2015 Project Abstract
For the Period Ending June 30, 2015

PROJECT TITLE: Prioritizing Future Management of North Shore Trout Streams
PROJECT MANAGER: Lucinda B. Johnson
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FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: M.L. 2015, Chp. 76, Sec. 2, Subd. 08a

APPROPRIATION AMOUNT: $ 416,000

Overall Project Outcomes and Results

Water temperature is generally considered one of the primary physical habitat parameters determining the suitability of stream habitat for fish species, but climate change is threatening these cold-water habitats. The primary goal of this project was to provide the information to ensure that restoration and management are targeted at stream reaches essential to ensuring long-term sustainability of cold-water fisheries. Project goals were: (1) collect temperature data and map the locations of thermal refuges in "top tier" North Shore trout streams; (2) determine the environmental characteristics (flow, geology, and land use / land cover) associated with cold-water refuges, and predict areas most resilient to climate change; and (3) recommend actions to protect / manage these cold-water features. We developed an inventory and database of cold water tributaries and features in North shore streams based on manual surveys (n = 121 stream reaches; of which 83 were found to contain cold-water features), and continuous monitoring (n = 36 locations); developed empirical models predicting the probability of encountering a cold-water tributary or a reach with a cold-water feature; assessed the relative influence of climate versus riparian shading on stream temperature; developed management recommendations to promote the persistence of cold-water habitat under future climate conditions. Fishery personnel were involved throughout the project development and execution to help assess results and develop recommendations. Recommendations for future data needs included: depth to bedrock, extent of bedrock fracturing, more detailed map of Quaternary Geology. Additional temperature monitoring is recommended to include locations within and outside cold-water features. Management actions focused on restoring or enhancing riparian vegetation near high value streams with narrow channels, streams in smaller subcatchments, and, where groundwater seeps enter warmer channels, maintaining tree cover to preserve lower groundwater temperatures. Data will be posted on a public website for distribution (https://data.nrri.umn.edu/data/).

Project Results Use and Dissemination

MN Trout Unlimited personnel have been involved in all aspects of this project, starting with the study design, development of sampling methods, site selection, data analysis / interpretation, and information dissemination. MN DNR staff were consulted extensively in site selection; data from MN DNR temperature surveys have been incorporated into modeling efforts. Personnel from the Minnesota Spring Survey were also consulted periodically to exchange site selection information.

We have given periodic talks to fishing organizations, attended fishing expos, and will meet with fishing organizations and DNR staff during the coming winter to further disseminate results and discuss recommendations. PI Johnson and student Jonathan Utecht made a presentation to the Arrowhead Fly Fishers group on February 16, 2015 to invite volunteers; they also attended two additional events at the Nemadji Water Fest in Carlton County (March 12th) and the Great Waters Fly Fishing Expo (March 19-20) in St. Paul. Informal interactions between project personnel and the angling community occurred at MN Trout Unlimited and MN Steelhead Association meetings throughout the project.

Environment and Natural Resources Trust Fund (ENRTF) M.L. 2015 Work Plan Final Report

Date of Report: February 7, 2019

Date of Next Status Update Report: January 31, 2019

Date of Work Plan Approval: June 11, 2015

Project Completion Date: June 30, 2018*

- As per request from project team and approval by LCCMR staff, the delivery of the final report was delayed to December 31 to provide further opportunity to complete additional analysis and modeling.

Does this submission include an amendment request? Yes

PROJECT TITLE: Prioritizing Future Management of North Shore Trout Streams

Project Manager: Lucinda B. Johnson

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Location: Cook, Lake, St. Louis

Total ENRTF Project Budget:	**ENRTF Appropriation:**	**$ 416,000**
	Amount Spent:	**$ 416,000**
	Balance:	**$ 0**

Legal Citation: M.L. 2015, Chp. 76, Sec. 2, Subd. 08a

Appropriation Language:
$357,000 the first year is from the trust fund and $59,000 the first year is from the Great Lakes protection account to the Board of Regents of the University of Minnesota Duluth for the Natural Resources Research Institute to identify key areas in North Shore streams that supply the cold groundwater essential to sustaining trout fisheries in order to focus habitat restoration, protection, and management efforts on the areas that are most essential for long-term stream health and sustainability. This appropriation is available until June 30, 2018, by which time the project must be completed and final products delivered.

I. PROJECT TITLE: Prioritizing Future Management of North Shore Trout Streams

II. PROJECT STATEMENT:

Water temperature is generally considered one of the primary physical habitat parameters determining the suitability of stream habitat for fish species. Stream temperature affects individuals throughout their life cycle, with impacts on mortality, metabolism, growth, behavior, and reproduction. In Minnesota's North Shore trout streams, cold groundwater is needed to keep stream temperatures below the thermal limit for trout and steelhead growth and survival, and for providing base flow during summer. Yet groundwater is not abundant in this region and thus is particularly important for sustaining these prized cold-water fisheries as the climate warms. MNDNR and NGOs such as Minnesota Trout Unlimited are focusing habitat restoration and protection efforts on a subset of North Shore watersheds most likely to sustain cold-water fisheries and quality angling into the next century. These groups need detailed information on the locations of groundwater discharge areas in priority watersheds to most effectively target habitat restoration and watershed protection efforts.

Trout streams are a scarce resource statewide, comprising just 7% of all stream and river miles. The North Shore of Lake Superior has one of the largest concentrations of trout streams in Minnesota and is a major recreational draw. However, most streams lack substantial groundwater and are therefore particularly susceptible to climate change. While climate change can impact these streams in many ways, previous research has shown that increased water temperature is the greatest threat to the persistence of trout and steelhead fisheries in North Shore streams. Certain tributaries and stream reaches with localized groundwater inflows provide thermal refuges (stretches of colder water which trout actively select), allowing trout to survive during periods when much of the stream approaches or exceeds the stressful or lethal temperature thresholds. These streams also have higher base flows, providing habitat during drought periods. Streams with more cold-water refuges are most likely to maintain trout and steelhead populations as air temperatures increase with global climate change. Anecdotal evidence has identified some of the thermal refuges in North Shore streams, but no systematic identification of these important areas has been undertaken, nor has site-specific data collection (stream temperature and channel morphology) been done. **This project will provide the scientific data essential to ensure that restoration, protection, and management are targeted at those reaches essential to ensuring long-term sustainability of cold-water fisheries.**

Our goals are to: (1) collect site-specific temperature data and map the locations of thermal refuges in "top tier" North Shore trout streams (~15 to 20 watersheds); (2) determine the regional and local channel characteristics, flow, geology, and land use / land cover associated with cold-water refuges, and predict which areas are most resilient to climate change; and (3) recommend targeted actions to increase the likelihood that these cold-water refuges will continue to exist in the future.

We will: (1) conduct extensive field surveys of "top tier" North Shore streams to locate reaches with locally cooler water temperatures and document soils, streamside vegetation types, and channel conditions at those sites; (2) document presence/absence of fish, particularly salmonids; (3) map locations of cold-water refuges and their association with fish presence/absence; (4) use local geomorphic data, new LiDAR tools, land cover, and soils data to determine the regional and local conditions that support cold-water refuges; (5) use hydrologic and temperature models to predict future stream flow and temperature based on climate projections; and (6) collaborate with MNDNR, Minnesota Trout Unlimited and other fishing groups to identify appropriate protection and restoration actions. This information will assist MNDNR, Minnesota Trout Unlimited, and other citizen angling groups and management entities in identifying priority locations for habitat restoration, protection, and management. Citizen volunteers from Minnesota Trout Unlimited, other fishing groups, and tribal entities (organized by the 1854 Treat Authority) will play an important role in collecting stream temperature data. Field protocols and location data encompassing cold-water refuges will be shared with the Minnesota Spring Inventory project, led by the MNDNR and MN Geological Survey.

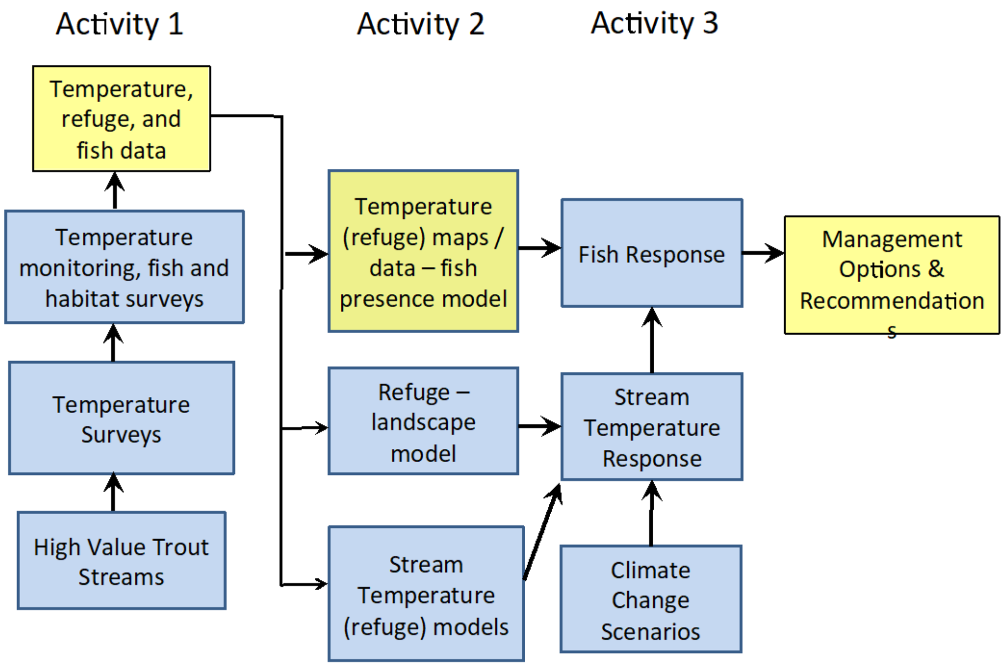

Figure 1. Flow diagram of tasks and activities. Yellow boxes represent outcomes and deliverables.

III. OVERALL PROJECT STATUS UPDATES:

Project Status as of: January 31, 2016

Starting on July 1, 2015 through present, most work was performed within Activity 1. A site selection model was developed to predict potential groundwater input from surficial geology, soils, and elevation data. The sample pool of catchments was randomly selected along a gradient of groundwater potential; the first field season focused on high-value streams identified by stakeholders and catchments which also had fish and/or temperature records provided by cooperators. Field supplies were purchased to outfit volunteers with temperature survey equipment (fast-reacting thermometers, GPS units, clipboards, etc.) and for NRRI monitoring of stream temperature. Volunteers surveyed 20 catchments in 2015 and discovered 70 individual cold-water refuges among 13 catchments. The volunteers also detected 150 potential barriers to fish passage, including 68 beaver dams. Coordinates were saved for all these unique features. The NRRI field staff deployed stream temperature loggers in six locations and assessed the fish community within four catchments. Lessons learned were: 1) volunteer recruitment proved more difficult than expected; and 2) many stream catchments were more difficult to walk than anticipated and required more time than anticipated to complete temperature surveys. Effort is underway to attract new volunteers to the project, and temperature survey protocol for volunteers will be revised to increase their efficiency while still collecting critical data. Two workshops were held with project team members, partners, and cooperators to discuss the overall project objectives and methods, 2015 accomplishments, and to plan for the 2016 field season. Collaborators include MNDNR Fisheries, MNDNR Spring Survey, MPCA, MN Trout Unlimited, and citizen volunteers.

Project Status as of: June 30, 2016

The winter and spring were spent developing the project database, conducting quality control on the project data collected in the fall, inputting the data into the database, and planning activities to recruit volunteers. Site selection and preparation for the summer field campaign was the dominant activity; 150 sites were identified based on the project criteria. Each site was reviewed using Google Earth and aerial photography to ensure lack of surface water within 1 km upstream and to identify potential access points. Site maps were created showing access points and delineating upstream and downstream points for the sample reach. Due to the time required to traverse each reach, the length of the sample reach was reduced from 1 km to 500 m this year. Due to the poor response from volunteers, we hired a two-person team whose sole responsibility was to deploy temperature loggers and to map stream temperature.

Several meetings were conducted with the extended project team and collaborators (MNDNR Fisheries, members of the MN Spring Survey project, MN Trout Unlimited volunteers) and the immediate project team and field crews to plan the summer field campaign and train individuals involved in the field effort.

