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

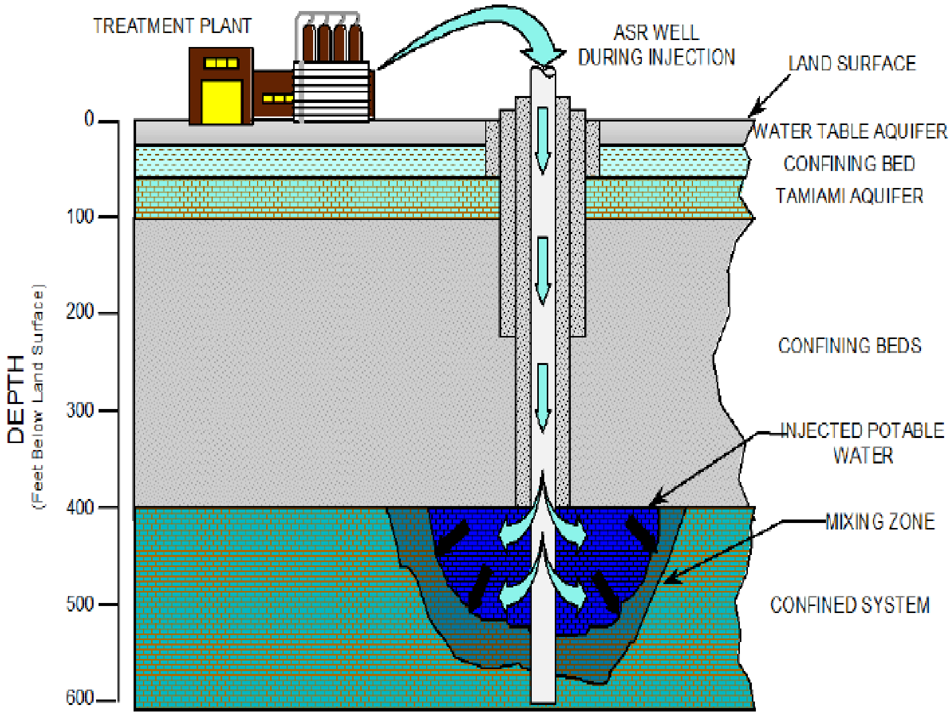
Chi Ho Sham, Ph.D., Eastern Research Group, Inc., Lexington, MA
Fred Bloetscher, Ph.D., Florida Atlantic University, Boca Raton, FL
Samuel Ratick, Ph.D., Clark University, Worcester, MA

February 18, 2020

Ground Water Protection Council, Underground Injection Control Conference, San Antonio, TX

Introduction

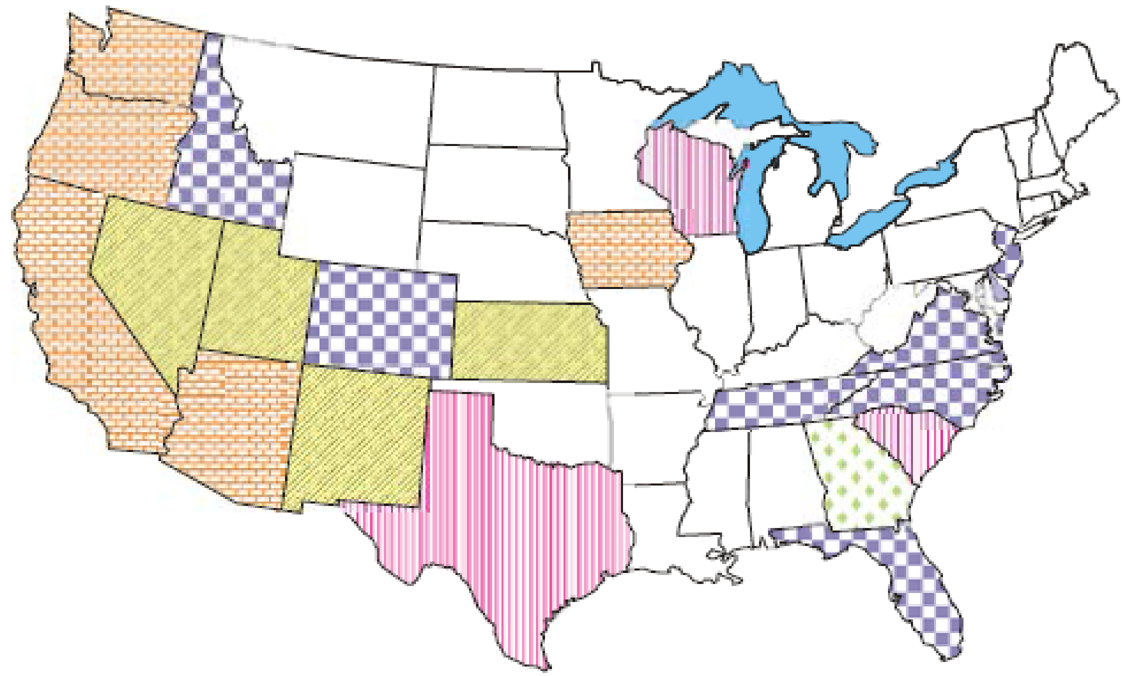
- The concept of Aquifer Storage and Recovery (ASR) has been applied in the U.S. since the late 1940s with limited development occurred until the 1990s
- Common applications are the injection of potable or raw surface water into an aquifer with the intention to provide future withdrawal for augmentation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

