ARTIFICIAL RECHARGE OF GROUND WATER IN COLORADO

– A Statewide Assessment

Environmental Geology 13

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FOREWORD

This report, *Artificial Recharge of Ground Water in Colorado – A Statewide Assessment*, was requested by the Executive Director of the Department of Natural Resources in June 2003 to assess the underground water storage options potentially available in our state. The study was a special assignment for the Colorado Geological Survey — information and recommendations were requested within six months of the study's commencement.

The urgency of the request came in response to several years of lower than average precipitation, culminating in the extraordinary drought conditions of 2002. The drought highlighted the need for additional water storage to help Colorado store available water from rivers originating in the state. With a growing population and substantial agricultural production, underground storage of water through artificial recharge could provide an important water storage option for the future of Colorado.

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Executive Summary

Throughout the Centennial State's history, its semi-arid climate, periodic multi-year drought cycles, and the needs of its growing population have all conspired to highlight the need for water storage. Once again, recent drought and increasing water demands of a growing population have made Coloradans critically aware of the need for additional water storage. Surface-water reservoirs have been the primary means of storing water to meet Colorado's needs, but due to site logistics, regulatory requirements, and public opinion, building large new reservoirs has become more complicated, requiring years of planning and ever-increasing construction costs. An alternative means of increasing water storage capacity is to store water underground in aquifers and voids.

The extreme drought conditions experienced in 2002 solidified the value of ground water as part of an overall water management strategy. In 2003, the director of the Colorado Department of Natural Resources requested that the Colorado Geological Survey conduct a statewide assessment study of artificial recharge potential. This study assessed the opportunities for using artificial recharge to meet water storage needs statewide, focusing primarily on the hydrogeologic properties of aquifers and other underground storage options. The American Society of Civil Engineers has recently identified six phases of planning that are typically needed to develop, operate, and maintain a project for artificial recharge of ground water. This study parallels this process, but represents only the beginning physical data collection and technology assessment stages of the initial phase.

Artificial recharge (AR) is defined as any engineered system designed to introduce water to, and store water in, underlying aquifers. This report discusses several aspects important to the understanding of artificial recharge potential in Colorado, including

- the design objectives for implementing artificial recharge;
- the various artificial recharge technologies available;
- the current application of artificial recharge in other states and countries;
- the present practice of artificial recharge in Colorado; and
- the physical suitability of various aquifers, abandoned mines, and caves to store water.

The objectives of most AR applications fall into one, or a combination, of the following categories:

- ***Manage water supply***, including short-term water supply regulation, seasonal storage, long-term storage (drought mitigation), emergency supply, and conjunctive use;
- ***Meet legal obligations,*** such as providing augmentation water, supplementing downstream water rights, or facilitating compliance with interstate agreements;
- ***Manage/mitigate water quality*** through the improvement of surface- or ground-water quality or treated wastewater disposal;
- ***Restore/protect aquifers*** by restoring ground-water levels, limiting aquifer compaction and surface subsidence resulting from excessive ground-water withdrawals, or mitigating saltwater intrusion;
- ***Protection of the environment*** by maintaining wetland hydrology, enhancing endangered species habitat, or controlling the migration of ground-water contamination.

Artificial recharge technologies are broadly grouped according to whether water is recharged at the surface or underground, and then by whether water is recharged into the unsaturated zone or directly into the saturated zone of the aquifer.

- ***Surface infiltration*** is the impoundment of water at the ground surface for the purpose of infiltration to the underlying near-surface, unconfined aquifer.
- ***Subsurface infiltration*** is the application of water below the ground surface for infiltration to the underlying unconfined aquifer.
- ***Direct injection*** differs from infiltration systems by recharging water directly into the saturated zone of the aquifer.
- ***Aquifer storage and recovery (ASR) wells*** are wells through which water is injected into aquifer *storage* during times of low demand and high surface-water supply and subsequently *recovered* by pumping at a later date when demand exceeds surface supply.
- ***Modification of natural recharge*** involves man-made changes to the land surface or hydrogeologic conditions to increase the amount of recharge from natural and local sources.
- ***Underground (non-aquifer) water storage*** technologies apply to storage and retrieval of water in natural or manmade voids in the subsurface, such as abandoned mines or natural caverns.

The selection of a particular technology requires detailed site investigation and depends on the hydrogeologic setting of the target aquifer, land availability and uses, and the project objectives.

