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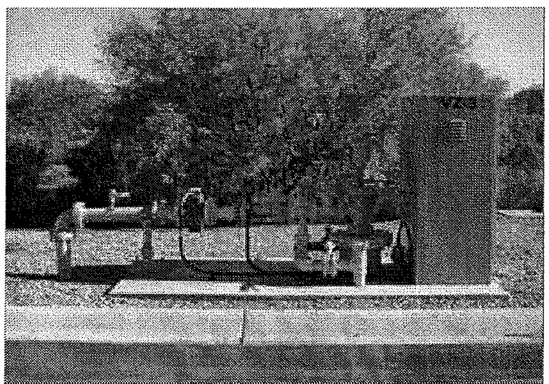
REPORT IN BRIEF

Prospects for Managed Underground Storage of Recoverable Water

Growing demands for water in many parts of the nation are fueling the search for new approaches to sustainable water management, including how best to store water. Society has historically relied on dams and reservoirs, but problems such as high evaporation rates and a lack of suitable land for dam construction are driving interest in the prospect of storing water underground. Managed underground storage should be considered a valuable tool in a water manager's portfolio, although it poses its own unique challenges that need to be addressed through research and regulatory measures.

People are moving to Las Vegas at a rate of several thousand per week, a phenomenon also observed in California, Arizona, and elsewhere. Today, when these newcomers turn on the taps in their new homes, water comes out—one day, it might not. Periodic droughts, changing land use, rising temperatures, overallocation of rivers, overdrafting of aquifers (underground water reserves), water quality changes, and environmental problems, combined with rapidly increasing populations, have heightened awareness of the pressing need to find sustainable, long-term water management solutions. Water problems are not confined to the western U.S.; eastern states are also feeling the crunch. There is little doubt that the future will bring increasing stresses on water supplies across the nation—as well as increasing burdens on water managers to keep meeting demands.

Several strategies have been proposed to address the need for sustainable water solutions by reducing water use, increasing water supplies, and reusing treated wastewater. In addition to such strategies, however, there will likely always be a need for temporarily storing water during times of abundance for later release during times of need. Historically, dams and reservoirs have been used for this purpose. But a number of factors—including high evaporation rates, environmental costs, and the decreasing availability of land for dam construction—have increasingly made building additional dams impractical. These factors have led to an increased interest in prospects for storing water underground as part of a long-term water management approach.



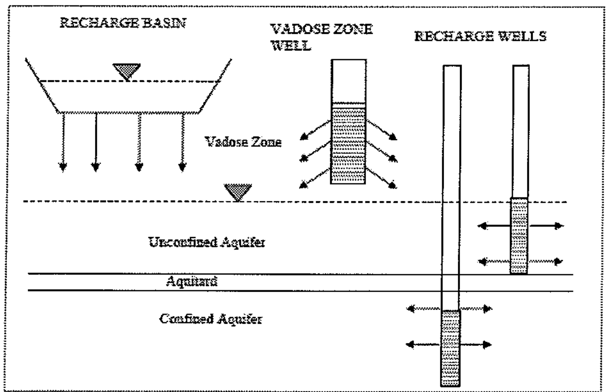
A reclaimed water recharge well in Phoenix, AZ. SOURCE: Andy Terrey, City of Phoenix.

The National Research Council convened a committee to evaluate past experiences with managed underground storage of recoverable water and to identify the research priorities for development of future underground storage projects. This report, resulting from the committee's activities, assesses the factors affecting the performance of such projects and recommends ways to implement and regulate managed underground storage systems.

What is Managed Underground Storage?

The concept of "managed underground storage of recoverable water," here shortened to managed underground storage, encompasses a number of approaches that purposefully add water into (recharge) an aquifer system for later recovery and use. In general, managed underground storage involves the following elements:

1. *Water is captured from a source.* These sources can include surface water, groundwater, treated effluent, and stormwater.
2. *Water is recharged into an aquifer.* Aquifers are recharged through use of recharge basins, vadose zone wells (wells above the water table), or direct recharge wells (see figure).
3. *Water is stored.* The water is stored in a wide spectrum of confined and unconfined aquifer types, from unconsolidated sands and gravels to limestones and fractured volcanic rocks.
4. *Water is recovered for use.* Recovery is typically achieved through extraction wells or dual-purpose recharge and recovery wells, but occasionally is achieved via natural discharge of the water to surface-water bodies.
5. *Water is used.* Recovered water is used for drinking water, irrigation, industrial cooling, and other purposes.



Methods for aquifer recharge.

Evaluation of Managed Underground Storage: Future Prospects

Some simple forms of managed underground storage have been used for millennia; the most recent developments were implemented about four decades ago. Adequate experience exists, therefore, for evaluating the overall success rate of managed underground storage systems and for identifying the challenges faced by these systems.

The report concludes that managed underground storage has a generally successful track record in a variety of environments. Given the growing magnitude and complexity of the nation's water management challenges, managed underground storage should be seriously considered as one means to satisfy the demand for water and cope with water scarcity.

