M.L. 2016 Projects

MN Laws 2016, Chapter 186, Section 2 (beginning July 1, 2016)

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Subd. 03 Foundational Natural Resource Data and Information

Data-Driven Pollinator Conservation Strategies

Research Project

Subd. 03a $520,000 TF

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Appropriation Language
$520,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to improve understanding of the relationships and interactions between native bee pollinators and rare and declining plant species and to determine optimal placement and species plantings for pollinator habitat in order to develop guidelines for planning, designing, and planting pollinator habitat. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

Tallgrass prairie in Minnesota has declined by over 98%. A critical tool for prairie conservation is ecological restoration. One goal of prairie restoration is to conserve, protect and restore native bees and the pollination services they provide. In Minnesota, there are over 450 species of bees with the prairies having the highest diversity and abundance. However, there is a lack of information available to enable land managers to effectively create and maintain restorations for bees. This project addresses three objectives. First, we test how surrounding landscape influences native bee communities in prairie restorations. This information can help land managers determine where to place restorations and which restorations to prioritize for management. Second, we examined how plant communities influence bee communities. Third, we studied pollination in restorations and evaluated which bee species were the most effective pollinators. We sampled bees at 26 sites in the summers of 2017 - 2019. We collected over 18,000 bee specimens and recorded over 11,000 bee by plant interactions. We found that surrounding landscape had less of an impact on bee communities than local flower communities. This suggests that increasing plant diversity is a critical tool for enhancing bee communities while exact placement is less important. We also found that restorations and remnants have unique bee and flower communities. This suggests that we might not be meeting restoration goals as bee communities in quite different than remnant prairies. Finally, we found large variation in the pollination effectiveness among bee groups. This research benefits Minnesotans highlights the importance of maintaining diverse plant communities in restorations. As surrounding landscape did not influence bee communities or pollination, restorations in areas of high agriculture can be effective. We have created a highly resolved

open-access dataset for future studies. We have published five peer-reviewed manuscripts to date and are attached as supplementary material.

PROJECT RESULTS USE AND DISSEMINATION

We have disseminated our results to the scientific community as well as the general public. We gave 6 presentations at national conferences. Two of these were invited presentations. Dan Cariveau also presented these results at three departmental seminars at other universities. We have published a total of 5 peer-reviewed manuscripts. We expect at least three more. Ian Lane will be submitting the second chapter of his dissertation in early 2021 and third chapter before May 2021. At which point he will defend his PhD thesis. Dr. Gabriella Pardee is finishing up a manuscript on pollen efficiency of prairie plants. In addition to publishing in journals, we have also made the data and code available and open access. All published work and presentations have and will continue to acknowledge this ENRTF support. We have also presented the results of this research at outreach events. Ian Lane has also been a guest on the Minnesota Department of Natural Resources Prairie Pod podcast. This podcast is focused on the science of prairie conservation. We led a highly successful field day on pollinators in prairies. This was co-led by Ian Lane and Dan Cariveau. In addition, we partnered with the United States Fish and Wildlife Service, Minnesota Department of Natural Resources and the Prairie Reconstruction Initiative. This brought in 50 natural resource professionals and was focused on prairie sites in southwestern Minnesota. Finally, this funding has supported two graduate students. Alan Ritchie defended his master's thesis in December 2019. He is now the Pollinator Coordinator for the Minnesota Department of Natural Resources. Ian Lane is finishing his PhD thesis. He has scheduled a defense date for May 2021.

All manuscripts with data and analyses have open-access data and code. These data can be found on the Digital Repository for the University of Minnesota. There have been 99 downloads of these data as of December 22, 2020. Publications as of December 2020 are included in Emerging Topics in Life Sciences, Journal of Applied Ecology, The Great Lakes Entomologist, and Restoration Ecology.

Project Completed: 06/30/2019 **FINAL REPORT**

Native Bee Surveys in Minnesota Prairie and Forest Habitats

Subd. 03b $600,000 TF

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Appropriation Language
$600,000 the second year is from the trust fund to the commissioner of natural resources to continue to assess the current status and distribution of native bee pollinators in Minnesota by expanding surveys into the prairie-forest border region and facilitating interagency collaboration and public outreach on pollinators. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

Wild bees provide vital ecosystems services including pollination, thus working to sustain resilient ecosystem functioning. Without baseline information about the diversity and distribution of bees in

Minnesota, we lack the ability to provide efficient and effective conservation actions to protect bees and their habitats. We addressed these knowledge gaps by surveying natural areas in the Prairie Parkland, Tallgrass Aspen Parklands, and Eastern Broadleaf Forest ecological provinces. Since 2016, we surveyed bees using bowl traps at 70 sites and hand netting bees from flowers at 93 sites across 38 counties. Bowl trap methods were used to survey bees every three weeks during the season, for a total of up to eight survey rounds each year. These survey efforts resulted in nearly 23,000 bee specimens collected across the two methods. Several new state records were added to the list for a total of 470 species, up from 432 at the beginning of the project. Our survey efforts have yielded countless county-level records for many species, thus gaining valuable knowledge about the distribution of bees in Minnesota. These specimens are continually being accessioned into the permanent repository at the University of Minnesota Insect Collection. Additionally, we trained a total of 35 individuals during partnered workshops held in collaboration between the MNDNR and the U of M Bee Lab to identify wild bees of Minnesota. Staff also participated in countless outreach events, promoting bees and other pollinators to Minnesotans.

PROJECT RESULTS USE AND DISSEMINATION

We have conducted countless outreach presentations to the public about bees in Minnesota. Likewise, we continue to update and maintain the various MNDNR pollinator-related websites. Specifically related to an update on the wild bee survey, we created a short two-page handout that summarizes the findings to date. These outreach and education efforts have provided easily-accessible information and facilitated communication concerning Minnesota's pollinators amongst researchers.

Project Completed: 06/30/2019 **FINAL REPORT**

Prairie Butterfly Conservation, Research, and Breeding - Phase II

Research Project

Subd. 03c $750,000 TF

Subd. 03c1 - $421,000 TF

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Subd. 03c2 - $329,000 TF

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Appropriation Language
$750,000 the second year is from the trust fund. Of this amount, $421,000 is to the Minnesota

Zoological Garden and $329,000 is to the commissioner of natural resources in collaboration with the United States Fish and Wildlife Service to continue efforts to prevent the extinction of imperiled native Minnesota butterfly species through breeding, research, field surveys, and potential reintroduction. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

ML2016 03c:

- *03c1: Prairie Butterfly Conservation, Research, and Breeding - Phase II* - $421,000
- *03c2: Prairie Butterfly Conservation, Research, and Breeding - Phase II* - $329,000

Subd. 03c1: Prairie Butterfly Conservation, Research, and Breeding - Phase II - $421,000 TF

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OVERALL PROJECT OUTCOME AND RESULTS

The Prairie Butterfly Conservation Program at the Minnesota Zoo has grown substantially during this project, and we have accomplished all Outcomes. We operate the only conservation rearing programs for two endangered butterflies in the United States. We launched the first Dakota skipper reintroduction program, rearing and releasing ~930 Dakota skippers at the Hole-in-the-Mountain Prairie Preserve near Lake Benton. , and reared thousands more. We are reinforcing one of the last populations of the Critically Endangered Poweshiek skipperling, the first of its kind in the US, releasing the two adults in 2018 and 14 more in 2019. We are also improving husbandry practices with the Minnesota Threatened garita skipperling. We currently hold thousands more of these three butterflies to continue the insurance, reintroduction, reinforcement, and research programs, supported in part by a new ENRTF appropriation.

We have improved our understanding of threats to wild populations and of conditions needed to sustain and re-establish healthy populations. We have contributed to a key research need by beginning to link the quantities of pesticides found on prairie grasses that the protected skippers feed on in the wild with experimental testing of the toxicity effects of those quantities on skipper caterpillars. Significant additional research is needed in this area to fully understand the scope of the risk, particularly from pesticides that we have commonly observed in the wild but have not yet tested.

The Minnesota Zoo has received significant attention through media interviews and invited speaking engagements. We have created and established a great deal, and many agencies and organizations seek our advice as experts, but recovery of these endangered butterflies can only be fully achieved through partnerships. Successful conservation of these butterflies and the prairies they depend upon will have broad benefits to a wide range of wildlife and Minnesotans.

PROJECT RESULTS USE AND DISSEMINATION

Our work has garnered attention and the Minnesota Zoo has become a key agency in the international conservation programs for Poweshiek skipperling and Dakota skipper. We remain active in multiple

planning processes and multi-party action teams for both species and have hosted multiple workshops and meetings, including the 2019 meeting for the International Poweshiek Skipperling Conservation Partnership. Similarly, the field component of the Skipper Identification Workshop of this joint Zoo-DNR ENRTF appropriation (Activity 4; to be discussed in greater detail in the Update provided by DNR) was held in late June 2019 at the Hole-in-the-Mountain Prairie Preserve at the site of the Dakota skipper reintroduction program as well as several other sites in southwest Minnesota.

Across the duration of this project, there have been five TV stories, two radio segments, three newspaper articles, two major blog posts, dozens of social media posts, and dozens of speaking engagements. The Dakota skipper reintroduction effort has recently been the subject of TV segments (including two live) and a newspaper story that was widely shared across other news outlets across Minnesota and the Northern Plains, including Public TV's Prairie Sportsman, Pioneer Press, KSFY-TV, (Sioux Falls, SD), and KARE11-TV, (Minneapolis, MN). The research generated by this Project will be submitted for publication a peer-reviewed scientific journals.

Subd. 03c1 Completed: 06/30/2020 **FINAL REPORT**

Subd. 03c2: Prairie Butterfly Conservation, Research, and Breeding - Phase II - $329,000 TF

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OVERALL PROJECT OUTCOME AND RESULTS

Butterflies are in trouble in western Minnesota prairies. Ten species are of statewide conservation concern and two species are federally listed. Knowing where these species persist on the landscape is important to their conservation. Likewise, understanding the factors that affect population size is important to the conservation of existing populations. The skipper butterflies are difficult for untrained individuals to identify with certainty. The lack of qualified surveyors limits the ability of biologists and managers to search for skippers.

Seven of the 13 species were not found across all sites surveyed. All of these missing butterflies are skippers. We monitored populations of Dakota skipper and Pawnee skipper in response to prairie management. Conservation grazing, or perhaps the lack of fire, appears to be beneficial to persistence of Pawnee skipper. The results of Dakota skipper monitoring are less clear and will require additional years of monitoring. Dakota skippers at the reintroduction site appear highly localized to within a few hundred meters of the point of release. This is perhaps due to low dispersal ability, mortality, and/or lower detection ability with increasing radius from the release point. The MNDNR, MN Zoo, and USFWS partnered to successfully train at least 30 individuals to identify imperiled skippers, thus increasing the statewide capacity for monitoring greatly. All of these actions work to make more informed, science-based decisions about the conservation of rare butterflies for all Minnesotans to enjoy.

PROJECT RESULTS USE AND DISSEMINATION

During this project, the USFWS consulted project staff in drafting the recovery plans for both federally listed species, the Dakota skipper and the Poweshiek skipperling. Information gained from the surveys conducted through this project were essential in writing the recovery plans. These draft recovery plans were then disseminated for public comment and review.

The project manager in collaboration with the MN Zoo and USFWS developed species identification cards for the imperiled skipper species and their look-a-likes as part of the training sessions. These cards are specific to western Minnesota skippers and are an important tool in the continued survey and conservation of these rare skippers. We continue to receive complements and requests for these identification cards.

Subd. 03c2 Completed: 06/30/2020 **FINAL REPORT**

Statewide Monitoring Network for Changing Habitats in Minnesota

Subd. 03d $500,000 TF

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Appropriation Language
$500,000 the second year is from the trust fund to the commissioner of natural resources to develop a consolidated statewide network of permanent habitat monitoring sites in prairies, forests, and wetlands to help guide and prioritize habitat protection and management decisions in response to environmental change. The design and testing methodologies of monitoring plots must address the status of pollinators and pollination. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

This project developed a network for monitoring change in the condition of prairies, forests, and wetlands across Minnesota to inform land protection and management in the face of rapid environmental change. The first activity was the development of long-term monitoring plots for the newly established Ecological Monitoring Network (EMN). We established 125 permanently marked plots on public and private lands, and collected data on native vegetation, soils, and other aspects of the environment. To address pollinators in monitoring plots, bee specialists visited six plots and hand-netted over 75 bees. The 125 plots represented a broad spectrum of quality. We recorded 885 vascular plant species, which represents 44% of the total number of species in Minnesota. The plot with the highest diversity was a tamarack swamp with 112 species. Over half (52%) of the plots contained at least one non-native plant species. Upland and wetland prairies were the plant communities with the most non-native species. In future years, we plan to install another 475 plots, and then to resample all plots every 6 years. Data analyses will include summaries of how native prairies, forests, and wetlands change over time, and how those changes are related to habitat patch size, past management, and other factors.

This project also included historic vegetation sampling to measure past changes in native vegetation by using relevé vegetation plots originally sampled 20-40 years ago. We sampled 80 relevés in prairies and forests in State Parks and Scientific and Natural Areas in east-central Minnesota, and sampled the first eight of 80 relevés to be sampled in 2019 on the North Shore of Lake Superior. We began analyses of the 80 relevé plots from southeastern and east-central Minnesota. Results indicate that we can detect significant changes in vegetation using the relevé resampling technique. For example, we found that

prairies that have had fire management had fewer non-native invasive species, less cover by vines, and higher native species diversity than those that have not had fire management. However, we did detect increasing frequency of non-native invasive species such as smooth brome and common buckthorn, as well as increasing frequency of native vines, over time on all plots. Further analyses will be completed and the results disseminated in 2020.

PROJECT RESULTS USE AND DISSEMINATION

A web page for this project was created and can be accessed here: https://www.dnr.state.mn.us/mbs/ecologicalmonitoring/index.html. The project goals, objectives, most recent brochure, and field methods, including a link to the Standard Operating Procedures (DNR Biological Report Number 121), can be found on this web site.

Reports summarizing data collected in each plot were sent to the respective landowner or land manager for that plot following each field season.

Email updates regarding the project's progress were shared with DNR Oversight and Project Teams following 2017 and 2018 field seasons.

PowerPoint presentations were developed and presented at a number of venues, including the Minnesota Biological Survey annual meeting, the Minnesota Native Plant Society, The Nature Conservancy, and the University of Minnesota's Conservation Science Symposium.

Project Completed: 06/30/2019 **FINAL REPORT**

Completing National Wetland Inventory Update for Minnesota

Subd. 03e $1,500,000 TF

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Appropriation Language
$1,500,000 the second year is from the trust fund to the commissioner of natural resources to complete the update and enhancement of wetland inventory maps for counties in central and northwestern Minnesota. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

The National Wetlands Inventory (NWI) update project was a collaborative effort lead by the Minnesota DNR that:

- Developed new methods for integrating lidar data into wetland mapping,
- Created of a suite of lidar-derived topographic datasets to assist with wetland mapping,
- Acquired new statewide, high-resolution spring leaf-off aerial imagery,
- Completely re-mapped and classified all wetlands larger than 0.5-acre in size,

- Engaged stakeholders in the development and review of the updated data,
- Enhanced the NWI with additional attributes, and
- Efficiently delivered data to various user groups through multiple means.

These data replace the original 1980s NWI data. In this final phase of the overall effort, we updated wetland inventory maps for the remaining 20,700 square miles of northwestern Minnesota covering 19 counties. All the wetland data from each project phase has been edge-matched to create a single statewide wetland inventory containing nearly 2.4 million wetland polygons.

Quality assurance of the data included visual inspection, automated checks for attribute validity and consistency, as well as a formal accuracy assessment based on independent field data. The updated NWI data have a 95% user accuracy for wetland identification. Further details on the methods employed can be found in the technical procedures document for this project located on the DNR wetland-mapping website.

PROJECT RESULTS USE AND DISSEMINATION

Wetland map data developed by this project are freely available through web-based data distribution hubs and online viewing through web mapping applications including the Minnesota Geospatial Commons and the DNR Wetland Finder. The final statewide updated data were posted to these distribution points on May 31, 2019.

The DNR issued a press release on June 3, 2019 announcing the availability of the statewide NWI. The DNR also included social media posts regarding this release. The story was picked up by several media outlets. The DNR developed a web application to support ongoing stewardship of the NWI data. The web application provides a simple and consistent method for state and local wetland professionals to submit change requests to the DNR. DNR plans to incorporate these user requests into annual updates of the NWI.

The DNR also developed a NWI User Guide and Summary Statistics. This guide provides a brief overview of the potential uses, limitations, access and technical aspects of the Minnesota Wetland Inventory. This guide also provides summary statistics of wetland types by county and major watershed. Printed copies are being distributed to local Soil and Water Conservation Districts, BWSR wetland specialists, DNR area hydrologists, and others. In addition, the DNR developed and printed 1000 copies of a map poster. These are being sent to a broad array of potential users of the NWI including SWCDs and local government units.

Project Completed: 06/30/2019 **FINAL REPORT**

An Updated and Enhanced National Wetland Inventory for Minnesota
Technical Procedures for Updating the National Wetlands Inventory of Northwest Minnesota
Press Media
Minnesota Wetland Inventory: Wetland Functional Assessment Final Report and Guidance Handbook
User Guide and Summary Statistics

Assessment Tool for Understanding Vegetation Growth Impacts on Groundwater Recharge

Subd. 03f $212,000 TF

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Appropriation Language

$212,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to develop a statewide assessment tool to help understand the relationship between vegetation growth and impacts on groundwater recharge under changing land use and climate. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

This project investigated the impact of varying plant growth on groundwater recharge using an ecohydrological computer model, the Community Land Model (CLM). With the model, we simulated recharge for two different vegetation conditions – one in which actual, year-to-year varying vegetation conditions were included, and the other (the standard approach) in which the average 16-year vegetation conditions were included. The study was carried out for 2000-2015 at a resolution of 25km for the entire state of Minnesota. The overall statewide average recharge for the 16-year period was 2.9 inches per year with varying vegetation and 2.8 inches per year with repeated, 16-year average vegetation. Although the difference between these results is very small, it is more variable on an annual and local scale and can differ up to 28% for certain times and locations. The impact on recharge due to the vegetation also varies by ecoregions. Recharge in the North Central Hardwood Forests (NCHF) is the most sensitive to varying vegetation, and the North Lake and Forests (NLF) in northeastern Minnesota (consisting primarily of coniferous forests) is the least sensitive. Across the state, we also found that most year-to-year variations in vegetation occur mostly due to temperature rather than precipitation, with the greatest temperature sensitivities in the Great Plains (GP) in the western Minnesota. With overall increasing and more variable temperatures projected for the future, accounting for dynamic responses in vegetation becomes even more important for accurately predicting changes in recharge, especially in sensitive areas of the state like western and central Minnesota. Through our study, we also found that southeastern and northeastern Minnesota suffer from sparser and lower quality groundwater level data compared to other parts of the state, serving as a major limitation in accurate recharge assessments there. Expanding groundwater monitoring in these areas will be important for managing and preparing for future impacts of climate and plant variability on recharge in these areas.

PROJECT RESULTS USE AND DISSEMINATION

The methodology and main results will be documented on the project website. Poster and oral presentations were made in multiple national and regional conferences, workshops, and seminars including: American Geophysical Union Fall Meeting (2017, 2018 and 2019), Community Earth System Model workshop, Colorado (2019), Earth and Environmental Sciences Student Research Symposium, Minnesota (2018), and Water Resource Symposium, Minnesota (2017).

Source code modifications for the ecohydrological CLM model and the Ensemble Kalman Filter (EnKF) calibration code have been publicly shared online via a GitHub code repository. An error in the source code of the ecohydrological CLM model – a model used by a large number of users globally - was discovered and fixed. We will be submitting the fix officially for the public review so that it can be included in future versions of the model. We filtered and removed erroneous observations for multiple wells in the Cooperative Groundwater Management (CGM) Database. We have communicated these issues to MN-DNR in order to help them improve this public dataset. Additionally, we are preparing a scientific journal article to share our findings with the academic community.

Project Completed: 06/30/2019 **FINAL REPORT**

Sentinel Lakes Monitoring and Data Synthesis - Phase III

Subd. 03g $401,000 TF

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Appropriation Language
$401,000 the second year is from the trust fund to the commissioner of natural resources for the third and final phase of a monitoring and multidisciplinary research effort on 25 sentinel lakes in Minnesota, which will integrate and synthesize previously collected data to enhance understanding of how lakes respond to large-scale environmental stressors and provide for improved ability to predict and respond to lake changes for water and fisheries management. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

We are grateful for the ENRTF's support, which has been instrumental for the development and success of the Sentinel Lakes Program. DNR and PCA have ensured the continuation of the program including DNR fisheries support for 3 permanent Sentinel Lakes staff positions who will direct program activities and lead remote monitoring and pelagic and juvenile fish sampling, area fisheries staff and IBI Program support through continued fish sampling and remote monitoring and PCA and EWR support through continued water quality, zooplankton, macroinvertebrate and aquatic plant collection and analysis. These monitoring activities will foster the continuation of the long-term monitoring framework and help collaborators utilize the existing framework to investigate specific questions.

Phase 3 of the Sentinel Lakes Long-Term Monitoring Program comprised a wide variety of data management, monitoring and research activities on the 25 Sentinel Lakes. During 2016-2019, Highlights include:

- The Sentinel Lakes datasets have been gathered, assembled, standardized, undergone QA/QC, and metadata have been created for each dataset with all data and metadata available upon request.
- We have outfitted all 25 Sentinel Lakes with continuous water temperature loggers for a total of 180 currently active recording loggers.
- We have summarized and analyzed trends in water quality, water temperature, water level, zooplankton, pelagic fish and game fish trends over time.
- We have established new sampling activities targeting juvenile fish with an emphasis on growth, and new aging protocols for pelagic fish to better track year class strength, growth, and mortality.
- We have identified dissolved oxygen monitoring as a data gap and we have already made progress to fill this gap.

- We have prioritized the dissemination of Sentinel Lakes data and information which has resulted in an updated public website (https://www.dnr.state.mn.us/fisheries/slice/index.html), data sharing with numerous collaborators, 30+ presentations, public media coverage, and research proposals and funded projects with collaborators.

PROJECT RESULTS USE AND DISSEMINATION

We have prioritized the dissemination of Sentinel Lakes data and information over the last 3 years which has resulted in an updated public website (https://www.dnr.state.mn.us/fisheries/slice/index.html), data sharing with numerous collaborators, 30+ presentations, public media coverage, and research proposals and funded projects with collaborators. Specifics are provided in the date specific updates with highlights below.

