M.L. 2016, Chp. 186, Sec. 2, Subd. 04n Project Abstract
For the Period Ending June 30, 2019

PROJECT TITLE: Impacts of Adding Salt to Our Minnesota Lakes, Rivers, and Groundwater
PROJECT MANAGER: John S. Gulliver
AFFILIATION: University of Minnesota
MAILING ADDRESS: St. Anthony Falls Laboratory, 2 Third Ave.
CITY/STATE/ZIP: Minneapolis, MN 55414
PHONE: (612) 625-4080
E-MAIL: gullli003@umn.edu
WEBSITE: http://stormwater.safl.umn.edu/, https://www.wrc.umn.edu/watersoftening
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: M.L. 2016, Chp. 186, Sec. 2, Subd. 04n

APPROPRIATION AMOUNT: $497,000
AMOUNT SPENT: $497,000
AMOUNT REMAINING: $0

Sound bite of Project Outcomes and Results
This project developed a statewide chloride budget demonstrating the relative impacts of fertilizers, water softening, livestock waste, and road salt on Minnesota's water resources. Experiments and field cores demonstrated the complexity of chloride transport through Minnesota's soils. Together these results illustrate that chloride must be carefully managed in Minnesota.

Overall Project Outcome and Results
Increasing chloride levels in surface waters and groundwater are an emerging concern in Minnesota, as they can negatively impact aquatic and plant life. This project developed two new chloride mass budgets: a wastewater treatment plant (WWTP) chloride budget and a statewide chloride budget. The results of the WWTP chloride budget accounted for 98% of the chloride discharged from included WWTPs and showed that water softener use was the largest chloride point source investigated in the WWTP chloride budget. At the statewide level, household and commercial water softening were estimated to contribute 65% of WWTP chloride discharge. Industries were also major sources, contributing 22% of the estimated chloride load of statewide WWTPs. In the statewide chloride budget, road salt use was the largest chloride source, contributing 403,600 metric tons (t) of chloride annually to surface waters. Chloride from fertilizer use was the next largest chloride source (221,300 t), followed by WWTPs (209,900 t), livestock waste (62,600 t) and residential septic systems (33,100 t). The results of the statewide chloride budget show that water softeners are major sources of chloride and indicate that increasing efficiency of water softener salt use could be a viable strategy to manage chloride levels in wastewater and receiving waters.

Column experiments and analysis of field soil cores were performed on soils common in Minnesota: silt loam, sandy loam, and sandy loam with 10% organic material. Analysis of these indicate that chloride is sometimes stored within the soil and is released at other times, likely due to storage in capillary spaces and anion exchange and/or adsorption. Thus, a long period of freshwater rinse (tens to hundreds of years) is required to fully remove chloride from soils in Minnesota and chloride in our groundwater will be a legacy for some time.

Project Results Use and Dissemination
The results of this project were disseminated throughout the project via presentations, workshops, listening sessions, interviews, surveys, emails, and webinars, among others. The first list of dissemination efforts is provided in the final work plan update for the project. In addition, fact sheets and final project reports were developed and are provided with the final status update for the project and online.

Environment and Natural Resources Trust Fund (ENRTF)
M.L. 2016 Work Plan Final Report

Date of Report: December 31, 2019

Final Report

Date of Work Plan Approval: June 7, 2016

Project Completion Date: June 30, 2019

PROJECT TITLE: Impacts of Adding Salt to Our Minnesota Lakes, Rivers, and Groundwater

Project Manager: John S. Gulliver

Organization: University of Minnesota

Mailing Address: St. Anthony Falls Laboratory, 2 Third Ave.

City/State/Zip Code: Minneapolis, MN 55414

Telephone Number: (612) 625-4080

Email Address: gullli003@umn.edu

Web Address: http://stormwater.safl.umn.edu/, https://www.wrc.umn.edu/watersoftening

---

Location: Statewide

Total ENRTF Project Budget:	**ENRTF Appropriation:**	**$497,000**
	Amount Spent:	**$497,000**
	Balance:	**$0**

Legal Citation: M.L. 2016, Chp. 186, Sec. 2, Subd. 04n

Appropriation Language:

$497,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to quantify the current water-softening salt loads in Minnesota lakes, rivers, and groundwater, assess alternative water-softening materials and methods, and quantify the transport of de-icing and water-softening salt through the soil. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

I. PROJECT TITLE: Impacts of Adding Salt to Our Lakes, Rivers, and Groundwater

II. PROJECT STATEMENT:

Minnesota uses an increasing amount of salt (sodium chloride) to de-ice our roads, parking lots, and sidewalks (increased by 230% between 1991 and 2006) and soften our water. Deicing salt infiltrates into roadside soils during snowmelt events or directly runs off into surface waters. Water-softening salt is often discharged from wastewater treatment plants to surface waters and also from private septic systems directly into adjacent soils. The sodium is trapped by the soil and other particles, but chloride will move through the soil to receiving water bodies or groundwater. We know from previous research that de-icing salt is the dominant source of chloride in the Twin Cities metro area, and is accumulating to toxic levels in many lakes, wetlands and rivers. We know relatively little about proportion of salt sources in rural Minnesota, and how chloride accumulates in soil-water and groundwater. We suspect that a high percentage of the chloride currently stays in the soil moisture and shallow groundwater, but how much in each and where is it going? How long does it take to get there? When will it impact our drinking water sources? How long until chloride concentrations in our surface waters and groundwater are no longer toxic to fisheries?

When water is softened to remove hardness, salt is used to regenerate the softener releasing chloride to septic systems and wastewater treatment plants (WWTPs). Monitoring to date has shown numerous WWTPs with discharge concentrations greater than limits for protecting aquatic life. Greater Minnesota may have similar problems, given the prevalence of private septic systems near lakes and streams. While the contribution of chloride from softening is less than from road salt, this may be the "low hanging fruit" in the reduction of salt use because it is not related to public safety. By better understanding softening salt use, we will determine potential methods required to make significant progress in the reduction of this salt use.

