Understanding Groundwater Sustainability in the I-94 Growth Corridor

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LCCMR Project number: 031-B

PROJECT SUMMARY

This project will assess groundwater sustainability in the Interstate 94 growth corridor between the Twin Cities and St. Cloud to characterize water-resource limitations and inform decision-making. This collaborative effort between the Minnesota Environmental Quality Board (EQB) and the U. S. Geological Survey (USGS) will provide a foundation to inform local agency partners and communities in planning for sustainable future land and water use. The project builds on Minnesota Environmental and Natural Resources Trust Fund (ENRTF) investments in the Minnesota Geological Survey's (MGS) County Geologic Atlas program and on emerging technology to measure streamflow with more precision. Because of these recent advances in scientific understanding, characterization of water quantity can now be assessed by measuring flows in the Mississippi River and in groundwater systems.

PROBLEM

Assessing groundwater resources in the urban growth corridor (corridor) between the Twin Cities and St. Cloud is a priority because of the corridor's significant expected growth, inherent natural limits of groundwater, and the vulnerability of that resource to contamination due to its sandy soils and proximity to the land surface. Furthermore, some areas in the growth corridor will need to invest in costly regional water-supply treatment and distribution systems that use a combination of surface water and groundwater supplies, so informed planning for these systems can maximize investment in their construction. Given these factors, local governments must carefully consider their plans for the corridor and water managers must incorporate a new understanding of the system and its limits into their management framework. The information developed by the project will build a foundation to ensure that corridor communities can meet the needs of the growing population sustainably.

BACKGROUND

This project will leverage and build upon on work being done by the Minnesota Geological Survey and by the Minnesota Department of Natural Resources (DNR) as part of the Minnesota County Geologic Atlas (Atlas) Program. Using wells and test holes from Atlas efforts, the USGS will conduct and analyze aquifer tests in a buried glacial-drift aquifer to measure the aquifer's hydrologic properties as well as those of overlying confining layer. The aquifer tests will use wells completed as part of the Atlas program in an area where the effects of vertical flow through confining layers can be measured. Properties from this and other aquifer tests will then be extrapolated over the study area using data from test borings from the Atlas program. Finally, new technology developed by the USGS will be used to measure base-flow gains in the

Mississippi River. This technology, termed an Acoustic Doppler Current Profiler, allows for more precise measurements of streamflow than using previous streamflow equipment.

Existing measurements of surficial and buried aquifer properties will be compiled in the study area. Where inadequate, new data will be gathered and analyzed to produce aquifer property measurements. Information from these efforts will form the foundation for data to develop groundwater models necessary for assessing water sustainability in the area.

OBJECTIVES AND SCOPE

Activity 1: Assess groundwater flows through the surficial aquifers in the corridor

Just as appropriations from the Mississippi River are limited by the river's flow, flow through aquifers determines the amount of water that people can safely appropriate over time from those groundwater sources. Under this activity, groundwater recharge and discharge to the Mississippi will be measured and estimates of water use, evapotranspiration, and irrigation and septic-system return flow will be made in the corridor.

Objectives:

- Estimate groundwater discharge to the Mississippi River, at base flow, along representative 6-mile reach of the river
- Determine variability in groundwater recharge in the corridor using groundwater hydrograph analyses from wells in an existing network and with precipitation data
- Compile water-use trends and variability in the growth corridor to asses future water needs
- Produce a groundwater mass-balance for the surficial aquifer in the corridor, based on project data

This objective involves measuring flow in a representative single reach (6- mile reach) between Clearwater and Becker, Minnesota. The spatial variability in components of the groundwater mass-balance will be assessed in representative areas over the corridor area. Changes to the original design for the project resulted from funding, at a level less that originally requested, from the Legislative and Citizens Commission on Minnesota Resources.

Activity 2: Describe and determine hydraulic properties of glacial-drift confining layers and buried aquifers in the corridor

Objectives:

- Perform an aquifer test using an existing pumping well and observation wells to characterize the hydraulic properties of the buried glacial aquifer to determine vertical hydraulic properties of confining units and leakage into buried aquifers from surficial aquifers.
- Update the MGS compilation of existing aquifer tests and specific-capacity data and assess variability across the corridor.

