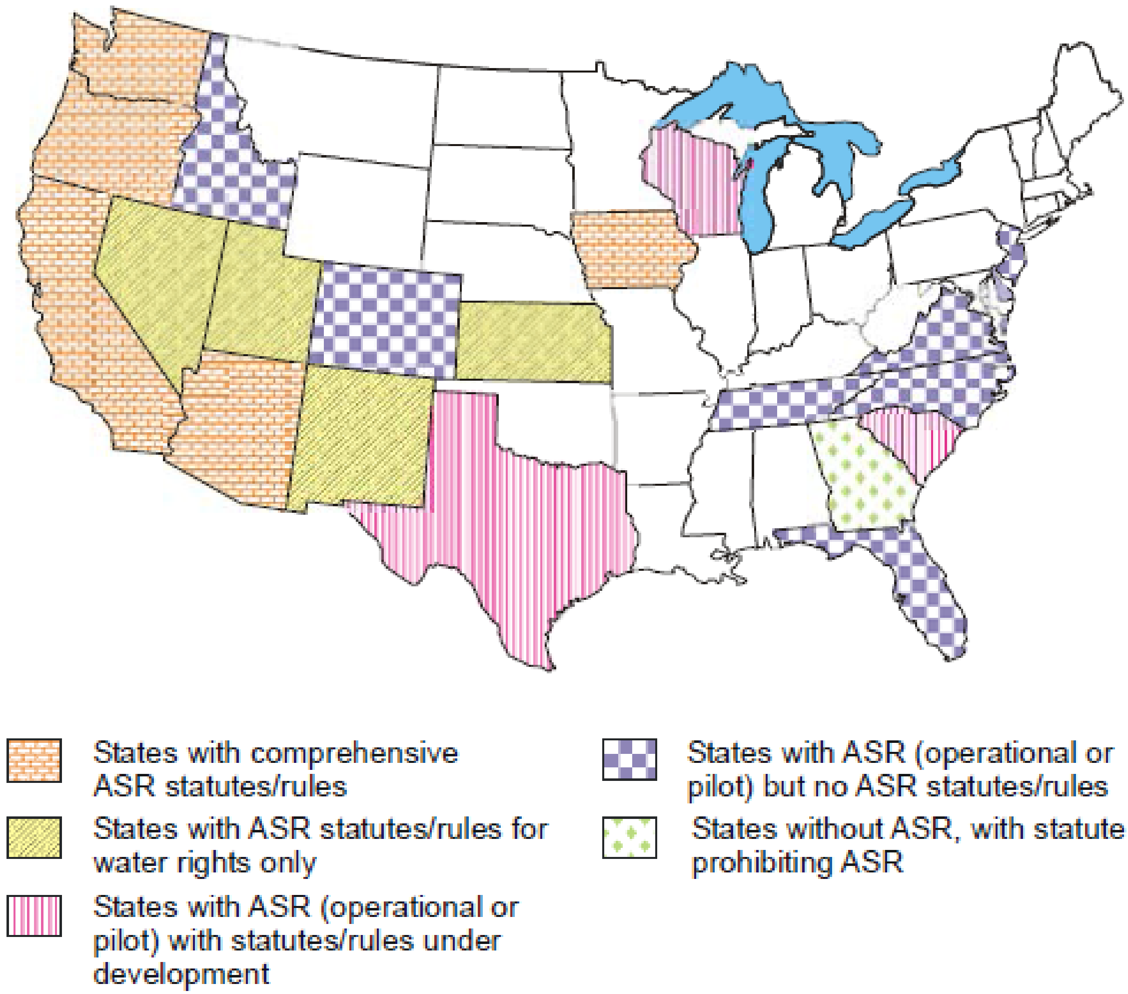
- The concept of Aquifer Storage and Recovery (ASR) has been applied in the U.S. since the late 1940s with limited development occurred until the 1990s
- Common applications are the injection of potable or raw surface water into an aquifer with the intention to provide future withdrawal for augmentation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



