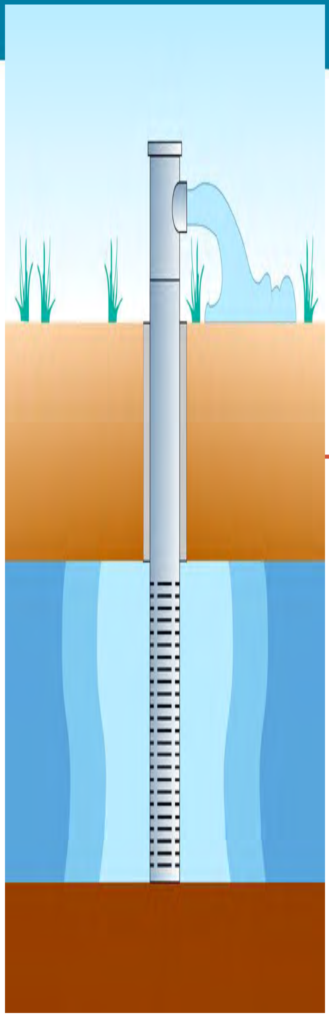
DROUGHT-PROOFING OKLAHOMA



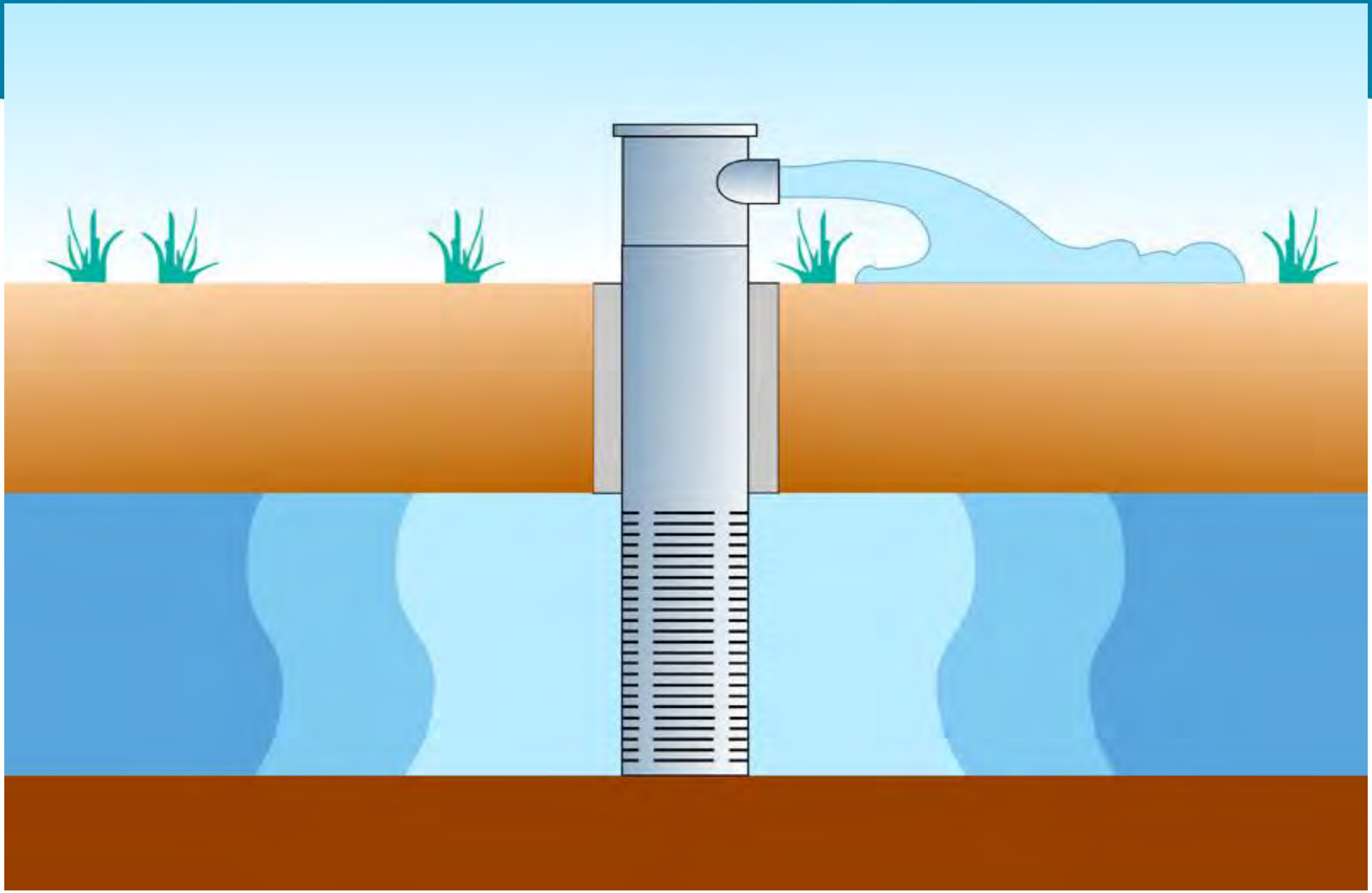
AQUIFER STORAGE RECOVERY (ASR)

