Groundwater:

Plan to Develop a Groundwater Level Monitoring Network for the 11-County Metropolitan Area

October 2009

Minnesota Department of Natural Resources

Waters

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EXECUTIVE SUMMARY

This report is produced in response to Minnesota Session Laws 2009 Chapter 37 Section 4 Subd. 3., which reads in part:

> *By October 1, 2009, the commissioner shall develop a plan for the development of an adequate groundwater level monitoring network of wells in the 11-county metropolitan area. The commissioner, working with the Metropolitan Council, the Department of Homeland Security, and the commissioner of the Pollution Control Agency, shall design the network so that the wells can be used to identify threats to groundwater quality and institute practices to protect the groundwater from degradation. The network must be sufficient to ensure that water use in the metropolitan area does not harm ecosystems, degrade water quality, or compromise the ability of future generations to meet their own needs. The plan should include recommendations on the necessary payment rates for users of the system expressed in cents per gallon for well drilling, operation, and maintenance.*

Background

Minnesota's water supply has long been taken for granted. This legislation recognizes the urgency for sustainable water management and the need for an integrated monitoring network to help achieve that goal.

The aquifers underlying the 11-county metropolitan area have provided a robust supply of water for an ever-growing population since statehood. Today, many communities in the metropolitan area are 100% dependent on groundwater for drinking water (Figure 1) and it is the source of drinking water for at least 75% of all Minnesotans. Demand for groundwater for all uses, especially public water supply, will continue to increase (Figure 2).

Considering the known risks threatening these critical aquifers, more decision-makers agree that it is imperative to increase efforts to learn more about flow pathways, rate of water movement and other characteristics of how they function. The current monitoring network, based largely on monthly individual hand measurements, is inadequate for the level of understanding needed. Automated systems capable of more frequent measurements are essential. We cannot manage what we do not measure.

Additional investments are needed to understand and protect groundwater systems so that future generations will also have an abundant source of clean water that is so integral to Minnesota's enviable quality of life.

Language in this law covers major work responsibilities for several agencies, including the Department of Natural Resources, the Pollution Control Agency, the Department of Agriculture, the Department of Health and the Metropolitan Council. Prior to passage of this law, these agencies along with numerous other partners were already working together to address more coordinated approaches to sustainable water management. This report was collaboratively produced by these agencies.

There are numerous initiatives currently underway that

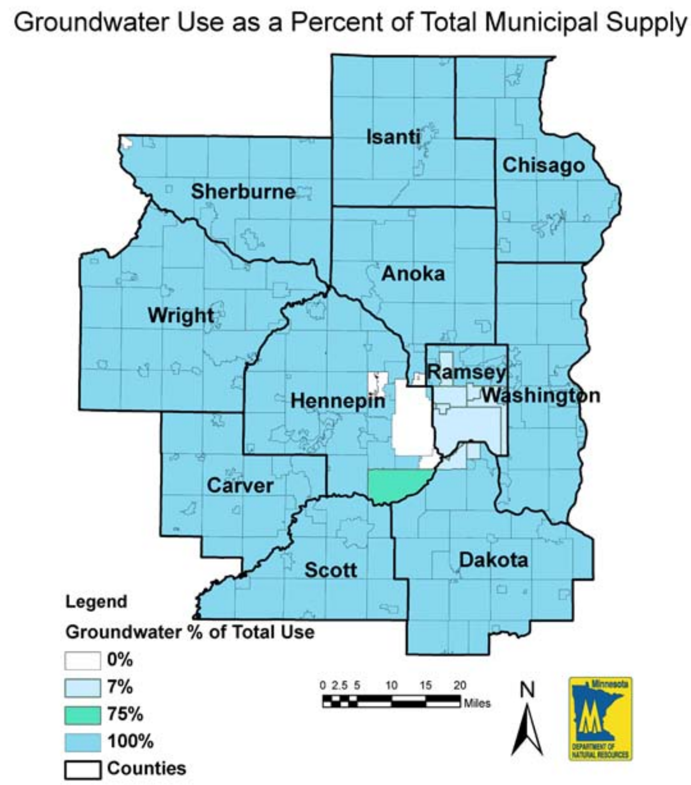


Figure 1: Dependency on groundwater for drinking water supply by municipality as a percent of total water used.

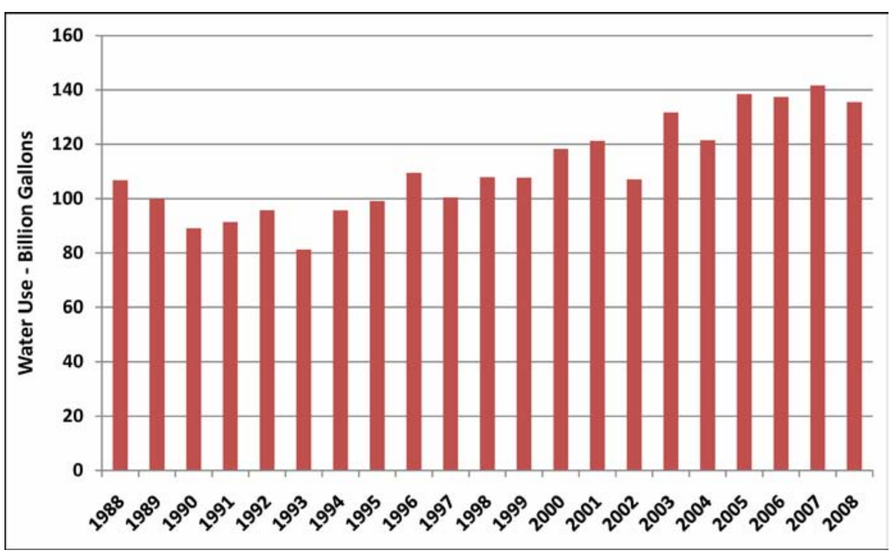


Figure 2: Groundwater use in the 11-County Metropolitan Area in billions of gallons.

will continue to move the state forward in addressing the very issues identified in this law. Nevertheless, we appreciate the legislative support and direction this law brings to help keep focus on the importance of achieving sustainable water use in the greater metropolitan area, as well as statewide.

Beginning with the first part of the legislative requirement:

By October 1, 2009, the commissioner shall develop a plan for the development of an adequate groundwater level monitoring network of wells in the 11-county metropolitan area.

The attached report entitled Plan to Develop a Groundwater Level Monitoring Network for the 11-County Metropolitan Area constitutes the major body of work related to this report. This report identifies a long-term plan for the data and monitoring systems needed to more fully understand these aquifers and flow pathways. That information will ultimately enable us to better protect long-term supplies, prevent water quality degradation, and ensure that water use does not harm ecosystems.

The plan, based on the National Framework for Groundwater Monitoring in the United States, is tailored to meet Minnesota's needs. The Groundwater Technical Work Group, comprised largely of technical groundwater professionals from the U.S. Geological Survey, Minnesota Geological Survey, University of Minnesota, Met Council, the departments of Natural Resources, Pollution Control, Health, and Agriculture, Environmental Quality Board, Dakota County and the professional consulting firms of Barr Engineering, Braun Intertec, and HDR, provided direction, input, content review and guidance in the development of this plan.

Additionally, we used guidance and recommendations from Groundwater Workshops sponsored by the Freshwater Society and the University of Minnesota Water Resources Center, the American Water Resources Association, the EQB, and other nationally recognized technical reports and papers on the topic of sustainable groundwater management in producing this plan.

Developing an integrated monitoring network and data management system called for in this plan will require both public and private involvement and investment in order to achieve the desired goals. It is essential to recognize that these investments will be much smaller than the cost of managing supply conflicts, remediation of threats to water quality and ecosystem health, and future treatment of impaired groundwater supplies if our current ample supplies of relatively clean water are permanently harmed.

Since a network must be viable for a long period of time, dedicated or endowed funding is recommended due to:

- the extensive amount of knowledge needed to be collected about the systems through research, sampling and monitoring points;
- the research required to gain a greater understanding of the geologic processes that formed the multiple aquifer layers that are buried beneath us; and
- the data and information systems that must be built to enable easy access to, and sharing of, historic information in conjunction with new data streams that will be added on an on-going basis.

The second part of the legislative requirement states:

The commissioner, working with the Metropolitan Council, the Department of Homeland Security, and the commissioner of the Pollution Control Agency, shall design the network so that the wells can be used to identify threats to groundwater quality and institute practices to protect the groundwater from degradation.

The groundwater level monitoring network plan identified in the first part will not replace the need for the existing and separate authorities and programs that are in place and designed to identify the threats and protect groundwater from degradation. Multi-agency coordination is at the heart of the Ground Water Protection Act and is how agencies will operate to a much greater degree going forward. We recognize that we must "Do together what we can't do alone."

Led by the Department of Agriculture, the Pollution Control Agency and the Department of Health, in collaboration with the Department of Natural Resources and the Metropolitan Council, an interagency groundwater monitoring strategy and groundwater protection strategy are under development that will enhance and support this plan from a water quality management aspect. All monitoring wells installed under this plan will be sampled for a basic set of water quality parameters.

The MPCA and MDA have plans to meet their statutory responsibilities to improve monitoring to help track both known and emerging threats in order to protect groundwater from degradation. Those plans should be utilized to provide the basis for continued support and funding for water quality management beyond needs described in this plan.

Beyond agency efforts, local government land use management decisions must avoid and, where possible, reverse trends that threaten our aquifers. Unsustainable usage demands and the introduction of pollutants will ultimately result in limits on availability and significantly higher long-term treatment costs for present supplies. Success will not come until all decision-makers understand the impacts of their decisions on groundwater resources.

The third part of the legislative requirement states:

The network must be sufficient to ensure that water use in the metropolitan area does not harm ecosystems, degrade water quality, or compromise the ability of future generations to meet their own needs.

The ultimate purpose of the monitoring network and data management system is to provide the information that will enable decision-makers to understand the threats to ecosystem health, water quality and sustainable supplies for future generations. Well data will enable us to better understand the flow pathways and rate of water movement of water through subsurface layers. Using improved models and actual measurements to understand the amount and rate of water movement into, through and out of the different aquifers will enable us to better manage supply and demand. Ecosystem managers and both water quality and water supply managers need this information to make more sustainable decisions. All water users will benefit from a systematic program for long-term collection of water level and chemical data.

Ecosystem impacts are difficult to measure for two primary reasons. First, there is a lack of knowledge about how much groundwater flows from aquifers to surface water systems, except where intensive monitoring has been undertaken to address known impacts from pumping. Second, we do not have sufficient understanding of all the lifecycle water needs of all the plants and animals that make up an ecosystem and how changes in volume of groundwater flow might affect their individual or collective health.

We will continue to improve our understanding of site specific management needs, expand monitoring, and require specific studies where modeling and data suggest ecosystem harm might occur from overuse of an aquifer. Where known sensitive resources such as calcareous fens, trout streams, lakes, wetlands and streams are at potential risk based on our analyses, DNR currently uses an adaptive management approach. Adaptive management is a structured, iterative process of decision making, with a goal of reducing uncertainty via system monitoring. Monitoring accrues information needed to improve future management. Adaptive management can be characterized as “learning by doing.”

The DNR will work to develop a monitoring plan over the next few years that will better address ecosystem health. The establishment of the monitoring network, outlined in our response to the final legislative requirement below, will be an important step to improve our understanding of water movement in our aquifers as a predictive tool for protecting ecosystem health.

The fourth and final part of the legislative requirement states:

The plan should include recommendations on the necessary payment rates for users of the system expressed in cents per gallon for well drilling, operation, and maintenance.

While the first three parts of the legislative requirement address broad concepts on sustainable management of our groundwater system in the 11-county metropolitan area, this final part will be limited to work necessary to understand and sustainably manage the water supply.

To address monitoring needs, a “backbone network” for long-term groundwater level monitoring must first be established for the 11-county metropolitan area and ultimately expanded statewide. The design of this network will include a long-term plan for the collection of data, development of systematic monitoring systems, and creation of a real-time water level information data management system that will help local and state water managers protect long-term supplies. Development of the monitoring system will occur sequentially as data from each successive year inform and guide placement of additional wells in subsequent years.

Monitoring is a shared responsibility of all users. Coordination of monitoring at the aquifer level rather than jurisdictional level is more appropriate since impacts of groundwater use can occur far from the point of taking. Also, no jurisdictional boundaries, not even watershed district boundaries, are necessarily accurate for purposes of groundwater management. While the backbone network will provide essential data on how water moves through the aquifers, to plan for sustainable supplies we will also need water users to accurately report water level information from their production wells and local groundwater level monitoring wells for inclusion in the data management system.

Our initial estimation for an adequate “backbone” water level monitoring network for the 11 county metropolitan area will consist of all useable existing monitoring locations, which is estimated at 200 sites. It will also require establishment of 60 well “nests” consisting of a series of closely located wells in each of the monitored subsurface formations at a selected location. All wells will need to be instrumented with automated data systems and each of the well nests will need to be instrumented with real-time access to the automated data systems.

Costs include well drilling and construction, monitoring equipment and installation, ongoing operations and maintenance, data storage system costs, land rights costs for the well nest locations, and costs for interpretation and analysis of the data. It is estimated this will cost $8,861,150 over a four year period. The annual on-going cost for operation and maintenance of the water level monitoring network is estimated to be $825,000. The following table describes cost components for the first four years of network build-out and for subsequent years.