Project Status as of: January 31, 2017
In summer 2015, temperature surveys were conducted on 19 stream segments, with 15 of those completed by volunteers and 4 completed by NRRI crews. Fourteen of these segments contained cool-water locations. In the summer of 2016, 102 stream segments were surveyed, with volunteers completing 23 and NRRI crews surveying 79 segments. Sixty-nine of these segments contained cool-water inputs. As of this reporting period, 121 segments have been surveyed (38 by volunteers and 83 by NRRI crews), with 83 segments found to contain cool-water locations.

All data from the field seasons has been entered into spreadsheets, QC'd, and backed up. All of the temperature loggers have been downloaded, and the files are being checked for data integrity.

Project Status as of*:* October 15, 2017
A validation survey was conducted in August to verify the existence of cool water within streams where models predicted such features to occur. Validation confirmed that 100% of sites (n = 15) with predicted cool water were found to have at least one cool-water feature.

Electrofishing surveys to detect trout were conducted in August and September at stream segments that intersected with any cool-water refuges that were found and/or temperature logger locations. During the surveys, general habitat information also was collected. A total of 59 stream segments were electrofished, and brook trout were found in 30 of these segments. An MS thesis is being developed based on these data.

During this period, we focused on gathering all the data together to create models that will predict the landscape context in which cold water, especially groundwater, can be found in North Shore streams. Thus, we compiled large amounts of landscape and temperature data. Landscape characteristics from 11 data layers with a total of 176 variables were compiled for 4,016 stream segment watersheds (NHDPlus catchments) in the North Shore region. In addition to the stream temperature data collected by NRRI, we assembled and QC'd stream temperature data collected by MNDNR from 155 sites in 2016. PRISM air temperature data were downloaded for sites in the proximity of stream sites. Models were created to classify cold/warm streams by simple linear regression modelling between weekly stream temperature and air temperature and by a classification tree method between stream temperature data and landscape variables. In addition, a simple empirical stream temperature model was used to estimate the potential influence of riparian shading and groundwater inputs. In mid-June, we deployed temperature loggers to 36 sites for recording air, ambient stream, and "cold spot" temperature throughout the summer to provide extra data for the models.

Project Status as of*:* January 31, 2018
Stream temperature models were assembled for two cold-water refuge sites that were monitored in the 2016 and 2017 field seasons. The models are being calibrated for current conditions and were used to predict the change in water temperature for several future climate scenarios, as part of Outcome 3.

Final Report Summary: December 31, 2018
Since the last report, we have used the stream temperature data collected by NRRI and MNDNR to develop models predicting the presence of groundwater and the presence of cold water in North Shore streams. Two different models were developed, predicting: 1) presence/absence of cold-water features; and 2) actual mean July mean, minimum and maximum July temperature. We then used a "weight of evidence" approach from these model predictions to predict the tributaries with a high probability of encountering a cold-water feature. Maps were developed to depict the location of these cold-water tributaries and reaches with cold-water features; a database was developed showing the location of sampled streams along with their status with respect to 1) observation of cold-water features; 2) existence of cold-water tributaries; and 3) no cold-water features. In addition, we created stream temperature models for several tributaries and used them to project future changes in stream temperature, and we studied the potential for mitigating temperature changes with increased riparian shading. Throughout this project, a member of the angling community was embedded in the project planning meetings, participated in project meetings in which data and models were evaluated, provided perspectives on data and outreach products, and has assisted in the development of management recommendations. This individual will be assisting with further outreach to the angling community throughout the coming spring (2019).

Overall Project Outcomes and Results:

1. Qualitative inventory of cold-water refuges (either tributaries or distinct features) in a set of high-value North Shore trout streams.
2. Empirical models to predict the major determinants of cold-water refuges from local and landscape features.
3. Deterministic and empirical models predicting the potential impacts of climate change on cold-water fish habitat.
4. Additional stream temperature data (instantaneous and warm months) for critical North Shore streams to add to the knowledge base and database at NRRI.
5. Management recommendations for prioritizing activities for restoring critical cold-water fish habitat.

Project Status Update:
Amendment Request (01/ 31/2019)
We are requesting minor shifts in funds between tasks and budget items to balance the final budget, as per budget sheet attached. As per previous discussions with LCCMR staff, the total amount of the contract with MNTU was underspent because MNTU's effort was largely taken care of by a volunteer. The $2000 that was underspent on the contract went to cover salary expenses for personnel involved in field work and modeling (Task 2). Conference travel and in-state travel, GIS fees and expenses in the Other category also were underspent and funds were allocated to personnel in Activity 2 and 3.
Amendment Approved by LCCMR 2/7/19

IV. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1: Survey Temperature and Fish in North Shore Streams
Description: A committee including fisheries managers (e.g., MNDNR), members of the angling community (e.g., MN Trout Unlimited, Steelhead Association, and others), and academics will be convened to initially identify the set of high-value streams to be included in this study. This group will identify a set of about 15-20 high-value North Shore watersheds for this study. Accessible stream segments will be walked in mid-to-late summer by teams of volunteers from MN Trout Unlimited and other angler groups using fast-reacting digital thermocouples to continuously read water temperature. Stream temperature and a GPS waypoint will be recorded at any location where temperature is at least 2°C cooler than ambient stream temperature, habitat types associated with each cold-water refuge type will be noted, and habitat features relevant to stream temperature control and

fish habitat will be recorded. This information will be used in Activity 2 to develop a map of stream temperature with types and location of cold-water refuges noted.

In-stream water temperature, cold-water refuge presence and quantity, and basic habitat data from temperature survey volunteers will be used to rank stream segments on a 1-5 scale for trout cold-water refuge potential (1 being highest potential and 5 being lowest potential). This ranking will be used to triage stream segments for further habitat and fish surveys by NRRI staff at about 100 stream reaches. At about 75% of these stream reaches, a qualitative habitat assessment will be performed, along with an electrofishing survey. The remaining 25% of sites will be selected from across the quality ranking scale for intensive fish sampling and habitat assessment. In addition, we will conduct intensive temperature monitoring in about 45 locations per year (Years 1 and 2). This monitoring will target specific refuge features within the stream; three loggers per site will be deployed to measure air temperature, water temperature within the cold-water refuge, and within the thalweg (area of greatest flow) of the stream. Continuous temperature data will be used to develop stream temperature models in Activity 2.

All field data will be downloaded and backed up daily to ensure data safety. Field data will be assembled into an existing database at NRRI, used for previous stream temperature studies of North Shore streams. All manual-entry data will be double-checked by another person. Continuous temperature data will be quality-checked and then summarized to reflect the range, variability, max and min for 1-, 7-, and 21-day periods. In addition, a GIS database will be augmented to include all available vegetation, land use, soils, and topography data for each catchment, along with links to the local habitat data in Activity 2.

Summary Budget Information for Activity 1: **ENRTF Budget: $ 178,587**
Amount Spent: $ 178,587
Balance: $ 0

Outcome	**Completion Date**
1. Identification of high-value trout streams	08/01/2015
2. Survey of temperature, fish and local geomorphology (field season 1 and 2)	10/01/2016

Activity Status as of: January 31, 2016
Trout Unlimited and MNDNR were consulted in stakeholder meetings to determine which priority watersheds should be included in this project. Consensus agreement was to include watersheds of unique importance, which was usually due to the presence of fish or water temperatures indicating favorable conditions for brook trout. The rest of the site selection process involved classifying Minnesota Lake Superior Tributaries into small catchments and characterizing each by GIS layers (soil type, surficial geology, etc.) along a gradient of groundwater potential. This produced several thousand catchments grouped into 21 categories. Three hundred catchments were randomly selected, distributed among the 21 stream categories. Of those 300 randomly-selected catchments, about 100 overlapped with historic temperature or fish records provided to NRRI by stakeholders, and those 100 catchments were the focus of 2015 data collection efforts.

NRRI purchased field supplies to outfit Trout Unlimited volunteers with fast-reacting thermometers (assembled into a “wand” at NRRI for ease of use), GPS units, and clipboards. Volunteers were provided instruction on how to conduct a mobile stream temperature survey, and a Trout Unlimited volunteer was assigned the task of collecting data and supplies after stream surveys were completed. In total, volunteers surveyed 20 catchments and discovered 70 individual cold-water refuges among 13 catchments. The volunteers also detected 150 potential barriers to fish passage, including 68 beaver dams. Coordinates are saved for all these unique features.

Temperature data loggers were also purchased, and NRRI field staff recorded stream temperature every 15 minutes at six locations in the late summer and into the fall. The preliminary results from the 2015 temperature data loggers indicate that our deployment method will be successful in capturing the desired information in 2016. The fish communities were assessed by NRRI field staff within four catchments, and brook trout were detected in three of those (including one with coho salmon). Preliminary results indicate the relative abundance of cold-water fish species increased when groundwater inputs were found nearby, so our approach appears valid to apply to a larger number of catchments in the next year.

Lessons learned were: 1) volunteer recruitment is more difficult than expected; and 2) stream catchments were more difficult to walk and required more time than anticipated to complete temperature surveys. Sampling protocols and the study design have been modified to account for the lessons learned during the 2015 field season. Specifically, habitat assessments have been modified to reduce the amount of time at each location, while concentrating on collection of essential data for the modeling effort. Efforts are already underway to attract new volunteers to the project, and temperature survey protocol for volunteers will be revised to increase their efficiency while still collecting critical data.

Two workshops were conducted after the completion of the field season to evaluate progress, assess methods, strategize ways to recruit additional volunteers, and plan for the 2016 field season. A staff member from the MNDNR Spring Survey participated in this workshop, along with staff from the MNDNR Fisheries Division (Duluth, Grand Marais), and MPCA. Volunteers associated with MN Trout Unlimited and elsewhere in the community also participated. Two UMD graduate students from the Water Resources Science Program have begun projects building upon data collected during this project. A talk was presented at the Lake Superior Stream Symposium in Duluth to an audience of approximately 150 individuals, mainly professional water resource managers from the state and region, along with some NGO staff and citizens. Talks are planned for February and participation in two fishing expos is planned for the month of March, during which we will work on recruiting volunteers.

Activity Status as of: June 30, 2016
PI Johnson and student Jonathan Utecht made a presentation to the Arrowhead Fly Fishers group on February 16th to invite volunteers; they also attended two additional events at the Nemadji Water Fest in Carlton County (March 12th) and the Great Waters Fly Fishing Expo (March 19-20) in St. Paul. A volunteer from Trout Unlimited (Peder Urista) helped organize the volunteer contributions. However, the low volunteer response rate required us to augment the volunteer effort with paid staff. Two individuals were hired with the sole responsibility to conduct temperature surveys and deploy temperature loggers. Additional equipment was purchased to augment the temperature survey activity.

Site selection activities were split between Activity 1 and Activity 2; an additional 150 sites were identified in addition to the sites selected for the previous year. Sites were then evaluated using Google Earth and aerial photographs to establish the sample reach (reduced from 1 km to 500 m) and determine appropriate access points. A map of the sample reach was created along with a second map depicting information about access points and logistical considerations. MN Trout Unlimited volunteer Peder Yurista scheduled and advertised multiple events during the summer from Duluth up to Grand Marais to recruit volunteers for stream surveys.

Activity Status as of: January 31, 2017
During the summer of 2015, 19 segments were surveyed; in 2016, 102 stream segments were surveyed, with volunteers completing 23 stream segments and NRRI crews surveying 79. Overall, 121 segments were surveyed (38 by volunteers and 83 by NRRI crews); a total of 83 of the segments were found to contain cool-water features or tributaries. All data from the field seasons has been entered into spreadsheets, QC'd, and backed up. All of the temperature loggers have been downloaded and the files have been checked for data integrity.

Volunteers conducted basic stream temperature surveying, taking stream temperature every 15 minutes while creating a GPS track and creating GPS waypoints for each cool-water location found. Volunteers documented the temperature of each cool-water feature, described the type (e.g., seep, pool, tributary), and estimated size. NRRI crews collected the same survey information and also measured dissolved oxygen at the bottom of cool-water pools to verify that they could actually serve as cool-water refuges for fish. NRRI crews also noted basic surficial geology characteristics and bottom substrate.