Presentation to Oklahoma Governor's Water Conference

December 3, 2015

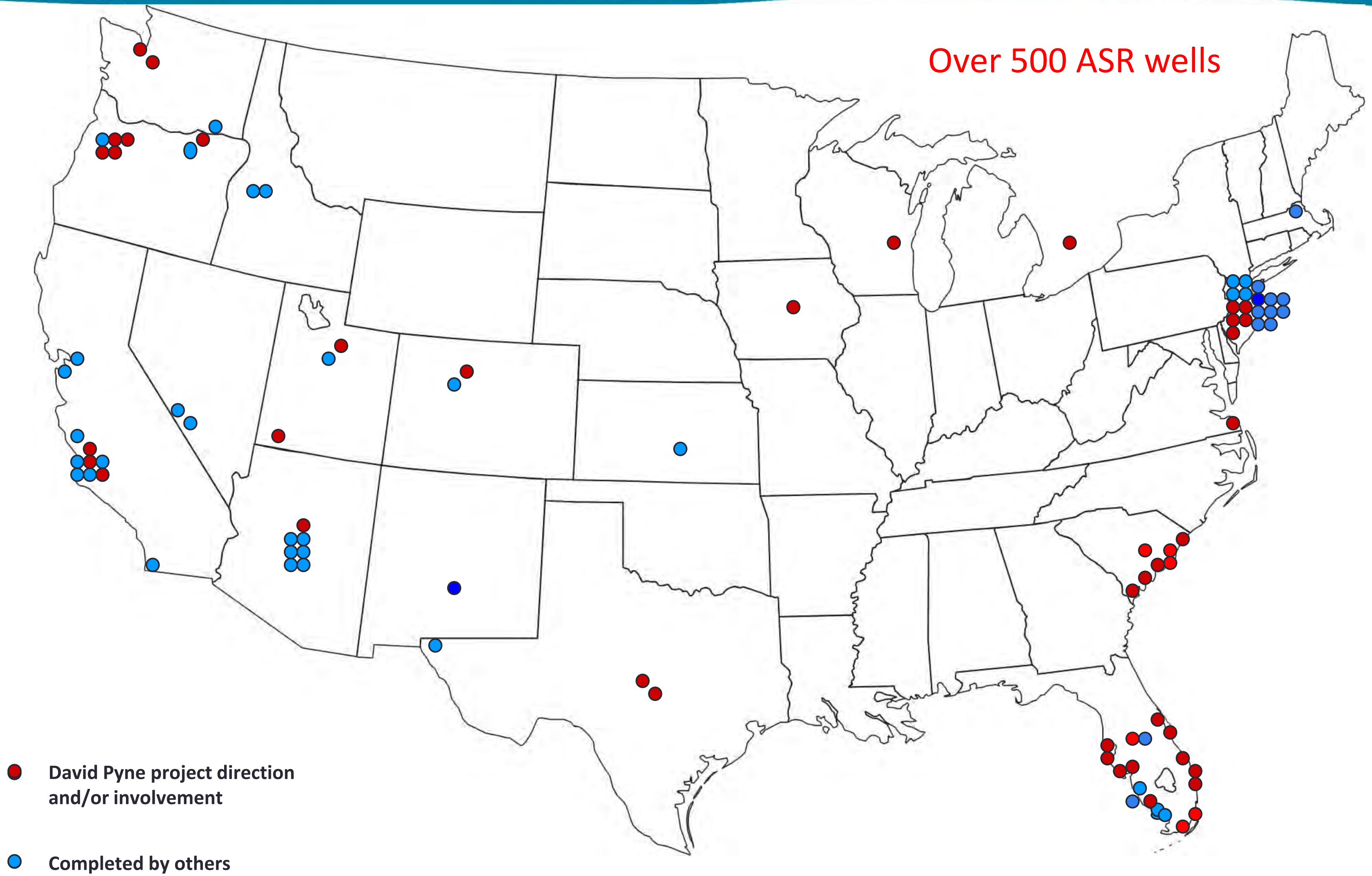
R. David G. Pyne, P.E.
ASR Systems LLC
Gainesville, Florida