Minimizing the impacts of increased use of salt to surface waters and groundwater in Minnesota is necessary because it is impractical and very expensive to remove chloride after it is dissolved in water. This project will quantify the current water softening salt loads in Minnesota, assess alternative softening materials and methods and quantify the transport of chloride from de-icing and softening through the soil. This project will enable us to minimize the long-term impacts of de-icing and softening salt on surface waters and groundwater across Minnesota.

The outcome of this project is to enhance strategies that improve water quality by providing methods to reduce the chloride load from water softening and developing tools that predict salt movement through the soil. The methods and tools developed during this project will inform state, municipal and private entities using de-icing salt, municipal wastewater treatment system operators, and thousands of rural communities and property owners with subsurface sewage treatment systems in Minnesota.

III. OVERALL PROJECT STATUS UPDATES:

Project Status as of January 1, 2017:

The project team has completed literature reviews, started stakeholder meetings and interviews, conducted surveys to collect data. The project is on track in schedule and budget and progressing as expected.

Project Status as of July 1, 2017:

A status report was not requested for this time period.

Project Status as of January 1,2018:

The project is on track in schedule and budget and progressing as expected.

Amendment Request (01/17/2018)
The Equipment/Tools/Supplies: Misc. Supplies for experimental setup and analysis in the budget was overspent because greater expenditure on supplies to measure flow were required. I am requesting that $2,000 be moved from Junior Engineering Trainee to supplies. The total budget for the Junior Engineering Trainee would then be $17,287 and the Equipment/Tools/Supplies: Misc. Supplies for experimental setup and analysis would then be $4,000.
Amendment Approved: [01/29/2018]

Project Status as of July 1, 2018:
The project is on track in schedule and budget and progressing as expected.

Project Status as of January 1, 2019:
For Activity 1, the additional analyses for mass balance and mass balance reported were completed. For Activity 2, fact sheets for water softening issues in homes and communities were created, water softening costs and benefits were reviewed and finalized, and a conceptual framework for online tool on water softening was developed. For Activity 3, an automated data collection system has been developed to collect data from 15 soil columns simultaneously and the project team met with soil experts and MnDOT partners to facilitate collection of the soil cores.

Amendment Request (01/31/2019)
No Cost Time Extension: We are requesting that the contract be extended for 6 months at no additional cost. This time extension is to finalize preparation of the final report.
Amendment Approved by LCCMR 2/26/2019.

Project Status as of July 1, 2019:
For Activity 1, the deliverables were finalized in the last reporting cycle, January 2019. For Activity 2, the framework for an online tool on water softening to evaluate softening alternatives was completed, and the deliverables were finalized in the last reporting cycle, January 2019. For Activity 3, Soil column experiments progress and soil cores were collected in a location specifically chosen to correspond with the soil types used in laboratory column studies and in an area in which the salt application rates are well-known. Soil cores were collected near the roadway, down the slope from the road, at the bottom of the slope and up the backslope away from the roadway. The soil cores will be analyzed to determine if there is a relationship between soil properties and salt content. It is anticipated that salt content will decrease as distance from the roadway increases. Analysis of soil column and soil core data will be included in the final report.

Amendment Request (7/30/2019)
We are requesting the budget be retroactively revised to account for changes in Supplies and Travel, as follows:
Salary for John Gulliver: Reduce from $24,270 to 23,696.
Analytical laboratory charge (Supplies): Reduce from $3,000 to $1,687
Miscellaneous supplies: Increase from $2,000 to $5,244
Travel: Reduce from $1,400 to $43.
Amendment Approved by LCCMR 10/07/2019.

Overall Project Outcomes and Results:
Increasing chloride levels in surface waters and groundwater are an emerging concern in Minnesota, as they can negatively impact aquatic and plant life. This project developed two new chloride mass budgets: a wastewater treatment plant (WWTP) chloride budget and a statewide chloride budget. The results of the WWTP chloride budget accounted for 98% of the chloride discharged from included WWTPs and showed that water softener use was the largest chloride point source investigated in the WWTP chloride budget. At the statewide level, household and commercial water softening were estimated to contribute 65% of WWTP chloride discharge. Industries were also major sources, contributing 22% of the estimated chloride load of statewide WWTPs. In the statewide chloride budget, road salt use was the largest chloride source, contributing 403,600 metric tons (t) of chloride annually to surface waters. Chloride from fertilizer use was the next largest chloride source (221,300 t),

followed by WWTPs (209,900 t), livestock waste (62,600 t) and residential septic systems (33,100 t). The results of the statewide chloride budget show that water softeners are major sources of chloride and indicate that increasing efficiency of water softener salt use could be a viable strategy to manage chloride levels in wastewater and receiving waters.

Column experiments and analysis of field soil cores were performed on soils common in Minnesota: silt loam, sandy loam, and sandy loam with 10% organic material. Analysis of these indicate that chloride is sometimes stored within the soil and is released at other times, likely due to storage in capillary spaces and anion exchange and/or adsorption. Thus, a long period of freshwater rinse (tens to hundreds of years) is required to fully remove chloride from soils in Minnesota and chloride in our groundwater will be a legacy for some time.

IV. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1: Estimate statewide sodium chloride use

Description: This activity will determine a chloride budget for Minnesota focusing on the amount of chloride that is being used statewide to remove hardness from water. The estimate will include amount of water softening salt used by municipalities, industrial sources and in private homes (discharges to wastewater treatment plants or septic systems). The estimate of the amount of water softening salt will be compared to purchase records to further refine the estimate. From this estimate, the percent contribution of chloride from water softening in Minnesota surface and groundwater will be estimated. This activity will also include evaluating the number, percentage of water softened, efficiency and calibration of in-home units compared to water softening at municipal water treatment facilities. A varying range of densities and watershed scales will be considered. We will identify locations where chloride loads are likely to impact aquatic life by identifying point discharges from wastewater treatment plants and non-point discharges through homes with septic systems.

