M.L. 2015 Project Abstract
For the Period Ending December 31, 2019

PROJECT TITLE: Southeast Minnesota Subsurface Drainage Impacts on Groundwater Recharge
PROJECT MANAGER: Erik A. Smith
AFFILIATION: U.S. Geological Survey
MAILING ADDRESS: 2280 Woodale Drive
CITY/STATE/ZIP: Mounds View, MN 55112
PHONE: (612) 386-1558
E-MAIL: easmith@usgs.gov
WEBSITE: https://www.usgs.gov/centers/umid-water
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: M.L. 2015, Chp. 76, Sec. 2, Subd. 04f as extended by M.L. 2019, First Special Session, Chp. 4, Art. 2, Sec. 2, Subd. 19

APPROPRIATION AMOUNT: $488,000.00
AMOUNT SPENT: $487,855.00
AMOUNT REMAINING: $145.00

Sound bite of Project Outcomes and Results

A two-year study of potential groundwater recharge rates across three monitoring plots found a statistically significant difference between actively drained agricultural fields and areas without drainage. Overall, drained areas had a lower potential groundwater recharge rate compared to the nondrained areas, as simulated through three different recharge estimate techniques.

Overall Project Outcome and Results

This project investigated the effect of agricultural subsurface drainage on groundwater recharge rates at three different monitoring sites in southeastern Minnesota. The monitoring plots included two plots with an actively drained area, and a third undrained monitoring plot. Multiple piezometer transects were set up across these plots to characterize the unsaturated zone and shallow water-table flow using pressure transducers and soil moisture probes. From these piezometers, potential groundwater recharge rates were derived using three different methods: the RISE Water-Table Fluctuation (WTF) method, the DRAINMOD model, and the USGS Soil-Water-Balance (SWB) model. The entire study, with details on the data collection methods, was summarized in a U.S. Geological Survey (USGS) Scientific Investigations Report (SIR): https://doi.org/10.3133/sir20205006). In summary, the primary method for estimating potential groundwater recharge rates was the RISE WTF method, with a mean recharge rate of 1.55 and 1.94 inches per year, respectively, for water years 2017 and 2018. When looking at recharge based on distance from the drain in the drained area, the subsurface drain did not affect potential recharge, although other factors such as variability in piezometer screen depths, piezometer construction, and specific yield variability could not be eliminated. Overall, there was a lack of agreement between the RISE WTF-based recharge estimates and the other two methods. These results were not remarkable, considering the fundamental differences in their methodologies. However, all three methods did show a fundamental difference between piezometers within the drained area and piezometers outside the drained area, including the third undrained monitoring plot. The drained areas show a lower overall potential groundwater recharge compared to the nondrained areas for all three estimates. These results require further studies for verification, but this study demonstrated that differences did exist between areas of an agricultural field with drainage and areas of a field without drainage.

Project Results Use and Dissemination

Two publications and three data releases have resulted from this project:

1. A U.S. Geological Survey Scientific Investigations Report, summarizing the data collection methods, data summaries, details on the groundwater recharge modeling, and full analysis of the study results. The landing page and a pdf version of this report can be found at https://doi.org/10.3133/sir20205006:

Smith, E.A., and Berg, Andrew M., 2020, Potential groundwater recharge rates for two subsurface-drained agricultural fields, Southeastern Minnesota, 2016–18: U.S. Geological Survey Scientific Investigations Report 2020–5006, 54 p.

2. Minnesota Groundwater Association white paper, published in 2018, with Erik Smith (project manager) as the primary author. This white paper discussed the relations of drain tiles and groundwater resources. The white paper also discussed the historical significance of agricultural drainage practices, the recognized positive benefits and potential negative consequences of agricultural drainage practices, and the gaps in understanding of the connections between agricultural drainage and groundwater resources. The landing page and a pdf version of this report can be found at: https://pubs.er.usgs.gov/publication/70204196

3. Three data releases, directly related to the models used for this study, have been published. Citations and web links to the landing pages:
   a) Smith, E.A., 2020, DRAINMOD simulations for two agricultural drainage sites in western Fillmore County, southeastern Minnesota: U.S. Geological Survey data release, https://doi.org/10.5066/P987N30U.
   b) Smith, E.A., 2020, Soil-Water Balance (SWB) model datasets used to estimate recharge for southeastern Minnesota, 2014-2018: U.S. Geological Survey data release, https://doi.org/10.5066/P90N4AWG.
   c) Smith, E.A., 2020, Potential groundwater recharge estimates based on a groundwater rise analysis technique for two agricultural sites in southeastern Minnesota, 2016-2018: U.S. Geological Survey data release, https://doi.org/10.5066/P94LMOPP.

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

Date of Report: February 28, 2019

Final Report

Date of Work Plan Approval: June 11, 2015

Project Completion Date: December 31, 2019

Does this submission include an amendment request? No

PROJECT TITLE: Southeast Minnesota Subsurface Drainage Impacts on Groundwater Recharge

Project Manager: Erik A. Smith

Organization: U.S. Geological Survey

Mailing Address: 2280 Woodale Drive

City/State/Zip Code: Mounds View, MN 55112

Telephone Number: (612) 386-1558

Email Address: easmith@usgs.gov

Web Address: http://mn.water.usgs.gov/index.html

Location: Goodhue, Wabasha, Dodge, Olmsted, Winona, Mower, Fillmore or Houston counties

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Total ENRTF Project Budget:	**ENRTF Appropriation:**	**$488,000.00**
	Amount Spent:	**$487,855.00**
	Balance:	**$ 145.00**

Legal Citation: M.L. 2015, Chp. 76, Sec. 2, Subd. 04f as extended by M.L. 2019, First Special Session, Chp. 4, Art. 2, Sec. 2, Subd. 19

Appropriation Language:
$488,000 the first year is from the trust fund to the commissioner of natural resources for an agreement with the United States Geological Survey to assess the relationship between agricultural drainage and water flow within the unique karst geology of southeast Minnesota to characterize the potential impacts of drainage on groundwater recharge and groundwater sustainability in the region. This appropriation is not subject to the requirements in 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.

Carryforward; Extension (a) The availability of the appropriations for the following projects is extended to June 30, 2020: (3) Laws 2015, chapter 76, section 2, subdivision 4, paragraph (f), Southeast Minnesota Subsurface Drainage Impacts on Groundwater Recharge;

I. PROJECT TITLE: Southeast Minnesota Subsurface Drainage Impacts on Groundwater Recharge

II. PROJECT STATEMENT:

Executive Summary: Artificial subsurface drainage is being increasingly utilized on agricultural land in southeast Minnesota. This region is underlain by thinner glacial deposits than are found in the historically drained areas of the State. Due to these thinner deposits, drainage in southeast Minnesota may have a greater impact on the amount of water that recharges underlying bedrock aquifers, a critical resource to many communities in the region. This project will collect field data and use numerical models to assess the potential implications of artificial subsurface drainage on groundwater resources in the region. Results from the field studies and modelling will be extrapolated to produce updated groundwater recharge estimates for southeast Minnesota. Project findings will inform future water resources policy decisions in the region.

Project outcomes:

- Hydrological & meteorological data at three field sites (two drained, one undrained control)
- Field-scale water budgets and groundwater recharge estimates for three field sites
- Numerical models to transfer field study results to areas having different landscape characteristics
- Updated recharge estimates throughout southeast Minnesota

Artificial subsurface drainage is the practice of installing networks of perforated conduit below the land surface to drain the upper soil horizons of excess moisture which can inhibit crop yields and field activities. In Minnesota, this practice has historically been implemented in the south-central and western portions of the state, which are regions underlain primarily by thick impermeable glacial sediments. Due to the impermeable nature of these glacial sediments, it has often been assumed that the natural pre-drained rate of groundwater recharge was so minimal that the net effect of the installation of subsurface drainage networks had a negligible impact on it. Recently, however, due to shifts in climatic and economic factors, installation of subsurface drainage networks has begun to increase in southeast Minnesota. Unlike historically drained regions of the state, much of southeast Minnesota is underlain by thin glacial sediments, often less than 25 feet thick, draped over permeable karstic bedrock aquifers that are the source of much of the region's municipal, domestic, industrial, and agricultural water supplies. Given consideration of the decreased thickness of the glacial sediments overlaying these bedrock aquifers in southeast Minnesota, the prevailing assumption that subsurface drainage has a minimal effect on groundwater recharge may be inappropriate for this portion of the state. Widespread adoption of the practice in this region could alter the amount of water that permeates past the thin glacial sediments ultimately recharging the regions aquifers.

Beyond the potential effects on groundwater recharge, numerous studies have established that subsurface drainage networks significantly alter the timing and magnitudes of flows to local streams. By design, subsurface drainage expedites the movement of water from fields to nearby surface water bodies. The balance between stream water sourced from overland runoff and groundwater is also likely altered by subsurface drainage in a watershed. For example, possible alterations in the amount of groundwater discharged to regional streams through surficial and bedrock aquifers could occur. Furthermore, research has also shown that subsurface drain flow can increase the loading of agricultural chemicals such as nutrients and pesticides to surface waters. Collectively, these potential shifts in flow dynamics, sources of flows, and chemical loading to surface waters associated with increased subsurface drainage could impact geomorphological processes, water quality, and stream ecosystems.

Through field data collection, analysis, and process based numerical modelling this study will assess the impact of subsurface drainage on field-scale water budgets and groundwater recharge in southeast Minnesota. Greater insights on the potential impacts of subsurface drainage on groundwater recharge are necessary to plan for long-term water sustainability within regions like southeast Minnesota. Results of this study will advance scientific understanding of comprehensive water budgets for agricultural fields with subsurface drainage, specifically for areas with similar geology to southeast Minnesota. This study will also provide important information for agricultural producers to design water management infrastructure that both adequately drains for crop production yet provides important ecosystem services such as groundwater recharge. Accurate quantification of potential groundwater recharge through this study will also benefit regional groundwater flow models, as recharge is an important calibration parameter for these models. Because accurate field estimates of potential recharge rates are lacking, current model analyses must largely rely on inferred data or the results of other modeling studies.

