

# Banking Groundwater

A study examining aquifer storage and recovery for groundwater sustainability in Minnesota

## Executive Summary

There are no substitutes for water. It is essential to life, our economy, and the environment. However, the social and environmental values of water are difficult to measure precisely because of water's essential and somewhat idiosyncratic role in our lives. The value of groundwater includes both its direct use because 75% of Minnesotans drink it and agriculture and industries rely on it, and its indirect or ecological use because groundwater supplies water to rivers, lakes, and wetlands. There is also value in reserving groundwater for future generations especially in an uncertain water future. Even if groundwater is not scarce now, its quality and availability vary across Minnesota. Clean water may be in short supply at critical times and pressure on groundwater reserves could also develop from beyond our borders. The primary purpose of investigating Aquifer Storage and Recovery (ASR) is to have a tool at the ready that could be deployed safely to ensure groundwater availability.

Managed aquifer recharge encompasses a number of techniques for improving groundwater recharge and maintaining aquifer levels. ASR is one of those technological approaches that involves treating and pumping clean water into an aquifer for temporary storage and later recovery. ASR wells may inject water into either a confined or unconfined aquifer.

Motivations to deploy ASR include:

- creating reliable seasonal water supply;
- meeting peak demand without building a larger treatment plant;
- creating water reserves that are less vulnerable to contamination;
- conserving land area used for water storage; and
- sustaining groundwater-fed ecosystems like trout streams, lakes, and fens.

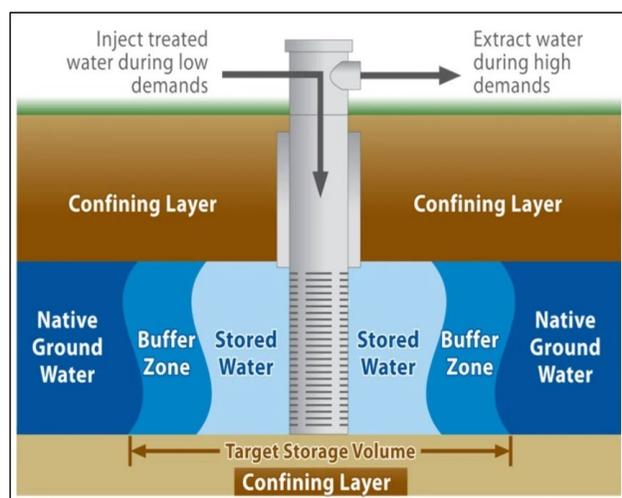


Diagram of an ASR system.

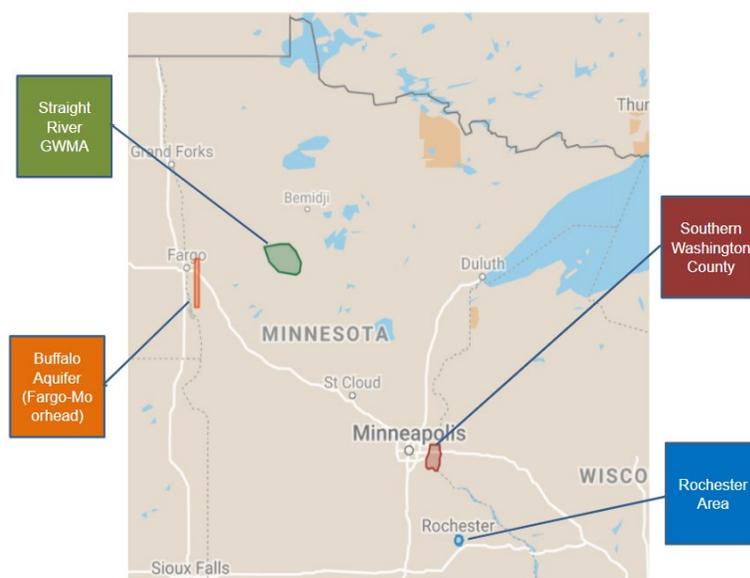
Image credit: Tarrant Regional Water District 2019.