Sustainable groundwater management requires information about the properties of buried aquifers and overlying confining layer through which water moves. Work under this activity will include estimates of groundwater flow through buried aquifers at selected locations. Understanding these flows will enable water managers to use models to estimate the effect of increasing withdrawals from buried aquifers on other parts of the overall hydrologic system, a key step in determining the sustainability of current or future groundwater withdrawals.

This activity will leverage and capitalize on work done through the MGS/DNR County Atlas Program. USGS will conduct one aquifer test in a buried aquifer to measure the aquifer's hydrologic properties and those of its overlying confining layer. Properties from this and other aquifer tests will be extrapolated to other buried aquifers in the study area identified in county atlases. The aquifer test will use wells completed in holes drilled for county atlases in an area where the effects of vertical flow through confining layers can be measured.

Activity 3: Develop decision-making tool for sustainable water use

(This activity will be conducted by staff from the Environmental Quality Board)

Sound land and water planning requires informed decision-making based on understanding of the surface water and groundwater systems in the growth corridor.

Objectives:

- Compile existing water quality information in the project area by engaging with other agency staff (e.g. DNR, MDH, Minnesota Department of Agriculture, Minnesota Pollution Control Agency and others).
- Evaluate current and future land use plans by engaging with staff from the Board of Water and Soil Resources and local entities to review existing land and water planning efforts.
- Develop a prototype web-based GIS tool to represent corridor land and water use demands and expected groundwater system responses based on data collected under Activities 1 and 2, as well as Activity 3.

This activity is focused on bringing together diverse water quality and water sustainability information in such a manner to assist in critical decision-making efforts. This tool will help communities understand the implications for sustainable land and water management throughout the corridor and will prepare a plan for future modeling to assess water sustainability in the corridor.

STUDY AREA AND SETTING

The growth corridor study area (study area) is underlain by part of the Anoka Sand Plain aquifer, an unconfined (water-table), surficial aquifer which overlies Paleozoic and Precambrian sedimentary and igneous rocks. Water from the Anoka Sand Plan aquifer is used for irrigation and domestic water supplies. The aquifer is composed primarily of glacial outwash sediments from several glacial advances and retreats during the Quaternary glaciations (Wright, 1972a; Wright, 1972b; and Wright and Ruhe, 1965). In addition to the outwash deposits, the Anoka Sand Plain aquifer also includes glacial ice contact deposits and post-glacial alluvial and terrace deposits. The outwash sediments were deposited primarily by glaciofluvial processes as glacial ice melted during the eastward diversion of the glacial Mississippi River around the Grantsburg sublobe of the Wisconsin glaciations (Cooper, 1935; Farnham, 1956). Gray till deposited by the Grantsburg sublobe is present at land surface on topographic high areas where outwash was not deposited. Underlying the outwash and gray till is red till deposited by the Superior lobe of the Wisconsin glaciations (Cooper, 1935; Farhnam, 1956). This glacial lob expanded out of the Lake Superior Basin in to the study area prior to the Grantsburg-sublobe advance. A small portion of the Anoka Sand Plain aquifer was reworked by eolian processes (Cooper, 1935). The portion of the Anoka Sand Plain aquifer that underlies the study area consists primarily of terrace deposits and, to a lesser extent, floodplain alluvium). The deposits of the Anoka Sand Plain generally range in thickness from about15 to 115 ft and consist of medium to coarse sand interceded with thin layers of clay, silt, salty sand, and gravel (Helgesen and Lindholm, 1977; Lindholm, 1980).

In the study area, the depth below land surface to the water tables generally ranges from 3 to 50 feet. The shallow depths make the aquifer vulnerable to land-surface sources of contamination, The aquifer typically ranges in saturated thickness from about 20 to 60 feet and in hydraulic conductive from about 50 to as much as 1,000 feet per day (Anderson, 1993). Transmissivities range from about 5,000 to as much as 30,000 square feet per day (Lindholm, 1980). About 20 percent of the aquifer is capable of yielding water to wells at a rate of at least 475 gallons per minute (Anderson, 1993).

