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

Date of Submission: 09/14/2016

Date of Next Status Update Report: 01/01/2018

Date of Work Plan Approval: 06/07/2017

Project Completion Date: 6/30/2019

Does this submission include an amendment request? __

PROJECT TITLE: Moose Calf Surveys and Monitoring

Project Manager: Dr. Mark A. Ditmer

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Location:Statewide

Total ENRTF Project Budget:		
	ENRTF Appropriation:	**$348,000**
	Amount Spent:	**$0**
	Balance:	**$348,000**

Legal Citation: M.L. 2017, Chp. 96, Sec. 2, Subd. 03j

Appropriation Language:
$348,000 the first year is from the trust fund to the Board of Regents of the University of Minnesota to assess the use of unmanned aerial vehicles in natural resource monitoring of moose populations and changes in ecosystems.

I. PROJECT TITLE: Non-invasive Moose Calf Surveys and Ecosystem Monitoring with Unmanned Aerial Vehicles

II. PROJECT STATEMENT:

Many species and ecosystems in Minnesota are facing a variety of threats ranging from changing patterns of natural disturbance and human land use to alteration in the timing and amount of precipitation. Broad-scale monitoring of populations and ecosystems is needed to improve conservation and management efforts; however, the required data are often expensive and time consuming to collect. Fortunately, technological advances in the fields of robotics and data processing are opening up new capabilities for natural resource biologists to better identify and understand when and where changes in management strategies are needed. Specifically, Unmanned Aerial Vehicles (UAVs) improve on current technologies and methodologies because they can access remote or difficult terrain, collect large amounts of data for lower cost with reduced risk for humans, and facilitate observations of species that are wary of human presence. The use of UAVs has tremendous potential to advance the quality, scale, and frequency of aerial imagery collection and will enable researchers to better monitor landscapes as they change through time and then understand how wildlife species respond to these changes.

The overall ***GOALS*** of the project are to develop UAV capabilities to **1) collect novel and important data on wildlife and ecosystems** using methods that **2) reduce or eliminate negative impacts on wildlife** by removing the need to drug and handle them. Specifically, we will attempt to develop novel UAV capabilities to home in on VHF signals from collared animals to collect fine-scale habitat use and behavior data without the need to approach or re-handle the individual. We will also develop survey methodologies to utilize UAVs equipped with infrared cameras to count and track the survival of the moose calves without ever needing to handle them; fixed-wing UAVs will fly at high altitudes to avoid affecting moose behavior. We will also produce easy to use software that works with a simple UAV system for the monitoring and analysis of imagery over threatened or sensitive ecosystems such as wetlands and areas experiencing encroaching invasive species. This project will directly lead to better management and conservation ***OUTCOMES*** for **i)** the MN moose population without needing to collar calves, and **ii)** better monitoring and management action for natural areas by providing an approach that could be adopted by natural resource managers to collect finer temporal scale and higher quality land-cover data, enable a fast and effective way to assess results of management actions, and provide a user friendly means of processing the imagery data. These outcomes will provide a set of tools that will help advance conservation in Minnesota and will eventually save taxpayer dollars while simultaneously reducing risk to biologists and pilots.

III. OVERALL PROJECT STATUS UPDATES:

Project Status as of 01/01/2018:

Project Status as of 07/01/2018:

Project Status as of 01/01/2019:

Project Status as of 07/01/2019:

Overall Project Outcomes and Results:

IV. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1: Non-invasive methods to monitor the MN moose population
Description:

For this activity, we will utilize UAVs with thermal imaging to better monitor the MN moose population without the need to re-handle adults or collar calves. We will utilize the collars already on adult moose in the Grand Portage Reservation. We will fly our UAV above the adults and utilize thermal imagery to determine the number and survivorship of calves. Data collected non-invasively on moose calves is critical because moose cannot be handled or collared in MN and the methods and technologies pioneered here may be later used in other areas of the state. This activity has two discrete components: **i) a lab component** where a graduate research

assistant in the Department of Computer Science & Engineering (CS&E) at the University of Minnesota will work with Dr. Volkan Isler and his lab to develop new UAV capabilities to home in on the location of a VHF signal and, **ii) a field component**, where a graduate research assistant in the Department of Fisheries, Wildlife, and Conservation Biology (FWCB) at the University of Minnesota working with Dr. Mark Ditmer and Dr. James Forester collect data on moose calves. The FWCB graduate research assistant will fly the UAV with thermal and regular (RGB) imagery over the locations of adult moose with GPS-collars and count the number of calves born, track their survival over time, and capture additional data about the habitat selected by the adult moose for giving birth and areas used after the calves are mobile. This data will be processed by the CS&E graduate research assistant and analyzed for ecological and biological interpretation by the FWCB graduate research assistant.

i) For this activity, Dr. Isler and the CS&E graduate research assistant will develop robot control software to autonomously home in on a signal source (i.e. the collar) of an adult moose. First, a multi-rotor aerial vehicle will be fitted with a small computer, a UHF radio signal receiver and a sound card. The characteristics of the signal and its relationship to the source-receiver geometry (in particular with respect to distance and bearing) will be investigated. Second, the flight controller will be modified so that it can take commands from an onboard computer. Third, a "home-in" behavior will be developed so that the UAV can approach the signal source. In ideal conditions, this could be achieved by following the gradient of the signal. However, preliminary tests indicated that due to obstacles such as trees as well as noise from the environment (including the rotors), signal strength is not a reliable indicator of distance. We will develop more sophisticated search behaviors which guarantee successful approach to the target. This capability will be demonstrated in field experiments using a collar and a multi-rotor vehicle near campus.

ii) Prior to developing survey methodologies for conducting UAV flights to collect data on moose calves, the FWCB graduate research assistant will obtain training on UAV flying during August or September of 2017. Following training, the FWCB graduate research assistant will first test out the capabilities of the UAV coupled with a thermal camera by doing field testing on the University of Minnesota's property during October of 2017. This testing will allow us to make any changes to the camera or UAV settings and determine the best altitude for collecting thermal data on large-bodied mammals. To collect data on moose calves, the FWCB graduate research assistant will fly the UAV over the locations of adult moose in the Grand Portage Reservation in northeastern MN, that were previously collared, after they have given birth (typically May through early June). The graduate student will work with the resident wildlife biology for the Grand Portage band, Dr. Seth Moore. We will know when an adult collared moose gave birth because moose based on an existing statistical model that identifies characteristic movement behavior that usually occurs just prior to giving birth. This specific movement, evident from GPS locations transmitted from the moose's GPS-collar via satellite to our computer, consists of a long distance movement away from the individual's usual home range, followed by relatively little movement for several days. Once the calving movement is identified, the FWCB graduate research assistant will fly the UAV to the location of the moose at the highest altitude that can be safely flown in the conditions that allows us to successfully capture thermal imagery for the moose and the calves. The Univ. of Minnesota has a Certificate of Authorization (2016-CSA-63-COA-R) provided by the Federal Aviation Administration that outlines all of the safety requirements and rules that all of our flights will adhere to. Along with the thermal imagery of the moose and the calves, the UAV will also collect regular aerial imagery of landscape using an RGB camera. Data from the cameras will be downloaded and stored on a Cloud-based system and later analyzed by the FWCB graduate research assistant to determine the habitat characteristics selected for by the adult moose for calving relative to the habitat in the surrounding area. During October and December of 2018, both the FWCB and CS&E graduate research assistants will test out the newly developed homing capabilities of the UAV using a similar VHF collar. During May through June of 2019, the same flights over moose in Grand Portage will be conducted by the FWCB graduate research assistant. The second season may involve alterations in methodologies to improve on the outcomes from Season 1 (2018).

