M.L. 2019, 1st Special Session, Chapter 4, Article 2, subd. 04t Project Abstract

PROJECT TITLE: Managed Aquifer Recharge: Banking Groundwater
PROJECT MANAGER: John Bilotta, Senior Research and Extension Coordinator
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FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: [Insert relevant year's citation here]

APPROPRIATION AMOUNT: $350,000
AMOUNT SPENT: $349,811.00
AMOUNT REMAINING: $189.00

Sound bite of Project Outcomes and Results

Aquifer storage and recovery can be a viable technique that could be deployed safely to ensure groundwater availability and sustainability to communities in Minnesota. Treating, injecting and temporarily storing clean water in aquifers may provide a solution to meeting future demands of residents, industry and agriculture.

Overall Project Outcome and Results (Abstract)

Some of the more than 75% of Minnesotans who rely on groundwater may find it in short supply in the face of population, land-use and climate change. Aquifer storage and recovery (ASR) is a technological approach to treat and inject clean water into an aquifer for temporary storage. The hydrogeological characteristics and the chemistry of the source water and aquifer impact treatment needs prior to injection and after extraction. Aquifer properties that control how water moves determine the volume and rate of water injected. This study examined four different kinds of aquifers across Minnesota with unique pressures to determine their suitability for ASR. The study findings suggest three may be suitable for ASR. The Buffalo aquifer in Moorhead has variable injection capacity and multiple sources of water for injection. Water quality issues of arsenic, sulfate, manganese, and hardness may require treatment before injection and after extraction. The Jordan aquifer in Rochester faces increased pressure from growth and nitrate contamination in agricultural areas. The wastewater treatment plant could provide adequate source water if treated. Woodbury faces pressure from increasing population and PFAS contamination of the Jordan aquifer. ASR could recharge groundwater from wastewater treatment plants and also be integrated with PFAS remediation scenarios by reinjection of treated groundwater. ASR is not recommended for the surficial sand aquifer in the Straight River Groundwater Management area in north central Minnesota because there is no feasible source of water at this time. Cost-benefit analysis combined with a sensitivity analysis of economic factors should be a component of ASR project feasibility studies. Modified state well code and a streamlined permitting path would allow more successful development and deployment of ASR. State adoption of control over Class V injection wells from the USEPA is also necessary. Improvements are needed to the state aquifer properties database.

Project Results Use and Dissemination

This project results in two reports. First, a full-color 10 page executive summary describes the project and provides recommendations for policy leaders, professionals, and stakeholders to consider for the application of ASR to Minnesota. A full scientific report encompassing each of the individual activities, methods, data, recommendations and discussion. They are both available online at https://www.wrc.umn.edu/banking-groundwater-managed-aquifer-recharge

Throughout the term of the project, policy leaders, professionals, and stakeholders were engaged in discussions. Meetings were held with multiple agencies including the Interagency Groundwater Team and multiple presentations were given to a broad list of stakeholders including to members of the Legislature, the Environmental Quality Board, MNDNR Groundwater Management Area leaderships, DNR Groundwater Technical Analysis Workgroup, and stakeholders in each of the study areas.

The Executive Summary has been sent to all interested stakeholders and a link to the full report with an expanded table of contents has been provided for deeper review. The final report has been submitted to the LCCMR and project recommendations introduced in bill language during the 2021 legislative session.

Multiple presentations were given during professional conferences and seminar opportunities. Multiple project updates were published through the Water Resources Center and the Freshwater Society regular electronic news updates. Individual activity researchers and authors are currently writing manuscripts for professional publications.

Environment and Natural Resources Trust Fund (ENRTF)
M.L. 2019 ENRTF Work Plan Final Report (Main Document)

Today's Date: February 8, 2021

Final Report

Date of Work Plan Approval: June 17, 2019

Project Completion Date: December 30, 2020

PROJECT TITLE: Managed Aquifer Recharge: Banking Groundwater

Project Manager: John Bilotta, Senior Research and Extension Coordinator

Organization: University of Minnesota

College/Department/Division: Water Resources Center

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Location: Statewide

Total Project Budget: $350,000.00

Amount Spent: $349,811.00

Balance: $189.00

Legal Citation: M.L. 2019, 1st Special Session, Chapter 4, Article 2, subd. 04t

Appropriation Language: $350,000 the first year is to the Board of Regents of the University of Minnesota, Water Resources Center, for a comprehensive study of the economic benefits of managed aquifer recharge and to make recommendations to enhance and replenish Minnesota's groundwater resources. The study must include, but is not limited to:

(1) examining the potential benefits of enhancing groundwater recharge in water-stressed areas; *(work completed and summarized in Final Report, Sections 1, 2, 3 and 7*);

(2) assessing the relationship to changing seasonality and intensity of precipitation on groundwater recharge rates *(work completed and summarized in Final Report, Section 1)*;

(3) reviewing the approaches to manage recharge in geologically appropriate areas *(work completed and summarized in Final Report, Sections 1, 3, and 7);*

(4) identifying policy options, costs, and barriers to recharging groundwater *(work completed and summarized in Final Report, Sections 3, 4, and 5.);* and

(5) assessing the economic returns of options for groundwater recharge *(work completed and summarized in Final Report, Sections 5)*.

In conducting the study, the Water Resources Center must convene a stakeholder group and provide for public participation.

I. PROJECT STATEMENT: An interdisciplinary team led by the Water Resources Center (WRC) will evaluate the engineering, hydrogeologic, economic and policy benefits of and barriers to aquifer recharge. The team will produce recommendations for recharge and how the state might proceed if recharge is needed for future water sustainability. Stakeholders will be engaged throughout the study for contributions and recommendations and results will be presented at the conclusion of the project.

For parts of Minnesota, groundwater recharge may be necessary to meet the competing needs of communities and agriculture that are expected to be exacerbated by changes in recharge that result from drainage and climate. This increases the uncertainty for a community. Options to increase water supply include conservation and reuse of water, but also recharging groundwater.