Summary Budget Information for Activity 1: **ENRTF Budget: $ 89,500**
Amount Spent: $ 89,500
Balance: $ 0

Outcome	Completion Date
1. Estimate overall sodium chloride use for water softening	*6/30/2017*

Activity Status as of January 1, 2017:

1. Literature review (July – August 2016)
   - Our team conducted a literature review of relevant chloride research among published and grey literature. Retrieved papers provided useful insights for the chloride mass balance analysis as well as its methods and needed data.
2. Project presentations and stakeholder meetings (September 2016 – January 2017)
   - We met with board members of the Minnesota Water Quality Association (MWQA) and the National Water Quality Association to introduce our project and discuss their questions, concerns, and potential areas of involvement. We gave a presentation on the project at the annual MWQA convention in October, which had many water conditioning professionals present.
3. Survey of water conditioning professionals (November 2016 – January 2017)
   - Team members developed a survey that will be distributed in January 2017 to plumbers and water conditioning professionals across the state about regional water softening practices.
4. Data collection and analysis (September 2016 – January 2017)
   - Our team has met with the MPCA to discuss the project approach, and the MPCA has provided several datasets for the analysis. These include data on water hardness, chloride concentrations in groundwater and surface water, septic system prevalence, and wastewater treatment plant effluent monitoring.
   - An analysis approach has been developed for the chloride mass balance, which will involve using our survey results to estimate the fraction of chloride from softening in municipal wastewater effluent data. We will also assess other point and non-point sources of chloride, including: human excreta; drinking

water background concentrations; road salt; fertilizer; and precipitation. Data sources and published estimates have been procured for each chloride source that will be assessed in the analysis.

Activity Status as of July 1, 2017:
A status report was not requested for this time period.

Activity Status as of January 1,2018:
1. Survey of water conditioning professionals (January 2017 – March 2017)
   - We disseminated a survey to plumbers and water conditioning professionals across the state about regional water softening practices. We received 183 responses and have incorporated the survey data into other project activities, including the mass balance.
2. Mass balance data collection and analysis (January 2017 – January 2018)
   - We collected additional data for our mass balance on chloride from fertilizer use, livestock excretions, dust suppressant, and deicing salt use. We also obtained data on drinking water sources for our analysis. Data were obtained through contacting state agencies as well as state reports. Spatial and statistical techniques were used to compile and analyze chloride contributions from these various sources.
   - The mass balance analysis was completed, incorporating statewide chloride contributions from: household water softener use; human excretions; household appliance use; industrial discharge; chloride background concentrations in drinking water; precipitation; livestock excretions; synthetic fertilizer use; dust suppressant use; and use of deicing salt. Deicing salt use was the highest contributor of chloride to the environment statewide, with chloride from fertilizer and livestock excretions being the next largest sources. Water softener use contributed slightly less chloride, but was still a major source and presents an opportunity for reducing chloride in the environment.

Activity Status as of July 1, 2018:
1. Additional analyses for mass balance (January 2018 – July 2018)
   - Additional analyses were conducted for wastewater treatment facilities with chloride monitoring data to characterize chloride from sources not included in the mass balance, since the results indicated that commercial and industrial organizations were major chloride sources. Data were requested from state agencies to better characterize residential water use and commercial and industrial chloride discharge.

Activity Status as of January 1, 2019:
1. Completed additional analyses for mass balance (August 2018 – November 2018)
   - Gathered monitoring data on industrial chloride discharge rates and estimated chloride contributions from wastewater treatment plant chlorination, drinking water chlorination, industries, and commercial organizations. Industries were found to be major chloride sources and commercial water softening was also a substantial source.
2. Completed mass balance report (November 2018 – January 2019)
   - Updated and finalized report on chloride budget. Published final report on Water Resources Center website and included in this report as an appendix.

Final Report Summary:
The Activity 1 deliverables were finalized in the last reporting cycle, January 2019. The statewide chloride budget showed that water softeners were the largest chloride contributors to wastewater treatment plants and septic systems. The findings have implications for state policy, demonstrating that communities exceeding their wastewater limits for chloride can examine residential, commercial, and industrial softening for opportunities to reduce their chloride discharge. In the statewide chloride budget, road salt was the largest chloride source statewide, and fertilizer was also identified as a major source. However, the impacts of fertilizer use on chloride levels in surface waters and groundwater is not well understood, since fertilizer is applied over a large area statewide.

ACTIVITY 2: Develop best management practices to reduce salt due to water softening
Description: This activity will compare private and municipal water softening. An evaluation of municipal softening options will be conducted. Next this activity will evaluate the efficiency of various

types of private softening units and the effectiveness of units that do not use chloride for removal of hardness. From this evaluation of municipal water softening, private chloride-based water softening, and private non-chloride-based water softening, a matrix of options will be developed.

The matrix will form the framework for private landowners, municipalities and watersheds to make smart decisions about reducing chloride loading to protect Minnesota surface and groundwater. This will include an economic assessment considering the effectiveness and cost of the system and the operation. This activity will evaluate the use of an online tool to help parties evaluate and choose the best water softening options in any particular situation. Recommendations on the proper use of in-home units to reduce the amount of sodium chloride will be developed. Best management practices (BMPs) will also be developed for municipalities. Information will be developed about the negative impacts of softening on water quality so homeowners, municipalities, and watersheds are able to make informed decisions about water softening.