Challenges and Research Needs

There is no simple solution to the nation's growing water problems. Although managed underground storage is generally successful in achieving its goals, it also poses its own set of challenges, which need to be addressed through careful planning and research. These challenges include generally high costs to design, construct, and monitor underground storage systems; loss of some percentage of the water; chemical reactions with aquifer materials; ownership issues; and environmental impacts.

The development of a managed underground storage system from project conception to a mature, well functioning system is a complex, multistage operation requiring interdisciplinary knowledge of many aspects of science, technology, and institutional issues. Water managers should consider these projects in a watershed and regionally-based context and as part of an overall water management strategy. Professionals from many fields, including chemists, geologists, hydrologists, microbiologists, engineers, economists, planners, and other social scientists should be involved in analysis of the options in managed underground storage projects. The report recommends that water agencies create an independent advisory panel at an early stage to provide objective, third-party guidance regarding design, operation, maintenance, and monitoring strategies for these projects.

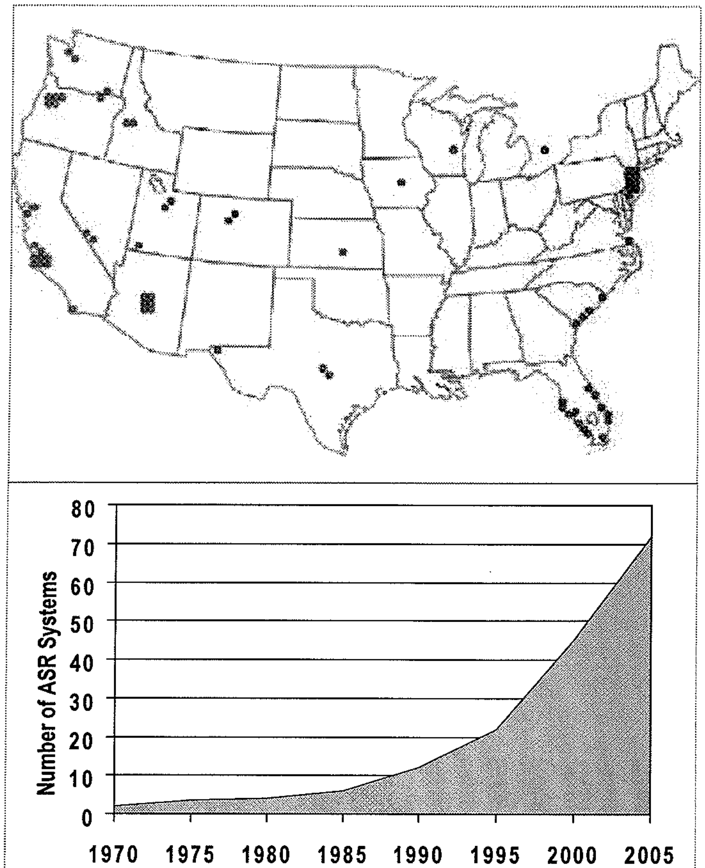
Some of the primary challenges to be considered at all stages of a managed underground storage system are described below.

Hydrogeological Issues

A first step in planning a managed underground storage project is identifying favorable locations. Some types of aquifers have hydrogeologic characteristics that are better suited for managed underground storage than others; aquifers with several different kinds of pore space such as fractured sandstone appear to present the greatest difficulties. The report recommends that water managers considering underground storage incorporate 3-D capable geographic information systems to map and analyze major aquifers as part of comprehensive, regional planning efforts.

Also in the planning process, monitoring and modeling should be used to predict likely effects—positive or negative—of managed underground storage systems on the surrounding physical system at various scales. Managed underground storage systems can have long-term impacts on both native groundwater and surface water. Appropriate measures can, and should, be taken in the design and implementation of these systems to minimize negative effects.

To enhance the ability to predict and assess the success and effects of a managed underground storage system, the report recommends further research on



Distribution of aquifer storage and recovery systems, 2005 and growth of aquifer storage and recovery systems in the U.S., 1968-2005. Adapted from David Pyne, copyright 2005.

various aspects of the hydrologic feasibility of managed underground storage projects, the impacts of these projects on surface water, and the hydrogeologic properties of underground aquifers.

Water Quality Issues

Preserving water quality is of utmost importance in any water management system. Managed underground water storage has both positive and negative effects on water quality. In some cases, recharging aquifers may improve the source water quality, because the subsurface has the ability to naturally decrease many chemical constituents and pathogens through physical, chemical, and biological processes. Recharging water can also displace saline groundwater and locally improve the quality of the groundwater. However, storing water underground can also increase the risk of contamination, depending on factors such as the source water used for recharge, the chemicals used to treat the water prior to storage, and the geochemistry of the aquifer matrix and mixed water.