Although the indirect or environmental benefits of ASR are tricky to evaluate in a true economic sense, assessing the environmental and social costs and benefits of groundwater can help clarify decision-making processes, raise awareness of the environmental impacts of depletion, and illuminate alternative water supplies before a crisis is upon us.

## Study Areas

Future growth, projected climate change, groundwater-level trends and other pressures like groundwater pollution have the potential to negatively impact future groundwater supply. These external forces informed the choice of four study areas with a range of geologic conditions. The availability of adequate aquifer data also constrained the choices to the following four areas:

1. A portion of the Buffalo aquifer near Moorhead, one of only a few aquifers available to the city. It has been adequately mapped and characterized and is an elongate, south trending, partly confined, sand-and-gravel aquifer that extends along much of the western part of Clay County. Alleviating flood pressure in the Red River valley was a secondary motivation for site selection.
2. Southern Washington County centered on Woodbury. Projected deficits in groundwater supply and groundwater pollution issues motivated this choice. Extensive data sets exist for the fine to coarse-grained Jordan Sandstone aquifer that supplies the City of Woodbury.
3. The City of Rochester in Olmsted County. The Jordan Sandstone aquifer extends across much of southeastern Minnesota. Rochester is totally dependent on groundwater and has projected significant growth.
4. The Straight River watershed. A surficial sand aquifer west of Park Rapids is part of the larger Pineland Sands aquifer and receives rapid recharge of about five to six inches per year that discharges as baseflow to the Straight River, a cold-water stream. Irrigated agriculture is reducing baseflow to the stream seasonally. The aquifer spans several counties; we focus on the portion within Becker County that has a recent geologic atlas and has been designated a Groundwater Management Area.



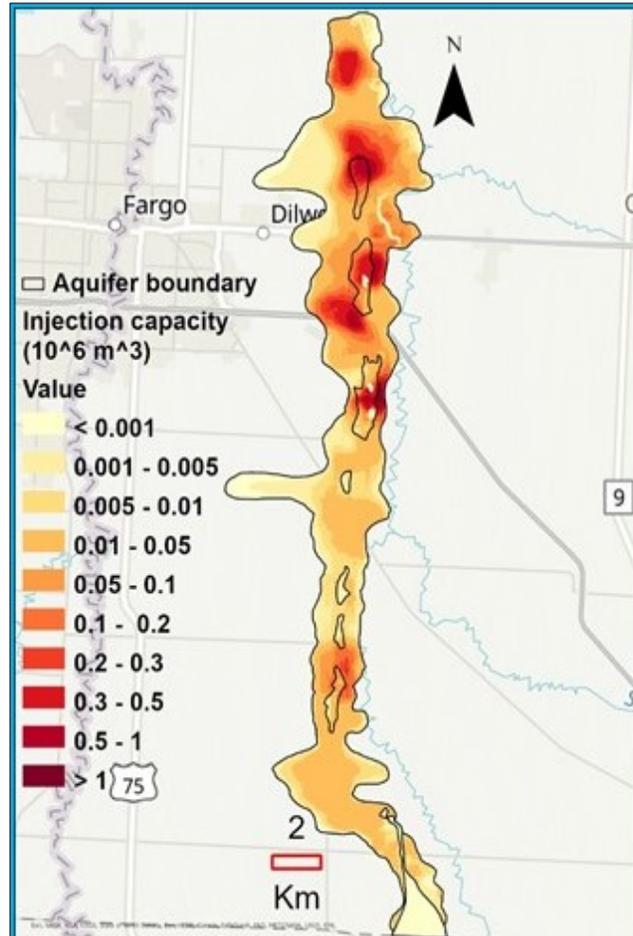
*Study area locations for the Banking Groundwater project.*

## Aquifer Injection Capacity

The volume and rate of water injected into an aquifer – the injection capacity – is a critical component of the geologic suitability of an aquifer for ASR. Injection capacity is primarily limited by how thick and how transmissive the rock or sediment layer is. Limiting conditions for ASR projects are that they do not flood the surface in an unconfined-aquifer setting or fracture the confining unit in a confined-aquifer setting.