At a subset of sites, temperature loggers were deployed to capture summertime temperatures every 15 minutes concurrently from the 1) cool-water feature, 2) stream temperature nearby but outside the influence of the cool-water input, and 3) air temperature in the shade. We were able to place these triple sets of temperature loggers at 25 cool-water locations to determine the impact of each "cold-water feature" relative to ambient air and water temperatures. In addition, we placed stream temperature data loggers paired with air temperature loggers in stream segments that did not have cool-water inputs. We deployed temperature loggers at seven of these locations. Temperature loggers were in place from June until the end of September or early October. These data were essential for summarizing temperature metrics (e.g., min, mean, and max July stream temperature) and the development of subsequent models predicting presence/absence of cold-water features and actual stream temperature.

Electrofishing surveys to detect trout began in the beginning of August and continued until the middle of September. The portion of each stream segment sampled for trout was set to intersect with any cool-water refuges that were found and/or temperature logger locations. During the surveys, general habitat information was collected including stream temperature, conductivity, dissolved oxygen, pH, turbidity, discharge, and an MPCA Stream Habitat Assessment (MSHA) worksheet. A total of 59 stream segments were electrofished, and brook trout were found in 30 of these segments. An MS thesis is being developed based on these data.

During the summer of 2017, we plan to resample a number of streams to validate model predictions, thereby using the remaining funds from this activity. In addition, volunteers have requested access to the sampling equipment to conduct further monitoring. These data also will be used for model validation.

Activity Status as of*:* October 15, 2017
In mid-June, we deployed 36 triple sets of loggers in North Shore streams. The triple sets record air, ambient stream, and "cold spot" temperatures throughout the summer. Set locations were identified from 2016 temperature surveys. One third of the logger sets were deployed in the same location as the 2016 logger deployments. The other 24 logger sets were scattered throughout North Shore streams in pools, seeps, tributaries, and undercut banks. Logger retrieval was completed in early October.

A key summer activity included sending teams of stream walkers with temperature wands to validate the predictive capabilities of the cold-water models. Crews were sent both to stream segments predicted to be cool or cold and to stream segments predicted to be warm in order to validate the models in both directions. All logger and stream walking data will be checked for integrity and loaded in a centralized database, which will conclude the field activities for this project.

Activity Status as of*:* January 31, 2018
We conducted stream temperature surveys to validate the predictive accuracy of the cold-water models. The models identified stream segments with the greatest potential for cold-water seeps from groundwater inputs. NRRI teams surveyed 15 streams for locations of cold water produced by groundwater seeps. The teams found cold-water seeps in all but four segments. In those streams where cold-water seeps were not located, ambient temperatures were below 18°C, so the entire stream was considered a cold-water tributary. Paired streams also were used to confirm presence of a cold-water stream or feature. The paired streams were located near the model-predicted streams, and were not predicted to produce "cold spots," so their ambient temps should be higher than the predicted cold-water streams. All paired streams were warmer than their cold-water pair,

confirming the model's ability to identify cold-water catchments. The models accurately predicted cold-water influence in all 15 validation catchments sampled.

Final Report Summary: December 31, 2018

Field measurements of stream temperature were conducted manually by walking 121 stream segments to identify locations of cold-water features and tributaries and by continuously measuring temperature using in-stream temperature sensors in 36 stream segments. Fish surveys were conducted in 59 reaches to confirm presence of cold-water-sensitive species. An additional 15 streams were surveyed to confirm model results. A comprehensive database of streams with (and without) cold-water features was developed and used to complete Activities 2 and 3.

Findings:

1. Reliance on volunteers for studies involving rigorous, randomized surveys and long periods of field work is questionable; volunteers were useful for surveys involving their "personal" fishing locations and short-duration efforts.
2. Paid undergraduate employees were extremely effective in sampling large numbers of streams.

ACTIVITY 2: Map local stream temperature and trout populations; relate local geology and land cover to temperature conditions

Description: The compiled cold-water refuge data (i.e., temperature data) from Activity 1 will be examined, and a discrete number of subclasses of refuges will be identified based on characteristics such as refuge type (see Activity 1), size, temperature range, or natural vs. artificial pools. Temperature data from field surveys will be used to create maps of water temperature within the high-value streams sampled. This set of maps will form one of the deliverables for this project. Map products will be designed to depict instantaneous or summarized thermal metrics (e.g., means, max, min over the assessment period). Data will be posted on NRRI's *LakeSuperiorStreams.org* website.

All temperature, fish, and habitat data collected in Activity 1 will be compiled into a spatially-referenced GIS database, which will build upon previous work in the region by L. Johnson and collaborators. Study reaches containing cold-water refuges will be identified, and local catchments (e.g., watersheds of about 100 ha) will be delineated using LiDAR data. The LiDAR data also will be used to calculate slopes, depressional storage, and other topographical parameters within each catchment. Land cover, vegetation, surficial geology, and soil type data will be attributed to the catchments for each study stream. These data, along with 3-m and 10-m digital elevation model data, are currently available at the Natural Resources Research Institute.

A series of models, listed below, will be developed in this activity. Both empirical (statistical) and deterministic (physics-based) models will be used; the empirical models are useful for studying the spatial distribution of temperature and fish over the region, and the deterministic models give more detailed information on hydrology and temperature at specific locations. These models will allow us to predict where thermal refuges are likely to be, what benefit the refuges are to the fish populations, and how (or if) the presence of these refuges will make the North Shore trout stream more viable in the future under climate change.

1) Trout presence/absence model: This model will be used to determine how the distribution of brook trout is controlled by temperature and other habitat factors using spatial data, field-collected habitat data, and results of the electrofishing survey.

2) Thermal refuge models: Empirical models will be used to predict where cold-water refuges tend to occur based on local landscape factors such as soil types, vegetation, and topography. Deterministic models will zoom in on specific stream locations to better understand how water temperatures in and near the refuges are controlled by local hydrology and landscape, and how they will respond to climate change.

3) Steam temperature models: Empirical and deterministic models will be used to predict stream temperature as a function of climate and local landscape variables such as riparian shading and wetland density. The empirical models will be used to estimate stream temperature in unsampled streams and to determine how temperatures in streams with and without refuges will respond to climate change.

The outcome of these tasks will be a map of the cold-water refuges identified during the field surveys, a set of data and models relating trout presence/absence to temperature (including presence of cold-water refuges); models predicting presence/density of cold-water refuges based on landscape and local habitat characteristics; and models that determine specific relationships between water temperature and climate-related variables.

Summary Budget Information for Activity 2: **ENRTF Budget: $ 133,796**
Amount Spent: $ 133,796
Balance: $ 0

Outcome	Completion Date
1. Map of the thermal refuges in surveyed streams	**12/31/2016**
2. Correlate fish presence/absence with thermal refuges	**04/01/2017**
3. Quantify relationships of thermal refuges to geomorphology, hydrology, and land cover	**06/30/2017**
4. Predict local conditions producing thermal refuges	**06/30/2017**

Activity Status as of: January 31, 2016
Activity 2 has had little activity except for purchase of equipment and supplies relevant to this activity.

Activity Status as of: June 30, 2016
Team members met with MNDNR and other collaborators and partners over the winter to establish protocols for fish and habitat sampling. Personnel from this activity also participated in screening sites for the 2016 field season. Temperature loggers were deployed at eight sites in June. In addition, a few sites were surveyed for temperature in late June, but heavy rains kept the rivers at high flow, limiting the amount of field work that could be accomplished.

Activity Status as of: January 31, 2017
Data collected from summer have been QA/QC'd and analyzed to be used in statistical modelling. Team members have met every two weeks since the end of the field season to update progress and discuss analytical approaches. Maps have been produced reflecting the location of thermal refugia along with associated features such as barriers to movement. An effort is underway to update the stream temperature and fish observation databases at NRRI to include the most recent (2016) data collected by MNDNR, MPCA, and others. The databases for soils and wetland coverage and type are also being updated based on the most recent SSURGO soils database and the update of the National Wetlands Inventory coordinated by MNDNR. These updated spatial data will then be used to improve previously developed, empirical models for stream temperature and brook trout presence/absence. Work on these stream temperature and thermal refuge models has begun.

Activity Status as of*:* October 15, 2017
During this time period, we compiled all data needed for the stream temperature modeling activities and created preliminary models to predict cold- or cool-water stream segments. These data types included landscape data, PRISM air temperature, and stream temperature data. Landscape characteristics data were compiled from the most recent map layers, including 3 m LiDAR, 10 m CTI, the most recent SSURGO soil database, the newly released National Wetlands Inventory, 15 m MN land cover classification, and impervious surface area by Landsat and LiDAR, lithology, sedimentary geology, forest type, groundwater recharge capacity,

depression storage, and stream density. These data were assigned into each of the stream segment watersheds (NHDPlus catchments) created for the entire North Shore by GIS analysis. Stream temperature data for a total of 155 sites were obtained from MNDNR for 2016. Weekly stream temperature data were linked with PRISM air temperature data by simple linear regression modeling, and the slope values of regression models were compared with threshold values to classify sites into cold-water sites or warm-water sites. Further classification tree and multiple regression modelling methods were used to model July mean stream temperature using air temperature and landscape variables in order to classify the sites into cold-water or warm-water sites to identify the locations of thermal refuges. We are continuing to refine the models based on the data and model validation sampling done by stream crews this summer.

Activity Status as of*:* January 31, 2018
Models predicting probability of occurrence of cold water were rerun using temperature data from MNDNR and field-collected data from 2016 and 2017 field surveys. The models classifying streams having cold-water features or tributaries predicted 277 stream segments with cold water; 120 stream segments have high groundwater potential. Fifteen cold-water segments were selected from candidate sites, and the presence of cold water was confirmed using field surveys in August.

Final Report Summary: December 31, 2018
Stream survey data collected during the stream walk-in surveys and validation survey in 2015-2017 (Activity 1) were classified as cold tributaries if the stream segment water temperatures were below 18^{o}C (see Fig. 2). These data were used in a logistic model to predict whether a stream segment is likely to be a cold reach using landscape characteristics as potential predictors. The model is expressed in Equation 1.