Summary Budget Information for Activity 2: **ENRTF Budget: $ 173,500**
Amount Spent: $ 173,500
Balance: $ 0

Outcome	Completion Date
1. Develop list of alternative methods to reduce sodium chloride use for water softening	*12/31/2017*
2. Evaluate capital and operational costs for alternatives	*6/30/2018*
3. Recommend best management practices	*12/31/2018*
4. Create framework for a tool to evaluate various alternatives	*6/30/2019*

Activity Status as of January 1, 2017:

1. Researching water softening options (July 2016 – January 2017)
   - Our team has researched existing methods for residential water softening as well as salt reduction strategies. Team members attended a MWQA trade show, used internet searches, spoke with water softener dealers, and visited big box stores to learn about the existing methods and ways to reduce chloride for residential water softening.
   - Team members examined current salt-based and no-salt methods for softening and salt use reduction, such as: physical specifications of water softeners; reverse osmosis; scale prevention and inducing technologies; template assisted crystallization; chelation; electrically induced precipitation; filters; and changes in plumbing, water use and calibration.
2. Survey of water conditioning professionals (November 2016 – January 2017)
   - The survey will provide data on water conditioning practices, such as use of iron filters, hardness settings, and salt use, that will be used to develop best practices for residential water softener use. The survey will also provide data on industrial softening practices.
3. Local case studies (September 2016 – January 2017)
   - Team members conducted interviews of city and other staff, and reviewed information found online to prepare case studies on chloride reduction for three cities (Jordon, Marshall, and St. Peter) and for the Shakopee Mdewakanton Sioux Community. The cities have chloride discharges that exceed the state limit and the Sioux Community needed to reduce the salt concentration in their stormwater pond because it is used for irrigation. The case studies discuss the actions taken by the communities to reduce their chloride as well as their effects on chloride concentrations in their wastewater discharge.

Activity Status as of July 1, 2017:

A status report was not requested for this time period.

Activity Status as of January 1, 2018:

1. Research water softening options (January 2017-January 2018)

- Our team has researched water softening methods for residential, commercial, and industrial users. These methods were identified through interviewing water quality professionals and searching for literature on water softening practices. The most common softening methods were listed for each user.

2. Develop matrix of residential water softening options (January 2017-January 2018)
   - Team members compiled information on residential water softening options and practices to reduce salt use from multiple sources. A framework has been drafted that compares salt savings, water savings, equipment life, cost, and other health or environmental concerns across water softening technologies and practices. This tool will be further developed for residential homeowners to compare and assess water softening options for salt reduction and potential cost savings.
3. Local case studies (January 2017 – January 2018)
   - Team members prepared eight case studies on municipal chloride issues that detail chloride reduction alternatives and actions taken by the communities to reduce their chloride. These case studies underwent review by the MPCA and have been published on the WRS website.

Activity Status as of July 1, 2018:

1. Finalize and disseminate matrices for residential and commercial water softening (January 2018 – July 2018)
   - Information on commercial water softening options was compiled into a matrix for commercial and industrial water users. Members of the Minnesota Water Quality Association reviewed the matrices for residential and commercial water softening, and final versions were published on the WRS website. Infographics and longer summaries of water softening options were also developed and published.
2. Draft review of water softening costs and benefits (January 2018 – July 2018)
   - A review was conducted of costs associated with water hardness, water softening methods, and environmental impacts of salt. Costs and benefits of water softening were highlighted and compared qualitatively, since the review found that little economic research has examined these issues. MPCA provided feedback on the draft and their comments were incorporated.

Activity Status as of January 1, 2019:

1. Created fact sheets for water softening issues in homes and communities. (August 2018 – January 2019)
   - Developed informational fact sheets for homeowners on chloride from water softening and best management practices for reduction. Created fact sheets on community- or watershed-scale chloride issues with guidance on investigating chloride sources and mitigating high chloride levels. Published fact sheets on WRC project website and disseminated to stakeholders. The fact sheets can be found in the appendix of this report
2. Finalized review of water softening costs and benefits (August 2018 – January 2019)
   - The review analyzing costs and benefits of water softening and other treatment alternatives was finalized and published on the WRC website (included in this report appendix).
3. Developed concepts for online tool on water softening (November 2018 – January 2019).
   - Outlined audience and scope of online tool. Discussed online tool with MPCA to align with their existing tools and future chloride work.

Activity Status as of July 1, 2019:

1. Completed the framework for an online tool on water softening to evaluate softening alternatives

Final Report Summary:

The Activity 2 deliverables were finalized in the last reporting cycle, January 2019. The review of softening costs and benefits found that while water softening can provide economic benefits to households by extending the lifespan of appliances and fixtures, there is little research evaluating the environmental impacts and costs of water softening. Limited research has indicated that optimizing softeners and installing centralized water softening can be cost-effective solutions for communities with chloride issues; however, their effects on chloride levels in wastewater discharge have not been evaluated, and these solutions may not be viable for all communities, depending on factors such as water quality, population, and economic status. Communities with elevated chloride in groundwater, surface water, or wastewater treatment plant effluent may need to employ multiple strategies to achieve meaningful and cost- effective chloride reductions.

ACTIVITY 3: Chloride transport through, and retention in, Minnesota soils

Description: A number of field sites across Minnesota will be chosen for collecting soil samples to measure the retention of chloride in soil moisture. Soil samples will be transported to St. Anthony Falls Laboratory, and sub-samples will be analyzed for soil properties such as soil classification, particle size distributions, hydraulic conductivity, moisture characteristics, organic matter and clay content, soil texture, initial chloride concentration, metal concentrations as Cd, Cu, Fe, Pb, and Zn and cation exchange capacity.

Soil samples will then be installed into column test equipment and experiments will be performed to simulate continuous (septic) or seasonal chloride loading (snowmelt water), and rinsing (by infiltrating rainwater or irrigation); conditions typically observed in Minnesota climates. Sequences and rates of chloride-laden water and freshwater applications will be varied in the laboratory tests. Important criteria such as flow rate, chloride concentration, saturation time, and temperature will either be measured or controlled during the experiments. After the column tests are complete, the soil properties and characteristics will be analyzed again to identify any changes due to chloride storage and transport.

