2017 Project Abstract
For the Period Ending June 30, 2021

PROJECT TITLE: Assessment of Public Benefits of Protecting Source Water
PROJECT MANAGER: Bonnie Keeler
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FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: M.L. 2017, Chp. 96, Sec.2, Subd. 03b as extended by M.L. 2020, First Special Session, Chp. 4, Sec. 2

APPROPRIATION AMOUNT: $ 320,000
AMOUNT SPENT: $ 319,992
AMOUNT REMAINING: $ 8

Sound bite of Project Outcomes and Results
Source Water protection is associated with multiple economic, environmental, and social benefits. We created new spatially-explicit datasets representing multiple socio-economic benefits of source water protection for all 821 drinking water management units in Minnesota. Our work gives practitioners a more complete picture of the outcomes of source water protection statewide.

Overall Project Outcome and Results
The goal of the project was to collect and synthesize economic, social, and environmental data relevant to source water protection in Minnesota. We created new spatially-explicit datasets representing multiple socio-economic benefits of source water protection for all drinking water supply management areas in Minnesota. Project outcomes include:

1) Mapping land use change and land protection costs for all 821 drinking water management areas.
- Estimated trends in land use change in each DWSMA in order to identify potential threats to source water from increasing agricultural expansion or development.
- Obtained new spatial data based on estimated market values of hundreds of thousands of parcels in the state in order to quantify the opportunity costs of source water protection in each DWSMA.

2) Valuation of the multiple public benefits of land protection for clean water.
- Applied best-available estimates for drinking water treatment to calculate potential costs of contamination in each DWSMA as a function of population served.
- Implemented a methodology for estimating the potential health damages and associated monetary costs of drinking water contamination.
- Generated 19 spatially-explicit environmental benefit maps that can be used to assess the potential for co-benefits of protection or restoration in each DWSMA.

3) Assessing the equity implications of source water protection and community capacity to protect land and improve water quality.
- Developed a technique for linking source water protection areas to municipalities served, allowing us to relate census data and demographic characteristics to each DWSMA.
- Administered and analyzed data from a statewide survey of water values in order to identify perceived threats to water quality and preferences for different water-quality related values and uses.

- Completed a series of participatory water valuation exercises using a Q-sort methodology to understand stakeholder preferences for water-related expenditures and tradeoffs among water quality objectives.

Project Results Use and Dissemination

We presented our work at venues targeting academic and state agency audiences, and held meetings with specialists at MDH and the interagency GRAPS team exploring application of the work in MN agency work. We shared findings with state agencies including MPCA, MDH, DNR, and BWSR, along with external stakeholders and advocacy groups such as Freshwater Society and the Environmental Working Group. Our work contributed to multiple students' master's theses and is being written up for publication in a peer-reviewed journal. Our work is summarized in a report (available on our website) and includes appendices with data useful for further analysis.

Environment and Natural Resources Trust Fund (ENRTF)
M.L. 2017 LCCMR Work Plan Final Report

Date of Submission: Nov 11, 2021

Date of Next Status Update Report: Final Report

Date of Work Plan Approval: 06/07/2017

Project Completion Date: June 30, **2021**

PROJECT TITLE: Assessment of Public Benefits of Protecting Source Water

Project Manager: Bonnie Keeler

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Location: Statewide

Total ENRTF Project Budget:		
	ENRTF Appropriation:	**$320,000**
	Amount Spent:	**$319,992**
	Balance:	**$8**

Legal Citation: M.L. 2017, Chp. 96, Sec.2, Subd. 03b as extended by M.L. 2020, First Special Session, Chp. 4, Sec. 2

Appropriation Language:

Assessment of Public Benefits of Protecting Source Water

$320,000 the first year is from the trust fund to the Board of Regents of the University of Minnesota to map and quantify source water risks, determine ecosystem service valuation of clean water, and provide analyses of equity and community capacity to improve decisions about the protection and management of groundwater and surface water. This appropriation is available until June 30, 2020, by which time the project must be completed and final products delivered.

M.L. 2020 - Sec. 2. ENVIRONMENT AND NATURAL RESOURCES TRUST FUND; EXTENSIONS. [to June 30, 2021]

I. PROJECT TITLE: What are the public benefits of protecting sourcewater?

II. PROJECT STATEMENT:

Access to clean safe water is essential for health, recreation, and economic development in Minnesota. However, many of our state's most pressing water quality problems remain unsolved. More than 40% of our lakes and rivers are rated as "impaired," and a growing number of households and communities face rising costs and health risks because of contaminated drinking water. If we hope to reverse current trends of water quality decline and preserve the valuable ecosystem services provided by clean water, we need to change how we account for the value of our water resources. Current systematic *undervaluation* of water is contributing to the overuse of water and degradation of water quality in Minnesota and elsewhere.

The emphasis of the proposed work is on the value of sourcewater in Minnesota - the surface and groundwater resources that supply households and communities with their drinking water. Approximately 75% of Minnesota households rely on groundwater for household use and the majority of the land area in sourcewater areas is under private ownership. Land use and management actions on these lands that increase nutrients and other contaminants can affect the health and welfare of millions of Minnesotans. There are successful examples of private and public partnerships that have worked together to protect sourcewater and enhance valuable ecosystem services while supporting agricultural and rural economic development (e.g. Worthington Wells Wildlife Management Area). At the same time, other communities in Minnesota are facing known or unknown threats to their water supply with consequences for health and rising treatment costs.

Agency leaders and Gov. Dayton have identified an urgent need to map and quantify the risks facing sourcewater areas in Minnesota, better articulate the ***true value of clean water***, and develop practical approaches that enhance community capacity to protect sourcewater and ensure safe and equitable access to clean water for all Minnesotans. This project responds to that need with investments in three activities:

1) **Mapping land use change and risks to clean water for all 584 drinking water management areas.**
2) **Valuation of the multiple public benefits of land protection for clean water.**
3) **Assessing the equity implications of sourcewater protection and community capacity to protect land and improve water quality.**

These activities highlight potential risks and opportunities to protect water quality and provide multiple public benefits, identify financial practices or incentive programs that protect the value of clean water, and build capacity among citizens and decision-makers to take action in sourcewater protection areas to improve water quality and realize additional public benefits from land protection.

The proposed work builds on the LCCMR-funded project "Understanding Water Scarcity, Threats, and Values to Improve Management" awarded in 2015 to PI Keeler. The water scarcity project will assess how changes in precipitation and temperature interact with alternative scenarios of water demand to predict where there is likely to be water depletion in the future. These scenarios of water quantity will be used as inputs into the sourcewater protection analysis proposed here. Whereas the water scarcity project emphasizes water quantity, this project emphasizes water quality. In Minnesota, quantity and quality are related and this project will benefit from data on trends in both quality and quantity to estimate the risks and opportunities for sourcewater protection.

The project will focus on the 1.22 million acres in Minnesota designated as sourcewater protection areas, including both groundwater and surface water catchments. Outcomes of the work include maps and risk assessments for each drinking water management area, including evaluating current assumptions about travel time, threats and delineation of management zones. Additional products include spatially-explicit information about the benefits and costs of changes in water quality and distribution of costs to Minnesotans and assessments and recommendations for how to enhance community capacity to protect sourcewater.

III. OVERALL PROJECT STATUS UPDATES:

Project Status as of August 3, 2018:
Due to staffing shortages, we have not been able to hire the research capacity needed to move forward with project deliverables at our anticipated pace. Less than 15% of the project total budget has been spent in the first year of the work plan. We are in the process of transferring GIS capacity to this project to complete Activity 1. Currently no progress has been made to this activity as no funds have been allocated to the task.

Work on Activity 2 and 3 are progressing as planned. We assembled biophysical, social and demographic data on sourcewater vulnerability, risk, and impacts to ecosystem services. We completed and distributed a statewide survey to Minnesota households to better understand values and perceptions about water risks and identify regions of high community capacity to adopt sourcewater protection activities.

Next steps include integrating the biophysical data collected in Activity 2. with updated risk modeling and analysis and follow-up engagements related to the survey.

Amendment request as of August 20, 2018:
To extend the project end date to June 30, 2020 and adjust completion dates for Activity 1. This request is being made given an almost 12 month delay in being able to staff the project to full capacity. We have now brought staff onto this project and expect to make steady progress on Activity 1. There is no change to the outcomes or activities, rather a shift in timeline given a shortage in staff capacity during 2017-2018.

Amendment approved by LCCMR by August 8, 2018.

Amendment request as of February 28, 2019:
Our records show that we have $13,400 remaining from general supplies, focus groups, and travel expenses combined, which was originally budgeted to our statewide survey effort. Since we were able to co-produce and co-administer the Minnesota Water Values survey and focus groups with CWC funds, those remaining funds are not needed. Instead, we would like to re-budget the full amount ($13,400) toward personnel (wages and benefits) to support staff in Activity 3. We will need staff time to analyze and report on the data as well as to plan and conduct focus groups. Below are the budget changes made stating the sources and budget transferred to personnel.

- $8,000 from “Supplies” was moved to “Personnel”.
- $4,000 from “Other” (Focus groups) was moved to “Personnel”.
- $1,400 from “Travel expenses in Minnesota” was moved to “Personnel”.