A new GIS-based mapping tool created for this study uses Minnesota's aquifer properties database along with data reported in publications and unpublished government and consulting reports. The tool produced maps for three of the four study aquifers that show: (1) the long-term, average groundwater level and depth-to-groundwater; (2) aquifer-characteristic data obtained from aquifer tests and specific capacity tests; (3) available headspace in the aquifer where water can be safely injected for storage, and (4) injection capacity of the aquifers.

For the three suitable aquifers, the spatial variability of the aquifers illuminates ideal injection sites. The Buffalo aquifer shows the highest variability in the injection capacity because the transmissivity variability is very large. In the Jordan aquifer, the allowable head change is significantly greater. In all cases, multiple injection wells could be deployed to store a three-month water supply. The fourth site, the surficial aquifer in the Straight River watershed in Becker County was not evaluated for injection capacity due to the unavailability of sufficient water volume for injection. However, its hydrogeologic characteristics are described.



*Example of injection capacity maps produced for the study aquifers. Injection capacity is a critical characteristic to determine the suitability for ASR.*

### Three study sites have the necessary injection capacity

This study confirms that three of the investigated sites are suitable for ASR practice in terms of injection capacity. The hydrogeological conditions of the aquifers provide sufficient storage space and transmissivity.

## Source Water for ASR Injection

Assuming that the injection capacity of the target aquifer is sufficient, evaluating the feasibility of ASR at a scale that would be significant to nearby communities can be divided into three steps:

1) identifying a source water of ample quantity and its required treatment; 2) evaluating the aquifer geochemistry and native groundwater quality to anticipate any potential reactions of source water with the aquifer and 3) determining the feasibility of treating the water after recovery to meet water-quality expectations. An assessment of cost-effective treatment technology prior to injection and after recovery should be incorporated into ASR project design.

### *Buffalo Aquifer, Moorhead*

The City of Moorhead obtains approximately 80% of their drinking water from the Red River and 20% from the Buffalo aquifer. The aquifer is also used by outlying municipalities for drinking water and for irrigation. The Red River can experience extended low flow due to drought. In anticipation of that possibility, ASR could be used to increase the available water volume in the Buffalo aquifer. The three potential sources of injection water are: 1) the Red River during high flow; 2) the Buffalo River, however the average flow of this river is low, or 3) effluent of the City of Moorhead wastewater treatment plant which is currently discharged to the Red River.

ASR could be a viable technique to provide water security for the City of Moorhead, however, arsenic, sulfate, manganese, and hardness are water-quality concerns. Water injected into the Buffalo aquifer should not be expected to maintain a potable condition but could be treated after extraction in the same way the city's drinking water is currently treated.

### *Jordan Aquifer, Rochester*

Rochester derives 100% of their drinking water from groundwater, primarily from the Jordan aquifer through 33 municipal wells, each equipped with their own treatment system. The only potential sources of injection water are: 1) the Zumbro River; 2) other bedrock aquifers, or 3) treated effluent from the wastewater treatment facility. Additional treatment of the wastewater would probably involve reverse osmosis and advanced oxidation unit processes. New wells would be needed for injection but existing wells could continue to be used for recovery.

### *Jordan Aquifer, Woodbury*

Washington County relies entirely on groundwater, primarily from the Jordan aquifer which may experience drawdown from overdrafting, contamination mitigation, and expected population increase. There are ample sources of water that could be injected: 1) the St. Croix River, 2) the Mississippi River, or 3) effluent from one or more nearby wastewater treatment plants. Remediation of known PFAS contamination could be integrated with ASR after water is treated.

### *Surficial Aquifer, Straight River Watershed*

The Straight River watershed is an area of irrigated agriculture which constitutes most of the groundwater use from the surficial aquifer. Withdrawals from the aquifer have steadily increased and the Straight River, a trout stream is threatened by a declining water table. However, there are no significant sources of water for ASR. Water treatment facilities in the City of Park Rapids are at the southeast end of the surficial aquifer, too far away to benefit the stream and aquifer. ASR is not recommended at this time and other approaches such as conservation should take priority.

