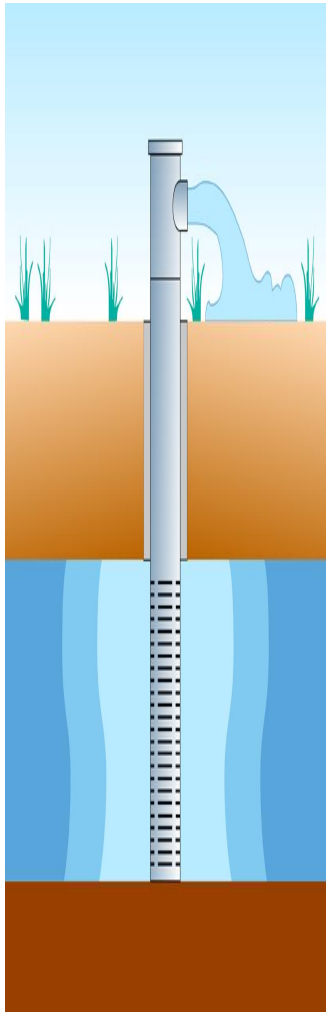
Current Status of ASR Research



A Regional Workshop on

Artificial Recharge Experience in the GCC Countries

17 March 2021

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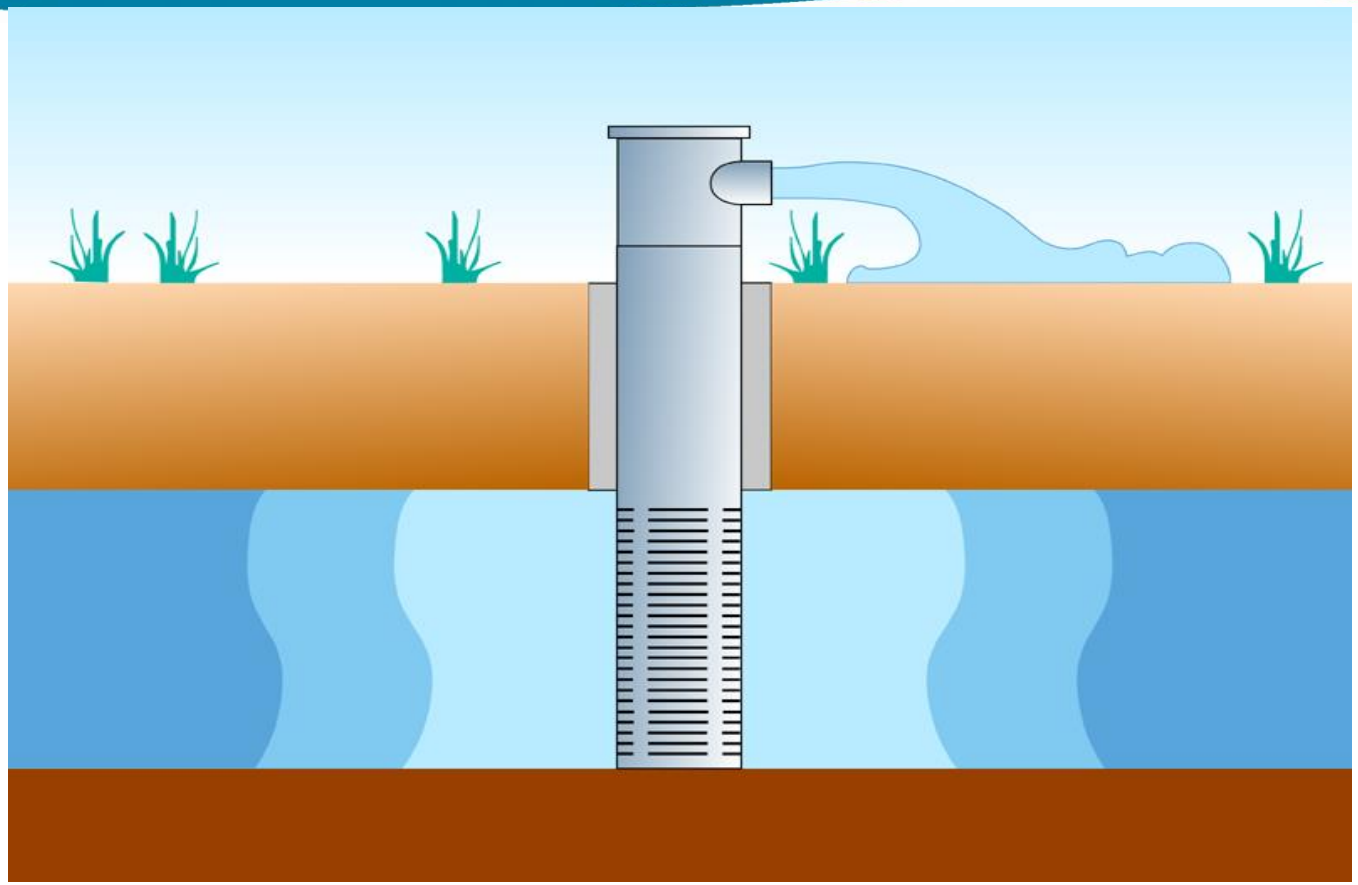
ASR SYSTEMS