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

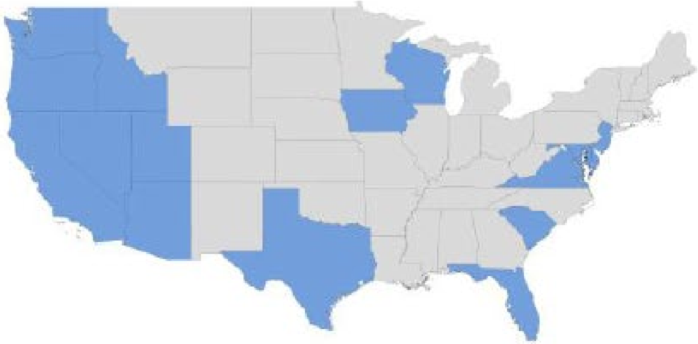
Introduction



States with ASR-specific Statutes or Rules

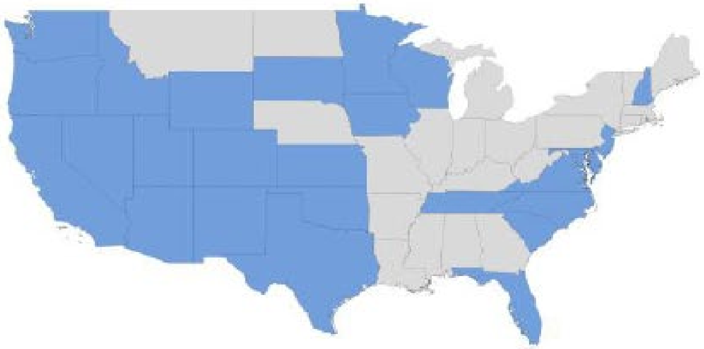
Introduction

1985 – ASR Projects in 3 states



2001 – ASR Projects in 15 states

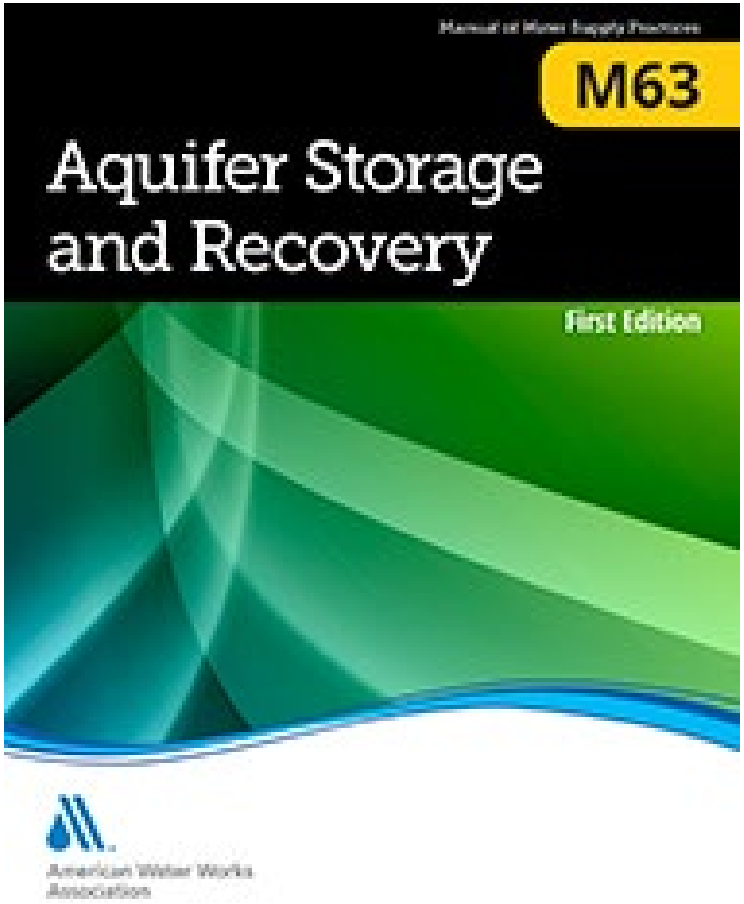
1995 – ASR Projects in 8 states



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

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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
  - Bloetscher, F., Sham, C.H., Danko III, J.J. and Ratick, S. (2014) Lessons Learned from Aquifer Storage and Recovery (ASR) Systems in the United States. Journal of Water Resources and Protection, 6, 1603-1629.
  - Bloetscher, F., Sham, C.H., Danko III, J.J. and Ratick, S. (2015) Status of Aquifer Storage and Recovery in the United States – 2013. British Journal of Science, 12(2), 70-88.

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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:
    - Bloetscher, F. (2018) Can Prior Experience Provide a Means to Predict Success of Future Aquifer Storage and Recovery Systems? American Journal of Environmental Engineering, 8(5), 181-200.

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

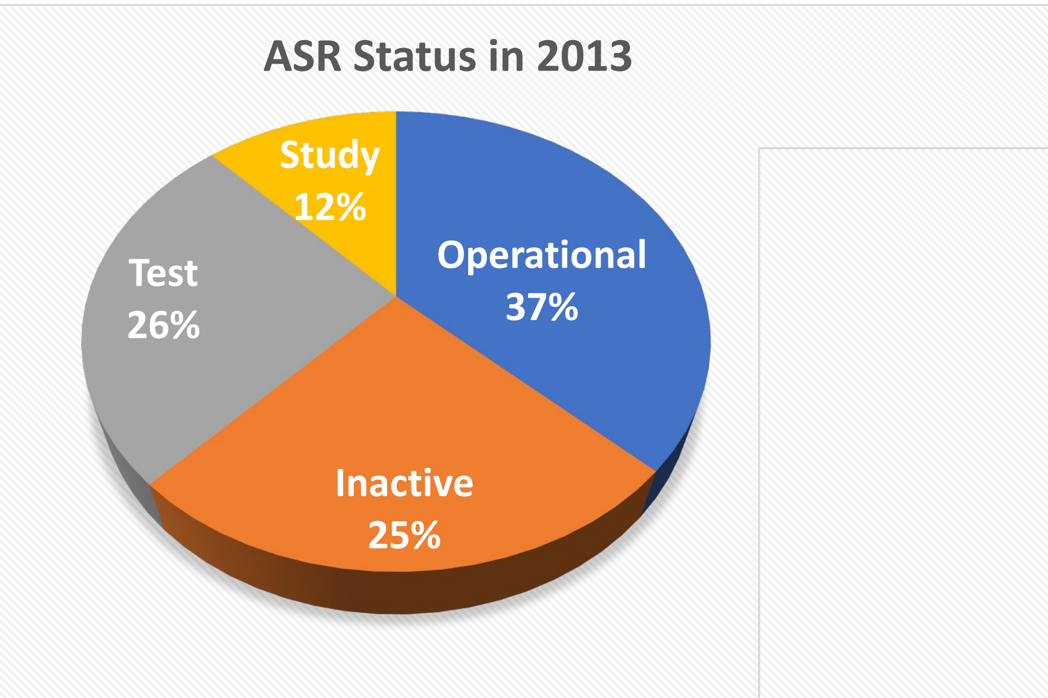
- Post-2013 updates
  - Georgia decided not to permit ASR systems
  - Texas included ASR in water resources portfolio
  - Florida & EPA entered into an agreement to address arsenic in recovered water
  - Washington undertook a feasibility study
  - Cheyenne, WY ceased pursuing its ASR project
  - Army 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