An estimated 140 billion gallons of groundwater per year are used in the 11-county metropolitan area. During the four years of network buildout, the costs will be:

$8,861,750.00 /4 years = $2,215,437.50 per year

$2,215,437.50 per year / 140 billion gallons per year= $0.00001582 per gallon =

0.001582 cents per gallon, or

$15.82 per million gallons.

Once the backbone network is established, costs for ongoing operation and maintenance will be:

$825,000.00 per year

$825,000 per year / 140 billion gallons per year= $0.00000589 per gallon =

0.000589 cents per gallon, or

$5.89 per million gallons.

Table 1: Costs for the Creation, Maintenance, and Operation of a Groundwater Level Monitoring Network for the 11-County Metropolitan Area.

	Year 1	Year 2	Year 3	Year 4	Total Development	Subsequent Years
Total Wells in Backbone Network	80	175	270	380	380	380
Backbone Network Establishment: Well Drilling, Easements, Instrumentation, Operation and Maintenance	$ 1,083,400	$ 1,310,750	$ 1,440,600	$ 1,627,000	$ 5,461,750	$ 627,000
Technical Support / Quality Control / Groundwater Analysis	$ 350,000	$ 350,000	$ 350,000	$ 350,000	$ 1,400,000	$ 105,000
Data Management and Access through Web Portal	$ 500,000	$ 500,000	$ 500,000	$ 500,000	$ 2,000,000	$ 93,000
	$ 1,933,400	**$ 2,160,750**	**$ 2,290,600**	**$ 2,477,000**	**$ 8,861,750**	**$ 825,000**
Dollars per Million Gallons	$ 13.81	$ 15.43	$ 16.36	$ 17.69	$ 15.82	$ 5.89
Cents per Gallon	0.001381	0.001543	0.001636	0.001769	0.001582	0.000589

Notes: All values 2009 dollars

By the end of the fourth year of network build-out, the backbone network will consist of 60 nests for which data are transmitted real time (approx. 3 wells per nest) and 200 monitoring wells with dataloggers

INTRODUCTION

The American Water Resources Association (2009) identified thirteen water resource challenges facing water professionals in the next decade; seven of which are listed here:

- Developing moderate, flexible policies aimed at reasonable use of water resources in order to sustain water quality, and to sustain groundwater and surface water supplies.
- Acquisition of credible long-term data and assessments, and the development of reliable predictive models.
- Integrating watershed-level thinking into water resources management decision development.
- Developing strategies to respond to the effects of climate change on water and the environment.
- Maintaining/upgrading the nation's physical water infrastructure.
- Protecting/restoring the natural infrastructure (watersheds, springs, streams, floodplains, and wetlands).
- Maintaining/enhancing in-stream water quality for ecosystem support.

Each of these challenges applies to Minnesota. All seven challenges must be faced in order to accomplish the goal of clean and plentiful water supplies for future generations. Minnesota's dependence on groundwater is great, even in the 11-county Metropolitan Area (metropolitan area) where both Minneapolis and St. Paul make use of surface water. Water use is rising and the trend is expected to continue due to population growth despite conservation efforts.

Sustainability of water resources in general and groundwater in specific is an urgent concern and federal and state activities are ongoing. The monitoring framework presented in this document in large part is an adaptation of the National Framework for Groundwater Monitoring in the United States (Advisory Committee on Water Information, Subcommittee on Groundwater, 2009) and of the Water Quality Monitoring Framework (Figure 3; National Water Quality Monitoring Council, 2003) to Minnesota's needs. The current status of coordinated, long-term management efforts are documented. These efforts are in need of improvement if Minnesota is to meet human and ecosystem needs for water.

A process for improvement of monitoring networks in support of sustainable water resources management is outlined herein. This report is produced in response to Minnesota Session Laws 2009 Chapter 37 Section 4 Subd. 3., which reads in part:

By October 1, 2009, the commissioner shall develop a plan for the development of an adequate groundwater level monitoring network of wells in the 11-county metropolitan area. The commissioner, working with the Metropolitan Council, the Department of Homeland Security, and the commissioner of the Pollution Control Agency, shall design the network so that the wells can be used to identify threats to groundwater quality and institute practices to protect the groundwater from degradation. The network must be sufficient to ensure that water use in the metropolitan area does not harm ecosystems, degrade water quality, or compromise the ability of future generations to meet their own needs. The plan should include recommendations on the necessary payment rates for users of the system expressed in cents per gallon for well drilling, operation, and maintenance.

In February 2008, DNR provided the Environmental and Natural Resource Division of the Minnesota House Finance Committee with a generalized initial estimate of the need to add approximately 6,000 additional groundwater level monitoring wells statewide to the 750 wells that are currently monitored. An estimated drilling budget of $120 million in 2008 dollars would be needed to meet this need. A plan to develop the metropolitan area portion of the groundwater level monitoring network is presented in this document.

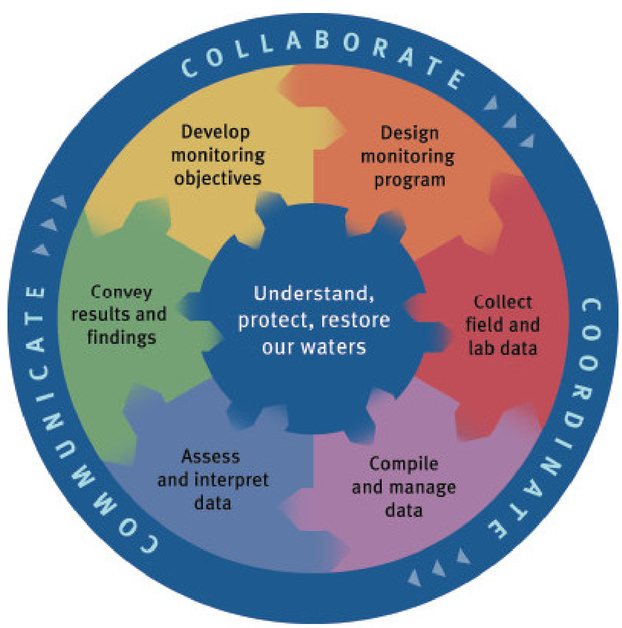


Figure 3: NWQMC proposed framework for water quality monitoring programs (NWQMC, 2003).

NETWORK DESIGN AND STANDARDS

Groundwater cannot be managed in isolation. Climate and surface water monitoring networks must also be improved and sustained; work to do so has been enhanced by funding provided under the Clean Water Legacy Act. Geologic and hydrogeologic mapping are indispensable and more of this mapping work remains to be done within the metropolitan area. The majority of the area is underlain by a thick sequence of productive aquifers (Figure 4). Most of what is known about these aquifers has been learned as wells have been drilled and pumped and as information has been compiled and analyzed in County Geologic Atlases. Figure 5 shows areas lacking adequate information about aquifers for the Metropolitan Council's regional ground water modeling purposes. Figure 6 shows progress toward complete coverage of the metropolitan area with County Geologic Atlases, which will provide a great portion of the necessary information for improving the understanding of aquifer properties and relationships between aquifers and surface water resources.

There is truth in the statement "you can't manage what you don't monitor". Continued monitoring over extended time creates the long term records needed for resource management. "Typically, collection of water-level data over one or more decades is required to compile a hydrologic record that encompasses the potential range of water-level fluctuations in an observation well and to track trends with time" (Figure 7; Taylor and Alley, 2001). Accurate water use data must also be available.

Climate norms are established over 30-year time intervals. Chemistry of ground water can change over similar time scales. Similarly, observation well records increase in value as more wells have a length of record of thirty years or more. A groundwater level monitoring network that is maintained indefinitely through funding cycles will be a stable backbone network providing information needed for sustainable water management.

Network goals

Data collection efforts that have defined and accepted knowledge goals, documented network design, and plans for design revision, data analysis and use are preferred. Minnesota's network will of necessity be comprised of a network of networks. We will share data among these networks and use the merged networks to form the active water level monitoring system.

Knowledge goals

Fundamental questions that network design must be responsive to include:

- How does this aquifer system work and how might we use the network to test conceptual models of the hydrogeologic setting?
- What is the unstressed condition of the monitored aquifer?
- How can we use the network to define the direction and gradient of groundwater flow?
- How is groundwater chemistry changing over time?
- What are the sources/causes of these changes?
- How might we use the network to establish background levels of water quality indicators?
- What are the groundwater level trends?
- What are the long-term and annual changes in groundwater storage due to effects of climate and of withdrawals?
- How much groundwater moves through the system?
- How much groundwater contribution is needed by critical ecosystems to maintain minimum (non-lethal) and maximum (successful reproduction of sustainable populations) suitable conditions?
- What is the relationship between climate, groundwater storage, groundwater appropriations, and groundwater contribution to critical ecosystems?
- What are the effects of periods of drought and above average rainfall?
- What are the long-term effects of climate change?
- What are the effects of groundwater withdrawals?
- How do groundwater management efforts impact chemistry, recharge, discharge, ecosystems, etc.?

Design Criteria

Network design determines the sampling locations, frequency of monitoring, variables to measure, and the standards for day-to-day operation of the entire system. Design criteria should:

- Answer the knowledge goals defined above.
- Describe a transparent network structure. It should be clear how the parts fit together to create a whole system more useful than the individual parts.
- Clearly define benefits resulting from involvement of multiple agencies and local units of government.
- Identify the aquifers and aquifer systems to be monitored.

Simplified Boundaries of the Major Bedrock Aquifers in the Twin Citites Metropolitian Area

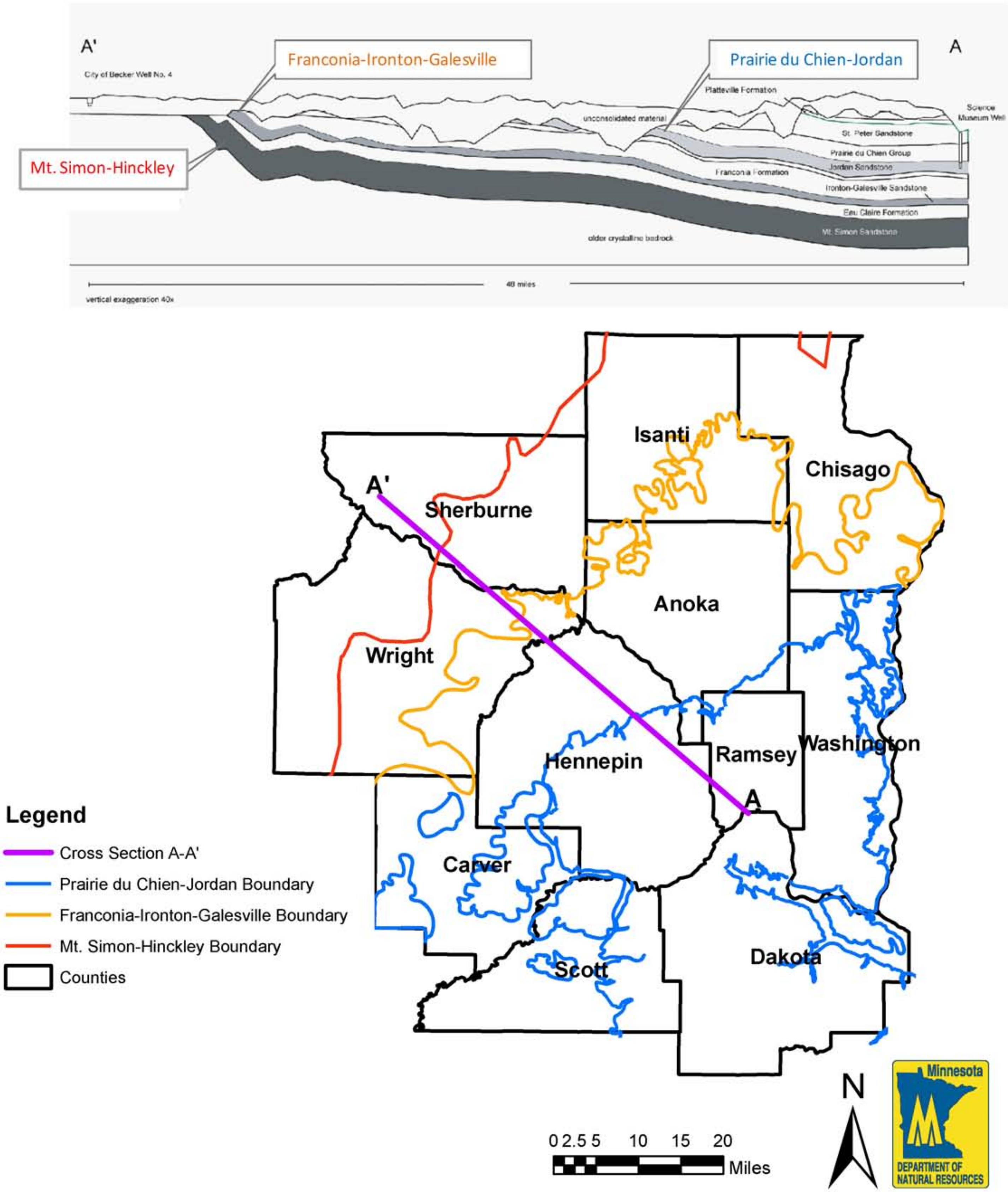


Figure 4: Extent of major bedrock aquifers in the metropolitan area.

