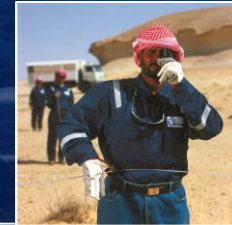
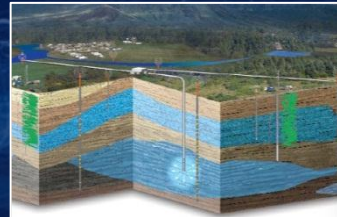


Aquifer Storage and Recovery Using Reclaimed Water: Successful Applications and Critical Opportunities



Agenda

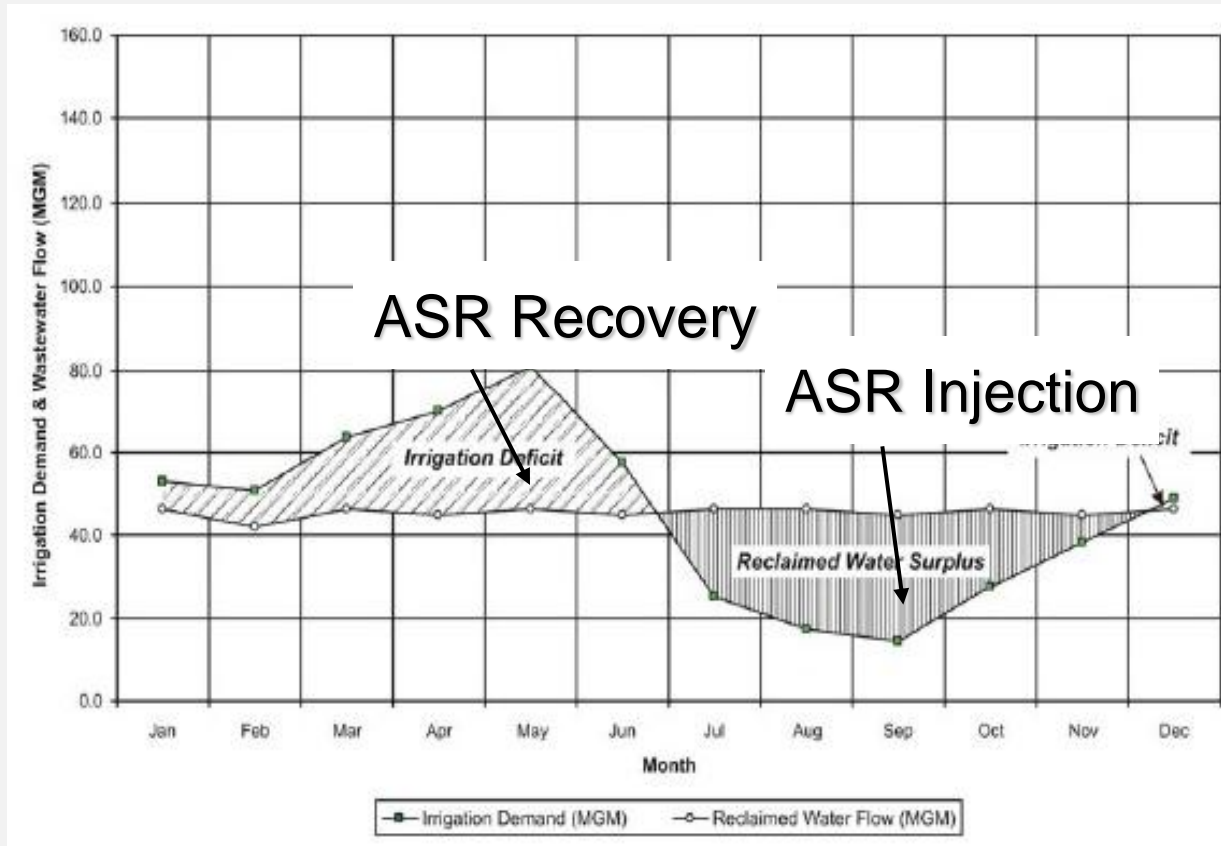
- Benefits
 - Water Resource
 - Water Quality Improvement
 - Energy Savings
- Existing Applications Around the World
- Future Opportunities – GCC Specific



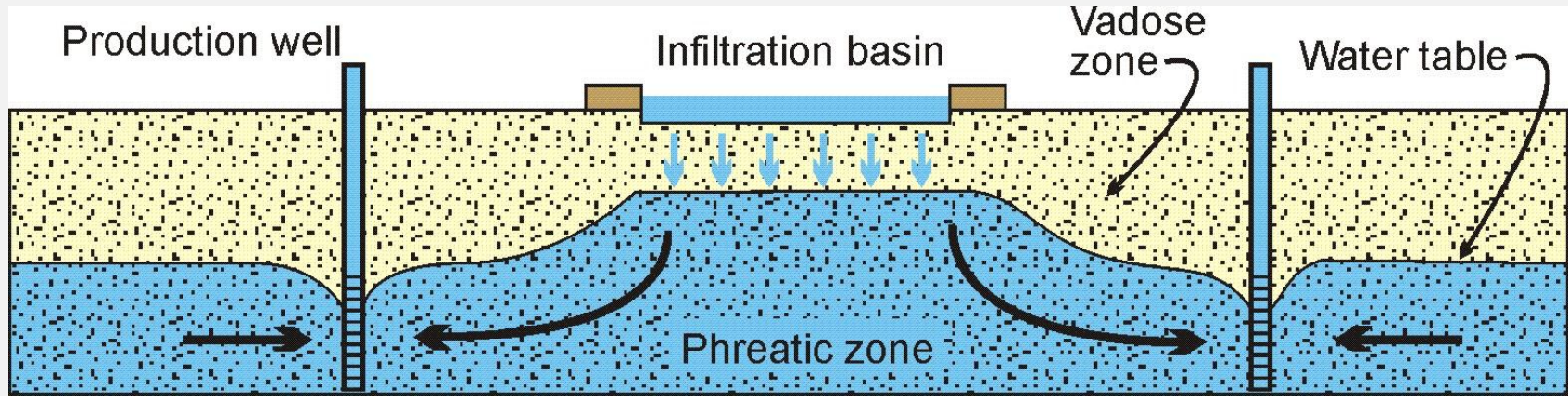
Reclaimed water as a source is of predictable volume with a fairly uniform rate of flow over time and of constant, but inferior quality (Murray and Tredoux, 1998).