Introduction to ASR



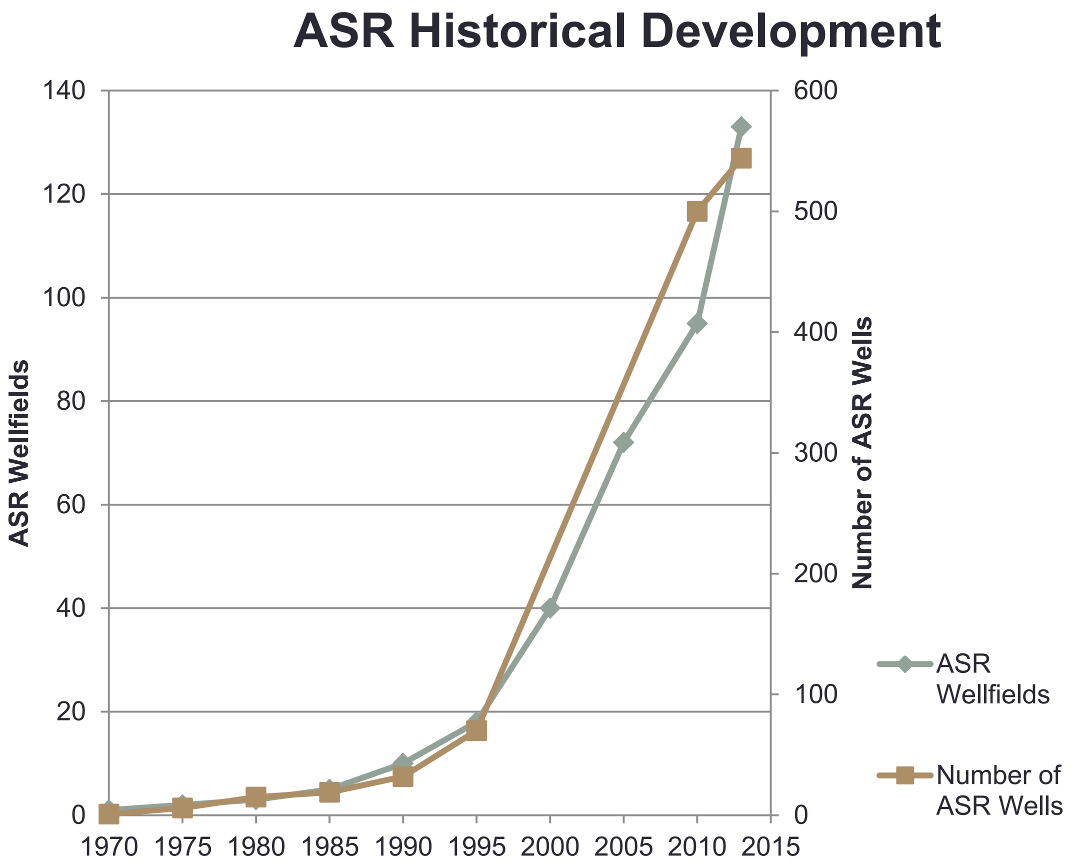
…a proven and cost-effective technology

Approximately 175 Operational ASR Wellfields in the United States (2015) in at least 25 States



ASR Development in the U.S. has been rapid during the past twenty years

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



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

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

Adelaide, Australia ASR Well

Several factors have contributed to ASR global implementation

- Economics
  - Typically less than half the capital cost of alternative water supply sources
  - Phased implementation
  - Marginal cost pricing
- Proven Success
- Environmental and Water Quality Benefits
  - Maintain minimum flows
  - Small storage footprint compared to surface reservoirs
  - No losses to evapotranspiration
  - Some lateral movement of stored water
- Adaptability to Different Situations
  - Fresh, brackish or saline storage aquifers
  - Drinking water, reclaimed water, stormwater or groundwater storage
  - Over 28 different applications

Mt Pleasant, SC – Well ASR-2

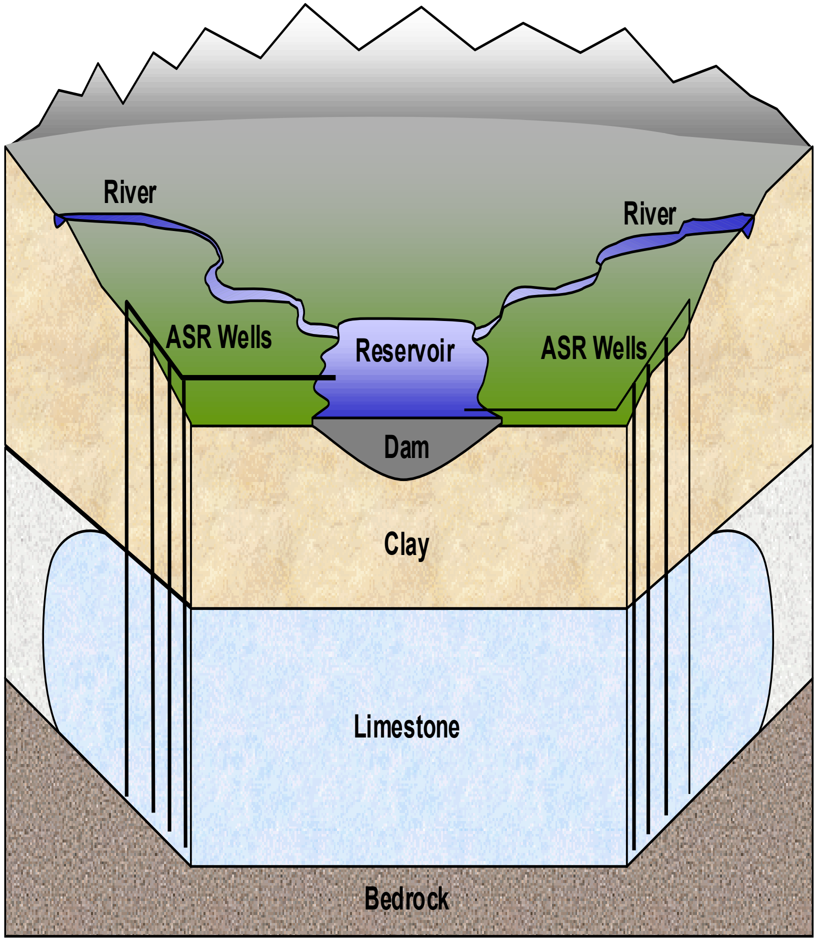
ASR wells provide storage of water from many different sources.