Passive aquifer recharge involves treating and directing surface water to unconfined aquifers. A more active approach is aquifer storage and recovery (ASR) through injection and recovery wells. Both methods are used around the world and have application to Minnesota.

II. OVERALL PROJECT STATUS UPDATES:

First Update September 1, 2019
The team has completed the necessary data collection and analysis to select four study areas for the project (Activity #1). The four areas are the Fargo-Moorhead region, Straight River Groundwater Management area near Park Rapids, Southern Washington County, and the Greater Rochester area. With those chosen, work has commenced on Activities 2,3 & 4. The team has also made initial steps to engage with stakeholders including giving a presentation to the Interagency Groundwater Working Group and by providing project briefs in the Water Resources Minnegram and the Freshwater Society newsletters. The team has had two in-person working sessions.

Amendment Request 12/04/2019
A request for budget amendment to shift funds within the project. This amendment does not increase or decrease the overall amount of the project. These changes are needed to complete the work related to Activity #4 Economic and Policy Analysis. Since the original work plan was submitted, the Water Resource Center staff and faculty have determined and developed a different and more effective approach to completing this work. Instead of utilizing a graduate student, the Center is using an existing staff member (Research I) to assist in the project and collaborating with the Center for Agricultural and Rural Development (CARD) Program at Iowa State. A search for a postdoc or researcher to work with the Center yielded insufficient ideal candidates. Those candidates that met some of needs and qualifications required work visas (the best candidates were from Canada and Ireland.) There were no candidates from Minnesota. Center staff also communicated with faculty in other University departments such as Applied Economics, the Water Resources Science Graduate Program, and CFANS to circulate the position posting. Individuals that may have had the necessary skill sets were unable to dedicate time to the project, especially with the short timeline. In lieu of that, our Center Director Jeff Peterson had worked with the CARD Director, John Crispi in past collaborative work and recognized CARD may be able to assist and has the expertise to assist in completing this project. This possibility also presents an opportunity to increase collaboration with CARD and Iowa State on future projects that involve water quality and agricultural issues. This potential for partnership growth can benefit Minnesota's future efforts. For this project, CARD staff have some unique skill sets in economic analysis that will add to and contribute to a more robust and comprehensive analysis of environmental economics and policy. Collaborating with CARD will result in completion of Activity #4 and will ultimately lead to stronger results of this project and strategies that can

benefit Minnesota water and natural resources. Ultimately, the goal of this project particularly activity #4 is to report on the economic and policy barriers and opportunities for aquifer storage and recovery for the State of Minnesota. The Center Staff feel strongly that collaborating with CARD and essentially doubling our mind-power (expertise and experience) will result in achieving the goal of this activity. In initial conversations with CARD staff, we all feel we can accomplish this together.

In short the changes include:

- Moving an additional $49K to Professional Services to compensate CARD staff. These funds will come from the original fund amount of $50,500 for a WRC graduate student.
- Adding a Researcher I staff member in the amount of $10K. Funds for this come from redirecting salary funds from John Bilotta's allocations in the spreadsheet and from the balance from the above transaction.
- A new budget spreadsheet is included that specifies these changes.

Second Update March 1, 2020

Significant progress was made during this period. The extent and hydrogeologic characteristics of the target aquifers were compiled for three of the four target areas: Fargo-Moorhead, southern Washington County, and the greater Rochester area. The Straight River Groundwater Management area near Park Rapids is nearly complete in this respect. The evaluation of recharge potential started for the Fargo-Moorhead target aquifer and the first version of the recharge potential map has been successfully produced. Collection and review of the geochemistry of Minnesota aquifers, as well as identifying the buckets from which recharge water could be sourced were started and continue. Case studies of domestic ASR projects in other states as well as an overview of ASR use throughout the world have been compiled. Initial compilation of regulations surrounding ASR has been completed. Additional expertise and capacity have been secured to assist with the project. Significant stakeholder engagement has been completed by presenting and discussing the project with agencies, organizations, and professionals across the state at various meetings, conferences and meetings. LCCMR approved an amendment for the project on December 12, 2019. The diverse research team continues to manage the project through regular communications and meetings. Some tasks are ahead of schedule and the project will be completed on time.

Third Update September 1, 2020

The major research work under activities #1-4 including modeling was completed during this period. The four areas of interest have been studied, data gathered and modeled and the research team has now started the process to summarize the findings and present an evaluation of the suitability of these areas for ASR. In addition, seven case studies have been compiled and will be presented as examples and comparative examples. Stakeholder engagement including to Minnesota Legislators and key staff from the Interagency Groundwater Protection Team has been constant throughout the process. The large research team has prepared an outline and strategy compile the various activities into one contiguous report and draft sections of the final report have been completed and all others are now underway. The team anticipates project completion by the end of the year.

This update includes a request for a budget amendment. A decrease in the subaward to Iowa State University in the amount of $4481 that will be reallocated to the Water Resources Center for personnel. The research team members at CARD at Iowa State have agreed to this though the request must be approved by LCCMR and the sponsored project administrative units at both Iowa State and the University of Minnesota. In addition, re-allocation from travel ($341) to personnel. Rationale. The team acknowledges original travel expenses would not occur due to the current health conditions and travel restrictions. These funds and the publication costs would be better utilized for personnel to extend a research assistant whose role is critical to completion of the project.

