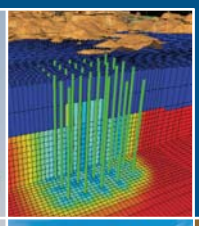
Schlumberger
WATER SERVICES

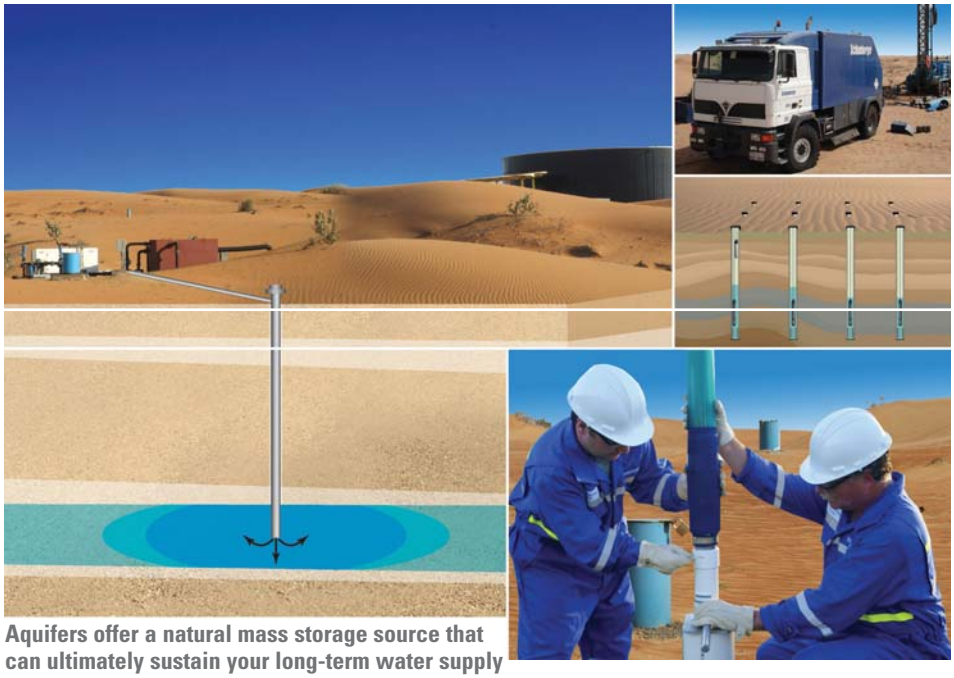


Aquifer Storage and Recovery

Engineered Water Solutions

We Make Sustainable Water Real

with technologies and expertise to make the most of your water resources



Aquifers offer a natural mass storage source that can ultimately sustain your long-term water supply needs. Can you afford not planning for Aquifer Storage and Recovery?

TO MAKE ASR VIABLE, YOU NEED:

- **high-resolution geophysical logging**
- **regional hydrogeologic interpretations**
- **3D geologic modeling and flow simulation**
- **optimization of recovery efficiency**
- **well network planning and pilot tests**
- **injection well construction and operation**
- **continuous aqueous geochemical analysis**
- **long-term groundwater monitoring**

WE KNOW AQUIFERS

With over 80 years innovating subsurface exploration technologies, Schlumberger has become one of the most trusted service providers to managers of underground resources.

Schlumberger Water Services' aquifer storage and recovery (ASR) systems offer a cost-effective, mass storage solution that lets you take back control of your water supply – naturally. Schlumberger Water Services offers a full range of services and technologies to help you grasp the full extent of your natural underground storage capacity. We help you use existing aquifers and reveal the ability to store billions of gallons of water underground at a fraction of the cost of conventional approaches.

ADVANTAGES OF ASR

- Ability to store billions of gallons of water
- Fraction of the cost of aboveground storage tanks
- No potential for in-tank water fouling
- Reduced environmental footprint
- Does not have the evaporative losses of surface water reservoirs
- Very low risk of contamination

A BALANCED SOLUTION

Schlumberger Water Services provides a viable process for industrial and domestic clients to balance water supply against water demands. The aquifer's storage capacity and hydraulic properties are critical to this balancing act.