Aquifer Storage Recovery (ASR) …

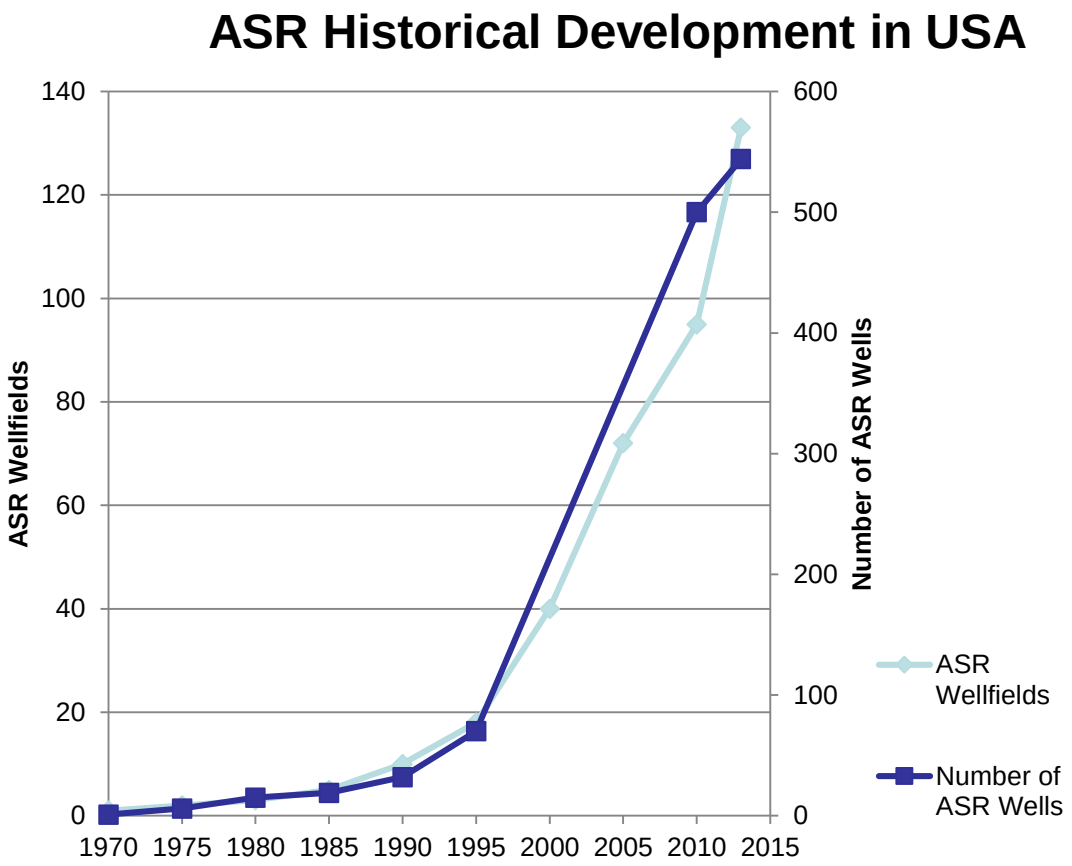
"Managed Aquifer Recharge" Through ASR Wells



Storage of water through a well in a suitable aquifer during times when the water is available, and recovery of the stored water from the same well when needed

ASR Development has been rapid during the past 25 years

- 30 different types of ASR applications
- Many different types of water sources for aquifer recharge
- Storage in many different types of aquifers and lithologic settings



February 2021: About 25 States in USA; Over 160 ASR Wellfields; Over 560 ASR wells

	ASR Wellfields	ASRWells
• Florida	51	123
• New Jersey	24	27
• California	18	68
• Arizona	14	52
• Oregon	11	37
• South Carolina	8	41
• Colorado	6	45
• Nevada	5	91
• Iowa	4	4
• Texas	5	45
• Washington	3	7
• Idaho	2	7
• North Carolina	2	2
• Delaware	2	2
• VA, NM, SD, UT, ME, MN, KS, MS	1 each	9

Global implementation of ASR since 1985 to achieve water supply sustainability and reliability

- Australia
- India
- Israel
- Canada
- England
- Netherlands
- Spain
- South Africa
- Namibia
- United Arab Emirates
- Bangladesh
- And others in development (Kuwait, Taiwan, Indonesia, Qatar, Serbia, Iran)

Adelaide, Australia ASR Well

ASR Metrics

- Well depths: 50m to 900 m
- Individual well capacity: up to 30,000 m^3/D
- Existing ASR wellfield production capacities:
  - 15 lps to 0.6 Mm^3/D
- Planned ASR wellfield production capacities:
  - Up to 1.5 Mm^3/D
- Storage aquifer water quality:
  - 30 mg/l TDS to 20,000 mg/l TDS
  - Successful ASR demonstrated at 35,000 mg/l TDS

Several factors have contributed to ASR global implementation

- Economics
  - Typically less than half the capital cost of alternative water supply sources or water storage options
  - Phased implementation
- Proven Success (30 different applications so far)
- Environmental and Water Quality Benefits
  - Maintain minimum flows
  - Small storage footprint compared to surface reservoirs
- Adaptability to Different Situations
  - Fresh, brackish or saline storage aquifers
  - Drinking water, reclaimed water, stormwater, groundwater storage

Well ASR-D1 New Braunfels Utilities, Texas

ASR has 30 applications (to date) to meet local & regional needs

- Seasonal storage
- Peak, diurnal and emergency water needs
- Water banking, or long-term storage
- Restore groundwater levels
- Reduce subsidence
- Maintain distribution system flows and pressures
- Improve water quality
- Prevent seawater intrusion
- Protect endangered species
- Agricultural water supply
- Temperature control
- Hydraulic control of contaminant plumes
- Defer expansion of water facilities
- Disinfection Byproduct reduction
- ….several other applications to date

