#### **ML 2016 Project Abstract** For the Period Ending June 30, 2019

PROJECT TITLE: Improving Brook Trout Stream Habitat Through Beaver Management
PROJECT MANAGER: Andrew W. Hafs
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FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: M.L. 2016, Chp. 186, Sec. 2, Subd. 03j

APPROPRIATION AMOUNT: \$225,000 AMOUNT SPENT: \$225,000 AMOUNT REMAINING: \$0

#### Sound bite of Project Outcomes and Results

Along the North Shore there was no measurable effect of beaver on brook trout habitat downstream of beaver ponds, however, 9 of 21 beaver ponds were unsuitable largely due to limited dissolved oxygen. Beaver populations recovered to previous levels by the 1990s and appear to have stabilized since that time.

#### **Overall Project Outcome and Results**

In Minnesota, beaver *Castor canadensis* are considered to have an overall negative effect on native brook trout *Salvelinus fontinalis*. Brook trout provide a valued and productive sport fishery to the North Shore streams of Lake Superior and since revival of the beaver population from past trapping and timber harvest, a reexamination of the complex ecological relationship where the two taxa interact is imperative.

Brook trout habitat data collection occurred on 79 stream sections and 21 beaver ponds spanning the North Shore during summers 2017 and 2018. Results indicated that there was no effect of beaver on brook trout habitat in sections downstream of beaver ponds. Brook trout habitat was dependent on microhabitat variables (depth, velocity, temperature) that are eminent in individual stream sites and growth was limited by velocity and prey availability. Results also indicated that 12 of the 21 beaver pond sites sampled contained suitable brook trout habitat, with dissolved oxygen identified as a threshold.

Since 1948, the beaver population has increased approximately 3-fold along the North Shore. Populations appear to have stabilized in the 1990s, and have remained at a similar size since that time. There is some variation in population trends among sub-watersheds, suggesting that local population and habitat characteristics are driving beaver population dynamics. Current population levels demonstrate that beavers have largely recovered from overharvest that occurred up through approximately 1900.

A focus on individual stream characteristics and beaver pond dissolved oxygen concentrations is recommended to achieve desired brook trout habitat and aid in the development of management strategies pertaining to these two taxa in North Shore, Lake Superior streams.

#### **Project Results Use and Dissemination**

Results from our work include a widely read review about beaver-trout interactions in the Western Great Lakes, a paper which has already generated significant conversations in the fisheries management world. Two MS theses were completed and will be made available through Bemidji State University and the University of Minnesota – Duluth libraries. Several other papers will soon be published in the peer-reviewed scientific

literature that will highlight our research findings on 1) the effects of beaver activities on brook trout habitat, 2) population dynamics of beavers in northern Minnesota, and 3) historical changes in beaver ponds and dams in the Lake Superior Watershed of Minnesota.

Overall, we digitized and geo-recitified over 1,200 historical photos, which will be stored on servers at the University of Minnesota Borchart Map Library for others to use going forward. We will also be making all of our GIS layers derived from aerial photo interpretation publicly available through Minnesota's Geospatial Commons (www.gisdata.mn.gov).

Finally results from the study were presented at numerous state, regional, national, and international meetings including but not limited to:

- Minnesota Forestry and Wildlife Research Review, 2017
- 8<sup>th</sup> International Beaver Symposium, 2018
- 78<sup>th</sup> Midwest Fish and Wildlife Conference, 2018
- Annual Meeting of the American Society of Mammalogists, 2018
- Minnesota American Fisheries Society Meeting, 2018
- 79<sup>th</sup> Midwest Fish and Wildlife Conference, 2019
- Annual Meeting of the Minnesota Chapter of The Wildlife Society, 2017, 2018, 2019

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

Date of Report: August 14, 2019 Final Report Date of Work Plan Approval: January 15, 2019 Project Completion Date: June 30, 2019

#### PROJECT TITLE: Improving Brook Trout Stream Habitat Through Beaver Management

Project Manager: Andrew Hafs

Organization: Bemidji State University

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Location: NE Minnesota (Cook, Lake, and St. Louis counties)

ENRTF Appropriation:	\$225,000
Amount Spent:	\$225,000
Balance:	\$0
	ENRTF Appropriation: Amount Spent: Balance:

Legal Citation: M.L. 2016, Chp. 186, Sec. 2, Subd. 03j

#### **Appropriation Language:**

\$225,000 the second year is from the trust fund to the Board of Trustees of the Minnesota State Colleges and Universities system for Bemidji State University to quantify how beaver activity influences habitat quality in streams for brook trout in northeastern Minnesota in order to improve current and future management practices. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered. I. PROJECT TITLE: Improving Native Brook Trout Stream Habitat through Beaver Management

# **II. PROJECT STATEMENT:**

Northeast Minnesota (NE MN) contains more than 1,500 miles of Designated Trout Streams (Fig. 1) and trout fishing is an important recreational and economic activity in the state. Beaver control is part of the DNR's management of several trout streams in NE MN (Fig. 2). There is a need to REFINE this tool to ensure that beaver management is only applied where it HELPS trout and does not HURT trout. In cases where beaver removal hurts brook trout populations, this is a LOSE-LOSE situation for Minnesotans, because we also lose wildlife habitat creation, water filtration, recreational trapping opportunities, climate change mitigation, and other positive benefits of beavers.

# Goal 1: Quantify how beaver activity influences habitat quality for stream dwelling brook trout in NE MN.

Often removing beaver from trout streams is related to the assumption that beaver activities degrade habitats by warming water temperatures beyond suitable ranges for trout. In addition to temperature, beaver dams also alter other important habitat characteristics for stream trout such as water flow and depth, sediment transport, erosion and connectivity of important seasonal habitat reaches. This project will quantify how beaver activity influences the amount of suitable brook trout habitat available in NE MN streams.

# Goal 2: Quantify importance of beaver in streams to ecosystems and to trout management.

Beaver populations fluctuate over time and space and the need to manage beaver in individual trout streams will differ for different parts of the state or at different periods of time. Beaver activities, such as creation of ponds and dams along with tree cutting, are easily visible on aerial photos. Aerial photos from different time periods can show changes in the distribution and abundance of beavers. Understanding historical and current beaver population levels will provide insight into landscape-level effects and ecosystem services provided by beaver, which will be critical for wildlife diversity conservation in the face of projected climate change. In particular, beaver activities create critical habitat for waterfowl, moose, frogs, and other wetland wildlife.