This proposed study will produce regional maps of recharge differences between the study's results and the statewide recharge estimates available at a one-kilometer grid spacing. The regional maps will be produced by delineating areas of southeast Minnesota with similar site characteristics to the study's fields. The study's findings applied to these maps will illustrate the potential effects of subsurface drainage on groundwater recharge under various build-out scenarios. The proposed study will increase the Minnesota Department of Natural Resources understanding of groundwater recharge, resulting in more sustainable groundwater appropriations in the affected areas. The Minnesota Pollution Control Agency and the Minnesota Department of Health will benefit from the study by gaining a better understanding of how changes in the water budget could affect the flux of agricultural chemicals to the bedrock aquifers. The Minnesota Department of Agriculture and the Minnesota Board of Water and Soil Resources will benefit from the study by reconsidering recommended agricultural best management practices (BMPs) if there is a net decrease in groundwater recharge by subsurface drainage. Generally, the study results will provide the colleges, universities, and the scientific community with basic knowledge important to educating the public on basic science.

Scope and Objective: This project will establish two separate field-scale monitoring sites in agricultural fields with subsurface drains in southeast Minnesota. A third field-scale monitoring site would be established in a non-drained agricultural field as a control. Study sites will be selected in areas with a shallow depth to bedrock and low surface slope to limit surface runoff. Other considerations will include choosing fields with similar agricultural practices (for example, tillage practices, nutrient management, and crop rotation), landscape characteristics, and include no supplemental irrigation. The overall goal for each of the three study sites is to quantify the field-scale water budget. A comprehensive water budget requires a full quantification of the water balance in the soil, where any change in the water storage in the soil can be quantified by the following:

$$\Delta S = (P + I + U) - (ET + PR + D + R_o),$$

where P represents the total precipitation across the monitoring site, I is irrigation, U is the upflux or capillary rise of water from shallow groundwater, ET is evapotranspiration, PR is deep infiltration or potential groundwater recharge, D is subsurface drainage, and R_o is surface runoff. By choosing a site with low surface slope, R_o will be limited or completely eliminated (depending on the site). For inputs other than U, P will be measured at each site and I will be zero. ET will be quantified for each study area by a Penman-Monteith or similar calculation. D will be measured by monitoring drainage outflow for one or more tiles at each field site, and using DRAINMOD or a similar modelling program to estimate subsurface drainage for the entire field site (modelling component will be part of Activity 2). Depending on the characteristics of the field sites, a smaller isolated plot within the field might be used in lieu of the entire field to limit poorly defined inputs or outputs. All aspects of the controlled study area will be quantified and compared against the water budgets of the other sites. Furthermore, comparisons will be made against the water budgets from another study being conducted by the University of Minnesota at two sites in southwestern Minnesota.

The overall goal of the project is to characterize and measure the water budgets for these three agricultural fields. Quantification of the effects of subsurface drainage on the flowpaths of water at the field scale will lend insight to the potential effects that subsurface drainage may have on groundwater recharge for the region. The results of the field study will be extrapolated to portions of southeast Minnesota with similar landscape characteristics to quantify the amount of recharge that could be diverted from regional aquifers under various subsurface drainage regimes. Study results will also be compared to the statewide recharge estimates at a one-kilometer grid spacing, available in early 2015, by the U.S. Geological Survey in cooperation with the Minnesota Pollution Control Agency.

III. OVERALL PROJECT STATUS UPDATES:

Project Status as of January 1, 2016:

For Activity 1, project personnel scouted for appropriate field sites. Early in the effort, the focus was on working with SWCDs from several different counties as well as contacting pertinent personnel in the various State agencies for assistance to find appropriate sites. Several fields were identified, but did not meet the criteria of the study. In order to find an appropriate site, the next step was to utilize ArcGIS to identify appropriate landowners based on the field characteristics necessary for the study and sent out letters requesting participation. As of early November, the appropriate farmers were identified but left little time between harvest and the time when poor field conditions set in. Also, late in the process, an agricultural producer backed out of the study due to unforeseen circumstances beyond the project and could not participate any longer. At the first drained site still secured, some shallow piezometers were attempted, but due to poor weather conditions, were unable to complete the piezometer network.

For Activity 2, no progress was made during this reporting period and none was scheduled.

For Activity 3, no progress was made during this reporting period and none was scheduled.

Amendment Request (12/14/2015)

In summary, this amendment request is to change work plan deadlines, add missing project status/activity status update lines, change interim project deliverables to reflect shifted field seasons, and to shift costs between the professional contracts listed on the budget.

The change in work plan deadlines includes a shift towards collecting the field data in 2017 and 2018, rather than 2016 and 2017. As explained briefly in the project status update for January 1, 2016, one of the two key agricultural producers dropped out of participation late in the process due to circumstances beyond the project. This producer was to provide both a drained and undrained site, so with these delays and in the interest of collecting two complete field seasons of data, the data collection will be pushed back to allow for more time to get new cooperators for the second drained site and one undrained site.

The missing project status/activity status update lines adds lines to reflect the new date in the appropriation bill of June 30, 2019, providing one more project/activity status update on January 1, 2019. All of the interim project deliverables have been pushed back accordingly, but the final deadline as listed in the appropriation is the same at June 30, 2019.

The budgetary change for professional contracts is mainly an increase in the amount allotted for agricultural producers. The original agreement was to pay each participating agricultural producer a sum of $1,000 per year per participating field for a total of $6,000 for the two years (3 field sites, 2 years = 3 * 2 * $1,000 = $6,000). However, as discovered during the search for sites, most if not all agricultural producers did not find this sum adequate so the new total per field per participating year is $2,250, for a total of $13,500 for the two years (3 field sites, 2 years = 3 * 2 * $2,250 = $13,500). The extra costs, based on interviews with several agricultural producers, not only will help to cover the loss in yields and area of the field taken out of production, but also the inconvenience and interruption of the study to their regular operations.

In order to pay for the higher costs for agricultural producer participation, the shift in costs for the project mainly reflects three minor changes. The first change includes less allotment for SWCD participation, as the SWCDs were to help manage the agricultural producer relationships and assist in find participating agricultural producers, but it is anticipated that there will be less direct participation by SWCDs. The second change is a shift in the cost of the final Scientific Investigations Report (SIR) from $10,000 to $5,000.

Amendment Approved by LCCMR: 12/23/2015

Project Status as of July 1, 2016:

For Activity 1, appropriate field locations have been secured for the overall project: two drained sites and one undrained site. For these individual sites, the project will work with two separate landowners (one site has both the undrained and drained field site in different portions of the same property, all owned by the same landowner). At the site with only a drained site, which is located approximately 2 miles southwest of Ostrander, Minnesota, installation of the field piezometer began in mid-April 2016 and was completed in mid-June 2016. At the second site, which is located 5 miles south of Ostrander, Minnesota, installation of the boundary piezometers around the undrained field site was completed in mid-June. The second site will also have a drained field site, but installation cannot occur until later this fall after the corn harvest.

For Activity 2, no progress was made during this reporting period and none was scheduled.

For Activity 3, no progress was made during this reporting period and none was scheduled.

Project Status as of January 1, 2017:

For Activity 1, a total of three different piezometer nests now exist in the agricultural field at the first field site. For the second field site, all piezometer installations were completed by the end of November 2016, including two piezometer nests in the drained field, a piezometer nest in the undrained field, and additional piezometers along the boundaries of both the two drained field sites and one undrained field site.

For Activity 2, no progress was made during this reporting period and none was scheduled.

For Activity 3, no progress was made during this reporting period and none was scheduled.

Amendment Request (12/31/2016)

In summary, this amendment request is to shift costs between the professional contracts listed on the budget, equipment costs, and personnel costs.

The budgetary change for professional contracts includes a final allotment adjustment for each of the two cooperating producers. Each will receive approximately $2,500 per year for two years (2 producers, 2 years = 2 * 2 * $2,547.50 = $10,190). Without the assistance of any SWCDs in the process, the USGS team developed an approach for finding cooperators. However, a verification of the in-field subsurface drainage is required by using an excavation company to expose the subsurface drainage lines in each of the two drained sites and also for the installation of the drain flow meters (total cost: $2,033). Other changes in professional services include working with the Minnesota Geological Survey for professional coring services to describe four complete cores from each of the two drained fields (total cost: $4,178). Finally, a slight change in the groundwater network contract (for the reference piezometers) will increase the cost from $34,400 to $36,000.

For equipment costs, cost savings are realized by purchasing less expensive pressure transducers because more piezometers/transducers are required for the study (decrease from $66,300 to $54,787); however, these new transducers due require more processing, so increased personnel costs are included for these new transducers in addition to the new piezometers added on to the study (increase from $131,200 to $144,447). Also, more costs are shifted to the project chief and hydrologic technician with the departure of the GS-11 hydrologist from the USGS. Finally, travel costs will decrease due to both the departure of the hydrologist (who would have been a part of the field trips) and a decrease in the number of field trips necessary for downloading the new type of pressure transducers (decrease from $19,200 to $15,465).

Amendment Approved by LCCMR: 1/4/2017

Project Status as of July 1, 2017:

For Activity 1, the overall project goal to install and outfit all field equipment by spring 2017 was realized.

For Activity 2, data compilation started with the first round of data downloads, and the initial processing of water level information, for a subset of the overall piezometer network.

For Activity 3, no progress was made during this reporting period and none was scheduled.