- Drinking water
  - conventional water treatment plants
  - desalination plants
- Surface water
- Groundwater
- Reclaimed water
  - 2 operational and many in development in Florida
  - 5 operational in Arizona
  - 1 operational in Texas
  - At least one operational in California

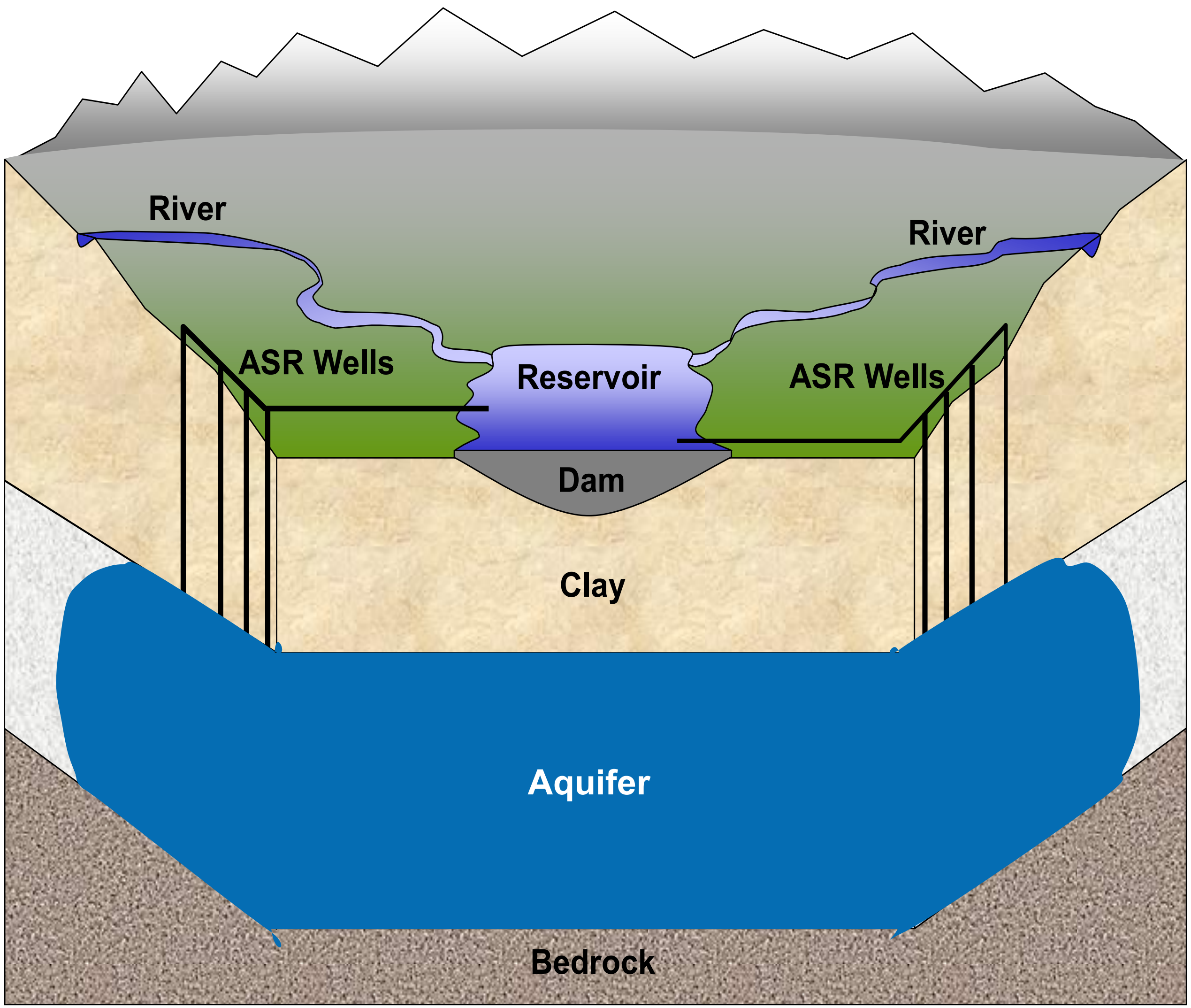
Mt. Pleasant, S.C.