The updated Sentinel Lakes section of the DNR website includes new information and a smart phone friendly design. In addition to the program description and contacts list we have also included detailed lake descriptions, methodology, and updated research project descriptions.

The Sentinel Lakes datasets have been gathered, assembled, standardized, undergone QA/QC, and metadata have been created for each dataset with all data and metadata available upon request. We are working with MNiT staff to ensure compatibility with existing DNR database architecture, branding and ADA requirements. Details located under Activity 1 Outcome 1.

We have fostered a data sharing philosophy that has encouraged outside researchers to request Sentinel Lakes data. Now that data are reviewed for QA/QC and metadata have been created, data requests can be filled quickly and are complemented by trophic level specific metadata. As noted, data sharing is an important part of the Sentinel Lakes Program and one that we will continue to promote. In the past 3 years we have shared data with collaborators who include: Universities (University of Minnesota Twin Cities, University of Minnesota Duluth and Large Lakes Observatory, Bemidji State University, University of North Carolina, Kalamazoo College), Federal scientists (Environmental Protection Agency, USGS, USFWS, NPS), Tribal Biologists (1834 Treaty Authority, Lac du Flambeau Band of Lake Superior Chippewa Indians, Red Lake Department of Natural Resources), state agencies (Wisconsin DNR, MN PCA, and MN DNR) and private industry (TetraTech).

Data sharing has resulted in numerous submitted research proposals including several funded grants and projects including $46,500 from Midwest Glacial Lakes Fish Habitat Partnership to support dissolved oxygen monitoring, 2 funded Sport Fish Restoration projects lead by DNR, and LCCMR support for Kathryn Schreiner (UMD and Large Lakes Observatory) and colleagues for the project “A Survey of Microplastics in Minnesota’s Inland Aquatic Food Webs”.

We have given 30+ presentations to groups like The Association for the Sciences of Limnology and Oceanography; Midwest Fish and Wildlife Conference; Annual Meeting of the Minnesota Chapter of the American Fisheries Society; Bemidji State University; the Fish and Wildlife Division’s Climate and Renewable Energy Steering Team; Section, Region, and Unit specific DNR meetings; Interagency research meeting with the Minnesota Department of Agriculture; Board of Water and Soil Resources; Minnesota Pollution Control Agency; University of Minnesota; the St. Croix Watershed Research Station; and the Department of Natural Resources. Also several webinars were given to EPA’s regional lake monitoring network and we presented and instructed participants at the Remote Sensing Workshop.

Several public media outlets have featured Sentinel Lakes stories including Minnesota Public Radio, The Star Tribune, The Echo Press, and the Outdoor News.

Manuscript “Stable isotopes indicate that zebra mussels increase dependence of lake food webs on littoral energy sources” by Brian Herwig and colleagues was published in 2018 in the journal of

Freshwater Biology documenting energy flow change pre and post zebra mussels infestation in Lake Carlos.

The Second Sentinel Lakes Summit brought 70 collaborators from DNR, PCA, university faculty and federal researchers together to learn, discuss, and advance the science related to long term monitoring and changes in Minnesota lakes.

Project Completed: 06/30/2019 **FINAL REPORT**

Stable isotopes indicate that zebra mussels *(Dreissena polymorpha)* increase dependence of lake food webs on littoral energy sources

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State Spring Inventory for Resource Management and Protection - Phase II

Subd. 03h $370,000 TF

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Appropriation Language
$370,000 the second year is from the trust fund to the commissioner of natural resources to continue a systematic inventory of springs statewide to provide fundamental data needed to maintain spring flows and protect groundwater-dependent resources. Increased outreach to the public and other entities must be conducted to assist in the identification, documentation, and publication of spring locations. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS
Springs are natural points of groundwater discharge. Springs provide flow for:

- coldwater (trout streams) and cool water fisheries;
- base flow in streams during dry periods;
- create and sustain unique ecological habitats; and
- maintain the integrity of aquatic systems against invasive species.

Sustainable management of natural resources requires easily accessible location and feature characteristics data. Natural resources cannot be managed and conserved if we don't know where they are.

A permanent, web accessible map and comprehensive, easy to use database (Minnesota Spring Inventory, or MSI) was finalized and populated with spring locations and associated information that had been assembled through previous projects. The Minnesota Spring Inventory currently holds approximately 6,900 features including a combination of field verified and likely, but non-verified locations. Field work during this funding period included most of the state with much of the activity focused on the greater Twin Cities area, east central (St. Croix River valley), and western Minnesota

(Minnesota River valley) for a total of 900 locations. Approximately 600 additional locations were added to the inventory through file searches, and an additional 200 likely locations were added through online citizen submittals with a DNR-created application.

Approximately 30 percent of the locations entered into the inventory during this funding period were seeps (groundwater flow rates less than a gallon per minute -- gpm). The remaining 70 percent of the locations were springs with flow rates as high as 100 gpm. Approximately 20 percent of the springs had flow rates of 10 gpm or greater. These higher flow locations were found in every portion of the state that was surveyed during this project.

These data can be accessed through the following link:https://www.dnr.state.mn.us/waters/groundwater_section/springs/msi.html. Data can be downloaded from the Minnesota Geospatial Commons: https://gisdata.mn.gov/dataset/env-mn-springs-inventory.

PROJECT RESULTS USE AND DISSEMINATION

In March 2018, the Minnesota Spring Inventory web page went live: https://www.dnr.state.mn.us/waters/groundwater_section/springs/msi.html. The webpage has an online, interactive map that allows users to quickly find information about springs throughout the state. The webpage also provides a link to a reporting app that can be used by citizens on a desktop or mobile devise to provide location and basic spring characteristic information. DNR staff evaluate these submittals for possible inclusion into the spring inventory. Background information about the project and springs are also available through the web page.

During this funding period the project was promoted (dissemination) through at least 28 formal documented outreach activities by 4 members of the spring inventory team including 17 presentations, 6 interviews and articles through media organizations, and 5 articles for science organizations. Numerous informal contacts have been made by team members and others.

Project Completed: 06/30/2019 **FINAL REPORT**

Enhancing Understanding of Minnesota River Aquatic Ecosystem

Subd. 03i $500,000 TF

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Appropriation Language
$500,000 the second year is from the trust fund to the commissioner of natural resources to accelerate collection of baseline data to enhance understanding of the Minnesota River ecosystem, measure future impacts of changing climate and landscapes on the aquatic ecosystem, and guide future management efforts. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

Land use practices, climate change, establishment of invasive species, conservation efforts, and other factors continually affect the Minnesota River ecosystem. This project accelerated collection of robust baseline datasets that provide a better understanding of plankton communities, physical habitat characteristics, backwater ecosystems, and sensitive fish species populations. These datasets provide the ability to better predict, measure, and understand future ecosystem changes. Specifically, we established a comprehensive understanding of lower trophic ecology in the Minnesota River by collecting 112 water chemistry, phytoplankton, and zooplankton samples across 7 sites and 16 months. We also quantified habitat features (e.g., longitudinal profiles, bathymetric maps) at 12 reaches along the Minnesota River and characterized fish communities inhabiting 12 unique backwater lakes. Lastly, we captured and tagged 85 Paddlefish and 391 Shovelnose Sturgeon from the Minnesota River providing an understanding of population dynamics (e.g., abundance, growth, recruitment, and mortality), habitat use, and movement patterns of these unique and understudied species. Our enhanced understanding of the Minnesota River ecosystem and information gained during this project will not only inform future monitoring efforts and guide management and restoration efforts, but also provide the critical ability to understand how the Minnesota River ecosystem responds to future changes. For instance, if invasive carps become established in the Minnesota River, we now have the ability to quantify consequent changes in plankton communities, displacement of backwater fish communities, and impacts on the Paddlefish population. Data collected during this project are publicly available for quantitative and qualitative analyses while accompanying in-depth reports for each project activity provide valuable context, interpretation, and comparisons with other aquatic ecosystems.

PROJECT RESULTS USE AND DISSEMINATION

Resulting from this project, we developed five comprehensive reports summarizing and analyzing the novel datasets we collected that provide important comparisons with other aquatic systems and discuss implications for future Minnesota River ecosystem monitoring and management (i.e., Activity 1 Final Report—Spatial and temporal trends of Minnesota River phytoplankton and zooplankton, Activity 2 Final Report—Evaluation of Minnesota River physical habitat features, Activity 3 Final Report—Minnesota River backwater fish communities, Activity 4A Final Report—Minnesota River Shovelnose Sturgeon: population dynamics and movement patterns, Activity 4B Final Report—Paddlefish inhabiting the Minnesota River). Condensed versions of the reports associated with activity one (e.g., plankton dynamics) and activity four (e.g., Shovelnose Sturgeon, Paddlefish) will be submitted for publication in open-access peer reviewed scientific journals (e.g., Journal of Fish and Wildlife Management; Journal of Freshwater Ecology). During the project, we provided project updates and preliminary results to scientific audiences at three annual meetings of the Minnesota Chapter of the American Fisheries Society and to members of the public at Hutchinson Area Avid Angler Meetings, Citizen Catfish Workgroup meetings, and a Minnesota River Congress meeting. Ultimately, we intend on providing data, project reports, and project summaries on the Minnesota River Fisheries page of the Minnesota Department of Natural Resources website (Minnesota River Fisheries Page). We are also seeking appropriate venues to present final project results with interested members of the public and other scientific and conservation entities as one of the most valuable outcomes of this project is the collection of novel datasets on important components of the Minnesota River ecosystem.

Project Completed: 06/30/2019 **FINAL REPORT**

Introducing and LCCMR Funded Minnesota River Project and Preliminary Telemetry Discoveries
Inventory of Minnesota River Backwater Fish Communities
Shovelnose Sturgeon and Paddlefish Populations and Movements in the Minnesota River
Minnesota River Paddlefish, Sturgeon, Backwaters, Plankton and More!
Project Summary: Activity 3 Inventory Minnesota River Backwater Fish Community

[Project Summary: Activity 4a Population Dynamics and Movement of Shovelnose Sturgeon]
[Project Summary: Activity 4b Evaluate Abundance and Movement of Minnesota River Paddlefish]
[Enhancing Understanding of the Minnesota River Ecosystem]

Improving Brook Trout Stream Habitat through Beaver Management

Subd. 03j $225,000 TF

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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.

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 (https://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
- 8th International Beaver Symposium, 2018
- 78th Midwest Fish and Wildlife Conference, 2018
- Annual Meeting of the American Society of Mammalogists, 2018
- Minnesota American Fisheries Society Meeting, 2018
- 79th Midwest Fish and Wildlife Conference, 2019
- Annual Meeting of the Minnesota Chapter of The Wildlife Society, 2017, 2018, 2019

Project Completed: 06/30/2019 **FINAL REPORT**

Casting Light Article

A Review of Beaver-Salmonid Relationships and History of Management Actions in Western Great Lakes (USA) Region

UMN Master Thesis: Factors Influecing Beaver (*Castor canadensis*) Population Fluctuations, and Their Ecological Relationship with Salmonids

Bemidji Master Thesis: Effect on Beaver on Brook Trout Habitat in North Shore, Lake Superior Streams

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Evaluate Temperature, Streamflow, and Hydrogeology Impact on Brook Trout Habitat

Subd. 03k $115,000 TF

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Appropriation Language
$115,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota for the Minnesota Geological Survey to evaluate links between southeastern Minnesota stream temperatures, trout habitat, and bedrock hydrogeology to improve trout stream management. This

appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

The recent discovery of resurgent brook trout populations in southeastern Minnesota streams has led to increased interest in documenting and improving critical habitat for this native species. Distributed Temperature Sensing (DTS) technology using fiber optic cables, combined with detailed mapping of geologic conditions and hydraulic head were used to identify areas of preferential base flow at three southeastern Minnesota trout streams— East Indian Creek in Wabasha County, Trout Brook in Dakota County, and Valley Creek in Washington County. Results were compared to fish inventories conducted by the Minnesota Department of Natural Resources to evaluate influence of focused groundwater input on brook trout distribution and abundance. Continuous stream temperature measurements along one meter segments over distances up to 1900 meters were taken in winter when air and groundwater temperatures are most different. Transition from mixed populations of brown and brook trout to predominantly brook trout corresponded specific stream reaches showing preferential base flow inputs from groundwater.

At the regional scale, artesian conditions were compared to bedrock geology and brook trout abundance to locate areas where brook trout, including remnant brook trout, may be most successfully established. Brook trout are found in almost exclusively in streams where the Oneota Dolomite and underlying bedrock units are uppermost bedrock. Streams in these settings have springs characterized by relatively constant temperatures, and are supplied by groundwater in generally poor connection to the land surface compared to near-surface aquifers. As such, they have relatively low susceptibility to high turbidity and contaminant pulses resulting from extreme storm events. At both regional and local cases our work (see attached) demonstrates to natural resource managers the direct geologic control on hydraulic head conditions – particularly on vertical head gradients between bedrock layers and the role they play both in stream base flow and brook trout distribution and abundance.

PROJECT RESULTS USE AND DISSEMINATION

The attached report is currently being revised for release as an Open-File Report available publically via the University of Minnesota's Digital Conservancy (https://conservancy.umn.edu/), and for peer-reviewed journal submittal. As a project that includes a hybrid of disciplines, it is expected that results will be presented at meetings with both groundwater and natural resource management focus. To date, the results have been presented to a group of local residents and landowners from East Indian Creek in Wabasha County, organized by Jen Wahls, Landuse Outreach Coordinator for Wabasha County SWCD and by Nick Budde, student scholarship recipient at the Minnesota Groundwater Association Spring 2018 Conference (also attached).

Project Completed: 06/30/2019 **FINAL REPORT**

Evaluation of temperature, streamflow, and hydrogeology impact on brook trout habitat

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Restoration of Elk to Northeastern Minnesota

Subd. 03l $300,000 TF

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Appropriation Language
$300,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota in cooperation with the Fond du Lac Band and Rocky Mountain Elk Foundation to determine the habitat suitability and levels of public support for restoring elk to northeastern Minnesota. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

Elk historically occupied most of Minnesota prior to the early 1900s, but now only 3 small groups occur in northwestern Minnesota. These groups are managed at low levels to reduce human-elk conflict. Forested areas of the state could avoid some conflict and see ecological and economic benefits from returning elk to the landscape. Evidence from other states indicates elk restoration can be successful, but success is dependent on forest management and public support for elk by local communities. This study examined the feasibility of restoring elk to 3 study areas in northeastern Minnesota. It provides information that will be useful for determining where elk restoration will be successful, should it occur, including information about social acceptance and habitat suitability. It resulted in 2 reports (McCann et al. 2019 and Walberg et al. 2019).

To assess landowner and local resident attitudes toward restoring elk to northeastern Minnesota, we surveyed 4,500 private landowners and 4,000 local residents. Eighty percent of landowners and 81% of local residents within the study areas strongly supported restoring elk to northeastern Minnesota. Landowner support for restoration was highest on the Cloquet Valley study area and lowest on the Fond du Lac study area. Local resident support was highest in southern St. Louis County, followed by Duluth, northern Pine County, and Carlton County.

To evaluate elk habitat suitability and to provide additional assessment of social support for restoring elk to northeastern Minnesota, we measured elk forage in the field and utilized GIS data to map habitat and social suitability. Our results show that habitat suitability and landowner support are not limiting factors for restoring elk to northeastern Minnesota. We sampled 186 field plots and found that mean summer forage at field plots exceeded amounts elk prefer and winter forage matched amounts where elk occur in Wisconsin. Estimates of how many elk are likely to be supported (5 to 8 elk/6 mi2) were similar to elk densities in Wisconsin and Michigan. Estimates of biological carrying capacity ranged from 287 on the Fond du Lac study area to 551 elk on the Cloquet Valley study area. Each of the 3 study areas: (1) had large amounts of habitat with suitability scores similar to where elk occur in Wisconsin; (2) a majority of land in public ownership; and (3) and relatively low human-elk conflict risk. Considering factors we assessed to be equally important did not result in statistically different study area rankings (on average, all 3 study areas were about the same) but some study areas ranked better than others when we weighted factors (considered some factor to be more important than others).

PROJECT RESULTS USE AND DISSEMINATION

Schrage delivered 16 presentations about this project to multiple groups, including: Rocky Mountain Elk Foundation banquets in Duluth and Prior Lake, the Minnesota Sharp-tailed Grouse Society in Hinckley, the Winton Historical Society, staff from the MNDNR's Northwest Region, the Minnesota Soil and Water Conservation District Forestry Association, the Breckinridge Chapter of the Izaak Walton League, Rocky Mountain Elk Foundation members in the Twin Cities, the Moose Lake Covenant Church Outdoor Expo, the annual meeting of the Minnesota Division of the Izaak Walton League, the Minnesota Forest Resources Partnership, St. Louis County Leaseholders, Northwoods Audubon, MNDNR Region 2 Assistant

Wildlife Managers, a joint meeting of Minnesota Forest Industries and MNDNR Forestry, and at a meeting of the St. Louis County Committee of the Whole. McCann and PhD student Eric Walberg delivered presentations about the project at the joint meeting of the State Chapters of The Wildlife Society and Society of American Foresters in Duluth, MN. Fulton and McCann delivered presentations about the project at the Western Association of Fish and Wildlife Agencies' Biennial Deer & Elk Workshop in Marfa, TX. This project was featured in the Duluth News Tribune, Pioneer Press, Brainerd Dispatch, the Minnesota Deer Hunters Association publication of "Whitetales", and Outdoor News. Educational displays about elk and this project were set up and staffed by tribal, Rocky Mountain Elk Foundation, University of Minnesota, and volunteer staff at the Carlton County and Minnesota State Fairs. Additionally, Schrage and other tribal personnel staffed booths that highlighted this project at the Minnesota State Fair and a second at the Cloquet Forestry Center's 50th anniversary celebration of their Conservation Education Day event, and Schrage and McCann ran an informational booth for the project at the Outdoor News Deer and Turkey Classic show. We held multiple project meetings that included MNDNR staff. We developed an internet presence, including a website (http://elk.umn.edu) and Facebook page (https://www.facebook.com/NE.MN.elk).

Project Completed: 06/30/2019 **FINAL REPORT**

A study of landowner and public attitudes toward potential elk restoration in Minnesota
Feasibility of restoring elk to northeastern Minnesota: habitat availibility and social acceptance

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Game and Nongame Bird Pesticide Exposure

Research Project

Subd. 03m $349,000 TF

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Appropriation Language
$349,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to evaluate the potential risk to game and nongame birds from exposure to neonicotinoid-treated agricultural seeds. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

Neonicotinoids are the most widely used pesticides worldwide and are commonly applied as a seed treatment to corn, soybean, and wheat seeds, which compromise the majority of Minnesota's row crops. Previous risk assessments have suggested that wild birds may be exposed to large doses of neonicotinoids through the ingestion of treated seeds. Using chickens as a model species, we evaluated the impacts of oral neonicotinoid exposure on the immune and neurological systems. We also assessed availability of treated seeds to wild birds on the agricultural landscape and analyzed grouse carcasses for residues of exposure. Accomplishments:

- We demonstrated neurological abnormalities in chickens exposed orally to imidacloprid, a commonly used neonicotinoid in seed-treatments
- We quantified seed spills on agricultural landscapes during spring planting season that may occur during loading or refilling seed hoppers
- We documented wildlife at neonicotinoid-treated seed spills with trail cameras and documented consumption of treated seeds.
- We documented neonicotinoid residues in the tissues of hunter-harvested grouse, indicating that those birds were exposed to the pesticides
- We identified 354 genes affected by imidacloprid exposure through RNA sequencing: 37 affected genes were detected in liver and 317 affected genes were detected in blood cells (which can be non-lethally collected, which may allow future development of detection assays)

The results of this project indicate that seed-eating birds in the wild may be exposed to seeds treated with neonicotinoids in the agricultural landscape through eating at seed spills. Ingestion of neonicotinoid-treated seeds by birds can produce neurological abnormalities that may impair survivability. Exposure can be evaluated through detection of pesticide residues in carcasses, as well as fecal pellets and blood cells. The results of this study may be used by the agricultural industry to reduce impacts to wild birds through education and process change (reduce spillage), as well as state and federal governmental agencies reviewing appropriate and safe usage of these pesticides.

PROJECT RESULTS USE AND DISSEMINATION

Results of this project have been communicated to a large audience of stakeholders, including directly with industry colleagues through meetings with agricultural stakeholders; with federal and state agencies through public commentary response as well as requested webinars, presentations and conversations; and with the scientific community through publications (1 paper published, 1 submitted and 4 pending), conference presentations (4) and scientific posters (2). Details of all communications are provided in the final report. The results of our work show that wild birds are at risk of exposure to agricultural seeds treated with neonicotinoids and that ingestion of field-realistic doses causes significant behavior changes in chickens that were severe at higher doses and may impair survival of free-living gallinaceous birds. The adoption of practices that would reduce seed spills on the agricultural landscape would reduce the exposure risk to wild birds.

Project Completed: 06/30/2019 **FINAL REPORT**

Report: Neonicotinoids on the Landscape

Multi-scale availability of neonicotiniod-treated seed for wildlife in an agricultural landscape during spring planting

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Evaluating Insecticide Exposure Risk for Grassland Wildlife on Public Lands

Research Project

Subd. 03n $250,000 TF

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Appropriation Language
$250,000 the second year is from the trust fund to the commissioner of natural resources to evaluate exposure risks of grassland wildlife to soybean aphid insecticides, to guide grassland management in farmland regions of Minnesota for the protection of birds, beneficial insects, and other grassland wildlife. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

Concerns about the impact of insecticides on birds, pollinators, and other wildlife are gaining increasing attention. Chlorpyrifos, lambda-cyhalothrin, and bifenthrin (hereafter, target chemicals) are three insecticides commonly used to control soybean aphids in Minnesota's farmland region. Lab studies have shown these chemicals to be highly toxic to non-target organisms including several bird and beneficial insect species, but few studies have investigated exposure of free-ranging wildlife to these chemicals. During 2017 and 2018, we collected samples from public grasslands across southwest, west central, and central Minnesota to determine direct and indirect exposure of wildlife to target chemicals, and indirect effects of the chemicals on insect prey important in the diets of grassland birds. We detected target chemicals at all distances examined (0-400 m from grassland edge) at both treatment and control sites, suggesting that some baseline amount of spray drift occurred in the environment regardless of landowner activities in the adjacent crop field. We also examined the importance of weather, vegetation, and other factors in explaining direct and indirect exposure. Notably, we found insecticide deposition directly onto passive sampling devices (used to measure direct exposure) was greater at the field edge than grassland interior, and deposition was also greater at mid-canopy than ground level. We also detected chemical residues on invertebrates (used to measure the potential for indirect exposure of insectivorous wildlife to these insecticides) but we did not find a strong relationship with distance from edge, possibly because we only evaluated indirect exposure ≤25 m from the field edge. We are currently evaluating the indirect effects of spray drift on invertebrate richness, diversity, and biomass. This fall, we will further interpret our findings to understand potential impacts (e.g., sublethal, lethal) of spray drift on various species of grassland wildlife. We will also begin more broadly sharing our findings with multiple constituent groups, including cooperating landowners, agricultural groups, and natural resource professionals. Ultimately, our research on the factors influencing soybean aphid insecticide deposition in grasslands in the agricultural matrix of Minnesota will help improve management of these set-aside habitats for wildlife.