Summary Budget Information for Activity 1:

ENRTF Budget: $ 192,667
Amount Spent: $ 0
Balance: $ 192,667

Outcome	Completion Date

1. Testing of UAV and thermal camera at captive animal facility to determine optimal settings for moose surveys.	11/01/2017
2. Conducting moose survey and habitat flights in Grand Portage collecting counts and survival data using thermal imagery. – Season 1.	07/01/2018
3. Alteration of UAS system to include the capability of tracking VHF collar and field tests with unused VHF collars on campus.	01/01/2019
4. Testing of newly engineered homing technology of VHF collars.	05/01/2019
5. Conducting moose survey and habitat flights in Grand Portage collecting counts and survival data using thermal imagery. – Season 2.	07/01/2019

Activity 1 Status as of 01/01/2018:

Activity 1 Status as of 07/01/2018:

Activity 1 Status as of 01/01/2019:

Activity 1 Status as of 07/01/2019:

Final Report Summary:

ACTIVITY 2:
Description: System to monitor and identify changes to sensitive ecosystems

We will utilize an existing UAV system, but develop a user friendly flight planning system that will maximize visual coverage, imagery collection, and post-processing capabilities to summarize collected data across space and through time. We will demonstrate this ability across several ecosystem types. The methods and software we develop for this activity can serve a wide array of ecological research questions, monitoring of the health of ecosystems, the effectiveness of management actions, the spread of disease or invasive species and potentially spills in waterways. This activity also has: **i) a lab component led by the Dr. Isler's graduate research assistant** that focuses on the development of the software and **ii) a field component, conducted by Dr. Forester's graduate research assistant**, to collect aerial imagery across a variety of ecosystems at the Cedar Creek Ecosystem Science Reserve (owned by the University of Minnesota).

i) The CS&E graduate research assistant will consider a number of trade-offs that need to be addressed to effectively use autonomous aerial vehicles in surveying and ecosystem monitoring tasks. The first one is the trade-off between coverage and resolution. Because an aerial vehicle has a downward looking camera, as the altitude of the vehicle increases, so does the camera footprint on the ground (i.e., the vehicle can cover larger areas by flying higher). However, this increased footprint comes at the expense of resolution (the number of pixels occupied by an object of interest in the image). Depending on the task and sensing requirements, the optimal altitude must be determined. Second, the amount of data collected by imaging sensors can easily overwhelm the storage and computation requirements of many systems. Most UAVs have limited storage and computation capabilities. Videos collected over time across multiple surveys can be hard to access and manage for users even after they are copied over to a workstation.

We will develop image processing software to summarize imagery collected in a single flight. This will be in the form of a 2.5 dimensional reconstruction of the environment. We will generate a mosaic corresponding to the (roughly flat) ground plane along with objects such as trees sticking out as convex polyhedral objects. Although existing software can mosaic aerial imagery, the programs usually fail when data are collected at low-altitudes. Therefore a new mosaic software will be developed. The map will be geotagged and aligned so that changes across time can be easily observed by going back and forth in time. We will demonstrate the effectiveness of the software by processing the imagery collected and stored from the UAV surveys conducted by the FWCB graduate research assistant at the Cedar Creek Ecosystem Science Reserve (CCESR). Time and resources permitting, we will investigate automated detection of major changes.

ii) The FWCB graduate research assistant will fly a UAV over areas of CCESR that experience ecosystem change through time. Based on where we have permission to fly transects, we will conduct case studies by collecting data over: 1) oak forests experiencing oak wilt, 2) fields where invasive plant species are spreading