The results of the column experiments will be analyzed to determine the residence time of salt and relate these to soil properties. An existing chloride transport model will be enhanced and further developed to incorporate chloride residence time from given soil properties based the results of the experiments. The transport model will then be able to predict the response of chloride transport into surface water and groundwater after reductions in salt application. The residence time is specifically of interest to management personnel and to understand the long-term impact of de-icing and softening salt reductions on chloride transport to receiving water bodies.

Summary Budget Information for Activity 3:	**ENRTF Budget:**	**$ 234,000**
	Amount Spent:	**$ 234,000**
	Balance:	**$ 0**

Outcome	Completion Date
1. Identify soil properties that affect, and are indicators of, chloride retention in soils	*3/31/2017*
2. Quantify chloride retention capacity and lag time of release from soils	*8/31/2018*
3. Enhance and further develop a predictive simulation model that can predict the transport and time lag in movement of chloride through the soil.	*6/30/2019*

Activity Status as of January 1, 2017:

1. Literature Review (July 1 - December 2016)
    - A thorough literature review of over 45 articles found that chloride retention was observed in soils, especially soils with organic matter that was susceptible to microbial chlorination. Release of chloride, however, via dechlorination and/or ion exchange was also documented. Chlorination/dechlorination was hypothesized as being dependent on aerobic/anaerobic conditions. The amount of retention/release of chloride was shown to depend on water residence time (soil characteristics), chloride concentration, and temperature (for supporting microbes). In one study, simulations showed that chloride transport within the unsaturated zone is mostly vertical and driven by molecular diffusion. Chloride was retained in the saturated zone for the first 10 years of simulation, but afterwards the soil became a long-term source of chloride to groundwater.
    - Previous studies have shown that most soils in Minnesota are Sandy Loam, Sandy Clay Loam, Sandy Clay, or Loamy Sand.
2. Test chloride-soil interactions using simplified (laboratory) soil conditions:
    - Sandy clay loam and sandy loam have been selected as representative soil types to be used in preliminary experiments. At first, uniform soils will be packed into columns with uniform compaction to represent ideal conditions. These experiments will evaluate several variables to determine most significant and important characteristics for more complex future experiments.

3. Collect Soil Cores (~5 cores per ~6 subwatersheds representing most common MN Soils)
    - Soil corers were evaluated and two soil corers were purchased for use in soil core collection.

Activity Status as of July 1, 2017:
A status report was not requested for this time period.

Activity Status as of January 1,2018:
1. Test chloride-soil interactions using simplified (laboratory) soil conditions:
    - Sandy clay loam, sandy loam, and organic material (compost) were obtained and used in column experiments for method development, calibration, and instrumentation testing. Columns were constructed and filled with various mixes of soil and organic matter, and cycles of fresh water and salt water were applied to the mixes within the columns. This process revealed unexpected challenges with instrumentation and obtaining accurate measures of low flow rates and electrical conductance of the water, thus requiring more effort. New instruments, however, were obtained, tested, and found to provide accurate water level measurements for the flow rates expected in the columns. The experiments are expected to proceed quickly and will be ready for natural soil columns. These experiments will evaluate several variables to determine most significant and important characteristics for more complex future experiments.
2. Collect Soil Cores (~5 cores per ~6 subwatersheds representing most common MN Soils)
    - Soil core collection will begin in Spring and/or Summer 2018.

Activity Status as of July 1, 2018:
1. Test chloride-soil interactions using simplified (laboratory) soil conditions:
    - Experimental challenges in testing soil conditions consistently and accurately have resulted in a short-term delay in data collection. The experiments have been simplified to reduce error, improve consistency, and generate data from many columns simultaneously which will increase the rate of data collection. The results of the experiments and recommendations provided will not be diminished due to these challenges or simplifications.
2. Collect Soil Cores (~5 cores per ~6 subwatersheds representing most common MN Soils)
    - Soil core collection will begin before winter 2018.

Activity Status as of January 1, 2019:
1. Test chloride-soil interactions using simplified (laboratory) soil conditions:
    - An automated data collection system has been developed to collect data from 15 soil columns simultaneously. This system will allow for continuous experiments and high-resolution data collection.
2. Collect Soil Cores
    - The project team met with soil specialists and MnDOT partners to determine the best location for collecting the soil cores.
    - Soil core collection will be collected in the next half-year period with analysis to follow immediately thereafter.

Activity Status as of July 1, 2019:
1. Test chloride-soil interactions using simplified (laboratory) soil conditions:
    - Soil columns to measure salt latency in sandy loam, sandy loam with 10% organic material, and silt loam are in progress. The purpose of the soil columns is to measure how much fresh water is required to flush out nearly all of the salt within the soil columns by tracking the mass balance of salt between salt water events and fresh water events. The amount of freshwater required to rinse sale from the soil can be converted to a cumulative rainfall depth and then compared to typical summer rainfall totals for Minnesota. If summer rainfall depths in Minnesota are less than the freshwater needed to rinse salt, then salt is expected to accumulate in these soil types.
2. Collect Soil Cores
    - Soil cores were collected along highway 52 in Mendota Heights, where MnDOT has detailed records of salt application and the road has not been reconstructed for many years. The soils in this area are sandy loam, sandy loam with organics, and silt loam. These conditions correspond with soil columns tested in

the laboratory. The soil cores were sent to the soil analytical laboratory on St. Paul campus for analysis to determine if there is a relationship between soil properties and salt content. In addition, analysis will determine if there is an inverse relationship between salt content and distance from the roadway (less salt as distance increases). The combination of salt application records and soil salt content may indicate a buildup of salt over several years of road salt application, suggesting that salt is held within the soils and is not washed out during summer rainfall events. This field data can then be compared to laboratory soil columns for verification.

Final Report Summary:
The purpose of this project was to measure the transport of chloride from road salt through soils commonly found in Minnesota. Previous research in Minnesota and other areas have shown that chloride does not always move freely with water but can interact with soil in unexplained ways. Involved processes appear to be anion exchange, temporary storage and subsequent release in organic compounds, and interactions with microorganisms, among others. Temperature and soil saturation levels may also impact the transport of chloride. The result is periods of chloride capture in soil and other periods of chloride release, which impacts chloride transport and can ultimately impact surface and groundwater resources.