Artificial recharge is being used in at least 32 states in the U.S. and at least 26 countries worldwide. The methods used span the entire spectrum of known technologies, but the dominant methods are injection wells and infiltration basins. The larger scale projects are generally located in drier areas of the U.S. (i.e., the west and southwest), or areas in which the growing population has overtaxed the available water supply (e.g., California, Florida, New Jersey, New York).

An inventory of artificial recharge projects within Colorado identified 19 active operations including

- ***augmentation*** in the lower South Platte River basin,
- ***seasonal storage*** as part of conjunctive use of ground water and surface water in the San Luis Valley,
- ***direct injection*** by two water districts in the Denver Basin, and
- ***regulation of water supply and water quality*** at several smaller municipal water systems.

The occurrence and distribution of Colorado's water resources are inherently linked to the state's geography and underlying geology. As a result of Colorado's complex geology, a multitude of aquifers in various areas of the state are suitable for artificial recharge projects. The geologic units containing these aquifers can be broadly classified as unconsolidated sediments, poorly consolidated sediments, or consolidated rock. The amount of storage available in an aquifer is dependent upon the aquifer's (1) storage coefficient (storage ability), (2) areal extent, and (3) freeboard (amount the water level could rise above present water level). In general, unconfined aquifers have smaller areal extent, tens of feet of freeboard, and a high storage coefficient. Confined aquifers, on the other hand, often have a large areal extent and hundreds of feet of available freeboard, but a very low storage coefficient.

A weighted ranking system was established to evaluate the key physical properties of the state's 16 highest-potential unconsolidated aquifers and 29 highest-potential consolidated aquifers. Hydrogeologic parameters taken into account in the "aquifer ranking value" include *areal extent, depth, saturated thickness, head freeboard, storage coefficient, and hydraulic conductivity*. In addition to calculating a final ranking for the aquifer, the quality of the input data was also assessed. The alluvial deposits of the South Platte River, its tributary Bijou Creek, and the Arkansas River are the top three ranked unconsolidated aquifers. The High Plains Aquifer, Dakota-Cheyenne Group of southeast Colorado, and the Denver Basin aquifers are the top three ranked consolidated bedrock aquifers.

The evaluation of the available storage capacity in Colorado's highest-potential aquifers was guided by the desire to find opportunities to develop large-scale artificial recharge projects, i.e. defined as having storage capacity in excess of 100,000 acre-feet. Thirteen of the 16 primary unconsolidated rock aquifers have sufficient storage capacity to accommodate a large-scale project. In aggregate, the lower South Platte River alluvium and the San Luis Valley alluvium have the capacity to store in excess of one million acre-feet. All but two of the 26 primary consolidated rock aquifers have sufficient storage capacity available to meet the 100,000 acre-feet criterion. Because of their large areal extent and head freeboard, the majority of these aquifers can store millions of acre-feet of water.

Three types of non-aquifer underground water storage possibilities were assessed statewide: abandoned coal mines, abandoned metal mines, and caves. Storage of water in abandoned underground coal mines is not a new concept, but has only recently been tried in Colorado, most notably by the City of Arvada at the former Leyden coal mine. Overall, the estimated storage capacities of non-aquifer alternatives are much smaller than those of aquifers. An estimated 55,000 acre-feet of underground water storage is available for artificial recharge in inactive coal mines, statewide. Major technical challenges to water storage projects in coal mines include maintaining hydraulic control of stored water, poor water quality (high salinity), and mine subsidence. The potential water storage volumes for abandoned metal mines and natural cave systems are much smaller than for coal mines. Metal mines and natural caves are not a viable option for water storage because of their limited storage capacity, water quality issues, leakage of stored water, and land ownership issues.

Artificial recharge projects can increase the total amount of stored ground water in a very specific and calculated fashion. In addition, indirect or passive methods of ground-water recharge such as vegetation control, storm-water retention basins, and leaky ditches are non-specific in application, but can significantly increase overall ground-water storage. Similar to water conservation measures, some changes in legislation and water facility design and engineering, combined with passive recharge structures, would benefit both ground-water and surface-water resources.

This study assesses the best aquifers in Colorado for their artificial recharge potential of ground water based primarily on their hydrogeological suitability. Implementation of an AR project must also consider several other factors, including (1) project objectives; (2) site-specific hydrogeologic conditions; (3) source water availability; (4) water law and water rights; (5) available land surface area and compatible land-use activities; (6) governing water-management districts or entities; (7) facility design criteria; (8) capital costs to construct; (9) operation and maintenance costs; and (10) general storage efficiency, recovery, and deliverability.