Uncertain Aquifer Properties

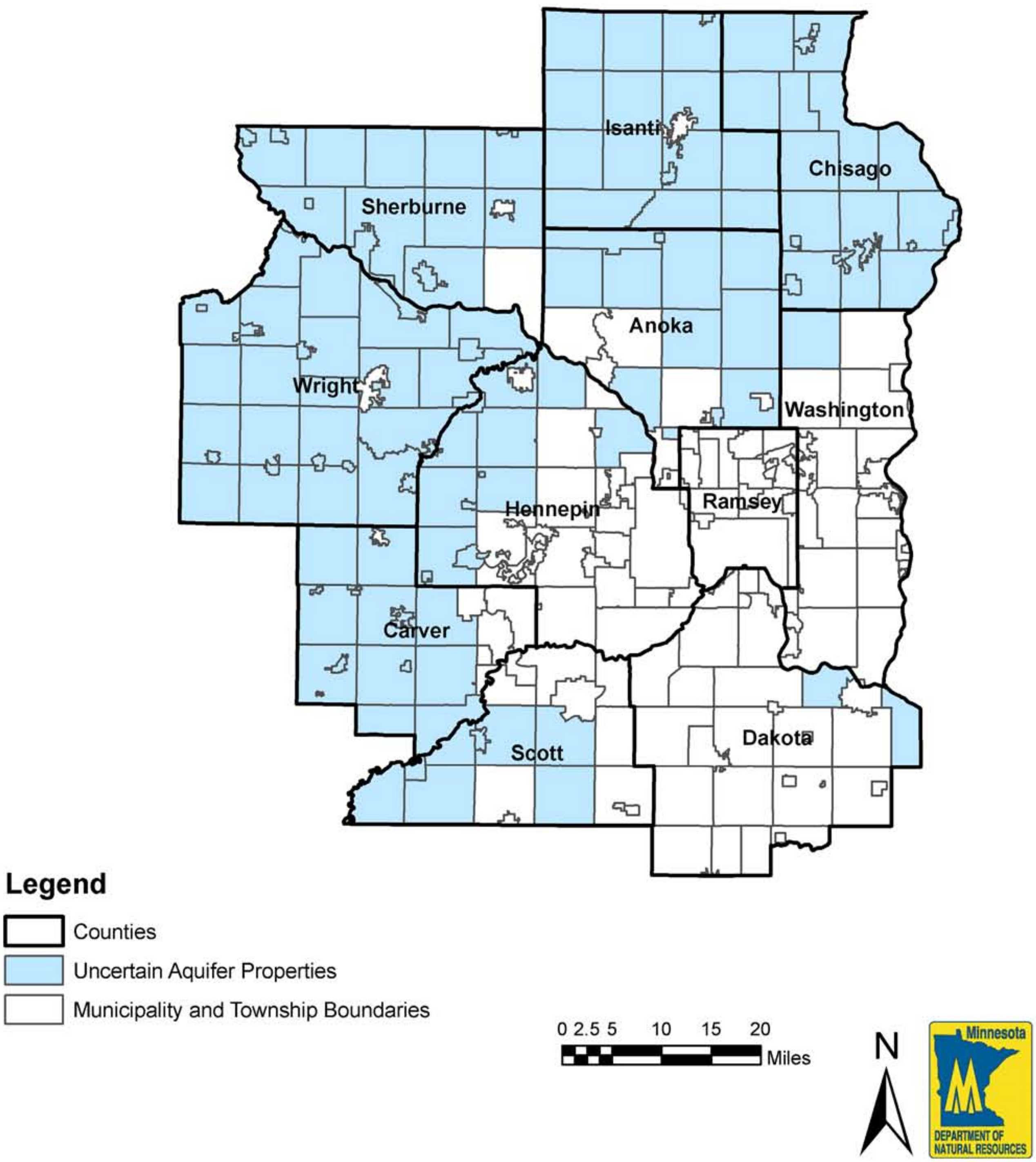


Figure 5: Areas lacking adequate aquifer information for ground water modeling purposes.

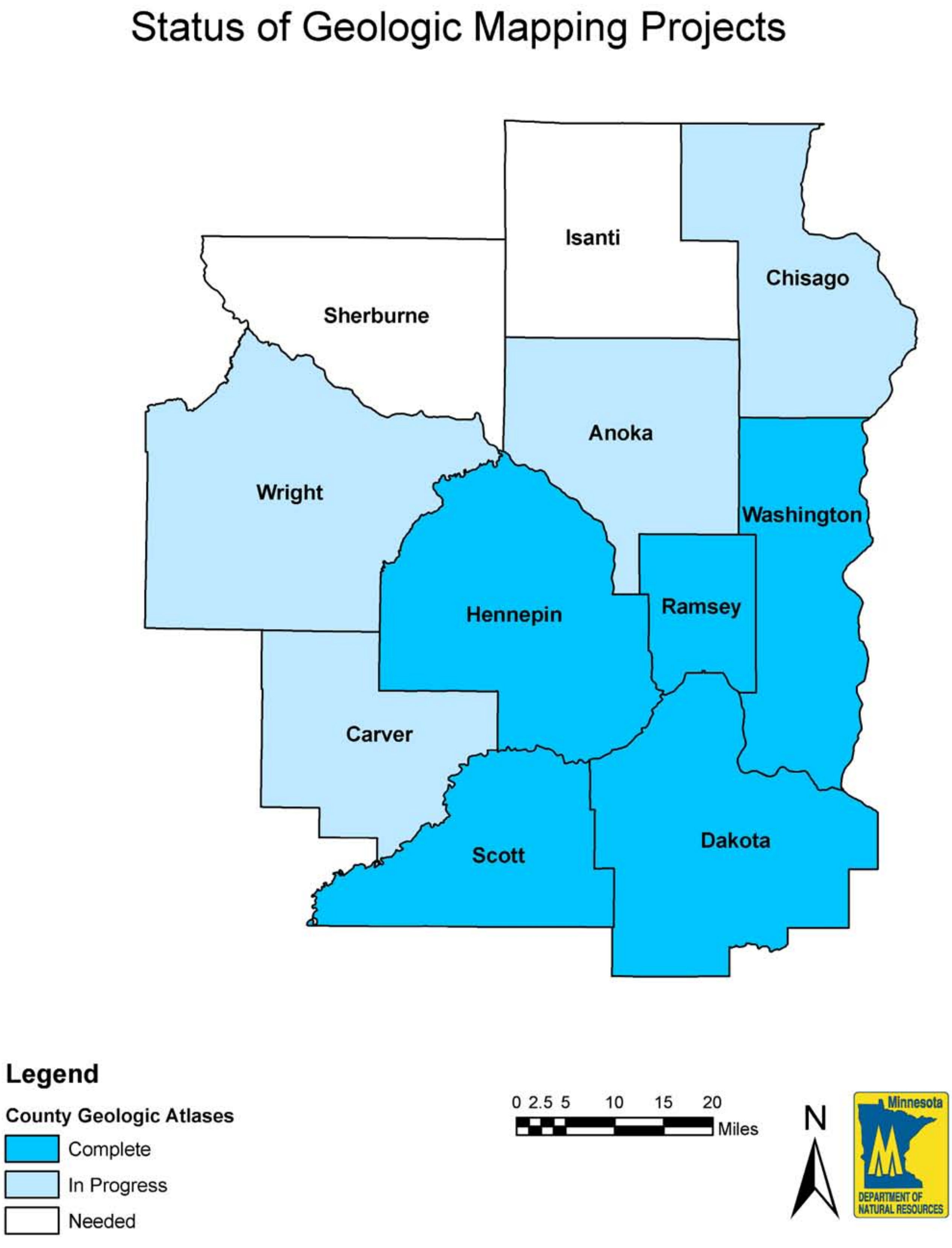


Figure 6: Status of County Geologic Atlases.

Intended use of water-level data	Typical length of data-collection effort or hydrologic record required			
	Days/weeks	Months	Years	Decades
To determine the hydraulic properties of aquifers (aquifer tests)	✓ (teal)	✓ (yellow)		
Mapping the altitude of the water table or potentiometric surface	✓ (teal)	✓ (yellow)		
Monitoring short-term changes in ground-water recharge and storage	✓ (teal)	✓ (teal)	✓ (yellow)	
Monitoring long-term changes in ground-water recharge and storage			✓ (teal)	✓ (teal)
Monitoring the effects of climatic variability			✓ (teal)	✓ (teal)
Monitoring regional effects of ground-water development			✓ (teal)	✓ (teal)
Statistical analysis of water-level trends			✓ (teal)	✓ (teal)
Monitoring changes in ground-water flow directions	✓ (yellow)	✓ (teal)	✓ (teal)	✓ (teal)
Monitoring ground-water and surface-water interaction	✓ (teal)	✓ (teal)	✓ (teal)	✓ (teal)
Numerical (computer) modeling of ground-water flow or contaminant transport	✓ (yellow)	✓ (teal)	✓ (teal)	✓ (teal)

EXPLANATION

✓ (teal) Most applicable for intended use

✓ (yellow) Sometimes applicable for intended use

Figure 7: Typical length of water-level-data collection as a function of the intended use of the data (Taylor and Alley, 2001).

- Identify additional natural features to be monitored such as springs, stream, and lakes.
- Incorporate measurement of the volumes of water moving through the system (flux monitoring) in the form of stream flows, spring discharge, rainfall, infiltration, evapotranspiration and related aspects of the hydrologic cycle.
- Incorporate initial chemistry monitoring to improve existing groundwater quality monitoring networks.
- Use a standard process based on a conceptual understanding of the aquifer system to select monitoring locations in three dimensions. Wells completed at different depths at a common location are called well nests. Well nests are the most efficient method of monitoring in three dimensions.
- Use an iterative process that incorporates the results of historic long term monitoring, synoptic measurements and regional groundwater modeling to guide network development and monitoring.

- Use a standard process to determine monitoring frequencies based on location and hydrogeologic conditions as well as any additional intended uses of the water level data.

- Establish a minimum groundwater level sampling frequency for the backbone network. Special projects may increase sampling frequency.

- Identify relevant design elements such as well construction that impact network effectiveness.

- Establish standard field and lab protocols to ensure comparability over time.

- Establish standard data exchange processes whereby all cooperators provide standardized data submissions.

- Ensure that monitoring locations meet the goals of multiple network partners.

- Establish standards for well construction and maintenance, including hydraulic testing and surveying of water level measurement points relative to permanent survey reference points.

- Create an accessible data management system with redundant back-ups that will allow cooperators to upload and verify individual measurements and electronic files of time-series data collected by automated dataloggers.

- Provide data immediately for management decisions and network maintenance through web-based data access in multiple formats (e.g. tabular, hydrograph, etc.) summary statistics calculated over selectable intervals, and allow downloading of the quality-controlled data.

Analysis and Use of Monitoring Data

Data analysis and quality control protocols will be developed for the backbone network and each subnetwork using the best available information. Such protocols will be included in the design and subsequent redesigns of the overall network. Provisions must be made to evaluate these protocols periodically.

Reporting protocols should follow a similar model and include public web access reporting standards which must be automated. Users will query the data set and create summaries and other derivative network products. Individual users of water at every scale are a primary audience; understanding and protecting Minnesota's groundwater resources for current and future uses will depend on the involvement of all users.

A schedule for review and refinement of network design and protocols should be established at the onset.

Types of Networks and Monitoring Categories

Several sets of definitions exist for different types of monitoring. For example, the terms baseline monitoring, ambient monitoring, and background monitoring are similar. Monitoring can be long term or short term, continuous in time or continuous in space, sample selection could be random or predetermined. We define four types of monitoring: Baseline Monitoring, Surveillance Monitoring, Trend Monitoring and Special Study Monitoring. These terms follow the usage in the National Framework for Ground-Water Monitoring in the United States (National Framework) (Advisory Committee on Water Information, Subcommittee on Ground Water, 2009; Figure 8) and define purposes for monitoring. A given well's record of water level measurements may be used for multiple purposes over time or simultaneously.