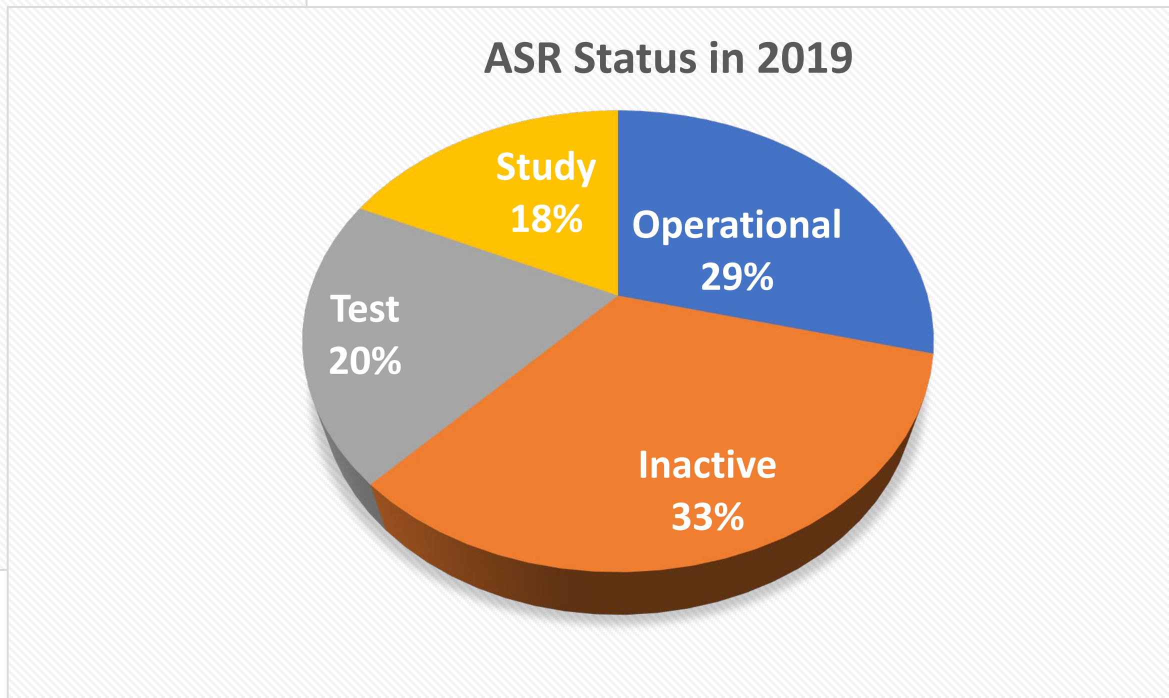
2019 Data Update Effort

- 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

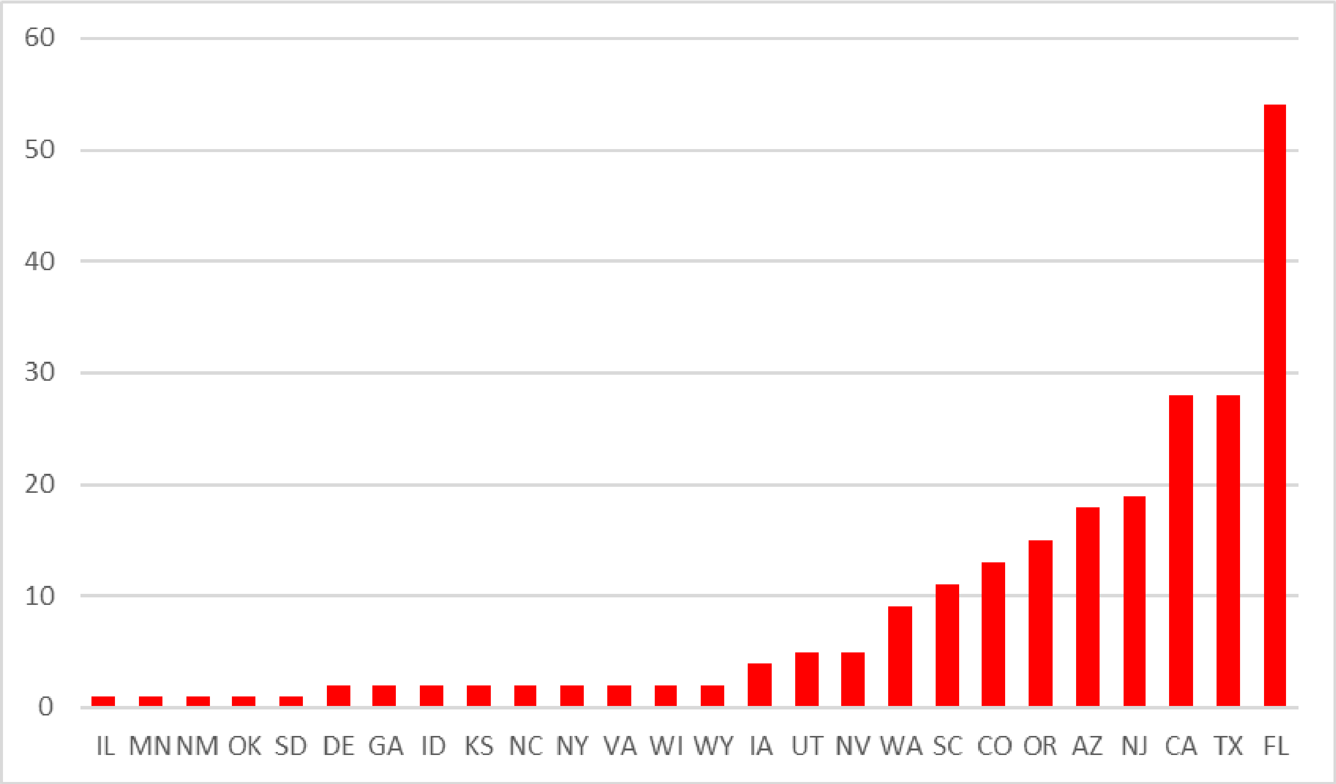
- 2013 data (204 ASR sites)
- 2019 data (29 new sites)