Manatee County, Florida ASR Well, 1983

ACEC Grand Award, 1984

Identifying and prioritizing these applications is a logical first step in ASR planning

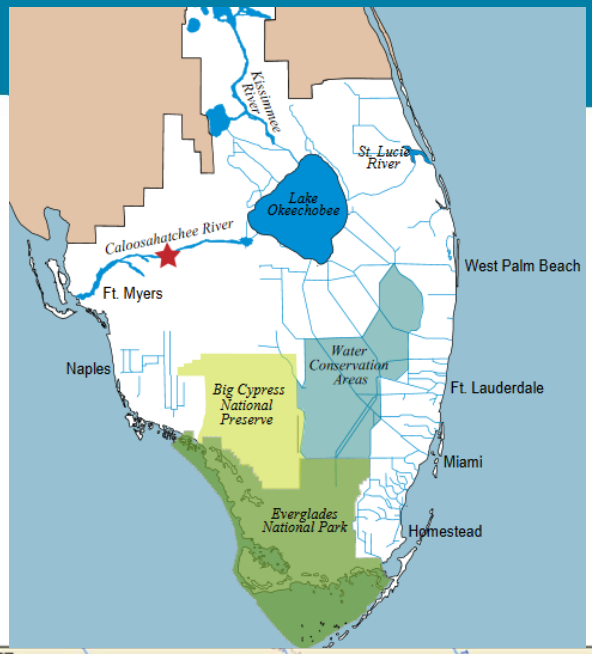
Some Keys to ASR Success

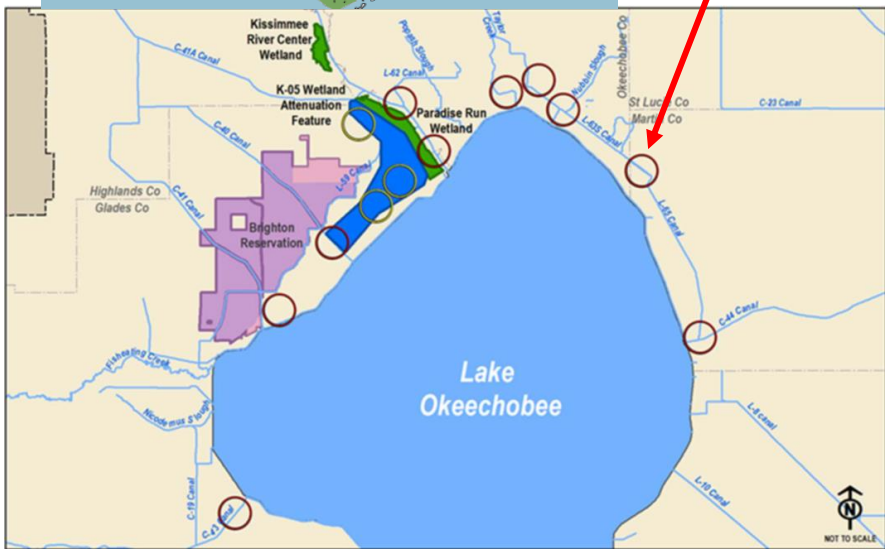
- ASR feasibility study
- Marginal cost water pricing
- Understanding local hydrogeology / geochemistry
- Appropriate engineering design
- Target Storage Volume and Buffer Zone
- Backflushing/ Redevelopment
- Appropriate regulatory framework

ASR Well 29
City of Woodland, CA

2019 ACEC Grand Award Winner

Lake Okeechobee ASR, Florida





Each circle represents a cluster of about 8 ASR wells in two brackish, confined, limestone and dolomite aquifers, 230-500m

