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

Date of Report: May 30, 2017

Date of Next Status Update Report: January 1, 2018

Date of Work Plan Approval: 06/07/2017

Project Completion Date: June 30, 2019

Does this submission include an amendment request? __

PROJECT TITLE: Techniques for Water Storage Estimates in Central Minnesota

Project Manager: John L. Nieber

Organization: University of Minnesota

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Location: 100 mile swath of area lying between the Twin Cities Metro Area and Moorhead, MN.

Total ENRTF Project Budget:		
	ENRTF Appropriation:	**$250,000**
	Amount Spent:	**$0**
	Balance:	**$250,000**

Legal Citation: M.L. 2017, Chp. 96, Sec. 2, Subd. 04h

Appropriation Language:
$250,000 the first year is from the trust fund to the Board of Regents of the University of Minnesota to improve water storage estimates in groundwater, soil moisture, streams, lakes, and wetlands through integration of satellite monitoring and ground-based measurements in central Minnesota. This appropriation is available until June 30, 2020, by which time the project must be completed and final products delivered.

I. PROJECT TITLE: Techniques for Water Storage Estimates in Central Minnesota

II. PROJECT STATEMENT:

Minnesota is known as a land of plentiful water – but nobody can tell us how much water there is. **This project will answer the question 'How much water is there?'** It will improve our ability to monitor and quantify the amount of water stored in groundwater aquifers, soils, lakes, wetlands, and streams throughout Minnesota. Knowledge of total water storage is essential to sustainable management and wise use of water resources throughout the state. For purposes of this proposal, water storage is defined as the total water volume at a single point in time in the groundwater aquifers, soil, and surface waters. This differs from water availability, which is a smaller volume, because the total volume stored cannot fully be extracted or used.

Water storage affects the availability of the water for human use (industry, irrigation, power production, domestic), and the availability of the water needed to support ecosystems throughout the state. Currently water storage in aquifers can be estimated using the sparse network of MNDNR observation wells, water storage in soils can be estimated from the very sparse network of soil moisture monitoring sites, and water storage in lakes and wetlands can be estimated from water level measurements at MNDNR/citizen monitoring sites. To our knowledge, to date none of these available data have been used to make estimates of total water storage throughout the state. In fact, to this day, we do not have an estimate of the total water present within Minnesota's borders or even to estimate the storage within a select region of the state.

We will improve the ability to monitor water storage by developing a methodology that joins data from remote sensing and ground-based measurements. Vast amounts of data are available from NASA satellites, but these are underutilized for Minnesota. For our project there are three satellites of particular interest. One is the GRACE satellite which provides data that can be used to quantify the change in storage of all water sources over large, multi-state size areas. A second is the SMAP satellite that provides data on the moisture stored in the soil over intermediate size areas. The third is the World-View3 satellite that provides high resolution images for outlining water levels in lakes and wetlands. Of course, ground-truth data are needed for proper interpretation of satellite-based data, and this is where the network of ground-based monitoring data is essential. The ground-based data sources include observation wells, meteorological stations, lake water levels, stream gages, surface topography, soil maps, and geological maps.

Within the scope of this project the methodology for water storage estimation and mapping will be conducted for a 100 mile wide swath of area lying along a line between the Twin Cities Metro Area and Moorhead, MN.

The effort in this project should be compared to other ongoing efforts around the world to derive estimates of water storage on the Earth. There are several documented efforts by university researchers and government agency personnel within the U.S., Canada, and countries in Western Europe to derive estimates of storage of water within watersheds in groundwater and surface waters. Examples include the estimation of changes of water storage in the Central Valley of California, Eastern Canada, the Eastern U.S., the Middle East, the Indian Subcontinent, and Mongolia. These documented efforts show that the methods to be used within this project are viable and supported by the success of those other efforts.

III. OVERALL PROJECT STATUS UPDATES:

Project Status as of January 1, 2018:

Project Status as of July 1, 2018:

Project Status as of January 1, 2019:

Project Status as of July 1, 2019:

Overall Project Outcomes and Results:

IV. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1: Acquire archived data and select hydrologic models.
Description: Hydrologic and meteorological data will be acquired from archived records available from main sources including the Minnesota DNR (MNDNR), Minnesota Pollution Control Agency (MPCA), the Minnesota Department of Health (MDH), the Minnesota Department of Agriculture (MDA), the National Weather Service, the Minnesota Geological Survey (MGS), the State Climatology Office, and the U.S. Geological Survey (USGS). Data will include gauged streamflows, lake water levels, wetland water levels, soil moisture, groundwater levels, and meteorological variables. These data will be used in Activity 2 in establishing the reference levels of water storage for the years 2002 and 2015. We will also conduct an exhaustive search of reports involving analyses of water storage estimates in the area of study.