Recharge in the study area is from rain and snowmelt that percolates to the water table (Lindholm, 1980). Most recharge occurs soon after spring snowmelt and spring rainfall and before active plant growth. A second period of recharge typically occur in the fall, soon after the end of the growing season, but prior to soil freeze-up. The average annual recharge to sand plain aquifers in central Minnesota, an area that includes portions of the Anoka Sand Plain aquifer, was estimated to be about 8 inches per year (Lindholm, 1980).

Shallow ground water in the study area generally flows from topographically high to low area and discharges to streams, lakes, and wetlands. Groundwater also discharges to the atmosphere by evapotranspiration during the growing season where the depth below land surface to the water table is less than about 10 feet (Anderson, 1993). The water table surface generally is a subdued reflection of the topography (Lindholm, 1980). Groundwater withdrawals, attributable to pumping high-capacity wells create cones of depression in the water table and therefore influence groundwater flow (Lindholm, 1980). Water table gradients generally are less than 2 feet per 1000 feet (Manger and others, 1990).

Land use and land cover in the study area is primarily agricultural and to a lesser extent urban, forest and open water. The agricultural areas include both irrigated and non-irrigated croplands that are used to grow row crops such as potatoes, corn and edible beans.

APPROACH

Activity 1: Assess flows through surficial aquifers in the corridor

The working hypothesis for the base-flow measurement in the Mississippi River is based on the law of conservation of mass. That law states that the total volume in minus the total volume out plus the change in storage is zero and applies because the density of water is constant so volume of water is a surrogate for mass.

Flow through aquifers characterizes the amount of water that can be appropriated on a long-term sustainable basis. Groundwater recharge and discharge to the Mississippi River will be measured and estimates of water use, evapotranspiration, and irrigation and septic-system return flow in the growth corridor will be made. Work elements include:

E. Conduct high-precision Mississippi River groundwater discharge measurement along a 6-mile reach from Clearwater to Becker.

F. Collect continuous groundwater recharge hydrographs and precipitation data during the non-freezing part of the year using existing sites and installations.

G. Compile water use information and determine variability of corridor groundwater use.

H. Analyze data to produce a groundwater mass balance for the surficial aquifer, including seepage run data.

Activity 1A will be conducted along a reach (Figure 1) of the Mississippi River between the cities of Clearwater and Becker. The reach was selected because it is long enough to receive a measurable amount of groundwater discharge, relatively free of islands and has only a small amount of water flowing in from tributaries.