A combination of ASR wells and surface reservoirs is very beneficial for providing water storage.

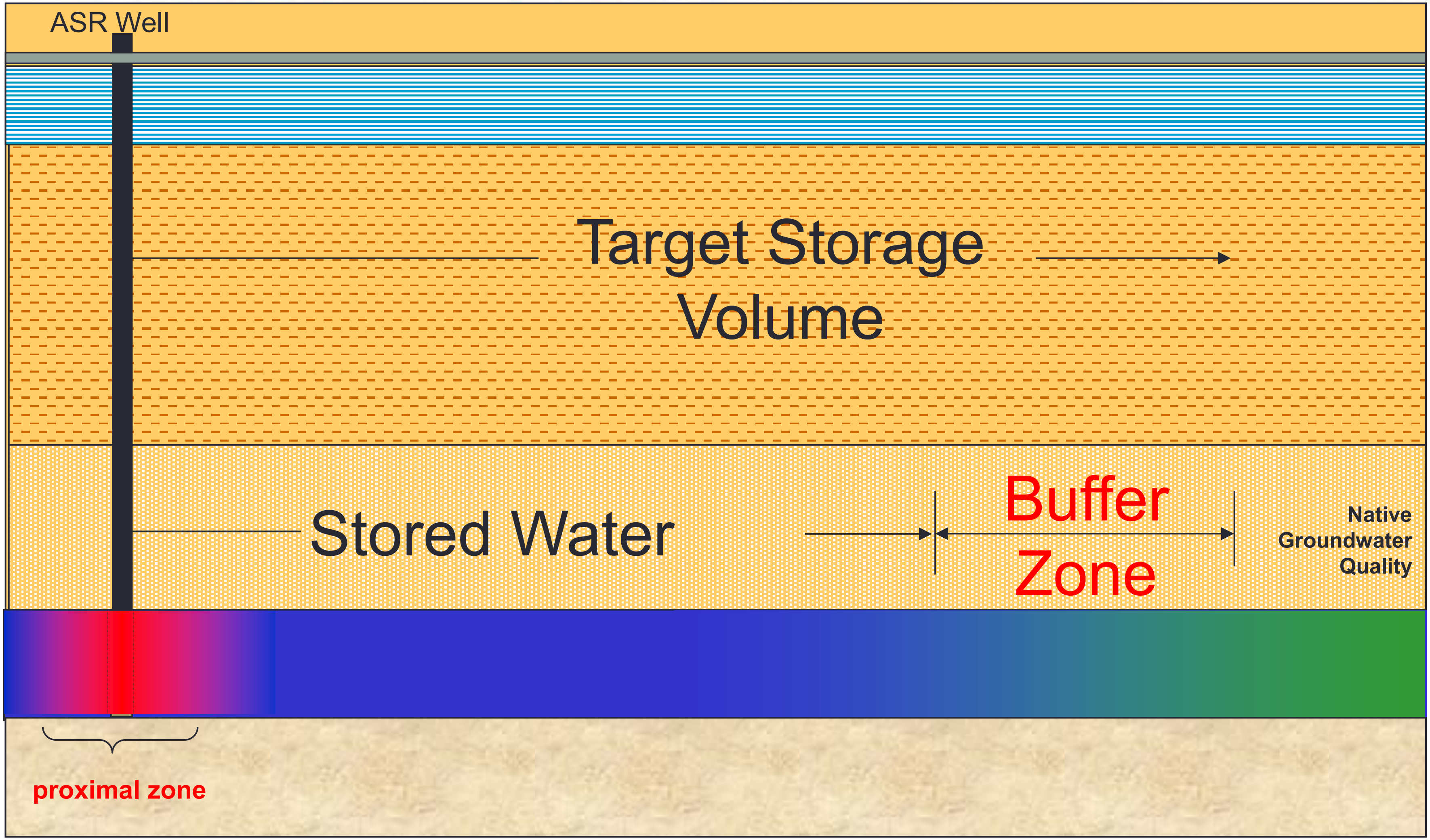
- Surface reservoirs capture water quickly, but…
  - are expensive
  - often have evapotranspiration and seepage losses
  - garner environmental opposition
- Where feasible, ASR wells can often store much larger volumes of water
  - occupy little land
  - can be built in increments
  - have few or no losses, but can only recharge and recover water slowly



Where feasible, we should consider operating reservoirs at lower levels to capture peak flows and transfer them to ASR storage, recovering the water when needed.