(*Elymus repens*), and 3) wetlands where cattails are highly prevalent. We will capture imagery from our UAV system equipped with multiple sensors (RGB and thermal imagery cameras) of these areas during September through October 2017. We chose oak wilt because it is a serious concern in Minnesota. This disease is caused by the non-native fungus *Ceratocystis fagacearum*, and is responsible for killing large numbers of oaks annually in Minnesota. Our second case study, focused on capturing the prevalence and spread of *Elymus repens*, is relevant because it will test our ability to identify the spread of terrestrial invasive plants. Finally, with our third case study, we will test the ability of our platform to map the extent of aquatic invasive species; cattails are of particular interest because the removal of the invasive cattail species often requires large expenditures or intensive management efforts. Collectively, our demonstrations of how UAV's can be utilized to quickly determine the extent and spread of disease and invasive species will be of great use to natural resource managers and researchers. Flights and corresponding safety precautions will follow rules and regulations set forth in the Federal Aviation Administration's Certificate of Authorization granted to the University of Minnesota. The altitude of the flights is will vary for each example, but all will be below 400 feet above ground level and likely about 200-300 feet above ground level. We have been granted access to fly over these areas by the Associate Director (Dr. Forest Isbell) of CCESR.

The aerial imagery provided from these flights will be utilized by the CS&E graduate research assistant to develop the software and provide data to researchers working at CCESR who have an interest in these questions. The FWCB graduate research assistant will conduct more flights at CCESR during 2018 (July- September). We will work with CCESR staff after 2017 to determine if the areas of image collection should change during the following year to answer new questions and also to test our newly developed software with different aerial imagery.

Summary Budget Information for Activity 2:

ENRTF Budget: $ 155,333
Amount Spent: $ 0
Balance: $ 155,333

Outcome	Completion Date
1. UAV flights to collect data over different ecosystems in the Cedar Creek Ecosystem Science Reserve (CCESR).	12/01/2017
2. Development of capabilities for geo-referencing imagery, comparing changes in the images, and creating a user-friendly interface for the software designed to handle aerial imagery from flights.	07/01/2018
3. Second year of flights at CCESR during a slightly different time of year (and potentially over different area in CRESR) to collect more imagery and further test the software developed in Outcome 2.	09/01/2018

Activity 2 Status as of 01/01/2018:

Activity 2 Status as of 07/01/2018:

Activity 2 Status as of 01/01/2019:

Activity 2 Status as of 07/01/2019:

Final Report Summary:

V. DISSEMINATION:

Description:

Our development of technology and software, as well as our field methodologies and analyses of biological data, will result in several manuscripts written and submitted for publication in peer-reviewed journals. Findings will be presented at state and national wildlife and ecology conferences (e.g., the annual Minnesota Moose Meeting, state and national meetings of The Wildlife Society). All publications resulting from this project will be made available through the FWCB website or Open Access journal websites.

We expect that as our technologies and methodologies are proven in field tests, there will be a large amount of informal dissemination because we will be working closely with researchers at the University of Minnesota and the Grand Portage Band of the Lake Superior Chippewa. We also have a history of working with researchers and managers from the Department of Natural Resources, The Nature Conservancy, and the US Geological Survey. We have also been approached by Mike Schrage, the wildlife biologist for the Fond du Lac Band, about potential future collaboration and use of our UAV based on this proposal. We expect the MN Department of Natural Resources to have a strong interest in the UAV capabilities and specifically the effectiveness and data resulting from Activity 1 (moose calf surveys and VHF homing technologies). We hope that in the future, we can work closely with them to expand UAV moose surveys in other areas of the state and use UAVs to reduce the impact of studying other species of interest in MN. We will work openly with any of these groups to share our capabilities, software and equipment (as availability dictates), to ensure that our technological advancements and research papers reach a broad audience within their agencies.

