New Mapping Tools for Groundwater Replenishment

FRESHWATER

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Knowing where and how groundwater can be reused and replenished aids long-term water sustainability. Two new map-based tools help identify suitable sites for groundwater replenishment to augment other approaches to water stewardship.

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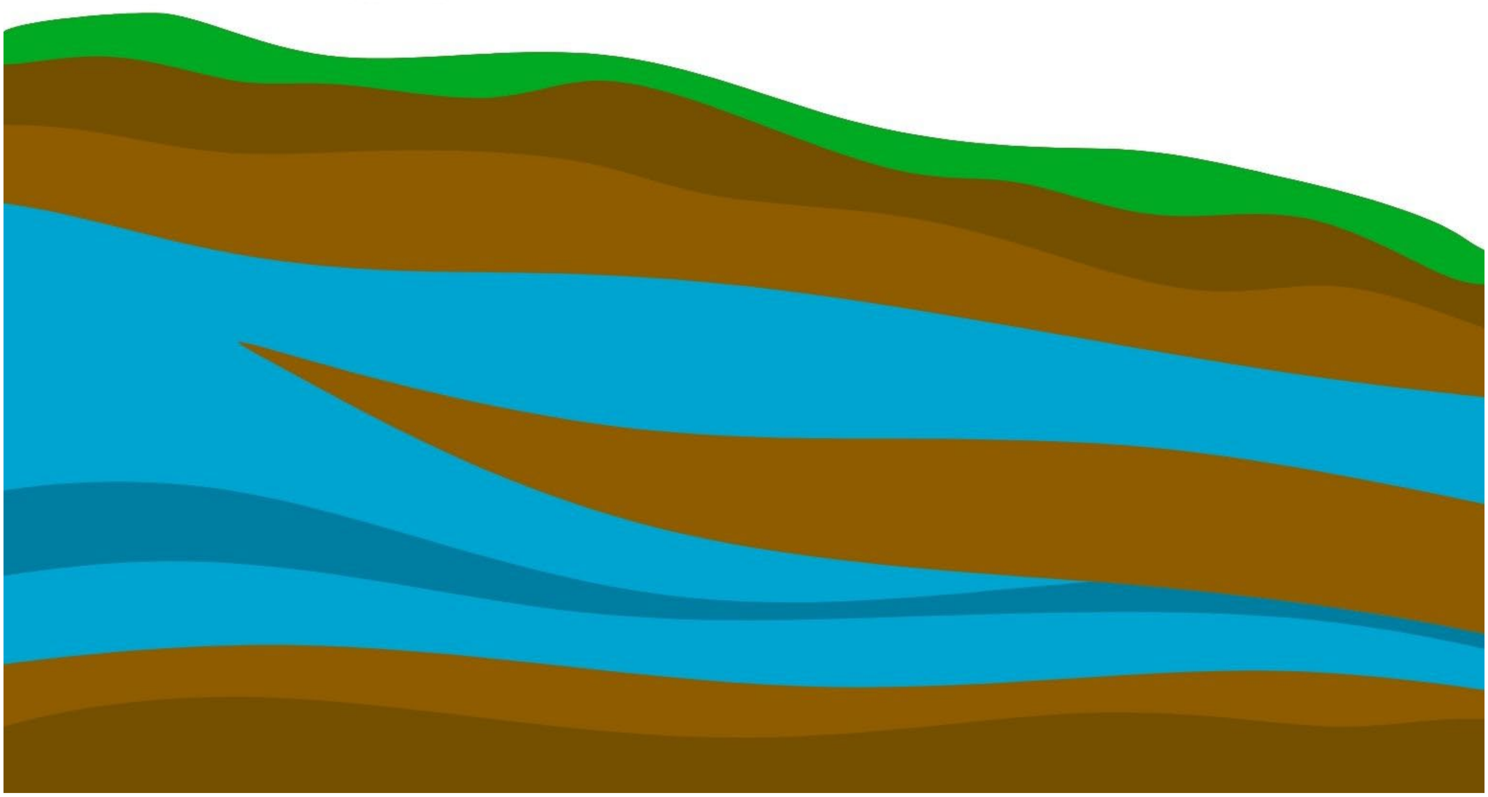

New Mapping Tools for Groundwater Replenishment

Foreword

In Minnesota water is assumed to be available when and where needed. It is typically pumped from a source – either groundwater or surface water – treated, used once, perhaps treated again, and returned to a surface water body where it travels downstream – out of state, out of mind.

In water-scarce parts of the world, where climate and geology limit water availability, water is reused – multiple times in some cases – before being discarded. Use is followed by treatment suitable for the intended reuse purpose. In some cases, water is even recharged to the aquifer it was pumped from.

Parts of Minnesota already experience at least seasonal water scarcity – periods when available water does not support people, agriculture, industry, and the environment. During these times, some water users may be told to conserve. In those communities and elsewhere, watershed management organizations, planners, and developers would benefit from having more tools beyond conservation.

Knowing where and how groundwater can be reused and replenished helps ensure long-term sustainability. New map-based tools are designed to help those managing water discharge identify suitable sites for groundwater replenishment. They screen areas with suitable topography, surface geology, and places where aquifers have the space to accommodate more water.