Phased Implementation

80 wells; 1.5 Mm^3/D capacity

Storage = 553 Mm^3/year

Preliminary Cost Estimate

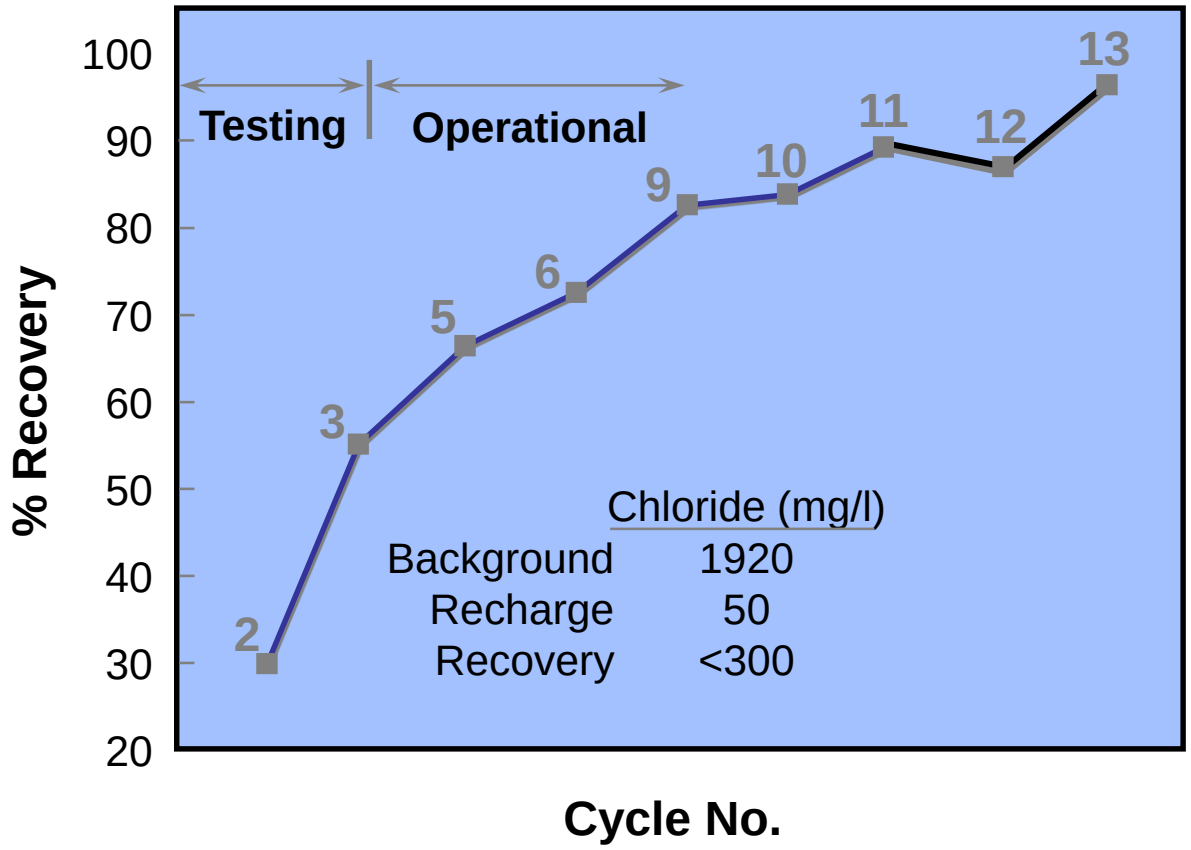
Wells - US$0.4B

Treatment - US$0.8B

The Science of ASR needs further development, despite 50 years of experience and reports

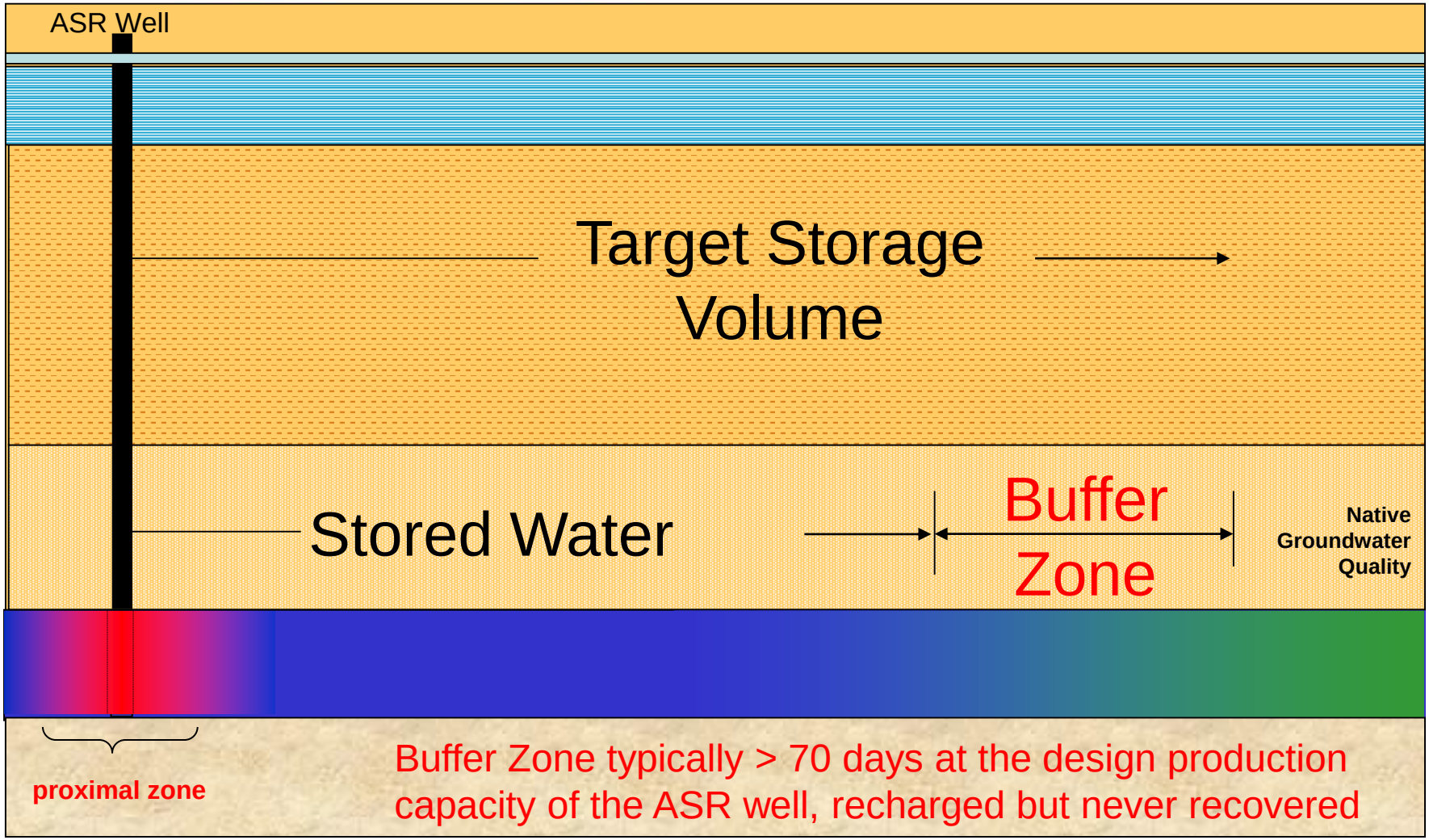
- Target Storage Volume (TSV), Buffer Zone Volume and Leakance
- Arsenic management
- Backflushing/ redevelopment
- Stacking
- Geochemistry
- Natural physical, microbial, geochemical processes occurring underground
- ASR Science Plan pending