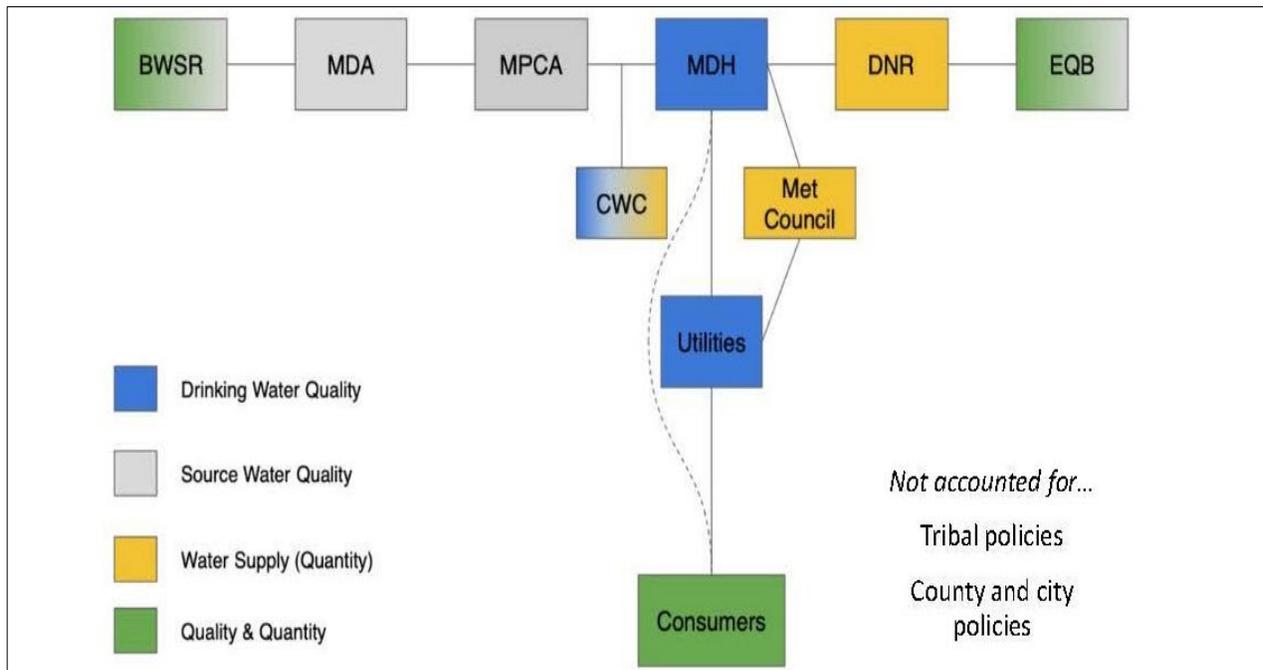
## Policies

State and federal policies impact the use of ASR and can be both drivers and barriers to its implementation. Nationally, the Safe Drinking Water Act enacts regulation to help ensure that aquifers maintain consumption standards and that threats from pollution are prevented. ASR involves the use of Class V injection wells and the primary authority over those defaults to the United States Environmental Protection Agency (USEPA). States may apply for primacy over Class V injection wells and gain the ability to issue permits directly but Minnesota currently does not have primacy over Class V injection wells.

Minnesota also has state codes and a regulatory framework that impact the use of ASR. The State's well code, specifically Minnesota Administrative Rule 4725.2050, disallows wells or borings from being used for injection or disposal of surface water or groundwater.