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Distribution of Large Water Users in Minnesota

A water permit appropriation permit from the Minnesota Department of Natural Resources (MN DNR) is required for withdrawals from either a surface-water or groundwater source that exceeds 10,000 gallons per day or 1 million gallons per year. During the 2025 legislative session, a new water-use category was defined to address hyperscale data centers who may consume more than 100 million gallons of water per year. Other large water users fall into these five MN DNR categories (Fig. 1):

1. Power Generation – typically surface water used to cool electrical power generating plants. Historically the largest volume, it relies almost entirely on surface water and most of the water is returned to the source.
2. Public Water supply - community drinking water systems.
3. Irrigation – agricultural watering and processing.
4. Industrial processing – mining activities, paper mill operations, food processing.
5. Other - activities including air conditioning, construction dewatering, water level maintenance, livestock watering and pollution confinement.

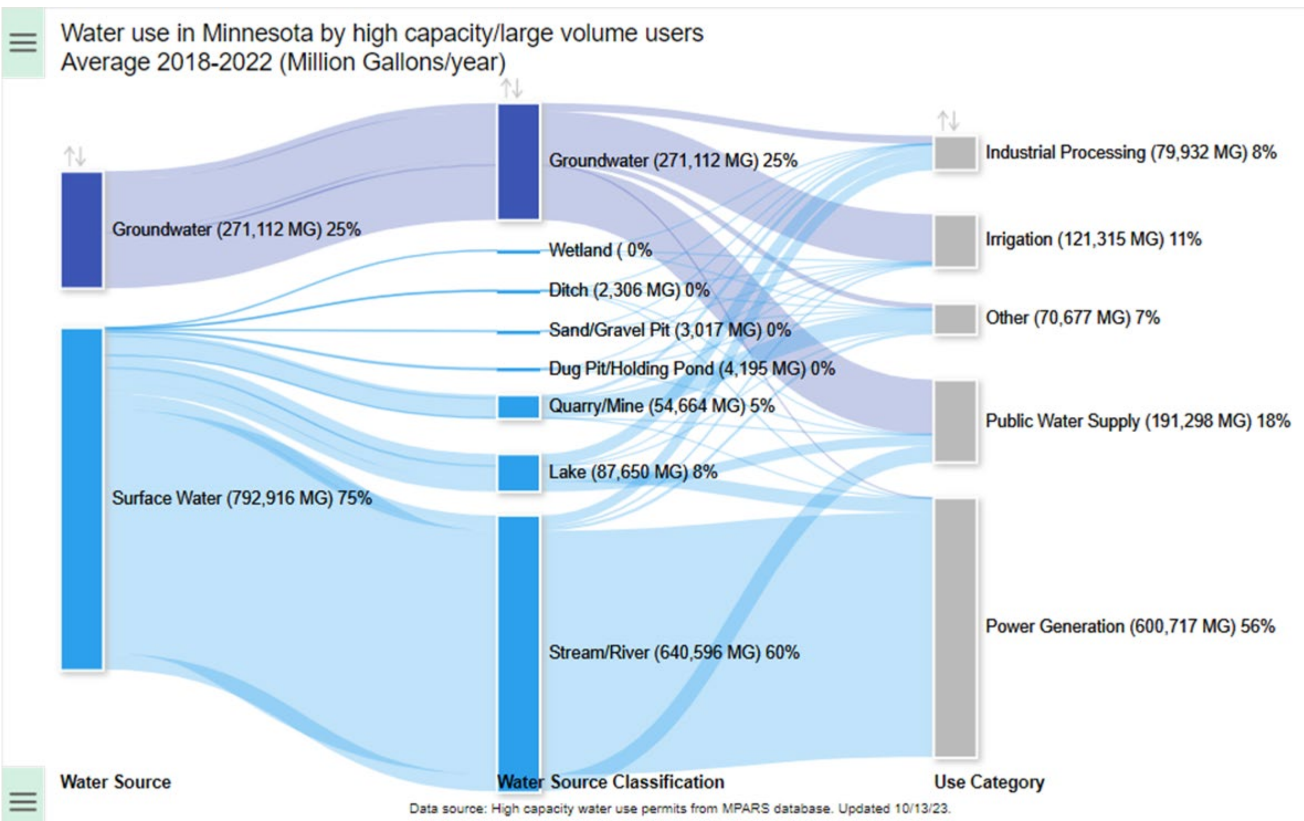

Figure 1. Water Appropriation Data Averages 2018-2022, Minnesota Department of Natural Resources.

Surface water is the primary source water in the state overall, accounting for 75% of all permitted withdrawals. Power generation is the largest user of surface water, and the largest water use category in Minnesota, accounting for 56% of overall withdrawal. Groundwater is used for 25% of statewide permits, with most used for public water supply. 75% of Minnesota's drinking water is from groundwater. Irrigation is almost entirely groundwater (source).