Within the project we will utilize satellite data in concert with ground-based data and water balance modeling to quantify the changes in water storage over space and time. The satellite data appropriate for this include the GRACE (Gravity Recovery and Climate Experiment) satellite, the SMOS (Soil Moisture and Ocean Salinity) satellite, the SMAP (Soil Moisture Active Passive) satellite, and the World View3 satellite. The satellite data will be acquired for all the area of study for the period 2002-2015 (the GRACE satellite was launched in 2002). These data will be processed, stored, and made ready for use in Activity 3.

A unique feature of this project is that data from different sources will be used to derive the estimates of water storage and estimates of changes in water storage. The data to be used represent different time scales and spatial scales. To combine all the data sources and make the most use of them for estimating water storage an appropriate hydrologic model will be used to fuse the information contained in the data. We will conduct a review of available models and will choose the one most appropriate for this project.

Summary Budget Information for Activity 1:

ENRTF Budget:	**$ 45,000**
Amount Spent:	**$ 0**
Balance:	**$ 45,000**

Outcome	Completion Date
1. Complete set of hydrologic, soil, geologic, groundwater level, meteorological, topographic data, and satellite data prepared for project use. All data will be archived and available on DVD. While used for this project, the summarized data will be useful to state and federal agencies, and to consultancies.	3/31/18
2. Model selected. Documentation of selection procedures and details of tests completed in making the model selection. The selected model will also be of use to consultancies, and for class instruction in hydrology courses.	6/30/18

Activity Status as of January 1, 2018:

Activity Status as of July 1, 2018:

Final Report Summary:

ACTIVITY 2: Develop estimates of baseline water storage for the study region.
Description: The data fusion methodology developed in this project is not intended to provide estimates of the absolute storage of water but instead to quantify the temporal change in water storage relative to a reference baseline. Therefore, a baseline of the water storage will be determined using available pointwise ground-based data. The baseline estimates will be derived for two dates, October 1, 2002 and October 1, 2015. The data to be used for this analysis will be acquired and processed in Activity 1. The storage estimates for these two reference points will then be used in Activity 3 to test the ability of the developed methodology to estimate the change in

stored water between those two dates. Brief descriptions of the approach for estimation of storage for the three domains, groundwater, soil, and surface water are given in the following paragraphs.

Groundwater storage. Estimation of groundwater storage will be based on water level measurements from MNDNR monitoring wells and also from monitoring wells operated by others. The MNDNR monitoring well network is the best available data because it is consistently monitored over time. Using the water level measurements at a given location, along with the porosity of the geologic formation at the location the volume stored is simply the product of the porosity times the saturated depth of the formation. The geological maps available from the MGS will be invaluable to deriving the depth and porosity information for the geological features.
These estimates will be at the point of the monitoring well and it will be necessary to integrate all the point measurements to get a total volume stored within an area. To achieve this methods of interpolation between points will be adopted, specifically methods that were developed in the mining industry, and applied in the soil science and groundwater hydrology disciplines.

Soil moisture storage. In estimating water storage in the soil profile it will be assumed that the depth of the soil profile is 5 feet. Where available, soil moisture measurements at point locations within the area of study will be used to estimate the average water stored in the soil profile. As with the groundwater storage estimation, the point estimates (measurements) of soil water storage will be interpolated between points to derive area average values so that total water stored in the landscape can be estimated.

Surface water storage. The storage of water on the land surface includes the water in lakes, wetlands and rivers. To estimate the storage it is necessary to have the water surface elevation within the given water body (lake, wetland, river), and also the bottom topography (or morphometry) of the water body. The morphometry of the lakes and wetlands within the study area will be acquired/derived within Activity 1. Water level data are available from the MNDNR and municipalities for selected lakes and wetlands within the study area.
Estimating the volume of water stored in rivers and streams will be made based on the use of stream gauging water surface elevations, and available (directly measured or else derived from LIDAR) channel cross-section data.