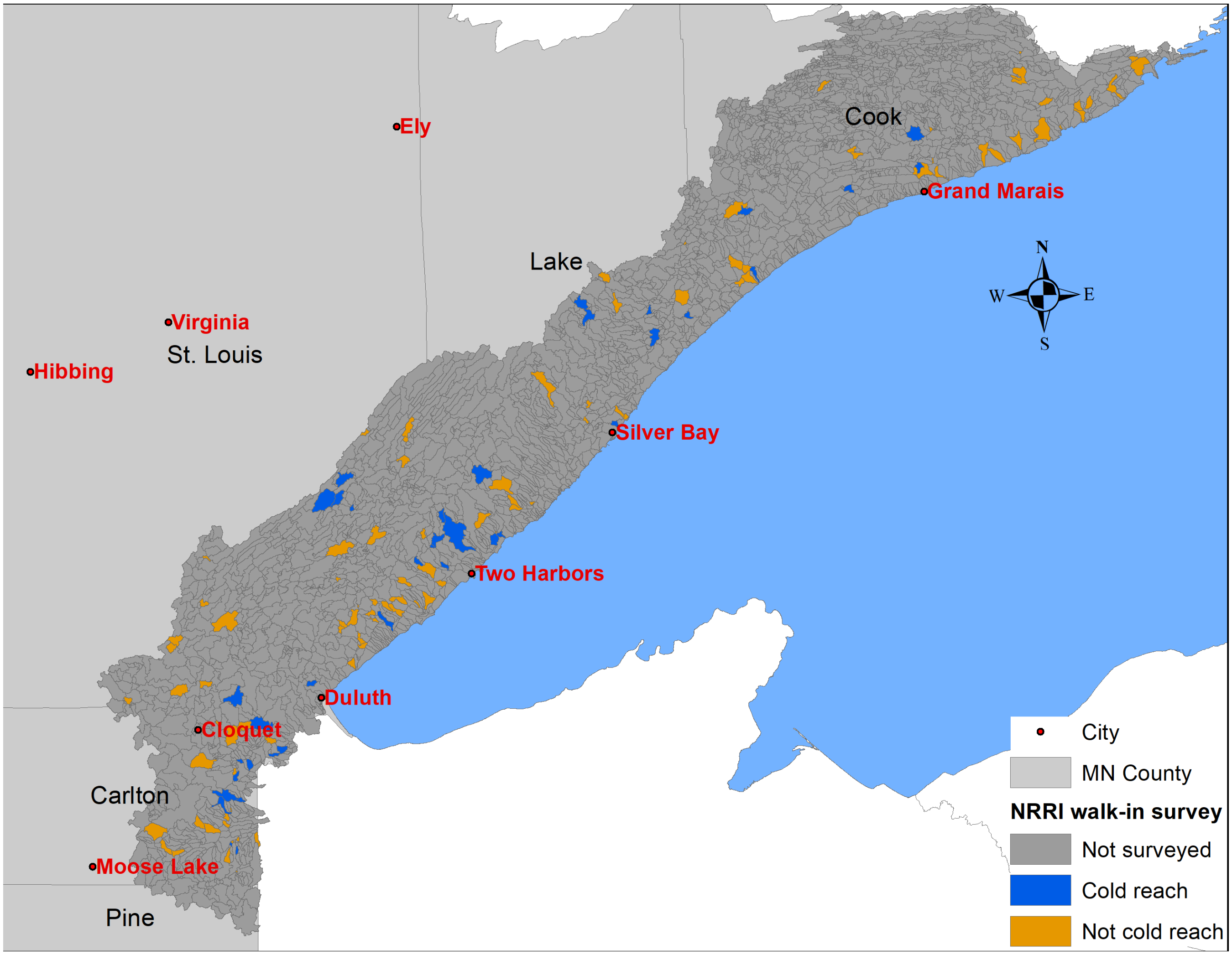

Figure 2. Walk-in temperature survey stream classification for National Hydrography Data (NHD) catchments. Surveys were performed in the summers of 2015, 2016, and 2017. As shown here, a cold-water tributary is one in which a cold-water feature was encountered during the manual survey. Cold-water features are those with temperatures that are 2°C lower than the ambient water temperature in the stream.

$$log\frac{p}{1-p} = -683.98 + 4.42 \times P\_MixedForest - 9.07 \times P\_OpenWater\_50m + 8.01 \times P\_\%Impervious\_150m + 1.89 \times Aspect\_Range$$

$p<0.001$ $R^2 = 0.27$ $n=124$ (Eq. 1)

Where p is the probability of presence of a cold tributary, P_MixedForest is the percent of mixed forest area in a flow-accumulated catchment, P_OpenWater_50m is the percent of open water area within a 50 m buffer around the stream segment, P_%Impervious_150m represents the percent of impervious area within 150 m of the stream buffer in the catchment, and Aspect_Range is the range of the aspect (cardinal direction to which a surface faces) for the catchment.

Using this logistic model (Eq. 1.), tributaries along the North Shore are predicted to be either a “cold-water tributary” or not (Fig. 3). Cold-water tributaries are most often present near the shore of Lake Superior and in the Nemadji River watershed. (Cold-water reaches are defined as those having mean July water temperatures <18°C and are distinct from streams having cold-water features.)

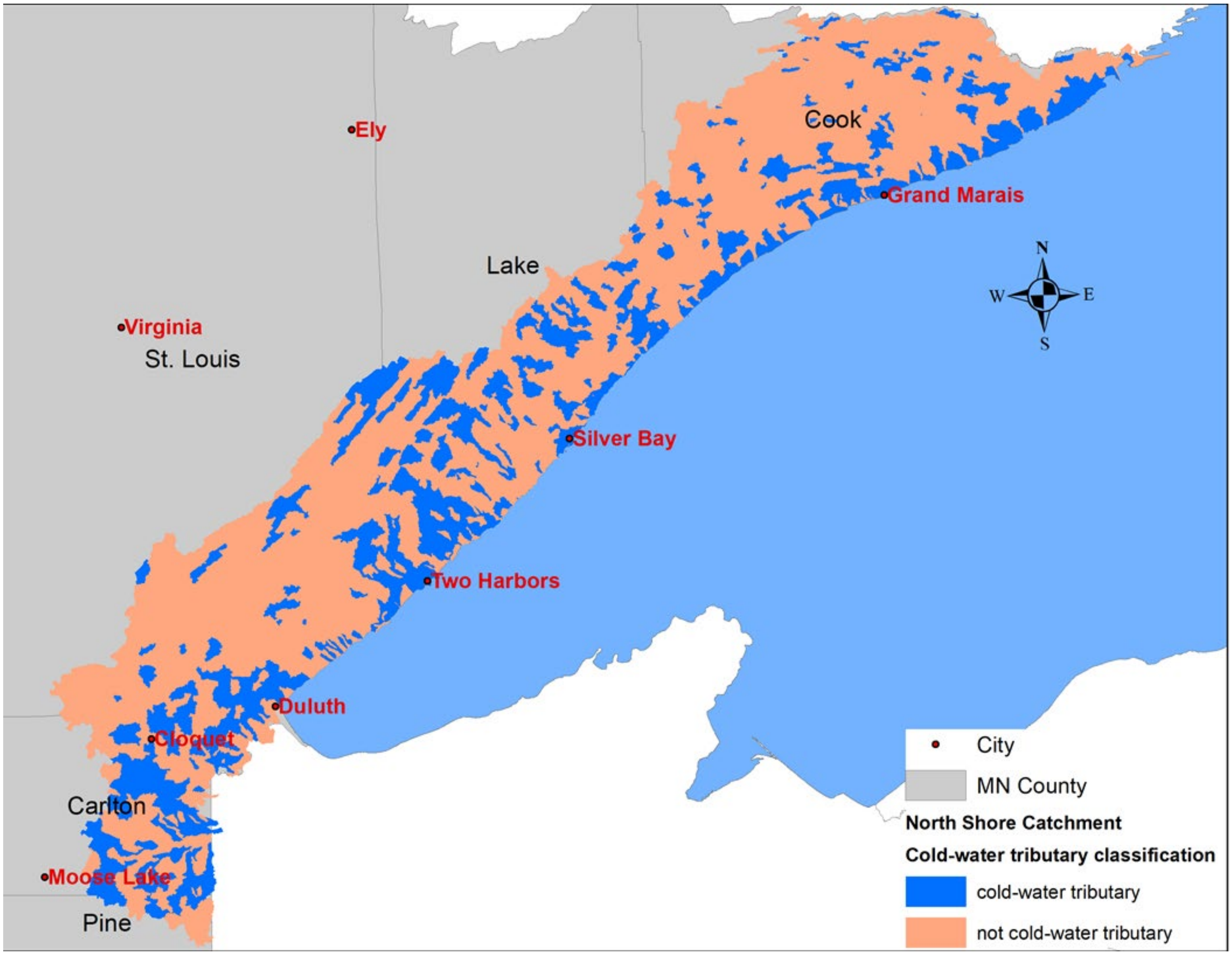

Figure 3. Classification of stream segments as cold-water reaches (or not) using the logistic model presented in Equation 1. A cold-water tributary is predicted to be a segment having water temperature <18°C; Not a cold-water tributary is a segment that could contain a cold-water feature but whose ambient temperature is ≥18°C .

Another set of temperature models was developed using logger temperature data collected from historical surveys from 1996 to 2009, the MNDNR surveys in 2016-2017, and NRRI's survey in 2016. July mean water temperature was predicted from July mean air temperature and other landscape variables from relationships expressed in Equation 2.

$$T_{water} = 2.88 + 0.57 \times T_{air} + 2.36 \times P\_lowland\_conifer\_hardwood\_150m + 6.24 \times P\_OpenWater + 0.37 \times CTI\_Median - 2.93 \times Depression\_Std - 1.29 \times Aspect\_min$$

$p<0.001$, $R^2=0.36$, $n=349$ (Eq. 2)

Where T_{water} is the July mean water temperature, T_{air} is the July mean air temperature downloaded from PRISM climate group, P_lowland_confier_hardwood_150m is the percent of lowland conifer hardwood forest area within a 150 m buffer around the stream segment, P_OpenWater is the percent of open water area in flow-accumulated watershed, CTI_Median represents the median compound topographic index, Depression_Std is the standard deviation of depressional storage within the flow-accumulated watershed, and Aspect_min is the minimum of the aspect (cardinal direction to which a surface faces) for the catchment.

To derive a conservative estimate of the probability of encountering cold-water features or cold-water tributaries, we used both Equations 1 and 2 to classify stream reaches as depicted in Figure 4. More than 60% of catchments in this region have a low probability of encountering a cold-water tributary (<18°C) or cold-water features (points within the stream having water temperatures <2°C cooler than the ambient water temperatures). These streams are primarily located in regions distant from the shore of Lake Superior or outside of the Nemadji River basin.

Fish data collected during the NRRI field surveys (Activity 1) and from MNDNR surveys were compiled. Stream segments were classified as having salmonids present or absent. Figure 5 shows the stream segments sampled and whether or not salmonids were found.

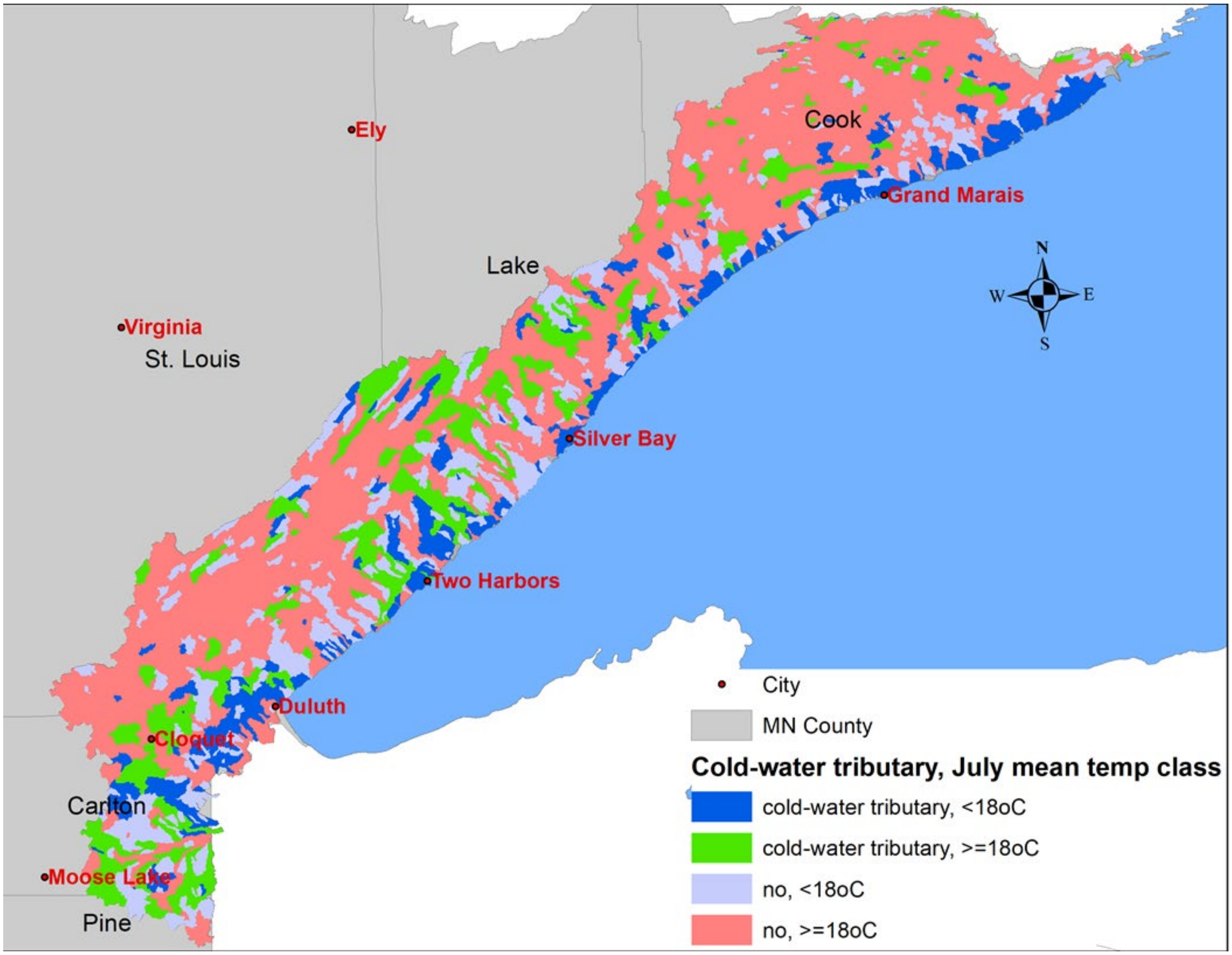

Figure 4. Catchment temperature classes predicted by models in Equations 1 & 2. Cold-water tributary, <18°C is predicted to be a cold-water tributary; Cold-water tributary > 18°C is predicted to be a cool- or warm-water segment having a cold-water feature; No, ≤18°C reflects a low probability of being a cold-water tributary but may still contain a cold-water feature; No, ≥ 18°C reflects a low probability of encountering a cold-water feature.