PROJECT RESULTS USE AND DISSEMINATION

To date, we have presented our preliminary results at wildlife professional society conferences, DNR regional wildlife meetings, LCCMR/University of Minnesota (UM) pollinator and partner project meetings, graduate student symposia, and a webinar focused on prairie habitat conservation issues. We have also prepared annual progress reports for DNR and the USGS/Minnesota Cooperative Fish and Wildlife Research Unit. Finally, we have mentioned the study during several media interviews when appropriate. The final results of this research will form the main chapters of a Master's thesis for a graduate student at UM, and the thesis is expected to be completed during fall 2019 as part of her graduation requirements. These thesis chapters will be used to create peer-reviewed publications that will be shared with other scientists and natural resource professionals. We will continue to disseminate

our results with DNR wildlife managers and other staff so they can incorporate our findings into their habitat acquisition, restoration, and management activities. We will also share our findings with our private landowner cooperators and the larger agricultural community to bring awareness to the issue of and factors influencing soybean aphid insecticide drift onto grasslands and other set-aside habitats.

Project Completed: 06/30/2019 **FINAL REPORT**

MNDNR 2016 Annual Report: Insecticide Exposure Risk for Grassland Wildlife on Public Lands
MNDNR 2017 Annual Report: Insecticide Exposure Risk for Grassland Wildlife on Public Lands
Evaluating Insecticide Exposure Risk for Grassland Wildlife on Public Lands
MNDNR Fact sheet

Development of Innovative Cost-Saving Methodology for Forest Inventory

Research Project

Subd. 03o $800,000 TF

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Appropriation Language
$800,000 the second year is from the trust fund to the commissioner of natural resources to develop and pilot a new and more cost-effective methodology for an enhanced stand-based forest inventory, with the goal of extending the methodology statewide. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

Comprehensive forest inventory systems are a universal desire, but the costs of maintaining such a system with boots on the ground, especially considering Minnesota's extensive and diverse forest land base, continue to be a challenge. This project served as an important pilot to explore the accuracies achieved and cost savings gained with changing the way forest inventory is conducted. Two field sampling methods were tested in this project in over 300 plots, measuring over 9,000 trees: fixed radius plots placed in a gridded array (pre-stratification) and random plots placed proportionately within strata (post-stratification). Model results show that a gridded allocation performs better and has greater flexibility to reduce/expand the number of plots without risking model performance. Several forest inventory models (combined forest types, broadleaf only, and conifer only) were evaluated using numerous spatial predictors and two sources of LiDAR data: new high density and old low density. Model results show higher accuracies for conifers compared to broadleaf for both sources of LiDAR, and the combined models showed high density LiDAR performs much better. Another area of exploration was mapping cover types, since this is a crucial characteristic of a forest stand. The suite of remotely sensed data used and machine learning techniques applied have enabled cover type mapping with relatively good accuracy. The forest inventory and cover type mapping results in this project are incredibly encouraging and the methods developed are ready for statewide application once high density LiDAR data are available. Overall, the project results show that using remotely sensed data can

cut inventory costs by about 55%, enables the analysis of this valuable information across all lands, makes data available much faster than traditional methods, and ultimately benefits the many agencies, organizations, and stakeholder groups who are hungry for an affordable change to how forest inventory is conducted.

PROJECT RESULTS USE AND DISSEMINATION

Analyses of the newly acquired high density LiDAR has resulted in several forest inventory metrics and cover type models created, utilizing more than 300 newly acquired field forest inventory plots with over 9,000 trees measured. All of the LiDAR and derived products will be provided free to the public and will be hosted as LiDAR point cloud files on an ftp server with other state LiDAR data holdings, as well as several web mapping services produced by the MNDNR and accessible via the Minnesota Geospatial Data Commons (https://gisdata.mn.gov/). The project team from DNR Resource Assessment has already and will continue to deliver the results of this project in a number of other ways, including presentations at regional and national conferences in the fields of forestry, geographic information systems, and remote sensing, meetings and conference calls to share information directly with stakeholder groups, as well as the eventual submission of peer-reviewed manuscripts to scientific journals. In addition, DNR Resource Assessment has created a webpage that will be a central repository for all of the methods, reports, and links to access data.

Project Completed: 06/30/2019 **FINAL REPORT**

Evaluation of Tree Retention Guidelines Pertaining to Wildlife - RESEARCH

Subd. 03p $232,000 TF

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Appropriation Language
$232,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota for the Natural Resources Research Institute in Duluth to assess the effectiveness of the Minnesota Forest Resources Council tree retention guidelines in sustaining Minnesota's wildlife populations, by quantifying and evaluating the impacts on birds, small mammals, and amphibian diversity. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

Forest management is increasingly focused on maintaining ecological functions, including maintenance of biodiversity and wildlife habitat. In 1998, the Minnesota Forest Resources Council (MFRC) established Minnesota’s Forest Management Guidelines, which were intended to reduce the potential for negative environmental impacts resulting from forest harvesting. The current guidelines recommend that 6-12 trees per acre or 5 percent of the harvest area in 0.25 acre clumps or greater be retained (left uncut) for wildlife and biodiversity benefits. The spatial arrangement of retained trees influence habitat suitability for wildlife species, but there is a lack of information on what configuration of tree retention will

maximize wildlife benefits. To examine and quantify the benefits of tree retention after logging on Minnesota's wildlife, we measured breeding bird and small mammal diversity by conducting systematic surveys at four experimental study areas and 69 sites that had been harvested between three and 15 years previously. We then quantified the habitat characteristics including tree retention density and configuration at harvest sites. Our results showed there is a positive relationship between tree retention and wildlife diversity. The clumped configuration was most beneficial for small mammal communities. Stands with clumped tree retention also maintained bird diversity over time and significantly increased the relative abundance of several breeding bird species. Overall, the results indicated that the current MFRC guidelines are beneficial for wildlife and increase the diversity and total abundance of bird and small mammal species that use forest stands post-harvest. We recommend that the MFRC continue to promote clumped tree retention, or the use of a combination of clumped and scattered retention, to mitigate harvest-related impacts to Minnesota's wildlife. The results of this project add to the scientific basis for MFRC's forest management guidelines and provide support for sustainable management of Minnesota's forest resources.

PROJECT RESULTS USE AND DISSEMINATION

The results of this project have been presented at a variety of workshops and conferences:

- Forestry and Wildlife Research Review, Cloquet Forestry Center, January 11, 2018.
- The Minnesota Chapter of The Wildlife Society Meeting, St. Cloud Minnesota, February 12-14, 2018.
- Charting the Future for Northern Forest Birds: Takin it to the Tweets workshop in Ashland, WI, April 16-17, 2018.
- Forestry for Lake States Birds, Long Lake Conservation Center, June 22-23, 2018.
- Forestry and Wildlife Research Review, Cloquet Forestry Center, January 10, 2019 and The Minnesota Chapter of The Wildlife Society Meeting, Duluth Minnesota, February 19-21, 2019.
- The results of this report were presented to the MFRC on March 14th, 2019 and the PDF version of the presentation is included with the final report submission.
- The results of this project were featured in NRRI's newsletter and can be found here: https://www.nrri.umn.edu/natural-resources-research-institute/news/tree-retention
- We are in the process of completing two peer-reviewed manuscripts for this project and plan to have them submitted by the end of the year; the manuscripts will be available on NRRI's website after they are published.
- The final report will be posted on the NRRI website.
- Results from this work will also be used by the MFRC during the next revision of the guidelines, contributing to the scientific basis for forest management guidelines to sustainably manage Minnesota's forest resources.

Project Completed: 06/30/2019 **FINAL REPORT**

Determine Impacts on Wildlife From Emerald Ash Borer Infection of Black Ash Forests

Research Project

Subd. 03q $334,000 TF

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Appropriation Language
$334,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota for the Natural Resources Research Institute in Duluth to assess impacts of emerald ash borer and adaptive management on wildlife diversity in black ash forests and to develop recommendations to mitigate wildlife impacts. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

Black ash wetlands cover over one million acres of northern Minnesota forests and provide critical habitat for wildlife. The future of Minnesota's black ash swamps is critically threatened by EAB, which has been eliminating native populations of ash throughout the Great Lakes Region. Although EAB impacts to wildlife are certain, the magnitude and relative degree of impact to individual species and species diversity is unclear. To quantify the impacts of EAB on wildlife we measured seasonal bird, mammal, and herptile diversity in black ash stands across Minnesota. We established 29 long-term monitoring plots and developed protocols for measuring the current status of wildlife communities and also used eight experimental research sites that simulated EAB mortality and adaptive management strategies for EAB (clearcutting and group selection harvests) to assess the impacts of EAB on wildlife communities. Our results show that black ash stands are structurally and compositionally more diverse than paired upland and emergent habitats, providing a variety of microhabitats that support a large and unique assemblage of birds and amphibians. The loss of black ash due to EAB will result in turnover of bird, amphibian, and mammal communities from forest dependent species to open-canopy and wetland associated species. Increased ponding and hydroperiods may be beneficial for some amphibian species, but the loss of the forest canopy will result in an overall decrease in bird diversity, reduce forest connectivity, and exacerbate impacts of habitat loss for many mammal species. Our results show that the long-term, large-scale impacts of EAB on forest-associated wildlife will be significant. Management strategies that focus on establishing alternative trees species to maintain long-term forest cover and structural complexity will help maintain and conserve wildlife diversity.

PROJECT RESULTS USE AND DISSEMINATION

The results of this project have been presented at a variety of workshops, conferences and included in the following publications:

- Joint Meeting of Ichthyologists and Herpetologists "Potential effects of emerald ash borer invasion on wetland community composition" in Austin TX, July 12-16, 2017.
- Science and Management of Ash Forests after Emerald Ash Borer: A workshop on the future of post-EAB ash forests "Potential effects of emerald ash borer invasion on wetland community composition" in Duluth, MN on July 25-27, 2017.
- Forestry and Wildlife Research Review, Cloquet Forestry Center, January 11, 2018.
- The Minnesota Chapter of The Wildlife Society Meeting, St. Cloud Minnesota, February 12-14, 2018.

- Charting the Future for Northern Forest Birds: Takin it to the Tweets workshop in Ashland, WI, April 16-17, 2018.
- Alexis Grinde presented a webinar “Determining Impacts on Wildlife From Emerald Ash Borer Infestations of Black Ash Forests” via EAB University on March 15, 2018. The webinar recording is available at http://www.emeraldashborer.info/eabu.php
- Forestry and Wildlife Research Review, Cloquet Forestry Center, January 10, 2019
- The Minnesota Chapter of The Wildlife Society Meeting, Duluth Minnesota, February 19-21, 2019.
- Rob Slesak and Alexis Grinde presented “EAB and black as wetlands: Holistic assessment of ecosystem impacts and potential for mitigation” at the Forest Resources monthly seminar on February 25, 2019. Recording is available on the Sustainable Forests Education Cooperative: https://youtu.be/9R5QKKNNMYU
- Alexis Grinde presented a poster “Emerald Ash Borer and Wildlife: A Look into the Future” at the 2019 Heart of the Continent Symposium in Duluth, MN on April 8, 2019.
- Melissa Youngquist gave a seminar "Potential effects of emerald ash borer invasion on wetland communities" at Arkansas State University on April 24, 2019.
- Melissa Youngquist presented "Protecting Our Threatened Wetlands: How Invasive Species Can Affect Wetland Communities." At the Shedd Aquarium on May 15, 2019.
- Rob Slesak discussed the implications of the work at MN Senate and House hearings during the 2019 legislative session.
- Rob Slesak gave an invited presentation “Impacts of Emerald ash borer on black ash in the lake states” at the Eastern Regional Meeting of the National Council on Air and Stream Improvement, Atlanta GA, June 4, 2019.
- Rob Slesak gave an invited presentation “Simulated effects of EAB on hydrology of black ash wetlands” at the Water and Watersheds annual conference of the MN Pollution Control Agency, Brainerd MN, February 6, 2019.
- Kolka, R.K., D’Amato, A.W., Wagenbrenner, J.W., Slesak, R.A., Pypker, T.G., Youngquist, M.B., Grinde, A.R. and Palik, B.J., 2018. Review of Ecosystem Level Impacts of Emerald Ash Borer on Black Ash Wetlands: What Does the Future Hold?. Forests, 9(4), p.179. https://www.fs.fed.us/nrs/pubs/jrnl/2018/nrs_2018_kolka_001.pdf
- The results of this project were incorporated into the updated version of the document “Managing Ash Woodlands: Recommendations for Minnesota Woodland Owners” this document is available on the UMN Digital Conservancy on-line and in a variety of print options. The persistent link to this item is: http://hdl.handle.net/11299/205052
- We are in the process of completing two peer-reviewed manuscripts for this project and plan to have them submitted by the end of the year; the manuscripts will be available on NRRI’s website after they are published.

Project Completed: 06/30/2019 **FINAL REPORT**

Subd. 04 Water Resources

Tracking and Preventing Harmful Algal Blooms

Research Project

Subd. 04a $593,000 TF

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Appropriation Language
$500,000 the second year is from the trust fund to the Science Museum of Minnesota for the St. Croix Watershed Research Station to identify species composition and timing of harmful algal blooms, understand the causes of bloom development in individual lakes, and determine how nutrients and climate interact to increase harmful algae outbreaks. This work must be done in cooperation with the University of Minnesota and the Minnesota Pollution Control Agency. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

Lakes are one of Minnesota's most precious resources and harmful algal blooms (HABs) threaten them both from an ecological and economic standpoint. This provides a survey of the current prevalence and toxicity of harmful algal blooms (HABs) in a subset of Minnesota lakes, determines if these blooms are increasing in frequency, and develops and refines modeling techniques that could be used to predict HABs in lakes across Minnesota. To this end, we intensively monitored five lakes in southwest and central Minnesota over 2 years for all major water chemistry parameters, algal biomass, and four cyanotoxins. In these lakes, and five additional lakes in northern Minnesota, we collected and dated sediment cores where fossil cyanobacterial pigments could be measured to track the occurrence of Cyanobacteria over the last 150 years. Finally, we chose one of the intensively monitored lake as a pilot study where we developed a watershed model (SWAT) and an in-lake hydrodynamic model (CE-QUAL-W2) to predict annual cyanobacterial bloom patterns. As a result of this project, we determined that in lakes which are already eutrophic, internal loading dynamics will play a key role in determining the size and toxicity of the bloom. Importantly, we found that even in shallow lakes (less than 16 ft maximum depth), temperature and oxygen dynamics are critical in terms of bloom timing and toxicity. Cyanobacteria pigment data from our sediment cores showed increasing HABs in some lakes over the 20th Century, but also demonstrate that conditions may have been even worse in the early to mid- 20th Century before the passage of the Clean Water Act. Our modeling results provide a framework for resource managers to predict seasonal bloom formation and persistence in lakes across the state using publicly available and widely used modeling techniques.

PROJECT RESULTS USE AND DISSEMINATION

Throughout this project we have provided numerous public updates on progress via the Science Museum of Minnesota's website and the St. Croix Watershed Research Station's blog, "Field Notes" including:

- "Featured Research Project" on SCWRS website: https://www.smm.org/scwrs/research/hab

- "Watching When, Where and Why Harmful Algae Happen in Minnesota Lakes" describing the beginning of the project: https://www.smm.org/scwrs/fieldnotes/watching-when-where-and-why-harmful-algae-happen-minnesota-lakes
- A primer on the "5 super powers of Cyanobacteria": https://www.smm.org/scwrs/fieldnotes/five-super-powers-cyanobacteria

We provided our expertise in major statewide news coverage of HABs over the course of this project, including:

- "Dogs as sentinels: Blue-green algae brings toxic mystery to Minn. Waters": https://www.mprnews.org/story/2016/05/24/water-toxic-algae-dogs-climate-change
- Two evening news spots on FOX21 Duluth in June of 2017 where reporters accompanied us in the field
- "Researchers search for clues to toxic algae blooms": https://www.mprnews.org/story/2017/08/17/researchers-search-for-clues-to-toxic-algae-blooms
- Participated in public call-in show on MPR for Minnesotans with questions about their lakes: https://www.mprnews.org/story/2018/04/03/water-month-state-of-minnesotas-lakes
- Participated in MPRs Climate Cast on the topic of HABs: https://www.mprnews.org/episode/2019/07/19/conditions-ripe-for-a-record-number-of-algae-blooms?fbclid=IwAR19XRU6hUPGjIt9-9d0Pj8H5pRfPLEYWSr-SpdE-g7yTlAANwQmZU7IaqQ

We co-organized two public workshops on HABs in cooperation with the University of Minnesota St. Anthony Falls Laboratory that were held in March of 2017 and 2018 which were each attended by ~70 people, including state agency personnel, local water district managers, academic researchers, private environmental consultants, and interested members of the public.

Major research results from this project were also presented at two separate meetings of the Association for the Sciences of Limnology and Oceanography in June of 2018 and February of 2019 using in-kind funding provided by the Science Museum of Minnesota. This is the largest meeting dedicated to aquatic science in the world and is held once a year. A PDF of the scientific poster presented in 2018 and the powerpoint presented in 2019 are included as a supplemental attachment to this report.

Additional Attachments include fact sheets created by SCWRS for HABs on Pearl Lake and the Madison Lake SWAT model and a report on the CE-QUAL-W2 model produced by USGS.

Project Completed: 06/30/2019 **FINAL REPORT**

USGS Report: Updates to the Madison Lake (Minnesota) CE-QUAL-W2 Water-Quality Model..
SCWRS Fact Sheet

Assessing the Increasing Harmful Algal Blooms in Minnesota Lakes

Research Project

Subd. 04b M.L. 2016 - $270,000 TF and M.L. 2015 - $71,000 TF

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Appropriation Language
M.L. 2016, Chp. 186, Sec. 2, Subd. 04b
$270,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota for the Saint Anthony Falls Laboratory to investigate lake processes and meteorological conditions triggering algal blooms and toxin production, develop models for tracking blooms, and provide outreach on the prediction, detection, and impacts of mitigation of algal bloom events. This work must be done in cooperation with the St. Croix Watershed Research Station of the Science Museum of Minnesota and the Minnesota Pollution Control Agency. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.
M.L. 2015, Chp. 76, Sec. 2, Subd. 10 - Emerging Issues Account (recieved $71,000)
$1,000,000 the first year is from the trust fund to emerging issues account authorized in Minnesota Statutes, section 116P.08, subdivision 4, paragraph (d).

OVERALL PROJECT OUTCOME AND RESULTS

Harmful algae, including cyanobacteria, have been populating a growing number of freshwater ecosystems including lakes, rivers, and wetlands in Minnesota. Excessive accumulation of harmful algal biomass and associated toxin generation is referred to the public as a harmful algal bloom (HAB). The algal toxins, called microcystins, are harmful to wildlife and humans. The overall objective of this study was to determine how lake physical processes and meteorological conditions control HABs in three Minnesota lakes. We designed and implemented a unique research station to document HABs and toxin generation. This research station provides full-depth water quality (hourly) and meteorological conditions monitoring (5 min) at the sampling site and the display of data over the Internet. The high cyanobacteria biovolume (BV) in the approximate 4 m of the lake surface water depth was observed in mid-July and persisted until late September. Two types of BV distributions were observed. The first distribution depicted BV uniformly distributed over the surface water depth, and the second BV distribution displayed local underwater BV maxima. A quantitative relationship was developed to determine the anticipation of observing a uniform or underwater peak distribution as a function of the lake physical and meteorological conditions. Toxin microcystins (MC) was observed to accumulate in the lake surface layer and had a vertical distribution similar to BV. The temporal variabilities of BV and MC were different. The maximum toxin concentration occurred on average, seven days before or after the maximum HAB concentration was established. The time-lag between the maxima of BV and MC is notable because the maximum toxin concentration could occur before the visual signs of enhanced cyanobacterial accrual are less recognizable to the public and monitoring. Our findings could have important implications for predicting toxin and cyanobacterial biomass distribution and guiding monitoring strategies for quantifying toxin concentrations in Minnesota lakes.

PROJECT RESULTS USE AND DISSEMINATION

Public education and outreach were an integral part of our project. We had a total of 19 separate outreach and educational activities. We held six (6) different public outreach activities conducting over 365 different individual conversations and conducted five (5) in-person workshops with over 460 participants. The project produced three (3) peer-reviewed publications (attached to this report). A new HAB focused webpage was also developed, which remains active. We also purchase, retrofitted, and set-

up a mobile educational trailer to provide hands-on HAB educational activities, including demonstrating the use of drones and spectral camera in detecting and monitoring HABs.

Project Completed: 06/30/2019 **FINAL REPORT**

Restoring Native Mussels in Streams and Lakes

Subd. 04c $600,000 TF

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Appropriation Language
$600,000 the second year is from the trust fund to the commissioner of natural resources in cooperation with the Minnesota Zoological Garden for a statewide mussel program to rear, restore, and re-establish native mussel species in streams and rivers. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

Minnesota's native mussels are critically important to aquatic ecosystems, but have been lost or diminished in many water bodies. Harvest for pearls and buttons, pollution, dams, and destabilized waterways have caused mussel populations to decline dramatically, 80% of Minnesota's species are effected. Improvements from Clean Water Act implementation and stream restoration work are creating opportunities to reverse this trend. Mussel dependence on fish hosting their larval stage, and dams blocking fish movement can prevent populations from recovering limiting ecosystem recovery. Laboratory propagation began in 2016 as a means to reestablish mussel assemblages and the ecosystem services mussels provide. Three watersheds were selected for reintroduction efforts based on historical mussel records, habitat type and fish communities. We constructed several propagation systems specifically designed for juvenile recovery and culture over this period. In total, the Center for Aquatic Mollusk Programs (CAMP) has produced 1,332,592 juveniles of eleven species. In addition, almost 1,000 inoculated fishes were placed in benthic plastic totes or metal cages. The range of survival in the laboratory after 90 days ranges from 0 – 84%; Mucket and Black Sandshell have been our most successful species. Almost 75,000 juvenile mussels were raised to 2mm in length and moved into secondary culture systems for continued growth for release within two years. By restoring mussels, we hope to recover mussel species and improve water clarity. Recovering mussels will improve habitat for fish communities. Minnesotan's value clean water and fish; this project intends to enhance both.