Benefits – Water Resource Management

Example of ASR to Meet Supply/Demand



Benefits – Water Quality Improvement

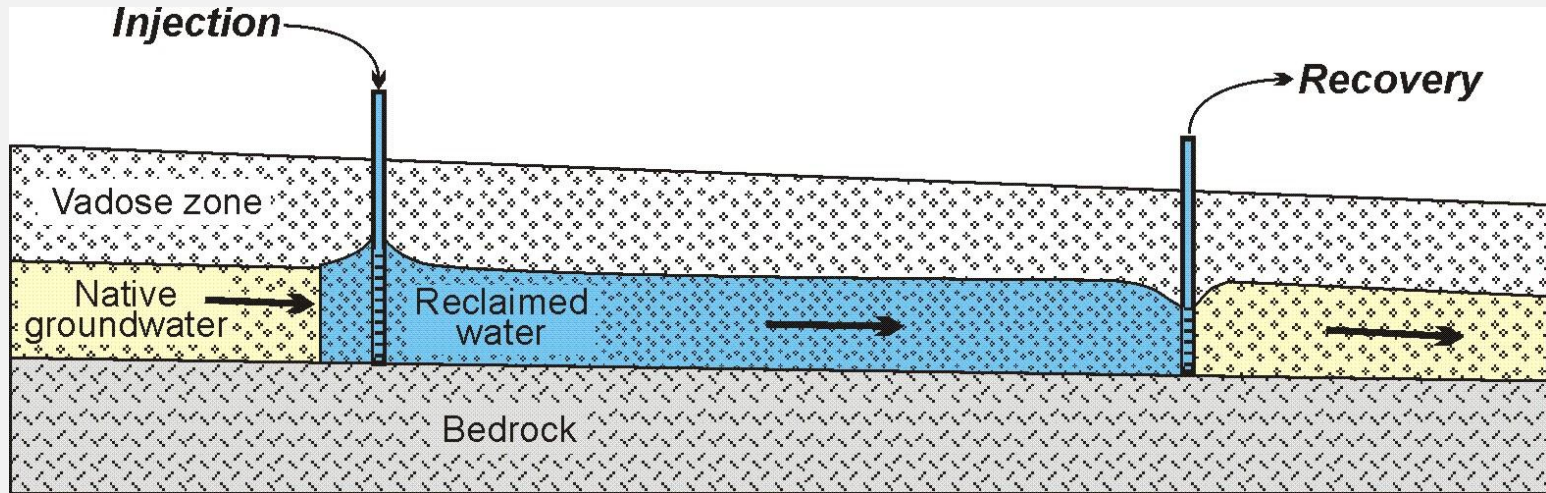


Soil-Aquifer Treatment

Water recovered using production wells.

Production wells control movement of recharged water and can prevent it from reaching more distant potable water wells depending on operational strategy.

Benefits – Water Quality Improvement



Aquifer Storage Transfer and Recovery

Injection and recovery using separate wells

Flow of recharged water through aquifer provides filtration and time for natural degradation (and other contaminant attenuation) processes to occur.

Constituents of Concern in TSE

- **Pathogenic microorganism**



- One time exposure → illness
- Presence and concentration depends wastewater treatment process and health of population in service area
- Variety of different pathogens may be present: bacteria, protozoa, viruses, trematodes.

- **Chemical constituents**

- **Typically present at low concentrations**

- **Long-term low-level** (chronic) exposure → Adverse health impacts

Natural Pathogen Attenuation Processes in Groundwater

- Most waterborne pathogenic microorganisms
 - are enteric (intestinal)
 - **do not survive long in groundwater environments**
- Groundwater = **hostile environment** for enteric microorganisms
 - different chemistry
 - already occupied by indigenous microorganisms
- **Log₁₀ removal times for most pathogens is several days to weeks, so several months of underground storage can result in high degrees of removal.**

Energy Savings

- Local Resource reduces transmission cost
 - Pipeline construction, maintenance and lift station pumping costs reduced
- Treatment costs reduced depending on water resources and level of treatment required
 - California recycled water costs 10 – 30% of cost of importing water due to decreased energy and infrastructure
- Increased aquifer levels mean lower pumping costs
 - 10% decrease in pump lift relates to about 10% reduction in energy required

Although it requires additional energy to treat wastewater for recycling, the amount of energy required to treat and/or transport other sources of water is generally much greater. USEPA

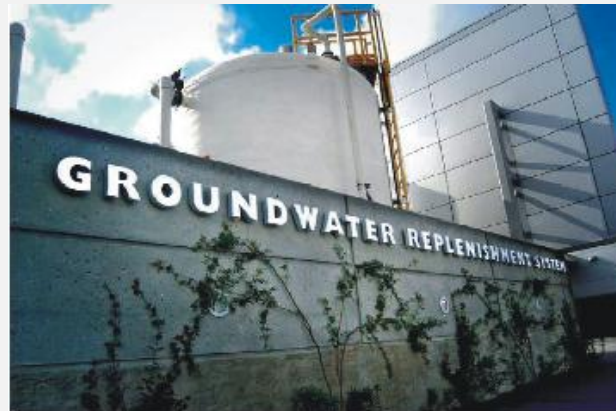
Existing Applications

Groundwater Replenishment System Orange County, California

■ Groundwater Replenishment System

Following conventional treatment:

- Microfiltration (MF)**, which removes small suspended particles, protozoa, bacteria, and some viruses from the water
- Reverse osmosis (RO)**, which eliminates salts, viruses, pesticides, and most organic compounds, creating near-distilled quality water
- Ultraviolet (UV) light and hydrogen peroxide treatment**, which breaks down remaining organic compounds

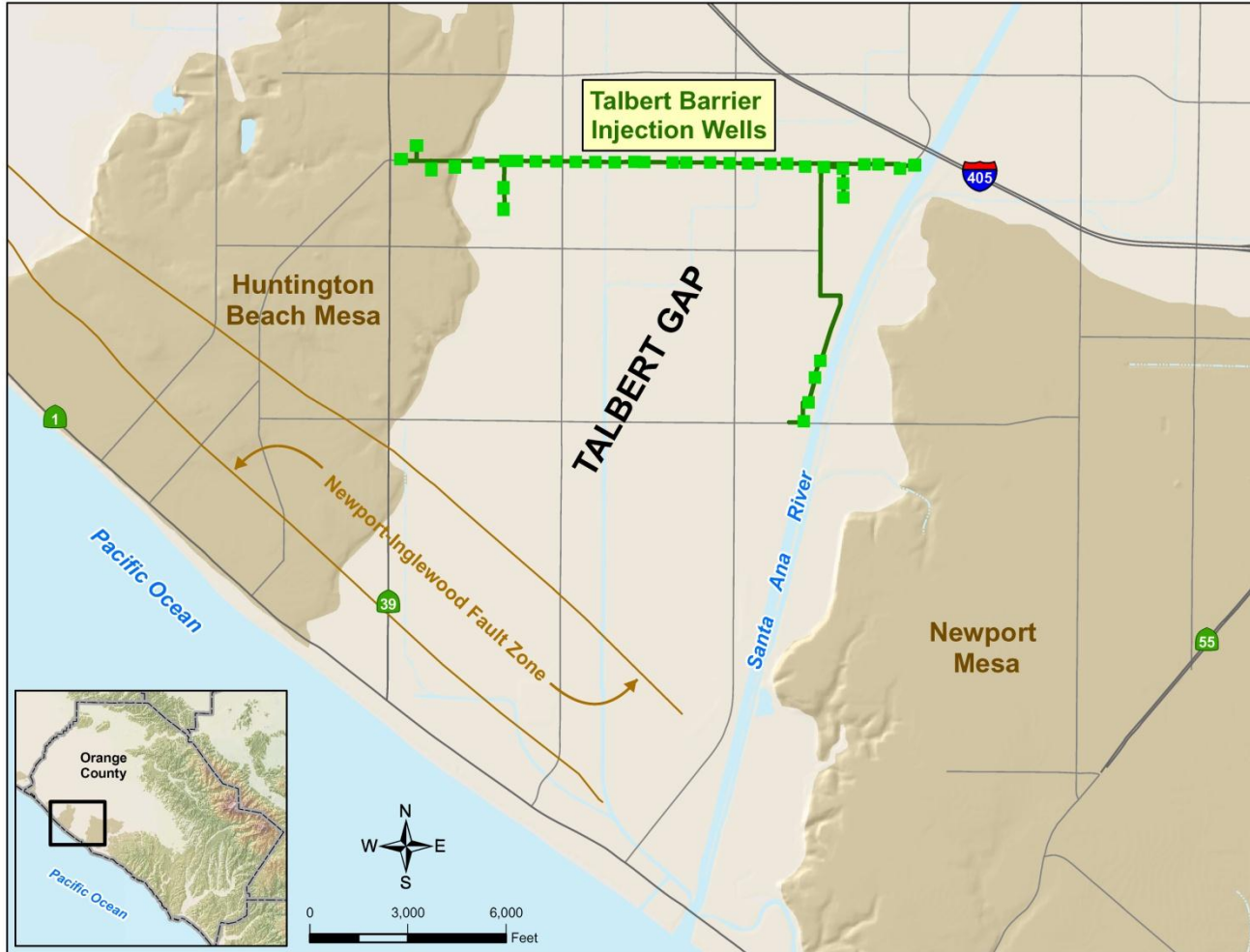


- **Groundwater Replenishment System, California, USA**
 - Capacity of 70 million gallons (264,960 m³) per day
 - Construction cost of approximately US \$485 million
 - Operational cost is US \$525 per acre ft => US \$1.61 per 1000 gallons or US \$426 per 1000 m³
 - SWRO ~ US \$600 per 1000 m³ (WaterReuse.org 2012)