Amendment Approved by LCCMR April 17, 2019.

Project status as of February 28, 2019:
Our initial analysis of the spatial data associated with sourcewater areas was completed and presented to MDH for their feedback. Our meeting with MDH yielded several new lines of inquiry, which we will be incorporating into our analysis. For example, we will identify what authorities have jurisdiction over source water areas, expand our database with information on co-benefits such as solar and pollinators and estimate the cost of protection and the human health costs of failing to protect source drinking water. We will incorporate this feedback and continue to refine our assessment of threats to sourcewater and co-benefits of protection.

We have begun analyzing data from the 1,498 responses to the statewide survey on resident water values, activities, and investment priorities. We have created a first round of data summary tables and presented them to MDH staff. The threats and vulnerabilities identified in Activity 1 will be used to target sourcewater areas and

communities “at risk” in which to carry out focus groups to further our research on community capacity to protect water sources. We have presented preliminary survey findings to the Clean Water Council.

Project Status as of August 1, 2019:
Our analysis of the public benefits of protecting source water is progressing on several fronts simultaneously. A recently hired senior scientist is enabling us to rapidly generate estimates of the probability of land use change throughout the state. Predicting changes of land that will influence the surrounding drinking water supply is essential for preventing threats before they occur and to ensure resources are prioritized on the areas with the most urgent threats.

We also made significant progress in linking consumption of drinking water with elevated nitrate levels to impacts on human health. Our model now links well-level nitrate data to municipality level changes in the incidence of three types of cancer. We can then estimate human health costs using the standard value of a statistical life approach, and compare that to the cost of interventions. We also made progress assessing public benefits beyond human health. In particular, we demonstrated that data and methods we developed to assess the environmental benefits of any parcel in MN can be used to identify parcels with known co-benefits of drinking water protection and pheasant habitat. Now that we have demonstrated we can identify parcels with known co-benefits, we are sharing our data and methods with Pheasants Forever so they can identify promising parcels they are not aware of yet.

Our analysis on the MN value of water survey continued, including the completion of a master’s thesis titled “Communicating risk and increasing civic engagement in water protection in Minnesota” (included as an attachment to this update). We are working to combine insights from the survey with demographic data on MN communities and biophysical data on the threats to their drinking water. These data sets will inform the selection of vulnerable communities for a follow up focus group.

Project Status as of February 19, 2020:
As we enter the final 6 months of this project, we are turning from data collection and analysis to synthesis and communication. Under activity 1 we have created a new statewide risk of conversion metric. While we will only be assessing risk within sourcewater protection areas, this new dataset has applications to any conservation activity in the state. We are continuing to leverage graduate student effort to add more samples to the training dataset, and plan to publish and make available the resulting data products.

Due to shared objectives on a similar project for the Lessard-Sams Outdoor Heritage Council, we were able to leverage a collaboration with the Natural Resources Research Institute to create new datasets on habitat quality for a variety of bird and mammal species and include these in our analysis for sourcewater protection analysis. Similarly, we were able to include sourcewater protection in the analysis of their programs, furthering the consideration of sourcewater protection co-benefits to programs beyond the scope of this project.

We also made progress in quantifying the cost of protection. We recently obtained new and detailed data on estimated market values of hundreds of thousands of parcels in the state. While the data doesn’t provide complete statewide coverages, it is a large improvement over the township-level averages we planned to use. Land value data is critical for assessing the tradeoffs between the environmental and health benefits of sourcewater protection, and the lost productivity of protected land.

While our focus was predominantly on activities 1 and 2, we continued to collect data while presenting our work at various venues throughout the state. Using a simple instrument called ‘Q-sort’ we are collecting data on how groups value a suite of benefits related to water. The results often differ from traditional economic assessments and provide a valuable point of comparison when we integrate the costs and benefits of sourcewater protection.

Project extended to June 30, 2021 by LCCMR 6/18/20 as a result of M.L. 2020, First Special Session, Chp. 4, Sec. 2, legislative extension criteria being met.

Project Status as of August 1, 2020:
As is the case with nearly everything, the covid-19 pandemic caused some disruption to work on this project. Fortunately, the major components of the project were able to be done remotely. It is only the focus group activity which will not proceed as originally planned. After further review of a statewide value of water survey and additional 'Q-sort' exercises completed before the pandemic, we plan to use these instruments to address our original questions on how sub-groups value and consider risks to water. Our typical dissemination activities through presentations to practitioners and stakeholders were initially disrupted, but quickly transitioned to similar activities in an online format.

Work continued on the drinking water supply management area risk and environmental co-benefit model development. We completed 21 environmental benefit maps that will be used to assess the potential for co-benefits in each sourcewater protection area. We also completed refinements to techniques for linking sourcewater protection areas to all municipalities served, including both the primary public water supply and consecutive connections to typically smaller municipalities that purchase that water.

Finally, we have begun drafting a manuscript that will synthesize all of the components of this, and other, research. We have added recent developments in methodology from valuing health costs associated with elevated drinking water nitrate to our modeling framework and will include the results for Minnesota in the upcoming manuscript. As the funds from this project are now almost entirely spent, we will not be allocating effort to it directly any more. However, we are delaying closing out the project because a manuscript synthesizing the findings of this work is continuing under the support of other projects. We will continue to update the work plan and overall project outcomes with the data and figures developed for the manuscript.

Project Status as of February 12, 2021:
In this period our work was focused on two main areas. First, we built the framework for attributing cases of disease to drinking water nitrate contamination. This entailed implementing methods recently developed and applied in Wisconsin (Mathewson 2020), and collecting data on incidences of disease in Minnesota, and the association of those diseases with drinking water nitrate contamination. We have not yet linked these cases to values of statistical life methodologies, but anticipate completing that this month. The second major area is the drafting of a manuscript that synthesizes the results from our analysis of health impacts from drinking water nitrate from an equity standpoint, informed by our value of water survey. We have submitted an abstract for this paper for an upcoming conference.

While we are focused on a peer-reviewed publication in the short term, we are cognizant that scientific publications are not always the most useful format for the public, or for the specific questions of state agencies. Our dissemination plan includes datasets and communications that are tailored to state agencies and the public, respectively.

Overall Project Outcomes and Results:

The goal of the project was to collect and synthesize economic, social, and environmental data relevant to source water protection in Minnesota. We created new spatially-explicit datasets representing multiple socio-economic benefits of source water protection for all drinking water supply management areas in Minnesota. Project outcomes include:

1) Mapping land use change and land protection costs for all 821 drinking water management areas.

- Estimated trends in land use change in each DWSMA in order to identify potential threats to source water from increasing agricultural expansion or development.

- Obtained new spatial data based on estimated market values of hundreds of thousands of parcels in the state in order to quantify the opportunity costs of source water protection in each DWSMA.

2) Valuation of the multiple public benefits of land protection for clean water.

- Applied best-available estimates for drinking water treatment to calculate potential costs of contamination in each DWSMA as a function of population served.
- Implemented a methodology for estimating the potential health damages and associated monetary costs of drinking water contamination.
- Generated 19 spatially-explicit environmental benefit maps that can be used to assess the potential for co-benefits of protection or restoration in each DWSMA.

3) Assessing the equity implications of source water protection and community capacity to protect land and improve water quality.

- Developed a technique for linking source water protection areas to municipalities served, allowing us to relate census data and demographic characteristics to each DWSMA.
- Administered and analyzed data from a statewide survey of water values in order to identify perceived threats to water quality and preferences for different water-quality related values and uses.
- Completed a series of participatory water valuation exercises using a Q-sort methodology to understand stakeholder preferences for water-related expenditures and tradeoffs among water quality objectives.

IV. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1: Mapping land use change and risks to clean water

Description: In partnership with the Minnesota Department of Health (MDH), we will conduct a comprehensive risk assessment for all 584 drinking water supply management areas in Minnesota. We will improve and expand upon MDH's current approach to risk assessment by including new data on land use change and other potential threats to water quality or quantity such as population growth and expected changes in precipitation patterns. The work on land use change will build upon existing tools and approaches developed by the Natural Capital Project. We will adapt these tools to Minnesota and run alternative scenarios of the extent and intensity of future land use change in each sourcewater area. We will also assess how changing assumptions about aquifer vulnerability class and travel time of pollutants currently used by MDH affect the acreage of lands needing protection and potential costs of treatment or protection. Finally, we will account for uncertainty and develop management-relevant storylines that reflect a range of plausible futures for Minnesota sourcewater areas and communities. These activities will expand upon and enhance tools used by MDH to map sourcewater areas and identify risks to water quality.