Status of Water Circularity in Minnesota

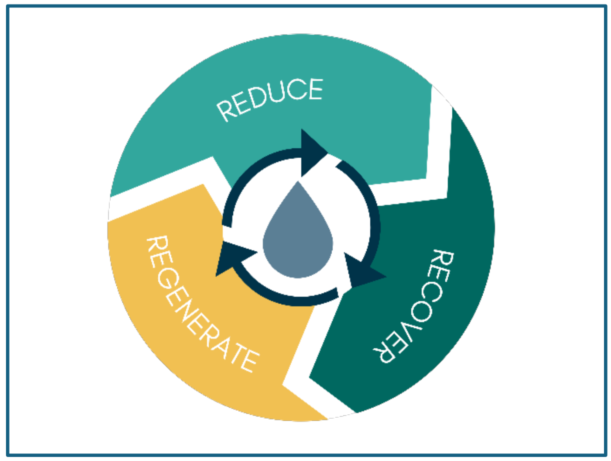

Figure 2. Circular Water Economy according to The Water Environment Federation reimagines water as a renewable, regenerative resource—one that can be continuously recovered, reused, and reintegrated to create value across communities, industries, and ecosystems. from wef.org

Local units of government trying to manage growth, encourage economic development, avoid negative impacts, and postpone the need for new infrastructure may be looking for alternate water supply to manage uncertainties while meeting current water needs. Private industry is currently leading the conversation about the need to reuse and recharge water. Their main drivers are sustainability, their corporate water stewardship goals, consumer or shareholder demands and managing water risk.

The greatest potential for water circularity in Minnesota is for groundwater to be used for non-potable purposes. The main hinderance is the low cost of water, and reuse projects may not move forward because the return on investment is longer than the 2-year threshold most businesses use.

The geography of water use might also not make reuse or recharge feasible. A facility with a large discharge may not be located near a large water user or in an area where managed aquifer recharge is possible. Piping and storing water add expense.

Status of Managed Aquifer Recharge (MAR)

Managed aquifer recharge (MAR) is the intentional capture and infiltration of water, whether it is stormwater or treated wastewater, for aquifer replenishment. The motivation may be to reduce runoff, improve sustainable water use, support ecosystems, maintain lake and river levels, and even moderate surface-water temperature.

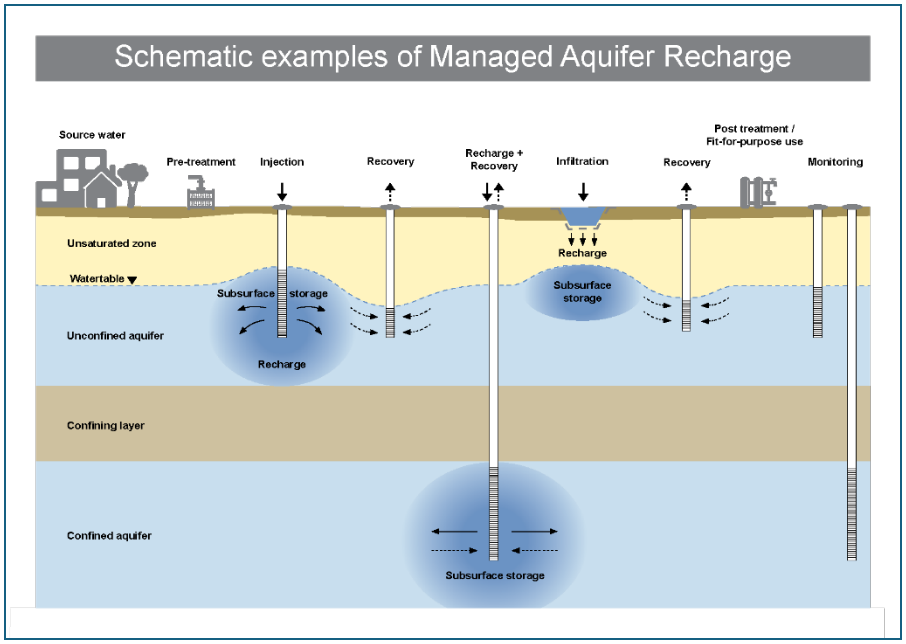

Figure 3. Examples of managed aquifer recharge. Source: Western Australian Government wa.gov.au

Minnesota's relevant policies on recharge were developed by an inter-agency workgroup led by the Minnesota Department of Health and include guidance on wastewater reuse, rainwater capture and use, and stormwater reuse (Interagency Workgroup on Water Reuse 2018). The interagency reuse website concludes "Despite increasing interest in water reuse, there is no comprehensive statewide guidance or policy on water reuse to ensure that projects are safe and sustainable."

Progress in the last decade has been episodic because beyond managing stormwater, there has not been a clear policy or economic driver to do more. That is, until now. Economic incentives drive large industrial water users to consider locating in Minnesota and have renewed interest from communities and corporations in circular water design.

The state's role in making MAR possible is to agree on the safest way to allow it and clarify the permitting path so that interested parties can design and implement systems in a competitive marketplace. This will allow for private investments in managed aquifer recharge systems that benefit the state, its residents, the economy, and ecosystems.

How is managed aquifer recharge different from stormwater capture?