PROJECT RESULTS USE AND DISSEMINATION

The results of this project has been featured in the Minnesota Conversation Volunteer in the September – October 2019 edition. Our Mussels of Minnesota poster was updated with all new photographs and text, and published in June 2019. CAMP's annual mussel newsletter generated attention, and our subscriber numbers have increased to over 2,300.

Project Completed: 06/30/2019 **FINAL REPORT**

Assessing Techniques for Eliminating Contaminants to Protect Native Fish and Mussels

Research Project

Subd. 04d $287,000

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Appropriation Language
$287,000 the second year is from the trust fund to the commissioner of natural resources for an agreement with the University of St. Thomas to evaluate the use of ultraviolet treatment of wastewater to remove certain commonly detected wastewater contaminants, in order to reduce the contaminants' toxicity to native fish and mussels. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

In 2009 the MPCA was directed by the legislature to monitor surface waters for endocrine disrupting compounds near wastewater treatment plants. In the resultant study, two of the most commonly detected compounds (tonalide and galaxolide) were polycyclic musks that are used as synthetic fragrances in a wide range of products. It has been demonstrated in mussels that musks can impair transporters involved in the first line of defense against toxicants. This is of great concern as 25 of Minnesota's 48 native mussel species are listed as endangered, threatened, or of special concern. Tonalide and galaxolide are also known to induce other types of toxicity (e.g. liver damage, DNA/genetic damage) and are suspected endocrine disruptors, meaning they can disrupt hormones and impair growth and reproduction, and are thus a potential threat to mussel and fish populations.

The goal of this project was to assess whether UV treatment of wastewater can effectively remove toxicity attributable to these compounds. When tonalide was exposed to sufficient UV light, it was eliminated and several photoproducts were formed. Biological assays were performed using tonalide and confirmed endocrine activity and inhibition of transporters as predicted, but only at high concentrations that would not be typically expected in Minnesota waters. Furthermore, biological effects were largely reduced or eliminated upon exposure to UV, suggesting photoproducts do not retain significant biological activity of the parent compound. Analysis of wastewater effluents reveals the presence of some parent tonalide and some photoproducts, supporting the prediction that higher UV doses than currently used may be required to completely remove tonalide. A major finding of this project is that galaxolide is much less stable in water than previously reported; it is unlikely to persist and be of concern in environmental waters. Therefore, overall this study suggests polycyclic musks are unlikely to be an imminent threat at the levels detected in Minnesota waters.

PROJECT RESULTS USE AND DISSEMINATION

Results from this project have, to date, been disseminated primarily via presentations given by undergraduate students from Gustavus and the University of St. Thomas. Locally, this included the 2019 "Scholars at the Capitol" event. Nationally, students have presented at American Chemical Society and

Society for Environmental Toxicology and Chemistry meetings; internationally, a student presented at the International Symposium on Liquid Phase Separations. Because the bulk of the substantive results have been finalized in the past few months, preparation of manuscripts for submission to peer-reviewed journals are forthcoming.

Project Completed: 06/30/2019 **FINAL REPORT**

Assessing Neonicotinoid Insecticide Effects on Aquatic and Soil Communities

Research Project

Subd. 04e $400,000 TF

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Appropriation Language
$400,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to identify neonicotinoid insecticide breakdown components produced in water and plant leaves and assess their toxicity to soil and aquatic species and related biotic communities. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

Neonicotinoid insecticides are widely used and detected at varying concentrations across diverse environments, including soil, surface water, and groundwater. A key component of how persistent neonicotinoids are in the environment is their degradation rate, and the residual toxicity of the products needs evaluation. Hydrolysis is the reaction process that occurs in water, which may be affected by the pH of the water or the presence of natural trace metals and minerals. Reaction driven by sunlight (photolysis) has also been reported as an important transformation pathway for neonicotinoids. The objectives of this study were to quantify hydrolysis and photolysis rates for neonicotinoid insecticides in water and on various surfaces; understand the effects of pH and natural trace metals on hydrolysis of neonicotinoids; characterize transformation products; and assess the toxicity of hydrolysis and photolysis products to soil and aquatic species. Hydrolysis and photolysis in aqueous solutions and on surfaces were examined for various neonicotinoids, including imidacloprid, thiamethoxam, clothianidin, acetamiprid, and nitenpyram. The results showed that neonicotinoids undergo base-catalyzed hydrolysis, and the hydrolysis rates were not impacted in the presence of divalent metal cations and minerals. Direct photolysis was observed for nitenpyram, imidacloprid, thiamethoxam, and clothianidin, but not for acetamiprid. When put onto various model surfaces to simulate application to a plant leaf, the photolysis rates and mechanisms were not only dependent on the surface, but also on whether a commercial formulation or solution of pure compound (analytical standard dissolved in ultrapure water) of the pesticide was used. Photolysis of commercial products was faster than pure compounds on the tested surfaces. Product analysis indicated that the urea derivative was the most commonly detected product for neonicotinoids reacting via hydrolysis and photolysis in water, while reduction and dissociation of the nitro group led to the major photoreaction products on surfaces. Toxicity tests on

mosquito (Culex pipiens) larvae were conducted with nitenpyram, imidacloprid, acetamiprid, thiamethoxam, clothianidin, and their reaction products generated via hydrolysis, photolysis in water, and photolysis on surfaces. No residual toxicity associated with reaction products was observed.

PROJECT RESULTS USE AND DISSEMINATION

Results from the work have been presented as oral and poster presentations at conferences (2017 Minnesota Water Resources Conference, 2017 MN Conference on the Environment, 2017 Society of Environmental Toxicology and Chemistry (SETAC) national meeting, 2019 American Chemical Society National meeting, 2019 Association of Environmental Engineering and Science Professors Conference). The paper "Neonicotinoid insecticide hydrolysis and photolysis: Rates and residual toxicity" was published in the journal Environmental Toxicology and Chemistry. It is open access and freely available at: https://doi.org/10.1002/etc.4256. The associated data set is archived at http://hdl.handle.net/11299/199764. Mr. Stephen Todey's MS Thesis is available via ProQuest (https://search-proquest-com.ezp3.lib.umn.edu/docview/2268373263) and will shortly be archived in the University of Minnesota Digital Conservancy. We are preparing a manuscript that describes the photolysis and toxicity results for experiments performed on surfaces. The findings from this project will aid the development of guidelines for the management and safe use of neonicotinoids to protect the health of Minnesota's waters.

Project Completed: 06/30/2019 **FINAL REPORT**

Environmental Chemistry Paper - Neonicotinoid Insecticide Hydrolysis and Photolysis: Rates and Residual Toxicity
Photolysis of Neonicotinoid Insecticide in systems simulating leaf surfaces: Rates and Toxicity Assessments Presentation

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Bacterial Assessment of Groundwater Supplies Used for Drinking Water

Research Project

Subd. 04f $299,000 TF

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Appropriation Language
$299,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to characterize and analyze bacterial communities in Minnesota groundwater used as drinking water supplies and link the microbiological data to other water quality indicators for drinking water supply safety. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

Recent reports out of the neighboring states of Wisconsin and Iowa have suggested that drinking water supplies obtained from groundwater wells can be contaminated with disease-causing microorganisms (i.e., pathogens), including viruses and bacteria. The main goal of this study was to assess the

microbiological quality of groundwater supplies in Minnesota with an emphasis on disease-causing bacteria. In this study, microorganisms were collected from large volumes of water (100 to 400 gallons) using a filtration system from 16 public groundwater systems throughout the State of Minnesota. The groundwater wells varied in depth from 37 to 1,204 feet and in the relative age of the groundwater. The groundwater systems were sampled at the wellhead or source, after treatment if any (i.e., two systems did not disinfect before distribution), and from one location in the distribution system. With one exception, the groundwater supplies were free of enteric pathogens (i.e., pathogens with a conventional fecal-oral exposure route that cause gastrointestinal infections). Escherichia coli (i.e., E. coli) was only detected in water from a non-potable well with a documented history of contamination. Legionella, bacteria that are considered opportunistic pathogens, were detected in four of the 16 public groundwater supplies. Legionella can cause potentially fatal lung infections in people with weakened immune systems such as the elderly and chemotherapy patients. Legionella levels decreased substantially in a system employing chlorine disinfection. The results from this study suggest that groundwaters supplying public water systems in Minnesota are largely free of enteric pathogens but may contain opportunistic pathogens. This research also suggests that lower bacteria concentrations in groundwater is generally associated with deeper wells (i.e., > 150 ft) extracting older groundwater. Disinfection should be considered for systems with shallow wells (i.e., < 150 ft) due to the potential for high bacteria concentrations and to control opportunistic pathogens when present.

PROJECT RESULTS USE AND DISSEMINATION

Dissemination activities included two poster presentations and one oral presentation by graduate student John Galt. John presented a poster entitled “Are Waterborne Pathogens in Minnesota’s Groundwater?” at the annual Minnesota Section AWWA Conference in Duluth, MN on September 14, 2017. John also presented a poster entitled “Are Waterborne Pathogens in Minnesota’s Groundwater?” at the AWWA Water Quality Technology Conference in Portland, OR on November 12, 2017. An oral presentation on the work was delivered by John at the Minnesota Section of the American Water Works Association meeting in Duluth, MN in Fall 2018. The MN Section AWWA meeting is an important audience for the work as it includes representatives from water utilities around the state, consulting engineers that work in the state and region, and representatives from state agencies (e.g., MDH). Tim LaPara also participated in outreach activities. Tim gave an oral presentation on the project findings at the Minnesota Section of the American Water Works Association meeting in Duluth, MN in Fall 2019. Tim also spoke to the City of Riverton's City Council and to the water quality manager at the City of Eagan about the results. Finally, Tim also participated in an open house concerning the water system in the City of Hastings.

Project Completed: 06/30/2019 **FINAL REPORT**

Understanding Bedrock Fracture Flow to Improve Groundwater Quality

Subd. 04g $183,000 TF

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Appropriation Language
$183,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota for the Minnesota Geological Survey to use new techniques of borehole testing and rock fracture mapping in the Twin Cities metropolitan area to achieve a better understanding of groundwater flow through fractured bedrock, in order to improve groundwater management. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

The goal of this project was to gain an improved understanding of groundwater flow through fractured limestone bedrock by using recently developed techniques. We focused on the Platteville Formation in the Twin Cities Metropolitan area, where the formation is one of the most heavily contaminated bedrock layers in the state. There were two primary activities. One was collection of a variety of geologic and hydrologic information from monitor wells. This was accomplished at two sites near the Mississippi River in Minneapolis; on the campus of the University of Minnesota, and near Minnehaha Falls. We used recently developed techniques that included borehole geophysical testing and instrumentation with multiple pressure and temperature sensors. Two monitor wells at each site were instrumented with sensors. A second activity was detailed mapping of fractures at an exposure of the Platteville Formation at the UMN campus site. Determining how water travels through the Platteville is achieved by combining the results of these two activities.

The project results greatly improved our understanding of how groundwater moves through the Platteville Formation. A key outcome was identification of predictable low permeability layers within the Platteville Formation that can hinder vertical transport of contaminants. The presence of these layers means that conventional techniques for monitoring and remediating contamination plumes would not be as effective as presumed. The results of our project can also be used in groundwater models to improve their accuracy to guide water management engineering. The relevance of our results to how groundwater contamination is characterized and remediated, and to water quantity issues, applies not only to the Platteville Formation, but to all fractured rock aquifers and aquitards in Minnesota. The rigorous techniques such as the inexpensive and efficient methods used in this project can therefore be used to improve water quality across much of Minnesota. A summary report provides greater detail on all the results of this project and their relevance.

PROJECT RESULTS USE AND DISSEMINATION

We have presented our results as the project progressed to water resources groups at the Minnesota Department of Health, Minnesota Pollution Control Agency, the regional division of the American Institute for Professional Geologists, and to local colleges training students who will ultimately become the next generation of groundwater managers in Minnesota. Our results will continue to be disseminated in this fashion, and in published reports. A summary report with greater detail on all our results is already available.

Project Completed: 06/30/2019 **FINAL REPORT**

Protection of State's Confined Drinking Water Aquifers - PhaseII

Research Project

Subd. 04h $433,000 TF

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Appropriation Language
$433,000 the second year is from the trust fund to the commissioner of natural resources for an agreement with the United States Geological Survey to continue to test methods of defining properties of confined drinking water aquifers, in order to improve water management. This appropriation is not subject to Minnesota Statutes, section 116P.10. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

Confined (or buried) aquifers of glacial origin overlain by till confining units provide drinking water to hundreds of thousands of Minnesota residents. The sustainability of these groundwater resources is not well understood because hydraulic properties of till that control vertical groundwater fluxes (leakage) to underlying aquifers are largely unknown. The U.S. Geological Survey, Iowa State University, Minnesota Geological Survey and Minnesota Department of Health investigated hydraulic properties and groundwater flow through till confining units using field studies and heuristic MODFLOW simulations. Till confining units in each of four major geologic deposits were characterized (location in parentheses): the Des Moines lobe (Litchfield), Superior lobe (Cromwell), Wadena lobe (Hydrogeology field camp [HFC] near Akeley), and Pre-Illinoian deposits (Olivia). Hydraulic and geochemical field data were collected from sediment cores and a series of five piezometer nests. Each nest consisted of five to eight piezometers screened at short vertical intervals in hydrostratigraphic units including (if present) surficial aquifers, till confining units, confined/buried aquifers, and underlying bedrock.

Till thicknesses varied from 60 to 166 feet, and till textures ranged from a sandy loam (HFC site) to a silt loam/clay loam (Olivia site). The Cromwell, HFC, and Litchfield 1 sites were examples of “leaky” tills with high vertical hydraulic conductivity (Kv, 0.001 to 1.1 feet per day [ft/d]) and extensive vertical hydraulic connectivity between the confined aquifer and the overlying till. Estimated groundwater travel times through till at these sites ranged from 1 to 81 years, and two of these sites had tritium throughout their till profiles. The tills at the other two sites, Olivia and Litchfield 2, were effective confining units that had low Kv (0.001 to 0.0005 ft/d). Estimated groundwater travel times through the tills at these sites ranged from 165 to nearly 1,800 years, and tritium was only detected in the upper one-third of these till profiles. A conceptual understanding that emerges from the vertical till profiles is that they are not homogeneous hydrostratigraphic units with uniform properties; rather, each vertical sequence is a heterogeneous mixture of glacial sediment with differing abilities to transmit water.

The heuristic MODFLOW modeling demonstrated that, for understanding sustainability of groundwater pumping from confined aquifers, knowledge of till hydraulic properties is just as important as knowledge of aquifer hydraulic properties. Over long periods of time (hundreds of years), pumping-induced hydraulic gradients are established in confined aquifer systems and, even in low hydraulic conductivity tills, these pumping-induced hydraulic gradients increase leakage into and through till compared to ambient conditions.

PROJECT RESULTS USE AND DISSEMINATION

Project results have been and will be disseminated through public presentations and publication of online reports. Results were broadly distributed to hydrology and geology professionals through 13 presentations at state, regional, and national meetings and 2 master’s thesis defense presentations.

Some of these events retain online versions of abstracts and presentations, which are listed below. The full list of presentations about this project is included in the project workplan. Two master's theses are also available online. A series of products from the Minnesota Geological Survey, Minnesota Department of Health, and the USGS provide geologic descriptions, aquifer test analysis results, geochemical data, and model documentation to support the interpretations written in the final, comprehensive USGS Scientific Investigations Report (SIR).

Project Completed: 06/30/2020 **FINAL REPORT**

Assessment of Surface Water Quality With Satellite Sensors

Research Project

Subd. 04i $345,000 TF

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Appropriation Language
$345,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota for a statewide assessment of water quality using new satellite sensors for high frequency measurement of major water quality indicators in lakes and rivers. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

Water quality monitoring is essential for managing Minnesota's surface waters, maintaining the services they provide, and detecting changes caused by environmental stressors. Direct measurements of water quality are possible, however, in only a small fraction of the thousands of lakes and river miles in the state. Methods developed in this project allow use of increasingly frequent satellite observations to measure water clarity and the three key water quality indicators that control it: algae, colored dissolved organic matter (CDOM), and suspended solids. Because these parameters have distinct impacts on water quality, the ability to measure them directly across the state's waters enables comprehensive assessment of water quality status and trends and increases understanding of the causes and consequences of water quality degradation. We developed methods to relate direct measurements of water quality to satellite imagery, assessed atmospheric correction techniques and validated methods using independent datasets. We applied these methods to measure water quality parameters on lakes >10ha, and provide the information at https://lakes.rs.umn.edu. Examples are included in appendix 1. Our methods extract information at seasonal to annual scales for algae, CDOM and suspended solids in lakes at state, regional, county, and watershed scales. Water quality parameters were linked to disinfection byproduct formation potential in drinking water treatment and degradation of contaminants driven by sunlight. CDOM levels were closely related to formation rates of two classes of disinfection byproducts, trihalomethanes and haloacetic acids, and to the production photo-induced reactive intermediates that degrade pesticides. This information can be used with remote sensing to assess pesticide persistence and suitability of surface waters for drinking water sources. An ongoing

LCCMR project uses methods developed here with automated imagery acquisition and analysis to gather information on lake conditions at potentially a weekly basis. Project outcomes are summarized at https://water.rs.umn.edu/ for use by researchers, managers, lake associations and the public.

PROJECT RESULTS USE AND DISSEMINATION
Information from this project has been disseminated through five ways during the three year project:

1. Data produced in the project is now freely available at https://lakes.rs.umn.edu/
2. Numerous presentations at meetings, agencies, and academic institutes have been given.
3. Five research articles documenting technical methodology and water quality relationships have been published. These publications have been included in our final report. Several other publications are being developed, and several others are planned.
4. We have engaged with state and agency partners in data gathering and interpretation, resulting in one publication, and plans for future collaborations with MPCA on refining water quality standards in the state based on project findings.
5. A widely used website for remote sensing of water quality (https://water.rs.umn.edu/) has been thoroughly revised with updated and expanded content.

Project Completed: 06/30/2019 **FINAL REPORT**

Water Research Article: Assessment of chlorine demand and disinfection byproduct formation..
Water Research Article: Limitations on using CDOM as proxy for DOC in temperate lakes
Remote Sensing of Enviroment Article: A harmonized image processing workflow using Sentinel-2/MSI and Landsat-8/OLI..
Ecological Application Article: Color, chlorophyll *a*, and suspending solids effects on Secchi depth..
Iron influence on dissolved color in lakes of the Upper Great Lakes States
Brochure: Colored Dissolved Organic Matter in Water
Brochure: Remote Sensning for Water Quality

Development of Innovative Sensor Technologies for Water Monitoring

Research Project

Subd. 04j $509,000 TF

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Appropriation Language
$509,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to develop inexpensive and efficient sensitive sensors and wireless sensor networks for continuous monitoring of contaminants in lakes and rivers in Minnesota. This appropriation is subject to Minnesota Statutes, section 116P.10. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

The University of Minnesota team completed the project successfully by June 30, 2019. Professors Cui, Ruan, and Chen worked with one full-time research assistant, one full-time visiting student, and one post-doc conducting the research. The team finished the proposed research in the proposed Activity 1 and Activity 2. The team developed graphene sensors for testing and continuous monitoring of water quality indicators including phosphate, nitrate, mercury, and chloride. They very successfully got initial testing results using tiny sensors in response to pollutants in lab. They developed software coding for signal process and data display for the small sensing system. They tested the graphene sensors in comparison with the conventional lab tests, and did a compressive assessment of the sensing results. They developed a prototype of sensing network with tiny graphene sensors. The detection limits of the developed graphene sensors for phosphate, nitrate, mercury, and chloride are 0.1 ppm, 0.1 ppm, 1 ppb, and 0.1 ppm, respectively. The response time of the graphene sensors are 10 seconds. The team developed sensing systems and networks for field tests at Mississippi River, Minnesota River, Minnehaha Creek and Bde Maka Ska in Minnesota. The testing results demonstrate the capability of using the graphene sensors and sensing network for real-time monitoring of water pollutants including phosphate, nitrate, mercury, and chloride.

PROJECT RESULTS USE AND DISSEMINATION

On-site demonstration and sensing tests as described in the activities at Mississippi River, Minnesota River, Minnehaha Creek and Bde Maka Ska in Minnesota from May to June, 2019. Communications with interested entrepreneurs have been ongoing with interested parties including local companies and individuals. Collaboration on using the graphene sensors and sensor networks with MPCA and Metro have been conducted in the last year. We use the testing station from MPCA for field tests of pollutants at their Fort Snelling stations in Minnesota River.

Multiple papers were published in archived journals and prestigious conferences. Professor Tianhong Cui presented five invited public seminars and talks on water sensors at: École Normale Supérieure (ENS), Paris, France; Imperial College London, London, UK; Plenary talk, Design, Test, Integration & Packaging of MEMS and MOEMS (DTIP 219), Paris, France; Invited Talk, Microsystems & Nanoengineering Summit, Shanghai, China; Plenary talk, IEEE Nano Conference, Macau.

Project Completed: 06/30/2019 **FINAL REPORT**

Wastewater Treatment Process Improvements

Research Project

Subd. 04k $398,000 TF

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Appropriation Language
$398,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to characterize and quantify the nutrient-removing microorganisms used for municipal wastewater

treatment, in order to improve the process used to reduce total nitrogen discharge. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

This project included the participation of 25 different wastewater treatment facilities located throughout the State of Minnesota. A total of 623 samples were collected from 38 wastewater treatment bioreactors, from 13 anaerobic digesters, and from 2 aerobic digesters. Metagenomic DNA was extracted and purified from all of these samples and used as template from which we were successfully able to quantify the numbers of total Bacteria, total Archaea, ammonia oxidizing bacteria, ammonia oxidizing archaea, polyphosphate accumulating organisms, denitrifying bacteria, and several different organisms known to be important to anaerobic digestion. DNA samples were also used to amplify and to sequence 16S rRNA gene fragments to characterize the microbial community composition in detail. In total, this project generated 19,064,646 DNA sequences that have been deposited in publicly-available databases. This project demonstrated that wastewater treatment bioreactors and anaerobic digesters generally contain similar levels of total bacteria and archaea, as expected. Substantial differences, however, were observed in the quantity of ammonia oxidizing bacteria, organisms that are critical in the removal of nitrogenous pollution. More importantly, perhaps, is that the quantity of ammonia oxidizing bacteria was connected to specific wastewater treatment process designs, suggesting that the removal of nitrogenous pollution can be controlled. Similarly, the quantity of polyphosphate accumulating organisms varied significantly between different treatment plants. Similar quantities of denitrifying bacteria were observed in all of the wastewater treatment bioreactors, independent of system design; this suggested that denitrifying bacteria are ubiquitous throughout all wastewater treatment bioreactors and their presence/quantity is neither enhanced nor suppressed by system design. This research makes a seminal advance in our understanding of the ecology of wastewater treatment bioreactors by delineating the factors that we can (process design, operating conditions, etc.) and the factors that we cannot (geographic location, weather, etc.) control and their effects on bacterial community composition.