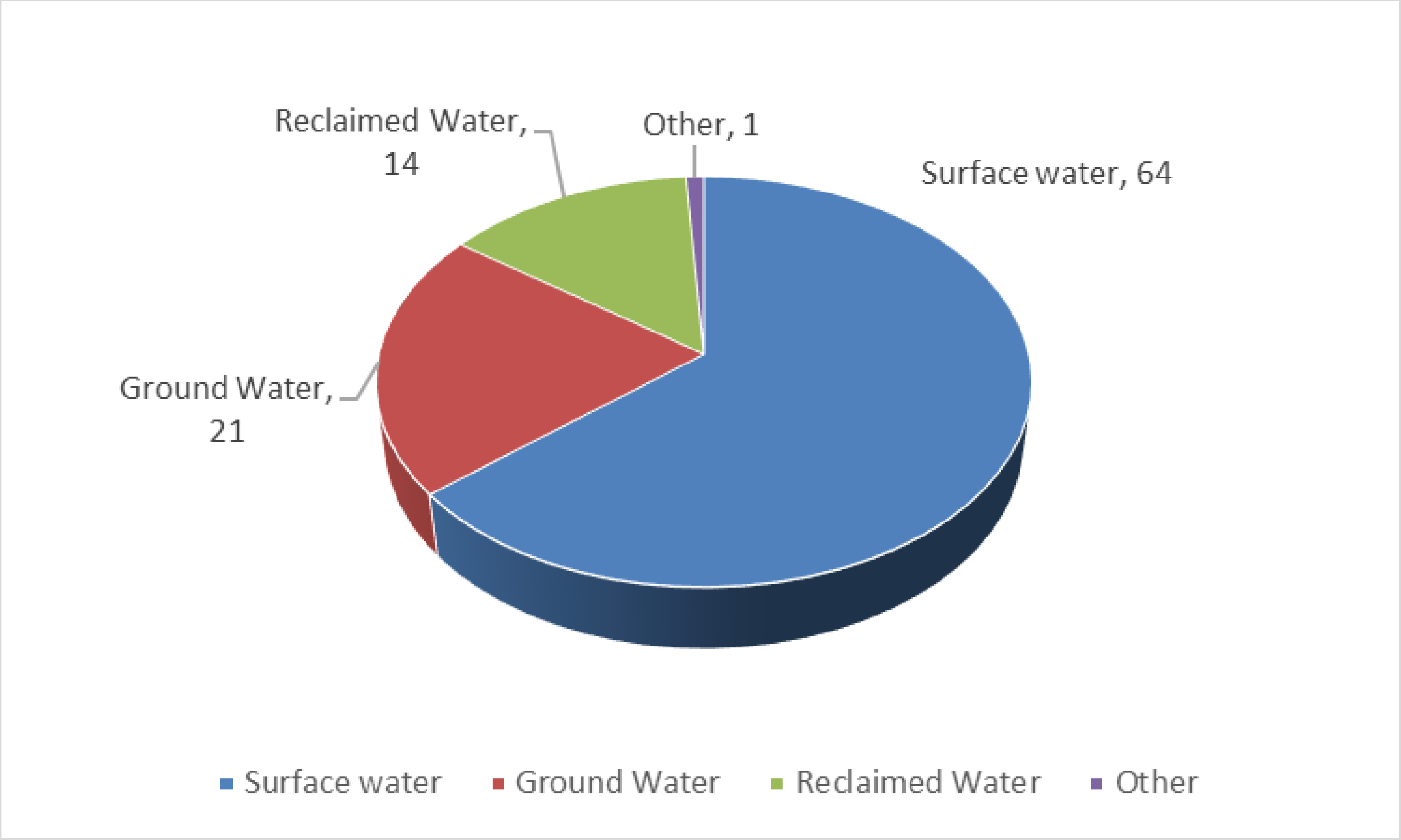
Current Effort

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



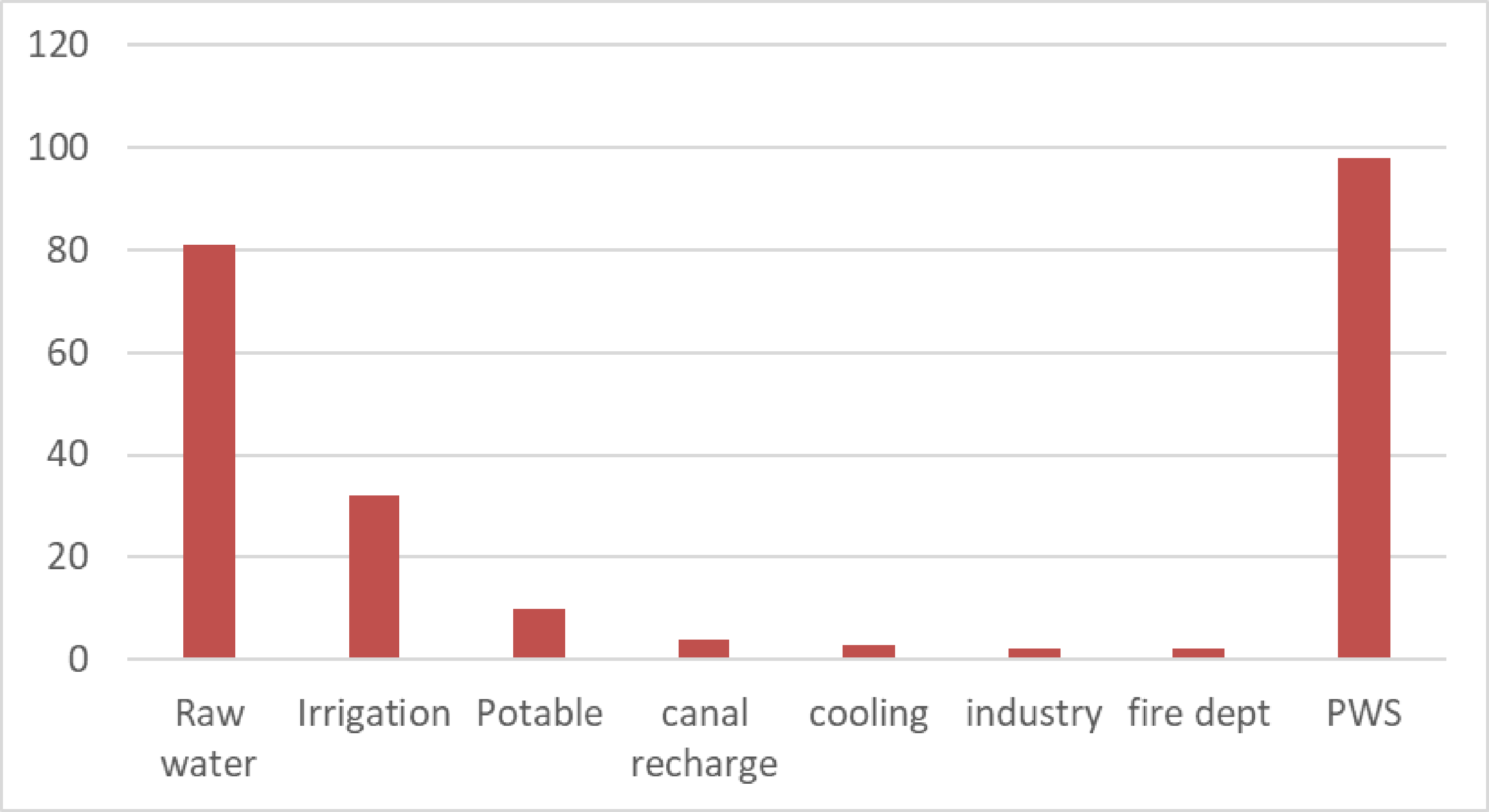
Current Effort

- Summary
  - Source of water – dominated by surface water



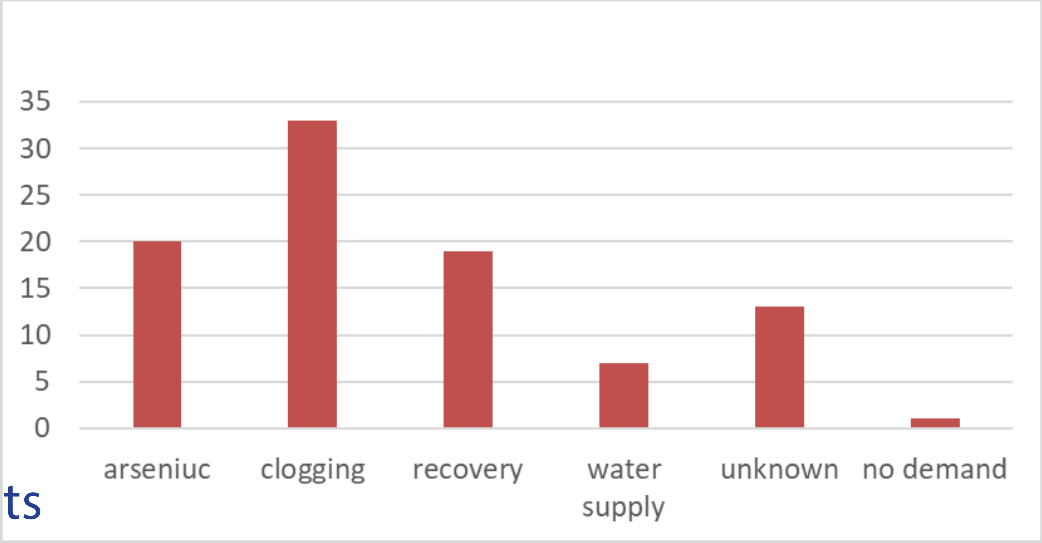
Current Effort