Recharging groundwater is one category in the broader water reuse discussion. The term managed aquifer recharge (MAR) includes bank filtration, infiltration ponds or galleries, dry wells, aquifer storage transfer recovery (ASTR) wells, and aquifer storage and recovery (ASR) wells (source).

MAR shares similarities with stormwater capture. Stormwater ponds are designed to control pollution to receiving waters that result from land-use change.

Figure 4. Smithtown Ponds Stormwater Management Project, Shorewood, Minnesota. Source: ci.shorewood.mn.us

An increase in impervious surface area increases runoff, which may have picked up pollutants, and is therefore commonly treated before it reaches the receiving water. Some, but not all approaches to handling stormwater include some form of infiltration to reduce volume of water being delivered to the receiving water.

The Minnesota Pollution Control Agency (MPCA) is the delegated state agency responsible for reviewing practices for stormwater management as required by the Clean Water Act. These practices must adhere to National Pollution Discharge Elimination System (NPDES) permit requirements. The EPA monitors Minnesota's compliance with this process. Best practices and tools for design of stormwater systems are covered in the comprehensive Minnesota Stormwater Manual.

Agency Involvement in Managed Aquifer Recharge in Minnesota

In the limited number of past examples of managed aquifer recharge in Minnesota, the MPCA has not been the only agency involved; the Minnesota Department of Health has also played a significant role. This is because Minnesota's water agency structure distributes authority across at least three executive branch agencies: 1) source water quality is managed by the Minnesota Pollution Control Agency; 2) aquifer quality and standards by the Minnesota Department of Health, and 3) quantity of withdrawal by the Minnesota Department of Natural Resources. Whereas this can be a structure of decision-making that is protective of water, it can also slow the acceptance of practices that cross over into different agency jurisdictions.

A stakeholder group was convened to identify the type of guidance needed to promote aquifer recharge. Their recommendations were focused on minimizing the risk of infiltration and clarifying agency roles and responsibilities.

A new national water reuse action plan has been released by the Environmental Protection Agency (WRAP 2.0). It specifically calls out aquifer recharge as a formal recommendation. The Minnesota Pollution Control Agency is the state-level entity that carries out EPA directives.

Two New Infiltration and Injection Capacity Screening Tools

The capacity of the ground to absorb water varies with the soil texture and saturation conditions. Using publicly available data, two new open-source QGIS plugins screen sites for injection and infiltration capacity at the aquifer and county scale. Dataset included are from the County Well Index (CWI), lithology data from the Minnesota Geological Survey (MGS), and hydrogeologic parameters from literature to estimate aquifer-scale injection capacity.

The infiltration plugin integrates Soil Survey Geographic Database (SSURGO) data, digital elevation models (DEMs), water table maps, and hydrologic data, with the option to incorporate field measurements to refine infiltration basin setup for a given drainage period. Both plugins allow users to generate recharge potential maps, providing a transparent, repeatable, and cost-effective screening tool to support preliminary MAR site selection (Figures 5a and b).

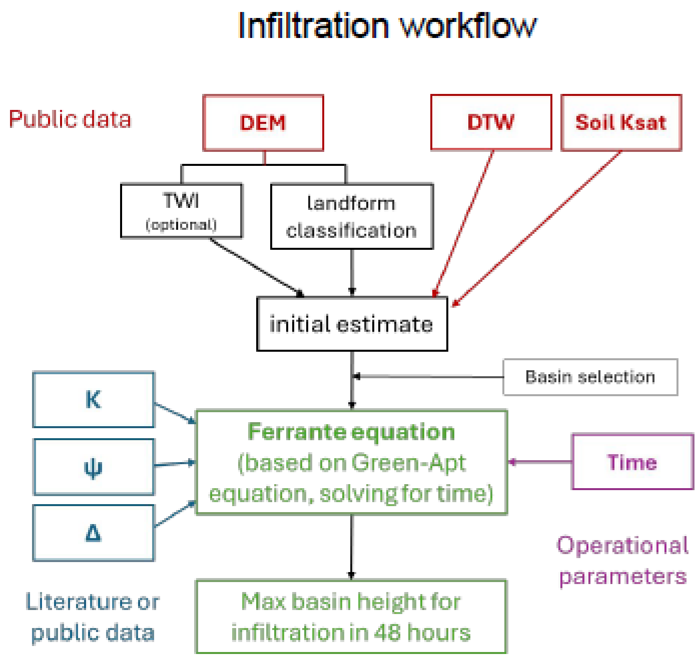

Figure 5 a. The injection plugin draws on publicly available data from the County Well Index (CWI), lithology data from the Minnesota Geological Survey (MGS), and hydrogeologic parameters from literature to estimate aquifer-scale injection capacity.