We are helping stakeholders worldwide adopt ASR for:

- Seasonal storage of treated potable water (e.g. desalinated water)
- Storage of non-potable water
- Supplemental and emergency water sources
- Long term (inter-year) storage
- Capture and storage of surface water that would otherwise be lost
- Development of strategic water reserves
- Prevention of saline-water intrusion
- Improvement of surface water quality and reclaimed water quality
- Maintenance of environmental flows in streams

Our experts are developing ASR systems in some of the most arid climates in the world

APPROACH

Schlumberger Water Services' approach to meeting the challenges of ASR is to provide superior team expertise and technology. Schlumberger is the global leader in sub-surface technology, giving Schlumberger Water Services access to a wealth of unmatched experience, knowledge, and advanced instrumentation. Many of our proven tools, originally developed for the oil and gas industry, can be applied directly to ASR and other water resources projects. In addition, Schlumberger Water Services has developed data analysis, modeling, and monitoring tools specifically for groundwater projects.

Technological tools are applied to ASR projects to the extent that they add value to reducing total costs, improving the potential system success, or improving system performance – ultimately securing effectiveness and affordability for all clients.

INTEGRATED AQUIFER CHARACTERIZATION

Our integrated approach allows us to highlight the imperfect properties (fractures, karsts, aqueous geochemical properties, water quality issues, heterogeneities, etc) that would affect water quality. This detailed understanding, unique to Schlumberger Water Services, allows us to find the properties of the aquifer that would inhibit successful ASR, and therefore, reduce the level of risk to clients.

Our advanced aquifer modeling abilities can incorporate a variety of data sources, including:

- geophysical interpretation
- surface imaging and mapping
- log interpretation and well correlation
- complex fault and fracture modeling
- facies and geophysical modeling
- hydrodynamic test analysis
- uncertainty analysis
- surface and subsurface interaction
- upscaling processes and property population
- flow and mass transport simulation
- surface geophysical surveys to assess the lateral extent and geometry of the aquifer

DESIGN CONSIDERATIONS

We optimize efficiency, total recovery rate, the area of influence, and the area covered by the well field. Schlumberger Water Services has the technology and expertise to determine geologic and hydrogeologic heterogeneities in the pre-design stage of the project. Knowing these details minimizes the unknowns and maximizes certainty of success. Key design influences include:

- Native groundwater quality - less saline better (mixing), desired water quality below 5000 mg/l TDS
- Hydraulic conductivity
- Water levels and pressures
- Aquifer heterogeneity
- Storage zone thickness
- Mixing due to hydrodynamic dispersion
- Confinement
- Regional flow gradient
- Geochemical – adverse water quality changes and plugging

IMPLEMENTATION

A successful ASR project requires excellent planning. Schlumberger Water Services increases the probability of success and reduces project costs by eliminating unexpected expenses during system construction, testing, and operation. Planning of ASR projects involves identifying, and giving due consideration to, the various factors that can impact the cost and success of an ASR project and proactively developing strategies for dealing with them.

Our ASR systems are implemented in a phased approach, during which the feasibility, implementation plans, design, and economics of the project are re-evaluated as data is obtained. Go/No Go decisions should be formally made after each project phase, in which the feasibility and cost-effectiveness of the ASR project at the investigated location(s) are objectively evaluated. The major advantage of a phased approach is that it affords early opportunities to change direction if an ASR project or location appears not to be feasible.

ASR CAN BE USED FOR:

Domestic/public water supply

The most common application of ASR is public water supply. ASR systems can be used to manage seasonal imbalances in supply and demand, eliminate or forestall the need for costly expansions in water treatment plant infrastructure, and provide a strategic supply of water that can be utilized when normal water supply is disrupted.

Mining – aggregate, mineral, and precious gems

In many parts of the world, mining occurs in areas with limited or ephemeral supplies of water. ASR can be used to capture and store seasonal excess surface water flows to support year-round mining operations. Water pumped during dewatering activities may also be stored for later beneficial uses.

Industry

ASR can be used by water intensive industries to provide seasonal or interyear water storage, which would help ensure a reliable year-round supply.

Energy – oil and gas

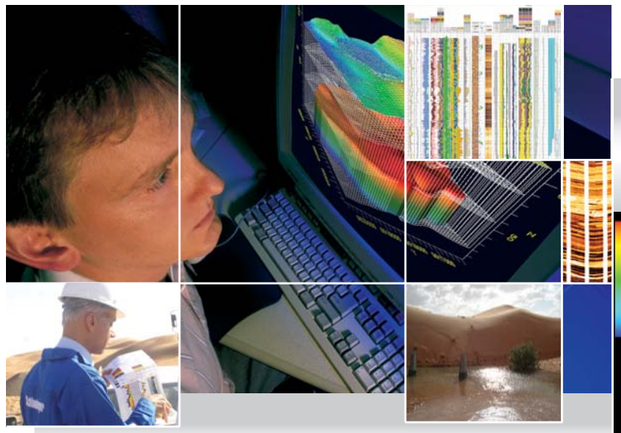
Oil and gas exploration and development activities may require large volumes of water for activities such as hydrofracturing and considerable quantities of water may be coproduced during oil and gas production. Treated oilfield waters may be stored in ASR systems for later use in oil and gas activities, reducing demands on local freshwater resources.