- 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)

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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

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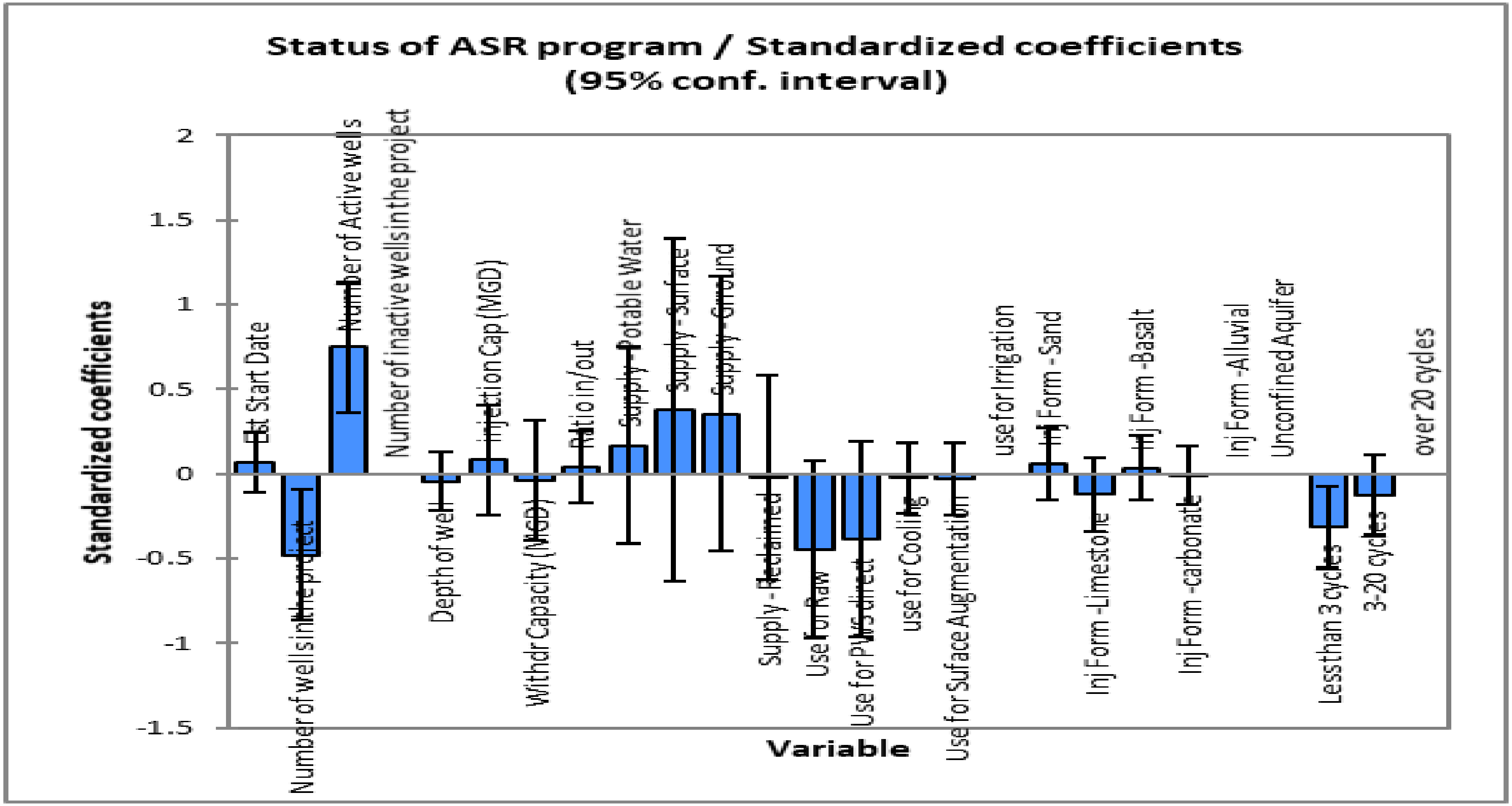
2019 Data Analysis