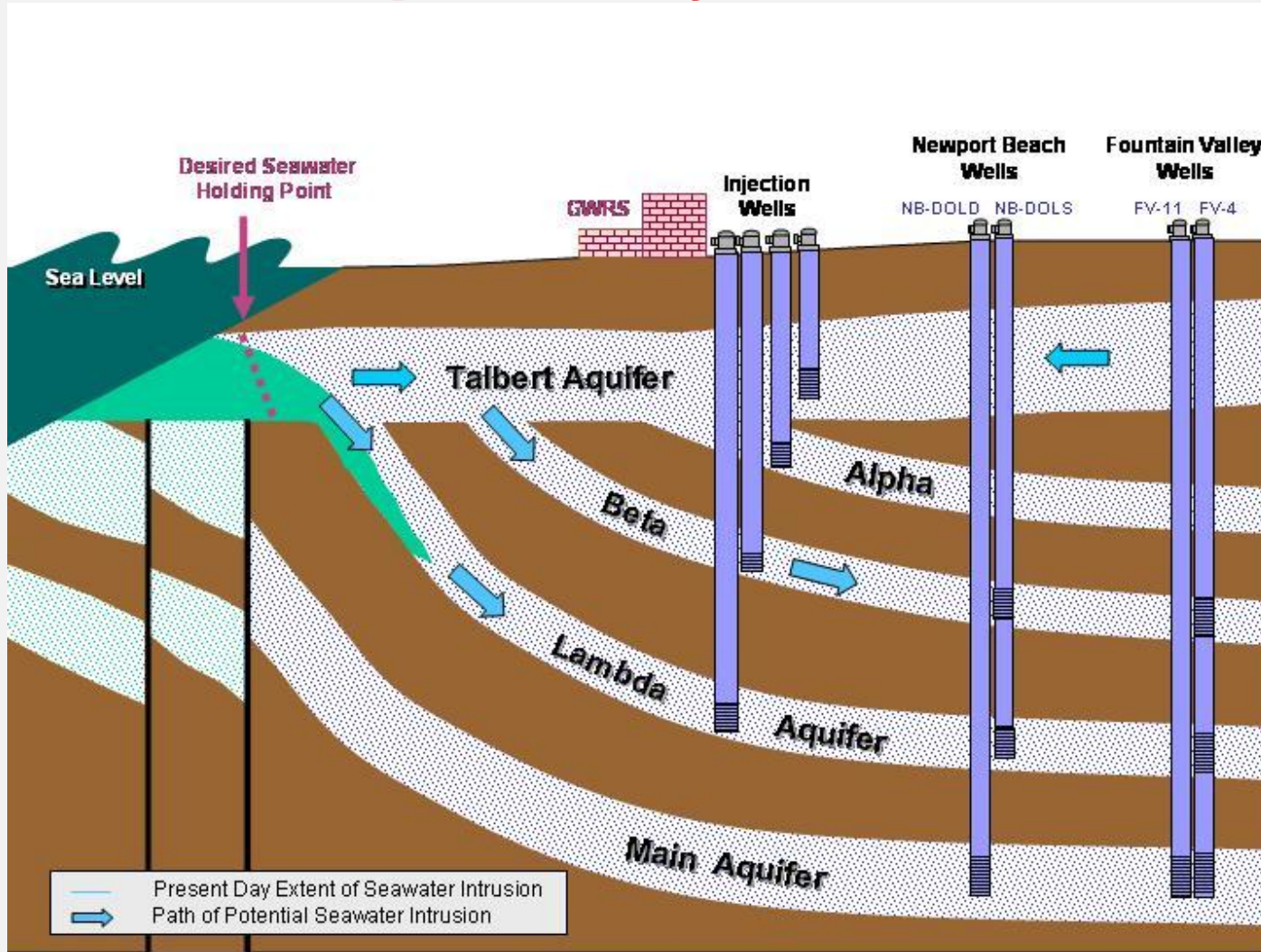


Uses less than one-third the energy that it takes to desalinate ocean water.

Talbert Gap – Orange County, California



Talbert Gap Salinity Barrier Cross Section

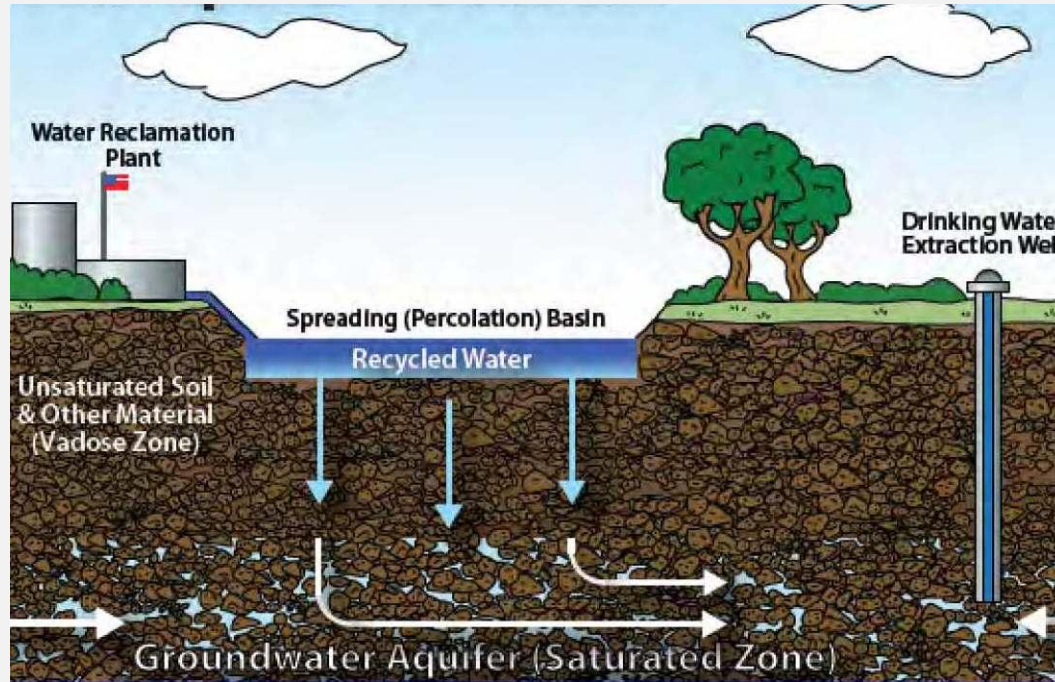


Water Quality and Water Levels Monitored with Westbay Multi-zone Monitoring Systems

Montebello Forebay Ground Water Recharge Project

For over 35 years, in the Montebello Forebay Ground Water Recharge Project, tertiary treated recycled water has been applied to the Rio Hondo spreading grounds to recharge a potable ground water aquifer in south-central Los Angeles County.