Amendment Request (7/1/2017)

Jared Trost is the new project manager for this project, also updating his new contact information.

Amendment Approved by LCCMR: 7/10/2017

Project Status as of January 1, 2018:

For Activity 1, all major installs were completed by the end of calendar year 2016 with some minor changes in 2017 for the major data collection sites. Due to some delays with USGS billing, many of the purchases, travel, and salary associated with Activity 1 will be charged in the next reporting cycle.

For Activity 2, the first year of data collection was processed under the Groundwater Network with further updates coming in the next couple of months.

For Activity 3, no progress was made during this reporting period except for the report's introductory section and background largely completed.

Project Status as of July 1, 2018:

For Activity 1, no more major installs or refurbishments of the sites. Currently, the major remaining activity is the final data collection for the remainder of 2018 and removing all equipment and piezometers from the field sites.

For Activity 2, the first year of all data collection, in addition to the Groundwater Network, through spring of 2018. Additionally, some of the preliminary recharge estimates have been characterized for 2017.

For Activity 3, minor activity took place due to parallel work on the Minnesota Ground Water Association white on agricultural drainage and groundwater.

Amendment Request (6/29/2018)

Erik Smith has returned as the active project manager for this project, with revised contact information.

The following budget items have been revised for this project report and budget spreadsheet: the excavation company costs, Geoprobe costs, and coring costs reflect revised cost estimates. Also, some of the removal costs for all the drainage sites (for example, piezometers, Agridrain, soil moisture probes) have been factored into the appropriate categories, such as the Geoprobe costs and excavation company costs.

The most significant set of changes for this amendment includes shifts in travel expenses, salary, and the groundwater network contract. Originally, the equipment planned for the project was more expensive and would require more frequent trips for retrieving data and calibrating instruments. We shifted to less expensive equipment, which has been accounted for in previous amendment requests and resulted in more data being collected for the benefit of the project. However, this decision resulted in several changes, which explains the money that has been transferred between categories for this amendment request.

First, travel costs have been subsequently decreased with this alternative equipment. However, with more data being collected and more post-processing required for this alternative equipment, more technician time is required for post-processing. Within the Minnesota USGS office, the groundwater network contract is an internal cost-accounting charge that accounts for the salary for this data processing by our local hydrologic technicians. Hence, most of the increases for the groundwater network contract are accounted for by the decreases in salary costs for Activity 2, which includes data processing and compilation. The remainder of those costs were recovered from the decreased travel costs.

Overall, these changes have resulted in approximately 33% more data being collected than originally planned for the project, but for the same overall cost. The increased data resolution will result in more calibration data available for the modeling being completed as part of field-scale water budgets (Activity 2) and the modeling of infiltration and recharge (Activity 3). As a result, the final product will have higher resolution at the field scale than originally planned, and therefore a better final deliverable.

Finally, within the dissemination section, we have added that our dissemination could happen through an open access peer-reviewed journal article(s) in lieu of a USGS Scientific Investigations Reports (SIR). All data and model results will still be published through the appropriate publicly available databases and model archives, respectively.

Amendment Approved by LCCMR: 7/28/2018

Project Status as of January 1, 2019:

For Activity 1, most efforts have occurred through the Groundwater Network, as this covers the data processing for the piezometer network. The final data collection effort for 2018 has proceeded under this activity with some additional processing effort in January through March 2019. Also, most of the abandonment process has occurred for all the sites deployed for this project, with the final removal of remaining piezometers most likely in early spring 2019.

For Activity 2, most of the 2018 data processing has proceeded for all the non-groundwater data collection activities, including: soil moisture and temperature, specific conductance, continuous subsurface drain flow, and meteorological data.

For Activity 3, some analysis work has begun for the groundwater recharge and overall water budgets for both drained sites and the undrained site. Furthermore, DRAINMOD scenarios to capture an alternate means of modeling the amount of groundwater recharge and the potential decreased amount of groundwater recharge due to agricultural drainage has also begun.

Amendment Request (12/21/2018)

The following budget items have been revised for this project report and budget spreadsheet: salary, Geoprobe/abandonment, travel, USGS report contract fees, and minor equipment cost changes. I also revised the Project Budget summary on p. 14 of this report – it appears that these figures had not been updated before so some of the figures are off base but now will be in line with the separate budget spreadsheet.

The most significant set of changes for this amendment includes refined estimates/costs for final well abandonment. Although the June 29th amendment did reflect a revision to factor for abandonment costs, the true costs were not well quantified until this past fall, hence the changes in the Geoprobe and well abandonment, travel, and excavation company categories. Furthermore, a minor revision in the equipment/tools categories is reflected in this request. The biggest cost shifts were the well abandonment and travel categories, which underestimated the final abandonment costs. Incremental weather during late October and early November complicated the well abandonment effort. This caused more travel time and labor, as captured through the Geoprobe drilling and well abandonment category.

The other significant change in costs is reflected in the USGS report category, which includes charges for the USGS Science Publishing Network. The increase in this category is supplemented by a decrease in salary costs, as it is a transfer of some of the final editing and reviewing to this contract service within the U.S. Geological Survey.

Amendment Approved by LCCMR: 1/22/2019

Amendment Request (2/22/2019)

The U.S. Geological Survey would like to formally ask for an extension to the final project and billing deadline from June 30, 2019, to September 30, 2019. The recent Federal shutdown caused significant hardships for project personnel to meet all the project deliverables by June 30th, particularly for getting the final report completed that covers the project synopsis and modeling. This analysis that is part of the report is dependent on final data processing effort through the Groundwater Network that was set to occur at the beginning of 2019, and that had to be pushed back as well. All efforts had to cease during the shutdown and that prevented any progress.

We (the USGS) are not requesting anything beyond changing the deadline. We would also still like to be able to bill for the project until this September 30th deadline, if possible. We would not be changing the project budget at all at this time – only the final deadline.

Amendment Request signed into law 5/31/2019

Project Status as of July 1, 2019:

For Activity 1, similar to previous updates, most efforts have occurred through the Groundwater Network, as this covers the data processing for the piezometer network. All data collection was finalized in late fall 2018. The entire abandonment process was completed by April 2019, with one exception of the southern site's AgriDrain structure (hence the revised budget estimates). The ground was too wet in both April 2019 for removal, so removal will proceed after harvest in November 2019.

For Activity 2, all data processing was completed by the end of June 2019, with two exceptions. Aside from data processing, the tentative water budgets for the two full collection years have been started, based on the methods described in this proposal.

For Activity 3, several DRAINMOD scenarios haven completed to independently calculate infiltration and subsurface drainage flow for most of the North Drained Site. All other DRAINMOD scenarios are set to be completed by the end of August 2019. Two other estimates of recharge have been completed for both the north and south drained sites.

Amendment Request (7/1/2019)

In summary, this amendment request is to change work plan deadlines, add missing project status/activity status update lines, add the adjusted legal citation for the project, and to shift costs.

As the last amendment request to shift the final deadline was approved, this report required the addition of new project and activity status updates, in addition to reflecting new deadlines. The original request had been for September 30, 2019, but we would like to extend the final deadline to December 31, 2019. We have some minor removal work in November 2019, so we would like to be able to spend against the project to capture these costs and to more realistically reflect USGS publication deadlines. The Legislature approved an extension to June 30, 2020, so this revised deadline still falls within this period.

Summary of budget shifts:

- $381 added for the excavation company, as the April 2019 delay to remove the AgriDrain will require the excavator to return in November 2019 to remove the remaining structure.
- $500 was added to Groundwater Network, as earlier estimates did not properly account for all piezometers.
- The Geoprobe drilling/abandonment account was revised from $7,100 to $4,500, per an abandonment process adjustment. Instead of using the Geoprobe to abandon piezometers, all piezometers were abandoned manually without Geoprobe aid. These costs have been shifted to labor instead.
- The Science Publishing Network (SPN) budget was increased from $8,538.01 to $11,275.00 to reflect a shift in preparation and reviewing costs to the centralized publishing network rather than direct project labor. Earlier estimates did not include the burden of preparing additional tables and figures (based on draft report estimates of the number of tables/figures). Alternatively, the personnel costs have been slightly adjusted down to reflect the SPN increase.
- Adjust travel expenses (to $524.50) to reflect travel costs associated with the November 2019 removal.
- Adjust supply expenses (to $50.00) to reflect supply costs associated with the November 2019 removal.

Amendment Approved by LCCMR: 7/29/2019

Overall Project Outcomes and Results:

This project investigated the effect of agricultural subsurface drainage on groundwater recharge rates at three different monitoring sites in southeastern Minnesota. The monitoring plots included two plots with an actively drained area, and a third undrained monitoring plot. Multiple piezometer transects were set up across these plots to characterize the unsaturated zone and shallow water-table flow using pressure transducers and soil moisture probes. From these piezometers, potential groundwater recharge rates were derived using three different methods: the RISE Water-Table Fluctuation (WTF) method, the DRAINMOD model, and the USGS Soil-Water-Balance (SWB) model. The entire study, with details on the data collection methods, was summarized in a

U.S. Geological Survey (USGS) Scientific Investigations Report (SIR): https://doi.org/10.3133/sir20205006). In summary, the primary method for estimating potential groundwater recharge rates was the RISE WTF method, with a mean recharge rate of 1.55 and 1.94 inches per year, respectively, for water years 2017 and 2018. When looking at recharge based on distance from the drain in the drained area, the subsurface drain did not affect potential recharge, although other factors such as variability in piezometer screen depths, piezometer construction, and specific yield variability could not be eliminated. Overall, there was a lack of agreement between the RISE WTF-based recharge estimates and the other two methods. These results were not remarkable, considering the fundamental differences in their methodologies. However, all three methods did show a fundamental difference between piezometers within the drained area and piezometers outside the drained area, including the third undrained monitoring plot. The drained areas show a lower overall potential groundwater recharge compared to the nondrained areas for all three estimates. These results require further studies for verification, but this study demonstrated that differences did exist between areas of an agricultural field with drainage and areas of a field without drainage.