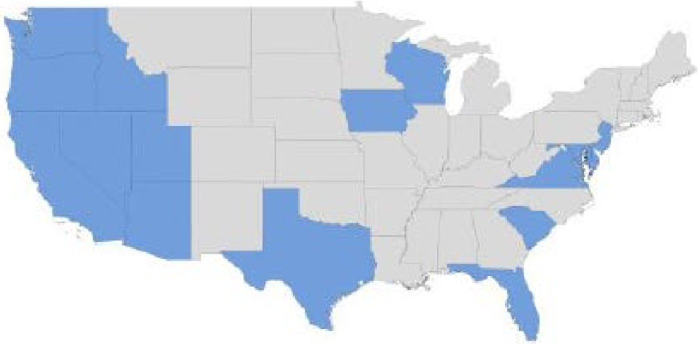


- States with comprehensive ASR statutes/rules
- States with ASR statutes/rules for water rights only
- States with ASR (operational or pilot) with statutes/rules under development
- States with ASR (operational or pilot) but no ASR statutes/rules
- States without ASR, with statute prohibiting ASR

States with ASR-specific Statutes or Rules

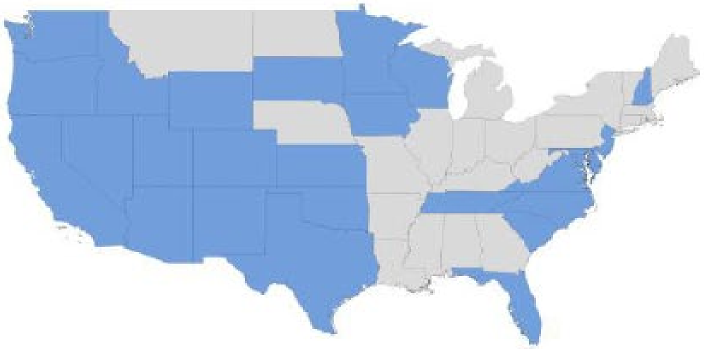
Introduction

1985 – ASR Projects in 3 states



2001 – ASR Projects in 15 states

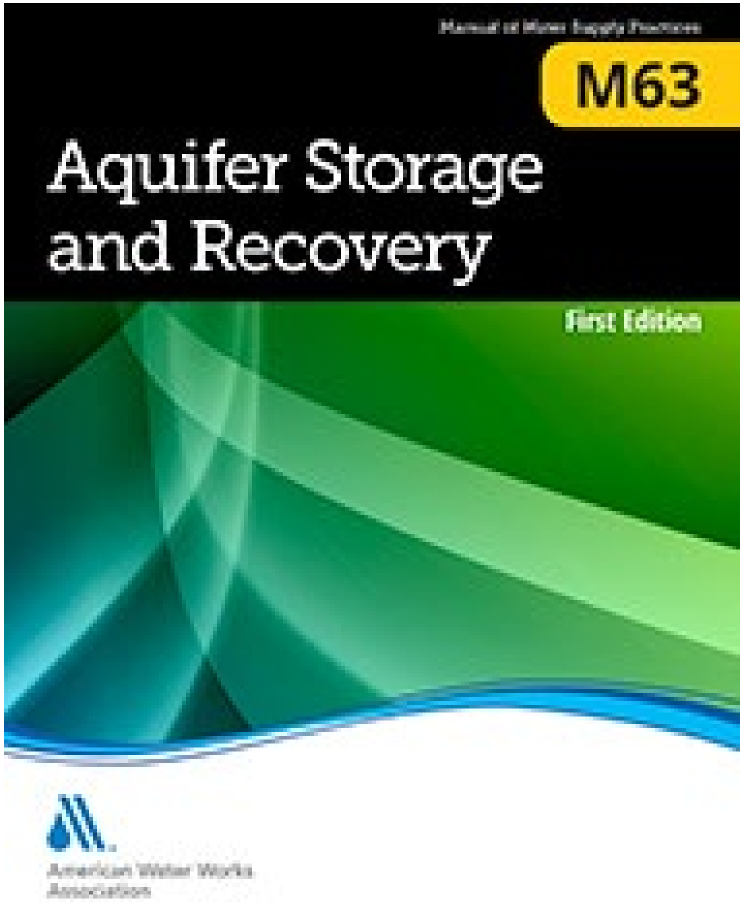
1995 – ASR Projects in 8 states



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

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.

ERG

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.