Overall Project Outcomes and Results

Some of the more than 75% of Minnesotans who rely on groundwater may find it in short supply in the face of population, land-use and climate change. Aquifer storage and recovery (ASR) is a technological approach to treat and inject clean water into an aquifer for temporary storage. The hydrogeological characteristics and the chemistry of the source water and aquifer impact treatment needs prior to injection and after extraction. Aquifer properties that control how water moves determine the volume and rate of water injected. This study examined four different kinds of aquifers across Minnesota with unique pressures to determine their suitability for ASR. The study findings suggest three may be suitable for ASR. The Buffalo aquifer in Moorhead has variable injection capacity and multiple sources of water for injection. Water quality issues of arsenic, sulfate, manganese, and hardness would require treatment after extraction. The Jordan aquifer in Rochester faces increased pressure from growth and nitrate contamination in the surrounding agricultural areas. The wastewater treatment plant could provide adequate source water if treated. Woodbury faces pressure from increasing population and PFAS contamination of the Jordan aquifer. ASR could recharge groundwater from wastewater treatment plants and also be integrated with PFAS remediation scenarios by reinjection of treated groundwater. ASR is not recommended for the surficial sand aquifer in the Straight River Groundwater Management area in north central Minnesota because there is no source of water to make it a feasible option at this time. Cost-benefit analysis combined with a sensitivity analysis of economic factors should be a component of ASR project feasibility. Modified state well code and a streamlined permitting path would allow more successful development and deployment of ASR. State adoption of control over Class V injection wells from the USEPA is also necessary. At the conclusion of this project and with the final report, all appropriation requirements #1-5 as well as robust and comprehensive stakeholder engagement were met (See final report section 6, pages1-6.)

III. PROJECT ACTIVITIES AND OUTCOMES:

Activity 1: Identify areas where groundwater will be used more quickly than it is replenished based on compilation of DNR permit and water level data, climate projections, demographic data, and recharge data.

- Assemble background materials to project changes in groundwater dependence and need by assessing: a) how water is currently being used; and b) how this use might change with anticipated demographic shifts.
- Put bounds on the magnitudes of projected groundwater availability from changes to: a) the seasonality and intensity of precipitation; b) evapotranspiration; and c) hydrology.

ENRTF BUDGET: $25,000

Outcomes	Completion Date
1. Collect, compile and interpret demographic and water level data; present and report (this meets appropriation requirement # 1 and 3)	*9/30/2019*
2. Narrow uncertainties: water balance, groundwater recharge and climate; report (this meets appropriation requirement # 2)	*12/30/2019*

First Update September 1, 2019

Activity 1 has largely been completed. Four areas have been selected and data collected. The four areas are: Fargo-Moorhead, Straight River Groundwater Management area near Park Rapids, Southern Washington County, and the Greater Rochester area. Outcomes 1: Collect, compile, and interpret demographic data has been completed. Report is underway. Work on Outcome #2 is underway.

Second Update March 1, 2020

Completed activity 1.

Third Update September 1, 2020

Not applicable. Activity 1 completed during previous update period.

Final Activity Report Summary

(Addresses appropriation requirement (1) examining the potential benefits of enhancing groundwater recharge in water-stressed areas and (2) assessing the relationship to changing seasonality and intensity of precipitation on groundwater recharge rates. See Section 1, pages 1-16 of final report.)

Aquifer water level trends *(outcome 1)*

In activity 1, existing data, trends and reports were compiled and summarized. The examination of past studies, monitoring data, and modeling indicates that for some parts of the state, groundwater sustainability is a real concern. The recharge to the water-table aquifer (shallow, and not frequently used for drinking water sources) can be an indicator of aquifer levels. Overall, Minnesota has positive annual recharge to the water-table aquifer however that decreases as you move west across the state. Therefore, deeper aquifers that communities and industry rely on may not have sustainable use. There are places in Minnesota that show a weak trend of declining groundwater level. Modeling conducted indicated that 36% of the state, predominantly in the west, were receiving an annual recharge of < 2 in/yr. That is insufficient to recharge aquifers given demands on use.

Uncertainties, water balance and climate *(outcome 2)*

The amount, seasonality and time between precipitation impact groundwater recharge and use. Consumption changes with population projections (growth) and withdrawal for agriculture. The water budget is strongly impacted by how much water plants transpire through their leaves but also on how much irrigation is needed to sustain them through a dry spell. If consumption is greater than or similar to inputs, the water table may be lowered. Results vary across the state but overall, total precipitation and temperatures are anticipated to increase and there will be longer frost-free periods. The month of May will be generally wetter, and August, much drier. The intensity of precipitation increases as does the length between dry spells. This will result in variation in both depletion and recharge of aquifers across the state.

Given these projections, researchers identified four specific areas where groundwater may be used more quickly than it can be replenished or where clean groundwater was projected to be in short supply. Those four areas and their trends are discussed as part of activity 2.

Activity 2: Characterize regionally shared aquifers for recharge and identify additional information needs.

- Identify at least 4 regionally shared aquifers that are projected to have decreasing water levels for evaluation.
- Compile existing available information including data from the county geologic atlas and develop list of characteristics for those aquifers; develop a process that describes how to obtain and compile existing data.
- Develop a methodology for estimating injection capacity of Aquifer Storage and Recovery (ASR) wells;
- Apply the developed methodology to estimate injection capacity of wells at the selected aquifers.

ENRTF BUDGET: $125,000

Outcomes	Completion Date
1. Describe regional aquifers, confined and surficial, extent, trends; present and report (this meets appropriation requirement # 1 and 3)	*6/30/2020*
2. Identify hydrogeologic data needs, how to acquire or compile if available; report (this meets appropriation requirement # 2 and 3)	*9/30/2020*
3. Develop understanding of recharge potential of aquifers; present and report (this meets appropriation requirement # 3)	*12/30/2020*

First Update September 1, 2019

Activity 2 is underway. As indicated above, four areas have been selected and data collected. The four areas are: Fargo-Moorhead, Straight River Groundwater Management area near Park Rapids, Southern Washington County, and the Greater Rochester area.

Second Update March 1, 2020
The mapped extent and hydrogeologic characteristics of the target aquifers have now been compiled for three of the four target areas: Fargo-Moorhead, southern Washington County, and the greater Rochester area. The Straight River Groundwater Management area near Park Rapids is nearly complete in this respect. This work was accomplished ahead of our anticipated schedule, and within budget. The evaluation of recharge potential started for the Fargo-Moorhead target aquifer and the first version of the recharge potential map has been successfully produced. *(Outcomes #1,2 & 3)*

Third Update September 1, 2020
The mapped extent and hydrogeologic characteristics of the target aquifers have now been compiled for all four target areas: Fargo-Moorhead, southern Washington County, the greater Rochester area, and the Straight River Groundwater Management area near Park Rapids. The methodology to estimate recharge potential (injection capacity) is successfully developed, and we have applied the methodology to evaluate recharge potential of three site (Fargo-Moorhead, southern Washington County, the greater Rochester area). The first version of the recharge potential maps has been successfully produced. This work was accomplished ahead of our anticipated schedule, and within budget.