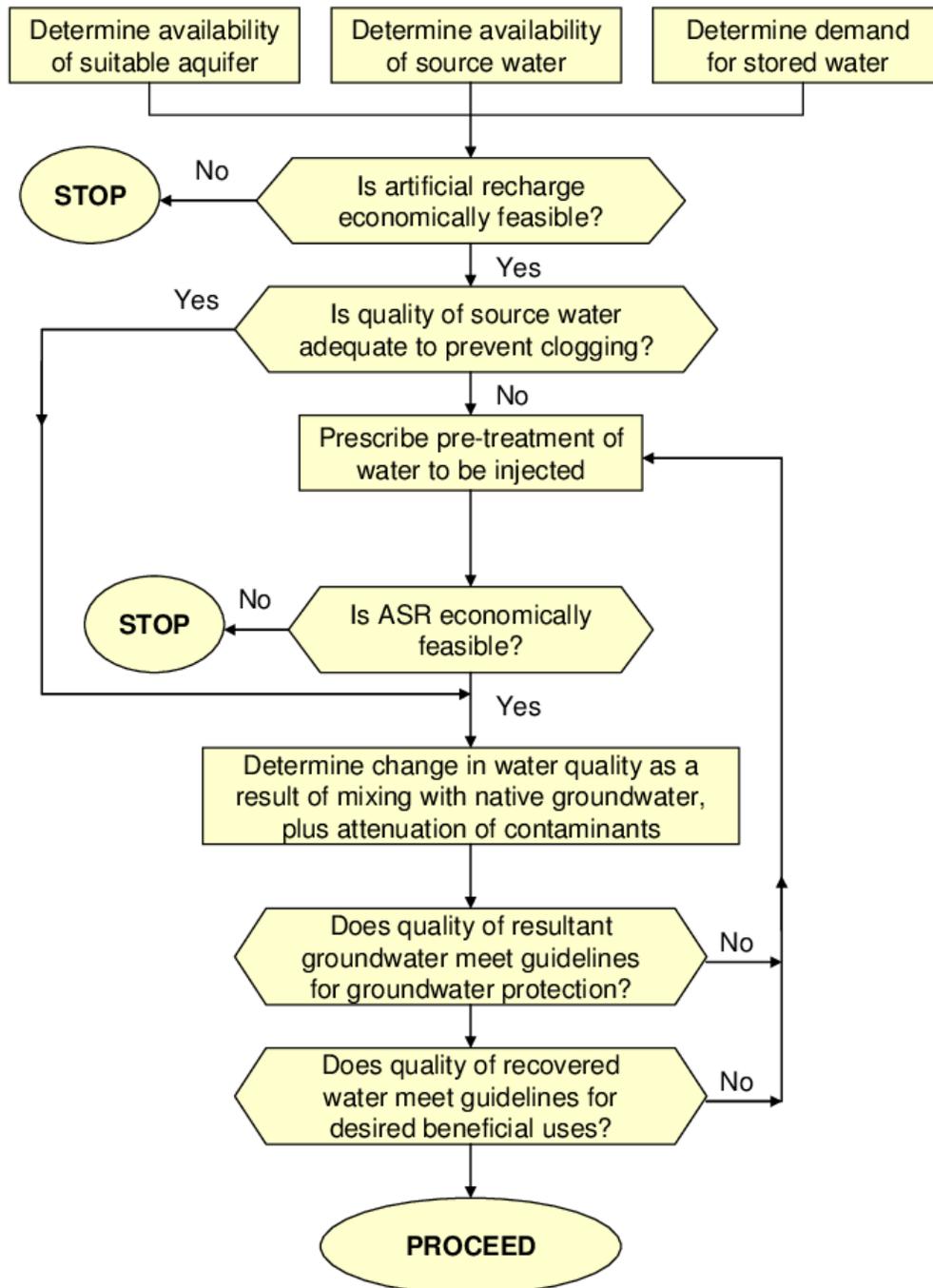
Multiple state agencies have jurisdiction over specific activities or processes within an ASR system. For example, source water quality is commonly managed by the Minnesota Pollution Control Agency, aquifer quality and standards by the Minnesota Department of Health, and quantity of withdrawal by the Minnesota Department of Natural Resources. Distributed water governance has both advantages and disadvantages, but more importantly for ASR, it requires conversation and collaboration across agencies. An ASR decision-support system *can* help assess ASR applicability and allow for a more streamlined navigation of state and local policies. *See page 6 for example.*

Given that aquifer boundaries do not align with political boundaries, there are additional jurisdictional concerns that may need to be addressed planning for ASR. This may be especially true for areas near tribal lands and in regions where specific drinking-water or groundwater policies are in place.



Minnesota's state codes, regulation and management spans multiple agencies and jurisdictions.

**A decision support system that includes cost-benefit analysis, such as the following, should be adopted.**



Source: Dillon, Peter & Molloy, Robert. (2006). Technical Guidance for ASR. Adapted from Dillon and Pavelic, 1996.