ERG

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

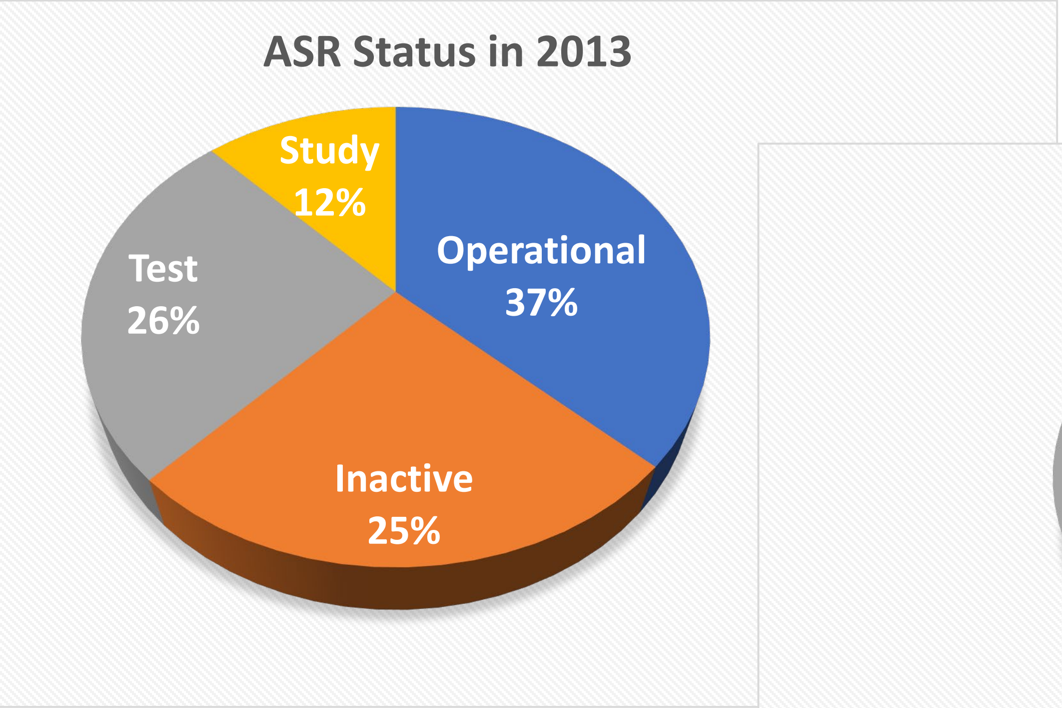
2019 Data Update Effort

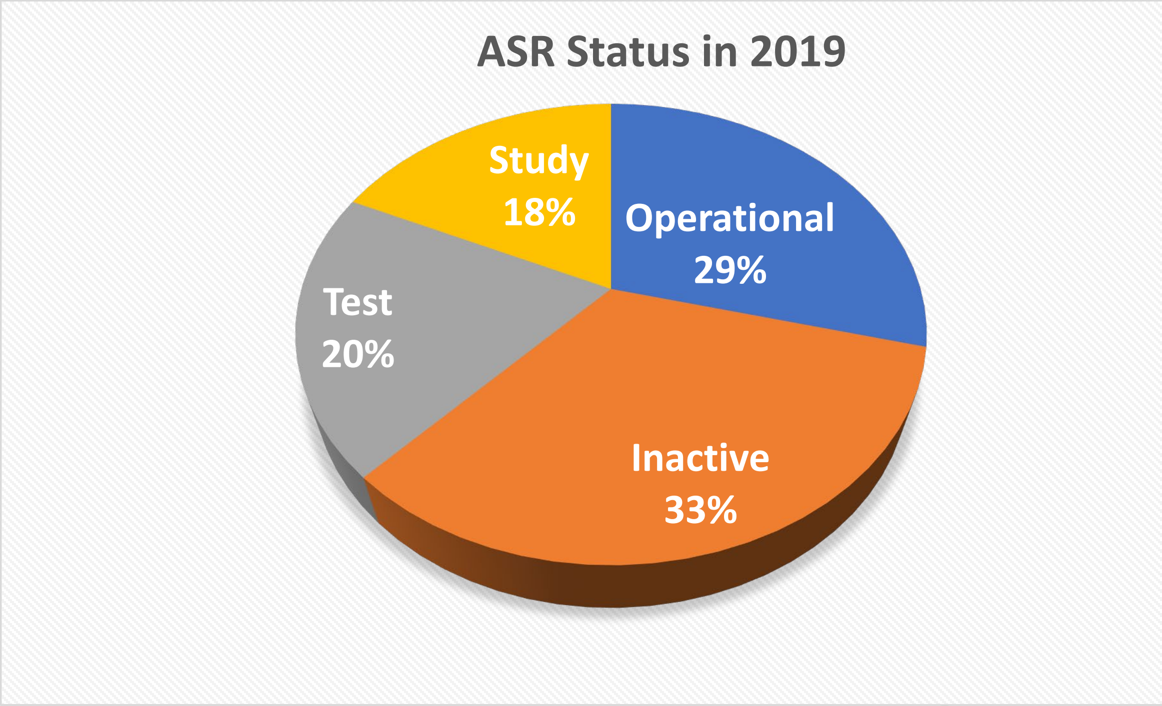
- Dataset updated through the Fall of 2019
- 29 new sites added
- Large increase in Texas – study mode (no new wells)
- Many inactive sites and wells
- A net decline in active sites (74 to 68)