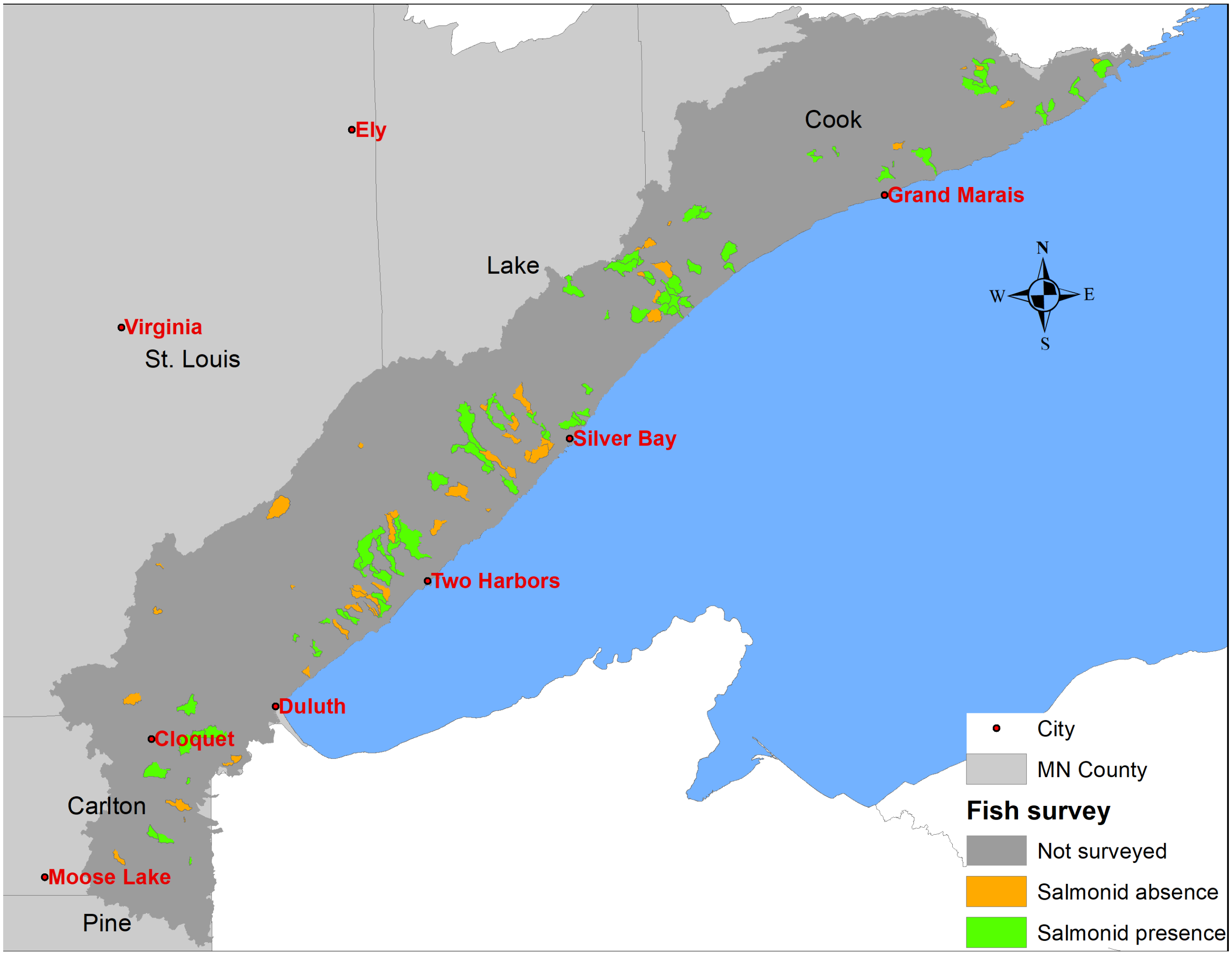

Figure 5. Map of surveyed catchments classified by whether salmonids were present or absent. Fish survey data were compiled from fish surveys conducted during Activity 1, other projects done by NRRI in 2013 and 2015-2018, and MNDNR field surveys from 2012 to 2016.

References:

Johnson, L.B., Herb, W., Cai, M. 2013. Assessing impacts of climate change on vulnerability of brook trout in Lake Superior's tributary streams of Minnesota. Natural Resources Research Institute technical report number NRRI/TR-2013/05.

Findings:

1. Individual models predicting either the location of cold-water features or actual July mean, max temperature tend to over-predict the number of streams with cold-water features. Thus, we derived a more conservative estimate using a weight of evidence approach, in which results of both model types are employed, to derive realistic predictions of streams with cold-water features (logistic model results, Fig. 3).
2. Predictor variables for models predicting probability of encountering cold-water features or tributaries (i.e., those with features with water temperatures at least 2°C colder than ambient water temperatures, or tributaries with water temperatures ≤ 18°C) vary substantially from model predictors of actual stream temperature. Probability of encountering cold tributaries or cold features appear to be largely associated with land cover features, while water temperature predictors based on previous work (Johnson et al. 2013) found that stream temperature was strongly predicted by air temperature, watershed area, percentage of woody wetlands, latitude, and soil permeability.

With a larger dataset reflecting both manual stream temperature measurements and continuous temperature readings from loggers, we were surprised that the presence of surficial deposits commonly associated with presence of groundwater was not a strong predictor of the presence of cold-water features. The model findings and our empirical observations suggest that cold-water features are also found in areas with thin soils (and thus little groundwater), suggesting more extensive surface-groundwater interactions than expected. The likely explanation for this is the existence of fractures within the bedrock, which serve to connect surface to deeper groundwater. The extent of fracture in the bedrock is poorly known for the study region. The project team therefore recommends that attention should be devoted to completing the MN Geological Survey's dataset depicting depth to bedrock (this coverage is currently incomplete for the study area), and geologic surveys quantifying extent of bedrock fractures should be pursued.

ACTIVITY 3: Regional projections of trout stream resilience to climate change
Description: The overall goal of Activity 3 is to use stream temperature – fish models previously developed by L. Johnson and colleagues (Johnson et al. 2013) and the data set and models developed in Activity 2 to predict how trout stream habitat will respond to climate change, taking into account cold-water refuges.

Predicting future viability of cold-water fish habitat will require us to obtain and compile future climate projections in a suitable form to serve as input to the flow, temperature, and habitat models. The availability of downscaled GCM (global climate model) projections will be evaluated when the project starts. Future climate scenarios will likely be assembled for a mid-century period (2046-2065) and a late-century period (2081-2100); the final decisions will be made based on availability of climate projections and fisheries managers' needs. Each climate scenario will be based on an ensemble of GCMs to give, for example, predicted median, low, and high increases in air temperature for each time period.

The seasonal response of stream temperature to the climate change projections will be calculated, and temperature statistics will be compiled for subcatchments of varying sizes, levels of riparian shading and land use type, and for at least two future climate periods. The exact form of the compiled temperature statistics (daily average, weekly average, etc.) will be based on results of Activities 1 and 2. Initial stream temperature results will represent a baseline response for stream reaches without cold-water refuges. Depending on the results of Activities 1 and 2, future temperature changes for particular stream classes may be made to give additional information in refuge areas.

The future climate projections will be applied to the stream catchment models developed in Activity 2 to estimate changes in the seasonal temperature of surface runoff and shallow groundwater. Depending on the exact form of the models, it may also be possible to make projections about seasonal changes in groundwater input rates, which might be caused by changes such as shorter winters and longer open water periods.

Based on the projected temperature response of stream reaches, pools, and groundwater inputs, the future viability of North Shore streams for trout will be evaluated. The projected changes in stream reach temperature and refuge temperature will be compared, and the overall change in viable refuge size or density will be estimated for different types of streams and sub-regions of the Superior North Shore. Using the empirical models of predicted stream temperatures and temperature – fish presence/absence relationships, the projected changes in overall stream temperature and cold-water refuges will be translated to projected changes in future viability of cold-water fish habitat.

The refuge and fish habitat predictions will be tested in a subset of unsampled streams using field data collected during the final year. Future fish presence/absence projections and risk of exceedances of trout thermal tolerances will then be made using the same procedures used for the sampled streams.

Management recommendations will be assembled based on the field data and the model results from all three Activities. A committee including fisheries managers (e.g., MNDNR), members of the angling community (e.g., MN Trout Unlimited, Steelhead Association, and others), and academics will be convened to initially identify the set of high value streams to be included in this study. This committee will also evaluate the results (i.e., projected changes in stream reach and refuge temperatures) and identify a set of recommendations to help protect and/or restore stream thermal refuges.

Summary Budget Information for Activity 3:

ENRTF Budget:	**$ 105,163**
Amount Spent:	**$ 103,648**
Balance:	**$ 1,608**

Outcome	Completion Date
1. Project future viability of sampled North Shore trout streams	**10/31/2017**
2. Validate predictions in unsampled streams with field observations	**10/31/2017**
3. Project future viability of North Shore trout streams	**12/31/2018**
4. Develop management recommendations to protect North Shore cold-water refuges	**06/30/2018**

Activity Status as of: January 31, 2016
Personnel involved in modeling participated in activities associated with the development of the experimental design and site selection, especially as it relates to the development of the classification system for predicting groundwater potential, which was used to select study streams.

Activity Status as of: June 30, 2016
During this period, we conducted some tests of the models that are intended to be used for stream temperature and flow. The stream temperature model developed for a previous study was refined to include some newly available stream temperature data as well as new environmental correlates. This model will be one of two approaches used for predicting stream temperature across the study region. Personnel from this activity also participated in workshops and project planning.

Activity Status as of: January 31, 2017
A simplified, conceptual stream temperature model, previously developed at St. Anthony Falls Lab, is being applied to a subset of the historical stream temperature data. The goal of this effort is to test if this conceptual stream temperature model can be used to extract the relative influence of riparian shading and groundwater inputs on stream temperature over the region. If successful, results of this modeling exercise will guide the thermal refugia mapping in the region.

Activity Status as of*:* October 15, 2017
Field validation confirmed model predictions for existence of cold-water features.

To help inform groundwater modeling efforts in this project, a simple stream temperature model was used to estimate the relative influence of riparian shading and groundwater on water temperatures at historical stream temperature monitoring sites. The model simulated weekly average stream temperature based on historical weather data and adjusts riparian shading and groundwater variables to best match the observed temperature record. The model was applied to a total of 496 stream temperature monitoring sites, including both MNDNR and USEPA sites on the North and South Shores of Lake Superior. The model correctly identified many of the South Shore streams as groundwater dominated and many of the North Shore sites as having relatively low groundwater influence. Figure 6 plots the distribution of the estimated groundwater influence coefficient for 48 USEPA monitoring sites from 1997-1999. The groundwater coefficient varies from 0 (for no groundwater influence) to 1 (for high groundwater influence).

Note: We assembled some historical stream temperature data from Superior South Shore streams as known examples of groundwater-dominated streams, i.e. streams where the water temperature is mainly controlled by the groundwater inputs. In doing so, we were able to check the validity of the conceptual stream temperature model for a case not available in the data set for the North Shore streams, which increased our confidence that the stream temperature model adequately handles the full range of stream types in the North Shore study area.