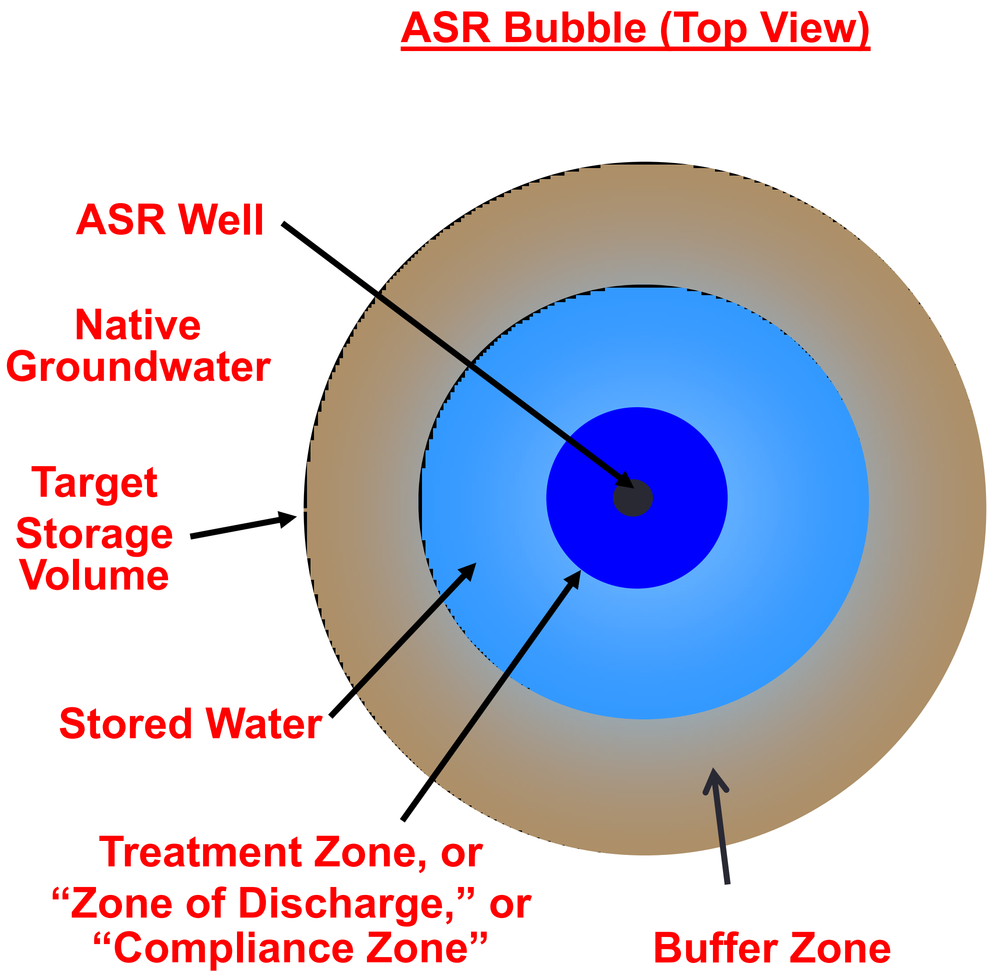
Target Storage Volume (TSV) is sum of stored water volume plus buffer zone volume. It is often expressed in MG/MGD of recovery capacity, or "days"



Forming and Maintaining the Buffer Zone is one of the keys to ASR Success

- Once the buffer zone has been formed, subsequent recovery efficiency should be close to 100%. This is a "one time" addition of water to the well.
- It is measured in terms of "MG/MGD of recovery capacity," or "days." Typical values are 50 to 350 days, depending primarily on hydrogeology, water quality, and anticipated recovery duration
- Once formed, the buffer zone should not be recovered since it risks causing a substantial deterioration in recovered water quality.
- The buffer zone is best formed upfront, prior to cycle testing, as the last step in ASR well construction. The cost of the water may be capitalized. It can also be formed over the course of several ASR cycles, during each of which up to the same volume stored is recovered. This approach is more time-consuming and expensive.

In addition to water storage, treatment occurs in an aquifer due to natural processes.