> 1.5MAcre Feet Since 1962 = 1.85M Megaliters

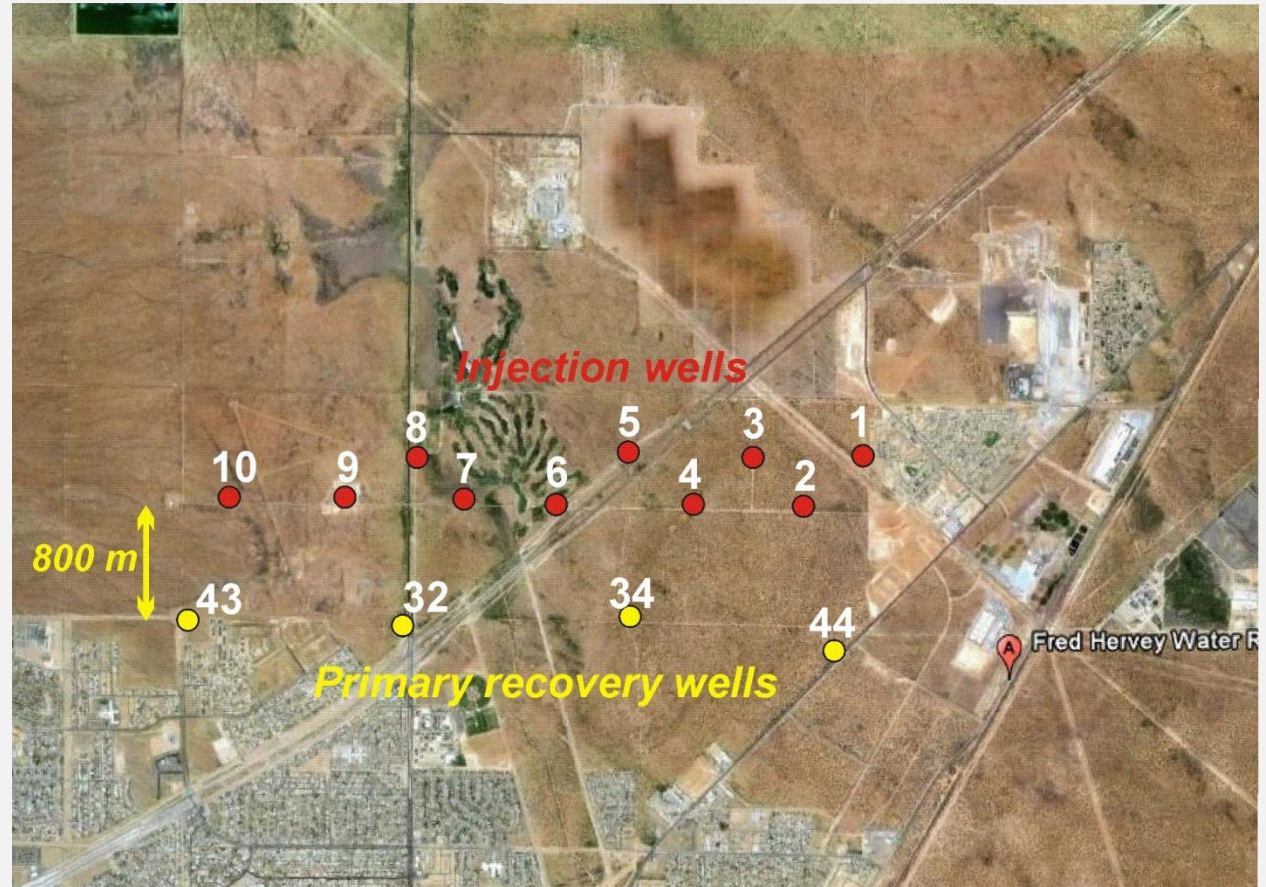


Other Projects of Note:
Nardò, Italy
Bolivar, Australia
Perth, Australia
Adelaide, Australia
Sabadell, Spain
Torreele, Belgium
Atlantis, South Africa
Florida, USA
California, USA
Texas, USA

Source: Los Angeles County Sanitation District

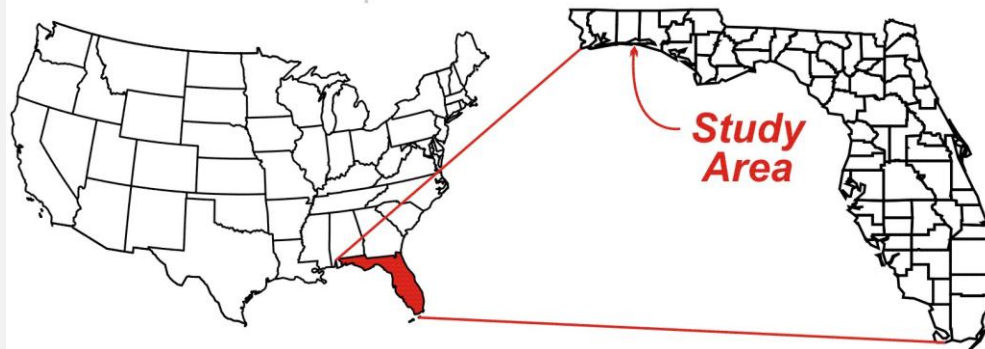
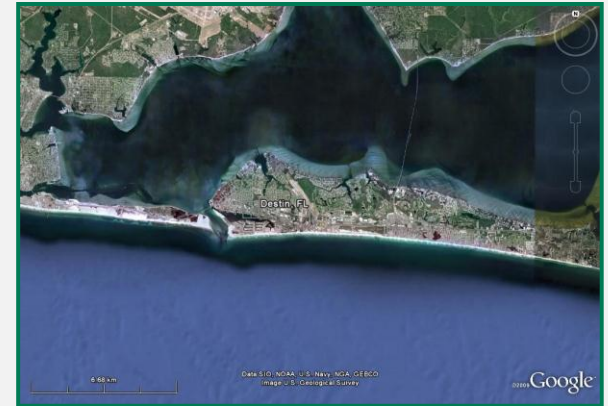
Aquifer Storage Transfer and Recovery Fred Hervey WTP – El Paso, Texas

- Minimum two-year travel time from injection wells to recovery wells
- Added infiltration basins for wastewater recharge