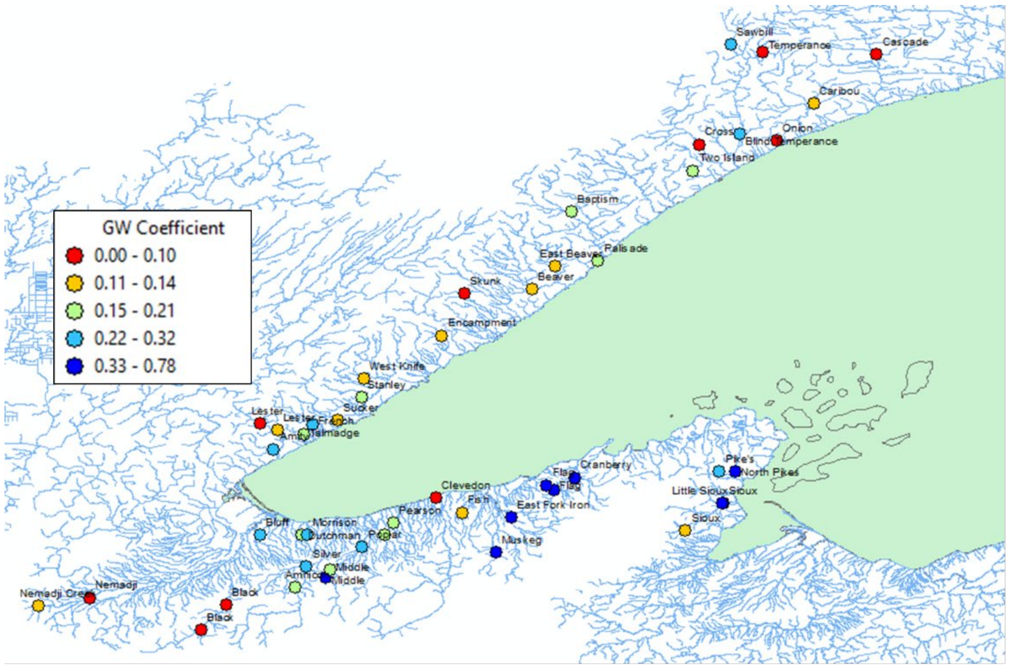

Figure 6. Distribution of the estimated groundwater influence coefficient for 48 USEPA monitoring sites from 1997-99. The groundwater coefficient varies from 0 (for no groundwater influence) to 1 (for high groundwater influence).

Activity Status as of*:* January 31, 2018

In this period, stream temperature models were assembled for several cold-water refuge sites that were monitored with temperature loggers in 2016 and/or 2017. For each site, the stream temperature model predicts the warmer, ambient stream temperature and the temperature of the colder refuge site. The stream temperature models are based on the USGS SNTEMP package, which predicts daily average and daily maximum stream temperature based on riparian shading, groundwater inputs, and the local climate conditions. Each model is calibrated to reproduce the measured stream temperature over the monitoring period and will be used to estimate the response of thermal refuges to climate change.

To help select a subset of the monitored cold-water sites for modeling, the temperature logger data taken at the cold-water sites in 2016 and 2017 was summarized for each refuge type (tributary, pool, seep). The July mean stream temperature was calculated for each site, and the distribution of July mean temperature was plotted for each cold-water refuge type and the difference in temperature between the cold refuge and the ambient stream temperature in July (Fig. 7).

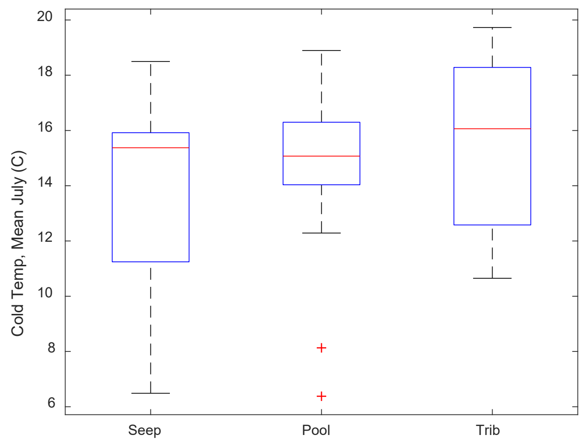

Figure 7. Summary of the distribution of mean July water temperature in the three types of cold refuges and the difference in temperature between the ambient tributary and the cold refuge.

Final Report Summary: In the final phase of the project, stream temperature models were assembled and calibrated for four monitored streams, including tributaries of the Pigeon, Brule, Skunk, and Cloquet rivers (Fig. 8). Each model was calibrated using the stream temperature and air temperature data collected in this project in 2017 and then used to project future stream temperatures based on climate change data. Each of the four monitoring sites includes an ambient (warmer) tributary with a cold tributary input (refuge); both the ambient and cold tributary water temperatures were simulated at each of the four sites using the SNTEMP modeling package.

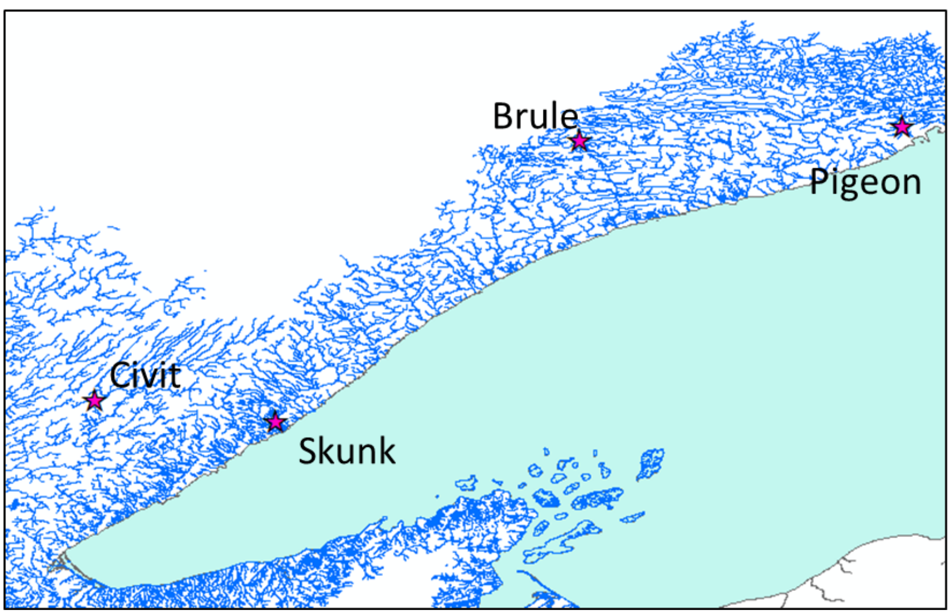

Figure 8. Map showing the location of the four modeled North Shore tributaries. Civit Creek is a tributary of the Cloquet River.

An important component of the stream temperature models was secondary models for the seasonal temperature of baseflow inputs from shallow and deep groundwater and lake outflows (Fig. 9). A previously developed groundwater/soil temperature model (Herb et al. 2008) was used to estimate the seasonal temperature variability of groundwater inputs. The groundwater/soil model was calibrated based on near-surface soil temperatures collected in 2010 in the Manitou River watershed by the Nature Conservancy. For each modeled tributary, an appropriate withdrawal depth of groundwater for baseflow was determined to best match the observed daily average and daily maximum stream temperatures. For the Brule River tributary, an existing lake temperature model (GLM 2.0; Hipsey et al. 2014) was used to estimate the temperature of baseflow to the tributary from the lake surface waters.

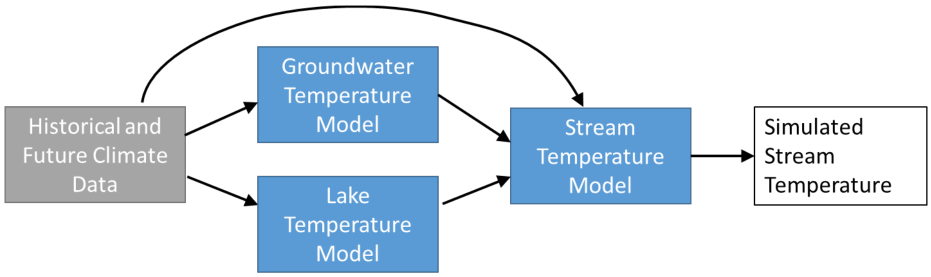

Figure 9. Schematic of the stream temperature modeling procedure.

The stream temperature models also require specification of stream flow rates in each modeled reach. Since stream flow rate was not logged at the temperature monitoring sites, several methods for simulating stream flow rates were explored. Attempts to estimate a varying flow rate for the model simulation period did not improve the accuracy of the stream temperature simulations. Therefore, a fixed flow rate was set for each modeled stream reach based on its catchment area using a regression of average summer flow rate versus catchment area that was developed based on the existing gaging stations. A typical example of the observed and simulated daily average stream temperatures is given in Figure 10 for the Skunk River tributary, with a root-mean-square error of 1.3°C.

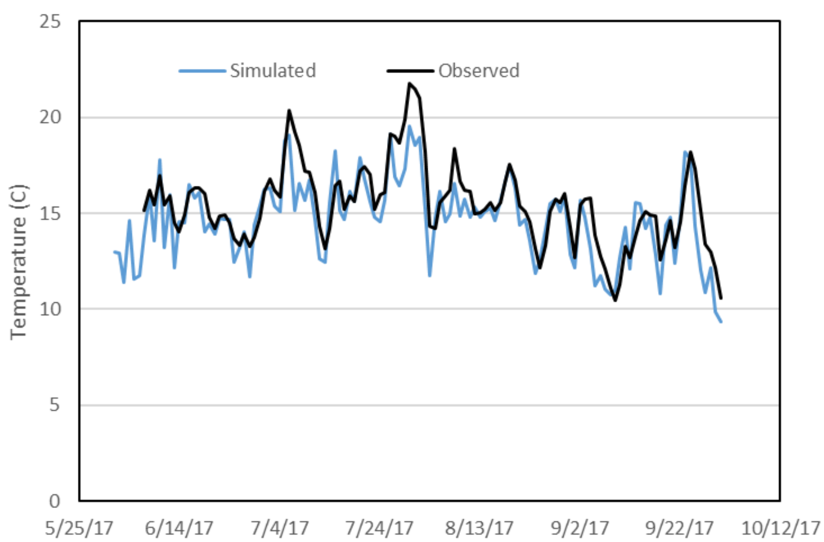

Figure 10. Observed and simulated daily mean stream temperature for the Skunk River tributary.

After model calibration, the four stream temperature models were used to project future stream temperatures. GCM output data were used from the CMIP5 RCP 8.5 high emissions scenarios (Riahi et al. 2011), downscaled by a University of Idaho group (Abatzoglou and Brown 2012). Two GCM model outputs were selected to represent a relatively warm and dry scenario (Hadley GEM2-CC365) and a relatively cool, wet projected future climate (GFDL-ESM2G). Projected climate data for 2061-2080 were used to first simulate the change in source (baseflow) temperatures using the soil/groundwater and lake models, and then stream temperature at each site. Projected changes in groundwater temperatures for each GCM scenario were similar to the projected air temperature change (about 2°C for the GFDL model and about 6 °C for the Hadley model; Fig. 11). While lake surface temperatures are relatively warm compared to groundwater, the projected increase in lake water temperature was lower (1.8 to 3.7°C) due to moderating effect of increased evaporation rates.

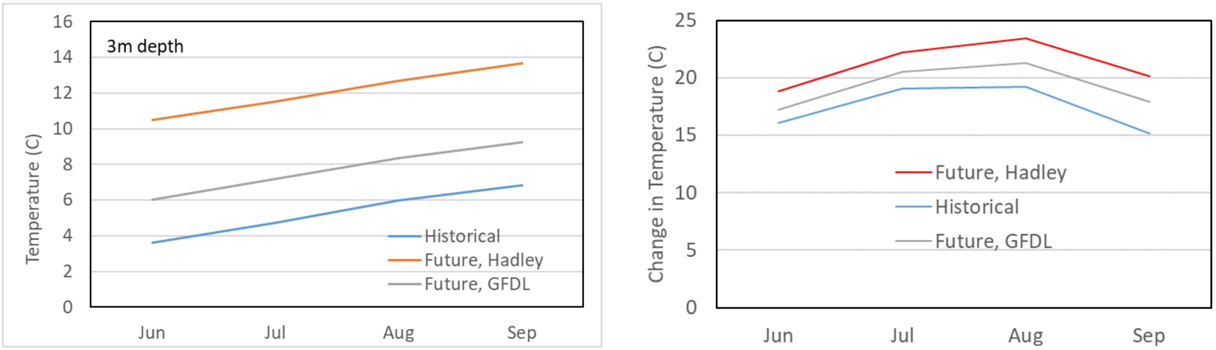

Figure 11. The simulated future groundwater and lake temperature data were then used as input to the stream temperature models. The projected increases in stream temperature were similar between streams, but the colder tributaries were found to have slightly larger temperature changes compared to the warmer tributaries.