Status as of 01/01/2018:

Status as of 07/01/2018:

Status as of 01/01/2019:

Status as of 07/01/2019:

Final Report Summary:

VI. PROJECT BUDGET SUMMARY:
A. Preliminary ENRTF Budget Overview:
***This section represents an overview of the preliminary budget at the start of the project. It will be reconciled with actual expenditures at the time of the final report.**

Budget Category	$ Amount	Overview Explanation
Personnel:	$ 281,014	1 project manager at 50%FTE for 2y; 1 engineer at 11%FTE for 2y; 1 wildlife biologist at 8%FTE for 2y; 1 graduate research assistant in CS&E at 50% FTE for 2y; 1 FWCB Master's student at 50% FTE for 2y.
Equipment/Tools/Supplies:	$9,642	Quadcopter UAV, Parts for both fixed-wing and quadcopter UAVs, and cameras/sensors
Capital Expenditures over $5,000:	$27,762	1 Fixed wing UAV w/ flight training ($13,870), computer supplies and ground materials for engineering work ($13,892).
Travel Expenses in MN:	$21,726	Travel to and between data gathering sites and truck rental .Food and housing for field work.
Other:	$7,856	Networking and Computer Services for storage to support UMN projects in the CS&E – such as large files provided by the aerial imagery
TOTAL ENRTF BUDGET:	**$348,000**	

Explanation of Use of Classified Staff:

Explanation of Capital Expenditures Greater Than $5,000:
The UAV and all of the additional equipment utilized for engineering purposes to enhance the UAV will continue to be used for similar projects and purposes by the Forester and Isler Labs at UMN for the life of the instrument. If other researchers, state or tribal agencies are interested in its use, we will provide it for them whenever possible. If the instrument is sold prior to its useful life, proceeds from the sale will be paid back to the Environment and Natural Resources Trust Fund.

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

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

B. Other Funds:

Source of Funds	$ Amount Proposed	$ Amount Spent	Use of Other Funds
Non-state			
National Science Foundation	$801,000	$0	Not Funded
State			
	$	$	
TOTAL OTHER FUNDS:	**$**	**$**	

VII. PROJECT STRATEGY:

A. Project Partners:

Partners receiving ENRTF funding

- Dr. Mark Ditmer, Research Specialist, Univ. of MN - Dept. of Fisheries, Wildlife and Conservation Biology, $60,549, Project leader – working with graduate students to collect and analyze the data
- Dr. James Forester, Assistant Professor, Univ. of MN - Dept. of Fisheries, Wildlife and Conservation Biology, $19,444 , Wildlife biologist – advising wildlife, ecological, and statistical aspects of the project
- Dr. Volkan Isler – Associate Professor, Univ. of MN - Dept. of Computer Science, $40,232, Engineer – assisting with the development of UAV technologies and imagery software

Partners NOT receiving ENRTF funding

- Dr. Joseph Knight, Associate Professor, Univ. of MN – Dept. of Forest Resources, consultant for remote sensing and aerial imagery classification procedures

B. Project Impact and Long-term Strategy:

Our interdisciplinary research team will develop and implement changes to UAV systems that will have lasting benefits for the ongoing monitoring of any wildlife species large enough to be VHF-tagged (e.g. bat species of concern in MN) and will enable managers to collect much finer resolution data in an autonomous fashion to monitor changes in sensitive ecosystems. Initially, our results will lead directly to better understanding of the conservation and management needs of moose and highlight the ability of our system to identify changes in sensitive ecosystems. Embracing the new capabilities that UAVs have to offer will provide better data, more cost-effective and safer research, while making research less invasive. Our work will not only research these methods but create easy to use systems that make UAV use and analysis of imagery accessible to researchers and managers. We will train and offer processing support for imagery as a means to get the systems more fully integrated into management and research.

We already have support from the UMN's Institute on the Environment who previously purchased a UAV system for our research on wildlife. The University of Minnesota currently has FAA approval for research in in nearly all areas within the state. Our research team has collaborated extensively with MN DNR researchers and managers in the past. We have access to previously collared animals (bear, bats, and moose), and strong working relationships with researchers throughout the state who have interest in this technology.