Linear Regression Variable Weight (full dataset)



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

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2019 Data Analysis

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

Variables	B	S.E.	Sig.	Exp(B)
Est_Start_Date	0.030	0.121	0.803	***1.031***
Numb_Wells	0.176	0.115	0.126	***1.192***
Numb_Active_Wells	8.489	3.099	0.006	***4862.431***
Supply_Potable_Water	18.347	17552.895	0.999	***92889739.897***
Supply_Surface	17.519	17552.895	0.999	***40604183.809***
Supply_Grround	16.574	17552.895	0.999	***15770496.574***
Use_for_Raw	-16.754	17552.895	0.999	0.000
Use_for_PWS_direct	-16.340	17552.895	0.999	0.000
use_for_Cooling	-15.153	27922.397	1.000	0.000
Use_for_Suface_Augmentation	-15.780	17552.898	0.999	0.000
Inj_Form_Sand	-3.529	4.226	0.404	0.029
Inj_Form_Limestone	-4.886	4.191	0.244	0.008
Inj_Form_Basalt	-1.514	4.092	0.711	0.220
Inj_Form_Alluvial	-7.798	4.177	0.062	0.000
Depth_of_well	0.000	0.002	0.874	1.000
Less_than_3_cycles	6.052	8.000	0.449	***424.801***
Three_20_Cycles	9.825	4.895	0.045	***18497.657***
injection_Cap_MGD	0.728	1.488	0.624	***2.071***
Withdr_Capacity_MGD	-1.218	0.900	0.176	0.296
Ratio_in_out	-5.952	3.770	0.114	0.003
Constant	-64.904	238.108	0.785	0.000

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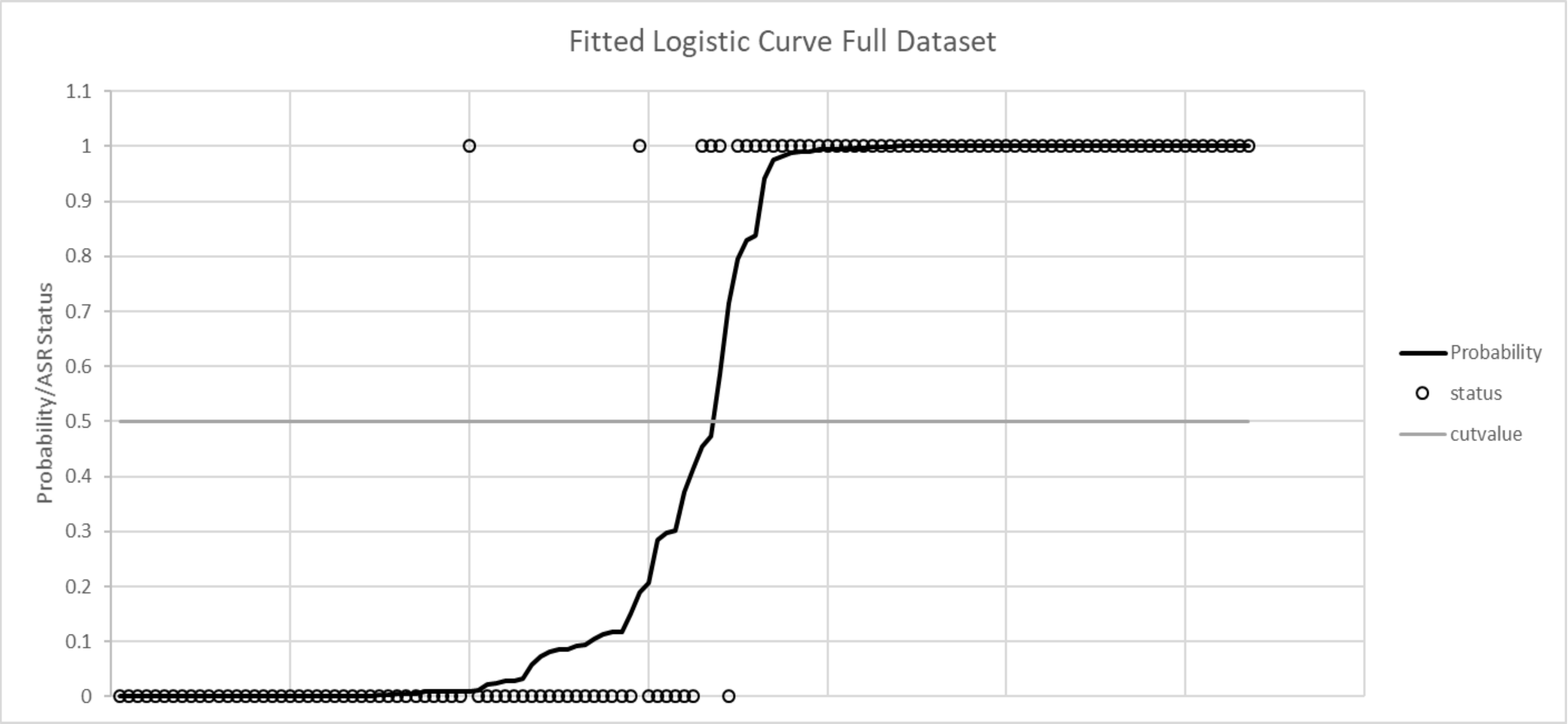
2019 Data Analysis