Percentage completion
1. Describe regional aquifers, confined and surficial, extent, trends; present and report: **90 % complete**
2. Identify hydrogeologic data needs, how to acquire or compile if available; report: **90 % complete**
3. Develop understanding of recharge potential of aquifers; present and report: **80 % complete**

Final Activity Report Summary
(Addresses appropriation requirement (3) reviewing the approaches to manage recharge in geologically appropriate areas. See Section 1, pages 1-2 and Section 2, pages 1-64 of final report.)

Four regions were selected to study the potential to manage and recharge aquifers: Moorhead in Clay County, the Straight River watershed spanning four counties in north central Minnesota; the city of Woodbury in Southern Washington County and the City of Rochester in Olmsted County. These areas were projected to have groundwater sustainability concerns for different reasons including projected demographic trends, water-use trends, limited aquifer availability and pollution concerns. They were also chosen to represent aquifers of different geologic types. Geologic and hydrogeologic data were compiled and summarized for each location from a variety of sources including from the County Geologic Atlas series and availability of these data refined the choice of study areas.

Managed Aquifer Recharge (MAR) describes the general practice of directing water to aquifers above what would naturally occur. Aquifer Storage and Recovery (ASR) is the injection of water into an aquifer for temporary storage with the goal of recovering it later and is one method of MAR. One group in this research team developed a method for estimating the injection capacity aquifers and applied this tool to the three confined or partially confined aquifers in this study. The method provides a first-order assessment of the maximum amount of water that can be safely injected through a well. The injection capacity depends on the transmissivity of the aquifer and the allowable head change in a radius around the injection well. Aquifers with high transmissivity, those that are more porous and permeable (hydraulic conductivity) and a thicker layer of aquifer material will have a higher injection capacity.

The concepts were incorporated into a new GIS-based mapping tool that produces injection capacity maps by combining the methodology with hydrogeologic data. The tool successfully produced injection capacity maps for three confined or partially confined aquifers, the Buffalo aquifer in Clay County, a glacial sand and gravel body partially buried by clay; the Jordan aquifer in Woodbury, Washington County and another portion of the Jordan aquifer in Rochester, Olmsted County.

The results are generally favorable but reveal large spatial variabilities in the injection capacity. The method informs the ideal injection location and duration. The number of injection wells required to store water will vary for each site depending on the location of injection wells and injection duration.

Work on this activity also identified existing data gaps. Groundwater level data are lacking and ideally would be measured over each season to gauge how much levels vary. Aquifer pump tests provide information about hydraulic conductivity, storativity and transmissivity and the longer the tests are run, the farther from the well these properties are measured. Specific capacity tests can be used but are of short duration. Aquifer pump tests involve the use of monitoring wells in the area; the more wells, the better the test. Reporting of pump test data is not standardized and not all values or test conditions are relayed.

Activity 3: Evaluate the environmental barriers and engineering requirements to treat water to the standard required to recharge groundwater while avoiding unwanted effects in aquifers.
Using local and regional examples of successful recharge, identify best practices for ASR required to minimize risk to groundwater quality, human health and ecosystems.

ENRTF BUDGET: $50,000

Outcome	Completion Date
1. Compile relevant case studies; present and report (this meets appropriation requirement # 3 and 4)	*12/30/2019*
2. In selected aquifers, review geochemistry, water sources (this meets appropriation requirement # 3)	*9/30/2020*
3. Evaluate engineering and pre-treatment options required to minimize risk; report (this meets appropriation requirement # 3 and 4)	*12/30/2020*

First Update September 1, 2019
Activity #3 is underway.

Second Update March 1, 2020

- Case studies of domestic ASR projects in other states as well as an overview of ASR use throughout the world have been compiled. Additional research is underway and compilation continues. (Outcome #1)
- Collection and review of the geochemistry of Minnesota aquifers, as well as identifying the buckets from which recharge water could be sourced were started and continue. (Outcome #2)
- The timeline of activities for the tasks associated with Activity #3 were adjusted and spaced out across the months of 2019-2020. For example, the “compile info about typical water chemistry of water to be recharged” is slated for October 2020, while the “identify potential waters to use for recharge” is set to be completed in July 2020.
- Some of the tasks for the activity are occurring in parallel and simultaneously rather than in a series one after the other. For example, some research has been completed on source water chemistry compatibility with existing groundwater and geochemistry, particularly in regards to arsenic mobilization. This research is certainly more applicable to a number of the tasks slated for mid- to late-2020, but has seemed like the appropriate progression.

- Therefore, the case studies are still in progress, because much of the research designated as future tasks is extremely applicable to the case studies, and provides essential context for the results of these highlighted ASR projects.
- Part one of the summary of regulations surrounding ASR has been completed and shared with the researchers for Activity #4. (Outcomes #1 & #2 plus application to Activity 4, Outcome #2)

Third Update September 1, 2020

- **Outcome #1**
  - Case studies have been written, reviewed, and compiled. They have been shared with the team. Presentation of case studies has also been made to a U of MN research group on multiple occasions for feedback and visibility.
  - Case studies are being prepared for the final report.
- **Outcome #2**
  - Information on aquifer geochemistry, water chemistry, geology, and hydrogeology have been compiled to the extent that data is available. Some aquifers have less data than others, but that is not unexpected.
  - Source waters are in the process of being identified.
- **Outcome #3**
  - Engineering requirements for other Aquifer Storage and Recovery or Managed Aquifer Recharge projects have been evaluated through the case studies and independent research.
  - Arsenic, nitrate, and radionuclides appear to be the contaminants of primary concern with these processes.
  - Pre-treatment options for different source waters are being evaluated on the basis of technology, price, efficacy, and scale.
  - Matching the source water chemistry to the chemistry of the native groundwater will minimize contamination from the aquifer media.