Removing beaver from trout streams can lead to increased brook trout populations. Yet maintaining beaver as a component of streams can provide benefits to stream and riparian habitat. Optimizing brook trout management and ecological health is the outcome of this proposed research.

Brook trout streams in northeastern Minnesota are mostly fed by surface waters and are sensitive to increasing summer temperatures projected in Minnesota. The effects of beaver dams on streams could magnify temperature-related changes expected over the next 50-100 years. However, increased pool habitat resulting from beaver dams could store water and maintain flows if precipitation decreases or becomes more variable. A comprehensive analysis of the ecological cost-benefit dynamics of beaver management for improvement of brook trout habitat would benefit fisheries managers and natural resource agencies.

Results for this project will provide new information allowing for improved ability to meet management objectives for brook trout while retaining the broader ecological benefits of beaver.

# **III. OVERALL PROJECT STATUS UPDATES:**

# Project Status as of January 1, 2017:

Since funding has been received in August 2016, two quality graduate students have been hired. Kathryn Renik was hired on at Bemidji State University to carry out all activities relevant to Activity 1 (mentored by Dr. Andrew Hafs); and Sean Johnson-Bice was hired on at the University of Minnesota Duluth to carry out all activities relevant to Activity 2 (mentored by Dr. Steve Windels). Both students are currently preparing proposals following University specific degree program requirements. Both are making excellent progress and should be ready to defend proposals this coming spring. This will allow for data collection over the upcoming summer

based on this work plan's proposed activities in section IV. Additionally, both students are working together to develop a comprehensive literature review summarizing the history of Salmonid-Beaver management in the Great Lakes region. They hope to eventually submit this literature review for publication in the Journal of Great Lakes Research. Currently there are no problems to report and everything seems to be on track for the upcoming field season.

## Project Status as of July 1, 2017:

Since January 1, 2017, research relevant to Activity 1 and Activity 2 has continued. Kathryn Renik has defended her proposal with her committee and was approved for fieldwork. Sean Johnson-Bice will be defending his proposal with his committee at the end of the summer (2017). Kathryn Renik, and technician, have deployed temperature loggers and began sampling sites pertaining to brook trout habitat in north shore streams. Sean Johnson-Bice has begun to analyze the beaver colony aerial survey data in the Northeastern region that the Minnesota DNR conducted from 1958-2002. Additionally, both students have worked together to develop a comprehensive literature review summarizing the history of Salmonid-Beaver management in the Great Lakes region and are aiming to submit it for publication in the Journal of Great Lakes Research this upcoming fall. Currently there are no problems to report and everything seems to be on track for this field season.

#### Project Status as of January 1, 2018:

Since July 1, 2017, research relevant to Activity 1 and Activity 2 has continued. Kathryn Renik completed her fieldwork for the 2017 season and is currently analyzing data. Kathryn will begin preparations for the 2018 field season and present her research at upcoming conferences. Sean Johnson-Bice defended his proposal with his committee, and was approved to progress with aerial image analysis. Additionally, both students have worked together to develop a comprehensive literature review summarizing the history of Salmonid-Beaver management in the Great Lakes region and are aiming to submit it for publication in the Journal of Great Lakes Research by January 1st. Currently there are no problems to report and everything seems to be on track for the upcoming field season.

#### Project Status as of July 1, 2018:

Since January 1, 2018, research relevant to Activity 1 and Activity 2 has continued in order to reach project goals. Kathryn Renik has been analyzing data from summer 2017 field season, with results from one of two models outlined in her proposal determined. Kathryn Renik, and technician, have deployed temperature loggers and began sampling brook trout habitat in North Shore, Lake Superior streams. Sean presented his research at three scientific conferences since January 1, 2018, and has made significant progress with the georectification and delineation of north shore wetlands. Additionally, the literature review that Sean and Kathryn were working on was recently accepted for publication in the North American Journal of Fisheries Management. Currently there are no problems to report and everything seems to be on track for this field season.

#### Project Status as of January 1, 2019:

Research relevant to Activity 1 and Activity 2 has continued since July 1, 2018. Kathryn Renik completed a second successful summer field season, with results from one of two models outlined in her proposal. She is currently preparing for an upcoming conference and analyzing macroinvertebrate data to apply to the second model. Sean presented some of his research at an international conference (International Beaver Symposium, Norre Vosburg, Denmark). In collaboration with graduate students at the University of Minnesota Twin Cities, the automated image-processing algorithm they have been working on is nearing completion. Wetland delineation of the study watersheds has continued as well. Finally, the beaver-salmonid literature review article Sean and Kathryn were working on was published in the North American Journal of Fisheries Management as a featured article.

#### **Overall Project Outcomes and Results:**

In Minnesota, beaver *Castor canadensis* are considered to have an overall negative effect on native brook trout *Salvelinus fontinalis*. Brook trout provide a valued and productive sport fishery to the North Shore streams of Lake Superior and since revival of the beaver population from past trapping and timber harvest, a reexamination of the complex ecological relationship where the two taxa interact is imperative.

Brook trout habitat data collection occurred on 79 stream sections and 21 beaver ponds spanning the North Shore during summers 2017 and 2018. Results indicated that there was no effect of beaver on brook trout habitat in sections downstream of beaver ponds. Brook trout habitat was dependent on microhabitat variables (depth, velocity, temperature) that are eminent in individual stream sites and growth was limited by velocity and prey availability. Results also indicated that 12 of the 21 beaver pond sites sampled contained suitable brook trout habitat, with dissolved oxygen identified as a threshold.

Since 1948, the beaver population has increased approximately 3-fold along the North Shore. Populations appear to have stabilized in the 1990s, and have remained at a similar size since that time. There is some variation in population trends among sub-watersheds, suggesting that local population and habitat characteristics are driving beaver population dynamics. Current population levels demonstrate that beavers have largely recovered from overharvest that occurred up through approximately 1900.

A focus on individual stream characteristics and beaver pond dissolved oxygen concentrations is recommended to achieve desired brook trout habitat and aid in the development of management strategies pertaining to these two taxa in North Shore, Lake Superior streams.

#### Amendment Request as of August 26, 2019

Within the budget for Activity 2, we are requesting funds be shifted from the In-state travel line, the aerial imagery line, and the GIS lab fee line to personnel.