Summary Budget Information for Activity 1:

ENRTF Budget:	**$ 104,000**
Amount Spent:	**$ 104,000**
Balance:	**$ 0**

Outcome	Completion Date
1. New risk maps and data on future land use trends and threats in each of the 584-sourcewater areas.	January 2019
2. Evaluation of current MDH approaches to assessing sourcewater vulnerability and recommendations for improved management and delineation of management areas. For example, we will evaluate how MDH estimates the travel time for pollutants and produce updated maps of sourcewater protection areas based on different assumptions of travel time and geologic vulnerability.	June 2019

Activity 1. Status as of August 3, 2018:

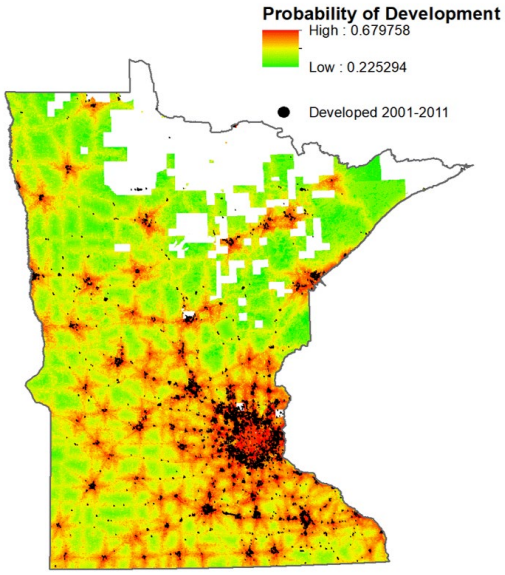
No budget has yet been allocated to this activity. Research staff working on other projects have now been assigned to this task and their efforts will be reflected in the next status update.

Activity 1. Status as of February 28, 2019:
The research under Activity 1. consists of an iterative process of compiling and analyzing data on the potential threats to source water areas, and soliciting feedback from MDH on how threats are considered in their vulnerability assessments. We have completed the first iteration of this process by constructing a database that contains changes in land cover data over the last 10 years for all source water areas. The database also includes information on the proportion of publicly held versus private land, environmental benefit scores created by previous ENRTF-funded research, and threat metrics derived from trends in each agricultural area, undeveloped land, and geologic vulnerability. In addition, we have also begun to explore the possibility for including demographic data from census data; however, further manual processing of the data is necessary to achieve a one-to-one match between census data and sourcewater areas.
We presented this database to senior MDH staff to solicit their feedback on the approach we took to analyze the data we compiled and to learn more about their existing data and approaches. Feedback from the MDH included the suggestion to expand our analysis to include data on the different jurisdictional authorities represented in sourcewater areas and add a proxy for land value. In addition, we learned that income is the only demographic data being explored by MDH and that it would be helpful to their assessments to incorporate a larger set of demographic data. Working closely with MDH, out team will work to integrate demographic data into our dataset in a way that aids with the assessment of sourcewater areas. Finally, we learned that the current assumptions around travel time reflect the difficulties of protection at large scales. Further analysis will explore the trade-offs associated with manageable planning efforts and capture threats beyond the current travel time assumptions.
We will continue to refine our analysis and metrics of threats while communicating with the MDH and expanding our understand of how assessment and prioritization of sourcewater areas happens at regional levels where MDH works.

Activity 1 Status as of August 1, 2019:
Recently hired senior scientist Christina Locke developed a prototype statewide risk of development metric. The metric assesses which drinking water management supply areas are more likely to experience stressors to water quality from future land use changes. Our work improves upon existing threat prioritization used by MDH and other state agencies by considering likely future changes rather than a snapshot of what the risks and vulnerabilities exist currently. State agencies and local governments can then use more cost effective protective actions, rather than reacting to threats after groundwater quality is already degraded.

The approach we developed uses a logistic regression model to associate variables such as slope, distance to water bodies, distance to roads, soil type, land value, distance to urban areas, and others with observed recent land use change. We then use this model to identify other areas of the state with characteristics associated recent changes. A model for urban expansion is complete and an agriculture expansion model is under development. Agriculture expansion is especially difficult to model because satellite based data often struggle to differentiate between natural grass, pasture, and fallow cropland, thus providing misleading training data. We are addressing this by manually reviewing historical aerial imagery to create better training data.

Prototype probability of development metric:

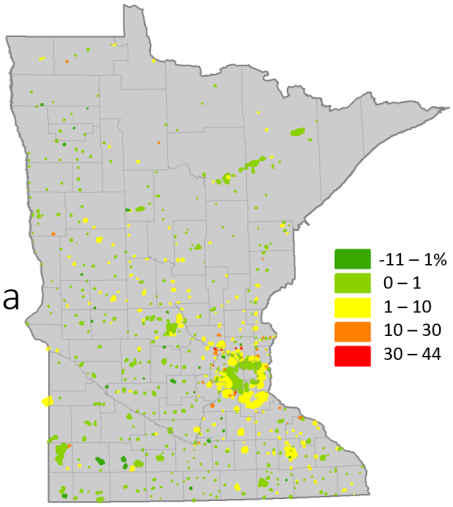


Activity 1 Status as of February 19, 2020:

A first round of manual review of historical aerial imagery and a statewide model for land conversion to cropland is now complete. Along with the previously completed model for urban expansion, we can now prioritize drinking water management supply areas (DWSMAs) based on risk of land conversion to agricultural and urban uses.

We also provided a summary to MDH on land-use change trends over the period of 2001 – 2016. MDH staff were mostly interested in how much land has changed between unprotected (urban development and agriculture) and protected (vegetated – not hay or grass) status over time. We found there to be 9,000 fewer acres of protected land and 30,000 more acres of unprotected land in DWSMAs over this time period, representing 0.7% and 2.3% of the total area in DWSMAs, respectively. The DWSMAs where most land changed to "unprotected" status were also some of the largest DWSMAs, like Hastings, Rochester Central, and Shakopee. See below for figure summarizing the proportion of developed or agricultural land uses.

Change in area of unprotected land 2001 – 2016 as % of DWSMA area



Activity 1 Status as of August 1, 2020:

In this period we updated the social cost of nitrogen methods with those that have been developed in the last two years. In addition to existing methods for bladder, colorectal and kidney cancers, new advancements

include methodologies for estimating increases in very preterm and very low weight births, neural tube defects, miscarriages, and two types of cancer associated with elevated nitrate in drinking water.

The new methods required not just population served by a given water supply, but also demographic data used to identify sub-populations at elevated risk. In the past we have established a one to one link between major municipality census data and water suppliers. However, distribution is often more complex, with small communities buying water from larger suppliers through consecutive connections. Using data on consecutive connections from MDH, we identified the population and demographic characteristics of communities that buy their water from a larger municipal supply.

These methodological advancements enable us to integrate data on risks from land use change with a wide range of research on the health impacts of elevated drinking water nitrate.

Activity 1 Status as of February 12, 2021:
Now that we have linked demographic information to municipal public water supplies in the state, the next step is to calculate the nitrate-attributable cases of diseases associated with elevated nitrate levels. We continued to build out the methods developed for Wisconsin in Mathewson (2020)[1] and apply them to Minnesota data. Specifically, we have been collecting the relative risk ratios from studies that examine links between drinking water nitrate exposure and health impacts. We also compiled disease incidence rates at the county level from the Minnesota Department of Health. These baseline rates are important for being able to distinguish how many cases of disease are in the population regardless of nitrate exposure, and the number of additional cases.

For identifying risks to human health at the DWSMA level, our focus is on the five cancers and three types of birth defects mentioned in the last update because they have strong links to drinking water nitrate and public health data is available for them. Our literature review also includes approximately 50 other diseases which can be included if there is sufficient data on baseline incidence in Minnesota and sufficient sample sizes in the literature.

Final Report Summary:
The outcomes of Activity 1 are documented in section 1 of our synthesis report. We also note that previous status updates under this activity have described estimating health costs associated with exposure to drinking water nitrate. We carried out that research, but believe it is most appropriate to discuss it in the context of other valuation analyses in section 2 of our synthesis report, and Activity 2 of this work plan. The outcomes of Activity 1 are summarized here as follows:

1.) Summarize past land use change trends and project risk of development in all DWSMAs

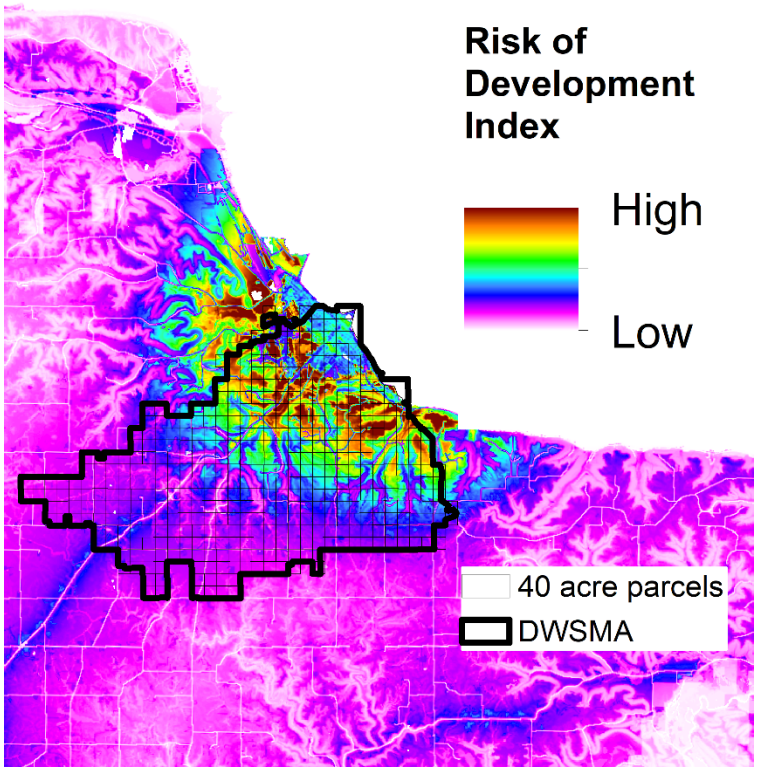
Outcomes: We applied two land use change analyses to capture threats from both observed and potential land use change. We used best-available data from the National Land Cover Dataset (NLCD) to quantify land use change trends in every DWSMA from 2001-2019 (Figures 2 and 3, Appendix B). We created Python scripts capable of analyzing DWSMAs independently to allow for assessment of land use changes in overlapping DWSMA over time, an approach not possible using traditional tools like ArcGIS. We created a spreadsheet with filter, aggregation, and visualization functions to allow users to calculate statistics and visualize land use change trends for individual, or collections of DWSMAs without specialized software.