Summary Budget Information for Activity 2:

ENRTF Budget: $ 80,000
Amount Spent: $ 0
Balance: $ 80,000

Outcome	Completion Date
1. Estimates of baseline water storage for 2002 and 2015 for specific locations (i.e., point estimates) within the study area. The location specific estimates will be useful to the MNDNR in evaluating the effectiveness of current water management procedures.	9/30/18
2. Maps showing distribution of water storage estimates for surface water, soil moisture, and groundwater across the study area for 2002 and 2015. The mapped area-specific estimates of storage will be useful to the MNDNR in evaluating the effectiveness of current water management procedures.	12/31/18

Activity Status as of January 1, 2018:

Activity Status as of July 1, 2019:

Activity Status as of January 1, 2019:

Final Report Summary:

ACTIVITY 3: Estimate the changes in water storage over the period 2002 to 2015.

Description: Of main interest is to be able to detect changes in water storage in a watershed or in a region. If there exists a reference value of absolute storage to go along with the change in storage it is then possible to derive the changed absolute storage if so desired. The methodology developed in this project will be used to quantify changes in water storage at spatial scales and time scales of practical interest.

The methodology for quantify changes in water storage will be based on the application of satellite remote sensing data in conjunction with ground-based measurements and water balance modeling. Some details of the steps to be taken in this methodology are presented in the following paragraphs. First the information of the hydrologic water balance model will be presented followed by the presentation of the assimilation of the satellite data.

Hydrologic water balance model. Hydrologic water balance models are typically used to quantify the water balance of an area. Models are used for different scales, ranging from the field-scale (acres) to the river basin scale (hundreds of thousands of acres). In the methodology to be developed in this project a selected hydrologic water balance model will be used with the readily available ground-based data to simulate the water balance of a watershed, and satellite data (GRACE, SMOS/SMAP, World View3) will be used to constrain the results of the water balance to keep the model calculating the water balance accurately. The outcome of this combined modeling and data processing will be accurate measures of water storage change at the spatial scale of interest.

GRACE satellite data. The GRACE satellite was launched into orbit in a collaboration between the German space agency and NASA. The satellite quantifies changes in density of different areas of the Earth. Since the amount of water present in an area is dynamic, it is changes in water storage that will cause a change in the satellite signal as the satellite passes over an area. Other researchers have shown that one can monitor changes in water storage on watersheds as small as 10,000 square miles through a combination of preprocessed GRACE data and hydrologic water balance modeling supplemented with ground-based data.

SMOS and SMAP satellite data. To further improve the ability to constrain the water storage change estimates the project will involve the use of soil moisture data quantified using the SMOS and SMAP satellites. These satellites provide soil moisture estimates on the spatial scale of about 90 square miles.

WorldView3 satellite data. High resolution digital images of the Earth surface are now available through the World View satellite data. With these data it will be possible to quantify the elevation of the surface of open bodies of water, including lakes and wetlands. Changes in storage of these open bodies of water can be determined by using the satellite measure of water surface elevation and the morphometry of the water body.

The developed methodology will be tested by selecting a watershed within the studied area to assess the change in water storage. The estimate of water storage change between 2002 and 2015 available from the analysis of ground-based data in Activity 2 will be used as the reference, or correct value of storage change. The hydrologic model will be run with the input ground-based data and constrained by the satellite data to derive an estimation of the change in storage for the same period of time. If the methodology is sound the reference change and the change calculated by the water balance model should be within reasonable agreement.

Summary Budget Information for Activity 3:

ENRTF Budget: $ 125,000
Amount Spent: $ 0
Balance: $ 125,000

Outcome	Completion Date
1. Completed methodology for estimating the change in water storage within the study area. Documentation on the methodology. The developed methodology will be suitable for publication in the scientific literature and also a part of the graduate student's Ph.D. thesis.	12/31/18

2. Validation of water storage change estimation methodology. The result of the validated methodology will be suitable for publication in the scientific literature and also a part of the graduate student's Ph.D. thesis.	3/31/19
3. Final completion report. The analyses derived from this project will be valuable to state and federal agencies for the tracking of water storage changes in areas of concern within Minnesota.	6/30/19

Activity Status as of January 1, 2018:

Activity Status as of July 1, 2018:

Activity Status as of January 1, 2019:

Activity Status as of July 1, 2019:

Final Report Summary:

V. DISSEMINATION:
Description:
Project results will be disseminated through seminars conducted within Minnesota and at national and international meetings. Example meetings in Minnesota will include the Minnesota Water Resources Conference held each October in St. Paul, seminars for the Water Resources Sciences Graduate seminar program at the University of Minnesota, other seminars held within the University, a webinar for the UZIG (Unsaturated Zone Interest Group) held quarterly, and an annual presentation at the annual meeting for the regional project W-3188 ("Soil, Water, and Environmental Physics Across Scales", J.L. Nieber is the University representative) held in Las Vegas. Opportunities to present the results in a seminar format to the MnDNR will also be sought. Seminars at national/international meetings include the American Geophysical Union meeting held in San Francisco each December (travel to national/international meetings will be funded from a University funding source).