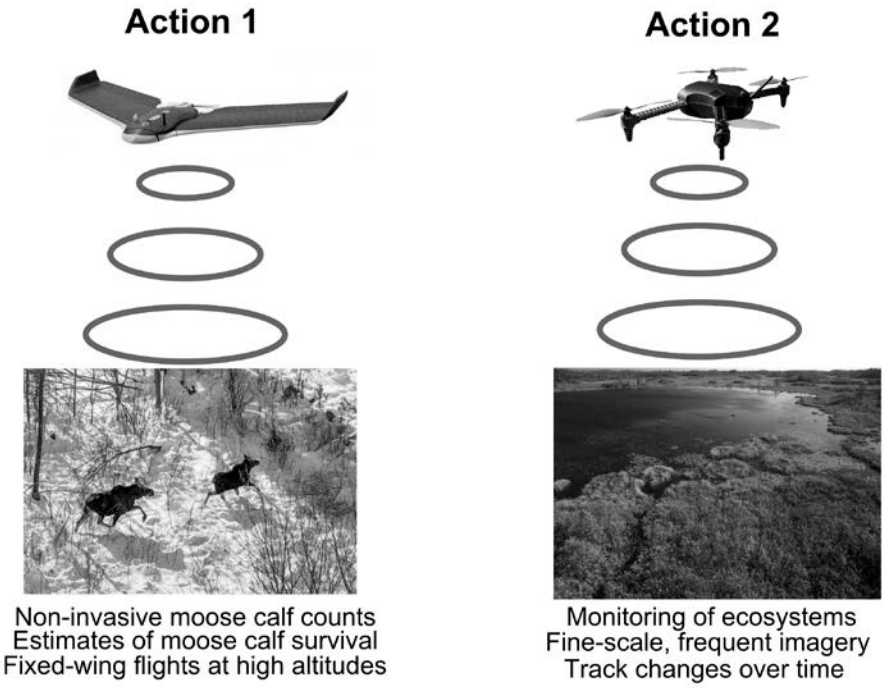
C. Funding History:

Funding Source and Use of Funds	Funding Timeframe	$ Amount
University of Minnesota's Institute on the Environment	12/2013-12/2014	$900
		$
		$

VIII. REPORTING REQUIREMENTS:

- **The project is for 2 years, will begin on 07/01/2017, and end on 06/30/2019.**
- **Periodic project status update reports will be submitted** *01/01* **and** *07/01* **of each year.**
- **A final report and associated products will be submitted between June 30 and August 15, 2019**.

IX. VISUAL COMPONENT or MAP(S):



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

Project Title: Moose Calf Surveys and Monitoring
Legal Citation: M.L. 2017, Chp. 96, Sec. 2, Subd. 03j
Project Manager: Mark Ditmer
Organization: *University of Minnesota*
M.L. 2017 ENRTF Appropriation: $ *348,000*
Project Length and Completion Date *: 2 Years, June 30, 2019*
Date of Report: 09/14/2017

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Activity 1 Budget	Amount Spent	Activity 1 Balance	Activity 2 Budget	Amount Spent	Activity 2 Balance	TOTAL BUDGET	TOTAL BALANCE
BUDGET ITEM	***Moose Calf Monitoring***			***Ecosystem Monitoring***				
Personnel (Wages and Benefits)	$140,507	$0	$140,507	$140,507	$0	$140,507	$281,014	$281,014
Project Manager (Mark Ditmer)- 50 %FTE each year for 2 years (77.6% salary ,22.4% fringe) - Total estimated at: $60,549								
Wildlife Biologist (James Forester) - 8% FTE each year for 2 years (66.3% salary, 33.7% Fringe). - Total estimated at: $19,444								
Engineer (Volkan Isler) - 11% FTE each year for 2 years (75% salary, 25% fringe). - Total estimated at: $40,232								
Master's Student - U of M - Dept. of Fisheries Wildlife and Conservation Biology: 50% FTE each year for 2 years: 49.7% salary, 8.7% fringe, 41.6% tuition). - Total estimated at: $66,925								
Grad Research Student - UMN Computer Science & Engineering - 50% FTE each year for 2 years (58% salary, 10% fringe, 32% tuition). - Total estimated at: $93,863								
Equipment/Tools/Supplies								
Unmanned aerial vehicle: quadcopter - selected through competitive bid				$1,500	$0	$1,500	$1,500	$1,500
Replacement and spare parts for either (quadcopter or fixed wing) unmanned aerial vehicle as needed	$800	$0	$800	$400	$0	$400	$1,200	$1,200