Final Summary between project end (Dec 30, 2020) and February 15, 2021

(Addresses appropriation requirement (3) reviewing the approaches to manage recharge in geologically appropriate areas and (4) identifying policy options, costs, and barriers to recharging groundwater. See Final Report section 3, Parts A –F.)

Evaluation of the engineering requirements and environmental barriers are reported in three main stages. The first stage consists of the identification and evaluation of a source of water of ample quantity. If no source water can be provided in a quantity that would meet the expected demands of ASR, then it is not a suitable tool in that region. Secondly, source water chemistry and aquifer chemistry must be considered and potential reactions anticipated. For example, oxygenated water injected into an aquifer may react with the aquifer media or native groundwater, clogging pores. This would result in increasing inefficiency and require treatment prior to injection to reduce the oxygen content. Those treatment procedures would need to be factored into both the economic considerations and project design. Finally, the need and cost to treat the stored water to mitigate any negative changes that occurred during storage must be assessed. The presence of carcinogenic substances like arsenic would prompt the need for treatment.

For the City of Moorhead and the Buffalo aquifer, ASR could meet future water needs. There are three potential sources of water for injection; the Red River, the Buffalo River and effluent from the city's wastewater treatment plant. There is concern regarding the mobilization of arsenic and high concentrations of sulfate, manganese and overall hardness of the water. Treatment before injection and upon withdrawal would most likely need to be factored into project design.

Rochester, a city completely reliant on groundwater, primarily from the Jordan aquifer, has over 40 separate water supply wells and no centralized drinking water treatment plant. ASR could be used to enhance water

supply. The Zumbro River may not be a viable source because of volume concerns. However, treated effluent from the City's wastewater treatment plant would be of sufficient volume and it treated sufficiently could be injected through wells drilled specifically for this purpose. Groundwater in Olmsted County has high nitrates and ASR may serve to ameliorate nitrate contamination were it to begin to impact the city. The economics of treating the wastewater would need to be factored into the project design.

Washington County is completely reliant on groundwater. Woodbury, in the southern part of the County uses the Jordan aquifer. Here, ASR was shown to be a viable way to enhance the water supply, but it could also be deployed as a method for remediation of contaminated aquifers in the County. There are many water sources for injection. The county's eastern and southern borders are the St. Croix and Mississippi rivers, respectively. There are several wastewater treatment plants with suitable volumes. Contamination of the Jordan Aquifer with PFAS began near the 3M disposal sites but is now widespread in the southern part of the county. Contaminated water that is removed for treatment could be injected to conserve groundwater and flush out lower levels of contamination. This is one scenario that is currently being considered.

The fourth study area, the Straight River Groundwater Management Area (SRGWMA) is a surficial sand aquifer with irrigated agriculture as the primary water use. Although the City of Park Rapids lies at the downstream end, it does not provide a source of wastewater to recharge the aquifer, nor are there any other viable water sources for injection. Aquifer property data were collected for this surficial unconfined aquifer in the event that modeling be needed in the future, but injection capacity was not calculated for this aquifer as ASR is currently not a possibility.

Also as part of this activity, seven case studies of MAR-ASR systems were compiled and summarized to illuminate scenarios, both successful and not, that would inform permit and rule development in Minnesota.

Activity 4: Evaluate the economic and policy barriers to recharge.
Assess the economics for aquifer recharge and evaluate the existing policy barriers for aquifer recharge.

ENRTF BUDGET: $ 75,000

Outcomes	**Completion Date**
1. Determine economic conditions where recharge is feasible; present and report (this meets appropriation requirement # 5)	*6/30/2020*
2. Assess existing rule and statute changes to implement recharge; present and report (this meets appropriation requirement # 4)	*12/30/2020*

First Update September 1, 2019
Activity #4 is underway. Team has been examining alternatives to completing analysis and has identified the various economic and policy benchmarks that may be evaluated.

Second Update March 1, 2020

- The research graduate assistant originally scoped for this project was replaced with a researcher from the Water Resources Center and her efforts in background research began in January 2020 (Outcomes #1 & #2).
- Most significantly, additional expertise and capacity was secured for the project through the Center for Agriculture and Rural Development at Iowa State for the contribution and completion of Outcomes #1 & #2; *see previous project amendment*.

- Compilation of case studies on economic analysis have been and are continuing to be gathered and assessed. (Outcome #1)
- The work from Activity #3 (case studies) is being reviewed and integrated into tasks for Outcomes #1 & #2.

Third Update September 1, 2020

- Identified and reviewed relevant literature for economics and policy of MARs/ASR: Completed 100%
- Proposed and finalized outline for economic review: Completed 100%
- Economic report in progress: Completed 30%
- Proposed and finalized outline for policy review: Completed 100%
- Policy section report: 40%
- Reviewed, selected, and summarized 7 case studies: Complete 100%
- Full length case study write ups (Including Ankeny): 90%
- Shorter case study write ups (in-report): 50%

Final Summary between project end (Dec 30, 2020) and February 15, 2021

(Addresses appropriation requirement (4) identifying policy options, costs, and barriers to recharging groundwater and (5) assessing the economic returns of options for groundwater recharge. See final report section 4 and Section 5.)

Economics

The purpose of this activity was to evaluate and summarize the economic factors and possible economic evaluation models that could be deployed when considering an ASR project. The research into the types of economic analysis used in other MAR systems, and the benefits and costs, as well as how a project may specify those attributes lays the foundation for the more project-specific considerations that depend on the local physical and hydrological conditions, the recovered and storage water uses, and alternative water supply and treatment options.

In standard economic analysis, markets dictate the monetary value (i.e. price) of the provided goods. However, MAR projects provide water for later use. Moreover, MAR projects can have social and environmental benefits (non-market benefits) the monetary values of which are not provided by the existing markets. Costs of MARs include capital, operation, maintenance, and financing costs.