We also created a risk of development layer (described in the August 2019 update above) to capture the threat of future changes. Because the layer is 30m resolution and DWSMAs are typically very large, we opted not to

[1] Mathewson, P.D., Evans, S., Byrnes, T., Joos, A., Naidenko, O. V., 2020. Health and economic impact of nitrate pollution in drinking water: a Wisconsin case study. Environ. Monit. Assess. 192. https://doi.org/10.1007/s10661-020-08652-0

average the results at the DWSMA level because it can hide variability between high and low risk areas. Instead, we only provide average risk of development scores at the parcel level in Appendix C. We also created a summary of risk of development across all DWSMAs using a simplified version of our risk layer and visualized our results in figures 9 and 10 or our synthesis report.

An example of our risk of development map is included below. The thick black line is a DWSMA. Averaging the risk index across the entire DWSMA would include both very high and very low values, thus producing a misleading average. The small black squares are 40-acre public land survey parcels. We aggregated most of our data to these units for several reasons. They are small enough that averaging across them is unlikely to produce misleading results, tabular data is easier for practitioners to work with than raster data, and the parcels tend to follow roads, natural features, and existing ownership boundaries. These attributes make them a useful level of aggregation for analyzing our data while still being relevant and familiar for land protection activities.



The risk index is calculated statewide, but because of missing data in the national soil database (gSSURGO) there are limited areas of no data in north east MN. Approximately 12 DWSMAs out of 821 fall in the no data area, but we believe the predictive value of the variables in the gSSURGO data is worth the tradeoff of not being able to be applied in these areas.

Executive summary: On average, land use in source water protection areas remained relatively stable from 2001 to 2019, with built area increasing by 12% while natural vegetation and agricultural land use areas declined by 5% and 8%, respectively. Although the area covered by agriculture declined, agriculture is still the dominant land cover, covering 49% of areas with high or very high vulnerability to contamination. Most DWSMAs had little change in land cover over the last two decades, but the overall trend was an increase in developed land covers. Some smaller DWSMAs, such as Willow River, Minnetrista Central, and Woodland MHP, had a more than 20 percentage point in built area in 18 years. DWSMAs experiencing increases of built and/or agricultural land covers face more potential threats to water quality within their water supply.

2.) Estimate the opportunity cost of protection activities by mapping land value in all DWSMAs

Outcomes: We estimated the opportunity cost of protecting all of the non-built land in DWSMAs. Opportunity costs reflect lost revenue from agriculture or development as a result of land acquisition or the adoption of best management practices that reduce yields or take lands out of production. We estimated the value of unprotected land using a novel dataset (Nolte 2020) that improves on previous underestimates of opportunity costs of conservation by using machine learning techniques to harmonize tax assessor and other datasets nationwide. We summarized the total value of the land in all of the MDH DWSMA vulnerability classes in Table 2 of our synthesis report. We also visualized this data by showing the proportion of land that could be protected if acquired in order from least to most expensive in Figures 6 and 7.

Executive summary: We used a novel dataset of land value to calculate the opportunity cost of protecting unbuilt land in source water areas. Our analysis demonstrates the high opportunity cost of acquiring land for protecting source water. The total area of unprotected and unbuilt land in source water protection areas is over 634,000 acres, with a value of $8.8 billion. Targeting a subset of the lowest value, highest vulnerability land reduces the cost substantially, but the opportunity cost remains high. Protecting 15% of this subset would cost over $100 million, and would produce inequitable protection that excludes high land value DWSMAs. Our addition of land value data at the DWSMA and parcel levels provides insights on the opportunity costs of protection that will help practitioners prioritize projects with a high return on investment.

3. Evaluation of current MDH approaches to assessing sourcewater vulnerability

Our original plan was to examine sourcewater protection costs and co-benefits in a buffer of DWSMAs. We discussed this activity with the MDH because they are responsible for the groundwater flow modeling that is required to delineate the 10-year path of travel the defines a DWSMA. Their feedback was twofold. First, a buffer does not represent groundwater flow well in many locations. Each DWSMA is delineated individually by an expert groundwater modeler because of the complexity of the flows. Using a buffer approach would not add value to MDH because it is not in line with their established practices. Second, they indicated that a 10-year path of travel is their preferred analysis timeframe because of the balance between immediate impact and long-term planning. Going beyond 10 years adds uncertainty and is a larger scale than can be effectively managed by public water supply planning efforts. Our analysis indicated that a 10-year path of travel based DWSMA already contains land value exceeding 8 billion dollars and high environmental benefits scores across all our metrics. We determined expanding this would run contrary to the guidance of MDH and would detract from the analysis of costs and benefits of protection within MDH's defined DWSMAs.

ACTIVITY 2: Valuation of the multiple public benefits of clean water

Description: By not fully accounting for the value of clean water and land protection, we risk undervaluing and mismanaging our natural capital. We will build on ten years of experience at the Natural Capital Project to advance our understanding of the multiple public benefits or "ecosystem services" associated with land protection or restoration with a focus on the value of clean water.

The proposed work will consist of three phases of analysis. First, we will assemble a dataset on avoided treatment costs for nitrate and other contaminants based on data provided by MDH and a comprehensive literature review from national surveys and datasets. We will combine treatment cost data with information on the potential economic impacts of exposure to nitrate and other contaminants. Second, we will estimate the economic value of agricultural production in each sourcewater area and other land uses in order to estimate the "opportunity costs" of land protection. Opportunity costs reflect lost revenue from agriculture or development as a result of land acquisition or the adoption of best management practices that reduce yields or take lands out of production. Third, we will quantify other valuable public benefits related to recreation and tourism, cultural identity, wildlife and aquatic habitat, and reduced soil loss and erosion. We will not engage in new data collection to assess these services, but rather rely on literature estimates and previous approaches developed by

the Natural Capital Project and elsewhere to estimate these values and how they compare to the values of water quality benefits. These activities will help to illuminate the true value of clean water and identify how this information can inform decisions ranging from payment programs or incentive schemes to evaluating the return on investment in land protection.

Summary Budget Information for Activity 2:

ENRTF Budget:	**$ 107,705**
Amount Spent:	**$ 107,697**
Balance:	**$ 8**

Outcome	Completion Date
1. Collection, visualization, and dissemination of ecosystem services valuation data for each sourcewater area (agricultural production, agricultural management practices, treatment costs, health, property values, recreation and tourism, cultural identity, habitat)	January 2018
2. Data and summary reports on the costs and public benefits associated with clean water and land protection and recommendations for mainstreaming these values in policy and agency decision making	December 2018

Activity 2 Status as of August 3, 2018:
As described in this activity, we are working on the collection and visualization of ecosystem services valuation data for each drinking water supply management area. We worked with MDH to obtain boundaries for each sourcewater area and have begun analyses to link each area to population and demographic data. We have assembled data on agricultural production, treatment costs, and the potential health impacts of exposure to nitrate. We are working with MDH to identify other contaminants of concern and track down data to quantify risks and potential impacts of exposure in sourcewater.

The first product of this work is a storymap based on spatial data collection and interviews with public health officials and rural water suppliers. For a copy of the blog and associated story map, see the link here: http://environment.umn.edu/discovery/natural-capital-project/integrative-approach-protecting-minnesotas-drinking-water/

We have met with MDH several times to better understand their needs for data and economic assessments of sourcewater costs and public benefits associated with clean water and land protection and recommendations for mainstreaming these values in policy and agency decision making. These insights are informing the literature and data collection tasks that are ongoing as part of this activity.

Activity 2 Status as of February 28, 2019:
Our meeting with MDH also revealed a strong interest in better accounting for the co-benefits of source water protection. Our preliminary work on this consisted of compiling existing data sources and creating an all new a dataset that is the first to estimate the number of people served by groundwater and surface water per public water supply (PWS) and on a statewide basis. Creating this dataset involved collecting information from 513 individual sourcewater assessments and contacting major water suppliers in the state that provide a blend of ground and surface water in order to determine the right assumptions about the proportions of people dependent on ground water versus surface water.

We have also identified lakes and trout streams that are hot spots for visitation using social media data, compiled MPCA's SPARROW modeling of nutrient export, and incorporated previous ENRTF-funded work on environmental benefits of conservation easements. Going forward we will analyze this information on a sourcewater area basis, so we can identify the unique co-benefits found in each sourcewater area. The data we

are compiling will also allow us to identify the hotspots for environmental benefits within sourcewater areas so that planners can maximize the public benefits of their protection activities.