This portion of the project used column experiments to illustrate chloride movement through three soils: silt loam, sandy loam, and sandy loam with 10% organic material which are common in Minnesota. The experiments totaled five phases of dosing with road salt followed by rinsing without road salt. The column experiments showed that chloride is sometimes stored within the soil and is released at other times. The trend approaching steady state was consistent with the three soils: Phase 1 dosing at 1000 mg/L resulted in the effluent approaching ~85% of the influent, indicating that ~15% of the salt dosing was not leaving the columns. Phase 2 dosing with 640 mg/L resulted in the effluent approaching the influent concentration, indicating that there were remnants of the phase 1 dosing leaving the soil columns. Phase 2 dosing with 1000 mg/L resulted in the effluent exceeding the influent concentration, indicating that the stored material had been adsorbed and was now released into the column effluent. Phase 3 dosing at 1400 mg/L resulted in the effluent approaching ~85% of the influent increased concentration. Phases 4 and 5 dosing at 1000 mg/L resulted in an effluent concentration that was higher than the influent concentration, which could be interpreted as a continued release of the chloride that was stored during Phase 3. It is unclear from these experiments what factors control chloride capture and release. Storage in capillary spaces in the soil could explain the results of phases 1, 4 and 5, but the result of Phase 2 indicates that adsorption of chloride is taking place. This explanation is contrary to the accepted process for chloride movement and fate in soils and needs to be investigated further.

Field cores were also collected at two sites targeting silt loam and sandy loam, though texture analysis revealed that the cores were primarily sandy clay loam with portions of silt loam and sandy loam. The results of the field cores demonstrate that chloride is present in the soil along roadways that are treated with deicing road salt. Sodium adsorption ratio and saturation extract electrical conductivity coincided with chloride content, which is expected. Other properties such as cation exchange capacity, organic content, and soil texture did not consistently correlate with chloride content and thus cannot be used to predict chloride presence or transport.

Although it is not clear from the column experiments or field cores which soil or hydraulic properties cause capture or release of chloride from road salt, the data demonstrate that chloride is stored within the soil, requiring a long period of freshwater rinse (tens to hundreds of years) before it can leave, and that chloride in our groundwater will be a legacy for some time even after alternative solutions to chloride-based salts have been established and accepted.

V. DISSEMINATION:

Description: Dissemination and transfer of new knowledge and technology will be directed towards homeowners, practitioners, regulatory units of government, and other interested stakeholders. The project team has a long history of providing training and dissemination of science through the Water Resource Center, the Erosion and Stormwater Certification Program and the MN Road Salt Applicator training. Information learned in this study will be incorporated into this and other certification curriculum. The team is well equipped to communicate and disseminate results. Outreach will occur through a variety of established formats. The results will be incorporated into MPCA chloride reduction programing and policy.

Knowledge transfer will also be completed through its written and electronic communications streams including St. Anthony Falls Laboratory's UPDATES, a quarterly stormwater research newsletter distributed to over 2,400 subscribers and the University of Minnesota Extension Water Resources News published 4-6 times per year. The team will also seek to include information in the Minnegram newsletter published by the Water Resources Center and in the Seiche printed by Minnesota Sea Grant. In addition, one or more journal articles will be submitted for publication from the results of this project.

The team is also well equipped to engage in dialogue and collaboration with public entities including watershed districts, municipalities, counties, universities, the Minnesota Cities Stormwater Coalition, and statewide entities working on stormwater management. Finally, the team is able to collaborate and communicate with researchers and educators across multiple campuses spread throughout the state.

Status as of January 1, 2017:

The project is currently in the data collection and measurement phase and thus no data or results are available for dissemination. However, the existence and intentions of the project have been communicated with stakeholders and target audiences (cities, homeowners, associations, etc.) and will continue throughout the project. The following presentations have discussed the project and preliminary results:

- Minnesota Water Quality Association Annual Convention in Lakeville, MN in October 2016. The project scope and objectives were presented and discussed with stakeholders and water quality professionals.

Status as of July 1, 2017:

A status report was not requested for this time period. The following presentations have discussed the project and preliminary results:

- May 9, 2017. "Recent, Current, and Developing Stormwater Research at the University of Minnesota-TC." Oral Presentation. 2017 Water Technology Export Roundtable. Duluth, MN.
- March 10, 2017. "Recent, Current, and Developing Stormwater Research at the University of Minnesota." Oral Presentation. 2017 CCWMO Stormwater Workshop. Chaska, MN.
- A presentation on the project scope, objectives, and preliminary analyses was given at the Minnesota Onsite Wastewater Association (MOWA) Conference in Duluth, MN January 2017. Implications of water softening for onsite wastewater treatment were discussed with septic system professionals and educators.

Status as of January 1,2018:

The project is currently in the data collection and measurement phase and thus no data or results are available for dissemination. However, the existence and intentions of the project have been communicated with stakeholders and target audiences (cities, homeowners, associations, etc.) and will continue throughout the project.

Status as of July 1, 2018:

The project is currently in the data collection and measurement phase and thus no data or results are available for dissemination. However, the existence and intentions of the project have been communicated with stakeholders and target audiences (cities, homeowners, associations, etc.) and will continue throughout the project. The following presentations have discussed the project and preliminary results:

- Fact sheets on residential and commercial/industrial water softening were published on the WRC website in June 2018, along with matrices of water treatment options outlining costs, water use, energy use, and applications.
- Results of the statewide chloride budget were presented at the EWRI World Environmental & Water Resources Congress in Minneapolis, MN in June 2018. The event was attended by environmental engineers and municipal stakeholders, and implications of chloride pollution were discussed in the presentation.