This review resulted in a recommendation to use cost-benefit analysis. The most robust and complete economic analysis uses both the market and non-market benefits and costs when possible. Cost-benefit analysis (CBA) is performed using the net present value methods, where the project-lifetime monetary benefits and costs are discounted to reflect the individual's time preference. The CBA could be extended by a risk or sensitivity analysis that considers the risk and uncertainties related to the CBA inputs.

Economic information was also gathered and summarized in the seven cases studies presented under activity #3.

Policy

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 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. Minnesota currently does not have primacy over Class V injection wells.

Minnesota 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. In addition, since ASR involves multiple processes of water transport, storage and pumping, multiple state agencies have jurisdiction over specific aspects of these activities or processes.

Policies and processes could be changed for the successful adaptation of ASR in Minnesota. Minnesota could apply for primacy for Class V injection wells from the USEPA, modify state well code, and develop a streamlined process for the involvement of multiple jurisdictional agencies.

Activity 5: Project management, stakeholder engagement, meeting facilitation, report and dissemination

ENRTF BUDGET: $ 75,000

Outcomes	**Completion Date**
1. Schedule and prepare for working meetings in which subgroups report out to full group (this meets appropriation requirement #1-5)	*9/30/2020*
2. Engage broad stakeholder group with relevant experience and public (this meets appropriation requirement #1, 4, 5)	*9/30/2020*
3. Publish and disseminate report to LCCMR and legislative committees, and stakeholders (this meets appropriation requirement # 1-5)	*12/30/2020*

First Update September 1, 2019

Activity 5 – Initial outreach to stakeholders has included presentation to the Interagency Groundwater Team and written project announcements through the Water Resources Minnegram newsletter and the Freshwater Society newsletter.

Second Update March 1, 2020

Project Management

- 10/11/2019 Meeting on Activity #4 and subcontracting CARD at Iowa State
- 11/15/2019 Meeting on Activity #4.
- 11/22/2019 Remote conference with Iowa State Card faculty on Activity #4
- 12/16 Meeting with Peter Kang, Tony Runkel, Etienne Bresciana, Raghwendra Shandilya on modeling needs and preliminary results
- 1/17/2020 Full research team meeting on all activities
- 1/31/20 Meeting with Tony Runkel, Brian Bohman and Galen Xiang

Stakeholder Engagement

- 9/3 Submitted ASR as an idea for 3M settlement for Woodbury
- 9/5/2019 Updated Interagency Groundwater Team (IAGT) on team and study area selection.
- 9/18/2019 Compiled a list of stakeholder contacts in each study area
- 9/18/2019 Initiated contact with DNR Groundwater Management Area leads in NE Metro GWMA (Dan Miller) and Straight River GWMA (Darrin Hoverson and Bob Guthrie), and DNR appropriations person in Moorehead, (Joshua Prososki)

- 10/14/2019 Attended Nibi Mahnomin conference at White Earth Reservation, held in conjunction with the U of M to meet appropriate contacts.
- 10/30/2019 Meeting with Dr. Bonnie Keeler and her group to understand impact of downscaled climate projections for water availability in Minnesota. https://keeler.umn.edu/portfolio/23-2/
- 11/7/2019 Included in weekly phone meeting of DNR modeling group working with 3M settlement money on groundwater model for Washington County. Briefed them on the concept of ASR, currently not being considered in any of their scenarios to provide safe drinking water for the area.
- 12/17/2019 Conversation with Ellen Considine, DNR Groundwater Technical Analysis Workgroup.
- 1/22/2020 Conversation with Moorhead Water Plant Operator, Kris Knutson
- 2/12/2020 Contact with Woodbury Water Plant Operator; Rochester Environmental & Regulatory Affairs Coordinator, Rochester Public Utilities Todd Osweiler and their Consultant, John Greer, Barr Engineering
- 2/26/2020 Updated bill sponsor, Rep. Sandell of Woodbury on status of work.

Third Update September 1, 2020

- 3/2 - 3/10, individual meetings with legislators: Bigham, Boe, Brand, Luek, Lee, Frenz, Fabian, Weber about various water issues
- 3/6/2020 met with Katie Pratt, interim EQB director
- 4/2/2020 IAGT update (outside of regular meeting)
- 4/23/2020 Iowa contacts identified, Ankeny project
- 5/5/2020 EQB small group meeting about State Water Plan
- 5/20/2020 Meeting with Keeler group, U of M, Humphrey School
- 7/10 Info on water use gathered from Harsh Anurag, Ng Hydrology/Hydrogeology Research Group, Earth and Environmental Sciences, U of M
- 8/4/2020 IAGT meeting update featuring policy issues
- 9/30/2020 Presentation to 3M settlement subgroup 1, drinking water planning
- 10/7/2020 Presentation to Washington County Water Consortium
- 11/9/2020 Presentation to water subcommittee in House
- 12/2/2020 Presentation at the U of M Dept. of Soil, Water and Climate seminar
- 12/9/2020 Conversation with bill sponsor, Rep. Sandell, Woodbury
- 12/11/2020 Conversation with water subcommittee staff, Jim Stark
- 12/21/2020 Conversation with water subcommittee co-chair P. Fischer
- 1/7/2021 Presentation to IAGT with recommendations
- 1/13/2021 technical presentation to MDH groundwater modeling group
- 1/14/2021 conversation with DNR management about aquifer properties database

Final Report between project end (Dec 30, 2020) and February 15, 2021

The project leadership developed an 18-month timeline for the project. Each activity had its own research team. Teams regularly convened with each other as work and findings complimented each activity. Engagement and communication with stakeholders was completed throughout the study duration. Meetings were held with multiple agencies including the Interagency Groundwater Team and multiple presentations were given to a broad list of stakeholders including to members of the Legislature, the Environmental Quality Board, MNDNR Groundwater Management Area leaderships, DNR Groundwater Technical Analysis Workgroup, Minnesota Dept. of Health groundwater staff and stakeholders in each of the study areas. Results of each activity were presented and discussed with each of these stakeholder groups during

the process. Draft results and recommendations were also presented and discussed in the final months of the project. In the end, stakeholder input was sought at the beginning, during and at the conclusion of the project. Engaging with stakeholders helped create support and kept individuals and agencies informed. More importantly, questions and concerns raised provided guidance to the project team and were incorporated and led to a more robust analysis of the suitability of ASR for Minnesota.