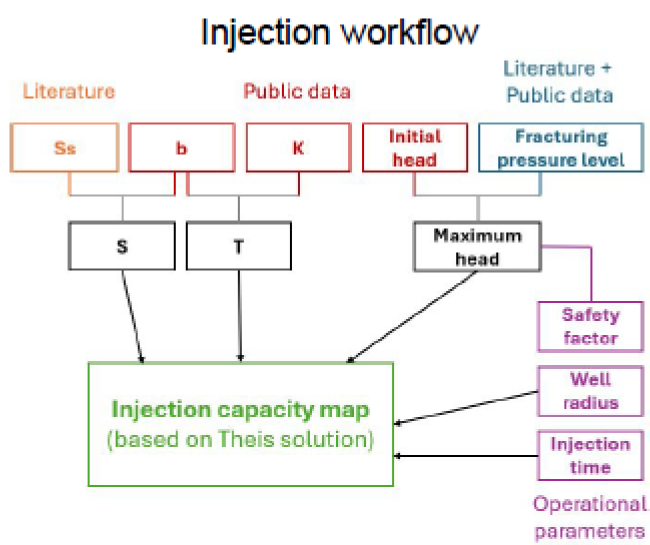

Figure 5 b. The injection plugin draws on publicly available well data from the County Well Index (CWI), lithology data from the Minnesota Geological Survey (MGS), and hydrogeologic parameters from literature to estimate aquifer-scale injection capacity. Source:

Can the way stormwater is managed inform aquifer recharge?

The MPCA's well-developed stormwater manual has gone through committee review and several iterations. It is a mature and living document that includes many of the considerations needed to evaluate MAR. The health risks of stormwater reuse as summarized in a 2022 MDH white paper are likely the same that they would raise for MAR.

"In 2018, an Interagency Work Group published a foundational report, "Advancing Safe and Sustainable Water Reuse in Minnesota," which recommended a risk-based management system, an information hub, and defined roles for overseeing water reuse initiatives. Following this effort, in 2021, the Minnesota Legislature called for a road map for water reuse implementation, aiming to establish a robust framework for SCU as a viable water management strategy. Subsequent reports, including the 2022 "Reuse of Stormwater and Rainwater in Minnesota: A Public Health Perspective," have further evaluated the risks and potential of SCU, using locally sourced data to assess microbial contents in stormwater systems."

Incentives for Managed Aquifer Recharge

A necessary step to advance reuse and recharge is to establish a clear permitting path so as not to impede the permitting process for conservation-minded industries. After that is achieved, incentivizing recharge by linking it to existing tax breaks offered to large industrial water users would result in more water-conservation practices.

Corporate Motivations and Volumetric Water Benefit Accounting:

Some water-intensive industries are voluntarily replenishing water in the watersheds in which they operate or that are involved in their supply chain. Corporations want clear, science-based metrics to support their water-benefit claims. The first guidance for volumetric water benefit accounting was released in 2019 and an updated method was released in Sept. 2025 by WRI, Limnotech, BlueRisk and the Bonneville Environmental Foundation. They promoted a 6-step approach to identifying projects that would replenish water (Figure 6).

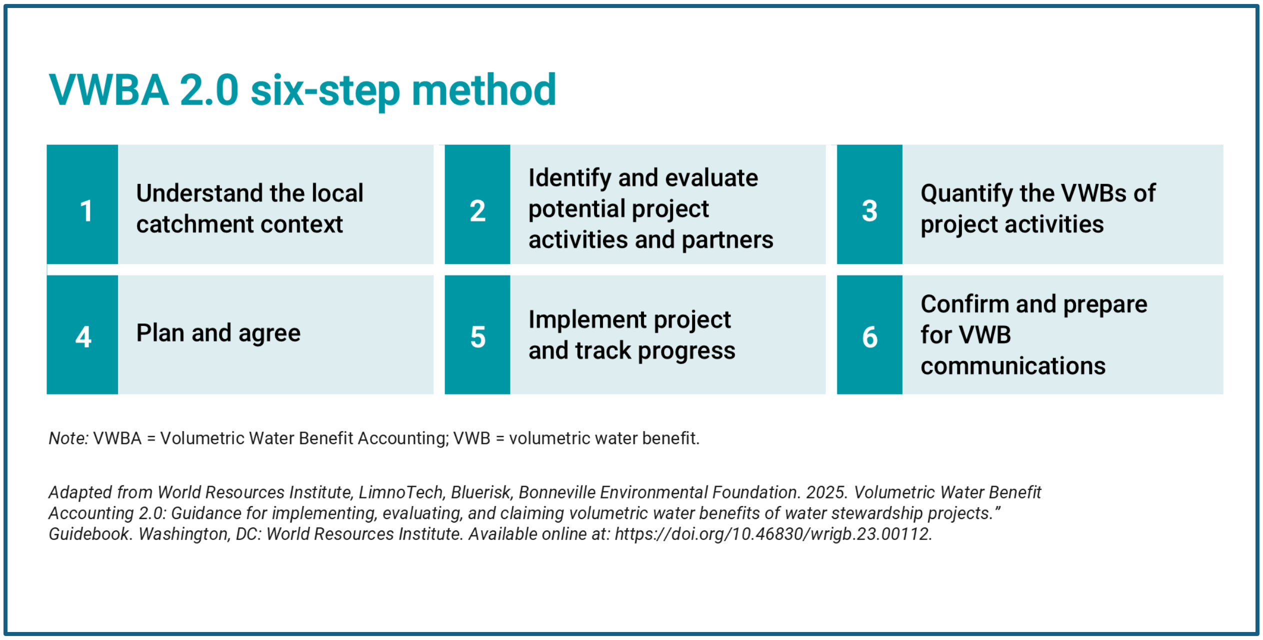

Figure 6. Volumetric Water Quality Benefits Accounting 6-step method. Source: https://www.limno.com/volumetric-water-benefit-accounting-2-0-vwba2-0/