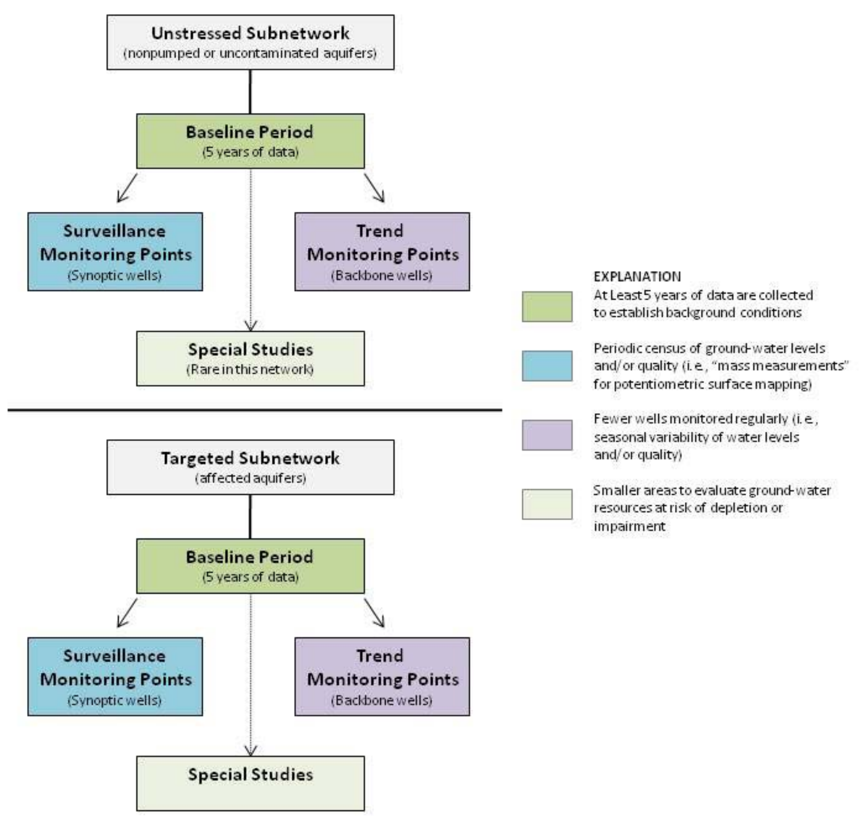


Figure 8: Network types and relationships among networks (National Framework for Ground-Water Monitoring in the United States, Advisory Committee on Water Information Subcommittee on Ground Water, 2009).

We refer to the monitoring network for the metropolitan area as a ‘backbone’ network in part to avoid the inherent assumptions and limitations included in using any of the established labels.

This discussion focuses on a network created to monitor water levels, but the goal is also to ensure that the network will be useful for water quality monitoring as needed.

Baseline Monitoring

Baseline monitoring may also be called background monitoring, condition monitoring, or ambient monitoring. It is typically long term and continuous in time. Baseline monitoring may be used to establish water levels at a location within an aquifer prior to the intervention of a stress or impact, i.e. prior to aquifer development. Baseline monitoring takes place at all monitoring locations during the first several years as the water levels are measured and a baseline pattern is established. In another sense, some wells may be selected for baseline monitoring because they are not expected to respond to an anticipated stress or impact. For wells installed after a stress on the system has begun (in an existing well field, for example), ‘baseline monitoring’ may reveal an ongoing trend in water levels.

Monitoring for Special Studies

Robert C. Ward, a monitoring network expert who has long struggled with these issues, states: “It is difficult for one monitoring system to answer the “what” and “why” questions at the same time” (Ward, 1989). Baseline, surveillance, and trend monitoring typically deal with the “what” question. Once, for example, the “what is the quality of the water” question is answered and reveals a problem, then special study monitoring can come into play to address the “why” or “how far have we come in fixing this problem” questions. This type of monitoring is also termed targeted monitoring, compliance monitoring or effectiveness monitoring and the nature of the monitoring is entirely dependent on the study parameters.

Limitations

The ultimate purpose of monitoring is to inform policy decisions and management actions. Groundwater quantity and quality information cannot prevent or solve problems on its own. No single network can address all groundwater concerns, but a regional backbone network is extremely important because it can provide information on trends, data for modeling, and assist in problem identification. Efforts to address specific concerns will usually require that more detailed information be added to that which can be obtained from the backbone network.

For management to be effective, a number of factors outside the control of groundwater specialists must be addressed:

- In general, the public’s understanding of the groundwater resource is poor. Groundwater systems are hidden from direct measurement and observation; they are more difficult to perceive and understand.
- Short-term social and economic issues must not veto groundwater management decisions.
- Risks to human and ecosystem health must be evaluated and, where there is uncertainty, human and ecosystem health must trump other needs.
- Costs of changes in water use that must occur to ensure sustainability, including costs that accrue when pumping is restricted, must be apportioned over those benefitting from water use. Minnesota water law, for example, allows for reductions in permitted water use volumes in a water use conflict area to protect the resource and highest priority uses.
- A regulatory framework is in place that allows managers to suspend (for a seasonal impact) or terminate (for a permanent impact) water withdrawals that will potentially impair ecosystem services. If adequate monitoring of both surface and groundwater resources is in place, regulators will be able to manage to prevent unintended impacts.

SUMMARY OF MINNESOTA'S CURRENT NETWORKS

Minnesota employs a multi-agency approach to groundwater monitoring and protection. It takes the concerted effort of all agencies, along with local and federal partners, to build a comprehensive picture of the status of the state's groundwater resources. These groundwater quality and quantity data are needed for water supply planning, permitting and other regulatory actions, best management practice implementation and better understanding of surface water and groundwater interactions that have the potential to affect water quality and availability.

A 2004 Memorandum of Agreement (MOA) between the Minnesota Pollution Control Agency (MPCA), the Minnesota Department of Agriculture (MDA), and the Minnesota Department of Health (MDH) clarified the agencies' respective roles (as specified by state statute) in ambient groundwater quality monitoring, and these agencies operate a statewide integrated groundwater-quality monitoring system. Figure 9 is a graphical depiction of agency roles, including the water quantity management responsibility of the Minnesota Department of Natural Resources (DNR).

Opportunities to better connect the information collected by the DNR for groundwater management with the Minnesota Pollution Control Agency's (MPCA's) groundwater quality database, the Minnesota Department of Health's (MDH's) drinking water well data, and data collected by public and private water suppliers to enhance data accessibility for groundwater management should be further explored. A merged dataset will give value to many different programs. There has not been adequate funding to compile current and historic groundwater data from the programs that collect it. Such an effort is a priority for all state agencies. Work has begun to refine the options and costs involved in creating a comprehensive groundwater data management system that retrieves, validates, and builds on historic data collection activities.

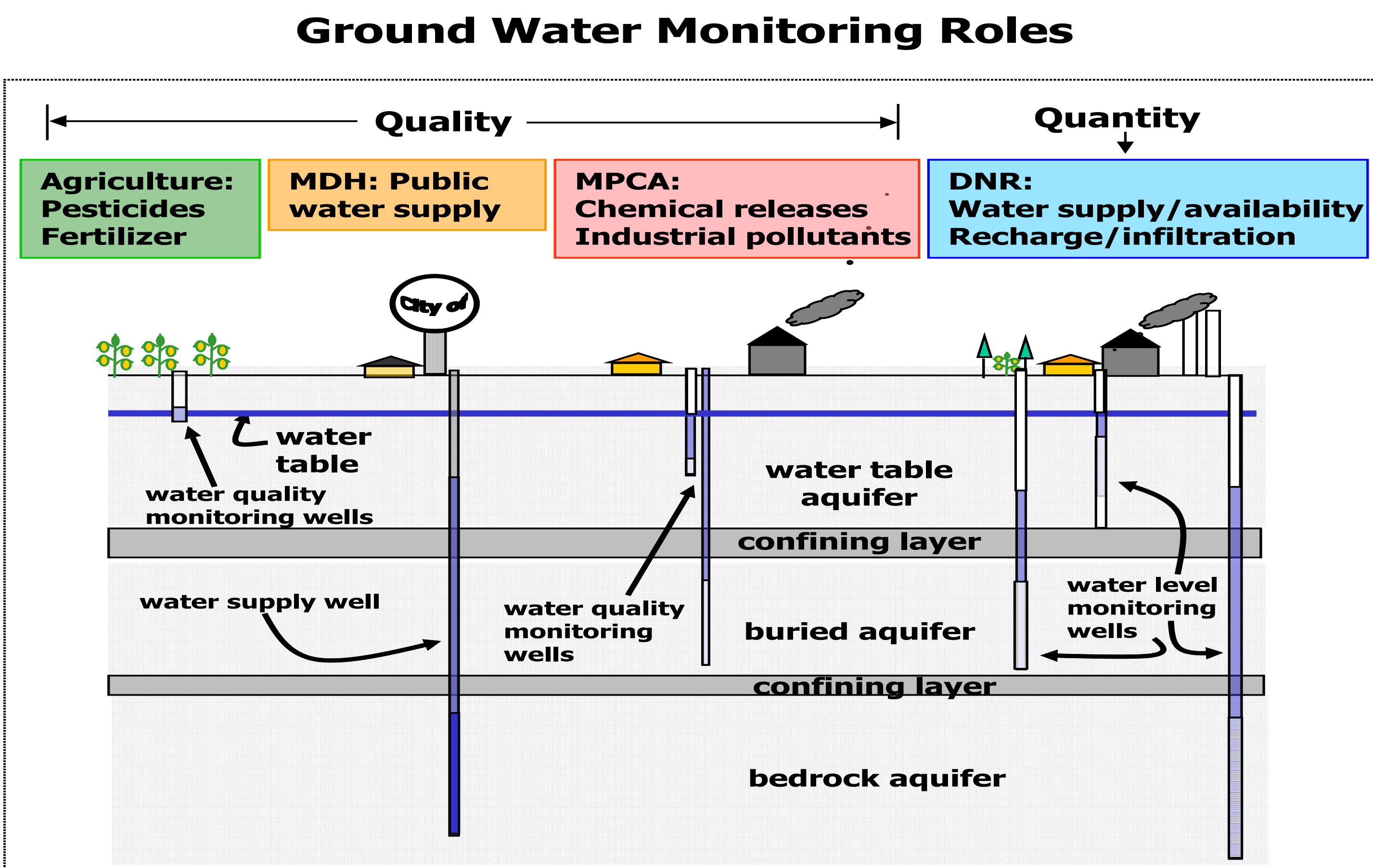


Figure 9. Groundwater monitoring roles of the state agencies.

DNR – baseline, trend and surveillance monitoring

DNR's primary focus is on water quantity. DNR manages a cooperative water-level monitoring network created in the 1930s (Figure 10). In the metropolitan area this network consists of 177 wells. It was built, with USGS assistance, by incorporating wells used for DNR and USGS studies and with supply wells that are no longer used. The DNR and USGS studies were not designed to be part of a regional water-level monitoring effort. Many wells are not on land under public control and cannot be considered to be permanent monitoring locations. Soil and Water Conservation Districts serve as data collection agents for the current network.

DNR has a ground water monitoring workgroup that is involved in planning and guidance for the current network. One immediate concern is that there is currently no comprehensive repository for groundwater level monitoring data. The DNR groundwater level monitoring network's database is being reworked to provide enhanced web access, but development of data management, processing and storage tools for time series data awaits adequate funding.

DNR's vision for the future includes the enhancement of the current network into a state-of-the-art 'backbone' network for ground water levels and a data system or portal that meets the needs of the state's water agencies, other cooperators and the public. The network also will inform and provide support for subnetworks, including subnetworks built primarily for water chemistry or quality monitoring goals.

To supplement the cooperative network, the DNR and partners conducted synoptic water level measurements in the Metropolitan area during March and August 2008 (Figure 11). The results are snapshots of water levels and can be compared seasonally and with other synoptic measurements to gain an understanding of major changes in groundwater storage and flow over time. These images from 2008 show that groundwater withdrawals had created a cone of depression in Mt. Simon water levels and that this impact was more pronounced during summer when more water was being pumped. Synoptic measurements should be repeated at five-year intervals.

Other water level information collected by and for DNR includes aquifer test data and permit-required monitoring data:

- DNR's aquifer tests are conducted to understand how groundwater withdrawals will impact the groundwater resource from which the water is being pumped. Impacts on other users and other natural resources are evaluated using aquifer test information. These data are provided to MDH for source water protection planning.
- Permitted groundwater users (Figure 12) are often required in their permit to measure and report water levels in specific wells when it is determined that monitoring will assist the DNR in water management. Permit-required monitoring data are used to evaluate water availability and predict long-term impacts of groundwater withdrawals on the ecosystem and on other users.

Ongoing DNR groundwater level monitoring network program activities:

- Many wells measured as part of the DNR cooperative network are in poor condition due to age. An ongoing inventory of wells and well condition allows the extent of deferred maintenance to be quantified (Table 2). Some wells need to be replaced and the old wells sealed; some wells are in locations or are constructed to depths which served the original study needs but are not needed for ongoing monitoring and should be sealed; some wells need preventive maintenance. All wells should receive routine maintenance.

- Well placement is being evaluated, both to determine which of the wells mentioned above may be redundant and to propose locations for new wells. Where gaps are identified, new wells must be drilled or permission to monitor appropriate existing wells must be obtained. Most recent progress has focused on the Mt. Simon aquifer; new wells have been sited and many have been drilled.

- DNR staff have developed draft guidance documents for the improved DNR network. Any new wells that will be drilled and any existing wells that will be part of the 'backbone network' must meet the standards established in the guidance documents and be suitable for long-term monitoring of at least twenty years. These wells must also be constructed to allow for water quality sampling. A basic suite of water quality parameters (pH, conductivity, temperature, cations, anions, trace metals [including low-level arsenic], tritium, and stable isotopes of hydrogen and oxygen), will be routinely analyzed for each well when it is completed or when it is added to the network. Repeated sampling and selection of additional parameters for analysis would depend on the location and possible subnetwork to which a well may belong. MDH monitoring well fees must be paid for all wells.

- Water level monitoring technology is improving. Automated data collection technology will allow better quality data (water level, temperature and conductivity, for example) to be collected at more frequent intervals. The nominal one-month sampling interval for water level data is not adequate for some of the purposes for which the data will be needed, e.g. assessment of recharge (Delin and Falteisek, 2007). Time and money may ultimately be saved because fewer routine site visits will be required.