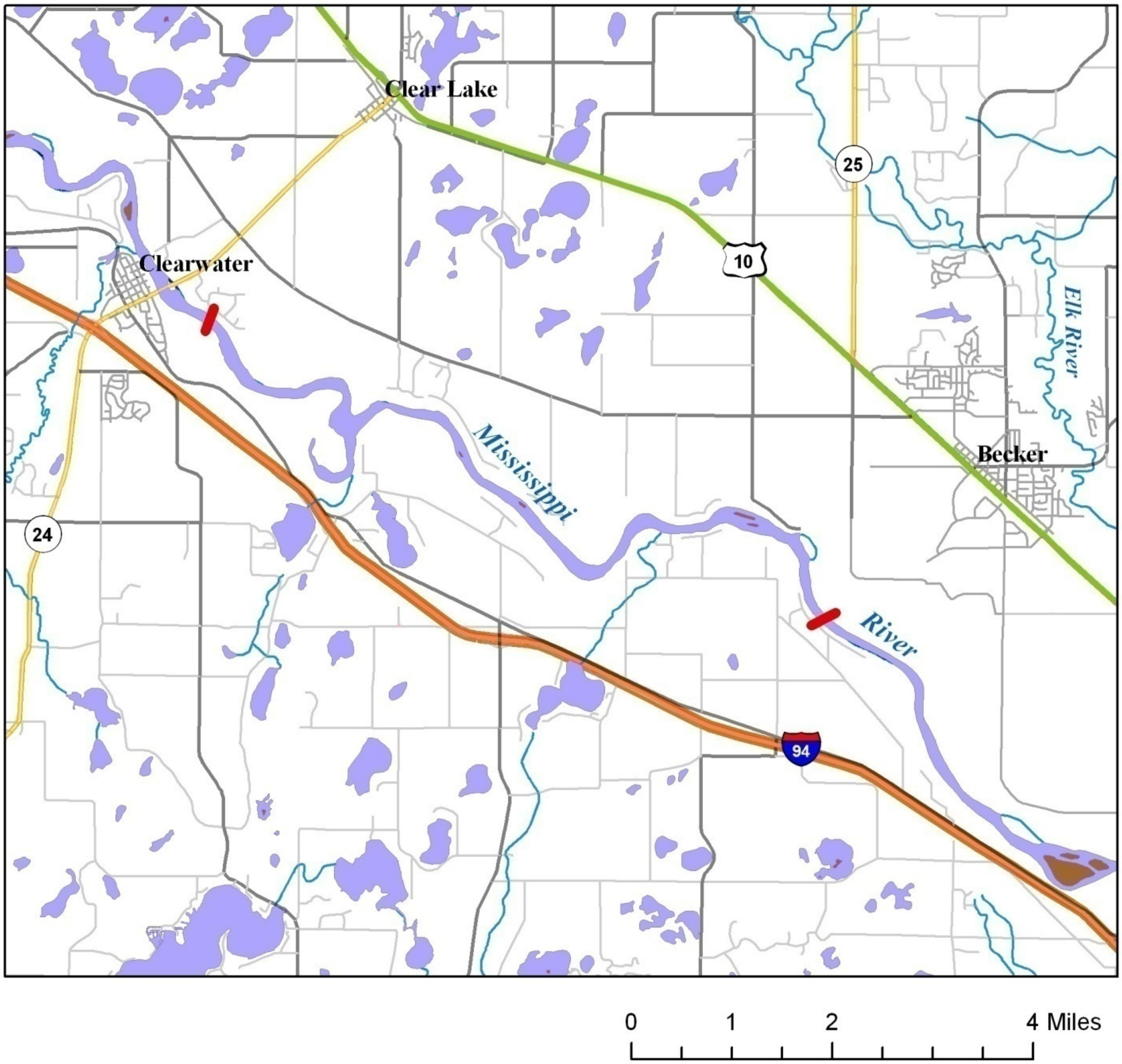

Figure 1. The reach, delimited by the two red lines, where the groundwater discharge measurement will be made.

The groundwater discharge will be estimated using a mass-balance equation (1).

$$V_o - V_i - V_{gw} - V_{et} + \Delta S = 0, \quad (1)$$

where V is the volume of water measured as outflow (o), inflow (i), groundwater discharge (gw), and evapotranspiration (et) and ΔS is the change in storage. The volume of water outflow will be measured by continuous acoustic Doppler current profiler (ADCP) measurements over an approximate 8-hour period. The volume of water inflow will be measured by simultaneous continuous ADCP measurements over an approximate 8-hour period plus individual measurements on tributaries, assumed to be constant over the 8-hour period. Dual ADCPs will be used at both the upstream and downstream ends of the reach and another will be rotated in so that all units can be compared against each other to control for any instrument bias. The volume lost to evapotranspiration will be estimated using the Penman equation, using information obtained from the National Weather Service, and applied to the area of the reach. The change in storage will be computed by deploying 7 temporary gages that record the elevation of the water surface. The change in storage is the change is elevation at each temporary gage applied to the respective are of the reach. The area of the reach will be computed by recording locations along both banks and around islands using real-time kinematic global positioning systems. The groundwater discharge will be estimated by setting the value for V_{gw} so that the sum is zero in equation 1. The estimated standard error of the estimated groundwater discharge is about 13 cubic feet per second[2]. The expected value of the estimated groundwater discharge is in the range of 20-30 cubic feet per second.