Agriculture

ASR can be a valuable drought management tool for agricultural operations. Seasonally or episodically available excess surface water can be stored for later use, when adequate water might not otherwise be available. ASR can also reduce or eliminate aquifer overdrafts by balancing production and recharge.

Desalination Plants

Membrane desalination water treatment plants operate most efficiently when the membranes are being used continuously to treat water. The storage provided by an ASR system can increase efficiency of membrane desalination facilities, and reduce overall costs, by avoiding the construction of an under utilized treatment capacity.

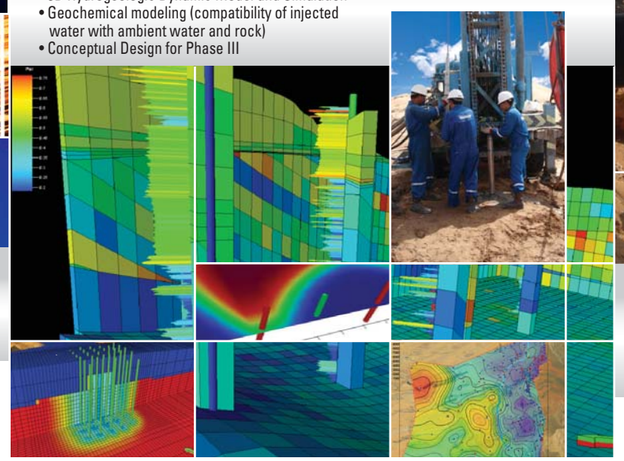


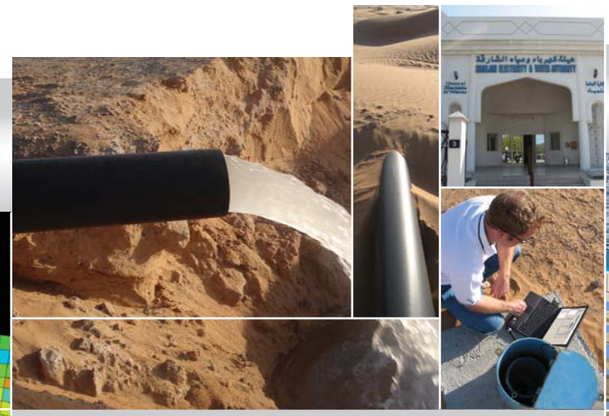
DESKTOP PRELIMINARY FEASIBILITY ASSESMENT

- Feasibility Study
- Site Selection
- Detailed Feasibility Study of Selected Site
- Conceptual Design for Field Pilot Test

EXPLORATORY WELL PROGRAM

- Drilling and Evaluation of Test Wells
- 3D Hydrogeologic Dynamic Model and Simulation
- Geochemical modeling (compatibility of injected water with ambient water and rock)
- Conceptual Design for Phase III





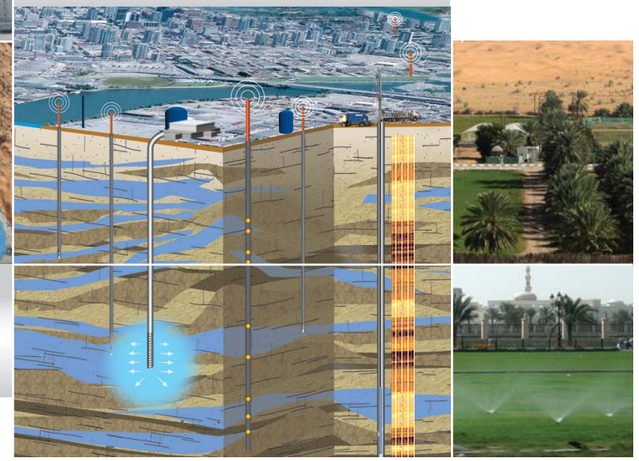
IMPLEMENTATION AND OPERATIONAL TESTING OF A PILOT ASR SYSTEM

- Preparation of final design drawings and technical specifications for the pilot ASR system
- Obtaining regulatory approval
- Construction of the pilot ASR system
- Testing to establish baseline well performance and storage zone hydraulics
- Operational (cycle) testing
- 3D Hydrogeologic Dynamic Model and Simulation updates

EXPANSION OF ASR SYSTEM TO MEET STORAGE NEEDS

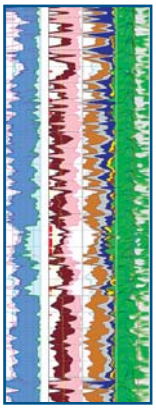
The system can be expanded to meet storage needs by the:

- design,
- permitting, and
- construction of additional ASR wells



Our Technologies

Site Characterization



Schlumberger Water Services offers a full suite of sophisticated geophysical well logging technologies, data acquisition instrumentation, and geologic modeling software designed to characterize subsurface environments.