Boynton Beach, Florida - ASR Well Percent Recovery by Cycle, 1993 to 1996

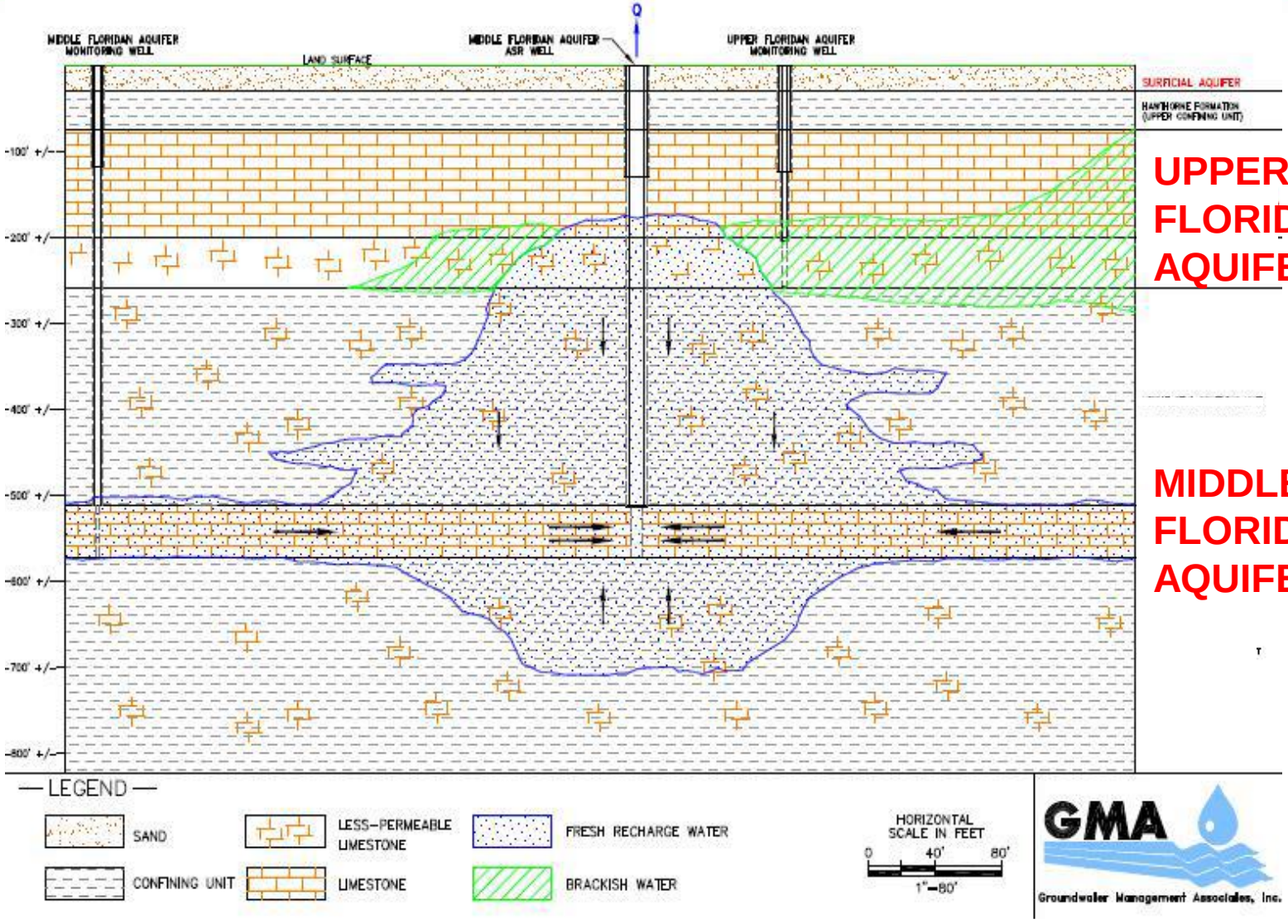


Each cycle approximately 200 Mm^3 stored and recovered

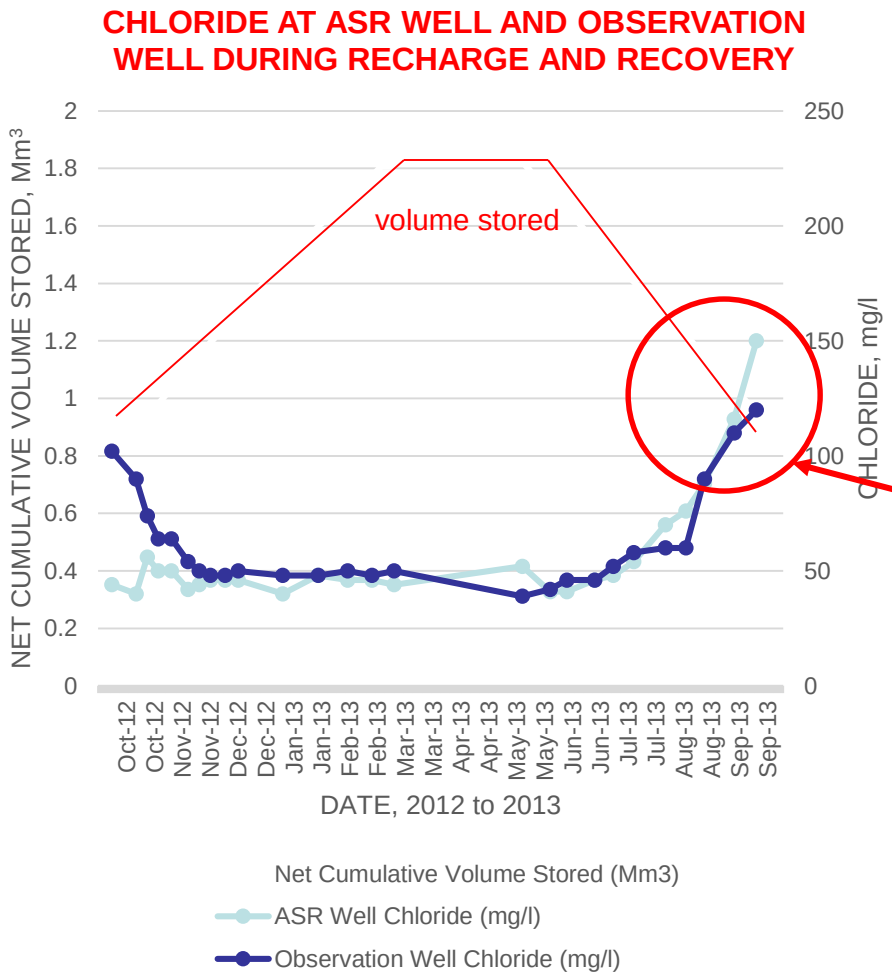