Activity 2 Status as of August 1, 2019:
We made extensive progress in linking the presence of nitrate in drinking water to changes in life expectancy based on previous studies. The code we are developing starts by aggregating records for individual wells up to the PWS and DWSMA level. This novel step makes it possible to link wells with census data to determine the demographics and of the communities with elevated nitrate levels. Our code then calculates the number people served by DWSMAs where the nitrate level is above previously studied thresholds, but typically below the Federal standard, giving use the population that would be affected by interventions which reduce nitrate loading in the groundwater.

Next, we use published factors that associate consumption of water with elevated nitrate levels with three types of cancer. Exposure increases the likelihood of an individual contracting these diseases by relatively small amount, but over the entire population, mortality increases with exposure. We use the value of a statistical life to value these marginal changes. We are working to compare the cost to human health to the cost and efficacy of various interventions.

In addition to refining estimates of human health impacts, we are also quantifying the other environmental benefits of interventions used to protect drinking water. A successful example of this type is a partnership between Pheasants Forever and the state to protect the city's water supply and restore pheasant habitat. We met with MDH and Pheasants Forever to discuss what made that partnership work, and how we can identify similar opportunities. In preparation of the meeting, we adapted a previous ENRTF sponsored research project, the Parcel Environmental Benefit Assessment Tool (pebat.umn.edu), to allow us to analyze all of the privately held undeveloped parcels in the state for both drinking water protection and pheasant habitat benefits. Using a series of queries, we were able to quickly identify the parcels that were included in the Worthington Wells project, as well as several dozen others elsewhere in the state that offered similar benefits. We will provide these and other data products to Pheasants Forever so they can better target multiple benefits in their acquisitions.

Activity 2 Status as of February 19, 2020:
We have created several new environmental benefit metrics, including bird species of greatest conservation need, upland game birds, and waterfowl game. We now have 14 metrics that can be used to assess parcels within sourcewater protection areas and will likely add several more before the end of the project. In particular we want to expand our metrics to make them applicable for restoration as well as protection.

In addition to environmental benefits, we are also considering cost. We have previously described methods for assessing human health cost. We intend to contrast those values with both environmental benefits and the cost of protecting the land. To estimate the value of the land we have acquired a state tax parcel database with nearly statewide coverage for parcels, and coverage for approximately half of the state for land values. We are in the process of estimating values for missing areas so that the cost of protection in each sourcewater protection areas can be included in our report.

Activity 2 Status as of August 1, 2020:
We further expanded and refined the environmental benefit metrics used for assessing co-benefits of sourcewater protection. There are now 21 metrics which, in general, are applicable for both restoration and protection. This is the final set of variables for assessing co-benefits of sourcewater protection:

Metric	Category	Description
Forest Bird Species in Greatest Conservation Need (SGCN) Habitat	Biodiversity and Wildlife	Breeding habitat quality for Species in Greatest Conservation Need (SGCN), derived from observations and modeling by the Minnesota Breeding Bird Atlas. (https://mnbirdatlas.org/)

Grassland and Prairie Bird SGCN Habitat	Biodiversity and Wildlife	Breeding habitat quality for grassland SGCN, derived from observations and modeling by the Minnesota Breeding Bird Atlas.
Wetland Bird SGCN Habitat	Biodiversity and Wildlife	Breeding habitat quality for wetland SGCN, derived from observations and modeling by the Minnesota Breeding Bird Atlas.
Bird Species Richness	Biodiversity and Wildlife	Measure of the number of different bird species observed within a township.
Mammal SGCN Habitat	Biodiversity and Wildlife	Climate envelop modeling of SGCN mammals in the state.
Lakes of Biological Significance	Biodiversity and Wildlife	Department of Natural Resources dataset combining data from biological sampling efforts and lakes throughout the state.
Pollinator Habitat	Biodiversity and Wildlife	InVEST[2] Pollination model output of habitat quality for pollinator species.
Upland Game Bird Habitat	Hunting and Fishing	Breeding habitat quality for American Woodcock, Wild Turkey, and Ruffed Grouse from observations and modeling by MNBBA.
Pheasant Habitat	Hunting and Fishing	Pheasant habitat suitability based on local land cover.
Waterfowl Habitat	Hunting and Fishing	Breeding habitat quality for all waterfowl species from observations and modeling by MNBBA.
Mammal Game Species and Furbearers	Hunting and Fishing	Climate envelop modeling of mammal game species and furbearers.
Deer Abundance	Hunting and Fishing	Climate envelop modeling supplemented by deer hunting permit data.
Trout Streams	Hunting and Fishing	Catchments and 66-foot buffers of legally designated trout streams.
Birdwatching	Other Benefits	Bird watching activity concentration derived from eBird reports.
Lake Recreation	Other Benefits	Lake catchments weighted by phosphorus sensitivity and recreation activity.
Wellhead Protection	Other Benefits	Land within a Drinking Water Supply Management Area, weighted by groundwater sensitivity.
Trail Proximity	Other Benefits	Within a 500-foot buffer of state and regional trails.
Wild Rice Sites	Other Benefits	Within the catchment of a current wild rice site.
Nearby Population	Access and Risk	Proportion of the state's population within 50 miles.
Risk of Development	Access and Risk	Risk of land use change to developed (built) uses.
Risk of Ag Conversion	Access and Risk	Risk of land use change to agriculture.

We have also refined the cost of land acquisition layer by merging data from multiple sources, including county tax records and the Minnesota Land Economics database.

Activity 2 Status as of February 12, 2021:

We created all of the environmental benefit metrics we intend to draw on in our last reporting period, so there was not further development under this activity this period. Depending on feedback from MDH stakeholders, we may refine these (e.g., by aggregating some related metrics) before packaging the data for MDH. We are also aware of recent research improving land value estimation methodologies[3] and intend to review these data to determine if they would offer improved estimates over the data we have already collected.

Final Report Summary:

The outcomes of Activity 2 are documented in section 2 of our synthesis report. They are summarized here as follows:

[2] https://naturalcapitalproject.stanford.edu/software/invest

[3] High-resolution land value maps reveal underestimation of conservation costs in the United States Christoph Nolte. Proceedings of the National Academy of Sciences Nov 2020, 117 (47) 29577-29583; DOI: 10.1073/pnas.2012865117

1.) Estimated treatment costs avoided with sourcewater protection.

Outcomes: We assembled a dataset on avoided treatment costs for nitrate based on data provided by MDH and a literature review from national surveys and datasets to estimate avoided treatment costs through sourcewater. Treatment costs for elevated nitrate have been previously estimated in Jensen et al. (2012). We reviewed the literature to confirm these estimates were consistent with recent observed costs in Minnesota. We then applied it to MDH data on PWSs to create cost estimates specific to the population served by each PWS. These results are discussed in section 2.1 and Table 3 of our synthesis report and the data are available in Appendix A.

Executive summary: We assembled data on the public water suppliers in the state and used estimates from the literature on the costs that similarly sized suppliers have paid to install and operate treatment for elevated nitrate. We estimated that the capital, operation and maintenance costs of installing reverse osmosis filtration for the 8% of PWSs with elevated (> 3 mg/L) nitrate concentrations ranged from 9.8 million to 45.7 million annually. If distributed uniformly between households, these costs would increase annual water rates by $161 to $751. However, rate increases would likely fall disproportionately on systems serving small populations. Our analysis estimated average annual household costs for systems serving fewer than 500 people of $803, while systems serving greater than 500 people had an average annual household cost of $269.

2.) Estimated value of health damages avoided based on potential health impacts of exposure to elevated drinking water nitrate.

Outcomes: Epidemiological research suggests a link between drinking water nitrate and some adverse health outcomes at levels below the U.S. federal maximum of 10mg/L. While uncertainty about relative risk remains, accounting for cases of cancer, neural tube birth defects, and preterm births may be plausibly attributed to elevated nitrate levels with implications for social costs of sourcewater contamination. We developed spatially explicit health-cost damage functions for Minnesota's public water supplies mindful of statistical and scientific uncertainty to help quantify potential health costs of N pollution. We summarized these values for all PWSs in the state in section 2.2 and Table 4 of our synthesis report.

Executive summary: We compiled demographic data on the population served by public water supplies, drinking water nitrate concentrations, and the risk for disease associated with exposure to nitrates. We used these datasets to implement a method for estimating disease incidence and associated costs attributable to exposure to elevated drinking water nitrate. Of the five types of cancer in our analysis, we estimated that 71 cases, roughly 1% of cases of these cancer types annually, can plausibly be attributed to elevated drinking water nitrate. Using recently developed methods, we also estimated 50 cases of adverse birth outcomes. We applied three valuation techniques that capture medical costs and the cost of premature mortality. The differing approaches to valuation produced annual cost estimates ranging from $27.2 million to $256.6 million.

3.) Quantified 19 other co-benefits associated with sourcewater protection.

Outcomes: These benefits (listed in Aug 2021 status update) were summarized first at the DWSMA level and then at the parcel level allowing practitioners to use the finest possible resolution to visualize co-benefits, and to allow for a multiple benefits approach to prioritizing land protection or restoration activities. These results are discussed in sections 2.3 and 2.4 of our synthesis report and the data are available in Appendix C.