IV. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1: Site selection, installation of field instrumentation, data collection, and field characterization activities.

Description: Initially, site reconnaissance will need to be carried out to find three different field sites for carrying the project. In order to narrow down the potential search field, the following counties in southeast Minnesota will be considered: Goodhue, Wabasha, Dodge, Olmsted, Winona, Mower, Fillmore or Houston counties. Based on preliminary conversations in fall 2014, all three county Soil and Water Conservation Districts (SWCDs) have indicated interest in assisting the U.S. Geological Survey (USGS) in carrying out the search. Further targeting within each county will be done by utilizing a map similar to fig. 1, which illustrates the preferred study areas for Goodhue County. Similar maps have been created for both Olmsted and Fillmore Counties. Fig. 1 considers three different categories of study suitability: preferred, acceptable, and marginal. The category score was calculated by an algorithm which considers the land slope, land cover type based on the National Land Cover Dataset classifications, depth to bedrock, and distance to a Department of Natural Resources (DNR) designated trout stream or protected tributary to designated trout stream. The ideal site has characteristics which would include a favorable combination of low slope, shallow depth to bedrock, and a short distance (< 1 kilometer) to a trout stream or tributary to a trout stream. Also, two of the three fields will have active subsurface drainage, preferably at a known configuration in order to improve the accuracy of the water budgets. The third agricultural field will not have subsurface drainage. Once candidate fields have been identified, relationships will be established with the agricultural producers to coordinate field installation activities in the fall 2015/spring 2016 and active data collection through fall 2018. Agricultural producers will be appropriately compensated for any impact on crop production caused by the project, in particular any portions of the field which have been taken out of production for field equipment installations.

Field installation at each of the field sites will proceed in fall 2015 and spring 2016, mainly in the months of October, November, and December, or in the spring and early summer of 2016 if necessary. The USGS will carry out approximately two weeks of installation activities at each of the three sites, for a total of six weeks in fall 2015 and spring 2016. This will include the installation of the piezometer network, weather stations, soil moisture probes, and subsurface drain flow monitoring. Each field installation at a drainage site will look similar to fig. 2, which shows a preliminary plan of field installation including an active weather station for measuring rainfall and collecting all data necessary for an evapotranspiration calculation, piezometer network for measuring continuous water levels, soil moisture probes, and subsurface drain flow. One subsurface drain per field site will have two different measuring points for subsurface drainflow. The piezometer network will include a series of piezometers around the perimeter of an established intensive monitoring area within the field, with additional piezometers within the field to characterize the subsurface drainage effect on the water table with respect to lateral distance from the drain. The field installation of the undrained site will look similar to fig. 2, with the exception of no subsurface drainage flow monitoring and few infield piezometers. In addition to subsurface drain flow, continuous specific conductance and temperature monitoring within the subsurface drain will assist with flowpath characterization. Soil coring activities with the usage of the USGS Geoprobe will take place during site installations to determine the various soil and glacial till horizons, in addition with confirming the depth to bedrock for the field site.

Summary Budget Information for Activity 1:

ENRTF Budget:	**$ 307,067.46**
Amount Spent:	**$ 306,922.46**
Balance:	**$ 145.00**

Outcome	**Completion Date**
1. *Site selection of the three field sites and selection of partner Soil and Water Conservation District (SWCD).*	September 30, 2016
2. *Installation of piezometer network with pressure transducers.*	November 30, 2016
3. *Installation of other field instrumentation, including soil moisture probes, weather station, and drainage flow monitoring.*	December 31, 2016
4. *Field characterization activities completed for the first field season, including tracer studies and soil coring activities.*	October 31, 2017
5. *Continuous data collection completed for the first field season.*	December 31, 2018
6. *Field characterization activities completed for the second field season, including further tracer studies and soil coring activities.*	October 31, 2018
7. *Continuous data collection completed for the second field season.*	December 31, 2018

Activity Status as of January 1, 2016:

Project personnel scouted for appropriate field sites. Early in the effort, the focus was on working with SWCDs from several different counties as well as contacting pertinent personnel in the various State agencies for assistance to find appropriate sites. Several fields were identified, but did not meet the criteria of the study. In order to find an appropriate site, the next step was to utilize ArcGIS to identify appropriate landowners based on the field characteristics necessary for the study (i.e., shallow depth to bedrock, low surface slope to limit surface runoff, and soils appropriate for drainage) and sent out letters requesting participation. In all, >400 letters were sent out and several potential farmers with pattern tiling were identified and visited. As of early November, the appropriate farmers were identified but left little time between harvest and the time when poor field conditions set in (i.e., too wet for the Geoprobe to install the shallow piezometers). Also, late in the process, an agricultural producer backed out of the study due to unforeseen circumstances beyond the project and could not participate any longer. At the first drained site still secured, some shallow piezometers were attempted, but due to poor weather conditions, were unable to complete the piezometer network.

Activity Status as of July 1, 2016:

Appropriate field locations have been secured for the overall project: two drained sites and one undrained site. For these individual sites, the project will work with two separate landowners (one site has both the undrained and drained field site in different portions of the same property, all owned by the same landowner). At the site with only a drained site, which is located approximately 2 miles southwest of Ostrander, Minnesota, installation of the field piezometer began in mid-April 2016 and was completed in mid-June 2016. At the second site, which is located 5 miles south of Ostrander, Minnesota, installation of the boundary piezometers around the undrained field site was completed in mid-June. The second site will also have a drained field site, but installation cannot occur until later this fall after the corn harvest.

A total of three different piezometer nests now exist in the agricultural field at the first field site. This first site has eight parallel subsurface drains that were verified in May by backhoe, and these subsurface drains will be the focus of the water balance activities at this field site. Other subsurface drains do exist on this agricultural field, but the project team will isolate this portion of the agricultural field by measuring the drainage flow out of this portion of the field. Each piezometer nest consists of 5 piezometers located at approximately equal distances between parallel subsurface drains (80 foot spacing between each subsurface drain line); these piezometers are also screened at approximately the same depth, capturing water from slightly above the subsurface drain depth to 2-3 feet below the subsurface drain depth. These piezometers will eventually have pressure transducers collecting water levels and temperature. Each piezometer nest also has an extra 1-2 piezometers that are screened at a deeper depth than the shallow piezometers to capture the deeper groundwater infiltration. Along the outside edge of the field, 5 individual piezometers have been installed to get boundary conditions. These boundary condition piezometers already have pressure transducers logging water levels and temperature to get an early indication of site conditions, although these measurements are not required for the scope and success of the project.

Activity Status as of January 1, 2017:
All field installations were completed by the end of November 2016, with the project on schedule to collect data for the 2017 and 2018 field seasons. A total of three piezometer nests were included for the first drained site, two piezometer nests for the second drained site, a piezometer nest on the undrained site, and boundary piezometers around all three field sites. Approximately half of the piezometers have pressure transducers installed, with the remainder to be installed before April 2017. The weather stations have been installed for the study. The drain flow meters were installed in November 2016, with the assistance of a local excavator to expose a section of the subsurface drain to install an Agridrain structure with an ISCO 2150 for continuous drain flow measurements.

Activity Status as of July 1, 2017:
The overall project goal to install, document, and outfit all field equipment by spring 2017 at all field locations was realized. Furthermore, as of this spring, all purchased instrumentation was installed, including: pressure transducers for water-level information (in the piezometer network), soil moisture probes at all six transects, flow and level information for the Agridrain (measuring drainage flow), and the climatological data. Data collection, slated to start by spring 2017, has begun as of March/April 2017 and will continue through the field season of 2018. Finally, the first round of data downloads occurred for a subset of data collection begun in September-November 2016.

Activity Status as of January 1, 2018:
The overall project goal to install, document, and outfit all field equipment by spring 2017 at all field locations was realized and any minor changes to the network were completed in August/September 2017. Furthermore, as of this fall, all major purchases and much of the salary associated with Activity 1 have been completed/realized although due to some delays with USGS billing those charges will be made on the next update.

Activity Status as of July 1, 2018:
All the data collection is proceeding along into the second full field season of data collection, with some minor analysis of the groundwater-level data. No other installations or modifications will be necessary through this fall, when the data collection will be wrapping up.

Activity Status as of January 1, 2019:
The second full field season of data collection has been completed. As the Groundwater Network covers the data processing for the piezometer network, all the piezometer data has been downloaded, uploaded to the USGS National Water Information System (NWIS), and is in the process of being finalized. The final data processing effort through the Groundwater Network will occur in early 2019. Finally, most of the abandonment process has occurred for all the sites deployed for this project, with the final removal of remaining piezometers most likely in early spring 2019.

Activity Status as of July 1, 2019:
Similar to previous updates, most efforts have occurred through the Groundwater Network, as this covers the data processing for the piezometer network. All data collection was finalized in late fall 2018, with most of the

data processing completed by the end of June 2019. All the abandonment process was completed by April 2019, with one exception of the southern site's AgriDrain structure (hence the revised budget estimates). The ground was too wet in both April 2019 for AgriDrain removal, so the AgriDrain removal will proceed after harvest in November 2019.

Final Report Summary:

The original project design was to compare at least two drained monitoring sites to a third, undrained site. For general site design, these sites were each intended to have the following characteristics: low slope, shallow depth to bedrock (less than approximately 50 feet), active agricultural fields with pattern tile drainage (for drained fields), and a relatively short distance (< 1 kilometer) to a trout stream or tributary to a trout stream. In general, this project met this criteria, although early difficulties in identifying candidate field sites did cause significant delays. Fortunately, with consideration from the LCCMR through amendment requests, the project successfully identified candidate field sites, and was able to fully carry out the study for the intended study length, just with the entire schedule offset by a year.

