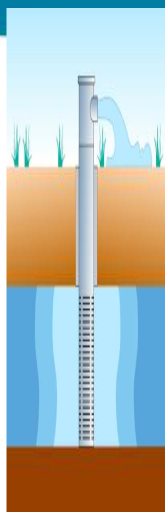
FRESH WATER IN THE NORTH CAROLINA COASTAL PLAIN



AQUIFER STORAGE RECOVERY (ASR) :

PROS, CONS, CONCERNS AND CONSIDERATIONS FOR TREATMENT OPTIONS

New Bern, North Carolina
February 16, 2016

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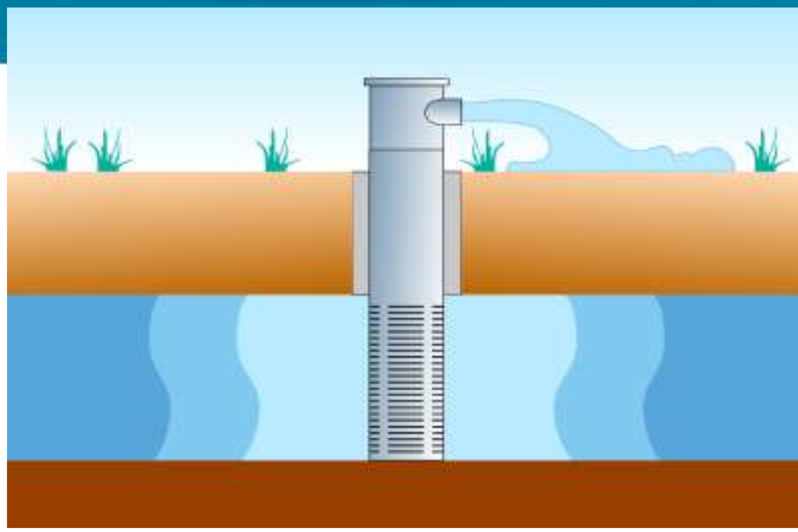
Approximately 175 Operational ASR Wellfields in the United States (2016) in at least 25 States, plus many other countries

ASR IS A STORAGE AND TREATMENT PROCESS

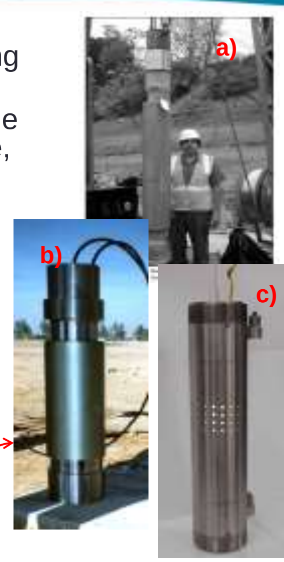


…and also a proven and cost-effective technology

ASR SYSTEMS

ASR Physical Treatment Processes

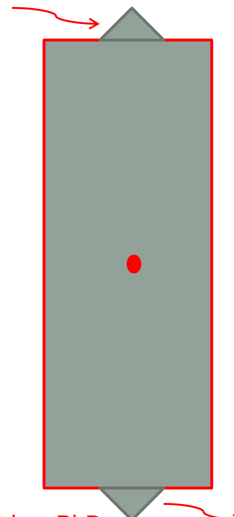
- Change from turbulent flow to laminar flow as water moves radially away from the well during recharge.
- Displacement, dispersion and advection as the stored water bubble expands during recharge, contracts during recovery, and moves downgradient in the aquifer.
- Pros: Precipitation and filtration of any particulates or flocs in intergranular spaces and other flow conduits.
- Cons: Well clogging and redevelopment.
- Cons: Air entrainment and cascading, if not controlled.
- Dissolved air solution and release.
- Subsidence and raising of ground surface elevations.