PROJECT RESULTS USE AND DISSEMINATION

We have presented our preliminary results at numerous conferences and technical meetings throughout the State of Minnesota. We will continue to make these presentations over the next 2-5 years (at no cost to the LCCMR). We have published one manuscript in the peer-reviewed literature so far, and we have drafted an additional five manuscripts that have been or will be soon submitted for publication.

Project Completed: 06/30/2019 **FINAL REPORT**

Membrane-Based Process for Decentralized Drinking Water Production

Research Project

Subd. 04l $191,000 TF

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Appropriation Language
$191,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to develop a low-energy use, membrane-based treatment technology to produce drinking water locally from surface waters by removing heavy metals and contaminants of emerging concern, including pesticides and pharmaceuticals. This appropriation is subject to Minnesota Statutes, section 116P.10. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

The main outcome of this project is a novel surface modification protocol for water treatment membranes. We showed that graphene oxide coatings, known to exhibit antibacterial properties, improve the efficiency with which the membranes remove micropollutants, such as N-nitrosodimethylamine (NDMA), which are common in Minnesota surface waters. Additional outcomes of this project were promotion of Minnesota's human capital through training of graduate and undergraduate students (2 graduate and one undergraduate student where supported at various points of the project), a M. S. thesis completed by Henry Croll (one of the graduate students supported by the project), a conference presentation (at the Annual Meeting of the American Institute of Chemical Engineers, AIChE 2017), and a recent publication in Separation and Purification Technology, a peer-reviewed international journal.

PROJECT RESULTS USE AND DISSEMINATION

This project accomplished the following dissemination outcomes:

Pee-reviewed publications (1): H. Croll, A. Soroush, M. Pillsbury, and SRVC. "Graphene oxide surface modification of polyamide reverse osmosis membranes for improved N-nitrosodimethylamine (NDMA) removal". Separation and Purification Technology 210 (2019) 973–980

The article is available from the following link without a subscription until November 2, 2018: https://authors.elsevier.com/a/1XjGX4wbrSvhOh

Conference papers (1): A. Soroush, H. Croll, and SRVC. "N-Nitrosodimethylamine (NDMA) Removal by Thin Film Composite Polyamide Reverse Osmosis Membranes". 2017 AIChE National Meeting, Minneapolis, MN. November 1st, 2017.

Dissertations (1): H. Croll. "Improvements to Polyamide Reverse Osmosis Membranes for Removal of Small, Uncharged, Hydrophilic Solutes". MS Thesis, University of Minnesota, 2018 (available from the UMN Libraries).

Project Completed: 06/30/2019 **FINAL REPORT**

Separation and Purification Technology: Publication

Analyzing Alternative for Muncipal Wastewater Treatment

Subd. 04m $180,000 TF

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Appropriation Language
$180,000 the second year is from the trust fund to the commissioner of the Minnesota Pollution Control Agency to analyze alternatives for improved treatment of sulfate and salty parameters at municipal wastewater plants to inform the development and implementation of wild rice, sulfate, and other water quality standards. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

A future surface water quality standard for sulfate may result in some municipal wastewater treatment plants having to reduce the sulfate in their discharge. This study evaluated options for sulfate treatment and examined the implications of those treatment options for typical municipal wastewater treatment plants in Minnesota. This study's findings gives regulatory agencies and MN communities' greater certainty of the cost of any future sulfate treatment technologies. This information will be used to guide the MPCA's future wild rice rulemaking efforts. 31 technologies for sulfate removal were ranked based on effectiveness, operability, cost, complexity of pre- and post-treatment, and waste management requirements. The types of technologies reviewed included chemical precipitation, ion exchange, membrane separation, electrochemical, biological, and evaporative treatment. The technology review indicated that reverse osmosis is the most well developed and effective alternatives available for sulfate removal at this time, despite the complexity and cost associated with final waste management. The study examined the implementation of RO for sulfate removal at Minnesota's municipal wastewater treatment plants in greater depth, using six hypothetical case studies covering a range of treatment plant sizes and sulfate treatment goals typical for the state. The case studies considered the technical, operational, and economic issues associated with integration of RO into conventional municipal treatment systems. Sulfate treatment using RO was found to be extremely expensive and operationally complex. The main driver of complexity and costs was membrane waste management, which in this study focused on mechanical evaporation and crystallization. Due to the complexity of the processes, which differ significantly from those currently employed for conventional municipal wastewater treatment, increased staffing levels and operator training would be needed for successful implementation. RO is effective in removing sulfate from wastewater, but waste management challenges remain a substantial barrier to implementation and affordability.

PROJECT RESULTS USE AND DISSEMINATION

The results of this study were disseminated through two presentations at a Minnesota wastewater treatment conference and two presentations at a national conference for city engineers. The results of the study were incorporated into the proposed wild rice sulfate rulemaking documents and used to inform testimony by the MPCA before both the Minnesota house and senate.

The final report, a one page summary of the report and a recorded video of the final results presentation is available on the MPCA webpage: https://www.pca.state.mn.us/water/protecting-wild-rice-waters

Project Completed: 06/30/2019 **FINAL REPORT**

MPCA Fact Sheet - Sulfate and municipal wastewater: Study confirms lack of affordable technology
Analyzing Alternatives for Sulfate Treatment in Municipal Wastewater

Understanding Impacts of Salt Usage on Minnesota Lakes, Rivers, and Groundwater

Research Project

Subd. 04n $497,000 TF

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

OVERALL PROJECT OUTCOME AND RESULTS

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

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

PROJECT RESULTS USE AND DISSEMINATION

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

Project Completed: 06/30/2019 **FINAL REPORT**

Reducing salt and metal removal costs with microbes

Research Project

Subd. 04o $596,000 TF

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Appropriation Language
$596,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to continue to research the potential of recently discovered microbes from Soudan Iron Mine in northern Minnesota for removing salts and metals from groundwater and surface water resources. This appropriation is subject to Minnesota Statutes, section 116P.10. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

Many Minnesota waters are contaminated with salts and metals. Removing these contaminants can be more difficult than removal of compounds such as oils or pharmaceuticals which can be destroyed by bacteria or heat treatment. Metals and salts must be physically bound, or made to pass through a specific membrane to clean the water, making such treatments expensive and energy intensive. However, technologies have been proposed that use microorganisms as the power source to drive salts across membranes, or as binding agents to remove metals, significantly reducing the cost and complexity of treatment. Before such technologies can even be imagined at scale, naturally-occurring microorganisms that are tolerant of harsh conditions and able to power removal of salts from water must be made available. A key goal of this project was to discover such organisms, subject them to the stresses of life under the conditions, and understand what could limit implementation of these remediation strategies. After surveying a number of contaminated sites in Minnesota, we focused specifically on the power-generating abilities of bacteria related to the genus Geobacter, the salt-tolerance abilities of bacteria related to the genus Marinobacter, and the metal transforming abilities of fungal Armilleria and Periconia genera. We verified that these organisms can grow in high salt conditions, power model salt-removal reactors, and in some cases remove multiple metals from solution. In the case of salt removal, we showed that many of the operating conditions proposed, such as cycling of the cell voltage or operation at low redox potential, can be harmful to cells and will need to be addressed before the technology can be successful, as will issues related to high calcium content of some Minnesota waters. In contrast, because the use of fungi for metal removal does not require as much equipment or electrochemical control, scaling of this approach using organisms obtained via this project is deemed much more feasible.

PROJECT RESULTS USE AND DISSEMINATION

Our primary scientific dissemination activities are manuscripts crediting this project, two of which are under revision or submission and not available online at the time of this report. We presented our

results at the 2nd Geobiology Society Conference in Banff, Canada, in June 2019 in the poster section titled as “Remediation of Metals by Mn-Oxidizing Fungi in Minnesota Soudan Iron Mine”. Other examples of local exposure include also the Mycological Society of America 2019 Annual Meeting in Minneapolis, MN, in August 2019. In October, the research results will be presented at the Society for Mining Engineers conference in Minneapolis, MN.

As part of this project we conducted outreach activities to show the potential offered by bacteria powering salt-removal devices. Some examples of outreach during this project include: three ‘Market Science’ events, bringing demonstration devices to farmer’s markets in the Twin Cities area, three events as part of the Bell Museum’s 3rd and 4th-grade science camps where students constructed microbial powered devices and meet scientists in our laboratory, assisting two local Lego League teams who were incorporating microbial power into their demonstration projects and providing materials for their devices (one group progressed to the State competition), hosting a short workshop training graduate students in construction of microbial electrochemical devices, participation in the MN clean water summit and the American Society for Microbiology science outreach series. Our other stated goal was to facilitate group meetings with other collaborators and interested parties so this work could expand or continue. Due to these collaborations, work initiated in this project in terms of searching for new organisms from metal-impacted environments will be able to continue in a 5-year NSF-funded project to be based in the Soudan Mine, fulfilling a key goal described in our Long Term Strategy. We have also applied for new support from other state-based programs (such as MNDrive) to support the scale-up of new technologies for bioremediation.

We will continue to share these results, including demonstration experiments about bioremediation strategy use the type 1 bioreactor to general audiences on August 22nd, 2019 at the Minnesota State Fair with Market Science. Further, these type 1 bioreactors will now be regularly prepared for Sound Underground Mine State Park science tours of the mine. Mine tour guides will demonstrate these at the mine, and the cultures have been shared for observation under a microscope in collaboration with State Park staff.

Project Completed: 06/30/2019 **FINAL REPORT**

Engineered Biofilter for Sulfate and Metal Removal from Mine Waters

Research Project

Subd. 04p $440,000 TF

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Appropriation Language
$440,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to develop an efficient, low-cost, biomass-derived adsorbent material for use in bioactive filters able to remove sulfate and metals from mining-impacted waters. This appropriation is subject to Minnesota

Statutes, section 116P.10. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

Biochar is a stabilized, recalcitrant organic carbon material, created from biomass heated to temperatures between 300-1000°C, under low oxygen concentrations. Biochars can be produced from a variety of biomass feedstocks. Recently, biochars have found several applications in environmental remediation of heavy metals contamination. In this project we compared the sorptive properties of different biochars for soluble copper (Cu2+) and nickel (Ni2+) removal from contaminated waters. In order to enhance the sorptive properties of biochars, we pyrolyzed hardwood biomass in the presence of magnesium hydroxide or magnesium chloride. Using the newly produced biochar-composite material we compared its sorption isotherms for copper and nickel with an unmodified biochar. Copper and nickel sorption capacities were greatly improved for the biochars pyrolyzed in the presence of magnesium salts, indicating that biochar mineral supplementation can increase the efficiency of metal adsorption and removal from solution. Scanning electron microscopy (SEM) coupled to energy dispersive X-ray spectroscopy (EDS) revealed strong surface localization of both copper and nickel after sorption onto magnesium hydroxide treated biochar, with a lesser extent of copper surface localization on magnesium chloride than magnesium hydroxide treated biochar. A subsequent study was conducted to test the effects of post-pyrolysis mineral modification (added as soluble Mg) on unmodified biochar's sorption capacity for heavy metals. This part of the project revealed that metal-mineral surface complexation, rather than covalent modification, was the major driver for enhancing copper sorption in treatments amended with either magnesium hydroxide or magnesium chloride. However, similar effects were not observed for nickel sorption. In this project we develop a biochar-mineral composite material that promotes heavy metal adsorption. The new sorbent material made from waste biomass is an efficient, low-cost, environmentally-friendly alternative to conventional sorbent materials that can be used for mine water treatment in water filters or permeable reactive barriers.

PROJECT RESULTS USE AND DISSEMINATION

Three peer-reviewed manuscripts are expected to be published from this work; these will be submitted to the LCCMR when accepted for publication. Multiple presentations about the research have been given at both regional and national/international conferences.

Project Completed: 06/30/2019 **FINAL REPORT**

Developing Biosponge Technology for Removal of Nitrates from Minnesota Waters

Research Project

Subd. 04q $198,000 TF

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Appropriation Language
$198,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to adapt and test an inexpensive biosponge technology for its effectiveness at removing nitrates from

drinking water. This appropriation is subject to Minnesota Statutes, section 116P.10. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

We have developed simple, effective, and inexpensive technology for dealing with nitrate in drinking water, a major problem in Minnesota today. The cost of continuous monitoring and treating nitrate problems with current technology is estimated to be $3500 per household, a huge burden for Minnesotans. To help in alleviating that burden, we have done the following on this project. First, the project director, Dr. Aukema, identified nitrate-removing bio-components. Second, Dr. Aukema investigated and was successful in obtaining different sponge-like materials to maintain the bio-components within the material. Third, water from different sites in the state of Minnesota were obtained and tested with respect to nitrate. The waters were from: Montevideo, Lake Itasca, St. Paul, Zumbro Falls, and Minneapolis. Much work went into designing the matrix that holds the bio-component. It was found that cellulose was best for retaining the bio-component. The bio-component will then reduce the nitrate which is then both measured and removed. The last year of the project was devoted to outreach, disseminating the information: (1) verbally at conference, agencies, universities, (2) in written form in a journal publication, and (3) by the social media platform YouTube. Overall, we conducted outreach over the course of the project, discussing nitrate treatment entirely in, or as part of, 14 outreach items, in Minnesota, other states, and internationally. Note that any and all travel was covered by resources outside of the LCCMR budget. This is important to Minnesotans as it provides a way to cheaply and easily monitor nitrate in any water source they would want, from their local lake to their well. This also provides information for bioremediation of nitrate and other chemicals that are found in Minnesota waters. While generally chemical levels in Minnesota are low, we are glad to develop technology to help in keeping our waters clean.

PROJECT RESULTS USE AND DISSEMINATION

We have conducted dissemination activities throughout the project, with the last year of the project being heavily engaged in that activity specifically. For example, we presided over an event at the Institute on the Environment at the University of Minnesota on March, 2019 to discuss and disseminate information dealing with nitrogen and nitrate contamination in Minnesota waters and how to deal with it effectively. We followed that up with a broader meeting on May 16, 2019. In the last year of the project, we also published a research article pertaining to new technology developed. We also posted a YouTube video.

Project Completed: 06/30/2019 **FINAL REPORT**

Morrison County Performance Drainage and Hydrology Management

Subd. 04r $209,000 TF

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Appropriation Language
$209,000 the second year is from the trust fund to the commissioner of natural resources for an agreement with the Morrison Soil and Water Conservation District to conduct an assessment of drainage infrastructure, in order to develop hydrology restoration priorities and a countywide performance drainage ordinance to address land use-change impacts to the hydrogeology. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

Morrison County, like other agricultural counties, has experienced a vast increase in drainage. Thousands of acres are being tiled with no approval or oversight and wet weather patterns have exacerbated drainage issues along township and county roads. Major conflicts have exploded between neighbors and road authorities' due to impacts of standing water on agricultural fields and topping of public roads.

Morrison SWCD historically has taken the lead in managing drainage, county wide, and starting in 2016 centerline and driveway culverts were surveyed to better comprehend the hydrology and storm water management for the county. Morrison SWCD documented locations, elevations and conditions of culverts throughout 23 townships in Morrison County. The complete database of this information was shared with each township and Morrison County Public Works department for a more complete understanding of drainage capacity and infrastructure replacement needs. In addition to being used by Morrison SWCD to resolve landowner conflicts, watershed and wetland protection, it is also being used by other state and federal for water quality protection and enhancement, identifying wildlife project areas and for floodplain mapping. Limited database information is available for public viewing through the Morrison County interactive GIS viewer, Beacon.

This information has led to the creation of a Morrison County Comprehensive Drainage Management Plan. This plan was created to protect state water resources from runoff pollution and degraded water quality, stabilize soils, shores and banks from erosion, protect or provide riparian corridors and preserve natural drainage ways and wetlands from being drained filled and manipulated.

Morrison SWCD is committed to serving the public through a leadership role in managing drainage and sharing a more complete understanding of drainage infrastructure within the county and with other areas of the state struggling with drainage issues.

PROJECT RESULTS USE AND DISSEMINATION

Reports of the culvert inventory data were finished and delivered to 23 townships. These reports included locations and elevation data for centerline and private drive culverts along township roads. The reports also detailed material size, type, shape and conditions of pipes and flow direction. Culverts were then rated based on their current conditions and recommended maintenance activities were noted.

We are continuing to keep all the partner agencies up to data with our data and progress, attending township and county board meetings and presenting the information to our partners. A subset of the data from the inventory was made available for public viewing on the Morrison County interactive GIS system, Beacon. Full data sets were shared with FEMA, DNR, Morrison County Public Works and US Fish and Wildlife Service.

LIDAR assessment of minor watersheds was done as data became available to determine drainage capacity and identify insufficient patterns. The number of requests made to the office for drainage assistance by Morrison County and township officials has significantly increased since the start of the

project many long standing issues were able to be resolved with the use of the culvert inventory data and the field expertise of the drainage technician afforded through this grant.

Discussions continue with county officials regarding a drainage ordinance which was drafted as part of this project. The Morrison County Comprehensive Drainage Management Plan was created to protect state water resources from runoff pollution and degraded water quality, stabilize soils, shores and banks from erosion, protect or provide riparian corridors and preserve natural drainage ways and wetlands from being drained filled and manipulated.

Project Completed: 06/30/2019 **FINAL REPORT**

Assessing Effectiveness of Wetland Restorations for Improved Water Quality - RESEARCH

Subd. 04u $420,000 TF

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Appropriation Language
$420,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to quantify the environmental benefits of sediment removal and native plant communities in wetland restorations by measuring resulting reductions in nitrogen and phosphorus delivery to groundwater and surface water. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

Wetland restorations are vital for enhancing habitat and protecting against growing threats from eutrophication to Minnesota's drinking and recreational waters. Using comparisons of standard wetland restoration practices with those that also removed accumulated sediment, we examined outcomes of restorations across gradients of wetland size, age, and hydrology. Our goal was to investigate the effects of 1) excavating accumulated eroded sediment, 2) time since restoration, and 3) hydrology, on the ability to store and remove nutrient input from the watershed over time, and on the abundance and diversity of native and invasive vegetation in restored wetlands. We studied 58 restored agricultural wetlands, collecting over 1000 water, 800 soil, and 258 plant samples over three years. Substantial water quality improvements resulted from both standard and sediment removal treatments. Excavation reduced total nitrogen (N) and total phosphorus (P) in soil and surface water, although the strength of effects varied substantially by nutrient and wetland type. In general, soil and water nutrient content increased with wetland age since restoration, suggesting that wetlands effectively stored incoming nutrients. Restored wetlands overall had a high capacity to remove nitrate under a wide range of temperature, age, size and geomorphic conditions, resulting in extremely low concentrations of nitrate. Permanent N removal via denitrification did not differ between excavated and standard restoration practices, but seasonally flooded wetlands had significantly higher denitrification rates than semi-permanent basins that dry out much less frequently. N removal by denitrification increased steadily following restoration, indicating improved capacity for nitrate reduction in older wetlands. In contrast to

nitrogen, seasonal flooding promoted mobilization of inorganic phosphorus to surface waters, suggesting effects of long term enrichment of phosphorus in watershed soils. Vegetation accounted for a substantial portion of N and P stored in wetland basins during the growing season, with invasive hybrid cattail containing over 70% of the N and P stored in plant biomass. Following restoration, excavated wetlands had significantly lower hybrid cattail cover and higher native species cover compared to wetlands restored without sediment removal. However, rapid expansion by hybrid cattail offset vegetation benefits of sediment removal within eight years following restoration. Our study demonstrated that sediment excavation promotes native species and at the same time, reduces nutrient availability and improves water quality in restored agricultural wetlands. Environmental factors such as basin inundation patterns and time since restoration influence the ability of wetlands to perform key services. Eutrophication is a growing threat to Minnesota's drinking and recreational waters, and our work showed that agricultural wetland restorations can substantially reduce the risk of eutrophication. Benefits of wetland restoration can be maximized by removing accumulated sediment during restoration and managing invasive species in the years following restoration.

PROJECT RESULTS USE AND DISSEMINATION

Information from this project has been used and disseminated in diverse ways during the three year project. Results from the project have been presented at national, regional, and state meetings and events including; the Society for Freshwater Sciences annual conference (May 2019), the Society for Wetland Sciences annual conference (May 2019), the Minnesota Chapter of the Wildlife Society annual conference (February 2017 and February 2018), the joint meeting of the Upper Midwest Invasive Species Conference and North American Invasive Species Management Association (October 2018), and a meeting of Minnesota private lands managers and conservation specialists including The Nature Conservancy, the US Fish and Wildlife Service, Minnesota Department of Natural Resources, Minnesota Land Trust, Ducks Unlimited, and the U.S. Department of Agriculture (June 2018). We have shared our research with local entities including the University of Minnesota's Shared Water, Shared Responsibility: Engaging Minnesota's Communities, Students, & Policy-Makers event (March 2017), the Water Resources Science Spring Research Symposium (January 2018), the Pomme de Terre Watershed Task Force (May 2018), Restoration Evaluation Specialists at the Minnesota DNR Division of Ecological and Water Resources (March 2018), and The Nature Conservancy (August 2018), and we continue to reach out to other stakeholders and land management groups to share the results of our research. Furthermore, the results from this research have been shared regularly with the US Fish and Wildlife Service Private Lands Office and restoration specialists working with landowners across the state. We have submitted one manuscript addressing the effects of sediment excavation on plant communities to the journal Restoration Ecology (submitted July 2018) and another manuscript to the journal Wetlands. In addition, two more manuscripts are in preparation, and others are planned. Copies of the manuscripts will be provided upon publication. Finally, we have developed a set of interactive tools to start conversations about wetlands with children and adults. Using visual aids, hands-on activities, and informational handouts, we were able to reach hundreds of people in the summer of 2018 at the West Ottertail County Fair and the Fergus Falls Aqua Chautauqua, by focusing on exploration and discovery in our backyard wetlands. Our activities and handouts are still being used by environmental and K-12 educators in the Ottertail Public School District. Appendix 2 provides examples of our outreach materials.