- In-state travel budget would be reduced by \$3,479 to a revised budget of \$2,521.
- Aerial imagery budget would be reduced by \$9,730 to a revised budget of \$1,270.
- GIS lab fee budget would be reduced by \$856 to a revised budget of \$1,144.
- Personnel budget would increase by \$14,065 to a revised budget of \$91,565.

These changes are being requested because more staff time was needed to accomplish Activity 2, Outcome #1 than originally anticipated. To pay for these costs, we used money from other areas in Activity 2 that were less expensive than originally anticipated.

#### Amendment Approved by LCCMR August 26, 2019

#### **IV. PROJECT ACTIVITIES AND OUTCOMES:**

#### ACTIVITY 1: Effects of beaver ponds on brook trout habitat characteristics

**Description:** In comparison to other stream systems where brook trout-beaver research has been conducted in the past, Northeastern Minnesota trout streams are unique in that base flow is limited because of the shallow depth to bedrock. Empirical evidence describing how trout habitat changes as result of beaver activity in this region is currently lacking. Agencies in charge of managing either brook trout or beaver in Northeastern Minnesota would benefit greatly from this type of data if it were available. Therefore, the main objective of this activity is to develop a relationship between the amount of suitable brook trout habitat per unit area and the amount of beaver activity in the stream.

To accomplish this objective we will measure habitat characteristics (e.g., water temperature, flow, depth, dissolved oxygen) in stream reaches with matched watershed size that have varying levels of beaver activity. It

is assumed that habitat characteristics such as depth, flow, and temperature will be most limiting in the summer and early fall, therefore, habitat measurements will be taken at that critical time. All stream habitat measurements will be accompanied with GPS coordinates which will allow us to plot the locations in GIS. Once the habitat measurements have been loaded into GIS, interpolation techniques will be used to create detailed maps that predict habitat conditions at all locations within each selected stream reach. This technique will allow us to estimate the total amount of usable habitat for brook trout within each stream reach during the time that mapping occurred.

The estimated amounts of usable habitat can then be related to measures of beaver activity such as beaver dam density and average size of beaver dams within and upstream of the mapped sections. MNDNR currently conducts beaver dam removal in selected streams within this region which will help provide varying levels of beaver activity for study site selection.

Once the objective described above is completed the relationships established will allow us to make detailed recommendations for the immediate future of beaver and brook trout management in Northeastern Minnesota.

#### Summary Budget Information for Activity 1:

ENRTF Budget: \$128,500 Amount Spent: \$128,500 Balance: \$0

Outcome	Completion Date
<b>1.</b> Habitat characteristics (flow, depth, temperature, etc.) measured and mapped in	8/31/2018
approximately 30, 300 m sections within approximately 9 NE MN brook trout streams in	
each summer of the three year study	
2. Provide management recommendations related beaver removal in brook trout	6/30/2019
streams based on the results from outcome 1	

# Activity Status as of January 1, 2017:

Since funding has been received in August 2016, Kathryn Renik was hired on as a graduate student at Bemidji State University to carry out all activities relevant to Activity 1 (mentored by Dr. Andrew Hafs). Kathryn is currently preparing her proposal following University specific degree program requirements. She is making excellent progress and should be ready to defend her proposal this coming spring. This will allow for data collection over the upcoming summer based on this work plan's proposed activities in section IV. Additionally, she is working together with Sean Johnson-Bice from the University of Minnesota Duluth to develop a comprehensive literature review summarizing the history of Salmonid-Beaver management in the Great Lakes region. They hope to eventually submit this literature review for publication in the Journal of Great Lakes Research. Currently there are no problems to report and everything seems to be on track for the upcoming field season.

# Activity Status as of July 1, 2017:

Kathryn Renik has made progress on her research and has defended her proposal and been approved by her committee (including advisor Dr. Andrew Hafs). A qualified Bemidji State University undergraduate was hired to assist with fieldwork this summer (2017). Sampling sites (30 stream sites and 15 beaver ponds) were chosen in the Northeastern region and temperature loggers have been deployed in each site. Kathryn and hired technician are currently collecting data pertaining to brook trout habitat at each sampling site chosen along the north shore. Data collection will be completed by September 1<sup>st</sup> in regards to the 2017 summer field season. Data analysis will directly follow in the fall. Kathryn and Sean Johnson-Bice are completing the initial draft of

their beaver-salmonid management review of the Great Lakes region, and are aiming to submit it for publication to the Journal of Great Lakes Research by fall.

# Activity Status as of January 1, 2018:

Kathryn Renik and a technician collected data pertaining to brook trout habitat at sampling sites along the north shore during the 2017 field season. Data collection was completed on 31 stream sites and 10 beaver pond sites during summer 2017. Data is currently being analyzed. Additional sampling sites (60 stream sites and 20 beaver ponds) will be chosen in the Northeastern region for the 2018 summer field season by January 1<sup>st</sup>. Kathryn and Sean Johnson-Bice completed the initial draft of their beaver-salmonid management review of the Great Lakes region, and are aiming to submit it for publication to the Journal of Great Lakes Research by January 1<sup>st</sup>.

#### Activity Status as of July 1, 2018:

Kathryn Renik has made progress on data analysis from summer 2017 fieldwork, with results from one of two models determined. A qualified Bemidji State University undergraduate was hired to assist with fieldwork this summer (2018). Sampling sites (60 stream sites and 20 beaver ponds) were chosen in the Northeastern region of Minnesota and temperature loggers have been deployed. Kathryn and hired technician are currently collecting data pertaining to brook trout habitat at each sampling site and this will be completed by September 1, 2018. Data analysis will directly follow in the fall. Kathryn and Sean Johnson-Bice submitted their beaver-salmonid management review of the Great Lakes region to the Journal of Great Lakes Research and it was determined to not be within the journal's scope. It was submitted to North American Journal of Fisheries Management in March 2018 and was recently accepted for publication, contingent on minor revisions.

#### Activity Status as of January 1, 2019:

Kathryn Renik has completed her second summer of fieldwork and sampled 49 stream sites and 11 beaver ponds for 2018. This brought the total number of sites sampled between the two summers to 79 stream sites and 21 beaver pond sites. Kathryn has made progress on data analysis from summer 2018 fieldwork, with results from one of two models determined. She hopes to have a draft of her manuscript pertaining to the effect of beaver on brook trout habitat in north shore streams completed by May 2019.