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

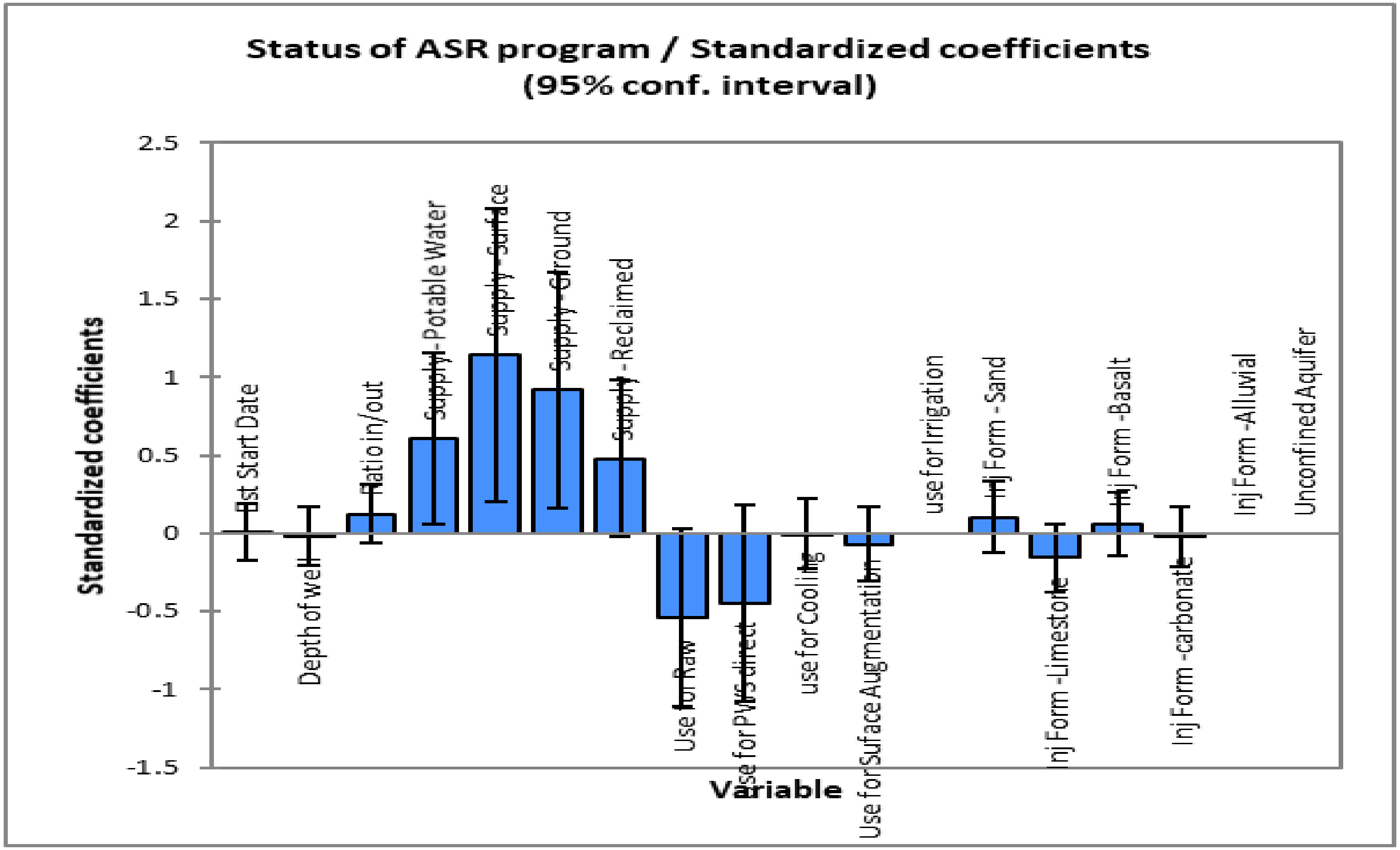
- Linear regression (reduced dataset)
  - Dependent variable – status of ASR site
  - Independent variables – weights
  - Correct prediction – 66%

- 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)



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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

Variables	B	S.E.	Sig.	Exp(B)
Est_Start_Date	-0.001	0.021	0.945	0.999
Supply_Potable_Water	20.953	22436.200	0.999	***1258338036.638***
Supply_Surface	21.217	22436.200	0.999	***1638277926.057***
Supply_Grround	21.302	22436.200	0.999	***1784379791.873***
Use_for_Raw	-21.647	22436.200	0.999	0.000
Use_for_PWS_direct	-21.136	22436.200	0.999	0.000
use_for_Cooling	-0.233	36160.264	1.000	0.792
Use_for_Suface_Augmentation	-20.391	22436.200	0.999	0.000
Inj_Form_Sand	0.872	1.661	0.600	***2.392***
Inj_Form_Limestone	-0.411	1.619	0.800	0.663
Inj_Form_Basalt	0.815	1.771	0.645	***2.260***
Inj_Form_Alluvial	0.455	1.585	0.774	***1.577***
Depth_of_well	0.000	0.000	0.843	1.000
Ratio_in_out	0.402	0.379	0.289	***1.494***
Constant	2.321	42.312	0.956	10.187