Downhole Flow Control Valves
a) Baski, b) V-Smart, c) 3-R

ASR Microbial Treatment Processes

- Aquifers may be envisioned as a seething, frothing mass of bacteria that haven't had anything to eat for a long long time and are waiting to be fed.
- It is complicated and expensive to characterize and investigate subsurface microbial reactions in wells, and to reverse microbial clogging mechanisms.
- Dissolved oxygen uptake by microbial activity can be rapid (hours to days), generating $CO_{2.}$
- Ammonia reduction and denitrification occurs more slowly (days to weeks).
- Pros: DOC, N, P, Disinfection Byproduct (DBP), bacteria, virus, protozoa reduction occurs during ASR storage due to microbial activity.
- Cons: Well clogging also occurs due to microbial activity.

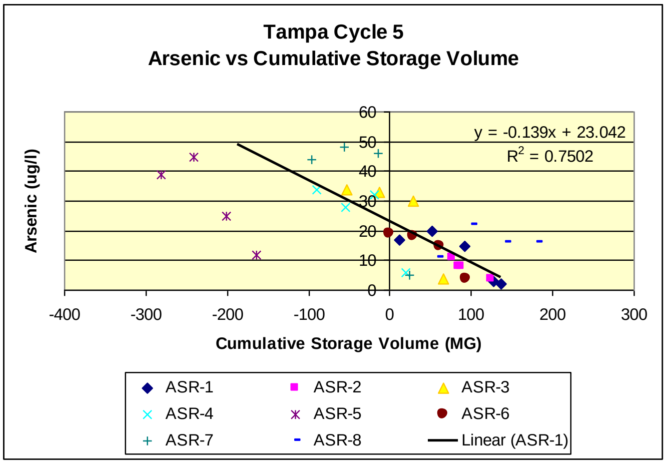


Well clogging "picture" courtesy: John H. Schnieders PhD

ASR Geochemical Treatment Processes

- Importance for successful ASR generally underestimated.
- Investigations expensive but necessary, particularly for finer-grained lithologic settings for ASR wells.
- Microbiological and geochemical treatment processes underground are two sides of the same coin, but the geochemical processes are relatively easier to investigate, given accurate input data.
- Processes include (but not limited to) oxidation, reduction, ion exchange, adsorption, diagenesis (weathering), leaching, dissolution, precipitation.
- Investigation tools include continuous wireline coring, core lab analysis, geochemical modeling, field and bench testing.
- Pros: Reactions can usually be controlled at low to acceptable cost (buffer zone, pH & alkalinity adjustment, deoxygenation).
- Cons: metals mobilization (Fe, Mn, As, U), formation of kaolinite clay, turbidity increase, well clogging, need for pre- or post-treatment.

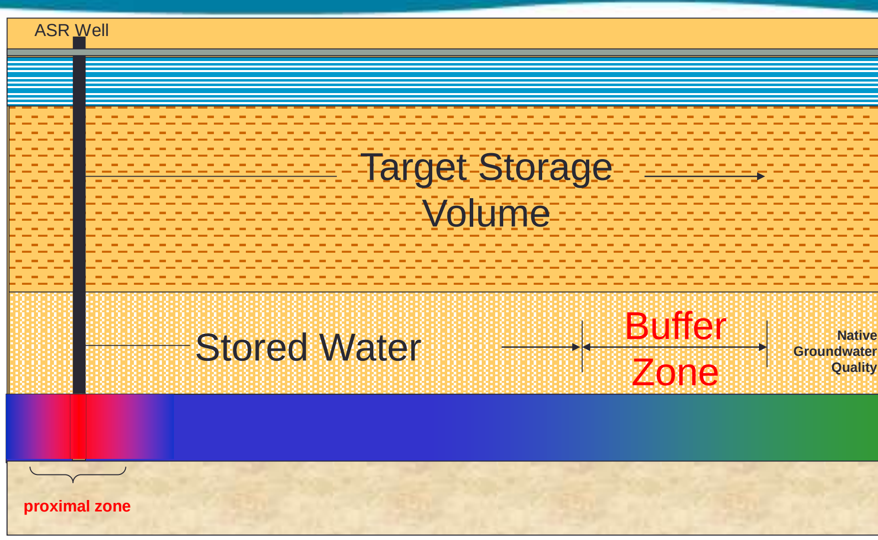
Arsenic declines due to geochemical processes as the cumulative storage volume increases



ARSENIC ALSO DECLINES WITH DISTANCE , WITH TIME, AND WITH INCREASING NUMBERS OF OPERATING CYCLES AT ABOUT THE SAME VOLUME