Most samples will be collected using equal-width increment techniques (EWI; Wilde and Radke, 1998). These EWI samples will be composited in a churn splitter. Split replicate samples will be collected from the churn and sent to the two labs. The purpose of the split replicate samples is to minimize any differences from sampling techniques in order to determine differences associated with the labs. Replicate error for the study period (2011-2012) will be calculated using relative percentage differences (see Christensen and others, 2009). An additional grab sample will be collected from the centroid of flow. This will provide a comparison between grab and EWI methods.

Historical continuous streamflow data and periodic total phosphorus data will be obtained from the HCWP. Protocols and methods of the Minnesota Valley Testing Lab will be reviewed in order compare to historical phosphorus values. Historical reference sample data (for example, USGS round robin data) for low level nutrients will be obtained from the labs. If comparable historical reference sample data is not available, low level nutrient samples for the USGS round robin sampling will be sent to Minnesota Valley Testing Laboratory to determine whether there are differences in bias or variability between labs. The HCWP used a third laboratory for some of the historical total phosphorus analyses. The USGS will obtain the data and quality-assurance information from this third lab in order to determine if the data is of acceptable quality to include in the analysis. The collection activities may be adjusted to send a third split replicate sample to this lab for quality-control purposes.

The environmental samples will provide a longer data set in which to assess the effects of land retirement and the quality-control samples will offer continued assurance that the data sets are comparable. The relative percentage difference (error) will be used to evaluate

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[2]Details on the computations necessary to estimate the standard error are not given here, but have been reviewed by USGS staff including Mark Smith, John Gray, and Tony Gottvald. See the review by Mark Smith for their comments.

approximately 10 years of existing data. The outcome of Activity 1 will be a quality-assured data set for use in Activity 2.

Activity 1B includes the collection of continuous groundwater recharge hydrographs and precipitation data during the non-freezing part of the year using existing sites and installations. Activity 1B will include two years of data collection, with the third year required to analyze the flows for sustainability. As shown in Figure 2, the USGS currently has a number of potential sites located throughout the study area that could potentially be used for monitoring groundwater recharge. In the current budget design, a total of five stations will be located throughout the study area, trying to maximize the limited number of sites with the widest areal extent and unique settings. Each station will include a pressure transducer inside of an existing observation well, with a collocated tipping bucket rain gage in order to get accurate estimates of local precipitation.

Activity 1C will compile water use information and determine variability of corridor groundwater use. All the available information on water use will be accounted for, including all municipalities, high-yield production wells for industrial purposes, and irrigation wells. Given the high number of current withdrawals, especially agricultural irrigation on the Anoka Sand Plain (ASP), it will be very important to get a good estimate on water withdrawals from each aquifer. Additionally, this information will need to be broken up by season, given the variable water withdrawals between the growing and non-growing seasons. Furthermore, septic return flow will need to be accounted for as an input back into the aquifers.

Finally, all the data will be analyzed to produce a groundwater mass balance for the surficial aquifer, including seepage run data. Previous modeling results from north of the study area will also be included as part of the analysis, given the similar hydrogeologic setting (Ruhl and Cowdery, 2004). Additionally, an unpublished groundwater model of some of the USGS land-use wells in the study area was completed by Tom Reppe (J. Stark, pers. comm.).