# **Final Report Summary:**

The main objective of this activity was to develop a relationship between the amount of suitable brook trout habitat per unit area and the amount of beaver activity in the stream. This objective was accomplished by measuring brook trout habitat characteristics in 79 (200m) stream reaches and 21 beaver ponds spanning the North Shore region during summers 2017 and 2018. The sites had varying levels of beaver activity and predictor variables (algal biomass, upstream dam abundance on main branch per drainage, area of upstream beaver pond, tree width of nearest upstream dam, distance to nearest dam, distance to headwater, stream order, maximum site temperature, spring presence, site slope) for each site were measured. Habitat suitability index (HSI) models were used to determine the average HSI and quantity of suitable brook trout habitat (m<sup>2</sup>/100 m<sup>2</sup>) in both stream and pond sites. A bioenergetics model was employed to calculate growth availability (m<sup>2</sup>/100 m<sup>2</sup>) and mean growth (g/day) and for brook trout in stream sites. Classification regression trees were used to identify significant thresholds in which beaver activity influenced the quantity or quality of brook trout habitat and growth.

No significant predictor variables were identified in the regression tree as affecting the average HSI, area of suitable brook trout habitat, brook trout growth availability, or growth rates in stream sites. Results, therefore, indicate that beaver activity may not be affecting brook trout habitat in sites located downstream of beaver dams located along the North Shore of Lake Superior. Alternatively, the quantity and quality of brook trout

habitat in streams of this region appears to be better described by microhabitat variables (depth, velocity, temperature) that are eminent in individual stream sites. Results indicated that higher quality brook trout habitat was present in streams that exhibited greater depths, slower velocities, and lower maximum temperatures and it did not appear that beaver activity significantly influenced any of these variables. A greater quantity of brook trout habitat was present in streams distinguished by greater depths and slower velocities, also not significantly influenced by beaver activity. Brook trout growth in stream sites was limited by velocity (m/sec) and mean prey concentration (mg dry mass/m<sup>3</sup>). Results from interpolated habitat maps of beaver pond sites indicated that 12 of the 21 ponds sampled contained suitable brook trout habitat, with dissolved oxygen (mg/L) identified as a threshold for determining if ponds contained suitable brook trout habitat.

Results from Activity 1 identified instream variables important to achieving desired brook trout habitat and gave insight to those involved with the management of the complex beaver and brook trout relationship. By measuring dissolved oxygen concentrations in a specific beaver pond, managers can discern potential brook trout habitat in addition to potential repercussions of beaver dam removal. Results provided by this project will allow agencies in the Northeast Minnesota region to efficiently make decisions in regards to beaver and brook trout populations and successfully co-manage these two species.

Kathryn Renik prepared her thesis following University specific degree program requirements and defended August 5, 2019. Immediately following Kathryn's defense, Activity 1 research was submitted for publication to North American Journal of Fisheries Management and detailed recommendations were provided to MNDNR agencies currently managing the two species in Northeastern Minnesota.

# ACTIVITY 2: Determine ecological effect of distribution and abundance of beaver in NE MN Trout Streams at the landscape scale

**Description:** We will compile existing data on beaver abundance and activity for northeastern Minnesota from approximately 1900-present. These data will be gleaned from trapping records, historical accounts, and survey data from MN DNR and other agencies. We envision generating both qualitative and quantitative histories of beaver activity/abundance at the study area, watershed, and individual trout stream scales.

We will map beaver activity in selected areas in St. Louis, Lake, and Cook counties using aerial photos from 1930s to the present to characterize changes in beaver populations over time in areas surrounding Designated Trout Streams in NE MN. We will employ established remote-sensing and GIS techniques to identify beaver activity such as beaver dams and associated ponds that appear between consecutive sets of photos. Landscape features such as dams, lodges, and pond outlines are digitized and then can be tracked through time on subsequent aerial imagery. Changes in beaver activity can then be tracked through time for individual trout streams, watersheds, or across the study area. Imagery in hard copy and digital forms exists for most areas in the project area dating to at least the 1940s, with some areas also having earlier imagery from the 1920s or 1930s. Most of the digital imagery is available for free through online repositories (e.g., MNDNR Data Deli or GoogleEarth). Hard copies of older imagery will be obtained from land management agencies or other sources as necessary.

#### Summary Budget Information for Activity 2:

ENRTF Budget: \$ 96,500 Amount Spent: \$ 96,500 Balance: \$ 0

Outcome	<b>Completion Date</b>
1. Report summarizing current and historical patterns of beaver activity in	8/31/2018
approximately 9 watersheds (or subwatersheds) containing brook trout streams	
measured in Activity 1.	

### Activity Status as of January 1, 2017:

Since funding has been received in August 2016, Sean Johnson-Bice was hired on as a graduate student at the University of Minnesota Duluth to carry out all activities relevant to Activity 2 (mentored by Dr. Steve Windels). Sean is currently preparing his proposal following University specific degree program requirements. He is making excellent progress and should be ready to defend his proposal this coming spring. This will allow for data collection over the upcoming summer based on this work plan's proposed activities in section IV. Additionally, he is working together with Kathyrn Renik from Bemidji State University to develop a comprehensive literature review summarizing the history of Salmonid-Beaver management in the Great Lakes region. They hope to eventually submit this literature review for publication in the Journal of Great Lakes Research. Currently there are no problems to report and everything seems to be on track for the upcoming field season.

#### Activity Status as of July 1, 2017:

Sean Johnson-Bice has made progress on his research proposal and will be meeting with his graduate committee (including mentor Dr. Steve Windels) by the end of summer to defend it. Sean and Steve have established a partnership with the U-Spatial program at the University of Minnesota - Twin Cities (UMTC) campus to conduct the digitization and geo-rectification of aerial photos from 1948-82. These aerial photos will be used in conjunction with aerial imagery from 1991-present that has already been digitized and geo-rectified, to characterize changes in beaver activity over the last century. Sean has selected 5 focal watersheds from the Lake Superior north shore to study in-depth. Additionally, Sean has started to analyze the beaver colony aerial survey data that the Minnesota DNR conducted from 1958-2002. Several survey routes were within and/or near to the north shore watershed, and will be used in conjunction with the aerial imagery to describe changes in beaver-abundance and distribution. Sean and Kathryn Renik are completing the initial draft of their beaver-salmonid management review of the Great Lakes region, and are aiming to submit it for publication to the Journal of Great Lakes Research by fall.