A project web site will be created on the network server at the University of Minnesota to provide the platform for illustrating the ongoing development of project outcomes. Included there will be visuals of maps, and information about databases created throughout the project. Data will be stored on this server so that interested parties will be able to acquire data compiled by the project activities. Also, reports/manuscripts prepared based on the results will be made available on the server.

Status as of January 1, 2018:

Status as of July 1, 2018:

Status as of January 1, 2019:

Status as of July 1, 2019:

Final Report Summary:

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

Budget Category	$ Amount	Overview Explanation
Personnel:	$ 195,160	The personnel working on the project from the University of Minnesota include research faculty J. Nieber, J. Baker, B. Wilson, T. Griffis, no funding required; graduate student (F. Lahoud,

		$79,416 (60% salary, 40% benefits), 0.5 FTE each year for two years); graduate student (TBD), meteorologist, $29,729, (60% salary, 40% benefits), 0.38 FTE for year 1; undergraduate students (TBD), $8,502 (100% salary), 0.5 FTE in summer of both years, and 0.2 FTE during school year of both years; research scientist (B. Hansen, Senior Scientist, $63,590 (73% salary, 27% benefits), 0.6 FTE in year 1 and 0.15 FTE in year 2; R. Kanivetsky, Hydrogeologist; $13,923 (67% salary, 33% benefits), 0.13 FTE for year 1.).
Professional/Technical/Service Contracts: Subcontract with the U.S.G.S.	$ 51,840	Mr. Jared Trost with the Water Resources Center of the U.S.G.S. located in Mounds View, who will work collaboratively with the University of Minnesota research group to accomplish the goals of Activity 1 and Activity 2.
Travel Expenses in MN:	$ 3,000	Travel within Minnesota is necessary to visit field sites where monitoring of groundwater, soil moisture, streamflow and weather is conducted. The project will not involve collection of field data, but acquisition of data collected by others. However, visiting field sites will be necessary to confirm documented local information about the field sites. Also, travel between St. Paul and Mounds View to conduct project meetings, or to travel within Minnesota to present research results.
Other:	$ 29,729	Summer salary for Tim Griffis received from a NSF/NASA grant that is directly related to the work being done in this project.
TOTAL ENRTF BUDGET:	**$ 250,000**	

Explanation of Use of Classified Staff: N/A

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

Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation: 3.15 FTE

Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation: 0.5 FTE

B. Other Funds: $29,729. Funding from a NSF/NASA grant for Tim Griffis which covers one month of his summer salary for both years. This is a match to the ENRTF funding for the project.

VII. PROJECT STRATEGY:

A. Project Partners:

A. Project Team/Partners

No ENRTF funding required:

John L. Nieber, Professor, Department of Bioproducts and Biosystems Engineeering, will serve as project principal investigator and will work on all aspects of the project.

Bruce Wilson, Professor, Department of Bioproducts and Biosystems Engineering, will work on the uncertainty analysis of water storage estimates.
Timothy Griffis, Professor, Department of Soil, Water and Climate, will conduct the research related to the water balance (hydrology) model. Dr. Griffis has summer support from a NSF/NASA grant to cover his part of the effort on the project.
John Baker, Professor and Research Leader, USDA-ARS, Department of Soil, Water and Climate, will work alongside Dr. Griffis on the application of the land surface/atmosphere interaction model to estimate soil moisture storage, aquifer recharge, and generation of surface runoff.