ASR TARGET STORAGE VOLUME AND BUFFER ZONE



Hilton Head, South Carolina
Conceptual ASR Storage Volume



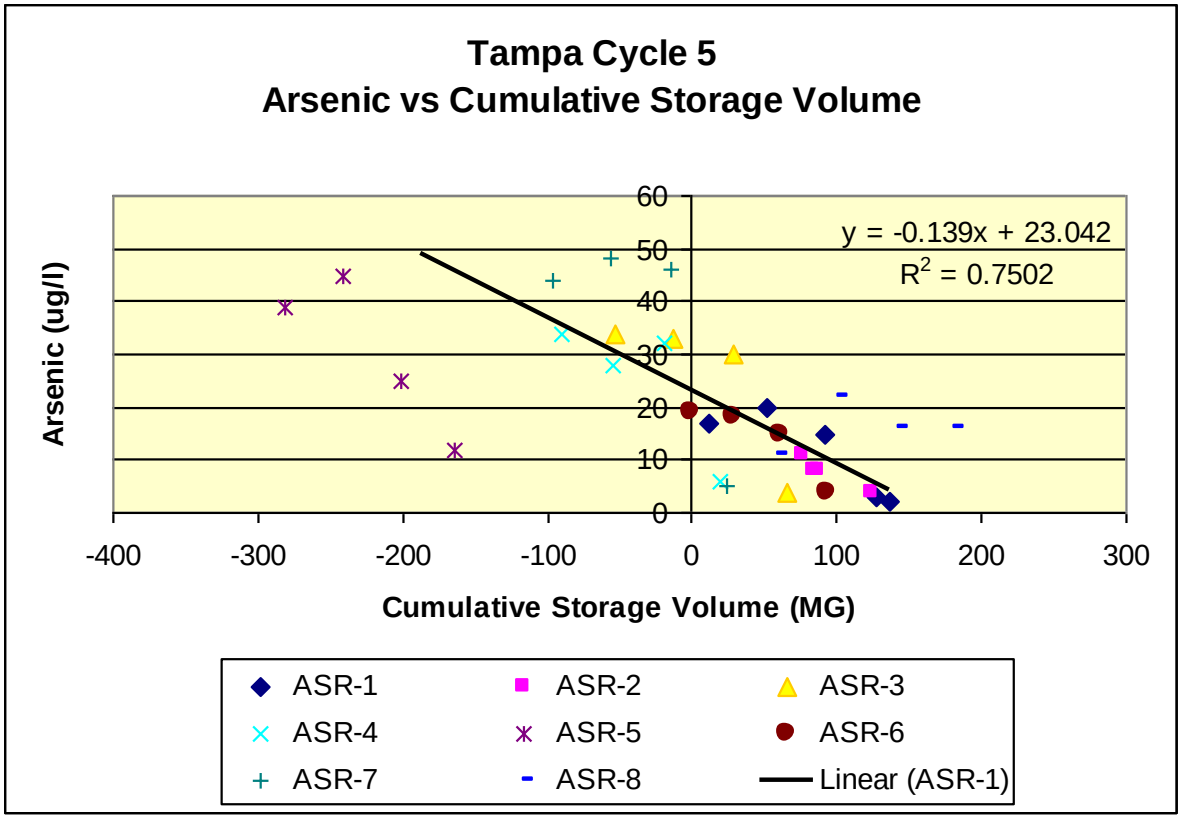
Hilton Head Island, South Carolina, USA Understanding Semi-Confining Layer Leakance is Important