ERG

Current Effort

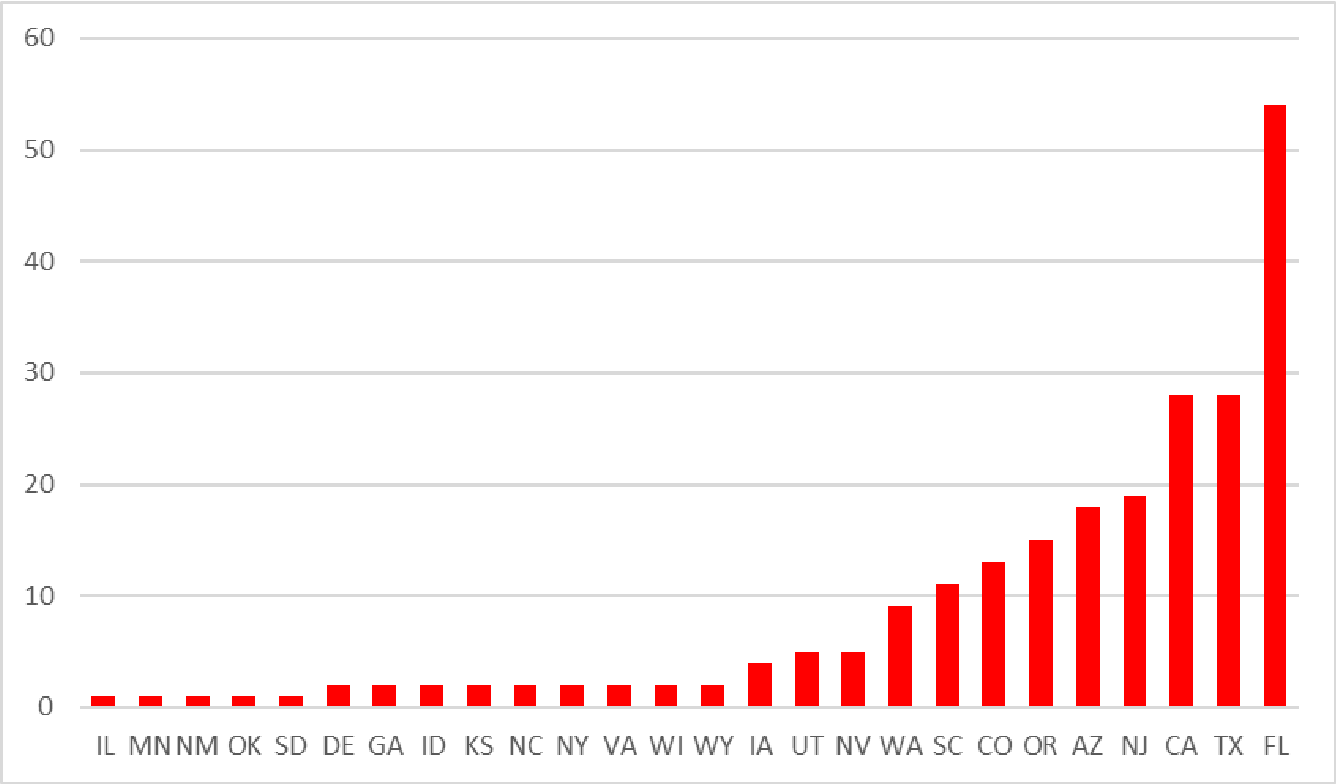
- 2013 data (204 ASR sites)
- 2019 data (29 new sites)