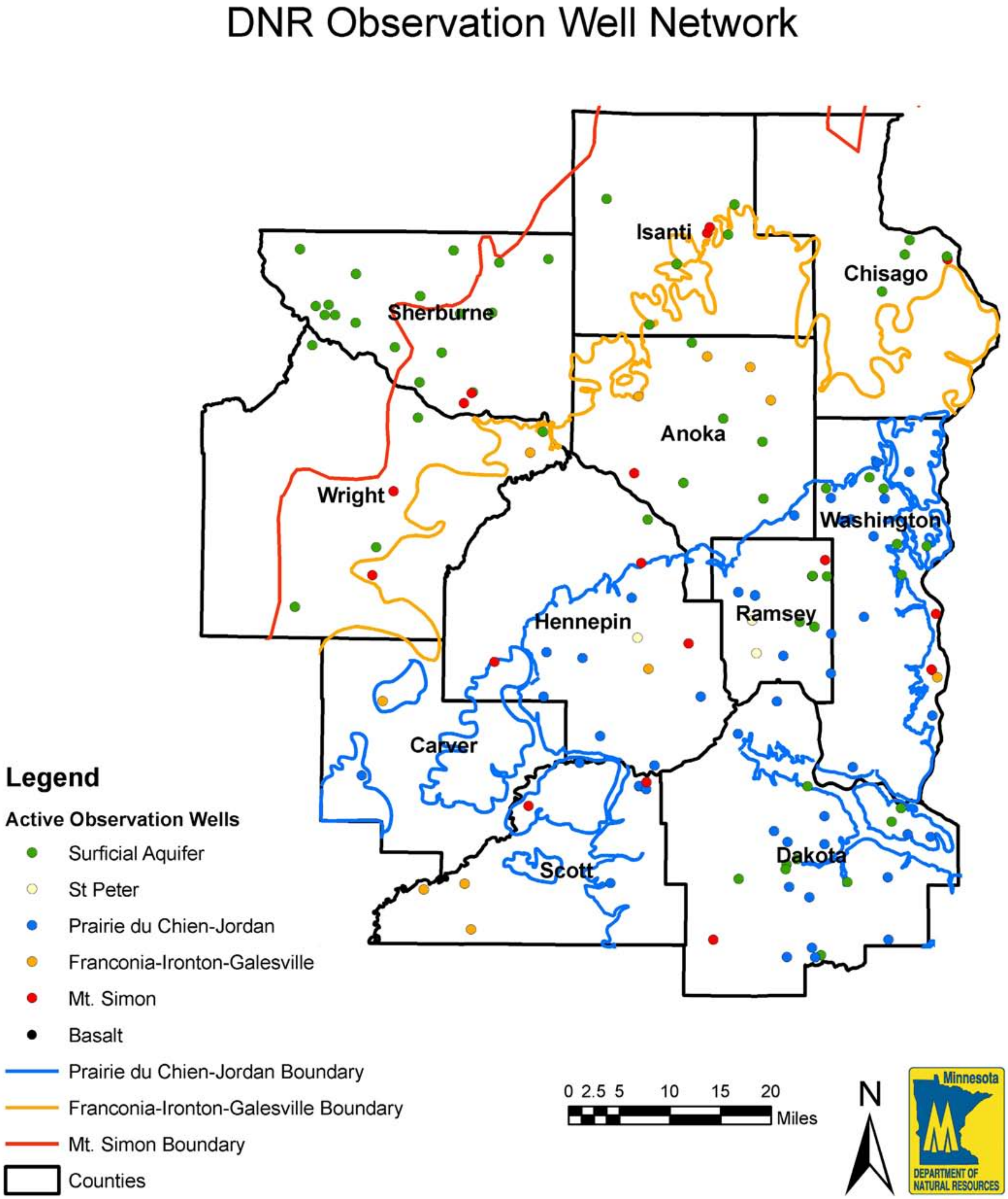
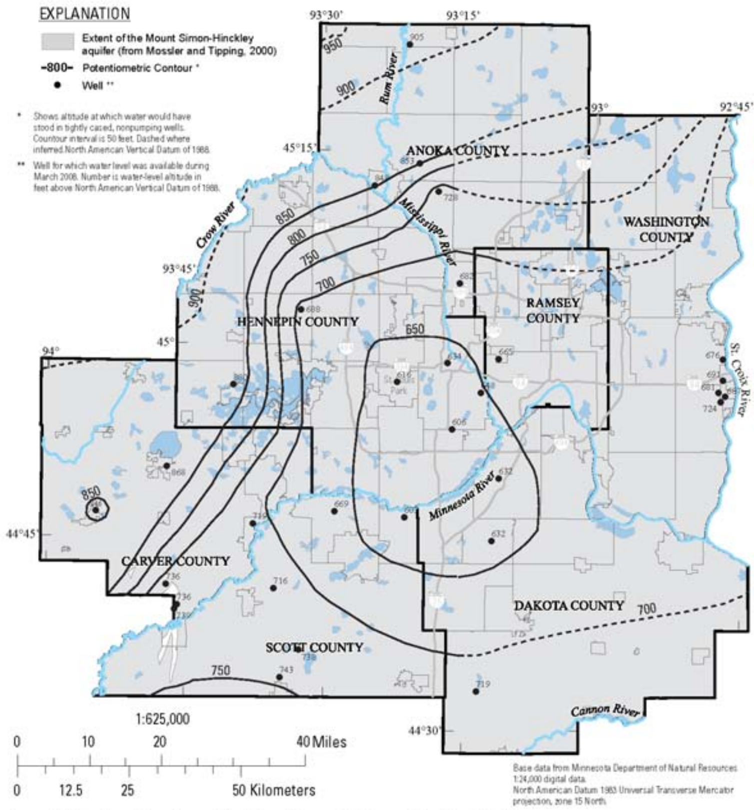


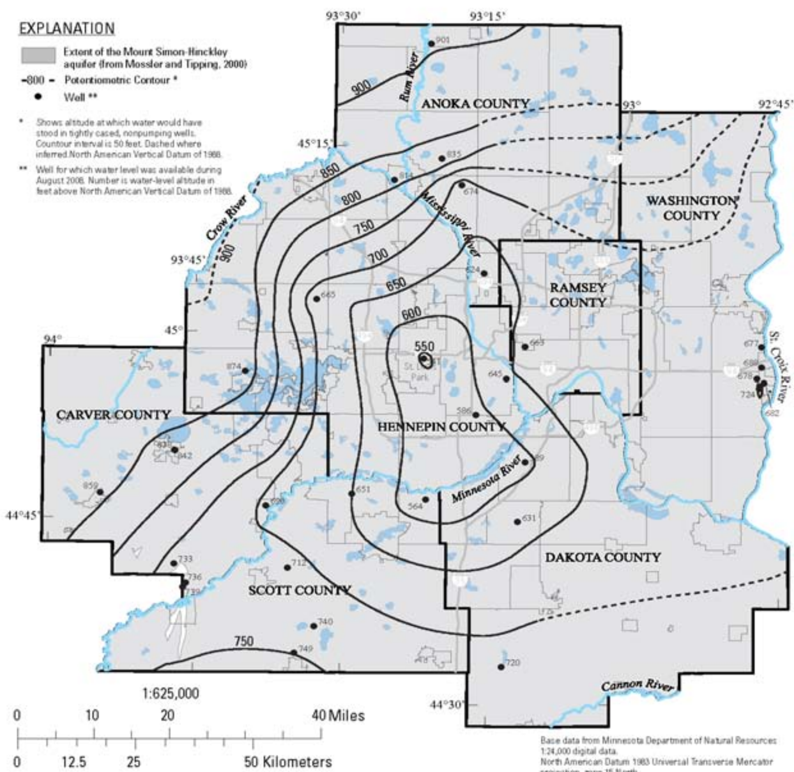
Figure 10: Current DNR observation well network in the 11-County Metropolitan Area.

Synoptic Water-Level Measurements Reveal Seasonal Changes



March, 2008

Figure 6. Potentiometric surface of the Mount Simon-Hinckley aquifer, March 2008.



August, 2008

Figure 11: Synoptic measurement results of the Mt. Simon-Hinckley Aquifer from March and August of 2008.

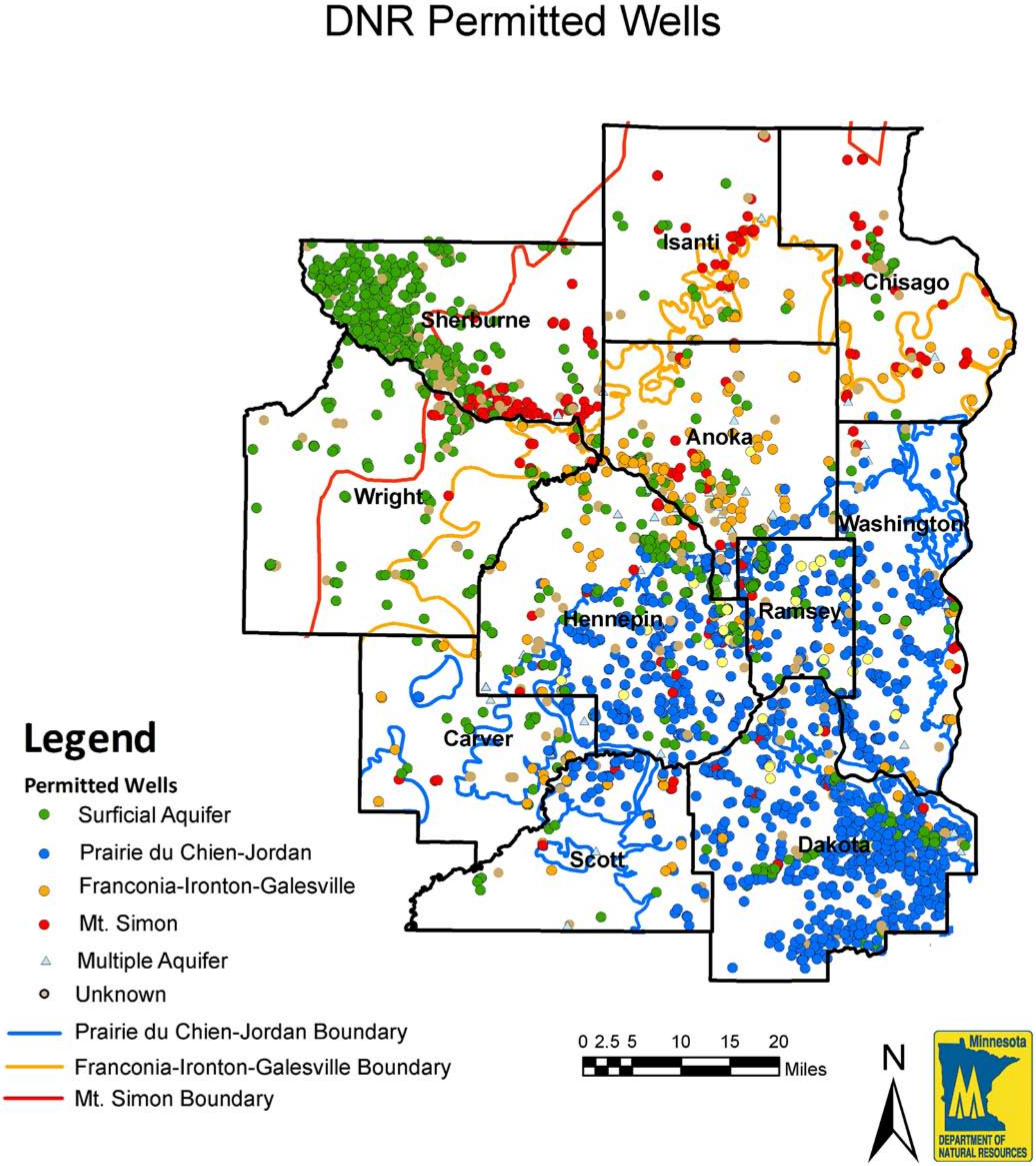


Figure 12: Permitted groundwater users by aquifer.

- Information routinely collected during aquifer tests and through permit-required monitoring cannot currently be stored in the database that holds 'traditional' DNR groundwater level monitoring data. The database structure must be changed to accommodate the larger amounts of information collected by dataloggers. The network upgrade also must address calibration of datalogger data.

The following sections briefly summarize monitoring efforts by other agencies. We will continue to closely coordinate with these efforts to create an integrated water quality and water quantity network for the metropolitan area.

Table 2: All active water level monitoring wells in the current DNR Cooperative network were evaluated. Seventy-seven of the wells need maintenance or have a problem that must be resolved before the well should be considered for inclusion in the backbone network. Well maintenance issues are being addressed as funds allow.