The stream temperature modeling results for the climate change scenarios were similar between the four modeled tributaries, summarized in Table 1. The cold tributaries increased in temperature slightly more than the warm tributaries. No relationship was found between catchment size and sensitivity to climate change.

Table 1. Projected increase in mean July stream temperature, based on the GFDL and Hadley GCMs, for the modeled warm (ambient) and cold (refugia) tributaries.

	GFDL	**Hadley**
Cold Tributaries	2.3 to 2.5 °C	5.0 to 5.6 °C
Warm Tributaries	2.1 to 2.2 °C	4.6 to 5.0 °C

Mitigating Climate Change Thermal Impacts with Increased Riparian Shading

Groundwater inputs and riparian shading are two of the most important controls on stream temperature. While groundwater inputs to streams are largely out of the control of watershed managers, some of the impacts of climate change on stream temperature can be mitigated by increasing riparian shading. To quantify the potential stream temperature reductions that can be achieved by increasing riparian shading, a sensitivity analysis was conducted using the previously assembled stream temperature models for North Shore tributaries. For each modeled stream system (Pigeon, Brule, Civit, Skunk), the future climate scenarios (GFDL and Hadley models) were re-run with the specified shading levels in the ambient and cold tributaries increased by 10% over the entire reach upstream of the monitoring point. For the Skunk tributary, another series of model runs were made with the increased shading specified over varying distances upstream of the monitoring point and varying flow rates.

The results of the increased shading scenarios were summarized in terms of mean monthly stream temperature and mean monthly daily maximum stream temperature (Table 2). The shade augmentation was least effective for the Brule cold tributary, because this tributary was modeled as very short (120 m), so that the shading does not have the length scale to change the water temperature more than 0.1°C. *This suggests that local shading augmentation will not be effective for reducing temperatures of groundwater seeps that drain directly into a stream channel.* The shading augmentation was most effective for the Skunk ambient tributary, which has the largest watershed (70 km^2), the most stream length (modeled as 20 km), and the lowest currents levels of riparian shading (40%). The 10% increase in shading gave up to a 1.6°C decrease in mean monthly temperature in the Skunk River tributary under the Hadley scenario (Table 2), but with quite a bit of variability between tributaries.

Table 2. Predicted decrease in mean July stream temperature (Tave) for a 10% increase in shading in the four modeled tributaries. All values are in °C.

Trib	GFDL scenario				Hadley scenario			
	Ambient Trib		Cold Trib		Ambient Trib		Cold Trib	
	Tave	Tmax	Tave	Tmax	Tave	Tmax	Tave	Tmax
Brule	0.8	1.6	0.1	2.1	0.8	1.5	0.1	1.7
Civit	0.5	1.1	0.4	2.0	0.5	1.0	0.4	1.9
Pigeon	0.6	1.3	0.8	1.6	0.6	1.2	0.8	1.5
Skunk	0.8	1.3	1.0	1.8	1.6	2.0	0.9	1.7

Shading augmentation of Skunk tributary (Fig. 12) was further analyzed by varying the length of the stream channel with augmented shading and by varying the flow rate. For the 20 km long, warm stream segment, the riparian shading level was increased from 40% to 50% for a varying distance upstream from the confluence with the cold tributary. For the Hadley future climate scenario, increasing the shading over the entire 20 km segment achieved a reduction in the average July stream temperature of 0.75°C (from 23.2°C to 22.5°C). Restricting the increase in shading to a 5 km stream segment resulted in a temperature reduction of 0.5°C, and shading a 2 km stream segment gave only a 0.25°C temperature reduction. Reducing the flow rate of this example tributary by 50% decreased the length of augmented shading needed to achieve the same temperature reduction by 50% because there is less thermal mass, lower velocity, and higher residence time in the shaded section (Herb and Stefan 2011). Conversely, *a given length of augmented shading will become less effective at higher flows, implying that larger streams (wider, higher average flow) will be more difficult to temperature-mitigate with shading, both because taller trees are needed to shade the wider channel and because the shading will need to be augmented over a longer distance to achieve a significant temperature reduction.*

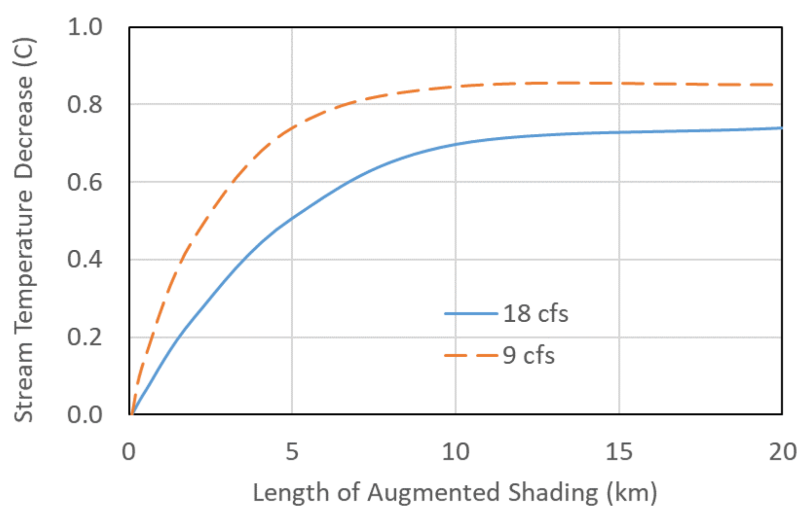

Figure 12. Predicted decrease in stream temperature for varying distances of augmented shading in the Skunk River tributary.

References:

Abatzoglou, J.T., and Brown, T.J. 2012. A comparison of statistical downscaling methods suited for wildfire applications. International Journal of Climatology 32:772-780.

Herb, W.R., and Stefan, H.G. 2011. Modified equilibrium temperature models for cold-water streams. Water Resources Research 47, W06519, doi:10.1029/2010WR009586.

Herb, W.R., Janke, B., Mohseni, O., and Stefan, H.G. 2008. Ground surface temperature simulation for different land covers, Journal of Hydrology 356:327-343.

Hipsey, M.R., Bruce, L.C., and Hamilton, D.P. 2014. GLM - General Lake Model: Model overview and user information. AED Report #26, The University of Western Australia, Perth, Australia. 42 p.
Johnson, L.B., Herb, W., and Cai, M. 2013. Assessing impacts of climate change on vulnerability of brook trout in Lake Superior's tributary streams of Minnesota. Natural Resources Research Institute, University of Minnesota Duluth, technical report number NRRI/TR-2013/05.
Riahi, K., Krey, V., Rao, S., Chirkov, V., Fischer, G., Kolp, P., ... and Rafai, P. 2011. RCP-8.5: exploring the consequence of high emission trajectories. Climatic Change 10:1007.

Findings:

1. Groundwater temperatures are expected to rise along with air temperatures and will be a significant contributor to increases in stream temperature.
2. The response of tributary temperatures to climate change was found to be similar over a range of catchment sizes, but the amount of temperature increase varied substantially between the two climate change scenarios used.
3. Increasing riparian shading is a management strategy that has the potential to partially mitigate water temperature increases. Riparian shading mitigation was found to be most effective for smaller tributaries, where a given distance of increased shading gives the most temperature benefit.
4. Shading mitigation is difficult for larger tributaries, both because they are wider (requiring taller trees to shade) and because tributaries with higher flow rates require shading mitigation over longer distances to achieve a given temperature reduction.
5. Riparian shading mitigation is not predicted to lower the temperature groundwater seeps directly enter warmer tributaries, but maintaining tree cover in the catchment may help lower shallow groundwater temperatures.

V. DISSEMINATION:

Description:

1. Temperature data from field surveys will be used to create thermal maps of water temperature within the high-value stream segments sampled. This set of maps will form one of the deliverables for this project. Map products will be designed to depict instantaneous or summarized thermal metrics (e.g., means, max, min over the assessment period). Data will be posted on NRRI's *LakeSuperiorStreams.org* website. Temperature data will be incorporated into a master data set of stream temperature data that has been assembled by NRRI and is distributed upon request.
2. Management recommendations will be assembled based on the empirical data and model results from all three activities. A committee including fisheries managers (e.g., MNDNR), members of the angling community (e.g., MN Trout Unlimited, Steelhead Association, and others), and academics will be convened to initially identify the set of high value streams to be included in this study. This committee will also evaluate the results (i.e., projected changes in stream reach and refuge temperatures) and identify a set of recommendations for future management. Management recommendations will be distributed in the form of personal contacts and presentations for local angling and management groups, documentation in the form of reports, and peer-reviewed papers to management agencies and non-governmental organizations (e.g., MNDNR, US Fish and Wildlife Service, The Nature Conservancy, tribes, local units of government.)
3. Results will initially be presented at the MN Water Resources Conference or other suitable venues. We expect one or more peer-reviewed papers to result from this work.

Status as of: January 31, 2016
Meetings have been conducted with volunteer organizations who will both assist with temperature sampling and with dissemination of results.

Status as of: June 30, 2016
Project PI and a student met with volunteers and took part in events to advertise the project and solicit volunteers.

Status as of: January 31, 2017
Project personnel have met and communicated with agency collaborators from MPCA, MNDNR, and S. St. Louis Co. SWCD to exchange data. Volunteer coordinator Peder Yurista wrote an article for Trout Unlimited Newsletter.

Status as of*:* October 15, 2017
Project personnel contacted agency collaborators from MNDNR to obtain more temperature and fish data from North Shore streams. Trout Unlimited volunteer coordinator Peder Yurista has joined us for several project meetings. Our research was presented to other NRRI researchers at a September poster session. Preparations are underway to engage end users to develop recommendations.

Status as of*:* January 31, 2018
Project personnel have repeatedly met with the volunteer coordinator (Peder Yurista), who serves as a liaison with MNDNR fisheries and fishing organizations to discuss project outputs. A set of meetings is planned for the coming month to disseminate results and discuss the design of output products.

Final Report Summary:
Ongoing meetings with the Minnesota Chapter of Trout Unlimited personnel have taken place throughout the entire duration of the project to ensure that project outputs are useful for on-the-ground decision making. The TU volunteer has also been involved in parallel discussions with MNDNR personnel involved in managing North Shore streams, and through those interactions has served as a conduit for project updates. Personnel from TU are organizing an outreach meeting to take place in early spring, during which we will present our final models and project outcomes. Meetings are planned with MN DNR as well. Preliminary recommendations have been proposed and will be vetted during those meetings.

Recommendations:
1. Special attention should be paid to restoration and/or enhancement of riparian vegetation.
    a. Prioritize high-value streams that have narrow channels, relative to the height of the adjacent tree cover.
    b. Prioritize high-value streams in smaller subcatchments over mainstem streams in large catchments.
2. Since riparian shading is predicted to be ineffective where groundwater seeps directly enter warmer channels or tributaries, maintaining tree cover within the catchment may help to preserve lower groundwater temperatures.
3. Further temperature monitoring is recommended, but where possible, an air sensor should be deployed in the immediate vicinity of the stream channel, and if monitoring a cold-water feature, a third sensor should be deployed within the channel outside of the cold-water feature.
4. The most current MN Geological Survey dataset depicting depth to bedrock is incomplete for the study area; further modeling would benefit from a completed dataset for the region.
5. Similarly, a more highly detailed map of surficial (Quaternary) deposits would also enhance our understanding of stream temperature dynamics and groundwater-surface water interactions. The current map resolution is very coarse and insufficient for detailed modeling.
6. Geologic surveys quantifying extent of bedrock fractures would be beneficial to a better understanding of groundwater-surface water interactions in the region. With additional mining activity in the region, it will be important to have a better understanding of water budgets and flows.