Reclaimed Water ASR in Destin, Florida

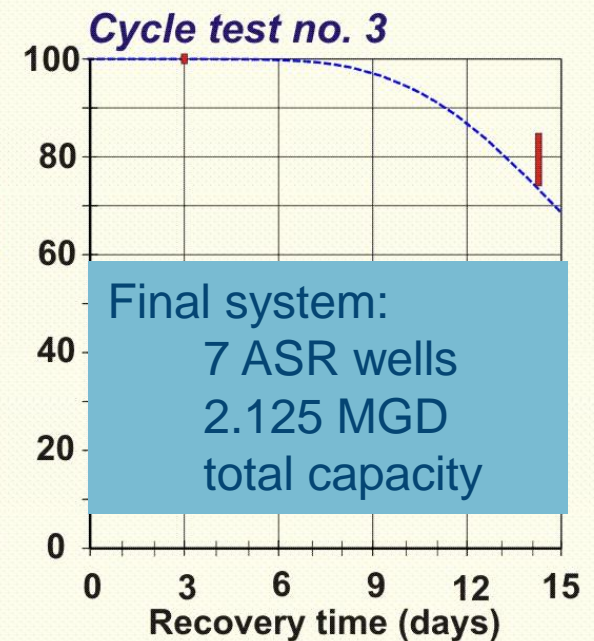
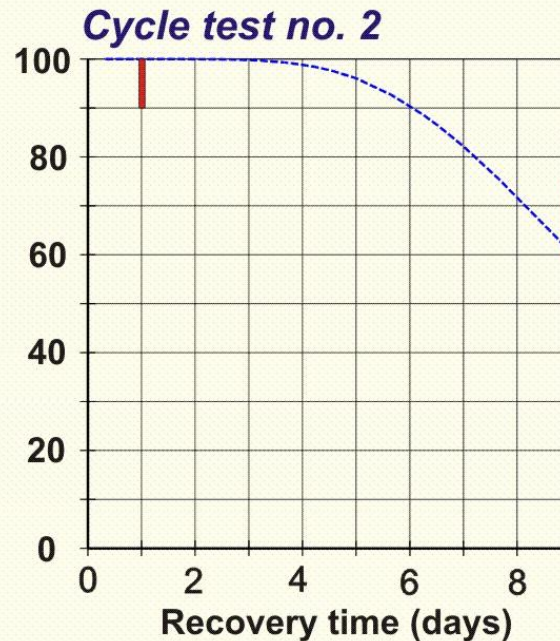
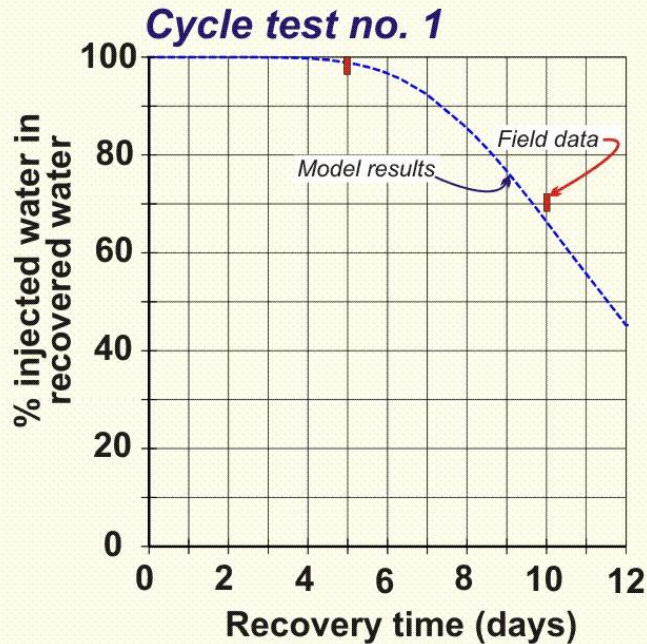
- TSE ASR needed for additional wet season reclaimed water disposal capacity (operational and regulatory requirement).
- Environmental issues are very sensitive because of tourism. Area is known for its beautiful beaches and sport fishing.



Pilot Testing Results

- Solute-transport modeling

- Modeling was used to analyze system performance and hydrogeology through calibration process
- Predictive tool for system expansion and operations optimization



Final system:
7 ASR wells
2.125 MGD
total capacity

Australia

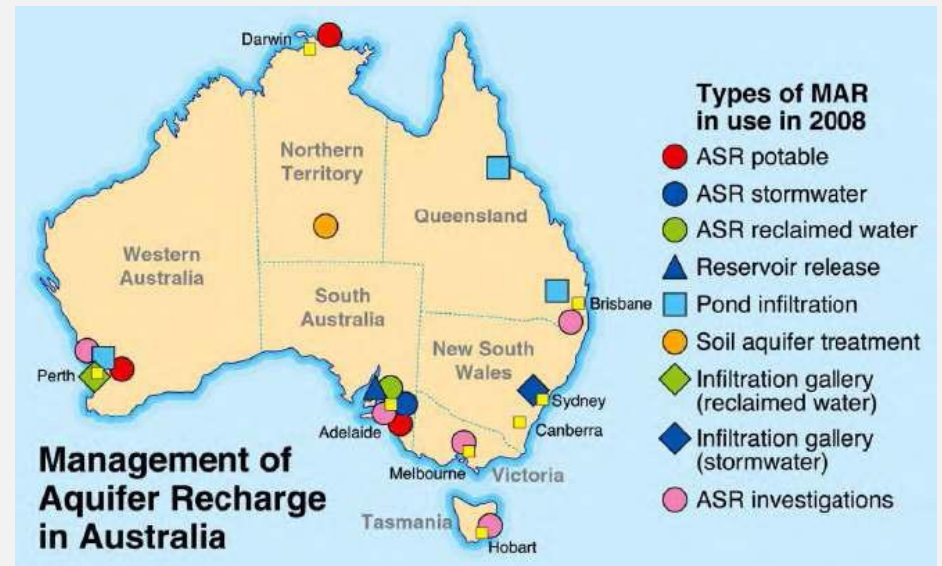
Adelaide

- ~22 ASR schemes using ponds, galleries & injection bores
- recharge treated stormwater and wastewater
- mostly confined limestone aquifers

Perth – sand aquifers

- gw supplies 70% of water use
- gw supplies 30% of potable water
- practice MAR with stormwater
- successful trials of infiltration galleries with treated wastewater

Source: UNSW Water Research Laboratory



TSE MAR Opportunities in GCC

- 1) ASR in reaches of aquifers downstream from cities (TSE typically available at downstream side of city).
- 2) ASR or salinity barrier systems in coastal areas. TSE used for increasing hydraulic head and holding back saline water migration.
- 3) Recovery of water levels in aquifers.
- 4) Water resource management tool for cities, power plants, industrial cities, etc. Large storage capacity depending on hydrogeologic conditions.