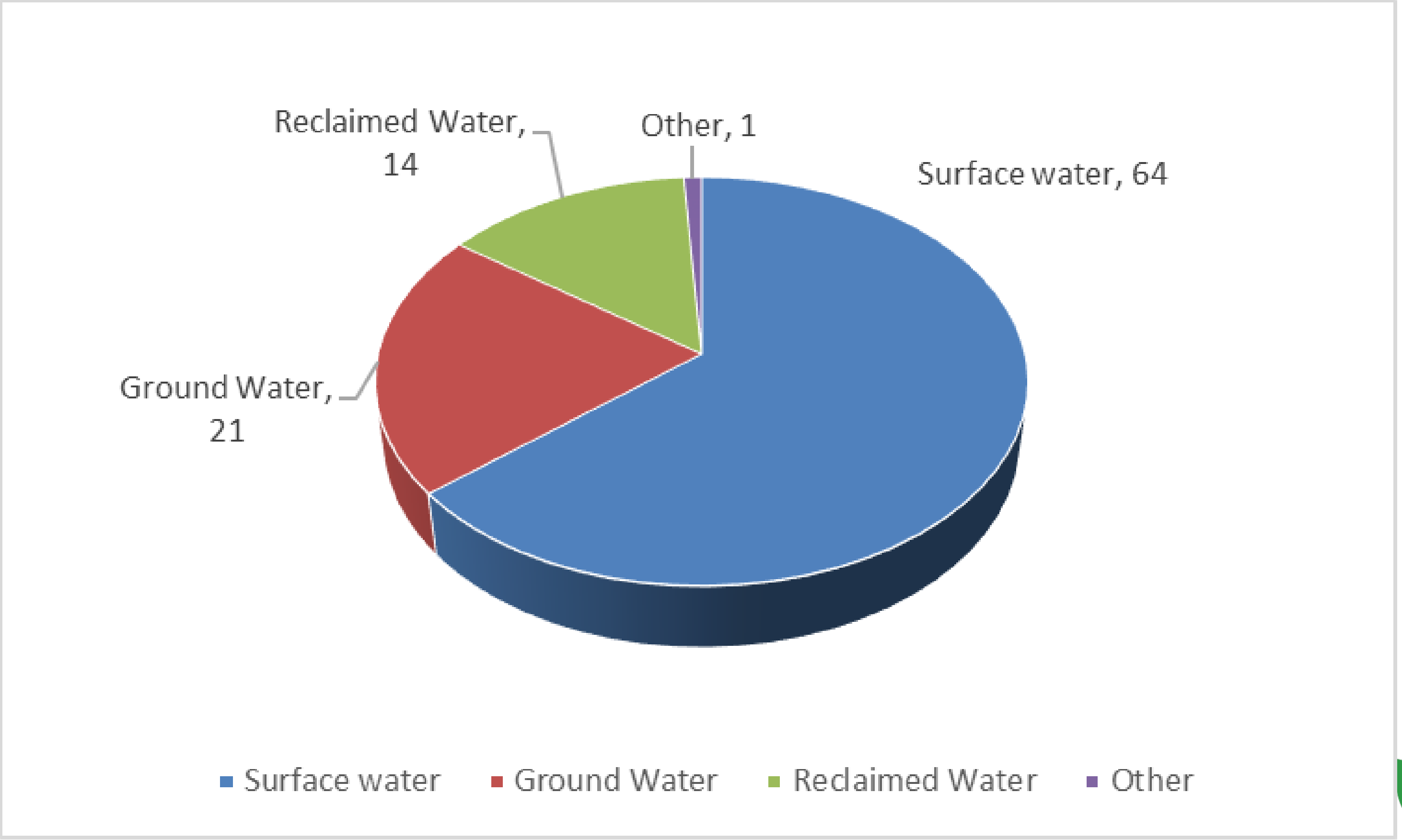
Current Effort

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



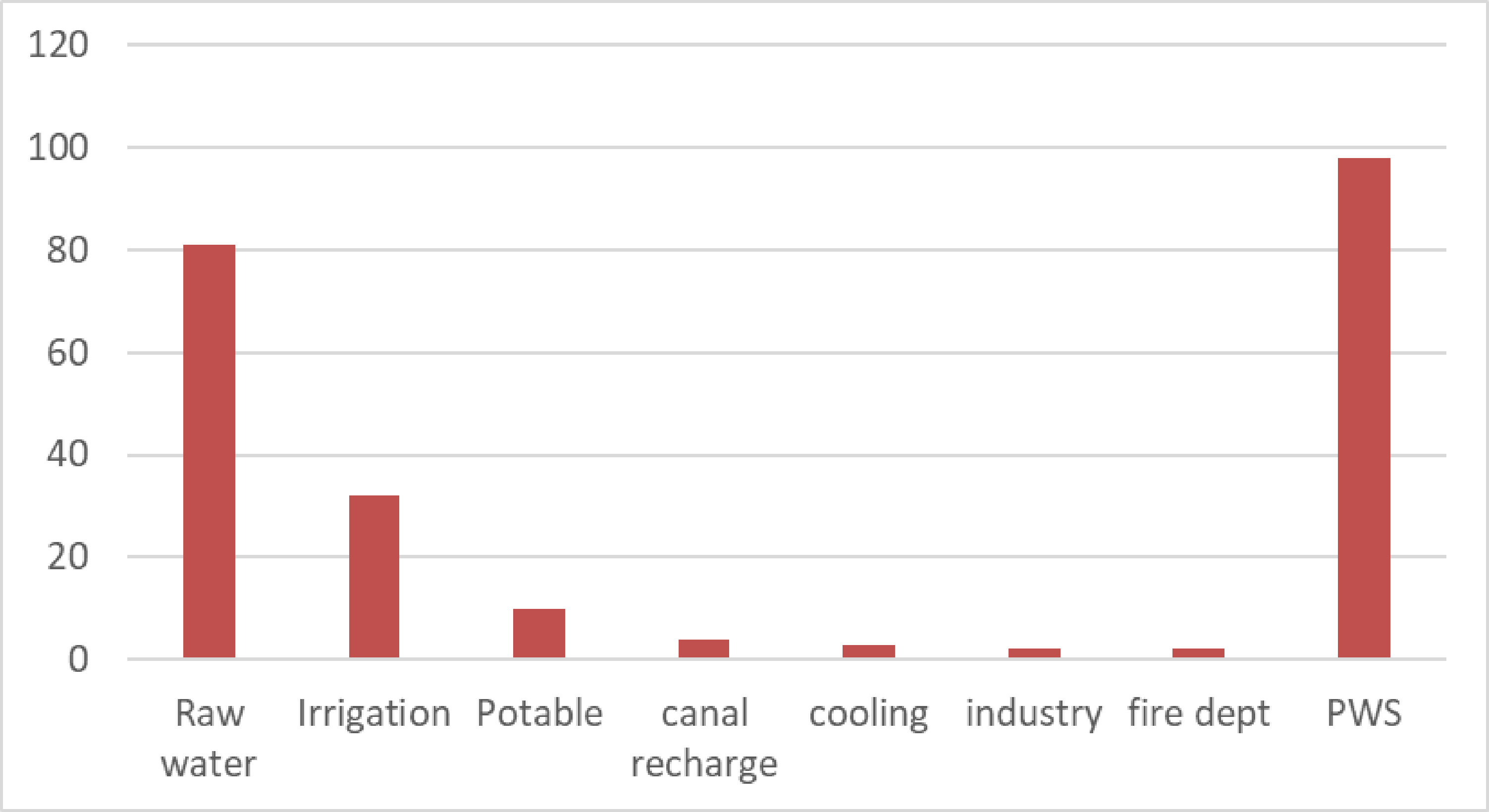
Current Effort

- Summary
  - Source of water – dominated by surface water



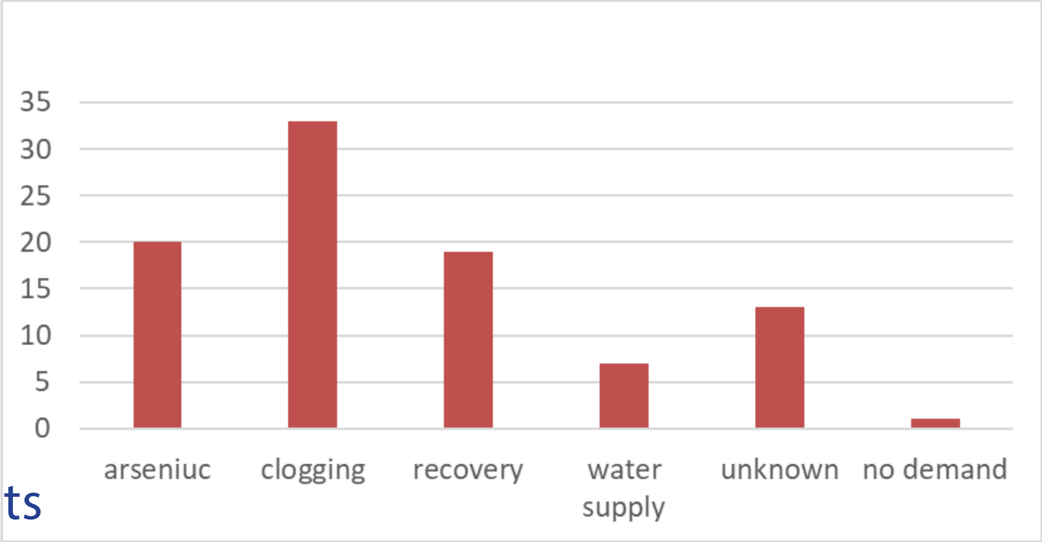
Current Effort