- Background storage aquifer chloride = 650 mg/l
- Chloride below 150 mg/l during recharge, storage, recovery at ASR well and storage zone monitor well
- Chloride crossover at end of recovery due to downward vertical flow of brackish water from overlying UFA aquifer, next to the ASR well
- 4 months vertical travel time from UFA to MFA

Improve Water Quality During ASR Storage

- Arsenic
- Fluoride
- Salinity
- THM and HAA
- Fe and Mn
- H_2S
- N & P
- TOC (carbon sequestration)
- Microbiota
- Temperature



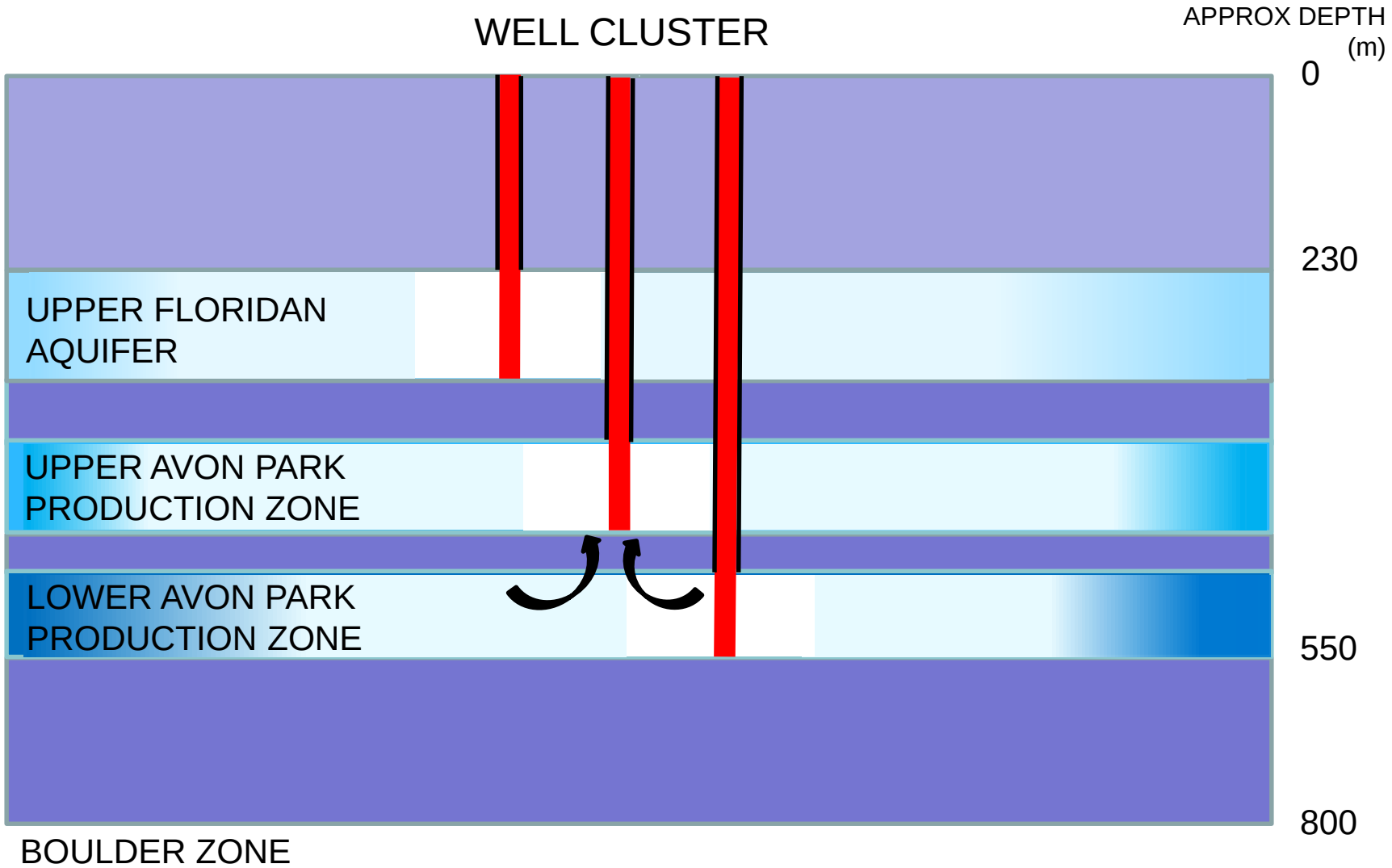
Arsenic Decreases as the Cumulative Storage Volume Increases, $r^2 = 0.75$

Poor correlation with Redox, $r^2 = 0.35$

Backflushing Frequencies at Selected Operational ASR Sites

Site	Backflushing Frequency	Lithology
Wildwood, New Jersey	Daily	Clayey Sand
Gordons River, New Jersey	Daily	Clayey Sand
Peace River, Florida	Seasonal	Limestone
Cocoa, Florida	Seasonal	Limestone
Palm Bay, Florida	Monthly	Limestone
Las Vegas, Nevada	Seasonal	Alluvium
Chesapeake, Virginia	Twice-Monthly	Sand
Seattle, Washington	Weekly	Glacial Drift
Calleguas, California	Monthly (approx.)	Sand
Highlands Ranch, Colorado	Monthly	Sandstone