The tools developed for this project will help in the initial three steps of the 6-step process: 1) understanding the local catchment context, for example where recharge might be possible; 2) identifying and evaluating potential project activities (and possibly partners) such as balancing water use with water recharge; and 3) quantifying the volumetric water benefits of proposed project activities, for example, calculating the rate and total volume of water that could be recharged (Figure 7).

Of the volumetric water benefit indicators mentioned below, MAR could maintain or increase recharge overall and seasonally, increase inundation area, maintain or increase the volume captured, and could be designed to include treatment options.

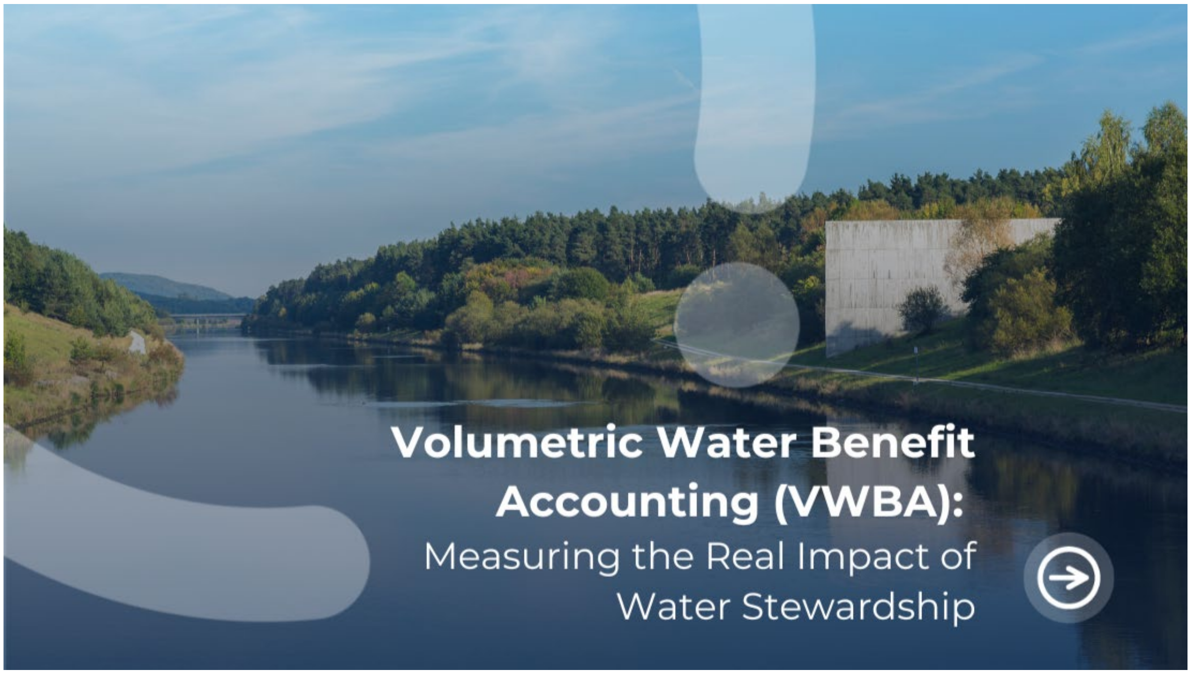

Figure 7. Developed by the World Resources Institute in collaboration with LimnoTech, Quantis, and Valuing Nature, VWBA provides a framework to calculate the volume of water saved by activities that positively modify local hydrology or resource usage.

Through a better understanding of infiltration locations and groundwater flow, tracking methods could also be illuminated, for example, where to put monitoring wells or piezometers or which existing monitoring wells to use.

A recent request for information on water replenishment projects by Google is an example of how they as a global company aim to replenish more water than they use in their priority watersheds. Their leadership will likely influence others in the tech industry and beyond. In Google's 2026 portfolio of projects they mention some managed aquifer recharge and aquifer storage and recovery efforts they have funded. Whereas a Google data center was announced for the Hermantown area, this is not yet a focus of their current RFI (Figure 8).