GCC Characteristics with Respect to Water Resources

- Rapid urban population growth.
- Diminishing groundwater supplies.
- Increasing TSE resource.
- Increasing reliance on seawater desalination.
- Best to diversify resources
- Energy resources of increasing concern



Conclusions

- TSE MAR projects demonstrate that the technology is viable and can provide significant water resources benefits.
- Significant energy savings can be realized over development of other water resources dependent on situation.
- The multiple barrier approach is typically employed to ensure that public health is protected, although the barrier elements used vary between systems.
- TSE MAR systems tend, if anything, to be over-designed in order to provide public with greater confidence in projects.
- Modern planned TSE MAR systems have a excellent safety record. No documented adverse health impacts.
- The GCC has many opportunities to employ this valuable water resource tool

Thank You – Questions??

Vertical migration of municipal wastewater in deep injection well systems, South Florida, USA

Robert G. Maliva · Weixing Gao · Thomas Missimer

Abstract Deep well injection is widely used in South Florida, USA for wastewater disposal largely because of the presence of an injection zone ("boulder zone" of Floridan Aquifer System) that is capable of accepting very large quantities of fluids, in some wells over 75,000m³/day. The greatest potential risk to public health associated with deep injection wells in South Florida is vertical migration of wastewater, containing pathogenic microorganisms and pollutants, into brackish-water aquifer zones that are being used for alternative water-supply projects such as aquifer storage and recovery. Upwards migration of municipal wastewater has occurred in a minority of South Florida injection systems. The results of solute-transport modeling using the SEAWAT program indicate that the measured vertical hydraulic conductivities of the rock matrix would allow for only minimal vertical migration. Fracturing at some sites increased the equivalent average vertical hydraulic conductivity of confining zone strata by approximately four orders of magnitude and allowed for vertical migration rates of up to 80m/year. Even where vertical migration was rapid, the documented transit times are likely long enough for the inactivation of pathogenic microorganisms.

Résumé Les injections par puits profonds sont largement utilisées au sud de la Floride (Etats-Unis) pour stocker les eaux usées, essentiellement du fait de la présence d'une zone d'injection ("zone des blocs" du Système Aquifère de Floride) apte à accepter des quantités considérables de fluides : plus de 75,000m³/jour dans certains puits. Le plus grand risque potentiel associé à ces puits vis-à-vis de la santé publique est la migration verticale des eaux usées, qui contiennent des microorganismes pathogènes et des

polluants, vers les zones aquifères d'eau saumâtre qui sont utilisées pour les projets de stockage alternatif. Des migrations ascendantes observées dans le sud de la Floride ont entraîné la migration verticale de soluté de la zone de stockage alternatif vers des zones aquifères d'eau saumâtre qui sont utilisées pour les projets de stockage alternatif. Les résultats de la modélisation de transport de soluté à l'aide du programme SEAWAT indiquent que les conductivités hydrauliques mesurées de la matrice rocheuse ne permettraient qu'une migration verticale minimale. La fracturation de certains sites a augmenté la conductivité hydraulique équivalente moyenne de la zone de confinement des strates de la zone de stockage alternatif, ce qui a permis une migration verticale de l'effluent des puits jusqu'à des vitesses de 80 m/an. Même lorsque la migration verticale était rapide, les délais de transit documentés sont susceptibles d'être suffisamment longs pour permettre l'inactivation des microorganismes pathogènes.

Resumen La inyección de aguas residuales en pozos profundos es ampliamente utilizada en el sur de los Estados Unidos para almacenar los desechos líquidos, principalmente debido a la presencia de una zona de inyección ("zona de bloques" del Sistema Acuífero de Florida) apta a aceptar cantidades considerables de fluidos: más de 75,000m³/día en algunos pozos. El mayor riesgo potencial asociado con estos pozos es la migración vertical de los efluentes de los pozos, que contienen microorganismos patógenos y contaminantes, hacia acuíferos de agua salada que se utilizan para proyectos de almacenamiento alternativo de agua. Se ha observado la migración vertical de aguas residuales en una minoría de los sistemas de inyección de Florida. Los resultados de la modelación de transporte de solutos utilizando el programa SEAWAT indican que las conductividades hidráulicas verticales medidas de la matriz de la roca permitirían sólo una migración vertical mínima. La fracturación en algunos sitios aumentó la conductividad hidráulica equivalente promedio de la zona de confinamiento de las estratas de la zona de almacenamiento alternativo, lo que permitió la migración vertical de los efluentes de los pozos a velocidades de hasta 80 m/año. Incluso cuando la migración vertical fue rápida, los tiempos de tránsito documentados probablemente son lo suficientemente largos como para permitir la desactivación de los

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Hydrogeology Journal

Reclaimed Water ASR in a Barrier Island Shallow Aquifer, Destin, F

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ABSTRACT

Management of reclaimed water in coastal communities is an increasing challenge because of population increases and associated reclaimed water flows, environmental concerns, and acquisition costs. Destin Water Users, Inc. (DWU) implemented an aquifer storage and recovery program that will provide cost-effective and environmentally sound additional peak flow and additional water to meet reuse demands during peak irrigation periods, which will be on freshwater resources. Tertiary-treated wastewater is stored in the shallow Sand-anthracite sand storage zone, arsenic leaching has occurred in the recovered water with a maximum of 41 µg/L. Concentrations have subsequently decreased suggesting depletion of a very arsenic supply. The DWU ASR project is the first of its kind in Florida and may serve as similar systems on barrier islands elsewhere in the world.