Thermal camera for sighting moose calves. A thermal camera will allow us to pick out their heat signature relative to surrounding cool spring ground and vegetation. A rugged camera that is used by several other studies that utilize thermal imagery to get imagery of wildlife from the air.	$3,200	$0	$3,200				$3,200	$3,200
High resolution multi-spectral camera for collecting data on vegetation beyond a typical RGB camera - (near-infrared, red-edge, red and green). This data will allow us to discern vegetation types and plant stress far better typical cameras.				$3,742	$0	$3,742	$3,742	$3,742
Capital Expenditures Over $5,000								
Fixed wing unmanned aerial vehicle: eBee by Sensefly (includes basic RGB camera and flight lessons). This unmanned aerial vehicle will be made available to other researchers and state agencies for future work.	$13,870	$0	$13,870				$13,870	$13,870
Computer supplies and materials to support the unmanned aerial vehicle flights such as ground workstation, onboard unmanned aerial vehicle micro-computer (nvidia jetson tx), which will send data to a laptop on the ground, batteries, cables, battery pack and stereo camera (zed from stereolabs). - $13,892	$9,892	$0	$9,892	$4,000	$0	$4,000	$13,892	$13,892
Travel expenses in Minnesota								
Travel to study areas by research assistants and project management staff and technicians: 1 UMN Fleet Truck Rental at $834 for 2.5 months a year for 2 years (4* $834 monthly rate)= $3,336 + (4 weeks* $274 weekly rate)= $1,096, Total vehicle rental = $4,432; Mileage for fleet vehicle @ $.037 per mile (UMN fleet rate) * 15,000 miles = $5,500; Personal vehcile use to get research assisstants and technicians to and from Cedar Creek (no vehicle rental) and project management to field sites (no vehicle rental) = $0.575 per mile (UMN personal vehicle rate) * 3120 miles = 1794. - $11,726	$10,470	$0	$10,470	$1,256	$0	$1,256	$11,726	$11,726
Room and board for field crew - 1 research assisstant + 2 field techs (2 yr of spring field seasons, 3 months/yr, lodging @ $1,000/mo = $6,000; meals(groceries) @ $800/mo (5 total months) = $4,000) - $10,000	$10,000	$0	$10,000	$0	$0	$0	$10,000	$10,000
Other								

Networking and Computer Services (U of M Computer Science and Engineering). Networking and computer charges are expenses charged to sponsored and non sponsored accounts to support the portion of networking and computer infrastructure used by sponsored and non sponsored research projects. In a formula found to be Uniform Guidance compliant by the Office of Treasury Accounting and Internal/External Sales and Sponsored Projects Administration, research specific computing is separated from general-purpose computing. The networking and computer support charge is based on FTEs and special projects that can be attributed to research-only projects. Project Engineer: (100% - 1 sum mo) 173 hrs * $2.26/hr = $392 * 2 years = ($784 total); Graduate research assistant (Computer Science & Engineering): (50% - 12 mos) 1,040 hrs * $3.40/hr = $3,536 * 2 years = ($7072 total). - $7,856	$3,928	$0	$3,928	$3,928	$0	$3,928	$7,856	$7,856
COLUMN TOTAL	**$192,667**	**$0**	**$192,667**	**$155,333**	**$0**	**$155,333**	**$348,000**	**$348,000**