- Research updates on the statewide chloride budget were disseminated through the MOWA Little Digger newsletter for septic system professionals in April 2018.
- March 8, 2018. Andy Erickson presented "Permeable Pavement, Winter, and Roadsalt" Webcast, co-presented with Ryan Winston, Ohio State University. Chesapeake Stormwater Network. https://cwp.adobeconnect.com/_a1124522395/pkvxxe16bmx3
- February 22, 2018. Andy Erickson presented "Chloride accumulation and transport research in Minnesota" Webcast, co-presented with William Herb and Benjamin Janke. Chesapeake Stormwater Network. http://epawebconferencing.acms.com/p1txow4jjxu/
- A poster displaying preliminary results of the statewide chloride budget was presented at the Water Resources Assembly and Research Symposium at University of Minnesota in January 2018, an event attended by researchers, students, and faculty across the campuses.

Status as of January 1, 2019:

The project is currently in the data collection and measurement phase and thus no data or results are available for dissemination. However, the existence and intentions of the project have been communicated with stakeholders and target audiences (cities, homeowners, associations, etc.) and will continue throughout the project. The following presentations have discussed the project and preliminary results:

- Fact sheets on water softening best management practices for homeowners and communities were published in January 2019 and disseminated to stakeholders in Douglas County.
- Educational slides on chloride pollution and impacts of water softening were created and disseminated through septic system trainings conducted by the University of Minnesota Onsite Sewage Treatment Program in January 2019.
- We were interviewed on our statewide chloride budget and water softening impacts for The Changing Earth project. The interview was published on their website in November 2018 and will be used as an educational tool for classrooms.
- The chloride budget results were presented to members of the Minnesota Groundwater Association, which includes professionals from water quality organizations and state agencies, as well as the Metropolitan Council Industrial Waste & Pollution Prevention group in October 2018. Methods to estimate chloride loading from water softeners and implications for wastewater treatment were discussed.
- Water softening research was also presented at the National Onsite Wastewater Recycling Association (NOWRA) Mega-Conference in Bloomington, MN in October 2018. Water softening impacts were discussed among septic system regulators, educators, and professionals.
- The chloride budget results were presented at the Minnesota Water Resources Conference in Saint Paul, MN in October 2018, which was attended by many state agencies, consulting groups, and researchers. Impacts of water softening and other chloride sources were discussed.
- A seminar was given on chloride from water softening and other sources for the Water Resources Sciences (WRS) department in October 2018. Chloride research and environmental impacts were discussed with university students, staff, and faculty. The event was live-streamed and published on the WRS website, and members of state agencies were in attendance online.
- Team members collaborated with the MPCA and MWQA to design a water softening exhibit for the State Fair Eco-Experience. Team members volunteered at the State Fair in August 2018 to man the exhibit and talk with fairgoers about water softening best practices to reduce chloride pollution.
- An article on the statewide chloride budget results was included in the WRC Confluence newsletter in July 2018. The research on water softening was featured by Minnesota Public Radio (MPR) and was subsequently picked up and disseminated to other news outlets by the Associated Press, including the Pioneer Press.
- Information learned through this project on softening is also regularly disseminated to participants of the MPCA's Smart Salting Level 1 and 2 classes (July 2018-present).
- July 26, 2018. "Road Salt Research at UMN." Oral Presentation. Legislative Water Commission. St. Paul, MN.

Status as of July 1, 2019:

The following presentations have discussed the project and preliminary results:

- Major findings from this research have been incorporated into the draft MPCA Statewide Chloride Management Plan. They have also been disseminated through presentations at MPCA Chloride Reduction Rallies in St. Paul, Duluth, and Alexandria (May-June 2019).
- A fact sheet was published to the WRS website in June 2019 with a description of the project and its major findings.
- Findings from this research were featured in a second MPR news article on chloride issues faced by many Minnesota communities.
- Tours of St. Anthony Falls Lab have described progress and demonstrated the laboratory soil column setup to various stakeholders and practitioners.

Final Report Summary:

VI. PROJECT BUDGET SUMMARY:

A. ENRTF Budget Overview:

Budget Category	$ Amount Spent	Overview Explanation (Actual)
Personnel:	$ 394,615	• Project manager at 4% FTE each year for 3 years ($23,591); • Research Associate at 30% FTE for 3 years ($90,357); • Research Associate at 6% FTE for 3 years ($13,909); • Research Fellow at 50% FTE for 3 years ($133,087); • 1 graduate research assistant at 50% FTE each year for 3 years ($103,268); • Junior Scientist at 4% for three years ($24,575); • Junior Engineer Trainee at 25% for 3 years ($2,571); • Editor at 2.5% time for 3 years ($3,075).
Professional/Technical/Service Contracts:	$95,411	Contract with Connie Fortin to provide expertise and experience with data collection and analysis related to road salt and water ($66,300); Visiting Professor (Peter Weiss) will be on-site 12 weeks each summer and work 1/4-time on the project ($29,111).
Equipment/Tools/Supplies:	$6,932	Analytical laboratory charge for soils analysis and Misc. Supplies for experimental setup and analysis.
Capital Expenditures over $5,000:	$	
Fee Title Acquisition:	$	
Easement Acquisition:	$	
Professional Services for Acquisition:	$	
Printing:	$	
Travel Expenses in MN:	$43	Travel to sites to collect samples. 2500 miles @ $0.56/mi.
Other:	$	
TOTAL ENRTF BUDGET:	**$497,000**	

Explanation of Use of Classified Staff: N/A

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

Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation: 1.71 FTE's over 3 years.

Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation: 0.177 FTE's over 3 years.