Executive summary: We estimated the co-benefits of protecting DWSMAs through an analysis of 19 environmental co-benefits. We found that benefits such as pheasant habitat, bird watching, and lake recreation are overrepresented in unprotected, unbuilt source water protection areas relative to unbuilt, unprotected areas in the rest of the state. We applied spatial models of land use change to estimate potential threats to DWSMAs. Due to the proximity of DWSMAs to population centers, DWSMAs face greater than average development risks.

ACTIVITY 3: Assessment of equity and community capacity

Description: The costs of water pollution disproportionately affect rural, low income, and traditionally underrepresented populations. We will combine census data on demographics, income, and immigrant populations with the data collected in Activities 1 & 2 to quantify and report the equity implications of alternative protection strategies for clean water. This activity will allow MDH and other end users of the results to understand how activities in sourcewater protection may affect different communities and subpopulations around the state.

We also will conduct a series of focus groups with community actors and surveys across a geographically and demographically diverse sample of households to examine how different subpopulations use and value water, perceive water risk, and engage in water and land protection. We will conduct up to two focus group sessions in three "at-risk" communities and a broader resident survey in the regions. Insight gained from the focus groups and surveys will be synthesized in a report identifying constraints to and opportunities for equitable sourcewater protection.

Focus groups will be conducted with community actors in rural, low income, and traditionally underrepresented populations to examine how varying subpopulations use and value water, perceive water risk and engage in water and land protection. We will identify opportunities and challenges to existing water protection programming with attention to issues of inclusion and equity. Comparative analysis will be conducted to examine convergent and divergent themes within and across study communities.

A resident survey will complement the focus groups to gain a broader understanding of water uses, values and risk perceptions. The survey instruments will be developed based on a review of relevant literature and previously tested instruments, as well as insights from project partners. Based on previous research, we hypothesize that sociodemographic characteristics (e.g., gender, age) will influence risk perception and ultimately civic engagement behaviors around sourcewater protection.

Summary Budget Information for Activity 3:	**ENRTF Budget:**	**$ 108,295**
	Amount Spent:	**$ 108,295**
	Balance:	**$ 0**

Outcome	**Completion Date**
1. Report of the equity implications of alternative water management strategies, including how different communities use and value clean water. The report will include maps and planning tools that can be used to inform future investments in sourcewater protection.	January 2019
2. Focus groups and surveys in communities identified as "at-risk" based on Activity 1 that reveal how different subgroups use and value water, perceive risk, and engage in protection. Results will be synthesized in a report identifying constraints to and opportunities for sourcewater protection based on community assessments.	June 2019

Activity 3 Status as of August 3, 2018:

We designed, piloted, and distributed a statewide resident survey to 6000 Minnesota households in order to gain a broader understanding of water uses, values and risk perceptions. The survey was designed to better understand how sociodemographic characteristics (e.g., gender, age) might influence risk perception and ultimately civic engagement behaviors around sourcewater protection. We have received over 1,300 responses

to the survey and data analysis of survey results is in progress. A copy of the survey instrument is included with this project report.

We have not yet completed the focus groups that will serve as follow-ups to the survey, nor the report on equity implications of water management. The next phase of our work on Activity 3 will prioritize these activities.

Activity 3 Status as of February 28, 2019:
The results of preliminary analyses of survey responses were presented to MDH and the Clean Water Council including what values are most important to Minnesotans, most popular activities in lakes, rivers, and streams and the top water concerns across the state. The results also included showing how responses varied when demographic characteristics were considered (i.e. socio-economic status, age, and gender). Based on these results, we created an informative fact sheet "Minnesota Water Values: Resident Survey Report," which will be disseminated across key state agencies and the public. Moving forward, we will identify "at risk" communities using threat and vulnerability data identified in activity 1. We anticipate identifying those communities before the next status update. Following that, we will conduct a focus group exercise in each community.

Activity 3 Status as of August 1, 2019:
We have continued to analyze the results of our MN value of water survey (1480 total responses, 28%), with a focus on understanding how communities differ in the water issues they face, and the resources they have to address those issues. Dr. Davenport's graduate student, Amelia Kreiter, used this survey as a foundation for a thesis analyzing the factors that influence the level of civic engagement of residents. Findings indicate that personal experience with water and feeling like they have enough information are the strongest predictors for water protection efforts. These findings are useful for developing successful outreach and communication programs to target and expand civic engagement on water protection issues. The completed thesis is included as an attachment.

Future work will use statewide survey results, combined with physical and social drinking water vulnerability characteristics co-developed with MDH to identify at-risk communities for further focus group based research.

Activity 3 Status as of February 1, 2020:
At several venues throughout the state, we have conducted a 'Q-sort' exercise, where participants receive 18 cards representing different water quality goals (e.g. protecting drinking water, protecting lakes for fishing, maintaining irrigation), and are asked to prioritize the cards. Several cards can be in the middle of the priority spectrum, but only one can be top priority, and one must be lowest priority. Initial results show consistent with our previous research, protecting drinking water quality is the top priority. We have observed this trend whether we are talking to water quality advocates or the general public. We intend to integrate and contrast the cost and benefits identified in activities 1 and 2 with the values expressed and an analysis of equity under activity 3.

Activity 3 Status as of August 1, 2020:
We did not conduct any further focus groups of community engagement due to concerns about covid-19. We believe between previously completed Q-sort exercises, and a statewide survey on the value of water we have sufficient data on perceptions of water quality and risk to complement the biophysical and economic analyses in activities 1 and 2. The linkages between public water supplies, consecutive connections, communities, and ultimately demographic data completed in activity 1 ads an equity dimension to the data collected in our survey work. We began drafting a manuscript that explores how the methods used to quantify water values can lead to very different recommendations for investments, and subsequent inequity in distribution of benefits and harms. This manuscript will merge all of the components of this, and other projects, into a synthesis of water valuation in Minnesota.

Activity 3 Status as of February 12, 2021:

As mentioned in our previous update, we continued to draft a manuscript synthesizing the insights we have from both the modeling of drinking water protection costs and benefits and the results from the statewide value of water survey, with a particular focus on at-risk communities. We have also submitted an abstract for the paper to the social cost of water pollution workshop entitled “Exploring Equity-Weighted Health Costs in the Social Costs of Nitrogen”.

Final Report Summary:
The outcomes under Activity 3 are split into two areas; demographic data curation and survey work. Both areas are summarized below, and additional results and discussion of demographic data curation are available in section 3 of our synthesis report and associated appendices.

1.) Developed a methodology to join data on public water supplies to census demographic data for municipalities or counties.

Outcomes: Activity 3 called for the incorporation of social vulnerability factors in the biophysical and economic assessments performed in the other activities. We addressed this by creating a new mapping of DWSMA data to census demographic data. Prior to this work, there was little information beyond the number of people served by a public water supply. Naming irregularities and complex distribution mechanisms made it difficult to link a public water supply with the municipality it served and thus access the rich data associated with the census. We made manual corrections necessary to increase the number of successful joins, and joined county level data when that was not possible. We created a dataset (Appendix A) that provides public water supply level demographic data for the municipalities they serve, or the county they are in if they do not serve a municipality. It also includes historical average and maximum nitrate concentrations (Table 5). The combined dataset enables practitioners to assess where elevated drinking water nitrate and associated costs might fall on a small and/or vulnerable population that would be disproportionately burdened by increased drinking water costs. They are also useful for refining predictions of cases of disease correlated with elevated drinking water nitrate, or analyzing the distributional effects of sourcewater contamination.

Executive summary: Many DWSMAs supply small or low-income populations that would be disproportionately burdened by an increase in water treatment costs. We designed and implemented a workflow that allows for combining information on public water supplies with census demographic data for municipalities or counties. We found that most PWSs did not have elevated drinking water nitrate, but those that did tended to be in the lower quartile for median household income. These datasets enable practitioners to assess where elevated drinking water nitrate and associated costs might fall on a small and/or vulnerable population that would be disproportionately burdened by increased drinking water costs.

2.) Survey and stakeholder outreach around the value of clean water.

We completed a statewide survey of water values (see the included file ‘MN Water Values Survey FACT Sheet UMN 2019.pdf’). One of the insights from the survey was that clean drinking water was consistently ranked as the most important water value and the top priority for state funding for water resources. Results of the statewide survey have been shared broadly with agency staff and water resource managers. The work is currently being revised for publication and two additional follow-up instruments are targeting water values of underrepresented communities in the metro area (Davenport et al. in prep) and water values of ratepayers in the selected regions served by MetCouncil. We also conducted a series of workshops using a Q sort methodology to assess water values of water resource professionals and communities. Results of the Q sort are also in the process of submission to a peer-reviewed journal (Keeler et al. in prep). The surveys and stakeholder workshops have revealed new insights into how subpopulations use and value water, perceive water risk, and engage in water and land protection.

V. DISSEMINATION:

Description: All data, analyses, and methods will be documented by the project team and shared with LCCMR and project partners at MDH. Insights from the work will be communicated to the public and the research community via blog posts on the IonE Eye on Earth blog, through the Natural Capital Project website, and through peer-reviewed publications. Plans are also underway to launch a web-based water valuation to be hosted on the Institute on the Environment website targeting an audience of users in Minnesota and globally interested in quantifying the value of clean water and seeking data resources, methodologies, and economic tools relevant to their question and projects of interest.