- Magnetic resonance measures pore size distribution, hydraulic conductivity, capillary pressure
- Epithermal neutron porosity estimates water-filled porosity
- Bulk density and photoelectric effect defines total porosity, lithology
- Well flow logging provides continuous measurements of upwards/downward flow velocity/rate
- Spectral natural gamma ray logs bulk matrix geochemistry and mineralogy
- Borehole electrical imaging highlights fracture orientation and aperture
- Geologic modeling provides a comprehensive view of the subsurface environment

Site Characterization Technology

- CMR* (Combinable Magnetic Resonance)
- CNL* (Compensated Neutron Log)
- FMI* (Fullbore Formation MicroImager)
- MRX* (Magnetic Resonance Expert)
- MSCT* (Mechanical Sidewall Coring Tool)
- RST* (Reservoir Saturation Tool)
- UBI* (Ultrasonic Borehole Imagery)
- WFL* (Water Flow Log)

Field Monitoring

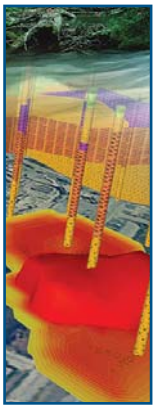
Fully integrated monitoring packages combine high-quality field instrumentation with sophisticated data transfer and data management technologies. Our field personnel are qualified to characterize, assess, and deploy optimal groundwater monitoring technologies for your site.

- Multilevel well systems monitor any number of zones in a single borehole
- Measure pressure under shut-in conditions
- Sample fluids without repeated purging
- Conduct a variety of hydraulic tests
- Frequent long-term measuring of conductivity, temperature, and depth
- Robust compact design to accommodate small diameter wells
- Ceramic housing offers corrosion-resistance in most environments
- Real-time, wireless data transfer to centralized information management systems

Field Monitoring Technology

- Baro-Diver*
- Cera-Diver*
- CTD-Diver*
- Hydro GeoAnalyst*
- HydroManager*
- Micro-Diver*
- Mini-Diver*
- Westbay System*
- Diver VisiONE*

Analysis and Management



Field data, analytical data and spatial data are all critical components of a successful groundwater management strategy. Schlumberger Water Services can help you to integrate, analyze, and report on these many data types.

- QA/QC functionality ensures data is accurate and within acceptable ranges
- GIS capabilities provide the spatial and temporal distribution of virtually any field parameter
- Cross-section interpretations of geologic and hydrogeologic data validates conceptual models
- Advanced borehole logs highlight geologic features critical to subsurface characterization
- Reports present project data to meet compliance guidelines and client needs

Data Analysis Technology

- AquaChem*
- AquiferTest Pro*
- Hydro GeoAnalyst*
- HydroManager*
- Visual HELP*

Advanced Modeling

Advanced modeling programs address geologically complex site conditions that extend beyond traditional flow and transport modeling. Our programs provide the highest degree of accuracy necessary to minimize uncertainty.

- Hydrogeologic conceptual models are developed directly within the data management system to support input for various numeric models
- Model input incorporates multi-phase flow, density-dependent flow, air flow, discrete fractures, surface water and groundwater interactions
- Aqueous geochemical analysis and modeling predict changes to water quality
- Model results are optimized and calibrated to site conditions
- Finite element, finite difference, and finite volume gridding capabilities provide the numerical power to address any modeling project
- Three dimensional visualization tools reveal spatial and temporal trends

Simulation Technology

- AquaChem* (PHREEQC)
- ECLIPSE*
- Petrel*
- Visual MODFLOW Premium*
- UnSat Suite Plus*
- Visual MODFLOW 3D-Builder*

Merging advanced technologies with innovative solutions

About Schlumberger Water Services

Managing the world's water resources is no small task. We tackle global water challenges with our worldwide network of hydrologists, geologists, and environmental experts. Combined with powerful and cost-effective technologies, we are successfully managing the world's water resources, for now and the future.

Our people deliver your success.

www.water.slb.com

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