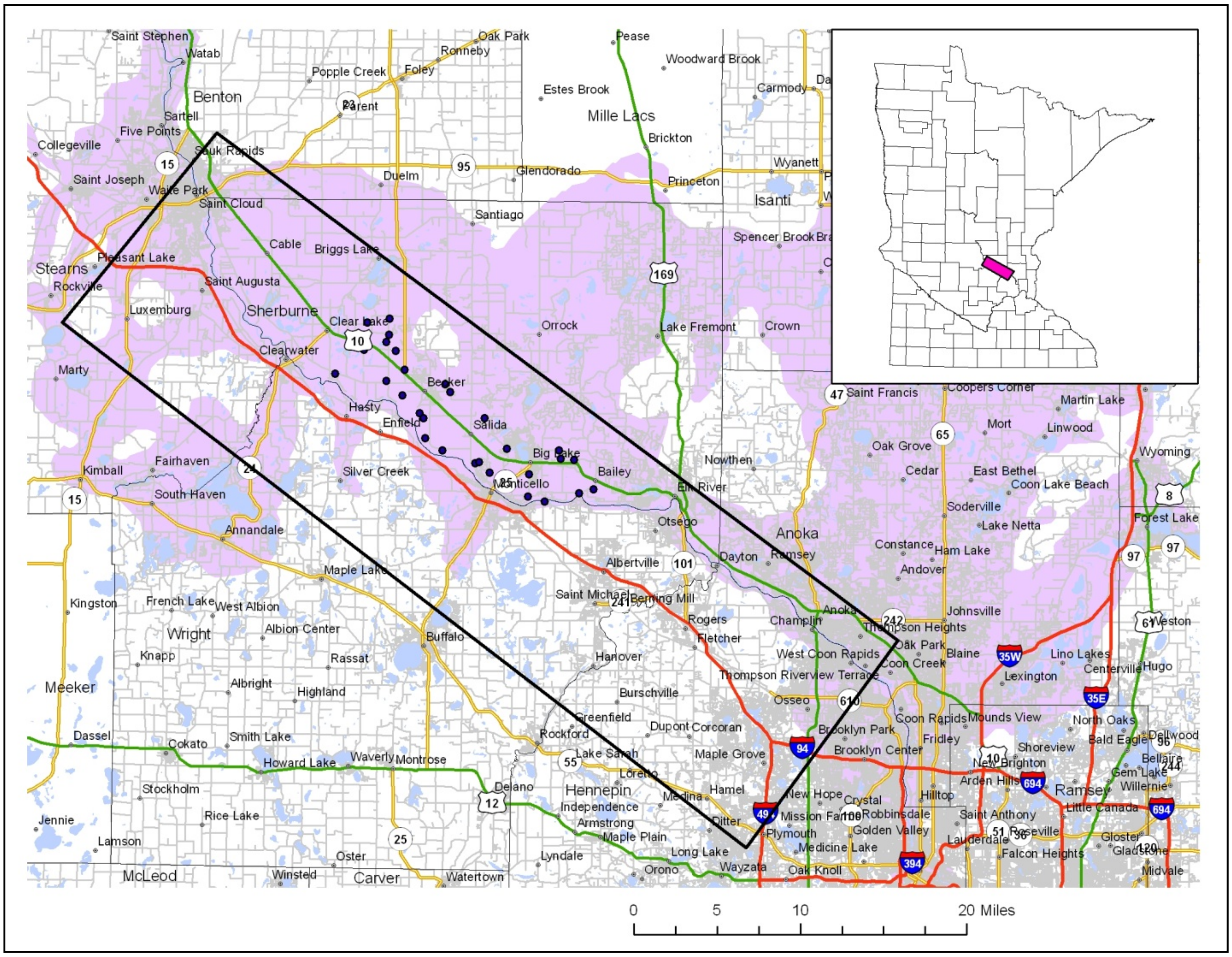

Figure 2. The estimated study region is shown, with the black box outlining the region from St. Cloud southeast to the edge of the Twin Cities Metropolitan Area. Final groundwater estimates will be determined based on a subsection of the outlined project area, with the estimates extrapolated to the entire study region. Pink areas on the map denote the areal extent of the Anoka Sand Plain, and the small black dots denote USGS land-use observation wells.

Activity 2: Characterize hydraulic properties in the corridor

Sustainable groundwater management requires information about the properties of buried aquifers and the confining layers through which water flows. Therefore, flow in and from buried aquifers will be estimated. Increased pumping from buried aquifers can induce flow from the overlying hydrologic system leading to a situation where the overlying water may no longer be available to sustain important surface waters. Understanding these flows will allow estimates of the effects of increased withdrawals from buried aquifers on other parts of the overall hydrologic system. This is a key step in understanding the sustainability of current and future groundwater withdrawals.

This activity will leverage and capitalize on work done through the ENRTF county atlas program. Work elements include:

a. Perform an aquifer pump test using an existing well to characterize the hydraulic properties of the buried glacial aquifer. These characteristics will be extrapolated over the entire study area.

b. Update the MGS compilation of existing pump test and specific capacity data.

c. Write final report.