## Cost-Benefit

Costs for ASR systems include design and analysis, construction and capital, and operation and maintenance. These are highly variable and depend on a number of factors, many of which are local and temporal. Costs and economics are project-specific and depend on the local physical and hydrological conditions, the recovered and storage water uses, and alternative water supply and treatment options. The acquisition of needed technical and geologic data to fully characterize an aquifer's extent, material properties, composition and grain size, recharge and discharge, conditions of confinement, and hydraulic conductivity is costly. These data are not available everywhere in Minnesota. This is especially true outside of the Twin Cities Metropolitan area. Making these data available will reduce site characterization costs and risks in future ASR projects.

Like any other investment project, ASR needs to be economically feasible, with monetary benefits at least as large as the total costs. Evaluating the cost of annual recharge in an ASR project requires dividing the capital, operating, and maintenance costs by the lifetime of the project. It is useful to determine which of the variables are the most uncertain and evaluate them over a range of values. Risks and uncertainties also arise if future demand does not materialize or if a system does not perform as anticipated. Therefore, in addition to conducting a careful needs assessment, detailed site characterization is important to avoid future complications that will result in higher costs.

The cost-benefit analysis is the most comprehensive and robust assessment method and the preferred method for state and federal agencies. Ideally, the analysis identifies all benefits and costs, both market and non-market, to all involved parties. The results should be compared to a "no-project" situation. Furthermore, a sensitivity analysis can help analyze the most uncertain variables including demand, discount rate, capital, operating costs, or the benefits included in the analysis. Adapting an existing cost-benefit analysis tool for use in Minnesota would be beneficial.

## Case studies – *Learning from others*

Seven case studies involving ASR were examined as part of this study to represent a cross-section of the kinds of systems being adopted by a range of U.S. municipalities. They showcase different environmental conditions, water sources and technology and include examples of ASR and ASR-type systems. Reflection on these and the lessons learned can provide valuable insight for future application of ASR in Minnesota. The seven case studies included in the full report are:

1. Shakopee-Mdewakanton Sioux Community, Minnesota
2. St. Michael, Minnesota
3. Des Moines and Ankeny, Iowa
4. Green Bay, Wisconsin
5. El Paso, Texas
6. Tucson, Arizona
7. Roseville, California

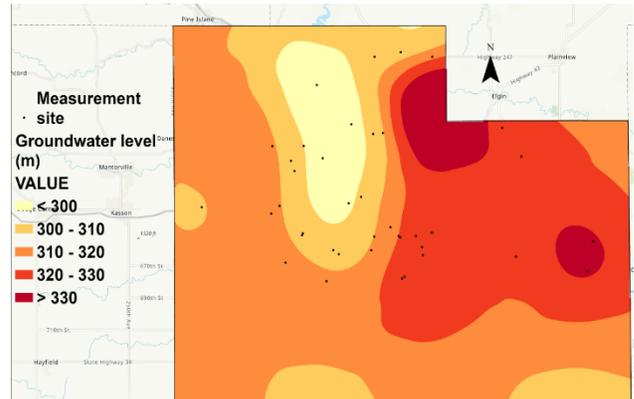


*See more about this project and the others in the case study section of the full report.*

## Aquifer Data Gaps – more information is needed

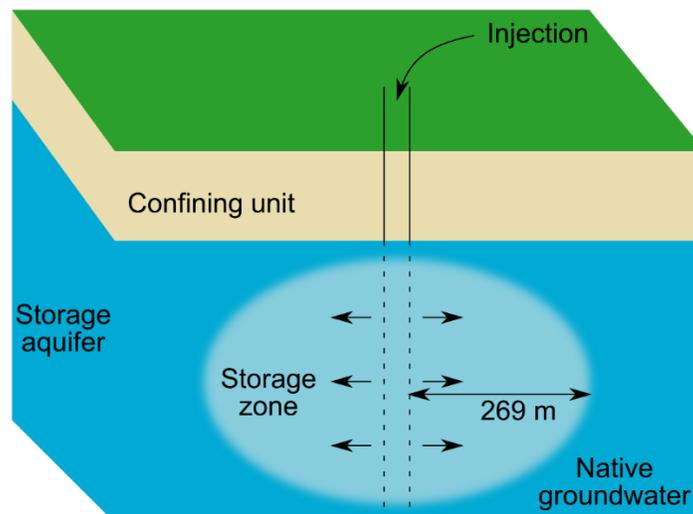
Low spatial density of groundwater levels and the absence of time-series data limits the understanding of allowable head change both seasonally and inter-annually. Pump test data of longer duration assess properties farther away from a well and are more desirable. The more common, specific-capacity tests measure properties closer to the well and are adequate but not ideal. For Woodbury and Olmsted County, storativity data were also scarce.