Project Completed: 06/30/2019 **FINAL REPORT**

Integrating Targeted Watershed Planning Tools with Citizen Involvement

Research Project

Subd. 04v $169,000 TF

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Appropriation Language
$169,000 the second year is from the trust fund to the Board of Trustees of the Minnesota State Colleges and Universities system for the Water Resources Center at Minnesota State University, Mankato, to use geographic information system (GIS) prioritization and modeling tools to develop pollution reduction strategies in five priority subwatersheds in the Le Sueur River watershed and to promote implementation of the reduction strategies through citizen involvement and outreach. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

The Le Sueur River Watershed (LSRW) is one of the leading contributors of pollutant loads in the Upper Mississippi River Basin. The 711,000 acre watershed is a listed as a priority watershed for both nitrogen and phosphorus in the Minnesota Nutrient Reduction Strategy and is a prolific source of total suspended solids which impacts downstream receiving waters from the Minnesota River to the Gulf of Mexico. The project goals were to use geographic information system (GIS) prioritization and modeling tools to develop pollution reduction strategies in five priority subwatersheds in the LSRW and to promote implementation of the reduction strategies through citizen involvement and outreach.

The project resulted an inventory handbook of GIS conservation planning and targeting tools to help local conservation partners better understand the diversity of available tools (link). A statewide survey of GIS tool users was also developed and summarized (link). Five subwatershed strategies were developed by citizens and conservation partners that illustrate conservation opportunities based on the latest targeting tool outputs, maps and citizen input (link). The project harnessed the energy of a citizen group, the LSRW Network to facilitate improvements in one of the most degraded watersheds in the state.

More broadly, this project demonstrates subwatershed scale planning that uses GIS conservation targeting tools integrated with civic engagement—a promising approach and scale for nonpoint source pollution clean-up. The project underscores the power of conservation partners engaging community members around locally relevant problem solving that aligns with existing social networks. Subwatershed groups learned and adapted together while citizen leaders networked with peers, building strong relationships and enduring partnerships. The project also raised awareness statewide about the need to re-create more water storage across the Minnesota River Basin to reduce peak flows that are destabilizing river systems and contributing to water quality problems (Water Storage Forum).

PROJECT RESULTS USE AND DISSEMINATION

Information about this project is housed on the Le Sueur River Watershed Network and the Minnesota River Basin Data Center websites. Project reports include an inventory handbook of GIS conservation

planning and targeting tools to help local conservation partners better understand the diversity of available tools (link). A statewide survey of GIS tool users was also developed and summarized (link). Five Subwatershed Strategy documents were created (link) that integrate GIS conservation targeting with citizen engagement. Information about Le Sueur River Watershed and priority subwatersheds are summarized on the Le Sueur River Watershed Network and MRBDC websites.

The project has resulted in hundreds of one-on-one, small and large group meetings to disseminate information with citizens and conservation partners at subwatershed, watershed, and basin scales. Project staff had the opportunity to share information about the project at international, national, state, regional and local conferences and meetings. International and national highlights include audio interviews housed at the Museum on Mainstreet, Smithsonian Institute, a presentation at the Soil and Water Conservation Society International Conference in Madison WI; presentations at the Watershed Leaders Network Meeting, Hannibal, Missouri and Dubuque, IA. Statewide highlights include Governor's Water Quality Town Hall Meeting, numerous presentations at Minnesota Water Resources Conferences.

Project staff have made over a dozen presentations and hosted tours regionally and locally to raise awareness about the project and outcomes ranging from local and regional government (County, SWCD, GBERBA), to state and elected officials (Minnesota Legislative Water Commission, Clean Water Council, Governor's Office) to conservation groups (Minnesota River Congress, Friends of Minnesota Valley, Izaak Walton League, Clean Water Minnesota). A project highlight was raising the awareness about the need for more water storage statewide by developing and hosting the Minnesota River Basin Water Storage Forum and website. During the project period, dissemination through media outlets include over 20 newspaper articles, four KEYC television interviews, and three nationally publicized audio interviews. In addition, project partners created the Le Sueur River Watershed Network website, created four videos, as well as numerous posters and summary maps and other public informational materials.

Project Completed: 06/30/2019 **FINAL REPORT**

Subd. 05 Environmental Education

Minnesota Conservation Apprentice Academy

Subd. 05a $433,000 TF

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Appropriation Language
$433,000 the second year is from the trust fund to the Board of Water and Soil Resources in cooperation with Conservation Corps Minnesota and Iowa for the final phase of a program to train and mentor future conservation professionals by providing apprenticeship service opportunities with local soil and water conservation districts in Minnesota. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

The Minnesota Conservation Apprentice Academy was designed to provide a mechanism for maintaining an experienced conservation workforce in Minnesota despite the recent wave of retirements that have occurred as baby-boomers leave the workforce. As these experienced conservation professionals retire, they take with them their practical, on-the-ground experience and skills. While college students may have knowledge of emerging technologies and other innovations that can improve and contribute to current conservation efforts, they often lack experience with on the ground projects and relating to landowners. The Conservation Apprenticeship Academy filled this gap by providing an opportunity for the two generations to exchange knowledge during the SWCD's busiest season.

This project funded the placement of 31 apprentices in 2017 and 33 apprentices in 2018. Over the course of the grant period, these 64 young adults gained skills and experience in water resource management, conservation inspections, surveying and habitat restoration.

The program had a mutually beneficial impact on both the students and the SWCDs they were placed in. 100% of the SWCDs that participated in the project indicated they would partner with the program again. SWCD staff noted that Apprentices added value to project work through their knowledge and skills while also becoming better prepared for future careers. Apprentices who responded to a survey request all indicated they felt more prepared for a future career in conservation as a result of the program.

PROJECT RESULTS USE AND DISSEMINATION

Information from this project has been disseminated through reports to LCCMR, information on the Conservation Corps website, blog posts, and in a Conservation Conversation podcast.

Conservation Corps provides a description of the program on the organization's website (updated in October 2018 to indicate the completion of the program as funded by LCCMR).

Additional coverage over the course of the project includes: 2017 Apprentice featured on Conservation Corps blog, 2017 Apprentice featured on KLQP "Conservation Conversation" podcast, 2017 Apprentice featured on Conservation Corps blog, and coverage of the project in the Austin Daily Herald.

Project Completed: 06/30/2019 **FINAL REPORT**

School Forests Outdoor Classrooms

Subd. 05b $440,000 TF

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Appropriation Language
$440,000 the second year is from the trust fund to the commissioner of natural resources in cooperation with Conservation Corps Minnesota and Iowa to renovate and restore 60 school forests and train students, teachers, school district facility staff, and community volunteers to be long-term stewards of the school forests and provide education and service learning experiences at school forest sites. This

appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

The Minnesota Department of Natural Resources worked with the Conservation Corp of Minnesota and Iowa to improve 67 School Forests throughout Minnesota, completing land management projects that schools were unable to do on their own. The work improved the safety, accessibility, and effectiveness of School Forests, making them better outdoor classrooms. DNR and CCMI staff worked with school leaders to identify needed projects that aligned with their existing School Forest Stewardship Plan, secure school contributions for materials, and complete all work. Efforts included repair of unsafe structures, removal of hazard trees and invasive species, building and maintenance of trails, and construction of amphitheaters, sitting spaces, boardwalks, and bridges. Project highlights can be found in attachments C, D, E, and F to the final report.

School communities were involved in all work. Over 3,300 students participated in service learning activities tied to the work projects done at their School Forest. To support long-term site maintenance, 412 school staff and community volunteers were trained to care for their School Forests.

At these newly improved School Forests, students will continue to learn math, science, art, social students and more for decades to come. These learning experiences connect students to their natural surroundings and provide hands-on, real-world experiences for Minnesota students. School staff and community volunteers have a renewed interest in using and increased confidence in maintaining the sites. They also report that these projects have enriched learning experiences, and bolstered relationships between students, staff, and their School Forest. Students enjoyed participating in the projects and have an increased sense of ownership.

This project furthered our knowledge of what elements make effective outdoor classrooms that support long-term outdoor education for Minnesota schools.

PROJECT RESULTS USE AND DISSEMINATION

The School Forests Outdoor Classrooms Project was featured in many newspaper articles, TV news stories, and school newsletters throughout Minnesota, such as a Lakeland Public Television story on the Dean Makey School Forest buckthorn removal project. The Pine River-Backus School Forest project was featured multiple times in their local news media, including a Lakeland Public Television story "Pine River-Backus Students Remove Buckthorn," and an article "Pine River-Backus School Board Revisits Buckthorn" featured in the PineandLakes Echo Journal. The Edgewood School Forest project and DNR School Forest Program were highlighted in a video created by the Mounds View School District titled "Edgewood School Forest Project" that was shared widely throughout the district via e-newsletters and social media. The Clearview Elementary School Forest project was featured in the local newspaper, Citizen-Tribune, with an article titled “Clearview Forest Gains a Handicapped Accessible Trail.” The Hutchinson School Forest service learning and invasive species education activities at Rollie Johnson Ecological Site project were featured in the Hutchinson Leader. Additionally, Lake Minnetonka Magazine printed an article in the Outdoors section about the 2018 St. David’s School Forest CCM project.

The DNR posted 62 tweets resulting in 54,615 impressions, 85 retweets, 346 likes, and 1,249 media views and engagements. Many schools and partners also tweeted or posted to Facebook. In 2016, the Minnesota Lottery created a short video about this ENRTF project that was shared by the Lottery during an event at the Mall of America and on its online blog.

Project findings have been shared with School Forest teachers and volunteers at School Forest conferences, summits, and regional trainings. Project learnings and evaluation results have been shared

with DNR field foresters to help improve their relationships and serves provided to local School Forest sites. Additionally, project evaluation results relating to how best to support teachers in outdoor classrooms will be shared with environmental educators through regional and state conferences and meetings.

Project Completed: 06/30/2019 **FINAL REPORT**

New Prairie Sportsman Statewide Broadcast Video Project

Subd. 05d $300,000 TF

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Appropriation Language
$300,000 the second year is from the trust fund to the commissioner of natural resources for an agreement with Pioneer Public Television to provide outreach on outdoor recreation, conservation, and natural resource issues, including water quality, wildlife habitat, and invasive species, through a series of interrelated public forums, educational and training videos, and statewide broadcast television programs. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

Prairie Sportsman celebrates our love of the outdoors and connecting to Minnesota's vast resources of lakes, rivers, trails and grasslands. As Pioneer Public Television's most popular production, the show had been on hiatus for five years until the Minnesota Environment and Natural Resources Trust Fund enabled Pioneer to produce 26 new episodes for the 2017-18 seasons.

Prairie Sportsman increased its focus on natural resource protections needed to preserve access to outdoor recreation and widened its appeal to a diverse, statewide audience. As a result, all six Minnesota Public Television Association members aired the 2018 season. This project has provided engaging environmental science education, increased awareness of environmental issues and provided ways for individuals, communities and organizations to restore and protect natural resources.

The 26 episodes including two live town hall broadcasts, 24 environmental science and conservation segments and 26 aquatic invasive species minutes, along with sports, recreation, outdoor lifestyle and audience Q&A segments.

Conservation segments featured topics such as strip tilling to reduce soil erosion, conducting burns to restore natural habitats, genetically diversifying purebred bison herds, evaluating beaver impacts on trout streams, using bioreactors to remove nitrates from farm drainage water, growing camelina and other cover crops, controlling buckthorn with goats, restoring prairie chicken and sandhill crane populations and tagging Monarchs for research. Every episode also included a video short on preventing the spread of aquatic invasive species with a "clean, drain, dry" message.

The Prairie Sportsman website, blog and social media have significantly increased the program's reach. For example, a Mallard research segment uploaded to Facebook reached over 53,000 people with 114 shares; a Monarch tagging segment reached 11,734 with 83 shares. Through broadcast television and digital media, Prairie Sportsman invested ENRTF funds in content that inspires Minnesotans to connect with the outdoors and protect precious natural resources.

PROJECT RESULTS USE AND DISSEMINATION

Prairie Sportsman has achieved statewide appeal and is now aired on all Minnesota Public Television stations, including KSMQ Austin, Lakeland Public TV Bemidji and Brainerd, WDSE Duluth, Prairie Public TV Fargo and TPT MN as well as Pioneer Public TV. Episodes are also widely viewed online at http://prairiesportsman.org/ , https://video.pioneer.org/ and Facebook.

In addition, each episode's three 6 to 12 minute video features and AIS video shorts are segmented and individually branded to stand alone. They are offered to all who participated in the segment to use for their own public outreach and education purposes. For example, the Riverside History & Nature Learning Center in New Ulm is showing a segment on Riverside at the center; Pheasants Forever chapters have aired pheasant hunting and habitat research segments at banquets; a segment on Fort Ridgely Equestrian Center endurance riders aired at the Horse Expo; SWCD Aquatic Invasive Species Task Forces are using segments for public education and outreach.

The segments are also promoted heavily on social media, with demonstrated results. Prairie Sportsman's digital space has had phenomenal growth, highlighted by a segment on Mallard tagging and research that was uploaded to Facebook and organically reached over 53,000 people with 613 reactions, comments and shares and a total watch time of 11,000 minutes. This was more than six months after the segment's air date of February 18, 2018, demonstrating how social media can extend the life and reach of "evergreen" Prairie Sportsman programs and increase the effectiveness of ENRTF funding in bringing educational videos to a statewide audience.

Facebook has been the most successful social media platform for marketing Prairie Sportsman and increased in likes by nearly 70 percent from January to August 2018. Snapchat and Instagram follow in popularity with Twitter being the least important in expanding Prairie Sportsman's audience.

Project Completed: 06/30/2019 **FINAL REPORT**

Standards-Based Dakota Indian Land Stewardship Education

Subd. 05f $197,000 TF

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Appropriation Language
$197,000 the second year is from the trust fund to the commissioner of natural resources for an agreement with Dakota Wicohan to enhance the capacity of approximately 1,250 students to be stewards of the land in Minnesota by learning about Dakota Indian values and environmental principles

through a standards-based experiential multimedia curriculum. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

Dakota Wicohan connected 1,678 sixth-grade students from 14 urban, suburban, and rural schools to Mni Sota Makoce: The Dakota Homelands, a multi-media, standards-based curriculum that teaches students about Dakota values and environmental principles through a teacher training workshop and ten student lessons. A rigorous evaluation of 986 pre and post surveys revealed increases in student knowledge and understanding. Moreover, the results showed that statistically significant increases in learning happened across all racial/ethnic groups and throughout all districts. For instance, after completing the curriculum, students were 2.5 times more likely to understand that the Dakota concept of Mitakuye Owaysin, which teaches that humans are a relative of the land and of all things that exist on the land, in the air, and in the water. To gather qualitative data, the research teams also conducted over 40 talking circles in two urban and two rural schools. Analysis of this data noted students' growing relationship to the land. As one sixth grader said, "I feel like having learned about more about the Dakota and the culture that was here before settlers made me feel more connected to our land (in Minnesota)." Given the strength of these results, Dakota Wicohan has already embarked on further sharing this valuable curriculum with schools around the state. At least ten schools and districts are planning to attend curriculum training in the coming year, with the potential to reach more than 17,000 additional Minnesota learners. The project's success was made possible through strong partnerships cultivated and nurtured throughout the grant period. By preparing teachers to bring a new lens to teaching about the land and the Dakota people through Mni Sota Makoce, both the 1,678 students reached during the LCCMR grant period and the thousands of future students are poised to learn a new way of connecting to our relative, the land. To learn more, please visit the Mni Sota Makoce Curriculum page on the Dakota Wicohan website.

PROJECT RESULTS USE AND DISSEMINATION

Dakota Wicohan's curriculum project director Darlene St. Clair shared information about the Mni Sota Makoce: The Dakota Homelands curriculum with thousands of educators and potential partners throughout the grant project. Through outreach and additional web-based materials prepared in Summer 2019, thanks to help from the CREATE Scholars at the University of Minnesota-Twin Cities, we have already booked trainings for the 2019/2020 school year with multiple districts around the state, including: Anoka-Hennepin, St. Paul Public Schools, the Bell Museum, District 196 (Rosemount/Apple Valley/Eagan), District 742 (St Cloud), Onamia and other Central Minnesota schools. We will also be training all sixth-grade pre-service teachers at University of Minnesota-Morris as well as local public school teachers in Morris. We are also in conversation with Rochester for a regional training as well as Eastern Carver County. In conclusion, Dakota Wicohan is optimistic about the potential for the Mni Sota Makoce: The Dakota Homelands curriculum to reach more sixth-grade students every year so that one day all our citizens will gain the opportunity to reconnect with our land as a relative. We encourage you to check in to our website for further updates on the curriculum.

Project Completed: 06/30/2019 **FINAL REPORT**

Master Water Steward Program Expansion

Subd. 05h $116,000 TF

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Appropriation Language
$116,000 the second year is from the trust fund to the commissioner of natural resources for an agreement with the Freshwater Society to train community volunteers as master water stewards who will work with neighborhoods to install water management projects that preserve and restore water quality. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

The Master Water Steward program quickly grew in size from its implementation in 2013 from 18 stewards to 340 at the beginning of 2019. A need also grew to expand the scope of the program as it reached the edges of the communities with urban water concerns (areas with curb and gutter). The program needed to address different issues and solutions for new areas of MN that had their own unique challenges. In addition, the program needed to be able to show the work of the many volunteers doing many different kinds of work, in a collaborative way.

The program needed a new "track" of the curriculum that taught rural stormwater runoff challenges and solutions for stewards that lived on the edge of or beyond the urban areas. Through this grant the program as able to implement that new track to the curriculum and offer it not just to new areas and people, but also offer it to certified stewards as additional learning.

The program also had a need for a collaborative approach to communicating the effectiveness of all of the Master Water Steward's work. The result of this grant is that we now have a functioning way of connecting stewards through a web application where they can report projects, volunteer time, and tell their stories. The work of the stewards is now available and accessible to stakeholders and program partners.

The overall success of this grant project was that it gave a well-established metro area program a solid new footing and improved educational and participatory structures to reach volunteers and program partners in all parts of Minnesota without losing the connection to the communities we have already built and continue to grow.

The number of Minnesotan's who will benefit from this work is unlimited. Each trained steward reaches hundreds of individuals through their work and keeps thousands of gallons of polluted stormwater from reaching our waterways each year. As we grow further, this will continue to be the case in each area we reach.

PROJECT RESULTS USE AND DISSEMINATION

Dissemination of these project outcomes has already begun and continues to be shared with every new partner organization and steward volunteer. We've created a Program Guide meant to help our partner organizations and volunteers work together and help them do their work. We have created a Capstone Guide that will help guide each project of a steward. We have a high-functioning web application to keep track of projects and volunteer time to help tell the collective story of the Master Water Steward

volunteers. And finally we have a curriculum that stewards who live inside of rural areas who can now take action for the health of their water and be included in the Master Water Steward community.

Project Completed: 06/30/2019 **FINAL REPORT**

Subd. 06 Aquatic and Terrestrial Invasive Species

Developing Membrane Filtration System to Treat Lake Superior Ballast Water

Research Project

Subd. 06b $151,000 TF

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Appropriation Language
$151,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to develop a filtration system utilizing bioactive membrane technologies for use in treating Lake Superior ballast water to remove at least 90 percent of suspended pathogens, invasive species, and contaminants. This appropriation is subject to Minnesota Statutes, section 116P.10. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

This project contributed novel membrane materials for water treatment, as well as new fundamental understanding of graphene oxide surface coatings that show potential in membranes for water purification. The materials explored in this work could find application in the treatment of surface water in Minnesota. An account of our work is provided in the Research Addendum that accompanies this workplan, as well as in our recent publication (Environ. Sci. Technol. Lett., 2018, 5 (1), pp 14–19). In summary, our work showed that graphene oxide coatings, covalently tethered to ultrafiltration membranes, inactivate bacteria and thus prevent membrane biofouling. Our work further showed that the nanoscale morphology of GO surface coatings affects membrane interfacial properties; we demonstrated that randomly oriented GO nanosheets are more desirable for membrane applications, since bacteria are less prone to adhere to disordered GO.

PROJECT RESULTS USE AND DISSEMINATION

Additional outcomes of this project were promotion of Minnesota's human capital through training of postdoctoral, graduate and undergraduate students (1 postdoc, 2 graduate and one undergraduate student were supported at various points of the project), a M. S. degree to be completed by one of the graduate students supported by the project (expected completion in early 2019), a conference presentation at the 2017 AEESP Research and Education Conference (presented by the postdoc supported by the project), a recent publication in Environmental Science & Technology Letters, a premier environmental engineering peer-reviewed journal, and a further manuscript currently under preparation.

In addition, the PM presented three oral presentations reporting the research funded by this project: a conference presentation at the ACS National Meeting in New Orleans on March 18th, 2018 ("Bacterial Adhesion on Surfaces Functionalized with Graphene Oxide: Insights from Single-Cell Force Spectroscopy"); and two invited seminars at the Department of Physics at Hamline University on April 6th, 2018 ("Computational and Experimental Studies of Aqueous Interfaces") and at the Department of Chemical Engineering at University College London on May 9th, 2018 ("Understanding Microbial Adhesion to Aqueous Interfaces using Single-Cell Force Spectroscopy").

Project Completed: 06/30/2019 **FINAL REPORT**

Bacterial Adhesion to Graphene Oxide (GO)

Biological Control of White Nose Syndrome in Bats - Phase II

Research Project

Subd. 06d $452,000 TF

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Appropriation Language
$452,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to continue research to identify, develop, and optimize biocontrol agents for white nose syndrome in bats by evaluating the biocontrol effectiveness of microbes collected at additional hibernacula throughout the state and conducting baseline characterization of the total bat microbiomes. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

White nose syndrome is a devastating disease of hibernating bats caused by the fungus, P. destructans (Pd). The primary goal of this project is to identify safe and effective bio-control treatments for WNS. We expanded our microbial strain collection and identified additional inhibitors of Pd, bringing our total of active strains to approximately 120. We identified the top five inhibitory strains, purified the active compounds, and determined their structures and activities. We identified approximately 15 structures new to science and 6 known compounds with antifungal activity. To determine the potential application of these active strains to substrates or bats, we developed a cell-based assay using bat skin cells derived from two bat species. By testing each compound against both the fungal pathogen and bat skin cells, we could calculate the relative potency and cytotoxicity. One of the most active and abundant compounds from an inhibitory fungus from the Soudan Iron Mine is completely nontoxic towards the cultured bat skin cells, which provides additional support for field testing with the producing strain.