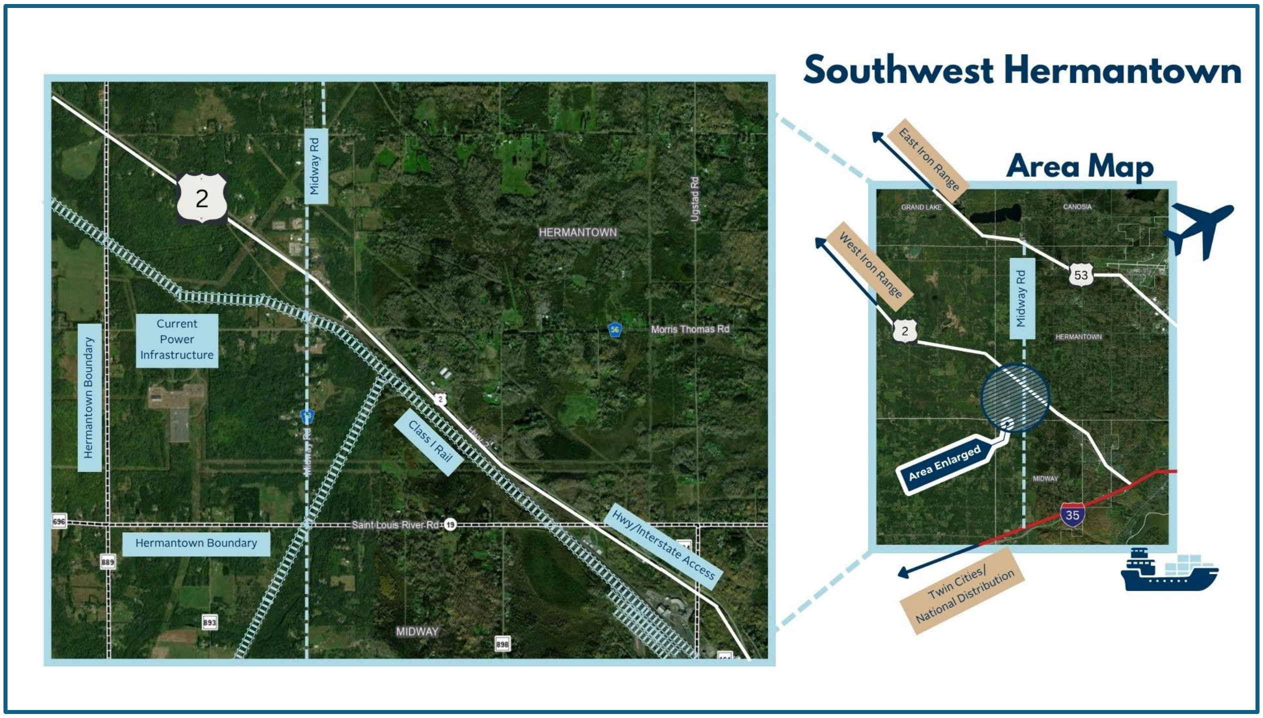

Figure 8. Proposed Google Data Center site in Hermantown, Minnesota. https://hermantownmn.com/project/

Industry Interviews

Freshwater conducted interviews with water users across sectors and asked the following questions:

1. Is water circularity, namely water conservation, reuse or water recharge a part of your current water management strategy?
2. Do you hope to implement more water circularity in the future?
3. What are your drivers to implement circular water strategies?
4. What barriers exist?
5. What tools or partners would help you with this work?
6. Who else should we talk to?

Details for each sector are summarized (Table 1) and expanded on in Appendix A.

Table 1: Summary of Water Circularity in Minnesota by Sector

	Now?	Future Opportunities?	Drivers	Barriers
Mining	Yes	Some	Operational continuity Water permits	Nearby users for excess water
Food and Beverage	Yes	Yes	Consumer and corporate sustainability Managing water risk	Health regulations Public partnerships Complimentary businesses not nearby
Agriculture	Limited	Yes	Land stewardship Public Health	Annual profitability Decentralization
Public Sector	Limited	Yes	Water stewardship Long term planning	Cost justification Stormwater health risks Private partnerships Complimentary businesses not nearby
Oil and Gas	Yes	Some	Water permits Managing water risk	Public partnerships Treatment costs
Power	Yes	Yes	Operational continuity Permits	Treatment costs
Manufacturing	Yes	Yes	Operational continuity Permits Managing water risk	Public partnerships Treatment costs Recharge limitations Longer return on investment
Data Centers	No	Yes	Social license to operate Corporate sustainability Managing water risk	Rapid pace of development Competitive market Co-location and timing

Conclusions

Knowing where and how groundwater can be reused and replenished aids long-term water sustainability. The two new map-based tools briefly described here, and available as open-source code, identify suitable sites for groundwater replenishment. These tools can be used in several ways. Proactively, they could be deployed when siting large water users to identify locations where groundwater could be replenished, either through passive infiltration into the water table aquifer or through pumping into confined aquifers.

Appendix A: Summary of Industry Interviews

Mining:

- Current state: Industrial processing is 8% of water use in Minnesota. Mine sites already try to reuse and recycle as much water onsite as possible. Usually there is excess water onsite, more than required for operational needs. Water efficiency improves the bottom line. Climate change and changes in precipitation patterns are a risk to business operations.

- Water uses: industrial plant water, slurry transport, mineral processing, or tailings management.

- Drivers for Circularity: limiting site discharge due to permit requirements; need to manage water onsite to stay in operation.

- Barriers: cost of water treatment for discharge; finding other users for water discharges offsite and nearby.

- Future: additional opportunities for using mine site water discharge for other applications if geographically nearby or for groundwater recharge. Mine sites may have favorable geology for MAR.