- 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

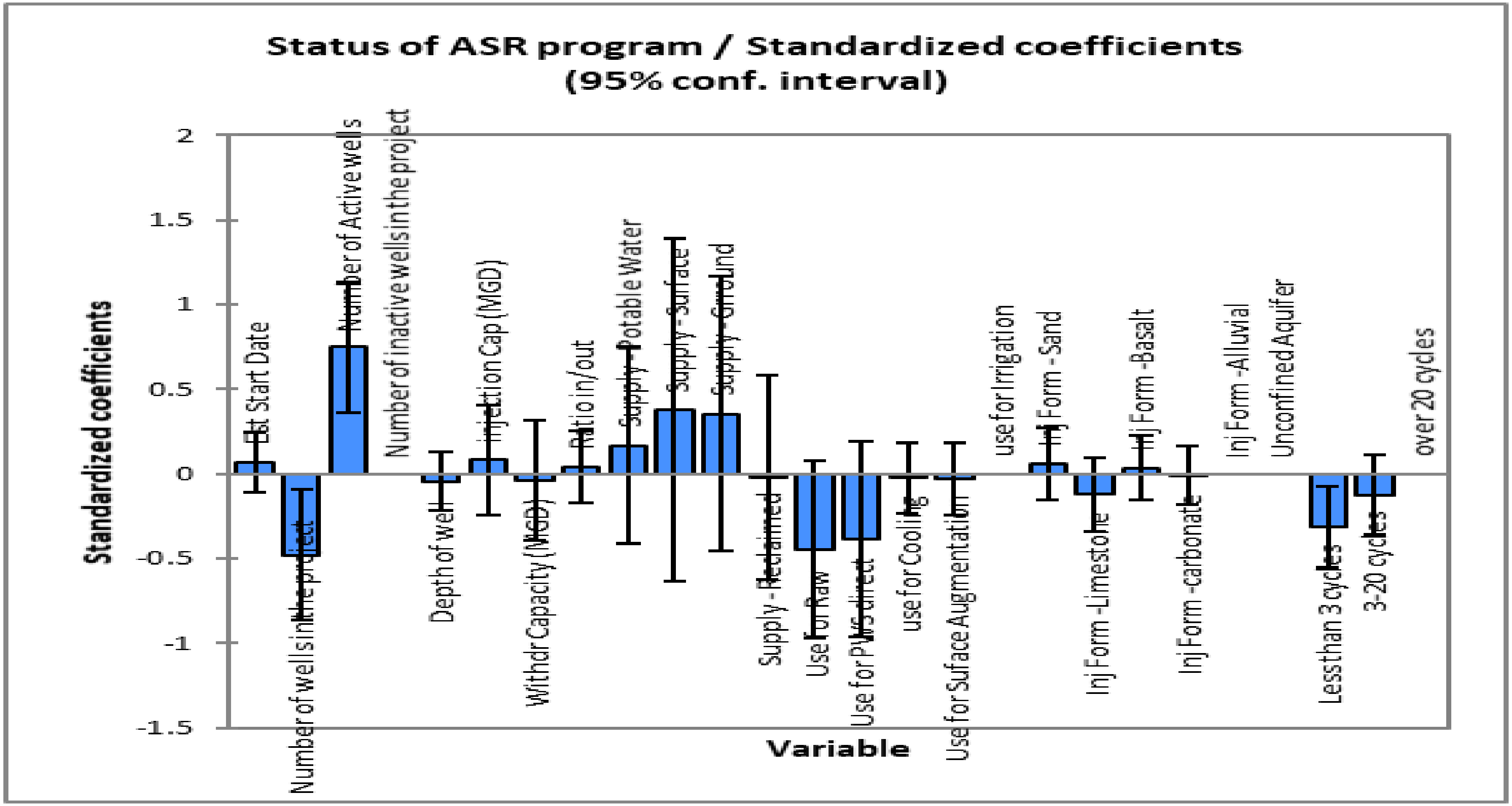
- Linear regression
  - Dependent variable – status of ASR site
  - Independent variables – weights
  - Correct prediction – 79%

- 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)