“Stacking:” ASR Proposed Conceptual Design at Lake Okeechobee, Florida



ASR Science Plan for Lake Okeechobee ASR Wellfield, Florida (1.5 Mm^3/D)

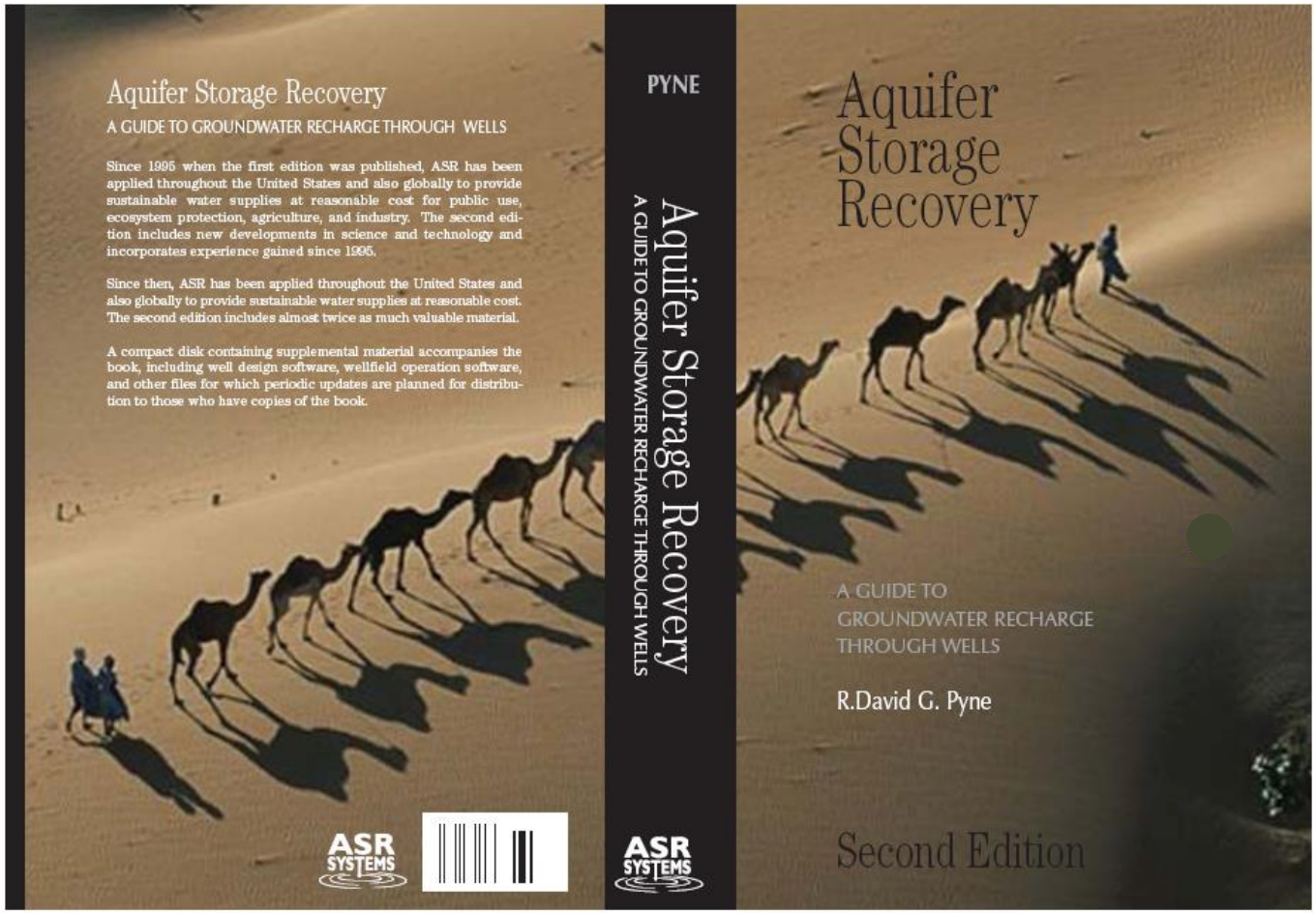
- Draft Issued October 2020 (20 pages) by South Florida Water Management District. Public Comment Period Through March 2021
- Peer Review Panel includes five eminent scientists (4 geologists / geochemists, 1 wetlands specialist)
- Final Science Plan pending (check SFWMD website)
- Continuous wireline coring underway at four locations
- Column tests planned, addressing physical, microbial and geochemical subsurface reactions and well clogging
- Flow-through tests to evaluate in-situ biofilm growth
- Dr John Lisle, Microbiologist, USGS, Tampa, Florida
- Mineralogic Analysis and Geochemical modeling
- PhD dissertations on ASR, completed and underway

Future Directions for ASR

- Regulatory frameworks that match ASR science/ technology
- Reclaimed water storage (IPR, DPR)
- Biotechnology/geochemistry advances to achieve subsurface treatment objectives
- Larger ASR programs to meet regional/national needs
- ASR wells for storage, treatment and conveyance
- Strategic Water Reserves
- Marginal cost pricing
- Thermal energy storage (ATES, BTES)
- Bank filtration/ASR combination technologies
- Desalination/ASR combination technologies (DASR)
- Horizontal Directional Drilled (HDD) ASR wells
- Well pairs and arrays to achieve storage/treatment
- Vertical stacking of storage zones
- Wellfield Protection Areas for ASR

ASR Book, Second Edition

www.asrforum.com



Or purchase from National Ground Water Association