Status of Observation Wells in the 11 County Metro Area

		Problems with Active Wells					
County	Ok	Failed [a]	Irrigation [b]	Private/Public [c]	Construction [d]	Redundant [e]	Total
Anoka	8	4	1	2	0	0	15
Carver	0	0	0	1	1	0	2
Chisago	5	0	0	2	0	0	7
Dakota	15	1	10	2	1	4	33
Hennepin	17	0	0	2	1	0	20
Isanti	5	3	1	0	0	0	9
Ramsey	10	0	0	4	3	0	17
Scott	12	0	1	1	1	0	15
Sherburne	7	9	2	0	0	4	22
Washington	20	5	2	0	1	0	28
Wright	1	5	0	2	1	0	9
Totals	100	27	17	16	9	8	177

a - failed slug test (slug tested wells were 4" diameter or smaller, had screens, did not have a pump)
b - irrigation wells (wells can be difficult to read due to pump and thick oil on top of water)
c - domestic or public wells (wells can be difficult to read because of pump, danger of contamination to well)
d - construction (insufficient well log, possible connection in well nest, pump needs to be removed)
e - redundant (well measures same aquifer as another nearby well

MPCA – trend monitoring and special studies

Under the MOA with MDH and MDA, the MPCA engages in water quality monitoring to assess the status and trends of Minnesota's groundwater system for non-agricultural chemicals. The data inform drinking water protection and supply efforts, identifies threats to groundwater quality, and provides information for Total Maximum Daily Load studies, and guides development of best management practices to avoid future groundwater impacts.

Ambient (i.e. baseline) groundwater quality monitoring has been conducted by the MPCA since 1978 to document the quality of the groundwater resources statewide and identify trends. Site-specific investigations (i.e. special studies) also are conducted by the agency to determine the extent of non-agricultural point-source contamination to the groundwater, such as from petroleum spills or landfills.

The MPCA's current ambient groundwater quality monitoring network focuses on aquifers that are most susceptible to pollution from human activities, namely the surficial sand and gravel and Prairie du Chien-Jordan aquifers. By focusing on vulnerable aquifers, the network provides an early warning of contamination introduced into the groundwater system and allows for earlier detection of trends in groundwater quality.

The MPCA is in the process of enhancing the ambient network to discern the effects of urban land uses on groundwater quality conditions. A total of 150 additional monitoring wells are needed to allow assessment of water-quality conditions and trends by land-use setting. Figure 13 details the MPCA's ambient network and planned additions in the metropolitan area. The MPCA is working closely with state agencies and local governments to site and install new wells to meet water quality monitoring and other monitoring needs. Funds have been appropriated from the Clean Water fund to install at least 60 of the needed monitoring wells during fiscal years 2010-2011.

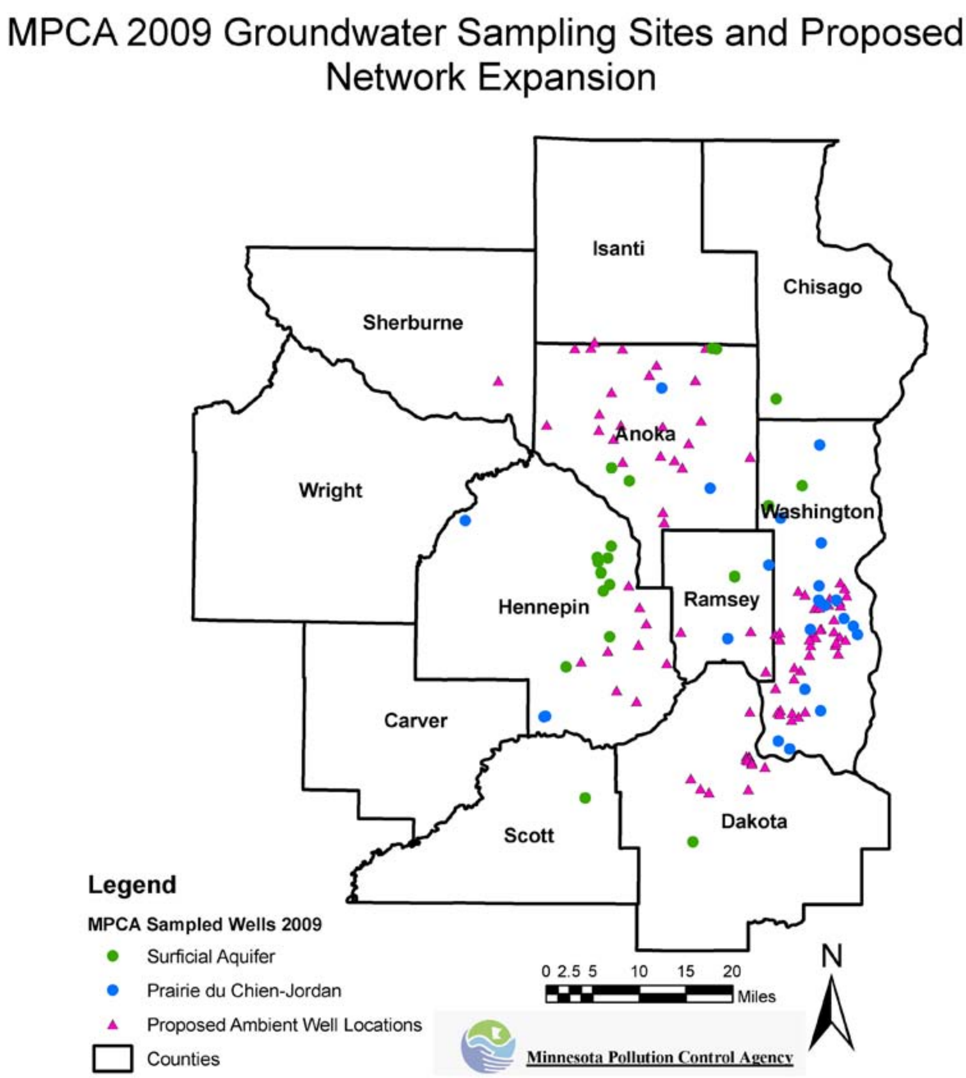


Figure 13: MPCA ambient well locations (43 wells) and proposed expansion (89 wells).

MDA – trend monitoring and special studies

The focus of MDA monitoring activities is on water quality impacts from pesticide use. Special study monitoring is primarily in response to site-specific incidents. Baseline monitoring for pesticides is conducted through specially designed monitoring well installed adjacent to farm fields. Data are used to evaluate water quality impacts, the need for alternative application methods and as a measure of the overall success of changes in pesticide management practices. In the metropolitan area the MDA monitors groundwater impacts from agricultural chemical applications in the rural fringe surrounding the suburban area as well as urban pesticide use impacts in cooperation with MPCA. MDA also conducts or assists with special studies of pesticides in drinking water wells. Figure 14 depicts wells that are being sampled by MDA in the metropolitan area.

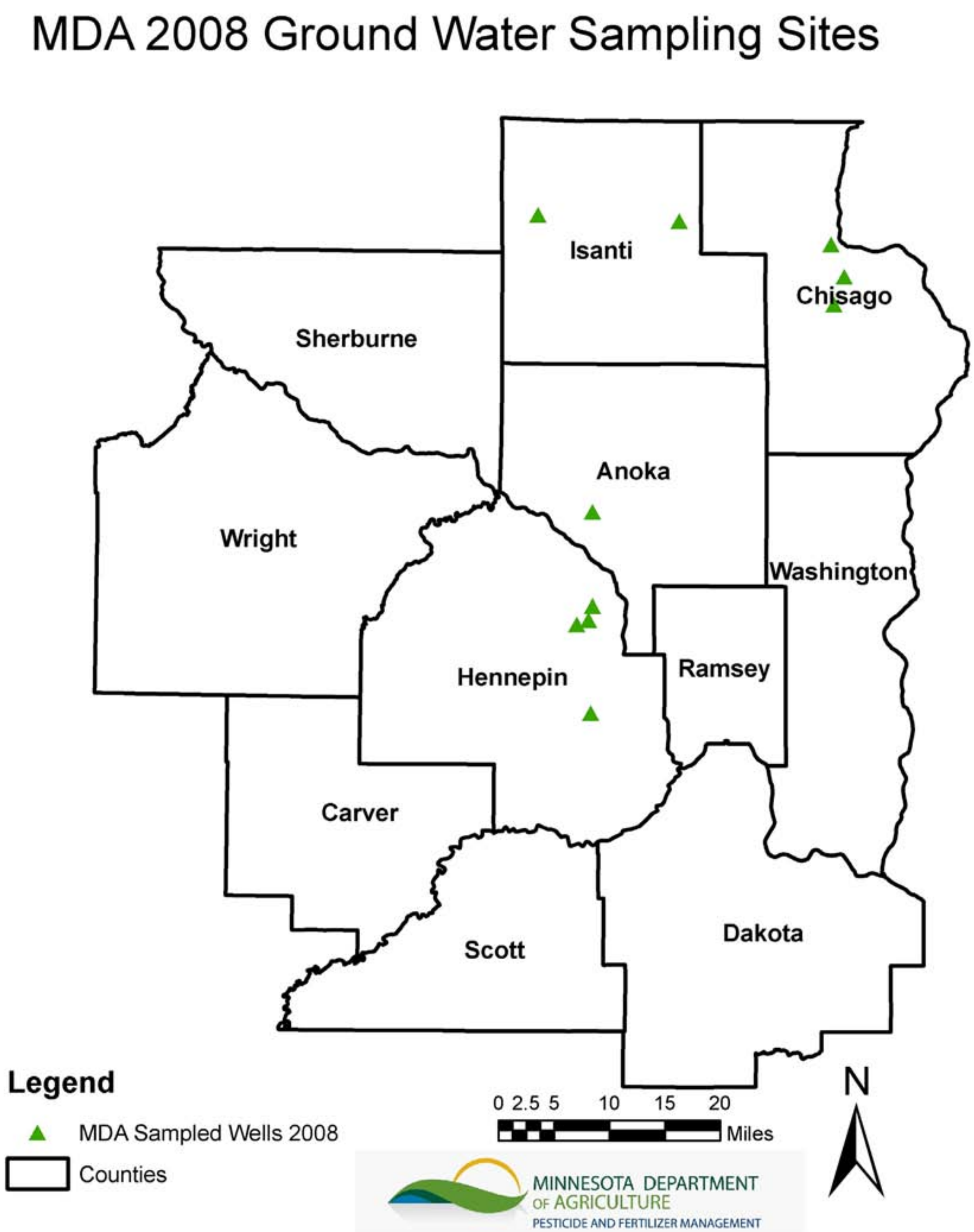


Figure 14: MDA 2008 groundwater sampling sites.

MDH – baseline and trend monitoring

MDH engages in statewide monitoring to evaluate groundwater chemistry conditions, to aid investigation of specific problems, and to demonstrate effectiveness relative to established standards. This monitoring and related activities conducted by the MPCA and the MDA are defined by a Memorandum of Agreement. Most of MDH's monitoring is geared towards safeguarding human health, especially with regard to drinking water protection. Figure 15 shows the distribution of public water suppliers in the metropolitan area. MDH has water chemistry monitoring responsibility for all public water supplies.

Specific examples of some of these monitoring activities are listed below:

Condition monitoring

- Occurrence and distribution of naturally occurring contaminants such as arsenic and radium.
- Characterization of general aquifer chemistry by sampling selected public water supply wells statewide (2010).

Effectiveness (compliance) monitoring

- Safe Drinking Water Act compliance sampling of all public water supply systems in the state. Frequency of sampling and contaminants of concern vary depending on many parameters including vulnerability to contamination and system type, e.g. community, non-community.

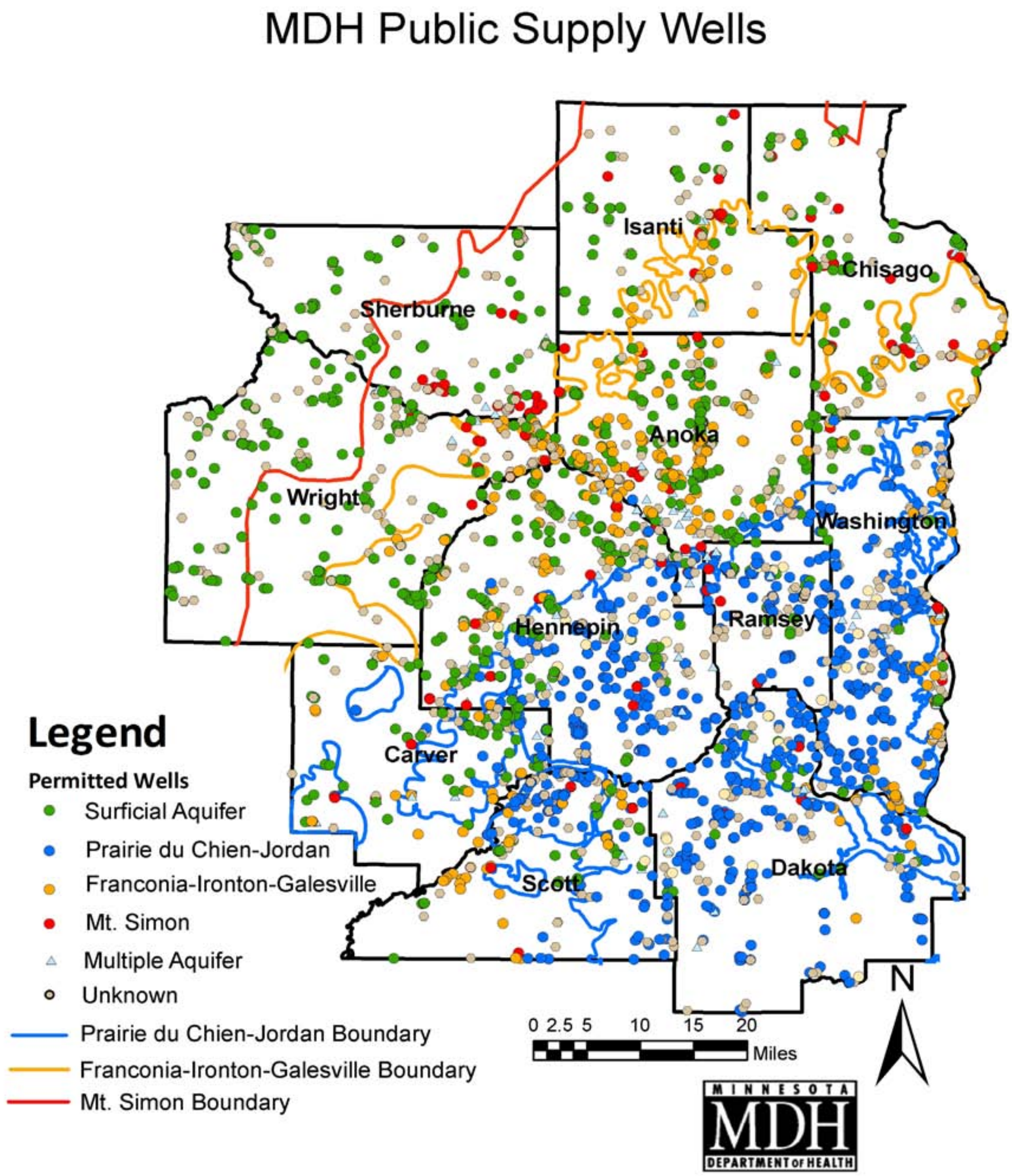


Figure 15: MDH Public Water Supply Wells.