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

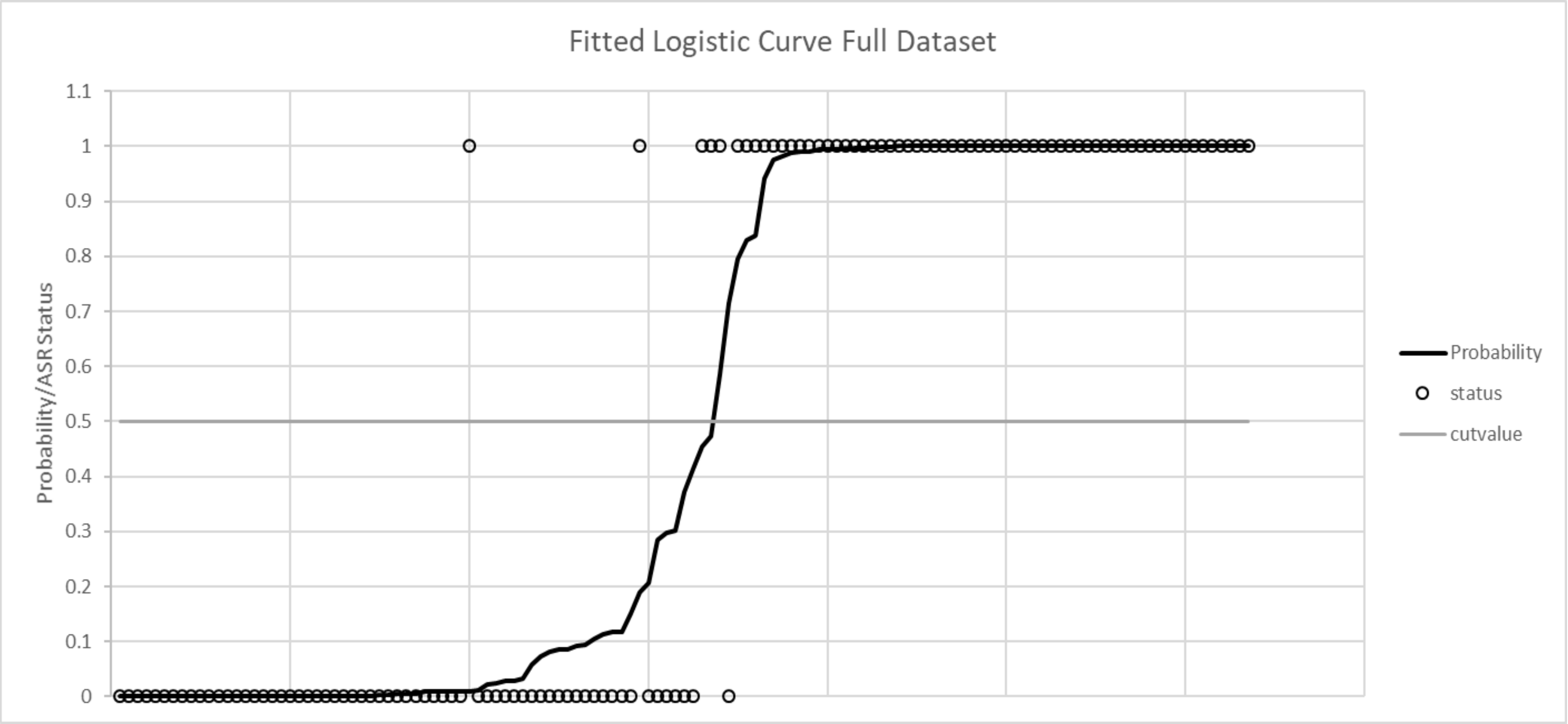
2019 Data Analysis

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

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

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

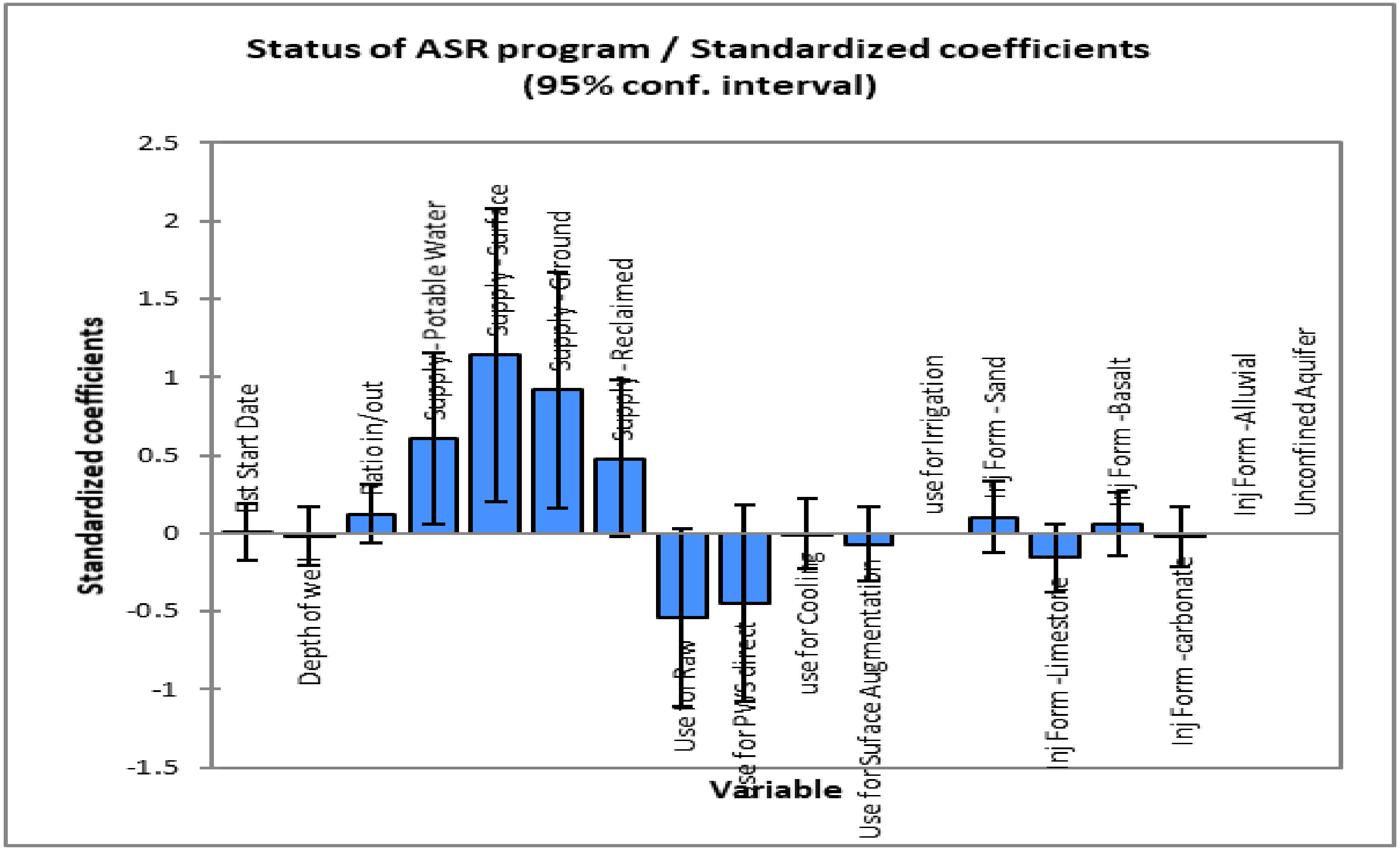
- Linear regression (reduced dataset)
  - Dependent variable – status of ASR site
  - Independent variables – weights
  - Correct prediction – 66%