Overall, this was a large project with significant data collection and modeling efforts. For all details on the site selection process and background, data collection methods, and summaries of the major data sets, refer to the final major deliverable (https://doi.org/10.3133/sir20205006):
Smith, E.A., and Berg, Andrew M., 2020, Potential groundwater recharge rates for two subsurface-drained agricultural fields, Southeastern Minnesota, 2016–18: U.S. Geological Survey Scientific Investigations Report 2020–5006, 54 p., https://doi.org/10.3133/sir20205006.

ACTIVITY 2: Data Compilation, Analysis and Field-Scale Water Budgets

Description: This activity will include the compilation and analysis of continuous soil, water, and climate data for all three monitoring sites. All data will be verified for integrity and completeness on an annual basis. Verified data will then be utilized as input parameters to mathematical relationships to derive water budget components or, when appropriate, explicitly quantify water budget components. In cases where water budget components are derived from mathematical relationships, several generally accepted methods will be evaluated in their derivation. Field-scale water budgets will be determined using these individual water budget components. Uncertainty and sensitivity analyses will be performed on calculated water budgets with respect to measurement precision, method of calculating individual water budget components, and the time step used in calculating water budgets and individual components. Finalized water budgets will be analyzed to assess the influence of subsurface drains, climate, and other environmental factors on water budgets at all three monitoring sites over a spectrum temporal scales (for example, single precipitation events to seasonal variations).

Summary Budget Information for Activity 2: **ENRTF Budget: $ 72,589.89**
Amount Spent: $ 72,589.89
Balance: $ 0.00

Outcome	**Completion Date**
1. *Data compilation and validation for growing season 1*	February 28, 2018
2. *Preliminary analysis and water budget calculations for growing season 1*	April 30, 2018
3. *Uncertainty and sensitivity analysis of water budget determinations for growing season 1*	July 31, 2018
4. *Data compilation and validation for growing season 2*	October 31, 2018
5. *Preliminary analysis and water budget calculations for growing season 2*	December 31, 2018
6. *Uncertainty and sensitivity analysis of water budget determinations for growing season 2*	February 28, 2019
7. *Finalized water budget with statistical and trend analyses of water budgets and water budget components at each site for two growing seasons*	June 30, 2019

Activity Status as of January 1, 2016:
No activity during this period.

Activity Status as of July 1, 2016:
No activity during this period.

Activity Status as of January 1, 2017:
No activity during this period.

Activity Status as of July 1, 2017:
Started data compilation with the first round of data downloads, and the initial processing of water level information, for a subset of the overall piezometer network.

Activity Status as of January 1, 2018:
Entire first year of data collection has been collected and uploaded to the appropriate databases. Further updates and some status/trends will be shown for the next update. Data collection is processed under the continuous groundwater network charges.

Activity Status as of July 1, 2018:
All meteorological, groundwater level, soil moisture data, and drainage flow data has been quality-assured up through spring of 2018, and will soon be available in a public database.

For data analysis, groundwater recharge estimates have been calculated for over 20 independent piezometers for 2017, with approximately the same number of independent estimates for 2018. The Minnesota Geological Survey contract provided full comprehensive cores for both primary drainage sites, allowing for a more detailed site characterization analysis of the impacts of the drainage on groundwater recharge through the subsurface.

Activity Status as of January 1, 2019:
All meteorological, groundwater level, soil moisture data, and drainage flow data has been quality-assured through the duration of active data collection. All data collected for this project will be available by March or April 2019 through a public database – the online locations for this data will be published both through the final USGS Scientific Investigations Report (SIR) and the final LCCMR project report.

For data analysis, groundwater recharge estimates have been calculated for over 20 independent piezometers for 2018.

Activity Status as of July 1, 2019:
All data processing was completed by the end of June 2019, with two exceptions. Aside from all piezometer data, including water levels and temperatures, the following data has been collected, downloaded, processed, checked, and published through the USGS database: meteorological data (solar, wind, temperature, rainfall), soil moisture data (soil moisture, temperatures). The following two data sets are close to having all data processed: specific conductance, and the subsurface drainage flow.

Aside from data processing, the tentative water budgets for the two full collection years have been started, based on the methods described in this proposal, $\Delta S = (P + I + U) - (ET + PR + D + R_o)$. Slight alterations have been adjusted to the methodology, based on few reliable estimates of surface runoff at the sight. Instead, surface runoff will be estimated by DRAINMOD model simulations rather than direct measurements. Water budget estimates will rely mostly on three independent estimates of recharge rates (PR = potential recharge), in addition to continuous on-site precipitation records, evapotranspiration estimates based on on-site meteorological data, and continuous drain flow measurements.

Final Report Summary:

All of the data collected for this study can be found in at least one of three sources: (1) the final USGS SIR, https://doi.org/10.3133/sir20205006; (2) the USGS National Water Information System, https://waterdata.usgs.gov/mn/nwis/uv/?referred_module=gw, with site names and numbers available in the SIR; (3) three data releases associated with this project – links to the releases are found in the *Dissemination* section.

Field-scale hydrologic budget analysis was performed to interpret the water-table surface elevation and soil volumetric water content time series. At one of the two drained plots, the transects exhibited varying water-table surface elevation patterns. Frequent backflow from the adjacent ditch caused subsurface drainage flow to slow down or stop drainage through the main collector drain and cause pipe pressurization, so the closest transect appeared to be mostly controlled by the drain pressurization whereas the farthest transect was more efficiently drained. Both of the drained monitoring plots had an elevation gradient parallel to the pattern tiles, sloping downward towards the collector drain that aggregated the parallel lines into a single drain. Because the transects were set at different gradients in the field, some of the water-table surface elevation differences were also attributed to lateral flow towards the lowest parts of the field. Additional analysis related to Activity 2 can be found in the final USGS SIR.

Full field-scale water budgets were not completed. Although tentative water budgets were explored, the study determined that field runoff from both monitoring drainage plots was higher than originally expected. Since this study was unable to effectively measure runoff rates, this missing component caused the errors in the water budget analysis to be too high to effectively estimate groundwater recharge rates through field-scale water budgets.

ACTIVITY 3: Modelling and Extrapolation of Estimated Recharge Rates

Description: An established hydrologic model (examples include DRAINMOD, APEX, GSFLOW, GSSHA) will be calibrated and validated to accurately reproduce overall water budgets and individual water budget components observed at field monitoring sites. These calibrated models will then be used to evaluate the effects of variations of subsurface drain configurations, soil characteristics and climatic variability on the field-scale water budgets. Specific scenarios to be modelled will include a series of model runs incrementally varying the depth of the glacial sediments, soil hydraulic properties, and subsurface drain configuration. The appropriate depths of glacial sediments and values for soil properties will be acquired from local and national repositories. The results from these series of model runs will enable the transfer of the previously calculated site-specific water budget and recharge calculations to other portions of the landscape within the region where landscape and drainage properties differ from those at the monitoring sites. Results from field-scale modelling will be used to inform a larger regional modelling effort to update groundwater recharge estimates across the entire southeast portion of Minnesota. The SWB regional model will be used to demonstrate the effects of subsurface drainage on regional groundwater recharge under various subsurface drainage build-out scenarios. Findings will be reported in a peer-reviewed USGS SIR, in addition to regional impact maps showing the changes in groundwater recharge rates as a result of various potential subsurface drainage scenarios.

Summary Budget Information for Activity 3: **ENRTF Budget: $ 108,342.65**
Amount Spent: $ 108,342.65
Balance: $ 0.00

Outcome	Completion Date
1. *Field-scale hydrologic model selection based on initial calibration to field data from season 1*	July 31, 2018
2. *Field-scale hydrologic model calibration and validation based on two growing seasons of field data*	March 31, 2019

3. *Field-scale modelling scenarios showing effect of changes in depth of glacial sediments, soil properties, and subsurface drain configuration on groundwater recharge and other water budget components*	January 31, 2019
4. *Incorporation of field-scale model outcomes into region model and evaluation of effects of several subsurface drainage build-out scenarios on regional groundwater recharge*	January 31, 2019
5. *Final peer-reviewed USGS Scientific Investigations Report (SIR) and regional maps*	June 30, 2019

Activity Status as of January 1, 2016:
No activity during this period.

Activity Status as of July 1, 2016:
No activity during this period.

Activity Status as of January 1, 2017:
No activity during this period.

Activity Status as of July 1, 2017:
No activity during this period.

Activity Status as of January 1, 2018:
No major activity completed during this period, although the USGS SIR introductory and background sections have been largely completed due to some work on a parallel subsurface drainage project effort.

Activity Status as of July 1, 2018:
No major activity completed during this period, although a few of the background figures have been completed due to some parallel work on the Minnesota Ground Water Association white paper on agricultural drainage and groundwater.

Activity Status as of January 1, 2019:
Some analysis work was completed for the final groundwater recharge and overall water budgets for both drained sites and the undrained site. Also, DRAINMOD scenarios to capture an alternate means of modeling the amount of groundwater recharge have also been set-up and will be run in February 2019.

Another activity update is that a major contribution to an understanding of the potential impacts of agricultural drainage on groundwater resources was published through the Minnesota Groundwater Association (MGWA).

Activity Status as of July 1, 2019:
Several DRAINMOD scenarios haven completed to independently calculate infiltration and subsurface drainage flow for most of the North Drained Site. All other DRAINMOD scenarios are set to be completed by the end of August 2019. Two other estimates of recharge have been completed for both the north and south drained sites: (1) using the RISE method to calculate recharge for all applicable piezometer records; (2) updating the Soil-Water-Balance (SWB) estimates for the two sites, based on meteorological conditions during the study period.