- Arsenic and nitrate sampling of all new wells.

Problem investigation monitoring

- Perfluorinated compound concentration and distribution in the eastern Twin Cities metropolitan area;

- Special projects, e.g. wellhead protection and health assessments of contamination sites.

While most MDH groundwater monitoring activities are focused on water quality, water level information is collected as part of aquifer testing projects for public water suppliers. It is recorded as part of regulatory programs associated with water use and construction permitting of new wells and the sealing of old wells.

USGS - Aquifer monitoring and surveillance monitoring

The United States Geological Survey (USGS) monitors the quantity and quality of water in the nation's rivers and aquifers, develops tools to improve the application of hydrological information and ensures that its information and tools are available to all potential users. Much of its mission has been carried out through the Cooperative Water Program (CWP), a cost-sharing partnership between the USGS and water-resource agencies at the state and local level. In the past, especially in the 1960s and 1970s, the USGS conducted many CWP studies for which monitoring wells were drilled. In many cases the wells are now being measured as part of the DNR groundwater level monitoring network. The USGS currently monitors locations in Minnesota for groundwater levels and quality in response to specific requests for assistance, as part of a real-time data collection network, and for special groundwater studies.

Ongoing USGS special project monitoring in the metropolitan area involves the network of shallow wells shown in Figure 16. These wells are being used to evaluate the impacts of land use on groundwater quality. During 2008, the USGS served as lead agency for the synoptic measurement of wells in the Twin Cities Metropolitan Area.

As envisioned in the National Framework, the USGS should play a major role in coordination of the national groundwater monitoring network for the principal aquifers of the United States. A new funding model is being developed (National Framework for Ground-Water Monitoring in the United States, Advisory Committee on Water Information, Subcommittee on Ground Water, 2009), which, if successful, will allow USGS to manage the day-to-day operations of the national network and to fund long-term monitoring in the principal aquifers of the United States.

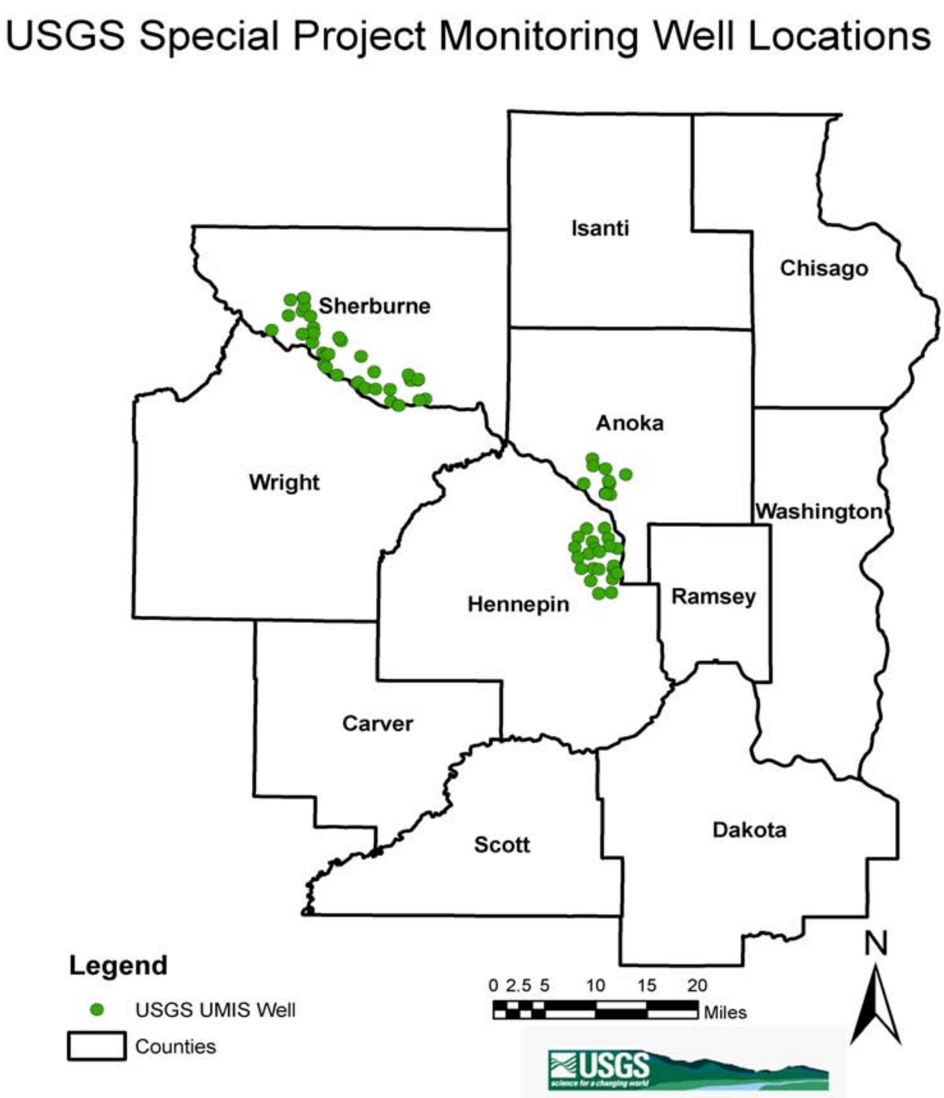


Figure 16: USGS monitoring wells sampled to detect impacts of land use on water quality.

Local Governments - trend monitoring and special studies

Monitoring is ongoing at many levels of government. Several counties are actively involved in assessment and monitoring of groundwater resources as are watershed districts, conservation districts and others. Washington County's groundwater monitoring network is shown in Figure 17. The network consists of DNR and county wells.

The management goals of the state's groundwater level monitoring network will be attainable only if the backbone network is augmented by high-quality data collected locally and submitted to the groundwater level database. Most such data will be supplied by users under conditions of their permits, the rest will come from subnetworks such as Washington County's.

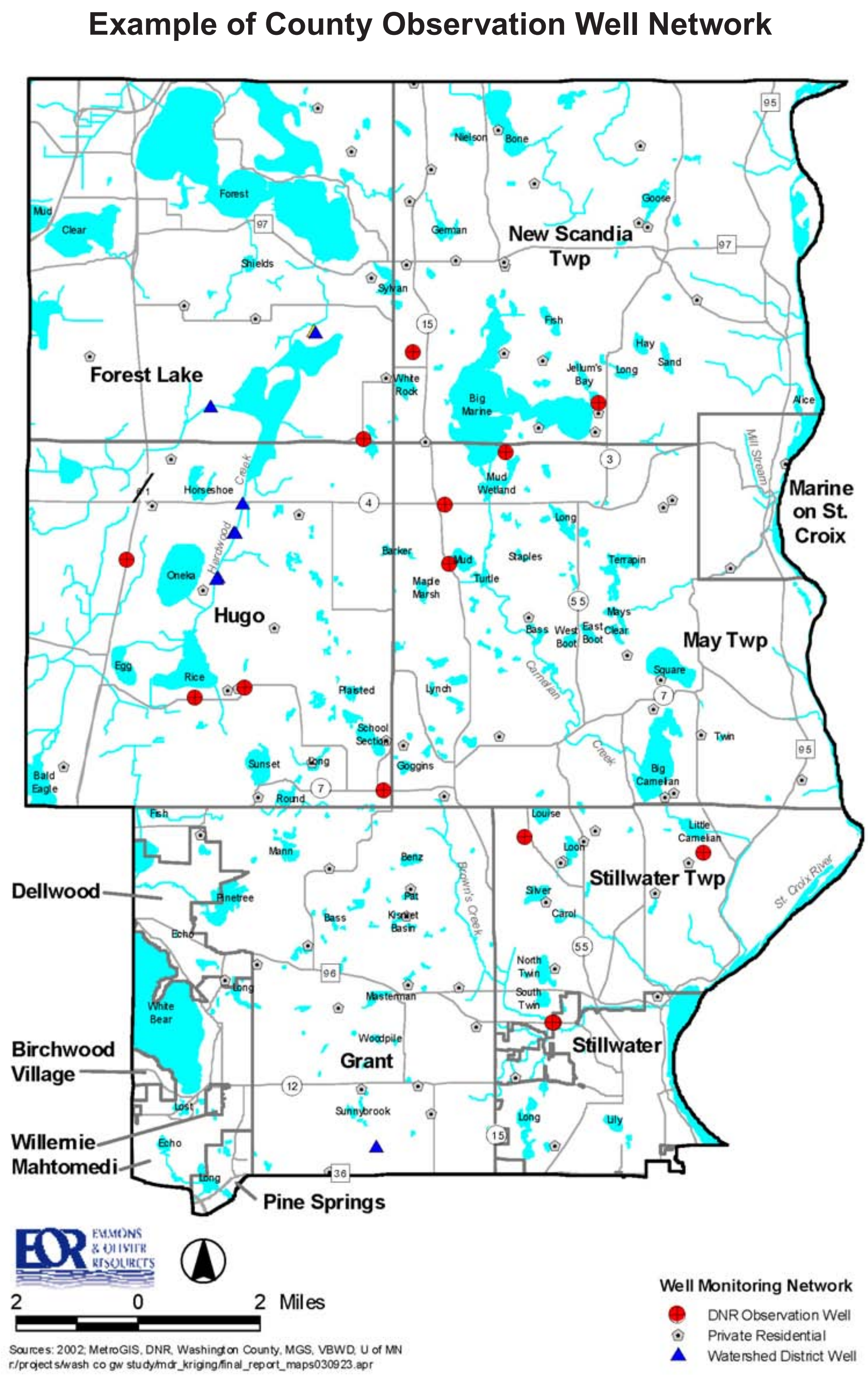


Figure 17: Northern Washington County groundwater monitoring network (Integrating Groundwater and Surface Water Management-Northern Washington County, Emmons and Olivier Resources, Inc., 2004).

NETWORK DESIGN FEATURES AND SPECIFICATIONS

A group of technical experts, the Groundwater Technical Workgroup, convened to discuss the sustainability of groundwater in Minnesota was queried about Minnesota's groundwater monitoring needs to provide for better management. The discussion centered on water quantity data needs, although all were mindful that where possible, needs for monitoring of other water parameters should also be met. The responses fell into three main themes, as follows:

More instrumentation on wells and collection of data on more parameters —

- Use of automatic level recorders and data loggers for continuous groundwater level monitoring. Increased use of telemetry would allow near real-time response to problems including equipment maintenance issues.
- Requiring water users to collect and report high-quality information about water levels and water use. Where appropriate, continuous water level data should be recorded.
- Routine collection of temperature and conductivity information concurrent with water level measurements where appropriate.

Additional well installations, preferably nests (which are multiple wells finished in different aquifers at a given location) —

- Near surface water gaging stations, springs, and near lakes and wetlands to allow assessment of groundwater - surface water interaction.
- Near users of large quantities of water, along with continuous records of pumping.
- To assess vertical gradients between aquifers and in areas where bedrock subcrops beneath thick layers of unconfined material.
- Include wells in confining units between aquifers.
- Installed at approximate ground watershed divides and regional discharge areas along major rivers to enhance understanding of baseflow contributing areas.
- Existing deep wells in good condition which are proposed to be sealed should be evaluated for possible suitability as observation wells under the criteria established for the network.

New tools for working with data —

- Software for working with data, especially long duration time series data.
- Quality control data processing routines.
- Database analysis routines that screen for anomalous data entries and assess trends in the data being submitted.

As the groundwater level monitoring network is enhanced, all partners will also work to identify opportunities and needs for existing water quality networks managed by MPCA, MDA and MDH.