#### Activity Status as of January 1, 2018:

Sean Johnson-Bice defended his research proposal, which was approved by his committee (which included Dr. Steve Windels). Sean has digitized all of the beaver survey routes conducted by the Minnesota DNR, which will be used for population estimations within the study area. Sean and Steve have continued their partnership with the U-Spatial program at the UMTC campus. Based on photo availability, Sean has identified time periods that will be used in the aerial imagery analysis. Georectification of all historical aerial imagery is currently being conducted, and should be completed by February 1, 2018, at which point Sean can begin to identify and delineate beaver wetlands within the 5 focal watersheds.

#### Activity Status as of July 1, 2018:

At this point, all historical photographs from the 5 focal watersheds have been georectified, and the delineation of these watersheds has begun. We expect to have the delineation of these watersheds completed by January 1, 2019. Sean has also established a collaboration with the Geospatial Analysis Center at the University of Minnesota Twin Cities campus. Sean is working with a graduate student at the UMTC campus to develop a novel methodology to use object-based image analysis to automate beaver pond delineations. They hope to have an effective methodology in place by March 1, 2019 that can assist in the wetland delineation process. Sean has made significant progress with his analysis on beaver population dynamics using the historical data collected by the Minnesota DNR. Sean expects to have a draft of this manuscript completed by November, 2018.

#### Activity Status as of January 1, 2019:

Wetland delineation has not been completed yet, but should be completed in early spring. The object-based image analysis algorithm that Sean was working on with UM Twin Cities graduate students, is nearly complete as well. Using this data, Sean will begin to compare manual vs. automated wetland delineations to determine the accuracy and efficacy of using automated software to delineate beaver wetlands. Sean's analysis on beaver population dynamics using the historical Minnesota DNR is also nearly finished. Sean expects to have a manuscript ready for submission by late spring.

#### **Final Report Summary:**

The main objective of Activity 2 was to evaluate the landscape-level changes beavers have had on the North Shore watersheds over the past century. Using historical and recent aerial imagery, we identified and mapped all of the beaver ponds within 5 focal watersheds (Cascade River, Kadunce River, Knife River, Manitou River, Split Rock River) over 8 separate time periods (1948, 1961, 1980/82, 1991, 2003, 2008, 2013, 2017) where imagery was available for all of the focal watersheds. Additionally, we obtained aerial imagery from 1934 for 2 watersheds (Cascade and Kadunce) and from 1939 for Knife River watershed, providing some additional context for the historical abundance of beavers at the beginning of the 20<sup>th</sup> century. Overall, we digitized and georecitified over 1,200 historical photos, which will be stored on servers at the University of Minnesota Borchart Map Library for others to use going forward.

Results from Activity 2 suggest that beaver populations have increased nearly 4-fold since the 1940s, and likely have increased at a higher rate since the turn of the 20<sup>th</sup> century. The average number of beaver dams that are retaining water has increased from approximately 0.5 per km<sup>2</sup> of land, to 1.8 per km<sup>2</sup> from 1948 to 2017. However, it appears that the beaver population in the North Shore has remained approximately stable since the 1990s, suggesting that the population has reached carrying capacity (i.e., population threshold allowed by habitat characteristics) throughout their extent in the region. This is even more interesting in that recreational trapping pressure has steadily declined during this same period. There is also considerable variation in the population trends among our 5 focal watersheds, suggesting that local watershed habitat and topographic characteristics are driving local beaver population dynamics.

Our analysis of the MNDNR historical beaver survey data revealed that changes in beaver populations are largely influenced by intrapopulation characteristics (e.g., territoriality, changes in birth rates, etc.) rather than external factors such as weather, human harvest, or even predation from wolves. These results suggest that beavers are resilient to changes in climate, and can sustain moderate mortality from human trappers. Thus, for areas where reductions in beaver populations are desired, extensive removal efforts will likely be needed to keep the population low. On the other hand, these results suggest that beavers will not continue to grow their population beyond the size which can be supported by their environment.

Based on the large increase in the beaver population since the 1930s/1940s we see from the mapping of beaver ponds over time, it is tempting to conclude that the number of beavers in the North Shore is greater now than it has historically been. However, what is 'historical' must be considered within context. If historical refers to the early 1900s, then this statement would be true. But if 'historical' refers to the population size before the Fur Trade Era/European Settlement, we cannot conclude that there are more beavers now than historically; beavers in this region were continuously over-harvested for more than two centuries during the Fur Trade Era, suppressing populations at extremely low levels. In order to adequately determine whether the number of beavers at present is more than in pre-settlement times, a separate study is needed to (1) link current (or recent) beaver carrying capacities to current (or recent) habitat characteristics, and then (2) predict historical carrying capacities based on historical habitat characteristics. Such an analysis was beyond the scope of our project but is likely going to be important in determining whether beaver populations are actually larger than they 'should be' (based on historical conditions), especially in light of our results from Activity 1 which demonstrated that beavers appear to have a minimal impact on brook trout habitats.

Management Recommendations - Based on the large increase in the beaver population since the 1930s/1940s we see from the mapping of beaver ponds over time, it is tempting to conclude that the number of beavers in the North Shore is greater now than it has historically been. However, what is 'historical' must be considered within context. If historical refers to the early 1900s, then this statement would be true. But if 'historical' refers to the population size before the Fur Trade Era/European Settlement, we cannot conclude that there are more beavers now than historically; beavers in this region were continuously over-harvested for more than two centuries during the Fur Trade Era, suppressing populations at extremely low levels. In order to adequately determine whether the number of beavers at present is more than in pre-settlement times, a separate study is needed to (1) link current (or recent) beaver carrying capacities to current (or recent) habitat characteristics, and then (2) predict historical carrying capacities based on historical habitat characteristics. Such an analysis was beyond the scope of our project but is likely going to be important in determining whether beaver populations are actually larger than they 'should be' (based on historical conditions). Regardless, when combined with our results from Activity 1 which demonstrated that beavers appear to have a minimal impact on brook trout habitats, our analysis of population trends suggests that current beaver populations may not warrant substantial reductions in beaver populations at large scales to favor salmonids in streams along the North Shore. Smaller or more focused beaver control efforts may be warranted to achieve local trout fishery goals, e.g, if upstream movements of trout are considered to be negatively impacted by beaver activities. Further to this point, we do recommend additional study to better understand the role of beaver dams in affecting movements of native and introduced salmonids. Lastly, beavers are ecosystem engineers and a keystone species who provide valuable ecological services to forest ecosystems in the WGL region, and the removal of beavers from stream reaches where their presence may actually benefit salmonids results in a lose-lose situation for forest ecosystems and natural resource management goals. We therefore suggest that the decision to remove beavers from coldwater streams should involve consideration of the secondary ecosystem consequences associated with decreased beaver presence before such management plans are implemented.