Final Report Summary
Three different models were used in support of this project to investigate potential groundwater recharge rates:

1. The DRAINMOD model was used quantify multiple water-budget components, including runoff, evapotranspiration, subsurface drainage, lateral seepage, and deep seepage. For this study, the deep seepage rates were assumed to be equal to the potential groundwater recharge to the bedrock aquifer below the restricting layer.

2. The continuous water-level data collected for this study were used to estimate potential groundwater recharge using the RISE Water-Table Fluctuation method. The selected water-table fluctuation method uses the RISE program to estimate recharge from the product of groundwater-level rises and specific yield. This method assumed that recharge could be restricted to small time increments in hydrologic settings with thin unsaturated zones, such as the unsaturated zone in all three monitoring plots.
3. The USGS Soil-Water-Balance (SWB) model was used as a third method for estimating groundwater recharge. The SWB model uses a modified Thornthwaite-Mather SWB approach. The water-balance approach of the SWB model estimates potential recharge on a daily basis.

Major conclusions from this work include the following:

- When looking at recharge based on distance from the drain, the subsurface drain did not affect potential recharge, although other factors such as variability in screen depths, well construction, and specific yield variability cannot be eliminated.
- Overall, there was a lack of agreement between the three methods. These results were not remarkable, considering the fundamental differences in the methodology for each method.
- All methods did show a fundamental difference between piezometers within the drained area and piezometers outside the drained area, including the third undrained monitoring plot. The drained areas show a lower overall potential groundwater recharge compared to the nondrained areas for all three estimates.

In addition to the field-scale groundwater recharge estimates, a methodology was used to transfer these results to estimate basic implications for southeastern Minnesota. The site screening process used for identifying potential study sites was used to classify all candidate fields that at least in part would benefit from subsurface drainage for a six-county area of southeastern Minnesota. Unlike other previous estimates of subsurface drainage extent (Sugg, 2007; Nakagaki and Wieczorek, 2016), this effort used the higher-resolution SSURGO dataset (NRCS, 2005; NRCS, 2020) and added in a slope component (5 percent or less) from the USGS digital elevation model (USGS, 2020). It should be noted, this new coverage only delineated areas that were considered both favorable for subsurface drainage and included a depth to bedrock less than fifty feet. In addition to the cultivated crop land cover/land-use extent from the National Land Cover Database (Homer and others, 2015), this coverage also factored in pasture/hay extent [land cover/land-use class 81].

Based on this screening criteria for southeastern Minnesota, this new coverage can be considered vulnerable areas for subsurface drainage impacts on potential groundwater recharge. This 30-meter resolution coverage might include small areas of an entire field, so subsurface drainage may or may not be expanded beyond this coverage depending on field characteristics. Also, the slope criteria of 5 percent and the 50-foot depth to bedrock were subjective but was considered useful for areal perspective. The six-county area, including Goodhue, Wabasha, Olmsted, Winona, Fillmore, and Houston counties, was isolated for simplicity, and also cover the majority of the Minnesota karst region.

Within the six-county area, pasture/hay plus cultivated crop land extent covers approximately 1.4 million acres (figure on next page). Based on this criteria, approximately 77,000 acres fell into the criteria of potential subsurface drainage area with less than 50 feet to bedrock. This acreage represented about 5.4 percent of the 1.4 million acres. Assigning the updated SWB model results to this area [Smith and Berg, 2020: https://doi.org/10.3133/sir20205006; Smith, 2020: https://doi.org/10.5066/P90N4AWG), with annual mean potential recharge between 2014-2018, 60.2 percent of the potential area had potential recharge less than 6 inches per year. Therefore, areas of potential recharge over 6 inches per year represented only 2.2 percent of the total land extent for pasture/hay plus cultivated crop with less than 50 feet to bedrock.

This coverage does not suggest all this area would be considered recharge areas, or that subsurface drainage could not affect other areas that could be recharge areas to the aquifers below. However, the 2.2 percent area is useful for context on how much subsurface drainage could impact groundwater recharge if it was installed in all of these areas. With differences from this study of less than 1 inch between perimeter piezometers (no drainage) versus transect piezometers (with drainage) (Smith and Berg, 2020), the impact of subsurface drainage on groundwater recharge across southeastern Minnesota would likely be small compared to the potential recharge differences that can be caused by year-to-year climatic differences. Naturally, a longer study might have found larger or even smaller differences between drained and undrained areas. Also, drainage could be expanded to areas not typically drained or fields with higher slopes, so this impact could be larger in such cases.

Homer, C.G., Dewitz, J.A., Yang, L., Jin, S., Danielson, P., Xian, G., Coulston, J., Herold, N.D., Wickham, J.D., and Megown, K., 2015, Completion of the 2011 National Land Cover Database for the conterminous United States—Representing a decade of land cover change information: Photogrammetric Engineering and Remote Sensing, v. 81, p. 345–354.

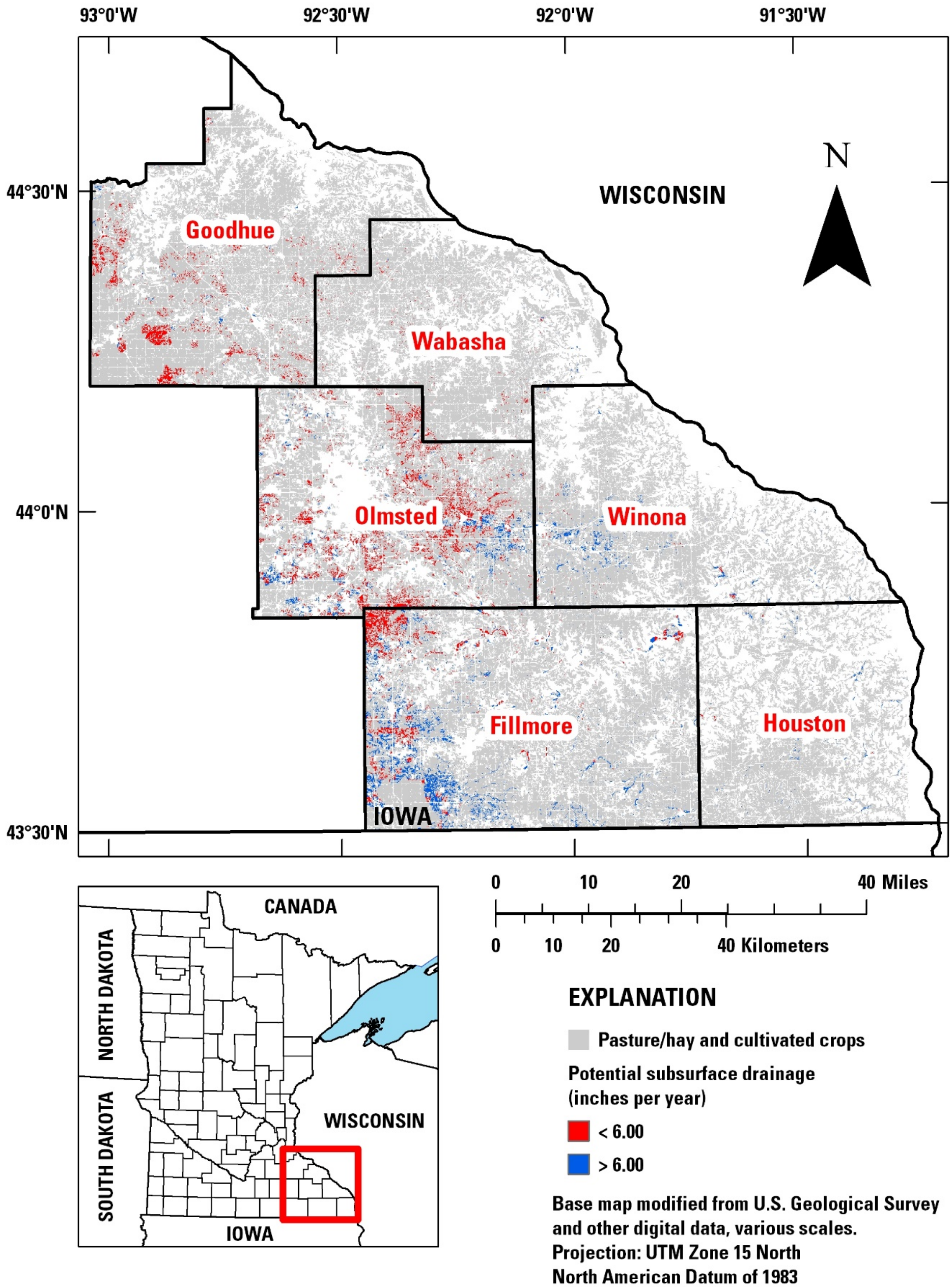
Nakagaki, N., and Wieczorek, M.E., 2016, Estimates of subsurface tile drainage extent for 12 Midwest states, 2012: U.S. Geological Survey data release. [Also available at http://dx.doi.org/10.5066/F7W37TDP.]

Natural Resources Conservation Service [NRCS], 2005, Soil survey geographic (SSURGO) data base—Data use information: Fort Worth, Texas, U.S. Department of Agriculture, Natural Resources Conservation Service, Miscellaneous Publication Number 1527, 110 p.

Natural Resources Conservation Service [NRCS], 2020, SSURGO web soil survey, United States of Agriculture, Soil Survey Staff, accessed on February 11, 2020, at https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx.

Sugg, Z., 2007, Assessing U.S. farm drainage: Can GIS lead to better estimates of subsurface drainage extent?, accessed February 11, 2020, at http://pdf.wri.org/assessing_farm_drainage.pdf.

U.S. Geological Survey [USGS], 2020, National Elevation Dataset: U.S. Geological Survey, The National Map, accessed February 11, 2020, at https://nationalmap.gov/elevation.html.