Activity 2A will consist of one aquifer test in a buried aquifer to measure the aquifer's hydrologic properties and those of its overlying confining layer. The aquifer test will be performed utilizing an existing high-capacity well, with the USGS providing all the materials for completing a 2” observation well if needed. The USGS will coordinate cities and other water users, capitalizing on a location that can characterize the vertical leakage to the buried glacial (Figure 2). As a preliminary plan, the USGS will be conducting the aquifer test close to a high-yield production well, following the basic methodology outlined in Ruhl and others, 2002. The main aquifer test will be a 72-hour monitoring period, keeping track of the exact amount of water withdrawn in order to get the best results for the observation well. The USGS will also provide a pressure transducer for the observation well. Properties from this and other aquifer tests will be extrapolated to other buried aquifers in the study area identified in county atlases.

Finally, all the results from Activities 2A-2B will be included as part of USGS Scientific Investigations Report, integrated with the results from Activity 1. Given the project’s goal to help understand the available groundwater resources for the I-94 growth corridor from St. Cloud to the TCMA, the report will try to gain reasonable estimates for all pertinent hydraulic parameters so a full-scale groundwater model can be designed in the future.

Activity 3: Develop decision-making tool for sustainable water use

Activity 3 will be completed by the Environmental Quality Board.

A decision-making tool for defining land and water interactions will be developed for the corridor based on existing data and information. Under this activity, staff will work with other agency staff (e.g. DNR, MDH, Minnesota Department of Agriculture, Minnesota Pollution Control Agency and others) to compile information on water quality in the project area. Additionally, staff will work with the Board of Water and Soil Resources and local entities to evaluate current and future water and land use plans. This information will be brought together with findings on water flows generated in the first two activities and merged with other characteristics of the system (e.g. protected features, etc.).

The outcome of this tool is to provide a foundation to local governments and other corridor water users for understanding how the groundwater system works, what its limits may be, and how future local plans and activities throughout the corridor collectively will affect the resource. During the second year, work will include the characterization of current and future land use plans, current and future water use and drinking water quality. In year three, the first phase of a model to represent corridor land and water use demands and expected groundwater system responses will be prepared. This tool will help communities understand the model’s implications for, and its role in, sustainable land and water management throughout the corridor.

QUALITY ASSURANCE PLAN

The quality-control data was discussed previously under Activity 1, which is primarily a quality-control activity. In addition to the split replicates and blanks discussed in the methods section, the quality-assurance plan includes certain activities to maintain the integrity of the samples. All samples will be collected using decontaminated equipment. All clean collection jars, bottles, and containers will be pre-packaged. Sampling equipment will be checked prior to field work. Pre-field preparation ensures that all equipment is in good working condition and that all necessary containers, supplies, and materials are available for all activities. The USGS has standardized procedures for the collection and processing of water-quality samples. Data interpretation will be reviewed by the project leaders as results become available.

For all groundwater hydrograph records, routine maintenance will include a site visit every six weeks throughout the year to clean rain gages and a manual steel tape measurement for water level in the observation well. Twice a year, calibrations on both the rain gage and pressure transducer will occur, as outlined in the Center's quality assurance plan. For activity 2A, as outlined in the approach section, a second observation well with a pressure transducer will be installed to account for the heterogeneity of hydraulic heads around a high-yield production well.

PRODUCTS

The results from activities 1 and 2 will be presented in an USGS Scientific Investigations Report. It will include a complete description of the study area and its hydrologic setting, a detailed description of the methods and error analysis where appropriate, and present and interpret the results of the study.

ARCHIVAL PLAN

Data archival for this project will follow procedures and guidelines of the National Water Quality Assessment Program. Water quality will be archived in USGS National Water Information Systems databases. Archival procedures and reviews will follow those used by the USGS Minnesota Water Science Center.