Sean Johnson-Bice successfully defended his Master's thesis on March 26<sup>th</sup>, and is finalizing work on his second chapter before submitting it for publication at *Ecological Applications*.

#### **V. DISSEMINATION:**

**Description:** We will generate outreach through Bemidji State University and University of Minnesota-Duluth. We will engage print and radio media when possible and appropriate. Fisheries managers within the Department of Natural Resources should find this research extremely valuable as brook trout and beaver are both important recreationally, commercially, and environmentally. This research will result in two completed master's theses which will be permanently housed in the libraries at the campuses in which they are completed (Bemidji State University and the University of Minnesota Duluth). Additionally, a pdf copy of the thesis completed at Bemidji State University, as result of Activity 1, will be permanently available electronically through a Bemidji State University website maintained by Dr. Andrew Hafs

<u>http://www.bemidjistate.edu/directory/facstaff/ahafs/</u>. We will prepare and disseminate information on the project through scientific papers submitted to peer-reviewed journals. We will also present our results at regional and national meetings (using funds other than those allocated through this grant). Finally, completed theses will be distributed to all Northeastern MN DNR regional offices so they can adjust future management strategies as needed.

# Status as of January 1, 2017:

As of January 1, 2017, Sean Johnson-Bice has submitted an abstract for an oral presentation at the upcoming Minnesota TWS (Wildlife Society) meeting in Feb. 2017. This presentation is related to the literature he and Kathryn Renik have been developing that summarizes the history of Salmonid-Beaver management in the Great Lakes region.

Kathryn Renik will also submit an abstract to present her plan of study for this research project via oral presentation at the upcoming Minnesota Chapter of the American Fisheries Society meeting in February 2017.

# Status as of July 1, 2017:

Since January 1, 2017, Sean Johnson-Bice has presented a poster and an oral presentation at the Minnesota TWS (Wildlife Society) conference. Presentations were related to the history of beaver management in the Great Lakes and entailed the literature review composed by Sean and Kathryn Renik.

Kathryn Renik presented a poster at the Minnesota AFS (American Fisheries Society) meeting pertaining to her research involving brook trout habitat sampling on the north shore occurring in summers 2017 and 2018. Kathryn also gave seminars to undergraduates in the Bemidji State University biology department and to members of the Minnesota Association of Watershed Districts. Presentations were related to the extensive literature review collaborated with Sean Johnson-Bice and her research occurring in north shore streams pertaining to brook trout habitat in summers 2017 and 2018.

# Status as of January 1, 2018:

Kathryn Renik has submitted an abstract to present her work as an oral presentation at the 78<sup>th</sup> Midwest Fish and Wildlife Conference in Milwaukee, WI in January 2018. She will also be submitting an abstract and giving an oral presentation at the Minnesota AFS (American Fisheries Society) meeting in February 2018 pertaining to her research involving brook trout habitat sampling on the north shore occurring in summer 2017. Kathryn was featured in a Bemidji State University article pertaining to her research on brook trout habitat along the North Shore during the summer of 2017. Kathryn and Dr. Andrew Hafs were also featured in an episode pertaining to their research on brook trout habitat in the Northeastern region of Minnesota, produced by Prairie Sportsman, and it will be aired in the new season beginning in January 2018.

Sean Johnson-Bice has submitted an abstract to present the literature review paper as an oral presentation at the 78<sup>th</sup> Midwest Fish and Wildlife Conference in Milwaukee, WI in January 2018. Sean will also be submitting an abstract and giving an oral presentation at the Minnesota Wildlife Society (MNTWS) conference in Saint Cloud, MN in February 2018. Additionally, Sean was invited to present his research at the University of Minnesota Duluth weekly biology department seminar in March 2018.

#### Status as of July 1, 2018:

Kathryn Renik presented her work as an oral presentation at the 78<sup>th</sup> Midwest Fish and Wildlife Conference in Milwaukee, WI in January 2018. She also presented her research as an oral presentation at the Minnesota AFS (American Fisheries Society) meeting in Saint Cloud, MN in February 2018. Kathryn and Dr. Andrew Hafs were featured in a Prairie Sportsman episode pertaining to their research on this project that aired on Pioneer Public Television in February 2018. Kathryn wrote an article pertaining to her fieldwork investigating the effect of beaver activity on brook trout habitat in Northeastern, MN for DUN Magazine, a women's fly fishing magazine, that will be featured in the Summer 2018 edition.

Sean presented findings from his research at three scientific conferences in the past 6 months: The 78<sup>th</sup> Midwest Fish and Wildlife Conference in Milwaukee, WI; the Minnesota Wildlife Society conference in Saint Cloud, MN; and the American Society of Mammalogists conference in Manhattan, KS. Finally, the literature review article that Sean and Kathryn Renik were working on was recently accepted for publication at the Journal of North American Fisheries Management, contingent on minor revisions to the manuscript.

#### Status as of January 1, 2019:

Kathryn Renik has submitted an abstract to present her research as an oral presentation at the 79<sup>th</sup> Midwest Fish and Wildlife Conference in Cleveland, OH in January 2019. She wrote an article pertaining to her fieldwork on brook trout habitat along the north shore that was featured in the fall edition of Dun Magazine, a women's fly fishing magazine. Kathryn also presented her research as an oral presentation to members of the Headwaters Chapter of Trout Unlimited in Bemidji, MN. She outlined this project as it pertained to the scientific method and had the opportunity to present it to a 4<sup>th</sup> grade class in Bridgeport, NE.

Sean presented findings from his beaver population analysis at an international conference (8<sup>th</sup> International Beaver Symposium, Norre Vosburg, Denmark). Sean has also submitted an abstract for an oral presentation at the 2019 Minnesota Chapter of the Wildlife Society annual meeting in Duluth, MN. Sean was also invited to give a lecture for a non-profit environmental conservation group in the Duluth area, Advocates for the Knife River Watershed; Sean gave his lecture in December at their monthly meeting. Additionally, the literature review that Sean, Kathryn, Steve, and Andy were working on was published as a *featured article* in the December issue of the North American Journal of Fisheries Management.