INTRODUCTION

Water resources management in many coastal areas of the world has become a great challenge because of a combination of limited freshwater resources, susceptibility of population growth to salt-water intrusion, and increasing demands associated with population growth concentrated in coastal communities. Barrier island communities are particularly vulnerable because of the paucity of fresh surface water and shallow, locally recharged groundwater.

Safe disposal of wastewater can also be a major challenge because of the environmental impacts of water conservation in that it reserves high-quality freshwater for other uses during high demand periods. Such seasonal, large-volume storage of reclaimed water is possible using aquifer storage and recovery (ASR) technology. The storage of reclaimed water possible with ASR can also increase the demand for reclaimed water by increasing the reliability of the supply. Irrigation users are often reluctant to commit to reuse systems unless they are guaranteed water during both seasonal dry periods and droughts, when they need the reclaimed water the most. Reliable supply thus results in increased demand.

Communities vary in the annual percentage of their reclaimed water flows that are reused. In some instances, the existing reuse infrastructure and demands may not be adequate to accept the entire reclaimed water flows. In areas with substantial seasonal variation in precipitation, and thus irrigation requirements, there may be relatively little demand for reclaimed water during wet periods. Greater reuse could occur if excess water can be stored during periods of excess supply for later use during high demand periods. Such seasonal, large-volume storage of reclaimed water is possible using aquifer storage and recovery (ASR) technology. The storage of reclaimed water possible with ASR can also increase the demand for reclaimed water by increasing the reliability of the supply. Irrigation users are often reluctant to commit to reuse systems unless they are guaranteed water during both seasonal dry periods and droughts, when they need the reclaimed water the most. Reliable supply thus results in increased demand.

Aquifer Storage and Recovery and Managed Aquifer Recharge Using Wells: Planning, Hydrogeology, Design, and Operation

Robert G. Maliva
Thomas M. Missimer

Proceedings of the International Conference on Energy, Environment, and Water Desalination, Tripoli, Libya, December 8-9, 2009

Salinity Barriers Using Reclaimed Water as a Component of Sustainable Water Supply Development in Coastal Arid Regions

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Abstract

A fundamental water resources challenge in coastal regions is optimizing the use of all available water resources. There are four main water-supply options in coastal areas: (1) fresh groundwater, (2) fresh surface water, (3) desalination, and (4) reuse of treated wastewater. Within arid regions both surface water and renewable groundwater resources are limited by low rainfall and recharge rates. Coastal groundwater resources face the additional threat of deterioration of water quality due to saline-water intrusion. Treated wastewater from municipal sewage treatment plants, referred to as reclaimed water or treated sewage effluent (TSE), is a valuable water resource that can be used to allow for the optimization of the use of other water resources.

Desalination of seawater or brackish groundwater is a feasible option in coastal areas, but it is a relatively expensive option, particularly where the water is being put to relatively low-value uses such as irrigation. The reuse of reclaimed water for low-value uses, and particularly for irrigation, is not cost-effective to build desalination capacity irrigation, when such irrigation can be performed much less expensively using reclaimed water that would otherwise require disposal.

An additional potential use of reclaimed water is to create salinity barriers to prevent or potentially reverse saline-water intrusion. The basic salinity barrier concept is to inject water in a row of wells located landward of the saline-water interface to create a hydraulic mound or divide. The injection wellfield is located approximately parallel to the coast. The injection wellfield allows for potable water withdrawals to be maintained or even increased landwards of the interface without causing saline-water intrusion. Salinity barriers using reclaimed water are operational in Salalah, Oman, Southern California, USA, and are under development and consideration elsewhere.

Salinity barrier systems have several main design issues. The location of the saline-water interface must be accurately located. The systems must be then designed so that they actually serve as effective barriers. This requires thorough aquifer characterization and groundwater modeling to determine the optimal wellfield location, well spacing, and injection rates. The well designs and potential pre-treatment processes need to be evaluated to keep well and aquifer clogging within acceptable rates. Landward movement of the injected water must also be evaluated along with its potential impacts on aquifer users. These impacts will depend upon the proximity of production wells to the interface and the sensitivity of the aquifer users. Protecting potable water supply wells is of paramount



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RESEARCH ARTICLE · EARTH SCIENCES

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Aquifer Storage and Recovery of Treated Sewage Effluent in the Middle East

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Abstract Treated sewage effluent (TSE) is becoming a critical resource in arid parts of the world. The high costs of desalinated potable water and the depletion of fresh groundwater resources necessitate increased use of TSE as an important component of water resource management throughout the Middle East. TSE can replace potable-quality water in irrigation, with the latter becoming too valuable a resource to use for irrigation purposes. In arid regions of the Middle East and North Africa, existing TSE is often available because of seasonal variations in demand and supply and that the development of reuse infrastructure has not kept pace with population growth, concomitant water use and TSE generation. Aquifer storage and recovery (ASR) technology provides an opportunity to store large volumes of TSE for later beneficial use. Natural attenuation processes that occur during underground storage in an ASR system can also improve the quality of stored water and thus provide an opportunity to "polish" already high-quality TSE. Aquifers containing brackish water or those depleted from over-pumping are present throughout much of the Middle East. These aquifers could potentially be used as storage zones for ASR systems. However, currently available hydrogeologic data are insufficient for assessment of potential system performance. Other key design issues are the selection of ASR system locations and storage zones so that TSE will not enter potable water supplies, and ensuring that the ASR systems will be readily integrated into existing or planned sewer treatment, TSE transmission and reuse infrastructure.

Keywords Aquifer storage and recovery · Treated sewage effluent · Reclaimed water · Water resources

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Thank You