Additional accomplishments include the sequencing of bacteria and fungi found throughout three distinct systems (iron mine, sandstone and calcium karst caves) from both culturable strains and mixed, non cultured microbial community samples. These taxonomic studies are significant because they allow

us to see patterns of microbial communities across diverse environments, including identifying taxa that are unique or common in different areas.

We also developed tools and techniques for monitoring P. destructans in caves for studies going forward. Mapping of P. destructans along two transects in the Soudan Mine and Mystery Cave using qPCR provides a clear picture of the density and occurrence of the pathogen. This information and testing will be used to target treatments in collaboration with the DNR and managers to ultimately protect the remaining bat populations.

PROJECT RESULTS USE AND DISSEMINATION

The primary dissemination of the results from this project has been through numerous seminars given at academic institutions, research symposia, and at professional science society meetings. Both lectures and posters have been presented at national conferences, and results have been shared with DNR staff through formal and informal communications. Two scientific manuscripts have been published on this work, and at least 5 more are in progress and should be published within the next 6 months. We have also participated in several outreach opportunities by having research tables at local bat week events, in collaboration with USFW staff.

The most immediate use of our results will be in collaboration with DNR staff and cave/mine park managers in locations affected by WNS. We are communicating our data about the pathogen locations to help inform any interventions and treatments, and to suggest specific areas for continued monitoring using our analytical approach.

Project Completed: 06/30/2019 **FINAL REPORT**

Complete Genome Sequence of Streptomyces Albus SM254

Resource Capture and Competitive Ability of Non-Pathogenic Pseudogymnoascus spp. and P. Destructans, the Cuse of White-Nose Syndrome in Bats

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Elimination of Target Invasive Plant Species - Phase II

Subd. 06e $750,000 TF

Subd. 06e1 - $511,000 TF
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Subd. 06e2 - $239,000 TF
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Appropriation Language
$750,000 the second year is from the trust fund. Of this amount, $511,000 is to the commissioner of agriculture and $239,000 is to the Board of Regents of the University of Minnesota to train volunteers and professionals to find, control, and monitor targeted newly emergent invasive plant species. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

ML2016 06e:

- *06e1: Elimination of Target Invasive Plant Species - Phase II* - $511,000
- *06e2: Elimination of Target Invasive Plant Species - Phase II* - $239,000

Subd. 06e1: Elimination of Target Invasive Plant Species - Phase II - $511,000 TF

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OVERALL PROJECT OUTCOME AND RESULTS

The goal was to eliminate highly damaging target invasive plants before they became widespread by 1) training people to identify and report invasive plants, 2) survey, coordinate control and monitor target plants, 3) control target plants and 4) implement the invasive species management database system from Phase 1. Targeted plants that cause severe ecological harm include black swallow-wort, dalmatian toadflax, cutleaf and common teasels, Grecian foxglove, Japanese hops, brown and meadow knapweeds, Oriental bittersweet and Palmer amaranth.

University of Minnesota Extension led the education and outreach efforts outlined in the dissemination section. The drone team transitioned from research to survey work by testing several different types of drones, cameras, weather conditions and self-produced and commercial post-processing software. We determined that surveying for Oriental bittersweet is best done with sturdy quadcopter drones and a high quality camera on mild winter days after leaf drop but with snow on the ground so the red fruit is most visible. High quality, stitched-together and geo-coded maps can now be produced in post processing and inform accurate eradication efforts.

The Minnesota Department of Agriculture (MDA) and Conservation Corps Minnesota (CCM) led invasive plant management. MDA led survey, invasive plant report follow up, monitoring and coordinated control with landowners and partners. CCM led the control effort with 157 unique crew members working on this project.

This project enabled us to find, document and manage infestations before they spread. We also initiated a response to Palmer amaranth in conservation plantings that was continued by the project Palmer Amaranth Detection and Control. Mitigating these invasive plant threats protected Minnesota forests, grasslands and riparian areas.

PROJECT RESULTS USE AND DISSEMINATION

University of Minnesota Extension led the education and outreach funded specifically by this project. Reaching 1,108 people via 11 workshops, field tours and public and professional presentations. Developed two national award winning videos: Planning invasive species events: Tips for working with volunteers and Planning invasive species events: Working with a natural resources professional. Created 14 innovative educational materials including: 3D-printed models of Palmer amaranth, Japanese hops and Grecian foxglove; pull-up banners for Palmer amaranth and giant hogweed; and identification kits available at the public library for Palmer amaranth, wild parsnip and Oriental bittersweet. Produced two new educational handouts and printed and distributed about 10,875 educational materials. In addition, the University of Minnesota and Minnesota Department of Agriculture (MDA) team members won numerous national, regional and state awards for effort including this project, from across an impressively wide spectrum of content areas. There were 13 media pieces about project activities; 13 presentations or booths reaching 5,137 gardeners, tribal youth, Extension volunteers and others; and 30 presentations or posters at 14 different professional conferences representing a broad spectrum of expertise reaching almost 1,000 natural resource or invasive species professionals. Two professional, peer reviewed articles were published that reference this work. MDA organized and led 6 field tours, gave 43 presentations, provided project updates at 32 meetings, authored 14 articles, sent an annual report to stakeholders and trained Conservation Corps Minnesota crew members at multiple workshops each year.

Subd. 06e1 Completed: 06/30/2020 **FINAL REPORT**

Subd. 06e2: Elimination of Target Invasive Plant Species - Phase II - $239,000 TF

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OVERALL PROJECT OUTCOME AND RESULTS

Butterflies are in trouble in western Minnesota prairies. Ten species are of statewide conservation concern and two species are federally listed. Knowing where these species persist on the landscape is important to their conservation. Likewise, understanding the factors that affect population size is important to the conservation of existing populations. The skipper butterflies are difficult for untrained individuals to identify with certainty. The lack of qualified surveyors limits the ability of biologists and managers to search for skippers.

Seven of the 13 species were not found across all sites surveyed. All of these missing butterflies are skippers. We monitored populations of Dakota skipper and Pawnee skipper in response to prairie management. Conservation grazing, or perhaps the lack of fire, appears to be beneficial to persistence of Pawnee skipper. The results of Dakota skipper monitoring are less clear and will require additional years of monitoring. Dakota skippers at the reintroduction site appear highly localized to within a few hundred meters of the point of release. This is perhaps due to low dispersal ability, mortality, and/or lower detection ability with increasing radius from the release point. The MNDNR, MN Zoo, and USFWS partnered to successfully train at least 30 individuals to identify imperiled skippers, thus increasing the statewide capacity for monitoring greatly. All of these actions work to make more informed, science-based decisions about the conservation of rare butterflies for all Minnesotans to enjoy.

PROJECT RESULTS USE AND DISSEMINATION

During this project, the USFWS consulted project staff in drafting the recovery plans for both federally listed species, the Dakota skipper and the Poweshiek skipperling. Information gained from the surveys conducted through this project were essential in writing the recovery plans. These draft recovery plans were then disseminated for public comment and review.

The project manager in collaboration with the MN Zoo and USFWS developed species identification cards for the imperiled skipper species and their look-a-likes as part of the training sessions. These cards are specific to western Minnesota skippers and are an important tool in the continued survey and conservation of these rare skippers. We continue to receive complements and requests for these identification cards.

Subd. 06e2 Completed: 06/30/2020 **FINAL REPORT**

Dutch Elm Disease Resistance - Phase II

Research Project

Subd. 06f $200,000 TF

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Appropriation Language
$200,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to continue to identify and evaluate native Minnesota elms that are resistant to Dutch elm disease and begin propagating disease-resistant specimens for field trial testing. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

After nearly a century since its introduction, Dutch elm disease (DED), caused by the fungal pathogen Ophiostoma novo-ulmi, remains a critical threat to elm populations in Minnesota. This iconic species has long been regarded as one of the most resilient and adaptive species for the upper Midwest, tolerating salt, pollution and many other stresses better than other trees. Elm also play a vital part in the ecology of Minnesota's forests, providing important food and habitat for wildlife, are excellent trees for wetlands and add to the biodiversity of a healthy forest. Combating this disease has been expensive and very difficult. Resistance to DED has been proven in American elm, however, it is poorly understood and a limited number of selections are available. Our objectives with this project were to survey and identify resistant elm trees in Minnesota, provide new insights on disease resistant mechanisms, and field test selections by inoculation studies. Our results showed different chemical and morphological characteristics that are in part responsible for resistant defense mechanisms. This information will lead to more rapid selection tools and development of increased resistance. We successfully identified, propagated, and screened 46 genotypes from which we hope to conduct continued long term trials with selections that perform well in field trials (based on 1 year inoculation data from a final field trial initiated 6/2019). In addition, because propagation of elm is variable and most often difficult, we developed enhanced propagation techniques that aid in and provide better efficiency to obtain the

numbers needed for screening trials. We are hopeful that this long term project aimed at developing and introducing resistant genotypes back into urban and forested areas will aid in overcoming the destructive impacts that this invasive disease has had on American elm.

PROJECT RESULTS USE AND DISSEMINATION

Presentation and demonstrations have been made at arborist and nursery meetings including the Minnesota Shade Tree Advisory Committee forum, the Minnesota Shade Tree Advisory Committee Annual Field Day, Minnesota Turf & Grounds Foundation and Minnesota Nursery and Landscape Association conventions, and a national workshop on American Elm Restoration in the United States. Documentation of results have been presented at scientific meetings and in general articles and scientific publications.

Project Completed: 06/30/2019 **FINAL REPORT**

Subd. 07 Air Quality, Climate Change, and Renewable Energy

Waste Heat Recovery with Efficient Thermoelectric Energy Generators

Research Project

Subd. 07b $400,000 TF

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Appropriation Language
$400,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to develop thermoelectric energy generators using advanced, high-performance materials able to more efficiently capture waste heat and transform the heat into electricity. This appropriation is subject to Minnesota Statutes, section 116P.10. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

Any thermal cycle, from combustion engines, to power plants, to refrigeration cycles produces waste heat that is not utilized but released into the environment. This project dealt with the fabrication of new thermoelectric materials, which are capable of converting part of that waste heat into electricity. The specific focus was on alloys of silicon (Si) and germanium (Ge), which are suitable for high temperature applications up to approximately 1,000 °C (approx. 1,830 °F). The focus of this project was on forming nanostructured materials that improve the thermoelectric performance by reducing the thermal conductivity of the material through scattering of heat conducting lattice vibrations at the abundant grain boundaries, without negatively affecting the electrical conductivity.

Initial work focused on forming bulk thermoelectric materials by sintering SiGe nanocrystals, particles with the size of only a few nanometers, into dense solids. However, this approach was found to be unsuccessful due to the brittleness of the material. Laser sintering of nanocrystals into thin film materials proved to be a much more successful approach, as it produced non-brittle thermoelectric thin

films, with performance comparable to the best SiGe materials previously reported in the literature. Furthermore, laser sintering was found to be a fast, high-throughput method which has the potential to be applicable in industrial processes.

The porosity of laser-sintered films was identified as a potential weakness. To overcome this issue, the team developed a new approach to from nonporous nanocrystalline thin films by first plasma depositing amorphous (non-crystalline) SiGe materials, and then using thermal annealing to transform these into nanocrystalline materials. This approach was found to yield virtually fully dense thermoelectric materials with good performance characteristics and the promise of low-cost production.

The work performed under this project has made important contributions to the scientific community, documented in several scientific papers, and may lead to the production of new thermoelectric materials that convert waste heat into electricity. This has the potential to improve the efficiency of thermal cycles and reduce the energy lost in waste heat, which will ultimately benefit Minnesota citizens and all of humanity.

PROJECT RESULTS USE AND DISSEMINATION

By the time of the project final report, results of this research have been disseminated in seven scientific journal publications and through five presentations at international conferences.

Project Completed: 06/30/2019 **FINAL REPORT**

Hydrogen Fuel from Wind-Produced Renewable Ammonia

Research Project

Subd. 07c $250,000 TF

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Appropriation Language
$250,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to develop a technical solution for converting wind-produced ammonia to hydrogen through catalytic decomposition, for use in reducing emissions from diesel engines and powering fuel cell vehicles. This appropriation is subject to Minnesota Statutes, section 116P.10. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

Project due to be completed: 06/30/2019 **Work Plan**

Utilization of Dairy Farm Wastewater for Sustainable Production

Subd. 07d $475,000 TF

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Appropriation Language
$475,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota for the West Central Research and Outreach Center in Morris to develop and evaluate an integrated system that recycles and uses nutrients in dairy wastewater from feedlots and milk processing, thereby reducing nutrients from agricultural runoff, and to provide outreach on adoption of new technologies. This appropriation is subject to Minnesota Statutes, section 116P.10. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

The work was a collaboration between the West Central Research and Outreach Center in Morris and in the Department of Bioproducts and Biosystems Engineering and Food Science and Nutrition at the University of Minnesota. The goal of our project was to use dairy cattle wastewater to produce green energy, foods, and feed for livestock. The project utilized algae cultivation to remove nutrients from dairy wastewater and produce algae biomass for dairy calf feed, as well as hydroponic vegetables. Chlorella species of algae was the most predominant algae studies in the project, and the fatty acid profile of Chlorella indicated it would be superior of livestock feed and energy. Our project found that algae can successfully remove nitrogen, phosphorous, and dissolved solids in dairy wastewater, thus improving the environmental effects of wastewater from livestock farms. Results also suggest that feeding algae grown from dairy wastewater provided acceptable nutritional requirements for dairy cattle and mice. No adverse growth of calves or feed intake was observed when adding algae to dairy calf rations. This project suggests that algae can clean Minnesota waterways through reduced nitrogen and phosphorous from agricultural runoff.

PROJECT RESULTS USE AND DISSEMINATION

We have provided tours of the algae biomass system at the WCROC to legislators, farmers, and industry representatives. We have also hosted dairy field days and the Midwest Farm Energy Conference at the WCROC that have shown the results and bioreactors to the public as well. Over 2,000 people have viewed the system and have responded with favorable interest in the system. Our graduate student on the project presented an abstract at the Algal Biomass Conference in Denver, CO on biomass production for livestock. So far, 18 peer reviewed papers have been published with more to follow. The website will be updated with the final results of the project and infographics for promotion of the project. An abstract on calf feeding with be presented at the American Dairy Science Association meeting in 2020. This applied algae livestock feeding component is the Master's thesis of Siane Luzzi in the Department of Bioproducts and Biosystems Engineering at the University of Minnesota and she will defend her thesis in 2019.

Project Completed: 06/30/2019 **FINAL REPORT**

Solar Energy Utilization for Minnesota Swine Farms - Phase II

Subd. 07e $475,000 TF

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Appropriation Language
$475,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota for the West Central Research and Outreach Center in Morris to continue to develop and evaluate the utilization of solar photovoltaic systems at swine facilities to improve energy and economic performance, reduce fossil fuel usage and emissions, and optimize water usage. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

American pork producers are trying to improve the environmental footprint of their production systems by reducing their reliance on fossil fuels. Keeping sows and pigs in their ideal temperature range during hot seasons is one way to improve animal performance and the carbon footprint of their production system. Use of solar-generated electricity is another approach for pig farmers to reduce their reliance on fossil fuels. We designed and installed a solar-powered system to cool heat-stressed sows during the farrowing and lactation periods. After installation and commissioning, we studied 84 sows and litters over two summer seasons in three contemporary groups of sows. The 20 kW solar array consistently provided enough electricity to operate the sow cooling system installed in a confinement farrowing barn. The sow cooling system studied in this project was able to significantly reduce heat stress and improve welfare of farrowing and lactating sows. Unfortunately, the reduced heat stress of sows did not support improvements in litter size at weaning or growth rate of suckling pigs. A basic economic analysis of the 20 kW solar PV system installed for this project suggested the system would breakeven after 60 years on a straight cash basis (revenues minus expenses). When tax incentives are added and fully utilized, the breakeven point is between 8 and 12 years but can depend on the utility provider in the area. A Life Cycle Assessment (LCA) of the carbon and energy footprints of the sow cooling system was completed. Because there was no increased output (number or weight of weaned pigs) as a result of the cooling system, neither the carbon footprint nor the energy footprint of the farrowing operation were improved by the cooling system. However, using electricity generated by the solar PV system did substantially reduce the carbon footprint and also significantly reduced the consumption of energy derived from fossil fuels for the swine farrowing operation. Solar-generated electricity can play an important part in reducing carbon emissions from Minnesota pork production.

PROJECT RESULTS USE AND DISSEMINATION

Information related to this project has been disseminated to many different audiences in a variety of formats. The target audiences for these publications include: pig farmers, engineers and builders of swine production barns, swine industry consultants, and consumers. Publications related to this project include: a video about the project (Cooling Sows and Heating Piglets with Solar Energy) and two factsheets (WCROC Farrowing Barn Heating and Cooling System and Lactating Sow Performance with Solar-Powered Cooling). Multiple conference presentations and posters were made for industry and professional audiences, and many articles were printed in newsletters and popular press, including the West Central Research and Outreach Center Newsletter, Land Magazine, Morris Star Tribune Ag Supplement, The Farmer Magazine, and Minnesota Pork Congress Magazine. Any of these publications are available upon request from the project manager. More publications are anticipated in the future.

Project Completed: 06/30/2019 **FINAL REPORT**

Life Cycle Assessment of Cooling Sows Using Solar Electricity
Effects of a Solar Cooling System on Sow Performance

Subd. 08 Methods to Protect, Restore, and Enhance Land, Water, and Habitat

Measuring Pollen and Seed Dispersal for Prairie Fragment Connectivity

Research Project

Subd. 08b $556,000 TF

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Appropriation Language
$556,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to determine habitat connectivity between prairie fragments by measuring plant movement by dispersal of pollen and seeds to improve prairie restoration implementation. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

Project due to be completed: 06/30/2019 **Work Plan**

Establishment of Permanent Habitat Strips Within Row Crops

Subd. 08c $179,000 TF

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Appropriation Language
$179,000 the second year is from the trust fund to the Science Museum of Minnesota for the St. Croix Watershed Research Station to research the viability of establishing prairie forbs and alfalfa as permanent cover strips in the bare soil between selected rows of corn and soybeans as potential pollinator, monarch, and gamebird habitat. Monitoring of the native plant strips must evaluate the effects of pesticides from adjacent crops on pollinators, including determining whether there is a reduction of pollinators that results in reduced setting of seeds on the native plants. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

This project successfully demonstrated three objectives: 1) that perennial vegetation can be established and maintained between rows of corn/soy within a field—without taking land out of production; 2) that the perennial vegetation in the inter-row plantings provides habitat value, and 3) that the plantings can be done in a manner that induces a minimal yield loss to the adjacent corn/soy rows. While establishment of many prairie species in the inter-row strips failed, several did not and are thriving after three years. We have demonstrated that species such as golden alexanders, bottlebrush grass and milkweeds can be established and maintained in a conventional corn/soy rotation. These strips of perennial forbs and grasses were documented to have provided habitat to pollinators and appear to be very good reproduction habitat for monarch butterflies. Perennial strips did induce a 5 to 20 bushel per acre yield loss, but since only 1 out of 24 inter-row strips were planted with perennials, we estimate that the total cost in lost yield for the whole field (80 acres) due the perennial strips is less than $200. Going forward, we think it is possible to plant and maintain just the outside row of a field with a mix of golden alexander, milkweeds, and woodland brome. This mix would provide some early season pollinator habitat and a significant amount of summer Monarch reproduction habitat. And, since only the outside row of a field would be impacted, the total annual cost in lost yield and maintenance of the strip should be under 40 dollars per 80 acres. If implemented on a widespread scale, this could offer a very cost-effective way to provide significant benefit to Monarch populations.

PROJECT RESULTS USE AND DISSEMINATION

Results of this project were presented at two farm-day tours as part of the semi-annual Agroecology summit hosted at Willow Lake farm. Combined, there were over 150 participants in the two Agroecology summits with nearly all of these participants given a first-hand tour of the inter-row perennial vegetation strips implemented during this project. Participants included many local farmers testing cover cropping techniques to improve soil health, as well as agency and advocacy professionals and practitioners working to implement perennial cover as habitat or new cropping systems. In addition to the on-site demonstration of the strips, the field days featured presentations and panel discussion by U of MN faculty, Science Museum scientists, MN-DNR biologists, BWSR planners, environmental advocacy groups and local farmers. Both Agroecology summits presented new concepts/methods about existing and emerging cropping systems that incorporate perennial vegetation (including results from the perennial inter-row system of this project); and policies and technology that could be used to stimulate perennial cropping systems. In-depth presentations were given on why perennial systems are needed, how they are critical to improving water quality and wildlife habitat, what future perennial systems could look like, and how manipulating food and energy markets could be a cost-effective method to getting perennial crops/vegetation adopted. The strips project, with its embedded objectives of habitat and water quality, while maintaining ag-profitability, provided a good backdrop to start the conversation about how we are going to modify cropping systems to more cost-effectively meet our natural resources goals.

Project Completed: 06/30/2019 **FINAL REPORT**

Controlling Reed Canary Grass to Regenerate Floodplain Forest

Research Project

Subd. 08e $218,000 TF

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Appropriation Language
$218,000 the second year is from the trust fund to the commissioner of natural resources for an agreement with the Minnesota state office of the National Audubon Society to determine the most effective regeneration methods for restoration of floodplain forests in southeast Minnesota impacted by invasive reed canary grass. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

As a result of this work, the research team has identified that the most important considerations for long-term control of Reed Canarygrass include:

- Treat reed canarygrass until it is controlled (this will take 2+ years)
- Controlling reed canarygrass before planting other species is key for survival
- Diversify your site and plant as many species as practical
- Floods and site conditions may delay treatments and tree planting

A decision making tool was developed to guide efforts to restore reed canarygrass to a native floodplain forest community. It includes guidance for treating the grass and restoring native species in both open field and forest gap settings. These recommendations are based on scientific field studies that tested a variety of approaches. Much of the research that forms the basis of these recommendations was conducted between July 2017-June 2019 at four sites in floodplain forest along tributaries of the Mississippi river between Red Wing, MN and the Iowa border (see case study from one site by Beebe 2019). These years were generally warm and wet experiencing longer duration and more frequent inundation than average conditions. Fall 2018 was warm and plants senesced late.

PROJECT RESULTS USE AND DISSEMINATION

The materials produced as part of the decision making tool to control Reed Canarygrass will be available electronically at the Audubon Minnesota webpage. Subsequently, computer files will be made available to state, federal and private land management agencies.