- 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

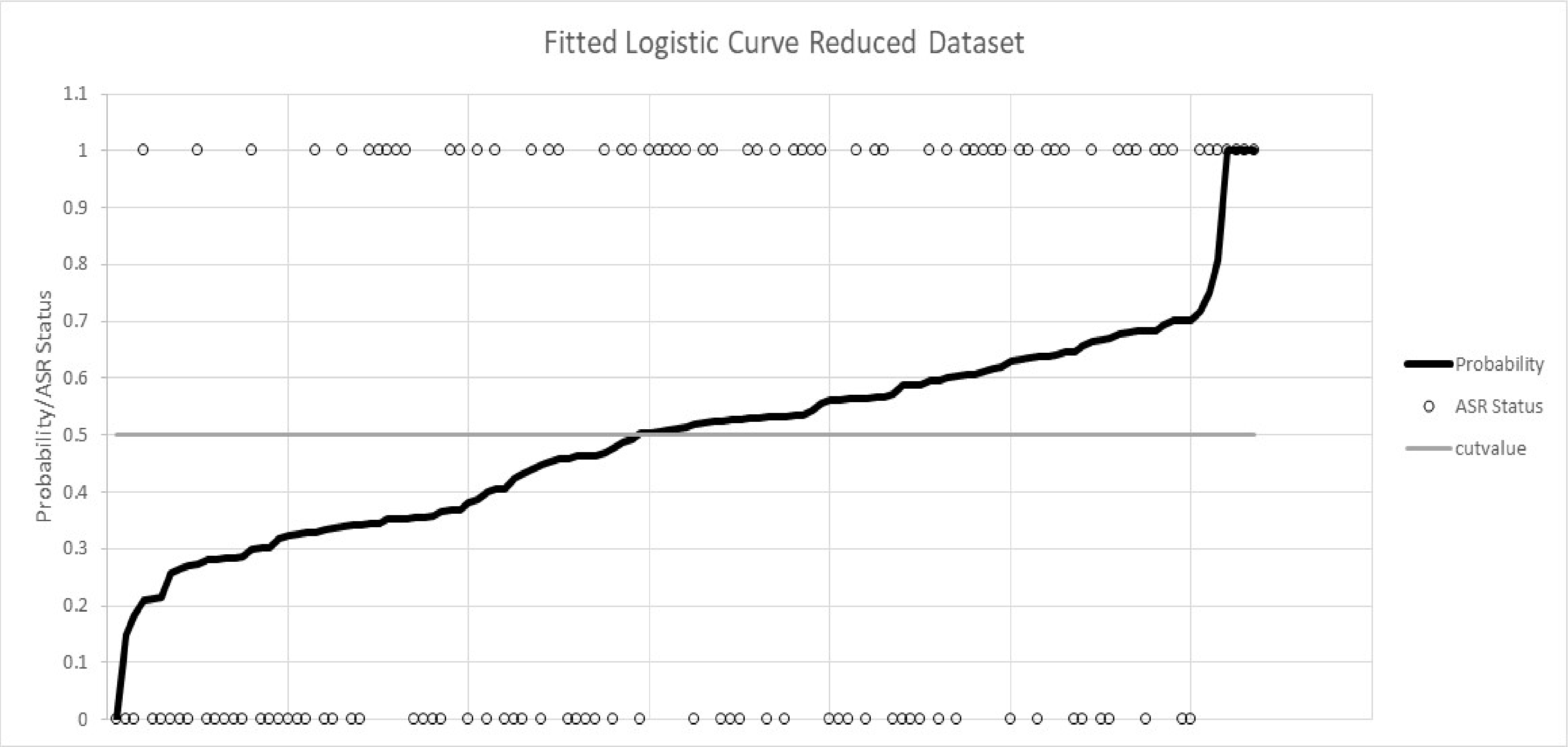
2019 Data Analysis

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

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

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?

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