Status as of August 3, 2018: To bring awareness to the project, we created and distributed an ArcGIS storymap that describes the project objectives and preliminary insights about the value of clean water, especially in rural communities. The storymap was highlighted in a blog posted on the IonE site and widely distributed throughout agency and advocacy channels: View the blog and associated story map here: http://environment.umn.edu/discovery/natural-capital-project/integrative-approach-protecting-minnesotas-drinking-water/

Status as of February 28, 2019: We presented our preliminary analyses to MDH and the Clean Water Council and received feedback on the type of analyses and data that would be most useful in vulnerability assessments of sourcewater areas. Based on that input, we have defined the next research steps including expanding our dataset with jurisdictional authorities represented in sourcewater areas, zooming in the co-benefits of sourcewater area protection, and analyzing the public health costs of nitrate exposure. In addition, we have also created a first one-pager report of survey responses "Minnesota Water Values: Resident Survey Report" to disseminate across agencies and other research and advocacy groups.

Status as of August 1, 2019:

We met with MDH and Pheasants Forever to demonstrate how the data we are synthesizing for this project can be used to identify more projects with multiple benefits, such as the successful Worthington Wells WMA.

A master's thesis (attached) was completed using data collected and analyzed for this project.

Status as of February 1, 2020:

We have highlighted our work at various presentations to state organizations, including MDH, EQB, and LSOHC. We have also had discussions about making the datasets directly available to TNC and the Freshwater Society to aid in their decision making for sourcewater protection.

Status as of August 1, 2020:

Our usual dissemination channels were limited by the pandemic, however, we still presented on this work early in the year at the MN environmental congress and virtually to groups such as the Clean Water Council, and Board of Water and Soil Resources. Notably, our engagement with TNC and Freshwater mentioned above has led to collaboration on several grant proposals that seek to reduce barriers to using water valuation methods in planning processes such as One Watershed One Plan.

The manuscript we are drafting to synthesize this and other research on the topic of drinking water protection valuation methodologies will form the foundation for communication and dissemination going forward. The manuscript will be peer-reviewed for scientific audiences, but we will also use it to create blog posts, figures, and presentations that convey its key findings in a simple and clear manner.

Status as of February 12, 2021:

We did not engage in dissemination activities in this period, however, we continue to prepare materials for dissemination through academic conferences, peer-reviewed publications, public facing blog posts, and reports and data for state agencies.

Final Report Summary:
Outreach and dissemination of our findings is ongoing. We presented our work at multiple venues targeting both academic and state agency audiences. We presented to academic audiences at the Cornell social cost of water pollution workshop in April of 2021. We presented to a primarily state agency audience at the MPCA consortium "Issues in water resources: Identifying the research and regulatory needs for the next 20 years". We also held smaller meetings with practitioners at MDH and the Groundwater Restoration and Protection Strategies (GRAPS) sub-team composed of representatives from multiple state agencies. We shared findings with state agencies including MPCA, MDH, DNR, and BWSR, along with external stakeholders and advocacy groups such as Freshwater Society and the Environmental Working Group. The updated State Water Plan led by the Environmental Quality Board features our research on the interaction between climate change and water resources. Our work contributed to multiple student professional papers and master's theses and several peer-reviewed journal products are in preparation for submission. A synthesis report and appendices are available on our lab website.

VI. PROJECT BUDGET SUMMARY:
A. Preliminary ENRTF Budget Overview:

Budget Category	$ Amount	Overview Explanation
Personnel	$61,000	One Lead Scientist and PI to oversee Activities 1 and 2 and lead project and dissemination at 25% FTE each year for 2 years; 66.3% salary, 33.7% benefits
	$16,000	One Faculty and Co-PI to oversee Activity 3 and lead project and dissemination at 10% FTE for 1 year (one month in year two); 66.3% salary, 33.7% benefits
	$36,000	One Project Coordinator and Research Support Staff Person to support project management, analysis and reporting at 25% FTE each year for 2 years; 72.6% salary and 27.4% benefits
	$115,000	One Research Analyst to support data collection, spatial mapping, and biophysical and economic analysis at 100% FTE each year for 2 years; 72.6% salary and 27.4% benefits
	$43,000	One University of Minnesota Graduate Student Assistant to support survey development, focus groups and analysis during Activity 3 at 50% FTE for 1 year; 17% salary and 83% benefits which include academic year tuition, fiscal year health care, and social security and Medicare for 6.5 summer pay periods
	$15,000	Two Summer Undergraduate Student Interns to support various project activities at 29% FTE total each year for 2 years.

Survey costs and supplies	$18,000	Survey distribution costs including printing and mailing for 4,500 surveys with cover letters and postage-paid return envelopes; 3 waves of mailing. Based on estimated costs incurred in previous surveys administered by PI Davenport.
Focus Group Expenses	$6,000	Focus group room rentals and hospitality. Based on estimated expenses incurred in previous focus groups conducted by PI Davenport in Minnesota.
Publication and dissemination of results	$3,575	Publication fees for disseminating project results in peer-reviewed open access journal such as the Journal of Soil and Water Conservation or PLOS One. Page fees at JSWC are $190/page plus $750 for open access = $1890 for a seven page article or $1,495 for PLOS ONE. We anticipate this work resulting in two open access publications for an estimated total cost of $3,385.
Presentation of work at regional conference or meeting	$425	Registration and fees for presentation of results at regional conferences. An estimated $425 is requested to support registration fees, poster printing, and attendance and presentation at one meeting or conference.
Travel	$6,000	Travel within Minnesota for data collection, focus groups and researcher attendance at regional conference to present project findings. Funds used to pay University of Minnesota rental vehicle and mileage (75%) and meals (25%) for researchers, graduate student and interns. Assumes $300 per trip for 2 people to 2 locations for Activity 2 ($1,200) and $300 per trip for 2 people to 8 locations for Activity 3 ($4,800). Expenses reimbursed per travel guidelines as set by the University of Minnesota.
TOTAL ENRTF BUDGET:	**$320,000**	

Explanation of Use of Classified Staff: N/A

Explanation of Capital Expenditures Greater Than $5,000: N/A

Total Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation: 4.18 FTEs

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

B. Other Funds:

Source of Funds	$ Amount Proposed	$ Amount Spent	Use of Other Funds

The Natural Capital Project and Institute on the Environment, University of Minnesota. In kind support. The IonE has supported and will continue to support research and outreach activities conducted by the Natural Capital Project. Total funding for the research program to date is $1.0 million, with an additional $125,000 projected for FY17 and FY18.	N/A	N/A, Secured	Although IonE funding is not dedicated or committed specifically to this proposal, the organization can support research, software, data hosting and complementary activities.
University of Minnesota. In kind support. UMN Facilities and Administrative rate is 53% of modified total direct costs (total direct less graduate student fringe, capital equipment, subawards over $25,000 and on-site facilities rental). The amount here is the total estimated contribution, if F&A expenses would have been allowed on the project.	$169,600	N/A, Secured	Office space, IT services, and administrative / financial services in support of the project.
TOTAL OTHER FUNDS:	**$169,600**	**N/A**	

VII. PROJECT STRATEGY:

The project will be led by Dr. Keeler, Director and Lead Scientist of the Natural Capital Project at the University of Minnesota's Institute on the Environment and Dr. Davenport, Associate Professor in the Department of Forest Resources at the University of Minnesota. The project will support several new positions, including a project coordinator, research analyst, two summer interns recruited from local colleges or universities, and one graduate research assistant. The project was developed in partnership with the Minnesota Department of Health and will be conducted in close collaboration with agency partners.

A. Project Partners:

Partners receiving ENRTF funding: N/A

Partners NOT receiving ENRTF funding

- Tannie Eshenaur, Planning Director, Drinking Water Protection, Minnesota Department of Health, Collaborator and Advisor

B. Project Impact and Long-term Strategy: This project is a stand-alone effort and not part of a longer-term funding request, although it builds and expands on a current LCCMR project led by Keeler, Brauman, and Twine entitled "Assessing Water Scarcity and Threats". The project also leverages a 2015 statewide assessment of Soil and Water Conservation District capacity to protect groundwater conducted by Pradhananga, Davenport, and Perry and funded by the Minnesota Department of Natural Resources.

The project outcomes include detailed assessments of risks to clean water and the value of sourcewater protection in Minnesota. In addition, the project will highlight the importance of considering equity and understanding local capacity in key sourcewater areas for community-based land protection for clean water. All data generated as part of the project will be shared with agency partners and made publicly available through publication in a peer-reviewed open access journal.

The project team is currently seeking funding to expand the work beyond Minnesota and across scales. We hope that success in this project will allow the team to extend the analyses to city and watershed planning audiences and to regional basin-scale work in the Mississippi River.