Food and beverage:

- Current State: Industrial processing is 8% of water use in Minnesota. The food and beverage industry has competing priorities. It must follow the Food and Drug Administration's strict rules on sanitation and safety. Some of which are prohibitive to water reuse and circularity. This sector already does a good job at coordinating and communicating.

- Uses: Product inputs or non-potable plant water.

- Drivers: for consumer-facing products, drivers are environmental stewardship and corporate sustainability goals.

- Barriers: Water quality and regulations depending on the facility and products. Communication outside of their sector among regulators, corporate personnel, water professionals, and consumers may be a barrier. To date, no singular guidance document defining terminology and naming conventions specific to water reuse practices has attained widespread consensus and can cause discussion over nuances of meaning. A noncomprehensive list includes terms such as drinking water, potable water, first-use water, source water, ingredient water, clean water, safe water, sanitary water, sterile water, water fit for purpose, process water, reuse water, recycled water, reclaimed water, recirculated water, treated water, and reprocessed water. (Advancing water reuse in the beverage industry (2024): https://watereuse.org/white-paper-published-advancing-water-reuse-within-the-beverage-industry/)

- Future opportunities: There may be opportunities for water efficiency and improving sustainability of their water supply.

Agriculture:

- Current State: Agriculture is 11% of permitted water use in Minnesota, and most of this is for crop irrigation. This is a large and decentralized water use and varies in the ability to implement water circularity and conservation strategies. Climate change and changes in precipitation patterns are a risk to business operations.
- Uses: irrigation, “wash down” water, or product inputs.
- Drivers: Local environmental stewardship and regulations.
- Barriers: Much of this sector is focused on economic drivers due to market costs, profitability, and is dependent on weather. Water is usually not stored onsite and is quickly conveyed to surface waters for discharge.
- Future opportunities: additional opportunities for water efficiency using advanced irrigation tools, or stormwater capture and use for irrigation. Water does not have to be drinking water quality for irrigation in most cases. Nutrient management may also present drivers for circularity such as spray irrigation for recycled water.

Public Sector/ Government:

- Current state: An informal list of water reuse projects in the MPCA stormwater manual lists over 53 projects, with the majority of the public sector projects being stormwater capture for irrigation, or rainwater capture for gray water use.
- Uses: drinking water, stormwater management, wastewater management.
- Drivers: environmental stewardship, managing public water for future generations.
- Barriers: prioritization on cost-effective spending, lack of funding, and competing priorities with private businesses and developers. There is also a hesitancy to partner with the private sector.
- Future: providing funding and encouragement to partner with the private sector for long term resource benefits would encourage this sector to implement more water conservation, reuse or recharge efforts. The public sector can also encourage the water efficiency of residents through rebate programs in their cities or districts.

Oil and gas:

- Current state: like mining, many oil and gas operations are already very water efficient as a business strategy.
- Uses: cooling, process water.
- Drivers for Circularity: water permit requirements, managing water supply and discharge risk, and the need for a constant water supply for safe operation.
- Barriers: cost of water treatment for discharge and finding other users for water discharges offsite that are nearby. There is also hesitancy from public and private partnerships with oil and gas companies.
- Future: There may be additional opportunities for use of water that is discharged offsite or use of recycled water as a source.

Power:

- Current state**:** Power is 56% of permitted water use in the state, the largest water user category in Minnesota. Most of this water is used for cooling. While facilities used to have single-pass cooling systems, some have implemented water reuse, closed-loop cooling, or multiple-pass cooling systems. Many return water to the surface-water source.
- Uses: cooling water, processing water.
- Drivers for Circularity: water permit requirements, managing water supply and discharge risk, and the need for a constant water supply to stay in operation.
- Barriers: geographic proximity to other water users.
- Future: additional opportunities for circularity may be driven by the large volume of water used and the low quality of water needed.

Manufacturing:

- Current State: Industrial processing is 8% of water use in Minnesota. Many manufacturing sites are already water efficient in their own facilities and are looking to create products that help reduce the global water crisis.
- Uses: cooling, industrial water, process water.
- Drivers: consumer and corporate sustainability goals, water permitting requirements, managing water risk and cost to operations.
- Barriers: the low cost of groundwater and longer return on investment.
- Future: Explore opportunities for manufacturing facilities to be co-located near other facilities with excess water use or discharge such as gray water or wastewater reuse. Treat and recharge groundwater to be a net positive water user.

Other Industries and New Economic Development:

- Current state: Industrial processing is 8% of water use in Minnesota. Minnesota is attracting water intensive businesses like dairy, data centers, and chip manufacturers so that number may increase.
- Drivers: Minnesota is a water rich state, and businesses may locate here for water security.
- Barriers: businesses are sited for economic incentives, power availability, and land use. The long-term water supply impacts are not evaluated early in the process, or with a view beyond their property. Public-Private partnerships to reuse water take time to develop and may not meet the confidentiality needs or timeline of the developer.
- Future: opportunities to co-locate new businesses using a large volume of water near those with excess water like mining facilities or wastewater treatment plants.