# **Final Report Summary:**

Outreach was generated to students, professionals, organizations, and the public. Kathryn Renik presented a poster at the Minnesota AFS (American Fisheries Society) meeting in St. Cloud, MN pertaining to her research in February 2017. Seminars to undergraduates in the Bemidji State University Biology Department and to members of the Minnesota Association of Watershed Districts during 2017 were also presented. Oral presentations given by Kathryn included the 78<sup>th</sup> Midwest Fish and Wildlife Conference (Milwaukee, WI) in January 2018, the Minnesota AFS (American Fisheries Society) meeting (Saint Cloud, MN) in February 2018, the Headwaters Chapter of Trout Unlimited (Bemidji, MN) in October 2018, 4<sup>th</sup> grade class (Bridgeport, NE) in November 2018, the 79<sup>th</sup> Midwest Fish and Wildlife Conference (Cleveland, OH) in January 2019, regional MN DNR employees (Duluth, MN) in April 2019, and the Advocates for the Knife River Watershed (Two Harbors, MN) in April 2019. Dr. Andrew Hafs gave an oral presentation pertaining to Activity 1 research at the 79<sup>th</sup> Midwest Fish and Wildlife Conference (Cleveland, OH) in January 2019.

Other outreach projects included Kathryn and Dr. Andrew Hafs feature in a Prairie Sportsman Season 9 episode pertaining to Activity 1 research that aired on Pioneer Public Television in February 2018 (<u>https://video.wfyi.org/video/sax-zim-bog-tzb57l/</u>). Kathryn wrote an article pertaining to her fieldwork on brook trout habitat along the north shore that was featured in the fall edition of Dun Magazine, a women's fly fishing magazine (<u>https://dunmagazine.com/posts/casting-light-on-a-century-old-controversy</u>).

Bemidji State also generated outreach related to Activity 1 research. Kathryn was featured as a 'Student to Watch' in a university article describing her research (<u>https://www.bemidjistate.edu/news/2018/07/03/student-to-watch-katti-renik/</u>). Another university article highlights Kathryn's research and publication in Dun Magazine (<u>https://www.bemidjistate.edu/academics/departments/biology/2018/11/07/bemidji-state-grad-student-featured-in-national-publication</u>).

Kathryn's master's thesis is permanently housed in the Bemidji State University campus library. Additionally, a pdf copy of Kathryn's thesis, as result of Activity 1, is permanently available electronically through a Bemidji State University website maintained by Dr. Andrew Hafs <a href="http://www.bemidjistate.edu/directory/facstaff/ahafs/">http://www.bemidjistate.edu/directory/facstaff/ahafs/</a>. All data collected pertaining to this research project (Activity 1) is also available electronically through this website. Her completed thesis was distributed to all Northeastern MN DNR regional offices immediately following her defense August 5, 2019, allowing for adjustment of future management strategies as needed. Additionally, Kathryn's completed thesis was shared with interested Wisconsin DNR biologists managing for beaver and trout. Results from Activity 1 research was summarized in a report for Minnesota State Parks staff and Duluth city park staff. Kathryn submitted a manuscript to the North American Journal of Fisheries Management in August 2019 pertaining to Activity 1 research.

Sean Johnson-Bice presented research related to Activity 2 at a total of 7 scientific conferences: (Minnesota Forestry and Wildlife Research Review, 2017; Annual Meeting of the Minnesota Chapter of The Wildlife Society, 2017, 2018, 2019; 78<sup>th</sup> Annual Midwest Fish and Wildlife Conference, 2018; Annual Meeting of the American Society of Mammalogists, 2018; 8<sup>th</sup> International Beaver Symposium). Sean was awarded the Best Student Presentation award at the 8<sup>th</sup> International Beaver Symposium. In addition, Sean was invited to present his research at a monthly meeting for the *Advocates for the Knife River Watershed* group in December, 2018 in Duluth, MN.

Sean defended his Master's thesis in March, and has submitted his thesis for publication at the ProQuest repository (also available from the University of Minnesota). His thesis titled 'Factors Influencing Beaver (Castor canadensis) Population Fluctuations, and their Ecological Relationship with Salmonids' will be available to the public in April, 2020, from ProQuest or the University of Minnesota repositories.

All members of the project published an article about beaver-trout relationships in the Western Great Lakes region in the *North American Journal of Fisheries Management* in 2018. This article was selected as a featured article, and was the most downloaded article from the journal in 2018.

Sean and Steve Windels are currently preparing to submit an additional three manuscripts related to research from Activity 2. We expect these articles to be published sometime in 2020, and the Environment and Natural Resources Trust Fund will be acknowledged in each of these manuscripts.

Budget Category	\$ Amount	Overview Explanation
Personnel:	\$ 167,640	BEMIDJI STATE UNIVERSITY
		1 project manager at 10% FTE each year for 3
		years (\$10,540); 1 graduate research assistant
		at 100% FTE for 3 years plus tuition and fees
		(\$64,600); 1 undergraduate research assistant
		at 33% FTE for 3 years (\$15,000).
		UNIVERSITY OF MINNESOTA-DULUTH
		1 graduate research assistant at 25% FTE for 2
		years (\$48,000); 1 undergraduate research
		assistant at 35% FTE for 18 mo. and 75% FTE for
		6 mo. (\$20,000); 1 GIS technician at 15% FTE for
		2 years (\$9,500).
		Allocation of effort among personnel categories
		are estimates that may be adjusted to best
		meet project objectives.
Equipment/Tools/Supplies:	\$26,360	72 Temperature loggers @ \$130 apiece
		(\$9,360); 24 depth/temperature loggers @
		\$500 apiece (\$12,000); flow meter (\$5,000).
Travel Expenses in MN:	\$18,000	BEMIDJI STATE UNIVERSITY
		Mileage (\$6000), lodging (\$3000), meals
		(\$3000)
		UNIVERSITY OF MINNESOTA-DULUTH

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

		Mileage (\$3000), lodging (\$1500), meals (\$1500)
Other:	\$13,000	UNIVERSITY OF MINNESOTA-DULUTH Aerial imagery acquisition (\$11,000) GIS Lab fee (\$2,000)
TOTAL ENRTF BUDGET:	\$225,000	