Outcomes – Activity 1	**Completion Date**
E. High-precision groundwater discharge measurement	10/30/2013
F. Collect continuous groundwater and precipitation data	10/30/2013
G. Compile water-use information	01/01-2014
H. Produce groundwater mass balance	01/01/2014
Outcomes – Activity 2	**Completion Date**
D. Aquifer pump test	11-30-2013

E. Update MGS data	06-30-2014
F. Write final report	06/30/2014
Outcomes – Activity 3	**Completion Date**
C. Compile water quality data and local planning information	12/31/2013
D. Develop prototype GIS model	06/30/2014

RELEVANCE AND BENEFITS

Data from the study will be used to assess the relation between phosphorus and length of time land has been in retirement. The combination of advanced technology such as remote sensing, geographic information systems, and computer science is widely recognized as an effective approach to assess the potential effects of complex natural and anthropogenic forces on the structure and function of water-quality and ecological resources at various temporal and geographical scales. This project benefits from using mostly existing data. The analysis of the affect of agricultural land retirement practices may provide valuable information for other Minnesota River watersheds. Because it is part of the Hawk Creek Watershed Project area, the effort can take advantage of cost sharing.

PERSONNEL

This project will include a team of scientists from the USGS. Part-time staff from the USGS Minnesota Water Science Center will include: project lead, GIS, groundwater, and surface-water specialists, hydrologic technicians and students.

A hydrologist (GS-12) will be required for an equivalency of one year for the planned project duration of three years. Further help will be required as an agreement with the data section to install and maintain five stations which include a pressure transducer and tipping bucket rain gage. Additional assistance will also be required for one week during the aquifer test.

PROJECT BUDGET

2011-2012 Detailed Project Budget

IV. TOTAL TRUST FUND REQUEST BUDGET 3 years

BUDGET ITEM	**AMOUNT**
Personnel: EQB personnel - Graduate research assistant (0.5 FTE) to support elements of Activity 3 (beginning in year 2) and communicate project findings with local, state and federal partners under the activity.	$ 50,000

Contracts: The Environmental Quality Board will contract with the U.S. Geological Survey for work under activities 1 and 2 to determine groundwater characteristics and sustainability of the I-94 Growth Corridor.	$ 360,000
Contracts: EQB also will contract with the Minnesota Geospatial Information Office, or a contractor, for the development of a model to represent the corridor's land and water activities and to communicate the project's groundwater sustainability findings. This item will focus on creating a robust prototype tool to facilitate stakeholder and local engagement	$ 38,000
Equipment/Tools/Supplies: N.A.	$ -
Acquisition (Fee Title or Permanent Easements): NA	$ -
Travel: This project will require travel by EQB staff throughout the Twin Cities to St. Cloud corridor to meet with local agency staff, conduct stakeholder meetings and interact with USGS field staff. This is based on mileage and minimal lodging of approximately $660 annually.	$ 2,000
Additional Budget Items: N.A.	$ -
TOTAL ENVIRONMENT & NATURAL RESOURCES TRUST FUND $ REQUEST	$ 450,000

V. OTHER FUNDS

SOURCE OF FUNDS	**AMOUNT**	**Status**
Other Non-State $ Being Applied to Project During Project Period: USGS will contribute $240,000 to the project	$240,000	Secured
Other State $ Being Applied to Project During Project Period: N.A.	$ -	
In-kind Services During Project Period: EQB will provide project management and guidance throughout the project's life. A number of other state agencies will participate in the project and donate in-kind services.	$75,000/25,000	Secured/ Pending

Remaining $ from Current ENRTF Appropriation (if applicable): N.A.	$ -	
Funding History: *N.A.*	$ -	

USGS Fiscal Year Estimates

	FY2011	FY2012	FY2013	FY2014[1]	Total
LCCMR Share	$100,000	$100,000	$100,000	$60,000	$360,000
USGS share	$66,667	$66,666	$66,667	$40,000	$240,000
Total Project Costs	$166,667	$166,666	$166,667	$100,000	$600,000

[1]It is anticipated that funds in USGS FY 2014 will be spent prior to June. 30, 2014.

SAFETY

Job hazard analysis (JHA) provided as an attachment.

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