- NO_3, NH_3, P
- THMs
- HAAs
- H_2S
- Fe, Mn, As
- Ra
- Gross Alpha Rad.
- Bacteria
- Protozoa
- Viruses

A broad range of water sources and storage zones is utilized for ASR

- Water sources for ASR storage
  - Drinking water
  - Reclaimed water (AZ, TX, FL, CA)
  - Seasonally-available stormwater
  - Groundwater from overlying, underlying or nearby aquifers
- Storage zones
  - Fresh, brackish and saline aquifers
  - Confined, semi-confined and unconfined aquifers
  - Sand, clayey sand, gravel, sandstone, limestone, dolomite, basalt, conglomerates, glacial deposits
  - Vertical "stacking" of storage zones

Chandler, AZ

Tumbleweed ASR Wellfield

Storing Reclaimed Water for Aquifer Recharge

ASR Operating Ranges

- Well depths
  - 30 to 2,700 feet
- Storage interval thickness
  - 20 to 400 feet
- Storage zone Total Dissolved Solids
  - 30 mg/L to 39,000 mg/L
- Storage Volumes
  - 100 AF to 270,000 AF
  - (30 MG to 80 BG)
- Bubble radius less than 1,000 ft
- Individual wells up to 8 MGD capacity
- Wellfield capacity up to 157 MGD
  - Planned up to 400 MGD

Calleguas MWD, California

ASR Well

Capital Cost Comparisons

Source/Storage Option	Typical $/GPD Capacity
Conventional Supply	0.50 – 5.00
ASR	0.50 - 2.00
Brackish Desalination	2.00 – 5.00
Seawater Desalination	7.00 – 12.00
Surface Reservoirs	3.00 – 30.00
Indirect Potable Reuse	7.00 – 25.00

ASR is complementary to other sources, increasing total yield and reliability. With adequate ASR capacity, 100% reliability can be achieved at reasonable capital cost.

Estimated ASR System Costs – Victoria, TX

- Phase 2 Testing Program: $3.6 million (included below)

- Total Capital Cost: $14.5 million
- Total Project Cost: $21.1 million
- Total Annual Cost: $ 1.5 million (**debt service + O&M**)
- ASR Project Unit Cost: $56 per AFY ($0.17 /K gal)
- Incremental cost of treatment/storage: $ 136 per AFY ($0.42/k gal)
- Total Unit Cost: $192 per AFY ($0.59/K gal)

Potential ASR Objectives (1/2)

Select and Prioritize One or More Pertinent ASR Applications for each ASR wellfield:

- **Seasonal storage**
- **Long-term storage ("water banking")**
- **Emergency storage ("strategic water reserve")**
- **Diurnal storage**
- **Disinfection byproduct reduction**
- Restore groundwater levels
- Control subsidence
- **Maintain distribution system pressures**
- **Maintain distribution system flow**
- Aquifer thermal energy storage (ATES)

Kiawah Island, South Carolina

Denver, Colorado

Potential ASR Objectives (2/2)

- **Reduce environmental effects of streamflow and/or reservoir diversions**
- Agricultural water supply
- Nutrient reduction in agricultural runoff
- Enhance wellfield production
- **Defer expansion of water facilities**
- **Reclaimed water storage for reuse**
- Stabilize aggressive water
- **Hydraulic control of contaminant plumes**
- **Maintenance or restoration of aquatic ecosystems**
- **Achieve water supply reliability**

Manatee County, Florida
ASR Well, 1983

ACEC Grand Award, 1984

Seasonal Storage

- May be an important benefit of ASR, in addition to providing storage for the Drought of Record.
- Annual benefit, not just once in a lifetime.
- Facilitates more efficient use of existing infrastructure, meeting peaks from ASR instead of from water treatment plants and transmission pipelines.

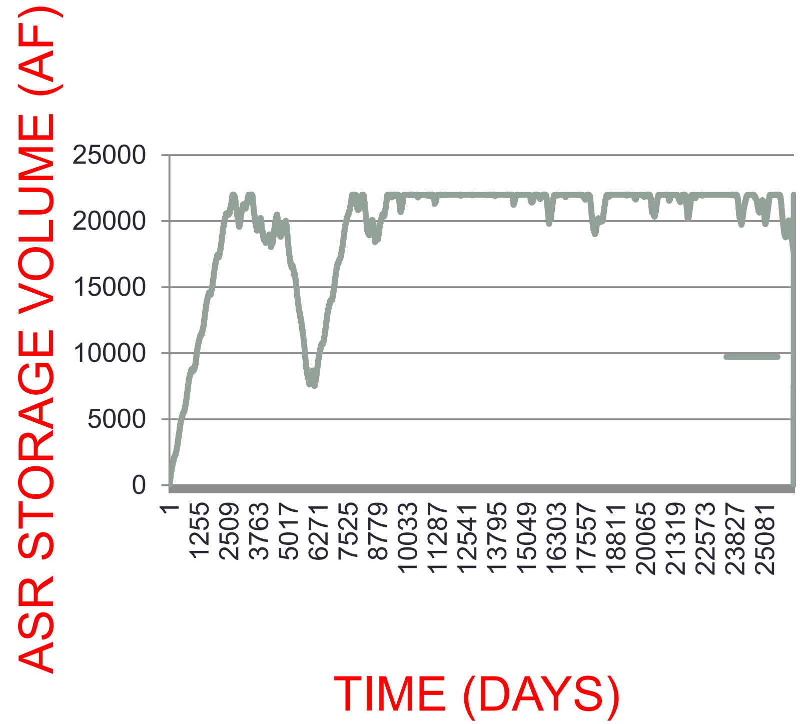
Orangeburg, South Carolina

Total 6.5 MGD

Two ASR wells in two different aquifers within a single wellhouse

Long-term storage, or
Water Banking for the "Drought of Record"