Six-county area of southeastern Minnesota, including Goodhue, Wabasha, Olmsted, Winona, Fillmore, and Houston counties. The 2011 National Land Cover Database (NLCD) classes for pasture/hay (class 81) and cultivated crops (class 82) shown, along with the classified potential subsurface drainage area. The potential subsurface drainage area was assigned the mean annual potential recharge from the updated SWB model, sub-categorized by areas with less than six inches of potential groundwater recharge per year and greater than six inches of potential groundwater recharge per year.

V. DISSEMINATION:

Description:

Project milestone results will be communicated to LCCMR staff with semi- annual written results. The results of USGS continuous data collection will be stored in the USGS National Water Information System (NWIS) database and made available to the public via the USGS Minnesota Water Science Center web site at http://mn.water.usgs.gov/index.html. Additionally, the final results from the project will be presented through the publication of either a peer-reviewed USGS Scientific Investigations (SIR) report or open access journal article and will be available at the end of the study. All of the approved continuous climate, water level, soil moisture, and subsurface drainage flow data will be provided in an attached appendix either in the SIR and/or in a separate final report to the LCCMR. Also, these data will be presented at various forums such as the Minnesota Water Resources Conference and the annual Soil and Water Conservation Society meetings.

Status as of January 1, 2016:

No activity during this period.

Status as of July 1, 2016:

The project was presented on June 29, 2016, to a national field expert team for the U.S. Geological Survey at Mounds View, Minnesota.

Status as of January 1, 2017:

No activity during this period.

Status as of July 1, 2017:

A presentation was made to the Minnesota Geological Survey on March 15, 2017, on groundwater recharge which included some drainage recharge project information.

Status as of January 1, 2018:

No activity during this period.

Status as of July 1, 2018:

No activity during this period.

Status as of January 1, 2019:

A major contribution to an understanding of the potential impacts of agricultural drainage on groundwater resources was published through the Minnesota Groundwater Association (MGWA). As the project chief, Erik Smith, was the first author, the LCCMR should be made aware of this publication and the final product can be found through the following online linkage:
http://www.mgwa.org/documents/whitepapers/Drain_Tiles_and_Groundwater_Resources.pdf

Status as of July 1, 2019:

No activity during this period.

Final Report Summary:

Two publications and three data releases have resulted from this project:

1. A U.S. Geological Survey Scientific Investigations Report, summarizing the data collection methods, data summaries, details on the groundwater recharge modeling, and full analysis of the study results. The landing page and a pdf version of this report can be found at https://doi.org/10.3133/sir20205006:

Smith, E.A., and Berg, Andrew M., 2020, Potential groundwater recharge rates for two subsurface-drained agricultural fields, Southeastern Minnesota, 2016–18: U.S. Geological Survey Scientific Investigations Report 2020–5006, 54 p.

2. Minnesota Groundwater Association white paper, published in 2018, with Erik Smith (project manager) as the primary author. This white paper discussed the relations of drain tiles and groundwater resources. The white paper also discussed the historical significance of agricultural drainage practices, the recognized positive benefits and potential negative consequences of agricultural drainage practices, and the gaps in understanding of the connections between agricultural drainage and groundwater resources. The landing page and a pdf version of this report can be found at: https://pubs.er.usgs.gov/publication/70204196
3. Three data releases, directly related to the models used for this study, have been published. Citations and web links to the landing pages:
    a) Smith, E.A., 2020, DRAINMOD simulations for two agricultural drainage sites in western Fillmore County, southeastern Minnesota: U.S. Geological Survey data release, https://doi.org/10.5066/P987N30U.
    b) Smith, E.A., 2020, Soil-Water Balance (SWB) model datasets used to estimate recharge for southeastern Minnesota, 2014-2018: U.S. Geological Survey data release, https://doi.org/10.5066/P90N4AWG.
    c) Smith, E.A., 2020, Potential groundwater recharge estimates based on a groundwater rise analysis technique for two agricultural sites in southeastern Minnesota, 2016-2018: U.S. Geological Survey data release, https://doi.org/10.5066/P94LMOPP.

VI. PROJECT BUDGET SUMMARY:

A. ENRTF Budget Overview:

Budget Category	$ Amount	Overview Explanation
Personnel:	$ 314,104	1 USGS Studies Chief at 4% FTE each year for 3 years; 1 USGS Project Chief at 39% FTE each year for 4 years; 1 USGS Geographer at 7% FTE each year for 3 years; 1 USGS Hydrologic Technician at 20% FTE each year for first 3 years; 1 Admin Support at 4.5% FTE each year for 3 years; 2 USGS Groundwater/Surface Water Specialists at 4% FTE each year for 3 years; 2 Database/IT Support Specialists each year for years
Professional/Technical/Service Contracts:	$ 106,420	Reimbursement to agricultural producers for agricultural field out-of-production; Minnesota Geological Survey for professional core logging services; USGS groundwater network for processing 12 reference continuous water-levels; USGS Geoprobe for drilling piezometers and coring activities; publication of USGS Scientific Investigations Report
Equipment/Tools/Supplies:	$ 55,291	Submersible pressure transducers, soil moisture probes, data loggers, storage modules, power supply, weather station housing, drain flow and water chemistry instrumentation, supplies for piezometer installation and coring activities
Travel Expenses in MN:	$ 12,185	Mileage (0.55/mile), lodging, meals
TOTAL ENRTF BUDGET:	**$488,000**	

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: 3.17 FTEs

Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation: 0.04 FTEs for each year for first two years

B. Other Funds:

Source of Funds	$ Amount Proposed	$ Amount Spent	Use of Other Funds
Non-state			
U.S. Geological Survey	$209,312	$209,312	Personnel, travel, supplies
State			
N/A	$0	$0	
TOTAL OTHER FUNDS:	**$209,312**	**$209,312**	

VII. PROJECT STRATEGY:

A. Project Partners: There are current agreements with partners to collaborate with this project.
Project Partners Receiving Funds:

- Two agricultural producers: $10,190 to reimburse agricultural producers for agricultural field out-of-production.
- Minnesota Geological Survey: description of four complete cores from each of the the two primary drained field sites (total costs: $4,178)

B. Project Impact and Long-term Strategy:

It is anticipated that this project will provide important data on the potential impacts of subsurface drainage on groundwater recharge in southeast Minnesota, as a current data gap exists for this type of information. With the continuous data collection at all three field sites, the calculated field-scale water budgets will help ascertain the overall groundwater recharge for these field sites. Further modelling efforts will be conducted to extrapolate estimated recharge rates to agricultural lands across the region with similar landscape characteristics. Calibrated models will be used to evaluate the effects of variations of subsurface drain configurations, soil characteristics and climatic variability on the field-scale water budgets. The results from these series of model runs will enable the transfer of the previously calculated site specific water budget and recharge calculations to other portions of the landscape within the region where landscape and drainage properties differ from those at the monitoring sites. Results from field-scale modelling will be used to inform a larger regional modelling effort to update groundwater recharge estimates across the entire southeast portion of Minnesota. The long term strategy for this project is to maintain the sites, if possible, with future partner funds acquisition to continue monitoring activities for calculating annual hydrologic budgets and to expand data collection to nutrients and pesticides to attribute the potential changes in loads due to the presence of subsurface drains.

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 attached figures.

X. RESEARCH ADDENDUM:
The U.S. Geological Survey will conduct internal peer reviews of this detailed proposal and will be revised based on those USGS peer review comments. The proposal will then be approved by the USGS and added to this document. The expected date of proposal approval is June 30, 2015.

XI. REPORTING REQUIREMENTS:
Periodic work plan status update reports will be submitted no later than January 1, 2016; July 1, 2016; January 1, 2017; July 1, 2017; January 1, 2018; July 1, 2018; January 1, 2019; and July 1, 2019. A final report and associated products will be submitted no later than December 31, 2019.