Project Completed: 06/30/2019 **FINAL REPORT**

Upland, Wetland, and Shoreline Restoration in Greater Metropolitan Area

Subd. 08g $509,000 TF

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Appropriation Language
$509,000 the second year is from the trust fund to the commissioner of natural resources for an agreement with Great River Greening to restore approximately 150 acres of forest, prairie, woodland, and wetland and 0.15 miles of shoreline throughout the greater Twin Cities metropolitan area, using volunteers, and to conduct restoration evaluation on previously restored parcels. A list of proposed restorations and evaluations must be provided as part of the required work plan. Plant and seed materials must follow the Board of Water and Soil Resources' native vegetation establishment and enhancement guidelines. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

Over the course of the appropriation,
we:

- Restored/enhanced 342 acres of high quality natural areas. This is more than double our original goal of 150 acres.
- Restored/enhanced 0.29 miles of shoreline, which is 116% of our original goal.
- Engaged 839 volunteers – 129% of our original goal of 650 - who participated in deeply engaging, impactful outdoor activities so they and the community better understand, support, and enjoy the ecological restoration/enhancement process.
- Continued to advance the practice of restoration/enhancement with developing feasible new approaches at a challenging site, and collected valuable information with a sample of restoration evaluations.
- Leveraged $176,000 in match, including cash and in-kind, from a variety of sources. This is 94% of our goal, comparable to our proportional spend of 93% of the allocation.

The successful use of this appropriation underscores the continued importance of our ecological restoration and enhancement work, which is rooted in partnerships, community engagement, and sound practice.

PROJECT RESULTS USE AND DISSEMINATION

Over 830 volunteers received active education including results of project, techniques, and answers to specific questions during participation in volunteer restoration/enhancement events. Emails about these volunteer events were sent over 15 times to our 8500 general subscribers, and over 30 times to our 350 Volunteer Supervisor subscribers who also received a packet of information when they led a small group of general volunteers. All volunteers received follow-up thank you emails recapping the project. Events were also posted several times on Twitter, with 600 followers, and at least 6 Facebook posts with 1400-1500 followers. Two website posts with 1500 views per month, featured volunteer events. Over 1300 hard copy fliers, and 4800 hard copy/digital mix of fliers featuring events were distributed at over 20 outreach events. One site was featured on a Kare11 news article.

To advance the practice of restoration and enhancement, GRG partnered with a subcontractor for their powerpoint presentation ‘Hay Now!’ at the 11th Annual Scientific Meeting ‘Cultivating Innovative Restoration Connections in the Midwest’ of the Society for Ecological Restoration Midwest Great Lakes Chapter April 12-14, 2019 at Central College in Pella, Iowa. The meeting was attended by over 200 restoration ecologists. This presentation featured two case studies of conservation haying at Pilot Knob Hill (ML2016) and South Washington Conservation Corridor (ML2015).

Project Completed: 06/30/2019 **FINAL REPORT**

Bluffland Restoration and Monitoring in Winona

Subd. 08h $99,000 TF

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Appropriation Language
$99,000 the second year is from the trust fund to the Board of Trustees of the Minnesota State Colleges and Universities system for Winona State University to inventory, restore, and monitor the 40-acre Garvin Heights Natural Area in Winona and provide related public outreach and education. Plant and seed materials must follow the Board of Water and Soil Resources' native vegetation establishment and enhancement guidelines. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

A 40-acre bluffland park in Winona, MN, containing rare dry bluff prairies and bur oak savannahs adjacent to a heavily visited (40,000+ visitors annually) overlook, became overrun with invasive buckthorn and honeysuckle. This project planned to restore the native plant community by 1) surveying the existing plant community, 2) removing invasive plants, 3) planting and seeding native plants, 4) conducting workshops on invasive plant management for the public, and 5) surveying the recovering plant community. Pre-restoration plant surveys indicated low numbers of native plant species. Cutting, treating, and burning by the MN Conservation Corps and browsing by goats (five separate periods over 3 years) were used to help reduce and manage the invasive plants. Native plants were planted and seeded to restore the natural community. During restoration, two public workshops were held to educate area citizens on methods for managing invasive plants on their own lands and restoring native plant communities. Recent plant surveys have documented the presence of 181 species at the site to date, with 127 of those not present before restoration. A large, reproducing population (>600 plants) of a state threatened species, Great Indian Plantain, has developed after buckthorn removal from one area of a savannah. A Winona State University (WSU) graduate student completed a thesis focused on the restoration effort and the workshops, developing a basic management plan for the site moving forward. Restoration efforts will continue, with ongoing management of buckthorn emerging from the seedbank and the germination and spread of newly planted native species. WSU has funded a new graduate assistantship (tuition plus stipend) to continue the restoration and monitoring work at the site. This project, along with new educational signage for the site, will demonstrate to the public the methods and benefits of managing invasive plants on natural habitats.

PROJECT RESULTS USE AND DISSEMINATION

1. Throughout the project period, various information about the project was posted on the project web site maintained by Winona State University (https://www.winona.edu/outdoored/garvin.asp), on a project-specific Facebook page

(https://www.facebook.com/Garvin-Heights-Natural-Area-Blufflands-Restoration-Project-357534101286304/), and on the Winona State Biology Department Facebook page (https://www.facebook.com/biologyWSU/). The community was informed of upcoming workshop opportunities via hard-copy postings within the community, targeted mailing, Facebook postings, group email lists, newspaper notifications, and a radio broadcast. Workshops, community presentations, on-site signage, and presentations at regional science meetings further served to present the project and its findings to the public.

2. Prior to site restoration, plant surveys on-site were used to produce a list of species present. In addition, a list species in the WSU herbarium collected from Garvin Heights was generated. (spreadsheets included via email)
3. Presentations about the project and its results were given by the PI (Winona Master Gardeners, Mississippi River Research Consortium) and by several undergraduate students (WSU Ramaley Undergraduate Research Celebration).
4. Graduate student Ryan Walsh recently completed his thesis (Walsh, R. 2019. Garvin Heights Restoration Project. Professional Science Masters Thesis, Winona State University, Winona, MN. 56 p.) that focused on the Garvin Heights project in general, the first workshop, and the effects of goat browsing on buckthorn. Included in his thesis are a series of recommendations for future management at the project site that will form the basis for a future management plan. In the near future, we plan to develop a manuscript from his thesis, on the effects of goat browsing, for submission to a peer-reviewed scientific journal. (thesis included via email)
5. Graduate student Tamberlain Jacobs is creating an up-to-date plant inventory list for the project site. She also is developing a bloom calendar for the site, which will allow visitors to determine what plants may be in bloom at various times of the year. (spreadsheets included via email)

Project Completed: 06/30/2019 **FINAL REPORT**

Master Thesis: Garvin Heights Restoration Project

Champlin Mill Pond Shoreland Restoration

Subd. 08i $2,000,000 TF

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Appropriation Language
$2,000,000 the second year is from the trust fund to the commissioner of natural resources for an agreement with the city of Champlin to restore the Champlin Mill Pond shoreline and adjacent habitat. Plant and seed materials must follow the Board of Water and Soil Resources' native vegetation establishment and enhancement guidelines. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

The Mill Pond is a reservoir lake within the City of Champlin that was created in 1867 with the construction of the first Mill Pond Dam on the Elm Creek, at the outfall to the Mississippi River. Since that time, the Mill Pond has become an important water feature for fishing and recreational activity in the region. Over the years, the Elm Creek and Mill Pond have become impaired due to poor agricultural practices and upstream erosion. The Mill Pond impairments are for Total Suspended Solids, phosphorous, bacteria and low dissolved oxygen. In 2012, the City completed the first stream restoration project upstream of the Mill Pond and completed the reconstructed Elm Creek Dam and shoreland restoration at the Mississippi River outfall in 2016.

In 2016-2017, the City established partnerships with the LCCMR, MN legislature, and Elm Creek Watershed to restore the Mill Pond and improve water access. A Technical Advisory Panel was formed to guide the design and develop project goals for Habitat Restoration; Water Quality Improvements; Public Education; Public Access and Recreation.

Phase I started in December 2017, and included the removal of phosphorus laden sediments, installation of the redesigned deep-water and shallow water habitat and in-lake structures. The project restored approximately 42 acres of shoreland area and aquatic habitat. The project restored native upland, riparian, and aquatic zones. The project outcomes include a reduction in erosion and improves water quality. The restored habitat will help maintain and enhance sensitive species like the Blanding's Turtle and sustain game-fish populations. The improved riparian and upland habitats help support migratory and resident wildlife populations.

The lake restoration was completed in June 2019 and the City held the first Mill Pond Citizen Science Event at the Mill Pond. The event provided hands-on interactive activities and educational experiences on fishery research, migratory birds and preservation of native plant communities. The project established an area of study for environmental science classes for area schools, which are expected to educate hundreds of students each year. Also, the completion Phase II Mill Pond Trail Access project has improved the water access and recreational experiences for area residents.

PROJECT RESULTS USE AND DISSEMINATION

Project status has been posted on Facebook and on the Champlin website. Public Hearing and related articles on regarding the project were published in the Champlin Dayton Press. Additional articles in the Champlin Chronical have been published and distributed to area residents. The City working with local Cable Station Quad City Television (QCTV) had production of "Champlin Matters" focusing on the Citizen Science and the development of the Mill Pond In-lake Habitat and Fishery. Also, Champlin Live and Local production focused on the Mill Pond.

Project Completed: 06/30/2019 **FINAL REPORT**

Subd. 09 Land Acquisition, Habitat and Recreation

Scientific and Natural Area Acquisition and Restoration

Subd. 09a $1,386,000 TF

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Appropriation Language
$1,386,000 the second year is from the trust fund to the commissioner of natural resources to restore and improve approximately 750 acres of scientific and natural areas. A list of proposed restorations must be provided as part of the required work plan. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

Through this appropriation, habitat restoration and enhancement activities took place across the state on Scientific and Natural Areas (SNAs) to sustain the unique plant communities and the endangered, threatened, and rare species housed within these SNAs. Activities included 50.2 acres of habitat restoration (see restoration evaluations included with final report), 539 acres of invasive species control, 460 acres of woody control, 523 acres of prescribed burning, site development work at 22 SNAs, development of 7 interpretive signs, the completion of 12 Adaptive management Plans, ecological monitoring at 54 SNAs and partnership project activities at 6 SNAs. Partnership Projects coordinated through this appropriation led to multiple invasive control, woody control, prescribed burning and prairie restoration activities being completed.

Knowledge gained through ecological monitoring efforts will enable managers to improve management of SNA's unique plant communities and the Species in Greatest Conservation Need, state special concern and state/federally threatened and endangered species that call these habitats home. As best management practices are evaluated and improved through these efforts, SNA will be able to disseminate this knowledge to other landowners and land managers.

PROJECT RESULTS USE AND DISSEMINATION

Seven new interpretive signs were developed and installed at SNAs to communicate the significance of protecting these unique habitats and the role that restoration and enhancement play in sustaining or improving habitat quality. Several management activities completed through this appropriation have been highlighted on the SNA Facebook page and in the SNA program e-newsletter.

Project Completed: 06/30/2019 **FINAL REPORT**

Conservation Easements in the Avon Hills - Phase III

Subd. 09c $1,300,000 TF

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Appropriation Language
$1,300,000 the second year is from the trust fund to the commissioner of natural resources for an agreement with Saint John's University in cooperation with Minnesota Land Trust to secure permanent conservation easements on approximately 500 acres of high-quality habitat in Stearns County, prepare

conservation management plans, and provide public outreach. A list of proposed easement acquisitions must be provided as part of the required work plan. An entity that acquires a conservation easement with appropriations from the trust fund must have a long-term stewardship plan for the easement and a fund established for monitoring and enforcing the agreement. Funding for the long-term monitoring and enforcement fund must come from nonstate sources for easements acquired with this appropriation. The state may enforce requirements in the conservation easements on land acquired with this appropriation and the conservation easement document must state this authority and explicitly include requirements for water quality and quantity protection. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

Conservation easements to permanently protect private land from development are the main goal of this project located in the Avon Hills 10 miles west of St. Cloud, MN. The project permanently protected 477 acres of forests, grasslands, wetlands, and almost 3 miles of undeveloped shoreline in the Avon Hills through the acquisition of two conservation easements. These two conservation easements continue to demonstrate the effectiveness of a reverse bidding system termed the MN Multi-faceted Approach for Prioritizing Land Easements (MMAPLE) to rank submitted easement locations. MMAPLE ranks proposed easements by comparing the land's inherent ecological features to the cost per acre for the easement, thereby focusing on the best value. Land which has many inherent ecological values receives a higher score. Conversely, landowners who bid a higher price per acre for the easement receive a lower score.

Using this competitive bidding process, MMAPLE again proved its ability to efficiently leverage the grant funding. For example, the Serenity easement acquisition was purchased for $201,100 below its full market value. Appraised value of the two purchased easements in this phase was $1,191,000, with the grant providing $989,900 towards acquisition; donated value of the bargain sale, in conjunction with landowner contributions to the Land Trust's stewardship fund ($40,000) amounted to $241,100 of total leveraged funds (almost $100,000 more than estimates in the original proposal).

The grant also provided funding to support outreach and education to increase landowner awareness of easements and land protection as well as overall conservation. Examples of the varied educational programming offered reaching over 2000 participants included the Living in the Avon Hills Conference, MN Master Naturalist Volunteer trainings, Collegeville Colors, monthly Landowner Learning Series, and an Avon Hills Master Woodland Owner Training.

PROJECT RESULTS USE AND DISSEMINATION

The Land Trust shared news of the easement acquisitions on both the Avon Hills (Serenity) and (Redhead) parcels on its website and Facebook page. Multipage newsletters and flyers featuring the easements and educational programming were mailed to every landowner with over 40 acres in the Avon Hills several times throughout the project. The MMAPLE process used in this project is being advocated for use in other grants and for other funders such as the Lessard-Sams Outdoor Heritage Council and will be presented as a topic at the national conference of the Land Trust Alliance in Raliegh, NC in October, 2019.

Project Completed: 06/30/2019 **FINAL REPORT**

Lincoln Pipestone Rural Water System Acquisition for Wellhead Protection

Subd. 09d $1,500,000 TF

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Appropriation Language
$1,500,000 the second year is from the trust fund to the commissioner of natural resources for an agreement with Lincoln Pipestone Rural Water to acquire and restore lands designated under an approved wellhead protection plan. Lands acquired with this appropriation must be from willing sellers and be identified by the Department of Health as targeted vulnerable lands for wellhead protection. Lands must be restored to permanent vegetative cover, but may be used for recreation and renewable energy if adequate protection of the drinking water aquifer is provided. A list of proposed acquisitions must be provided as part of the required work plan. Plant and seed materials must follow the Board of Water and Soil Resources' native vegetation establishment and enhancement guidelines. Income derived from the lands acquired with funds appropriated under this paragraph is exempt from Minnesota Statutes, section 116P.10, if used for additional wellhead protection as provided under this paragraph until adequate wellhead protection has been achieved, as determined by the commissioner of health. Any income earned after that must be returned to the environment and natural resources trust fund. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

Lincoln-Pipestone Rural Water (LPRW) System, a regional public drinking water system located in 10 counties in southwestern Minnesota, faces a number of water quality issues within its wellhead areas. These shallow, highly vulnerable aquifers are situated within intense agricultural areas; having row copping as the primary land use. Excess nutrients, particularly nitrates, and chemical applications can move quickly through the porous soil profiles contaminating drinking water supplies. Conservation practices to guard against agricultural contamination can help but most have severe limitations for drinking water protection. Thus, Fee Title ownership and permanent control over restoration and maintenance by the public water supplier is needed to best protect drinking water supplies.

LPRW applied for and received $1,500,000 in funding from the Environmental Natural Resource Trust Fund to identify and purchase parcels in Fee Title within three highly vulnerable wellhead areas. Parcels were ranked according to proximity to drinking water supply wells and in correlation to hydrogeological information documented within LPRW’s Wellhead Protection Plan. Individual landowners were engaged, according to their parcel ranking, to determine willingness to participate in a land transfer/purchase. Acquisition(s) would be through negotiated, voluntary or by direct purchases. Grant requirements stipulated that any land acquisition could not exceed the appraised value for that property. Any parcels acquired were to be restored to native grassland adhering to Minnesota Board of Water and Soil Resources Native Vegetation guidelines.

Several properties were investigated; with little success. Setbacks included lack of interest, absentee ownership or values exceeding project budget. A property containing approximately 200 acres located in the Verdi Wellfield, Lincoln County, became available through public auction. LPRW obtained this critical property through winning bid, having bid under appraised value. This parcel was taken out of agricultural production and restored to permanent grassland; providing long-term protection for highly vulnerable drinking water supplies.

PROJECT RESULTS USE AND DISSEMINATION

The Lincoln-Pipestone Rural Water (LPRW) System Land Acquisition for Wellhead Protection Project focused on targeting acquisition of land parcels residing within three (3) highly vulnerable wellhead protection areas. No material resources, tools or documents were generated for intended public use as a result of this project. However, information about this project has been published through various platforms including LPRW Annual Newsletters, LPRW website and presentations given to community service events. Three Annual Newsletters (2016, 2017 and 2018) were produced by LPRW and reference this project.

Project Completed: 06/30/2019 **FINAL REPORT**

Mesabi Trail Segment from Highway 135 to Town of Embarrass

Subd. 09e $1,200,000 TF

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Appropriation Language
$1,200,000 the second year is from the trust fund to the commissioner of natural resources for an agreement with the St. Louis and Lake Counties Regional Railroad Authority for engineering and construction of segments of the Mesabi Trail, totaling approximately six miles between Highway 135 and the town of Embarrass. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

The project as originally described in the ML 2016 Work Plan changed significantly. The wetlands encountered due to the fact that Lane 51 had settled into the Wildlife Management Area required construction of a 0.9 miles floating bridge. The Historic Embarrass River Bridge required rehabilitation. These improvements made it necessary to phase the project and apply for additional funding. The route from Soini Palo Tia intersection to Embarrass changed and the north terminus of this trail segment in Embarrass also changed. The total length of the revised Hwy 135 to Embarrass segment is 5.23 miles.

Phase 1 of this trail segment starts at the intersection of Highway 135 and the trail from the Giants Ridge Ski and Golf area and runs 3.33 miles east and north to the intersection of the Soini and Palo Tia Roads. The 3.33 miles includes the 0.9 miles floating bridge.

Phase 2 of this segment starts at the terminus of Phase 1, intersection of Soini and Palo Tia Roads, follows Palo Tia Rd. north to CR 21, and then east along on CR 21 and terminates at Sauna Rd. (CR 627) for a length of 1.9 miles. This will be the beginning of the next proposed segment of the trial from Sauna Road to Wahlsten Road (CR 26) which will be 9 miles in length. The construction of Phase 2 and the Sauna Road to Wahlsten Road CR 26 segment will be completed by future grants.

Construction of the segment from Darwin Meyers WMA to County Road 21 (Phase 2) is now being considered for 2019 LCCMR funding as seen within the approved draft WP dated November 29, 2018. In addition, construction of the proposed Embarrass to Kugler, trail segment also being considered for

2019 LCCMR funding as seen within the approved draft WP dated November 29, 2018. The bituminous paving, aggregate shouldering, erosion control, seeding, signage, floating bridge ramps, pavement handicap truncated domes, culvert extension for floating bridge construction, silt fence removal and ditch check construction were completed in August and September. The project is complete and will start the one year warranty period when the final project documents have been filed.

This segment of the trail offers a variety of geography and trail construction features. As you travel the trail you experience glacial boulders and ledge rock, to the old Lane 51 alignment, to the massive Darwin Meyer's Wildlife Management area on the 0.9 miles long floating bridge, and back to Lane 51 over the historic Embarrass River bridge. The WMA also has evidence of turn of the century farmsteads that were grubbed out of the wilderness by the early settlers.

PROJECT RESULTS USE AND DISSEMINATION

There are 180,000 trail users per year and 700 riders registered for the yearly "Mesabi Trail Tour." A group from the University of MN Duluth will be visiting the bridge in August 2019. We have also received calls from the Gitchi Gammi State Trail and the Lake Vermillion Trail requesting information on the bridge for use on their projects.

Progress of this trail development has been posted on multiple websites (noted below) and has drawn attention particularly for the design/construction of the floating bridge including: Club Mesabi (10,000 maps & web site), Iron Range Tourism (30,000 brochures & web site), MN Office of Tourism, Ampers Radio, Parks & Trails, Home & Away, other private magazines, Named by the Star Tribune as "Best of Minnesota" in year 2013, Named by Bicycle Magazine as" top 10 in the country", and Mesabitrail.com.

Project Completed: 06/30/2019 **FINAL REPORT**

Tower Historic Harbor Trail Connections

Subd. 09f $679,000 TF

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Appropriation Language
$679,000 the second year is from the trust fund to the commissioner of natural resources for an agreement with the city of Tower to construct recreational trails along the harbor in Tower and to connect to the Mesabi Trail. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

OVERALL PROJECT OUTCOME AND RESULTS

The Tower Historic Harbor Trail Connection in Tower, Minnesota, located in the East Two River and West Two River waterway to Lake Vermilion, is completed. A new pedestrian/biking trail was constructed around Tower's redeveloped harbor and routed under the highway bridge to enhance and connect to existing recreational and natural resource assets.

On the north side of the harbor trail 150 feet of trail length was identified to have wetland, waterway, and open water vegetation impacts. Helical piers were installed to support this area from future settlement and a floating walkway was installed at higher cost to avoid natural resource impacts. Soil conditions created challenges for the project. Less than ideal soils in the trail area on the harbor south side required helical piles in the trail areas where docks will be connected to the trail. Unsuitable subgrade material was removed and replaced to construct a suitable base for the trail. The trail under the bridge required a great deal of steel modification of the sheet piles and connections to get the proper grade and support of the trail.

Users will enjoy wetlands and unique environmental, historical and geological characteristics of the harbor, which early in Tower's history was a bustling commercial center. Interpretive historical signage was installed. Signage describes the harbor as a transportation hub and critical to the development of Lake Vermilion, and the role its waterway played in pioneering Minnesota's unique lake resort identity.

The connecting trail to the Mesabi Trail was rerouted in subsequent design updates to minimize wetland impacts along the shoreline. The revised trail connection will be more cost effective by constructing it with the LCCMR trailhead project, and better supports the goals in protecting and preserving Minnesota's natural resources while trail users enjoy the unique features of the area's geology, plants and wildlife.

PROJECT RESULTS USE AND DISSEMINATION

The public has been informed of this project through local news media coverage of each city council engineering update since 2016. The Lake Vermilion Chamber of Commerce has informed the public on their Facebook page. The page has over 1,000 fans and averages 40,000 contacts per week. The local Timberjay newspaper has informed the public of the project's completion and will provide information on the opportunities for recreational and educational aspects of the project.

Project Completed: 06/30/2019 **FINAL REPORT**