ENRTF funding required:
Jared Trost, Hydrologist, USGS, Mounds View, will work on the estimation of water storage in the aquifers of the study area.
Roman Kanivestsky, Adjunct Professor, Department of Bioproducts and Biosystems Engineering, will assist with the interpretation of quaternary and bedrock geologic data for the study area for the estimation of unsaturated zone and aquifer storage.
Brad Hansen, Senior Research Scientist, Department of Bioproducts and Biosystems Engineering, will work on the acquisition of monitoring well data, soil data and lake/wetland data for the study area. He will work on the estimation of water stored within the surface waters of the study area, and will also assist with the estimation of water storage in the subsurface.
Francisco Lahoud, Graduate Student, will work on the satellite data and combining it with ground-based data. He will be involved in acquisition of data, data processing, modeling, and data analysis.
Graduate student in meteorology (TBD), will work on the modeling of evapotranpiration and will also assist with the water balance (hydrology) model.
Undergraduate Research Assistant, will assist with acquisition of data and data processing, and preparation of visual-aids for presentation of results.

B. Project Impact and Long-term Strategy:
Quantification of water storage on the surface and in the subsurface across Minnesota is essential for sustainable management of water use and improvement of the quality of Minnesota water resources. The quantification of water storage will help to reduce the uncertainty about the state of water resources and reduce the potential for conflicts between competing users. It will also assist with accounting for the needs of adequate flows of water in streams and rivers for sustaining aquatic health. In early discussions with the MNDNR it was been established that a method for estimating changes in water storage, regionally and locally will be useful to the MNDNR water allocation planning activities. It is also expected that the methodology will be helpful to state and federal agencies in the forecasting of potential flooding as well as assessments of impacts of drought on available water supplies, and useful as well to agencies and consultancies in conducting water quality assessments. The scope of the current project is limited to a study of the mid-central region of the state. It is hoped that the methodology will be found valuable enough that additional funding will be available to expand the data-base and methodology to the entire state. In the long-term, but beyond the scope of the current project it is hoped to install the developed methodology, which will be data intensive and modeling intensive, on a server computer at the University of Minnesota, and made available to state agencies for installation on agency computers and use by state agency staff. If that happens the methodology will be taught to water resource managers within the agencies. It is also expected that the methodology will be taught to graduate students at the University of Minnesota.

C. Funding History: N/A

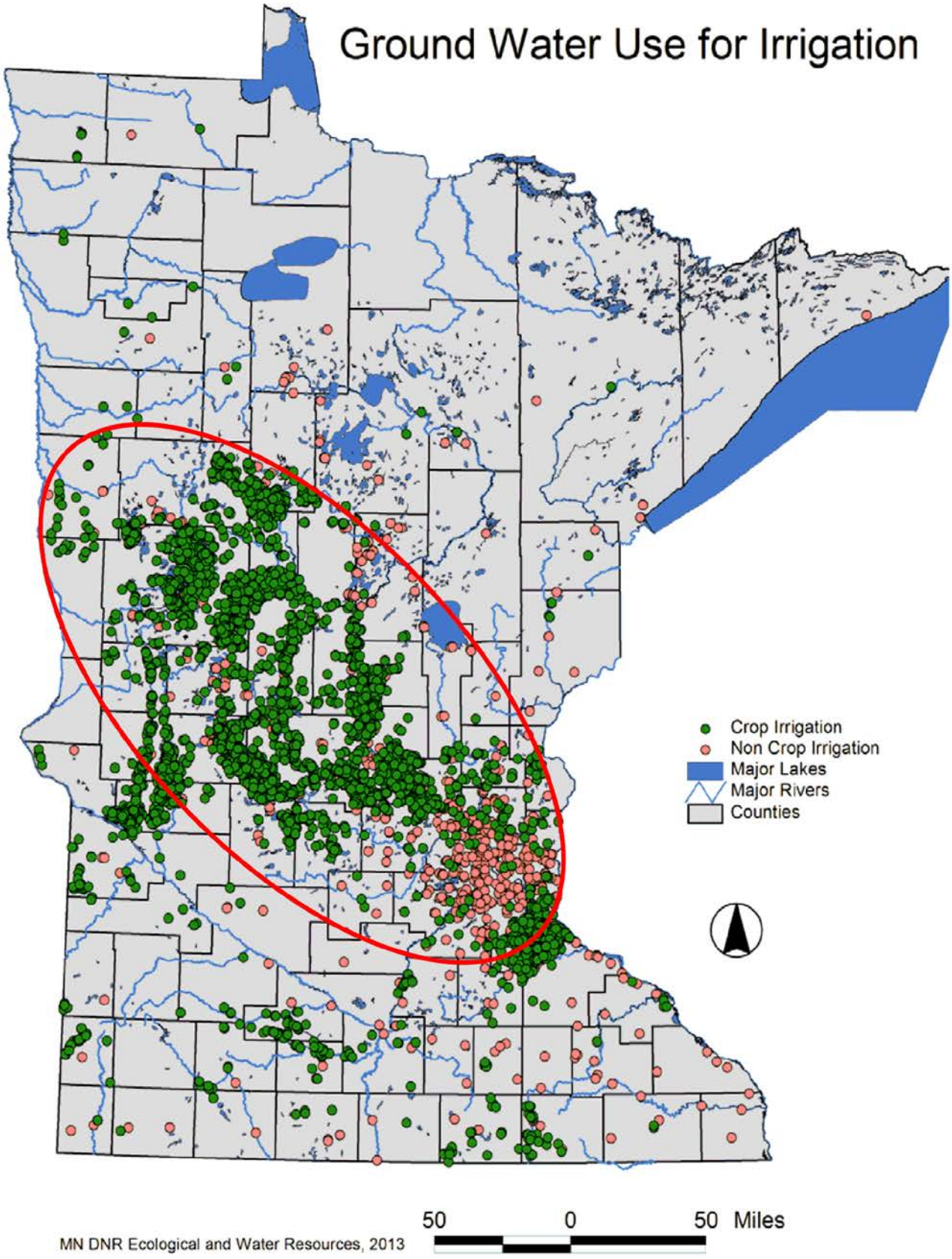
VIII. FEE TITLE ACQUISITION/CONSERVATION EASEMENT/RESTORATION REQUIREMENTS:

A. Parcel List: N/A

B. Acquisition/Restoration Information: N/A

IX. VISUAL COMPONENT or MAP(S):
See map on the next page for the study area.

Area for proposed study for project O18-A.



X. RESEARCH ADDENDUM:

XI. REPORTING REQUIREMENTS:
Periodic work plan status update reports will be submitted no later than January 1, 2018, July 1, 2018, January 1, 2019, and July 1, 2019. A final report and associated products will be submitted between June 30 and August 15, 2019.

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

Project Title: Techniques for Water Storage Estimates in Central Minnesota
Legal Citation: M.L. 2017, Chp. 96, Sec. 2, Subd. 04h
Project Manager: John L. Nieber
Organization: University of Minnesota
M.L. 2017 ENRTF Appropriation: $250,000
Project Length and Completion Date: 2 Years, June 30, 2019
Date of Report: May 30, 2017

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Activity 1 Budget	Amount Spent	Activity 1 Balance	Activity 2 Budget	Amount Spent	Activity 2 Balance	Activity 3 Budget	Amount Spent	Activity 3 Balance	TOTAL BUDGET	TOTAL BALANCE
BUDGET ITEM	***Fill in your activity title here.***			***Fill in your activity title here.***			***Fill in your activity title here.***				
Personnel (Wages and Benefits)	$27,948	$0	$27,948	$42,712		$42,712	$124,500		$124,500	$195,160	$195,160
Roman Kanivetsky, Hydrogeologist: $13,923 (67% salary, 33% benefits); 0.13 FTE for first year.											
Brad Hansen: Senior Scientist; $63,590 (73% salary, 27% benefits); 0.6 FTE in year 1 and 0.15 FTE in year 2											
Francisco Lahoud, Graduate Student: $79,416 (60% salary, 40% benefits); 0.5 FTE each year for two years.											
TBD, Graduate Student, Meteorologist: $29,729 (60% salary, 40% benefits); 0.38 FTE for year 1 of the project.											
TBD, Undergraduate assistant: $8,502 (100% salary); 0.5 FTE in summer of both years, and 0.2 FTE during school year of both years.											
Professional/Technical/Service Contracts	$15,552		$15,552	$36,288		$36,288	$0		$0	$51,840	$51,840
Jared Trost, Hydrogeologist, Water Resources Center, U.S.G.S., Mounds View: $51,840 (75% salary, 25% benefits); 0.0.35 FTE for first year and 0.15 FTE for second year. Jared will assist with acquisition of data on monitoring wells and interpretation of geologic formations, and he will work on the estimates of storage in the subsurface.											
Travel expenses in Minnesota	$1,500		$1,500	$1,000		$1,000	$500		$500	$3,000	$3,000
Travel will be conducted to visit field sites for locations of monitoring wells, soil moisture measurements, and streamflow measurements. Also travel to project meetings between St. Paul and Mounds View.	**$45,000**		**$45,000**	**$80,000**		**$80,000**	**$125,000**		**$125,000**	**$250,000**	**$250,000**