The Executive Summary has been sent to all interested stakeholders and a link to the full report with an expanded table of contents has been provided for deeper review. The final report has been submitted to the LCCMR and project recommendations introduced in bill language during the 2021 legislative session.

(See final Report Section 6 for details.)

IV. DISSEMINATION:

Description: Results of this work will be disseminated to stakeholders assembled for the project and to the legislature, public and interested professional community through various publications and local and regional presentations.

Publications may include: journal submissions derived from the contributions of the principle investigators; white paper distillation of results by Freshwater and intended for a legislative and stakeholder audience; Minnesota Geological Survey Report of Investigations with accompanying map.

Presentation venues may include: Water Resources Conference, St. Paul; interested Minnesota legislative committees, councils or commissions (e.g. Clean Water Council, Legislative Water Commission, LCCMR); local professional groups (e.g., Association of Professional Geologists, Minnesota Groundwater Association); Interagency Groundwater Team (members from all executive branch agencies with water authority); gatherings in affected communities or regions including regional agency (MPCA, DNR, MDA, MDH) and SWCD staff.

The Minnesota Environment and Natural Resources Trust Fund (ENRTF) will be acknowledged through use of the trust fund logo or attribution language on project print and electronic media, publications, signage, and other communications per the ENRTF Acknowledgement Guidelines.

First Update September 1, 2019
No direct dissemination, however initial outreach has occurred to stakeholders including a presentation to the Interagency Groundwater Team and written project announcements through the Water Resources Minnegram newsletter and the Freshwater Society newsletter.

Second Update March 1, 2020

- 9/11/2019 Proposed a session on the topic of Aquifer Storage and Recovery for the UCOWR meeting to be held in Minnesota in June, 2020.
- 11/6/2019 Presentation to Water Resources Center research staff and Extension Educators
- 11/8/2019 Presentation to NE Metro Groundwater Management Area team at their regular meeting
- 12/6/2019 Talk at Minnesota Association of Watershed Districts Annual Meeting
- 12/10/2019 Talk at Minnesota Association of Soil and Water Conservation Districts
- Mention of project include in the January Minnesota Water Policy newsletter from Jim Stark
- 2/13/2020 Submitted abstract for UCOWR meeting
- 2/19/2020 Submitted newsletter article for Breeze", a publication for the Minnesota Section of the American Water Works Association (MnAwwa).

Third Update September 1, 2020

Dissemination of preliminary findings and research work was completed as specified under activity #5 above. It included multiple presentations, meetings, and written materials given to stakeholders and interested agency representatives. Dissemination and communication includes meetings with Minnesota Legislators and the Interagency Groundwater Protection Team.

Final Summary between project end (Dec 30, 2020) and February 15, 2021
(See final Report Section 6 for details.)

The project and methodology was discussed and disseminated during the initial stages of the project and continued throughout the project duration.

Engagement and communication with stakeholders was completed throughout the study duration. Meetings were held with multiple agencies including the Interagency Groundwater Team and multiple presentations were given to a broad list of stakeholders including to members of the Legislature, the Environmental Quality Board, MNDNR Groundwater Management Area leaderships, DNR Groundwater Technical Analysis Workgroup, Minnesota Dept. of Health groundwater staff and stakeholders in each of the study areas. Results of each activity were presented and discussed with each of these stakeholder groups during the process. Draft results and recommendations were also presented and discussed in the final months of the project. In the end, stakeholder input was sought at the beginning, during and at the conclusion of the project. Engaging with stakeholders helped create support and kept individuals and agencies informed. More importantly, questions and concerns raised provided guidance to the project team and were incorporated and led to a more robust analysis of the suitability of ASR for Minnesota.

The Executive Summary has been sent to all interested stakeholders and a link to the full report with an expanded table of contents has been provided for deeper review. The final report has been submitted to the LCCMR and project recommendations introduced in bill language during the 2021 legislative session.

Multiple presentations were given during professional conferences and seminar opportunities. Multiple project updates were published through the Water Resources Center and the Freshwater Society regular electronic news updates.

Individual activity researchers and authors are currently writing manuscripts for professional publications.

The summary along with the full project report encompassing all the activities in excess of 150 pages will be posted on the project website https://www.wrc.umn.edu/banking-groundwater-managed-aquifer-recharge

V. ADDITIONAL BUDGET INFORMATION:

A. Personnel and Capital Expenditures

Explanation of Capital Expenditures Greater Than $5,000:

Explanation of Use of Classified Staff:

Total Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation:

Enter Total Estimated Personnel Hours for entire duration of project: 4,576	Divide total personnel hours by 2,080 hours in 1 yr = TOTAL FTE: 2.2

Total Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation:

Enter Total Estimated Contract Personnel Hours for entire duration of project: 1,087	Divide total contract hours by 2,080 hours in 1 yr = TOTAL FTE:.52

VI. PROJECT PARTNERS:

A. Partners outside of project manager's organization receiving ENRTF funding

- Tony Runkel and a Hydrologist, Minn. Geological Survey: *Aquifer and aquitard characterization*
- Bill Arnold, Faculty, CEGE, U of M: *Engineering analysis*
- Brian Bohman, Research Fellow, Freshwater Society and WRC: *Research*
- Lucia Levers, Research Associate, WRC: *Economic analysis*
- Carrie Jennings, Research and Policy Director, Freshwater Society: *Research, stakeholder engagement, facilitation*
- Peter Kang, Faculty, Earth Sciences: *Aquifer storage and recovery through wells*
- Center for Agricultural and Rural Development (CARD) at Iowa State University.