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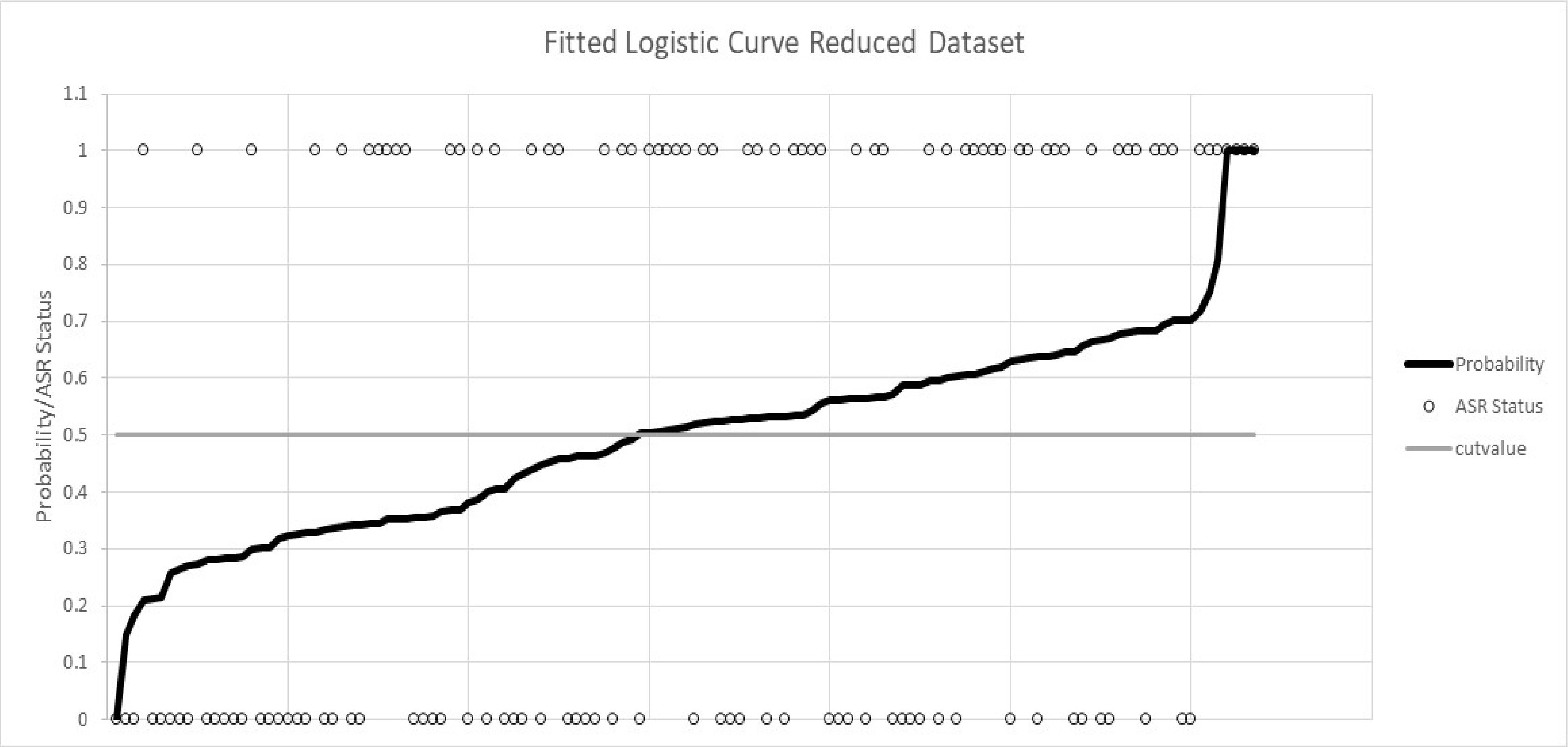
2019 Data Analysis

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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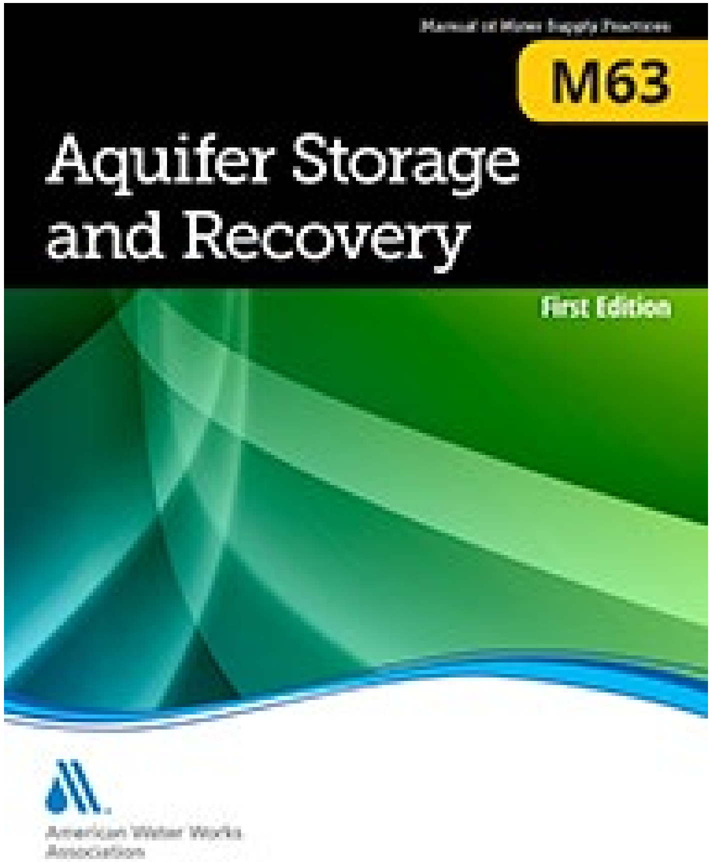

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