DISTANCE USUALLY LESS THAN 200 FT

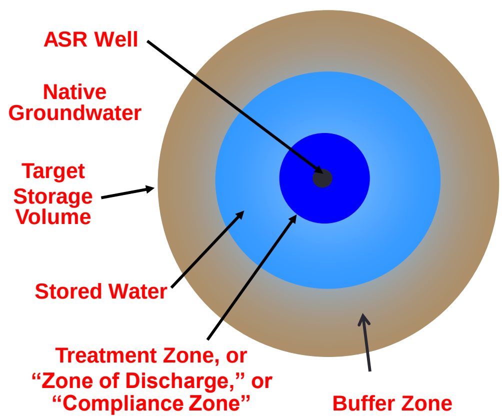
Target Storage Volume (TSV) is sum of stored water volume plus buffer zone volume. It is often expressed in MG/MGD of recovery capacity, or “days”



Treatment occurs in an aquifer due to natural physical, geochemical and microbial processes.

Improvements in Water Quality

ASR Bubble (Top View)



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

Forming and Maintaining the TSV, including 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.

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

A second key to ASR success is having an appropriate regulatory framework

- Provide reasonable time and distance around an ASR well for natural physical, microbial and geochemical treatment processes underground to enhance water quality.
- Evaluate compliance with water quality standards at appropriately located monitor wells during ASR recharge and storage, and at the distribution system connection during recovery.
- Provide for Wellfield Protection Areas (WPAs) for stored water around ASR wells.

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

Emergency Storage: Des Moines ASR Objectives

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

Retrofit of Existing Abandoned Production Well

Early Geochemical Surprise !

Primary ASR Objective
- Emergency Water Supply after 1993 Flood
- 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

Seasonal Storage

- Most common application of ASR.
- 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

Maintain pressures, flows and water quality in a distribution system

- Common application of ASR.
- 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

ASR well design and WTP process design need to be integrated

- Conventional surface water treatment processes with alum and lime to reduce color and meet drinking standards in product water can produce recharge water that is highly aggressive to Atlantic Coastal Plain aquifers, producing Fe and Mn through dissolution of pyrite, siderite and feldspars. Increasing the alkalinity and pH of the product water can probably resolve this issue. Phosphate addition for corrosion control in the distribution system may not be effective in the aquifer due to microbial activity and geochemistry.
- Ozone and other WTP processes can accelerate oxidation processes in the aquifer, potentially mobilizing metals.
- Other strong oxidation processes such as hydrogen peroxide, often utilized for reclaimed water treatment, are probably aggressive to clastic aquifer geochemistry.
- Meeting peak demands from ASR storage can greatly reduce WTP capital and operating costs, and overall unit costs for water supply.

Potential ASR Objectives for NC (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

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

ASR Wellfield Conceptual Plans are Getting Larger

- Strategic Water Reserve for Middle East Country –
  - 400 MGD for 90 days
- Environmental Flows for Coastal Texas Estuarine Area –
  - 350 MGD for up to 180 days
- Environmental Flows for Apalachicola Bay to Resolve GA-FL-AL Water Wars –
  - 250 MGD supplemental flow as needed
- Las Vegas Valley Water District –
  - 157 MGD recovery capacity in service, but no water to recharge
- San Antonio Water System –
  - 60 MGD ASR wellfield in highly successful operation

Storing large volumes of water underground is gaining acceptance as a relatively low cost solution to meeting many water management needs, supplementing other water supply and storage options.

Conclusions

- ASR is proven and has many different applications to achieve water supply goals.
- There is a recommended approach for achieving ASR success. Ignoring this can lead to inappropriate perceptions of ASR “failure.”
- Water treatment occurs during ASR storage. WTP process design needs to be more effectively integrated with ASR facilities design and operations
- ASR solutions are targeting ever larger (regional, national) water management issues.
- Storing water underground is increasingly accepted as a viable and cost-effective water management option.
- ASR can help to meet water supply goals with high reliability and sustainability in the North Carolina Coastal Plain.

ASR Book, Second Edition

www.asrforum.com