Explanation of Use of Classified Staff: None

Explanation of Capital Expenditures Greater Than \$5,000: None

Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation: 5.6

Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation: 0

#### **B. Other Funds:**

Source of Funds	\$ Amount Bronosod	\$ Amount	Lice of Other Funds
Non-state	Proposed	Spent	
Dr. Steve Windels (In-kind support)	\$30,000	\$30,000	Dr. Steve Windels will mentor a graduate student at the University of Minnesota Duluth on his personal time outside the scope, duties, and function of his current position with the National Park Service (valued at \$60/hr @ 500 hours).
State			
Dr. Andrew Hafs and Bemidji State University (In-kind support)	\$15,500	\$15,500	Provide access to backpack electrofishing equipment, additional YSI meters, temperature loggers, flow meters, and canoes already owned.
Bemidji State University (In-kind support)	\$69,075	\$69,075	Will provide indirect costs (30.7%)
Minnesota Department of Natural Resources (In-kind support)	\$33,000	\$33,000	MN DNR Fisheries spends approximately \$11,000 annually on beaver dam removal
Minnesota Department of Natural Resources (In-kind support)	\$5,000	\$5,000	MN DNR staff time (~\$50/hr salary/comp*100 hours) to provide access to data (temperature, flow, other habitat data) and input in project scope, development, and final projects as requested
TOTAL OTHER FUNDS:	\$152,575	\$152,575	

#### VII. PROJECT STRATEGY:

# A. Project Partners:

Dr. Andrew Hafs, trout ecology expert with Bemidji State University (will mentor 1 graduate student).

Dr. Steve Windels, beaver ecology expert and adjunct faculty at University of Minnesota-Duluth (will mentor 1 graduate student). Dr. Windels' work on this project would be outside the scope, duties, and function of his current position with the National Park Service and would be completed on his own time.

Dr. Lucinda Johnson, cold water fish habitat and climate change expert with UMD.

MNDNR staff from Area Fisheries Offices (Deserae Hendrickson and Dean Paron), Fisheries Research (Peter Jacobsen), Wildlife Research (John Erb), and Stream Habitat Coordinator (Brian Nerbonne) will provide access to data and input during all phases of the project.

#### B. Project Impact and Long-term Strategy:

This project will develop management recommendations that will optimize both stream dwelling brook trout and beaver populations and the associated ecological services they provide under current and future climate scenarios. Future funding is needed to evaluate how management actions affect individual movements, survival, and population growth of trout and beaver using radio tags and other techniques.

#### **C. Funding History:**

Funding Source and Use of Funds	Funding Timeframe	\$ Amount
MN DNR Fisheries and Wildlife spends money annually on		\$
beaver dam removal as part of their management actions. The		
total amount spent on these action in the past is very difficult		
to estimate.		

#### VIII. FEE TITLE ACQUISITION/CONSERVATION EASEMENT/RESTORATION REQUIREMENTS: NONE REQUIRED

#### IX. VISUAL COMPONENT or MAP(S):



Figure 1. Location of cold water trout streams (Designated Trout Streams) where the effects of beavers on brook trout habitat will be studied.



Figure 2. Photo of a beaver dam that was recently removed from a NE MN brook trout stream (left). Also included are photos of a beaver (center) and a stream reach in which beaver activity is limited (right).

#### X. RESEARCH ADDENDUM:

#### **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, and January 1, 2019. A final report and associated products will be submitted between June 30 and August 15, 2019.

# Final Environment and Natural Resources Trust Fund M.L. 2016 Project Budget

Project Title: Improving Brook Trout Stream Habitat Through Beaver Management
Legal Citation: M.L. 2016, Chp. 186, Sec. 2, Subd. 03j
Project Manager: Andrew Hafs
Organization: Bemidji State University
M.L. 2016 ENRTF Appropriation: \$ 225,000
Project Length and Completion Date: 3 Years, June 30, 2019

Date of Report: 8/26/2019

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND	Activity 1		Activity 1	Revised Activity 2 Budget August 27,		Activity 2	TOTAL	TOTAL
BUDGET	Budget	Amount Spent	Balance	2019	Amount Spent	Balance	BUDGET	BALANCE
BUDGET ITEM	Effects on trout habitat characteristics							
Personnel (Wages and Benefits)	\$90,140	\$90,140	\$0	\$91,565	\$91,565	\$0	\$181,705	\$0
Andrew Hafs, Project Manager: \$10,540 (81% salary, 19% benefits); 10% FTE								
each year for 3 years								
1 Graduate Research Assistant, BSU: \$52,800 (90% salary, 10% benefits);								
100% FTE for 3 years, \$11,800 for tuition and fees								
1 Graduate Research Assistant, UMD: \$62,065 (80% salary, 20% benefits);								
25% FTE for 2 years								
1 Undergraduate Research Assistant, BSU: \$15,000 (90% salary, 10%								
benefits); 33% FTE for 3 years								
1 Undergraduate Research Assistant, UMD: \$20,000 (100% salary:0%								
benefits); 35% FTE for 18 mo, 75% for 6 mo.								
1 GIS Technician, UMD: \$9,500 (92% salary:8% benefits); 15% FTE for 2 years								
Equipment/Tools/Supplies	\$26,360	\$26,360	\$0				\$26,360	\$0
72 Temperature loggers @ \$130 apiece (\$9,360)								
24 Depth/temperature loggers @ \$500 apiece (\$12,000)								
Flow meter (not to exceed \$5,000)								
Travel expenses in Minnesota								
Travel to and between field study sites. Mileage: \$6000; lodging: \$3000;	\$12,000	\$12,000	\$0				\$12,000	\$0
meals: \$3000								
In-state travel for UMD personnel. Mileage: \$1500; lodging: \$1021; meals:				\$2,521	. \$2,521	\$0	\$2,521	\$0
\$0								
Other								
Aerial imagery; publicly available imagery will used whenever possible, but				\$1,270	\$1,270	\$0	\$1,270	\$0
additional imagery, either digital or hard copy, may need to be purchased to								
maximize coverage of study watersheds located in NE MN.								
GIS lab fee for UMD	 			\$1,144	\$1,144	\$0	\$1,144	\$0
COLUMN TOTAL	\$128,500	\$128,500	\$0	\$96,500	\$96,500	\$0	\$225,000	\$0