VI. PROJECT BUDGET SUMMARY:

A. ENRTF Budget Overview:

Budget Category	$ Amount	Overview Explanation
Personnel:	$ 341,509	1 Project Manager 4% FTE each year for 3 years; 3 Co-managers – W. Herb 50% FTE years 1&3, 45% year 2; M. Cai 20% FTE years 1 & 2, 25% year 3; V. Brady 5% FTE each year for 3 years; 1 Research Fellow 20% FTE years 1 & 2, 10% year 3; 1 GIS Tech 10% FTE each year for 3 years; 1 Principal Lab Tech 20% FTE each year for 3 years; 2 Senior Lab Techs 10% FTE each person, each year for 3 years; 2 Temp Interns 60% FTE year 2 summer only
Professional/Technical/Service Contracts:	$ 15,264	1 contract: John Lenczewski, Minnesota Trout Unlimited: organization of volunteer activities
Equipment/Tools/Supplies:	$ 23,905	Fast-reacting thermo-couple with wand ($500 ea x 11); temperature sensors ($130 ea x 105); download device ($250); software ($300); base station for temperature sensors ($125); GPS Units ($500 ea x 5); waterproof paper ($140); waders ($110 ea x 4); software license ($600), backup drive + memory and disk storage ($400)
Travel Expenses in MN:	$ 27,450	Project personnel Duluth to Twin Cities to confer w/collaborators & agencies $2,472 (mileage only -4 trips/yr x 3 yrs @ 350 mi RT ea @ $0.56/mi=$2,352 + car rental fee of $10/day*12 days=$120); In-state conference, yrs 2 & 3, $2,368 (mileage: 2 trips @350 RT ea @ $0.56/mi=$392: dept. car rental @ $10/day *3 days*2yrs=$60: lodging @ $133/day*2 days* 2 ppl*2yrs=$1064; meals @ $71/day *3 days * 2 ppl*2yrs=$852); Field travel $22,610 (9375 mi @ $0.56/mi=$5250: dept. car rental @ $15/day*86 days=$1,290: lodging @ $200/day*47 days=$9,400: meals @ $46/day*5 days*2ppl=$460, meals @ $46/day*45 days*3ppl=$6,210). Note-lodging rates allow for group lodging/cabins.
Other:	$ 7,877	Conference calls $822 with collaborators to reduce travel costs ($330/yr*2yrs+$162/yr*1yr; cost is $0.10/minute); GIS lab service ($4.10/hr, projected 500 hrs per year); Conference registration $900 ($225/ea*2 yrs * 2 ppl)
TOTAL ENRTF BUDGET:	**$ 416,000**	

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: ~~4.4~~ 4.7 FTEs

Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation: 0.12 FTEs

B. Other Funds:

Source of Funds	$ Amount Proposed	$ Amount Spent	Use of Other Funds
Non-state			
NOAA	$ 10,000	$ 10,000	Herb and Johnson completed a stream classification system for North Shore streams for use in extrapolating temperature and flow models across the entire study area.
State			
TOTAL OTHER FUNDS:	**$ 10,000**	**$ 10,000**	

VII. PROJECT STRATEGY:

A. Project Partners:

Project Partners Not Receiving Funds:

- MNDNR partners will provide advice, existing data and, where feasible, field support. They will participate in developing management recommendations to protect cold-water stream habitat.
- MNDNR and MN Geological Survey personnel involved in the spring inventory will communicate survey methods to identify region-specific considerations (primarily related to access issues related to the remote nature of the north shore streams). The spring survey protocols and inventory will be considered for data dissemination.
- Local fishing groups have been contacted and have agreed to provide volunteer labor for the temperature surveys in Activity 1 (organized and coordinated by Minnesota Trout Unlimited, which is receiving funding for coordination, see below).
- The 1854 Treaty Authority may be able to assist with volunteer temperature surveys, depending on their workload and the timing of the surveys.

Project Partners Receiving Funds:

- Minnesota Trout Unlimited: $10,000 for a stipend for the MNTU coordinator to organize volunteers to collect temperature data and for travel expenses. This amount will also cover volunteer expenses of MNTU members assisting with temperature surveys and other data collection in years 1 and 2.

B. Project Impact and Long-term Strategy: This project is self-contained in its scope and will contribute towards the long-term strategy of state agencies to maintain trout populations in North Shore streams. The project builds on data and results from several projects, including an MNDNR-funded project studying the impacts of climate change on MN cold-water lakes and North Shore trout streams. The data and results produced by this project will inform a wide variety of stream management and restoration efforts and could be extended to other regions of the state or to a regional or national scale project.

C. Funding History:

Funding Source and Use of Funds	Funding Timeframe	$ Amount
Not applicable		$
		$

IX. VISUAL COMPONENT or MAP(S):

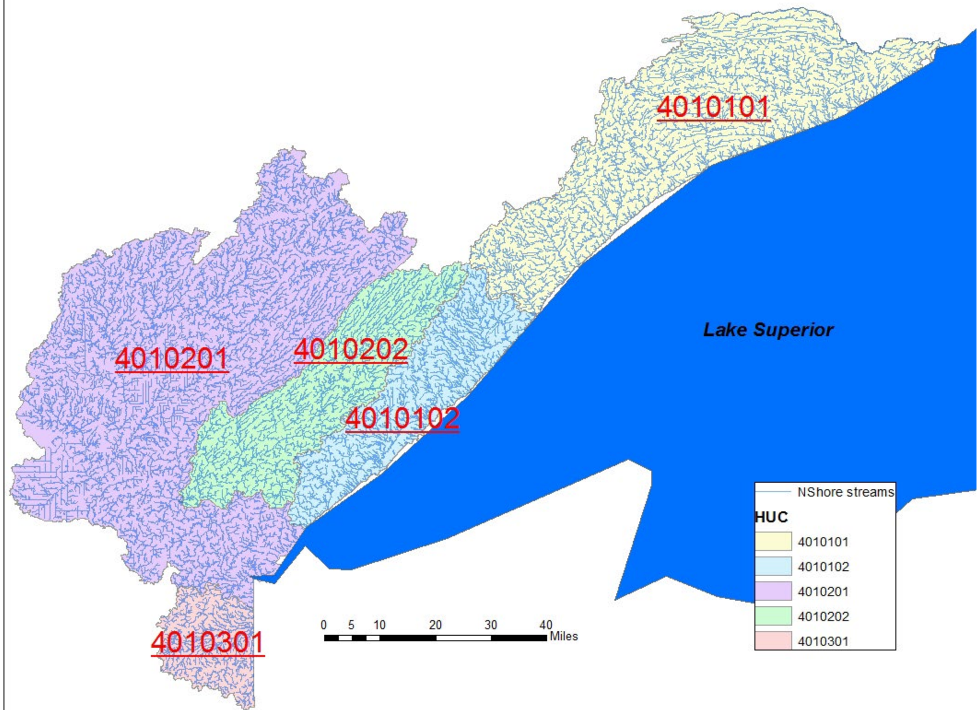

Figure 1. Location of Lake Superior South and North major Minnesota watersheds (4010102 and 4010101) and the stream networks located within them. This study will explore streams and stream segments just within these two major watersheds. All of these streams drain to Lake Superior and, thus, theoretically have the potential to support lake-run salmonids.

X. RESEARCH ADDENDUM: N/A

XI. REPORTING REQUIREMENTS:

Periodic work plan status update reports will be submitted no later than January 31, 2016; June 30, 2016; January 31, 2017; June 30, 2017; and January 31, 2018. A final report and associated products will be submitted by December 31, 2018.

Environment and Natural Resources Trust Fund
M.L. 2015 Project Budget
Project Title: Prioritizing Future Management of North Shore Trout Streams
Legal Citation: M.L. 2015, Chp. 76, Sec. 2, Subd. 08a
Project Manager: Lucinda Johnson
Organization: Natural Resources Research Institute, University of Minnesota Duluth
M.L. 2015 ENRTF Appropriation: $416,000
Project Length and Completion Date: 3 Years, June 30, 2018
Date of Report: February 7, 2019

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	**Revised Activity 1 Budget**	**Amount Spent**
BUDGET ITEM	Survey Temperature and Fish in North Shore Streams	
Personnel (Wages and Benefits) $341,509	$125,147	$125,147
Lucinda Johnson, Project Manager: $23,612 (66.2% salary, 33.8% benefits); 4% FTE each year for 3 years		
William Herb, Co-Investigator: $137,247 (66.2% salary, 33.8% benefits); 50% FTE yrs 1&3, 45% FTE yr 2		
Mei Cai, Co-Investigator: $57,251 (66.2% salary, 33.8% benefits); 20% FTE yrs 1&2, 25% FTE yr 3		
Valerie Brady, Co-Investigator: $14,345 (66.2% salary, 33.8% benefits); 5% FTE each year for 3 years		
Josh Dumke, Research Fellow; $29,931 (66.2% salary, 33.8% benefits); 20% FTE yrs 1&2, 10% FTE yr 3		
~~Jeremy Erickson,~~ Kris Johnson, GIS Tech; $19,272 (66.2% salary, 33.8% benefits); 10% FTE each year for 3 yrs		
Robert Hell, Principal Lab Technician: $34,965 (73.7% salary, 26.3% benefits); 20% FTE each year for 3 years		
2 Senior Lab Technicians: $24,886 (73.7% salary, 26.3% benefits); 10% FTE each person, each year for 3 years		
2 Temp/Casual field technicians $20,800 (92.1% salary, 7.9% benefits); 60% FTE each person, Y2 summer only		
Professional/Technical/Service Contracts $15,264		

John Lenczewski, MNTU project coordinator:Payment for organization of MNTU volunteers' activities including stream walking to locate thermal refuges that will be instrumented with temperature data loggers ($10,000); project coordinator and volunteer travel reimbursement in yrs 1 & 2 for mileage: 4,700 mi/yr @ $0.56/yr ($5,264)	$7,953	$7,953
Tools/Supplies $23,905		
Fast-reacting thermo-couple with wand ($500 ea x 11); temperature sensors ($130 ea x 105); download device ($250); software ($300); base station for temperature sensors ($125); GPS Units ($500 ea x 5); waterproof paper ($140); waders ($110 ea x 4); Activity 2: software license ($600), backup drive + memory and disk storage ($400)	$23,776	$23,776
Travel expenses in Minnesota $27,450		
Project personnel Duluth to Twin Cities to confer w/collaborators & agencies. Mileage only -4 trips/yr x 3 yrs @ 350 mi RT ea @ $0.56/mi=$2,352 + car rental fee of $10/day*12 days=$120		
In-state conference, yrs 2 & 3. Mileage: 2 trips @350 RT ea @ $0.56/mi=$392: Dept. car rental @ $10/day *3 days*2yrs=$60: Lodging @ $133/day*2 days* 2 ppl*2yrs=$1064; Meals @ $71/day *3 days * 2 ppl*2yrs=$852		
Field travel-9375 mi @ $0.56/mi=$5250: Dept. car rental @ $15/day*86 days=$1,290: Lodging @ $200/day*47 days=$9,400: Meals @ $46/day*5 days*2ppl=$460, Meals @ $46/day*45 days*3ppl=$6,210 Note-lodging rates allow for group lodging/cabins	$20,580	$20,580
Other $7,877		
Conference calls with collaborators to reduce travel costs, $330/yr @ $0.10/min	$147	$147
GIS lab service: $4.10/hr, projected 500 hrs per year	$969	$969
Services-Conference registration to present findings from this project at in-state conferences @ $225/ea*2 yrs * 2 ppl=$900		
COLUMN TOTAL	**$178,572**	**$178,572**

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Activity 1 Balance	Revised Activity 2 Budget	Amount Spent	Activity 2 Balance	Revised Activity 3 Budget	Amount Spent
	Map local stream temperature and trout populations; relate local geology and land			Regional projections of trout stream resilience to climate change	
$0	$133,200	$133,200	$0	$103,102	$103,102

$0				$0	$0
$0	$250	$250	$0		
				$260	$260
				$0	$0
$0					
$0	$346	$346	$0	$101	$101
$0	$0	$0	$0	$0	$0
				$169	$169
$0	**$133,796**	**$133,796**	**$0**	**$103,632**	**$103,632**

Activity 3 Balance	TOTAL BUDGET	TOTAL BALANCE
$0	$361,449	$0

$0	$7,953	$0
	$24,026	$0
$0	$260	$0
$0	$0	$0
	$20,580	$0
$0	$594	$0
$0	$969	$0
$0	$169	$0
$0	**$416,000**	**$0**

$416,000