The type of source water used for recharge influences the quality of the native groundwater. Urban stormwater, for example, is highly variable in quality; for this reason, caution is needed in determining whether stormwater is of acceptable quality for recharge. Additional research should be conducted to evaluate the chemical and microbial constituents in urban stormwater and their behavior during infiltration and subsurface storage. In general, there is a need for better understanding of the potential contaminants in the various sources of recharge water.

Pathogen removal or disinfection is often required prior to storing water underground. If primary disinfection is achieved via chlorination, disinfection by-products (DBPs) such as trihalomethanes and haloacetic acids may be formed. These have been observed to persist in some managed underground systems. To minimize the formation of DBPs, alternatives to chlorination, such as ultraviolet light, ozone, or membrane filtration, should be considered. However, chlorine is generally considered the most cost effective agent for control of biofouling in recharge wells; hence, it may not be possible to entirely eliminate the use of chlorine in these systems.

Successful managed underground storage requires thorough chemical and microbiological monitoring. A proactive monitoring plan is needed in order to respond to emerging contaminants and to increase knowledge about potential risks. There is a need for a better understanding of the potential removal processes for chemical and microbial contaminants in different types of aquifer systems. Research on new surrogates or indicators for chemical and microbial contaminants will help document the performance and reliability of managed underground storage systems.

Economic and Policy Considerations

Planning and implementing managed underground storage projects raises new questions for states, counties, and water authorities. This new approach has its own set of economic impacts and will likely require adjustments to traditional water rights allocation schemes.

Economic Aspects

Managed underground storage has numerous economic benefits, but it also entails costs. An economic analysis of a project should capture its multiple benefits and costs. These projects invariably entail the achievement of multiple objectives; for this reason, the report emphasizes that third party impacts, such as the environmental consequences, should be included in the overall economic analysis of a project. Failure to account for all benefits and costs, including ones that may not be reflected in market prices for water, can lead to underinvestment in groundwater recharge, overconsumption of water supplies, or both.

Water resource development has historically been characterized by substantial federal and state subsidies; as water shortages intensify, the political pressure for investment in new technologies will increase. In order to ensure that there is optimal investment in managed underground storage and other technologies, subsidies should only be provided when there are values that cannot be fully reflected in the price of recovered waters—for example, an environmental benefit that accrues to the public at large.

Regulatory Frameworks

Regulatory frameworks play a key role in ensuring the safety, reliability, and quality of water storage systems. There is, however, inconsistency in the federal regulatory requirements for managed underground storage. Federal Underground Injection Control regulation, for example, only addresses projects that recharge or dispose of water directly to the subsurface through recharge wells, while projects that infiltrate water through recharge basins are regulated by state standards that may vary by state. Also, there are incompatibilities between the Clean Water Act and the Safe Drinking Water Act that impact managed underground storage systems. For example, some jurisdictions try to control surface water contamination problems by diverting polluted water from above ground to groundwater systems. This approach may undermine managed underground storage programs by putting contaminants underground without appropriate controls.

Federal and state regulatory programs should be examined with respect to the need for continued federal involvement in regulation, the need for a federal baseline for regulation, and the risks presented by inadequate state regulation. The report recommends that a model state code be drafted to assist states in developing regulatory programs for managed underground storage systems. At a minimum, states should help in defining property rights for water before, during, and after it is stored underground.

Science-based criteria should be developed to help determine adequate subsurface residence time or travel distance of recharged water before withdrawal for later use. These criteria should take into account site variables such as aquifer type, geochemical conditions, and source water quality, and need to be adequate for both pathogens and chemical contaminants. Finally, they should consider the time needed to detect and respond to any water-quality problems that may arise.

States should review their water laws and regulations and create a regulatory structure specifically tailored for the unique characteristics of managed underground storage projects. Moreover, state laws and regulations should provide regulatory agencies with discretion to weigh the overall benefits of managed underground storage while resolutely protecting groundwater quality. For any managed underground storage project—including storage of potable water, stormwater, and recycled water—it is important to understand how water quality differences between native groundwater and the stored water will be viewed by regulators.

In addition to water quality factors, a broader consideration of benefits, costs, and risks would provide a more desirable regulatory approach. Therefore, weighing water quality considerations together with water supply concerns, conservation, and public health and safety needs is essential.

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This report brief was prepared by the National Research Council based on the committee's report. For more information or copies, contact the Water Science and Technology Board at (202) 334-3422 or visit http://nationalacademies.org/wstb. Copies of *Prostpects for Managed Underground Storage of Recoverable Water* are available from the National Academies Press, 500 Fifth Street, NW, Washington, D.C. 20001; (800) 624-6242; www.nap.edu. Support for this study was provided by the American Water Works Association Research Foundation, WateReuse Foundation, U.S. Geological Survey, The CALFED Bay-Delta Program and the California Department of Water Resources Conjunctive Water Management Branch, Water Replenishment District of Southern California, City of Phoenix, Inland Empire Utilities Agency, Sanitation Districts of Los Angeles County, Chino Basin Watermaster, and the NRC President's Committee of the National Academies.