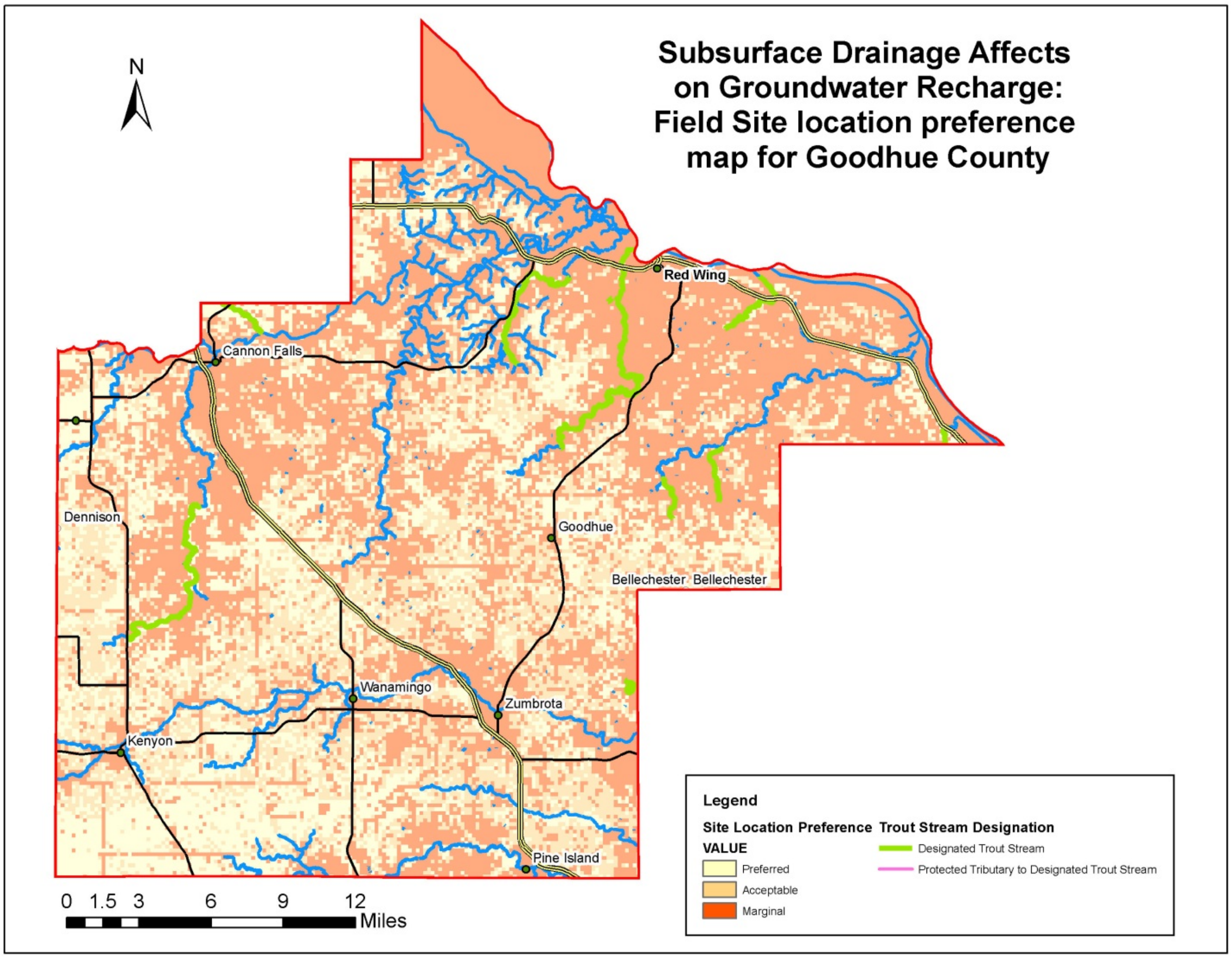


Figure 1. Site location preferences for Goodhue County, shown as preferred, acceptable, and marginal. Site location preference values based on an algorithm which considers the land slope, land cover type based on the National Land Cover Dataset classifications, depth to bedrock, and distance to a Department of Natural Resources (DNR) designated trout stream or protected tributary to designated trout stream.

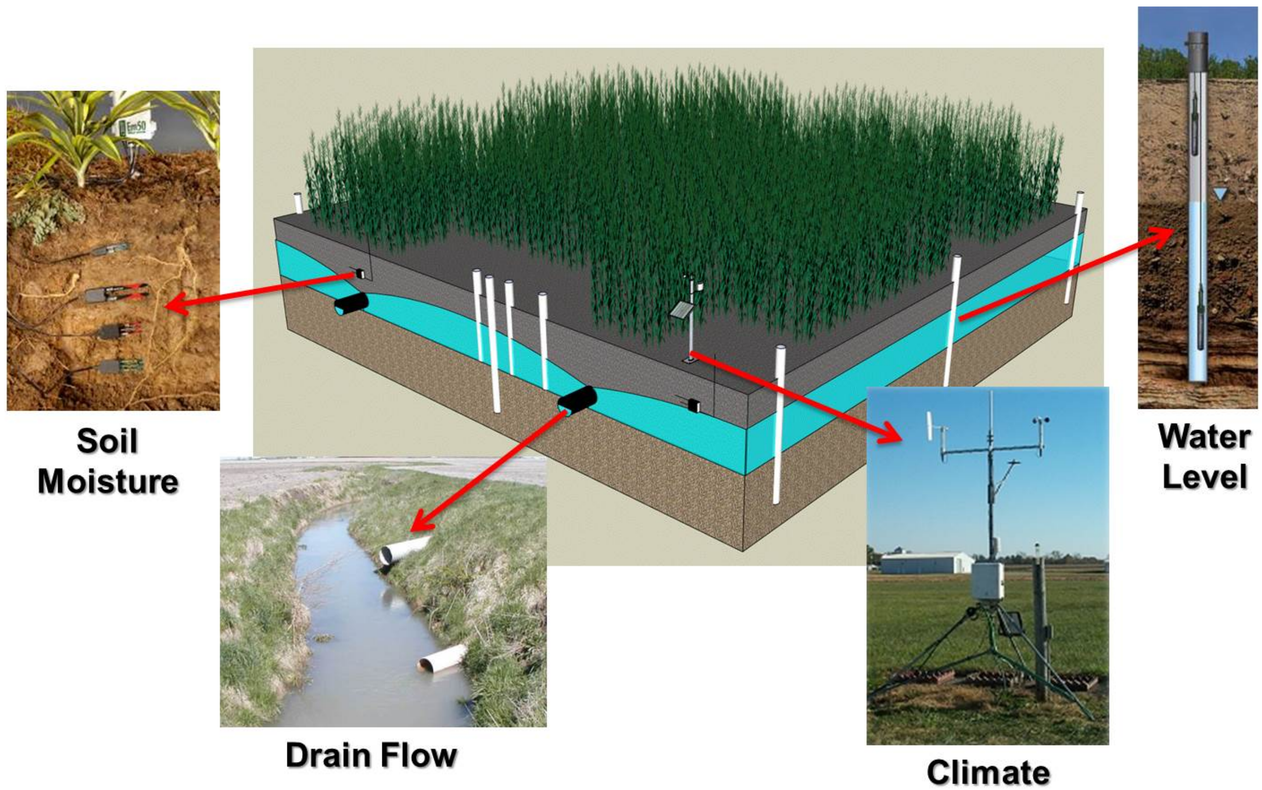


Figure 2. A hypothetical configuration of one of the two drained field sites, including a weather station for measuring climate data, a piezometer network for continuous water level measurements, soil moisture probes, and subsurface drainage flow. The third undrained field site will have a similar configuration, with the absence of subsurface drainage flow.

Environment and Natural Resources Trust Fund
Final M.L. 2015 Project Budget

Project Title: Southeast Minnesota Subsurface Drainage Impacts on Groundwater Recharge
Legal Citation: M.L. 2015, Chp. 76, Sec. 2, Subd. 04f as extended by M.L. 2019, First Special Session, Chp. 4, Art. 2, Sec. 2, Subd. 19
Project Manager: Erik Smith
Organization: United States Geological Survey
M.L. 2015 ENRTF Appropriation: $488,000
Project Length and Completion Date: December 31, 2019
Date of Report: 2/28/2020

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	Site Selection, Installation of Field Instruments, Data Collection, and Field Characterization Activities			Data Compilation, Analysis and Field-Scale Water Budgets			Data analysis and upscaling calculated recharge rates.				
Personnel (Wages and Benefits)	**$144,447.00**	**$144,447.00**	**$0.00**	**72,589.89**	**72,589.89**	**0.00**	**97,067.65**	**97,067.65**	**0.00**	$314,104.54	**$0.00**
1 USGS Studies Chief, (GS-13): $16,200 (73% salary, 27% benefits); Position at 4% FTE each year for 3 years											
1 USGS Project Chief, (GS-12): $177,900 (76% salary, 24% benefits); Position at 39% FTE each year for ~~3~~4 years											
1 USGS Geographer, (GS-12): $29,100 (73% salary, 27% benefits); Position at 7% FTE each year for 3 years											
1 USGS Hydrologic Technician, (GS-7): $51,647 (83% salary, 17% benefits); Position at 20% FTE each year for first 3 years											
1 Admin Support, (GS-9): $12,600 (69% salary, 31% benefits); Position at 4.5% FTE each year for 3 years											
2 USGS Groundwater/Surface Water Specialists (GS-13): $37,100 (75% salary, 25% benefits); Position at 4% FTE each year for 3 years											
2 Database/IT Support Specialists (GS-12): $31,300 (73% salary, 27% benefits); Position at 4% FTE each year for 3 years											
Professional/Technical/Service Contracts											
Agricultural producers in Fillmore County (depending on final site locations); reimbursement for agricultural field out of production for 2 years, at 3 field sites, for activity 1	$10,190.00	$10,190.00	$0.00							$10,190.00	$0.00
Excavation company for assistance with tile drainage location and installation of subsurface drainage flow meters.	$2,794.91	$2,731.91	$63.00							$2,794.91	$63.00
Minnesota Geological Survey and METER Group: description of 4 complete cores from each of the the two primary drained field sites	$4,159.98	$4,159.98	$0.00							$4,159.98	$0.00
USGS: Groundwater network contract, 12 individual reference piezometers total over 3 field sites for activity 1	$73,500.00	$73,500.00	$0.00							$73,500.00	$0.00
USGS: Geoprobe drilling and well abandonment, 6 weeks total at $750/week, operations and maintenance for activity 1	$4,500.00	$4,500.00	$0.00							$4,500.00	$0.00
USGS: Contract fees for USGS report (Science Publishing Network) that includes editing, reviewing, and preparation for electronic publishing and distribution							$11,275.00	$11,275.00	$0.00	$11,275.00	$0.00
Equipment/Tools/Supplies	$55,291.06	$55,291.06	$0.00							$55,291.06	$0.00
40 submersible pressure transducers (Average ~$500/each)											
14 soil moisture probes ($225/each)											
3 Data Loggers, Storage Modules, Power Supply, and Housing ($3,400 each)											
3 Sets of Weather Station Sensors ($3,300 each)											
2 Drain flow and water chemistry instrumentation ($4,500 each)											
Supplies to install shallow piezometers and coring supplies											
Travel expenses in Minnesota											
Travel to and between data gathering, including annual summer field weeks, site exploration and coring, and periodic trips for data collection activities.	$12,184.51	$12,102.51	$82.00							$12,184.51	$82.00
COLUMN TOTAL	$307,067.46	$306,922.46	$145.00	$72,589.89	$72,589.89	$0.00	$108,342.65	$108,342.65	$0.00	$488,000.00	$145.00