- Achieve 100% Water Supply Reliability
- How to estimate the Target Storage Volume (TSV)
- "Will the stored water still be there when we need it?"
- Lateral velocity of groundwater in the storage aquifer(s)?
- Proximity of other groundwater users?
- Measures available to protect availability of the stored water



Strategic Water Reserve for Emergencies

- Water systems dependent upon a single source and/or a long transmission pipeline
- Accidental loss, contamination, warfare, terrorism, natural disaster
- Build one or more strategic water reserves deep underground

Des Moines Water Works, Iowa – 100 MGD WTP
Before and After 1993 Flood

Emergency Storage: Des Moines ASR Objectives

Deepest ASR well in the world – 2,700 ft in Jordan Sandstone Aquifer

Retrofit of Existing Abandoned Production Well

Primary ASR Objective
- Emergency Water Supply
- 30 MGD for 90 days – 2.7 BG

Secondary ASR Objective
- Seasonal Water Storage
- 10 MGD for 90 days – 0.9 BG

Tertiary ASR Objective
- Eliminate need for nitrate removal during spring thaw

Maintain pressures, flows and water quality in a distribution system

- Keep the water moving
- Locate ASR wells in seasonal low pressure areas such as at the top of a hill, the end of a long transmission pipeline, or a summer beach resort.
- Avoid the need for flushing pipelines to waste to maintain water quality in distant portions of a water distribution system

Murray Avenue ASR Well
Cherry Hill, New Jersey

Defer expansion of water facilities

- Operate treatment facilities to meet slightly more than average demands, providing for maintenance periods and times of inadequate supply
- Meet maximum day demands from ASR wells; peak hour demands from elevated and ground storage tanks
- Reduce capital costs by typically more than 50%

Highlands Ranch, Colorado
One of 26 ASR wells underground in vaults

What are the more significant challenges to ASR implementation?

- Legal, regulatory and policy framework (“Governance”) that, in some areas, is not well-matched to the scientific and technical realities and opportunities.
- Water is power. The control of water is therefore the currency of personal, regional and national ambitions.
- For some people and interests, ASR is too cost-effective.
- General lack of awareness and understanding of the broad range of potential applications of ASR to meet end-user needs
- Misinformation

Manatee County, FL

Florida’s First ASR Well, 1983

ACEC Grand Award, 1984

Nine Suggestions: Legal, regulatory and policy measures that may enhance ASR viability in Oklahoma (1 of 2)

1. Start with conducting an ASR Feasibility Investigation. Then expand in phases, learning as you go.
2. Manage ASR wellfields so that <u>cumulative</u> volume recovered does not exceed <u>cumulative</u> volume stored. Do not manage according to <u>annual</u> volume stored and/or recovered.
3. Operate ASR wellfields by initially forming and then maintaining the Target Storage Volume (TSV).
4. Develop ASR Wellfield Protection Area (WPA) provisions that work for Oklahoma
5. Clearly establish that storage of water through ASR wells, and recovery of the stored water for beneficial uses when needed, is a beneficial use of water, along with municipal, industrial and agricultural uses of water.

Nine Suggestions: Legal, regulatory and policy measures that would enhance ASR viability in Oklahoma (2 of 2)

6. Establish that water recovered from ASR wells is not subject to demand management and critical period management rules, and is also not subject to any production limits applicable to native groundwater.

7. Evaluate compliance with water quality standards at appropriately-located monitor wells during ASR recharge and storage. Provide (time and distance) for natural processes underground to enhance water quality.

8. Establish a single regulatory framework that is consistent statewide, or coordinated ASR regulation by multiple agencies.

9. Avoid use of the term "injection" as applied to ASR wells. Instead use the term "recharge." Semantics is everything.

West Palm Beach, Florida
ASR Well – 8 MGD Capacity
Largest ASR Well in the World

Conclusions

- ASR is proven, cost-effective, environmentally-beneficial, and has many different applications to achieve water supply reliability and sustainability.
- There is a proven approach to achieving ASR success. Ignoring this can lead to inappropriate perceptions of ASR "failure."
- ASR solutions are targeting ever larger (regional, national) water management issues.
- Storing water underground, whether through surface recharge methods or through wells, is increasingly accepted as a viable and cost-effective water management option.
- ASR can help to "drought-proof" Oklahoma

ASR Book, Second Edition

www.asrforum.com