The details of how an aquifer is tested and the results of the test are important to assessing the suitability of a site for ASR. A complete, unified aquifer-property database would save the state money by avoiding the need to repeat pump tests. It would also make ASR project design and other groundwater modeling efforts less expensive. A database structure has been created and MnDNR is populating it, focusing on areas of interest to them. However, information created and housed by other agencies, consulting companies, archived in technical documents and in published articles is slow to be interpreted and entered. This is complicated by pump tests and aquifer property data not being reported in a standardized way. The database is not user-friendly so data are not easily retrieved. A complete and useful database will require continued collaboration and additional resources.



*Olmsted County – map of monitoring wells and groundwater levels. Increasing the spatial density of monitoring wells would help us better understand groundwater level trends and better evaluate ASR, as well as other groundwater related activities.*

The modeling conducted for this study made simplifying assumptions using available hydrogeologic data. The next steps for future studies could address factors that affect the recovery of injected water from an ideal, uniform scenario (below) including: leakage, density differences of the two waters, dispersive mixing, hydraulic gradient that could migrate the water, storage duration, and fractures in the aquifer or confining unit.



## Recommendations

If we can all agree that water is a public good, then it is the responsibility of the government to make it accessible to all. Where groundwater levels are depleted and not naturally recovering with sufficient speed, we recommend that artificial recharge options be considered and implemented where feasible and appropriate. ASR is a tool that may be useful in ensuring groundwater sustainability in some places with strict oversight, clear guidelines and a permitting path. However, ASR should remain a tool of last resort after other approaches to meet groundwater sustainability needs are exhausted. To this end, the State should first encourage conservation efforts and second, eliminate barriers to water reuse.

The suggested actions are tentatively assigned to the implementers with a potential timeline.

Action	Implementers	Timeline
Develop and support legislation to advance ASR as a tool for sustainable groundwater use	Legislature	Now
Develop an ASR-decision-support system for interested communities	Interagency groundwater team; study authors; interested communities	Near term
Apply to EPA for primacy over Class V injection wells	MDH, as directed by the legislature	Near term
Modify State well code to allow injection wells	MDH lead with interagency groundwater team and stakeholders	Mid term
Review progress and evaluate need to modify centralized aquifer-property database	DNR with other agencies and MGS	Now
Acquire aquifer properties and apply GIS-tool to other aquifers where ASR is being considered.	Kang Group at the U of M, Earth and Environmental Sciences with MGS and DNR	as requested by municipalities
Make a cost-benefit analysis tool available for ASR projects following FEMA's 2016 Methodology for Aquifer Storage and Recovery Benefit Cost Analysis.	MDH lead with Water Resources Center	Mid-term
Develop permit process with engineering and environmental requirements that must be met that may include: 1) source water considerations including pre-treatment; 2) avoidance of potential aquifer impacts; 3) post-treatment requirements; 4) pilot project requirements, and 5) on-going reporting and monitoring.	MDH lead	Mid-term

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### Water Resources Center

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## Full report information

A full report is available that accompanies and supports this executive summary. The full report includes:

- Introduction to groundwater use in Minnesota
- Introduction to ASR
- Hydrogeological characterization of aquifers and injection capacity
- Engineering and environmental requirements
- Policy considerations
- Economics
- Case studies

The full report is available online at [www.wrc.umn.edu/banking-groundwater-managed-aquifer-recharge](http://www.wrc.umn.edu/banking-groundwater-managed-aquifer-recharge) or in alternative formats by request.

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