C. Funding History:

Funding Source and Use of Funds	Funding Timeframe	$ Amount
Environment and Natural Resources Trust Fund – **M.L. 2015, Chp. 76, Sec. 2, Subd. 04a**: "Understanding Water Scarcity, Threats, and Values to Improve Management." Appropriation of cash funds ($234,936, with $190,000 remaining from existing ENRTF Appropriation as of January 2016) awarded July 1, 2015 to PI's Keeler, Brauman, and Twine used to assess water scarcity and threats in MN. This project will generate statewide maps and data on future precipitation, temperature, and water scarcity that will inform the sourcewater risk assessments proposed in this study. This project has an end date of June 30, 2018.	July 1, 2015 – June 30, 2018	$234,936 ($190,000 remaining as of January 2016)
Minnesota Department of Natural Resources. **Groundwater management: Capacity assessment at the local level.** PI M. Davenport. Cash funds of $16,868 awarded to support Davenport, Pradhananga and Perry in analysis to identify threats to groundwater quality and quantity across the state as perceived by Soil and Water Conservation District staff. The study helps to prioritize threats, as well as identify areas for capacity building. Outcomes of the study have been a series of workshops for Soil and Water Conservation District staff and other water managers.	January 1, 2015 – September 30, 2015	$16,868 (project completed in 2015)

VIII. REPORTING REQUIREMENTS:

- **The project is for 2 years, will begin on 07/01/2017, and end on 06/30/2021.**
- **Periodic project status update reports will be submitted 02/01 and 07/01 of each year.**
- **A final report and associated products will be submitted between June 30 and August 15, 2021**.

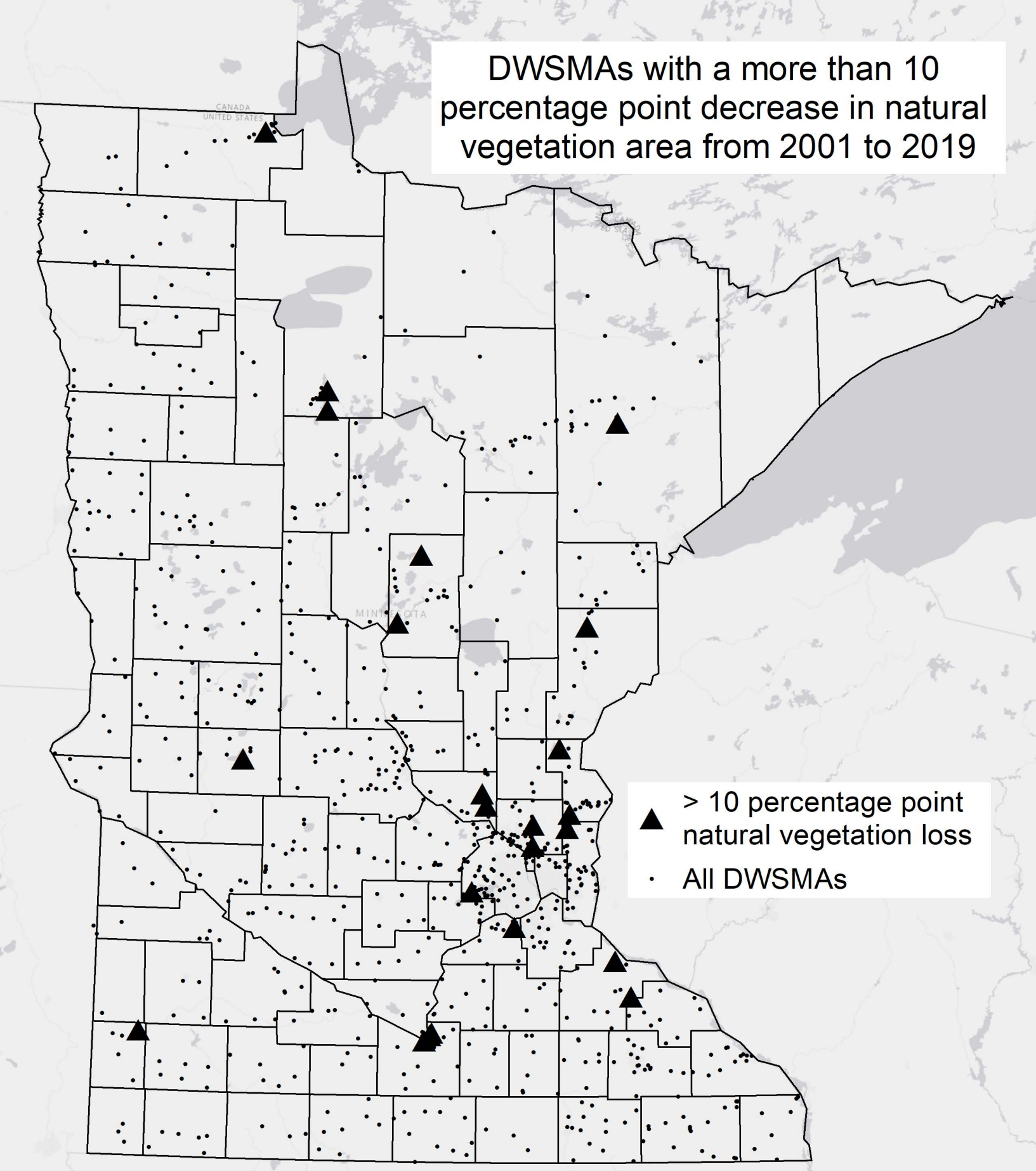
IX. VISUAL COMPONENT or MAP(S): See attached figure.

Environment and Natural Resources Trust Fund
M.L. 2017 Project Budget

Project Title: What are the public benefits of protecting sourcewater?
Legal Citation: M.L. 2017, Chp. 96, Sec.2, Subd. 03b
Project Manager: Bonnie Keeler
Organization: Humphrey School of Public Affairs, University of Minnesota
M.L. 2017 ENRTF Appropriation: $320,000
Project Length and Completion Date: 4 Years, June 30, 2021
Date of Report: Sep 15, 2021

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Activity 1 Budget	Amount Spent	Activity 1 Balance	Activity 2 Budget	Amount Spent	Activity 2 Balance	Activity 3 Budget	Amount Spent	Activity 3 Balance	TOTAL BUDGET
BUDGET ITEM	***Mapping land use change and risks to clean water***			***Valuation of the multiple public benefits of clean water***			***Assessment of equity and community capacity***			
Personnel (Wages and Benefits)	$104,000	$104,000	$0	$104,000	$104,000	$0	$91,400	$91,400	$0	$299,400
Bonnie Keeler, Lead Scientist and PI: $61,000 (66.3% salary, 33.7% benefits); 25% FTE each year for 2 years										
Mae Davenport, Faculty and Co-PI: $16,000 (66.3% faculty salary, 33.7% benefits); 10% FTE for 1 year (one month in year two)										
1 Project Coordinator and Research Support (support project management, analysis and reporting): $36,000 (72.6% salary and 27.4% benefits); 25% FTE each year for 2 years.										
1 Research Analyst (support data collection, spatial mapping, and biophysical and economic analysis): $115,000 (72.6% salary and 27.4% benefits); 100% FTE each year for 2 years										
1 University of Minnesota Graduate Student Assistant: $43,000 (17% salary and 83% benefits which include academic year tuition, fiscal year health care, and social security and Medicare for 6.5 summer pay periods); 50% FTE for 1 year										
2 Summer Undergraduate Student Interns: $15,000 (100% salary, part-time, hourly pay; $12.50/hr for 300 hours per student per year); 29% FTE each year for 2 years										
Supplies										
Survey distribution costs including printing and mailing for 4500 surveys with cover letters and postage-paid return envelopes; 3 waves of mailing							$10,000	$10,000	$0	$10,000
Other										
Focus group room rentals and hospitality. Based on estimated expenses incurred in previous focus groups conducted by PI Davenport in Minnesota.							$2,000	$2,000	$0	$2,000

Publication fees for disseminating project results in peer-reviewed open access journal such as the Journal of Soil and Water Conservation or PLOS One. Page fees at JSWC are $190/page plus $750 for open access = $1890 for a seven page article or $1,495 for PLOS ONE. We anticipate this work resulting in two open access publications for an estimated total cost of $3,385.				$2,080	$2,080	$0	$1,495	$1,495	$0	$3,575
Registration and fees for presentation of results at regional conferences. An estimated $425 is requested to support registration fees, poster printing, and attendance and presentation at one meeting or conference.				$425	$417	$8		$125		$425
Travel expenses in Minnesota										
Travel within Minnesota for data collection, focus groups and researcher attendance at regional conference to present project findings. Funds used to pay University of Minnesota rental vehicle and mileage (75%) and meals (25%) for researchers, graduate student and interns. Assumes $300 per trip for 2 people to 2 locations for Activity 2 ($1,200) and $300 per trip for 2 people to 8 locations for Activity 3 ($4,800). Expenses reimbursed per travel				$1,200	$1,200	$0	$3,400	$3,400	$0	$4,600
COLUMN TOTAL	**$104,000**	**$104,000**	**$0**	**$107,705**	**$107,697**	**$8**	**$108,295**	**$108,420**	**$0**	**$320,000**



Map of all 821 DWSMAs in the state, with those that experienced a 10-percentage point or greater decrease in natural vegetation area between 2001 and 2019 highlighted. Development pressure is a current issue for the protection of drinking water supplies. Development in DWSMAs is primarily urban or other built land covers, but agricultural expansion and intensification are issues as well. The distribution of DWSMAs with elevated natural vegetation loss indicates that source water protection is an issue affecting all regions of the state.