B. Partners outside of project manager's organization NOT receiving ENRTF funding

- Peter Boulay or Kenny Blumenfeld, State Climatologist, DNR: *Climate projections*
- Jeff Paddock or employee under Sandeep Burman, Hydrologist, MDH: *Health oversight*
- Greg Kruse or Joy Loughry, Groundwater Monitoring, DNR: *Groundwater monitoring and projections*
- Jared Troost, or Stephen M. Westenbroek, Hydrogeologists, USGS: *Water Balance projections*
- Tracy Twine, Faculty, Soil Water and Climate: *Climate projections*
- Ali El Hassan, Water Supply Planning, Metropolitan Council and Environmental Services: *Water supply projections*
- Chuck Regan, Modeler, MPCA: *Recharge partitioning (HSPF) models*

VII. LONG-TERM- IMPLEMENTATION AND FUNDING:

A critical component for the long-term implementation of this project is gaining input from a broad range of stakeholders to enhance the legitimacy of decisions, increase local buy-in, and build the capacity of those involved to understand issues and move to solutions. By providing for meaningful engagement, we can surface and work through differences and highlight the shared goals and strategies. This will lead to summary reports of stakeholder input that apply directly to the development of goals, objectives, and strategies for managing groundwater. Both the Water Resources Center and Freshwater have a long-term history in developing and providing solutions to water-resources challenges in the state. Their base funding will allow them to disseminate results and build the community capacity for implementation.

VIII. REPORTING REQUIREMENTS:

- Project status update reports will be submitted March 1 and September 1 each year of the project
- A final report and associated products will be submitted between December 30, 2020 and February 15, 2021.

IX. SEE ADDITIONAL WORK PLAN COMPONENTS:

A. Budget Spreadsheet
B. Visual Component or Map
C. Parcel List Spreadsheet--NA
D. Acquisition, Easements, and Restoration Requirements--NA
E. Research Addendum

Final Attachment A: Project Budget Spreadsheet
Environment and Natural Resources Trust Fund
M.L. 2020 Budget Spreadsheet
Legal Citation: M.L. 2019, 1st Special Session, Chapter 4, Article 2, subd. 04t
Project Manager: John Bilotta
Project Title: Managed Aquifer Recharge
Organization: University of Minnesota
Project Budget: $350,000
Project Length and Completion Date: 18 months, December 30, 2020
Today's Date: 2/8/2021

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET		Budget 8-20-2020	Spent through 12.30.2020	Balance
BUDGET ITEM				
Personnel (Wages and Benefits)		**$ 232,978**	**$ 232,789**	**$ 189**
Tony Runkel/hydrogeologist (70.50% salary, 29.5% benefits),9.533% FTE for 18 mo. 12943.63 + 3818.37		$ 16,762	$ 32,159	$ (15,397)
John Bilotta/project manager [To 11K from $15K] (64% salary,36 %benefits),8.154 %FTE for 1.5 years $25K for project management 11029.41 + 3970.59		$ 11,000	$ 6,785	$ 4,215
John Bilotta/policy analysis [To $7733 from $12,233] (64% salary, 36 %benefits),6.650 %FTE for 1.5 years ($35K for policy analysis*) $8994.85 salary + 3238.15 fringe		$ 7,733	$ 6,785	$ 948
Lucia Levers/economic analysis (64% salary, 36% benefits), 13.036%FTE for 1.5 years - $12,696.32 salary+ $4,570.68 fringe		$ 17,267	$ 9,436	$ 7,831
Jeff Peterson/economic analysis (64% salary, 36% benefits), 1.382% FTE each year for 1.5 years = 3676.47+1323.53		$ 5,000	$ 2,832	$ 2,168
Bob Tipping/hydrogeologist (70.50%salary, 29.5%benefits), 9.533%FTE for 18 mo. = 11889.58+3507.43		$ 15,397	$ -	$ 15,397
Eileen Kirby, Research I, WRC $10,000 = $xxx salary + xxx fringe Hourly $xx hour fringe 16.1% Total XX hours ~~W~~		$ 14,819	$ 29,897	$ (15,078)
Bill Arnold/engineering analysis (74%salary 36%benefits), 1.731%FTE Supervise U of MN CEGE research assistant, assist with data analysis and report writing for Year 1. 4264.71+1535.30		$ 5,800	$ 5,576	$ 224
CEGE Graduate Student Research Assistant, (56% salary, 44% benefits) 50% FTE for year 1 Perform review to determine water quality guidelines for recharge, potential engineering issues, and analysis of water quality effects on aquifers. Tuition = $20.50 hour @780 = $15,990.00 Salary 24298.02+Fringe 3911.98		$ 44,200	$ 44,318	$ (118)
Peter Kang/aquifer recharge capacity (75%salary 25%benefits), 7%FTE 3850.74+1386.26		$ 5,237	$ 6,086	$ (849)
Earth Sciences post doc salary (81% salary, 19% benefits), 95% FTE 72214.80 + 17548.20		$ 89,763	$ 88,914	$ 849
Professional/Technical/Service Contracts				
Center for Agricultural and Rural Development, Iowa State University for assistance Activity #4: Economic and policy analysis as specified in work plan.		**$ 44,519**	**$ 44,519**	**$ -**
Freshwater Society contracted services for project management, stakeholder engagement, facilitation, and research tasks as identified in proposal and work plan. Single-source, pre selected as project partner.		**$ 72,500**	**$ 72,500**	**$ -**
Travel expenses in Minnesota				
Parking expenses for non-University stakeholders, work group and subcommittee members at the University of Minnesota. Parking subject to all University policies.		**$ 3**	**$ 3**	$ -
Other				
COLUMN TOTAL		**$ 350,000**	**$ 349,811**	**$ 189**

SOURCE AND USE OF OTHER FUNDS CONTRIBUTED TO THE PROJECT	Status (secured or pending)		Spent	Balance
Non-State: Unrecovered 54% F/A minus tuition cost		$ 167,414	$ 180,600	$ (13,186)
State:			$ -	
In kind:			$ -	

Other ENRTF APPROPRIATIONS AWARDED IN THE LAST SIX YEARS	Amount legally obligated but not yet spent		Spent	Balance
			$ -	