B. Other Funds:

Source of Funds	$ Amount Proposed	$ Amount Spent	Use of Other Funds
Non-state			
	$	$	
State			
University of Minnesota (in-Kind Support)	$233,103	$258,440	Unrecovered F&A at 52% MTDC
John S. Gulliver (In-Kind Support)	$68,611	$75,658	In-kind time for supervision of project, 12% of appointment
Brooke Asleson (In-Kind Support)	$22,500	$23,715	Staff from the Minnesota Pollution Control Agency will donate 5% time to gather information regarding salt used and its impacts related to septic systems and wastewater treatment plants.
TOTAL OTHER FUNDS:	**$324,214**	**$357,813**	

VII. PROJECT STRATEGY:

A. Project Partners:

Project Partners Not Receiving Funds:

Minnesota Pollution Control Agency: Andrew Ronchak, Brooke Asleson, Scott Kyser, Rachel Olmanson

Project Partners Receiving Funds:

Fortin Consulting: Connie Fortin, Carolyn Dindorf, Lauren Schulzetenberg, Katie Farber, Jessica Jacobson: $66,300

Peter T. Weiss (Visiting Professor from Valparaiso University) $29,111

B. Project Impact and Long-term Strategy:

Understanding the relationships between salt usage and chloride in our lakes, streams and groundwater will allow regulators and water resource managers to reduce our chloride load strategically, which will protect the environment at minimum cost. The predictive tools developed with this project will be valuable to estimate future impacts of our current salt usage and expectations of the length of time required to recover the water quality of our lakes, streams and groundwater resources. For example, is the current strategy sufficient to protect our lakes, or will the reduction of chloride concentration stop short of the goal? How long until our groundwater tastes salty to the citizens of the state of Minnesota? Do we need better long-term solutions? The impact of the research will help prioritize and focus salt reduction strategies for long-term solutions.

C. Funding History: N/A

VIII. FEE TITLE ACQUISITION/CONSERVATION EASEMENT/RESTORATION REQUIREMENTS:

A. Parcel List: N/A

B. Acquisition/Restoration Information: N/A

IX. VISUAL COMPONENT or MAP(S):
(provided with Work Plan)

X. RESEARCH ADDENDUM:
(Provided with Work Plan)

XI. REPORTING REQUIREMENTS:
Periodic work plan status update reports will be submitted not later than January 1, 2017; July 1, 2017; January 1, 2018; July 1, 2018, January 1, 2019, July 31, 2019. A final report and associated products will be submitted before December 31, 2019.

Final Attachment A (Budget Sheet): Budget Detail for M.L. 2016 Environment and Natural Resources Trust Fund Projects
Project Title: Understanding Impacts of Salt Usage on Minnesota Lakes, Rivers, and Groundwater
Legal Citation: ML 2016, Chap. 186, Sec. 2, Subd. 4n.
Project Manager: John S. Gulliver
Organization: University of Minnesota
M.L. 2016 ENRTF Appropriation: $497,000
Project Length and Completion Date: 3 Years, June 30, 2019
Date of Report: December 31, 2019

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Activity 1 Budget	Amount Spent	Activity 1 Balance	Activity 2 Budget	Amount Spent	Activity 2 Balance	Revised Activity 3 Budget 10/07/2019	Amount Spent	Activity 3 Balance	Revised Total Budget 10/07/2019	Total spent	TOTAL BALANCE
BUDGET ITEM	*Estimate statewide sodium chloride use*			*Develop best management practices to reduce salt due to water softening*			*Chloride transport through, and retention in, Minnesota soils*					
Personnel Overall (Wages and Benefits)	$66,937	$66,937	$0	$129,763	$129,763	$0	$197,915	$197,915	$0	$394,615	$394,615	$0
Personnel: Professor (J. Gulliver), Supervisory and Analysis, 4% FTE (75% salary, 25% benefits) each year for 3 years.Estimated total $23,696												
Personnel: Research Associate (S. Heger), Supervisory, data gathering and analysis related to water softeners, 30% FTE (75% salary, 25% benefits) each year for 3 years. Estimated total $83,174												
Personnel: Research Associate (W. Herb), Analysis, 6% FTE (75% salary, 25% benefits) each year for 3 years.Estimated total $17,133												
Personnel: Editor (C. Hansen), Proof and edit documents, 2.5% FTE (78% salary, 22% benefits) each year for 3 years.Estimated total $3,826												
Personnel: Research Fellow (A. Erickson), Field sample collection, laboratory experiments and Analysis, 50% FTE (75% salary, 25% benefits) each year for 3 years. Estimated total $131,242												
Personnel: Graduate Student, Data gathering and analysis related to water softeners, 50% FTE (53% salary, 47% benefits) each year for 3 years. Estimated total $109,700												
Personnel: Junior Scientist (A. Ketchmark), Field sample collection and experimental apparatus, 4% FTE (78% salary, 22% benefits) each year for 3 years. Estimated total $6.557												
Personnel: Junior Engineer Trainee, Field sample collection and laboratory experiments, 25% FTE (100% salary) each year for 3 years. Estimated total $19,287												
Professional/Technical/Service Contracts												
Professional/Technical/Service Contracts: Contract with Fortin Consulting Inc. to provide expertise and experience with data collection and analysis related to road salt and water softening. 11.7% FTE (100% Salary) each year for 3 years.	$22,562	$22,562	$0	$43,738	$43,738	$0				$66,300	$66,300	$0
Professional/Technical/Service Contracts: Contract with Peter Weiss (Visiting Professor) to provide oversight and expertise with column experiments. 6% FTE (100% salary) each year 3 years.							$29,111	$29,111	$0	$29,111	$29,111	$0
Equipment/Tools/Supplies												
Equipment/Tools/Supplies: Analytical laboratory charge for soils analysis $1,687							$1,687	$1,687	$0	$1,687	$1,687	$0
Equipment/Tools/Supplies: Misc. Supplies for experimental setup and analysis $5,244							$5,244	$5,244	$0	$5,244	$5,244	$0
Travel expenses in Minnesota												
Travel: To sites to collect samples. 77 miles @ $0.56/mi $43							$43	$43	$0	$43	$43	$0
COLUMN TOTAL	**$89,499**	**$89,499**	**$0**	**$173,501**	**$173,501**	**$0**	**$234,000**	**$234,000**	**$0**	**$497,000**	**$497,000**	**$0**