Monitoring Element Goals

Quantity (Levels, Flows, Rates of Use and Discharges)

Weather and climate data used to estimate areal rainfall and evapotranspiration amounts are needed at high spatial resolution to complement groundwater and surface water data. Users of groundwater annually report monthly water use. Surface water elevations are also needed at high resolution to compute changes in storage which is especially important for computations of baseflow to streams and rivers. There is a need to monitor stream flows through the winter for assessment of the contribution to baseflow from groundwater.

Quality (Constituents of the Water)

Physical, chemical, and isotopic sampling for age-dating and source assessment should be conducted on all wells in the backbone network. This sampling should occur when a well is constructed or 'adopted' into the network. This baseline water quality data can then be evaluated by the groundwater monitoring workgroup to determine the frequency and list of constituents for any additional quality monitoring needed to meet specific subnetwork goals including special studies.

In addition to "routine" monitoring of groundwater conditions, data should periodically be collected on the presence and trends of contaminants that are just beginning to be investigated and are not well understood (such as endocrine disrupting compounds). This monitoring should start where the data will be most useful to inform health risk assessments and policy development.

Resources Monitored

The primary management goal is to monitor water levels in the major aquifer systems in use in the metropolitan area. Management of aquifer systems necessarily relies on a thorough understanding of inputs and outputs. Thus we must also have access to high quality information about streamflows in the major rivers and streams in the metropolitan area. Under the Clean Water Legacy Act, the MPCA and DNR are cooperating (along with USGS, the Metropolitan Council and local partners) to enhance the collection and analysis of streamflow monitoring data. The

Metropolitan Council is proposing to use new methods for stream gaging that may allow groundwater contributions to streamflow in major rivers to be calculated. Additional stream gaging sites on major rivers and tributary streams and trout streams may need to be established to meet the groundwater level monitoring network goal of understanding water flow through the aquifer systems of the metropolitan area.

Water levels in wetlands and lakes in many cases reflect the water level of the surficial aquifer. Lake level and wetland level monitoring sites may need to be enhanced to gather data about the surficial aquifer. Figure 18 shows existing surface water monitoring locations that provide important information for groundwater management. Systematic improvements in the distribution and quality of these monitoring points are advisable.

Spring discharge comes directly from aquifers. The inventory of springs in the metropolitan area needs to be completed and spring discharge monitoring at key locations begun.

Groundwater and Ecosystem Function

Groundwater both influences, and is influenced by, ecosystem function. Ground water quality and quantity influence ecosystem processes and services, such as plant productivity, as well as native plant and animal community composition and associated rare species. Functional ecosystems, in-turn, influence groundwater quality, such as through bio-filtering processes and sediment removal through infiltration, and influence groundwater quantity

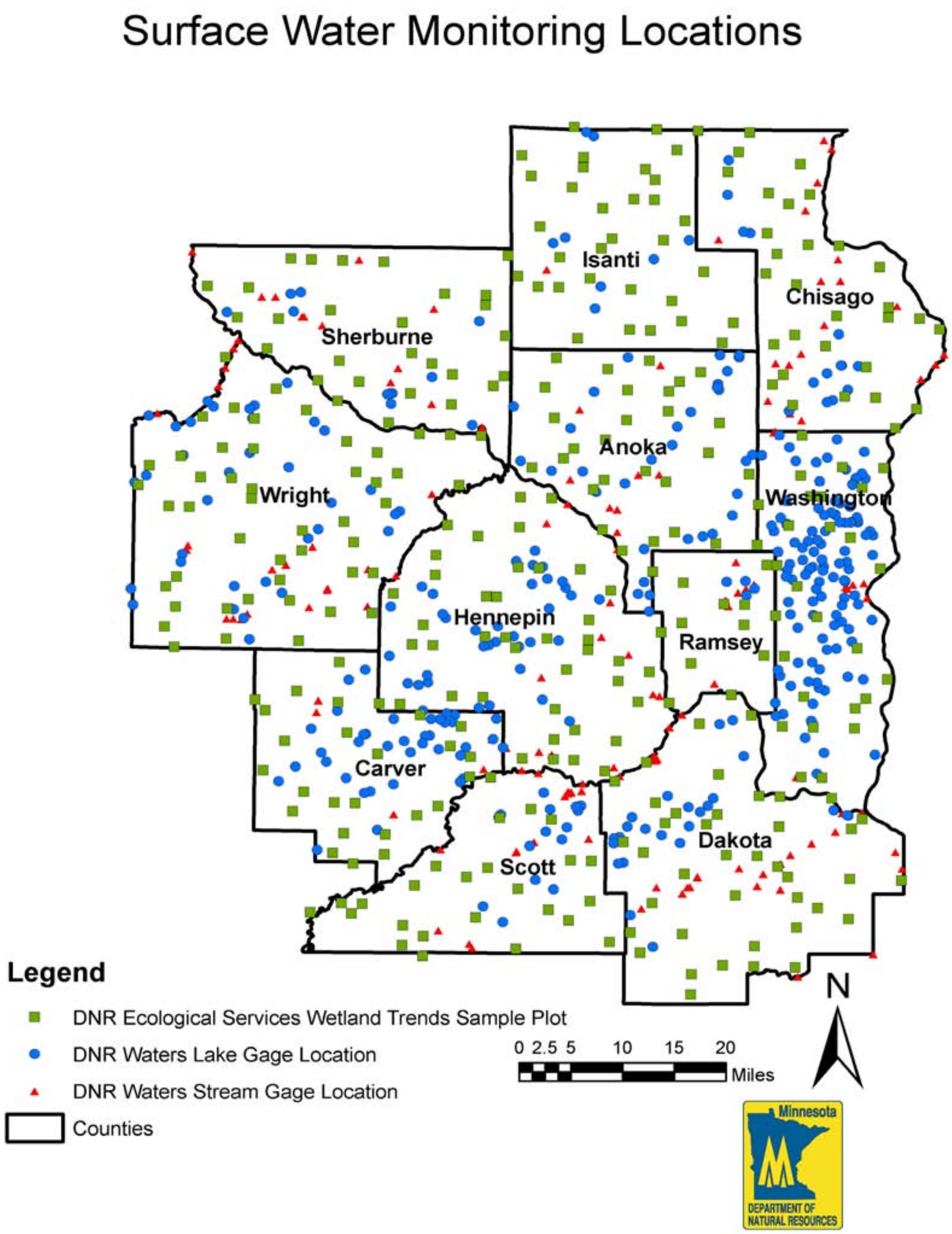


Figure 18: Active DNR surface water monitoring locations.

by facilitating groundwater recharge and minimizing variability in groundwater recharge rates.

Ecosystem influences on groundwater

A functional ecosystem is critical for maintaining groundwater quality and quantity. Wetlands and other natural plant communities intercept precipitation and overland flowing water. These natural systems act as filtering agents, removing pollutants and sediment from water as it infiltrates to the groundwater. Native vegetation and intact communities attenuate overland flow of water to rivers and streams and facilitate groundwater recharge. Recharge in functional ecosystems can also occur at a steadier pace, minimizing variability in groundwater availability.

Groundwater influences on ecosystem processes and services

Ecosystem services are benefits provided by ecosystems to humans. According to the United Nations 2004 Milennium Ecosystem Assessment, ecosystem services can be grouped into four major categories: “provisioning, such as production of food and water; regulating, such as control of climate and disease; supporting, such as nutrient cycles and pollination; and cultural, such as spiritual and recreational benefits”.

Groundwater is itself an ecosystem service that is depended upon by most municipalities in the Twin Cities

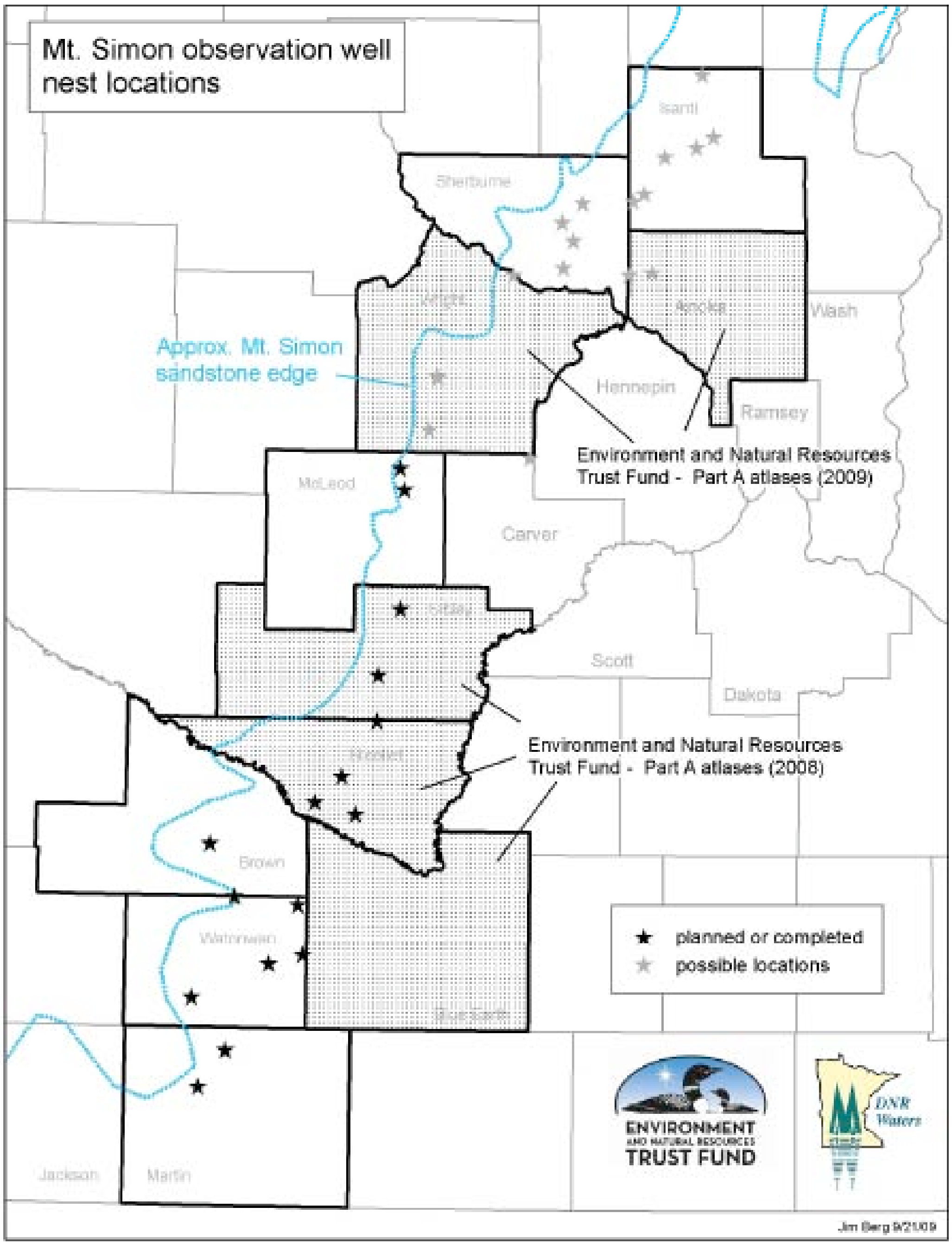


Figure 19: Mt. Simon boundary study monitoring well locations.

metro area and throughout Minnesota. The quantity and quality of groundwater as a direct ecosystem service is discussed in other sections of this document.

Groundwater, in turn, affects other ecosystem functions and services, such as plant and animal productivity, and nutrient cycling and transport. The influence of groundwater on these and other ecosystem components depend on a host of interconnected factors including topography, soil type, connections between shallow water and deep water, plant community type, watershed position in the landscape, and position within a watershed. The combination of these factors make certain features of an ecosystem more dependent upon groundwater features. Monitoring must address these complex relationships, and the first step toward better understanding is inclusion of appropriate monitoring sites in the backbone network.

Monitoring Site Distribution Goals

The monitoring network must cover the areal extent of the major aquifers in the metropolitan area. Development of a conceptual model of the ground water flow system in each major aquifer must underlie the network design. To this end, wells in the major aquifers that extend outside the metropolitan area must also be included in the backbone network. These wells will establish boundary conditions for more detailed assessments of water level changes within the metropolitan area. The ongoing well-drilling program to expand monitoring of the Mount Simon-Hinckley aquifer is an example of how the edge of a major aquifer could be monitored (Figure 19). A similar effort will be required for the edge of the Franconia-Ironton-Galesville aquifer (Tunnel City-Wonewoc aquifer). Completion of the remaining county geologic atlases for the metropolitan area and updates for older atlases will assist with this effort.

Groundwater monitoring locations must be adequate for regional planning and enough detail must be provided to allow adaptive management in response to observed changes in water levels. Groundwater monitoring locations must also be adequate for watershed-level assessment of groundwater – surface water interaction.

Monitoring Frequency Goals

The DNR ground water level monitoring network as it currently exists collects data nominally on a monthly basis. The network's database infrastructure is not optimized for storage or manipulation of large amounts of data. As currently structured, it is designed to store one to several monthly water level measurements per well. It is now understood that monthly measurements are not wholly adequate for water level monitoring in areas where groundwater is extensively used.

More frequent measurements of groundwater levels are appropriate where climatic conditions are variable, where the aquifers supply large quantities of water, where shallow aquifers are part of the monitoring program, and where recharge rates are high (Figure 20).

Figure 21 shows the data record from a DNR observation

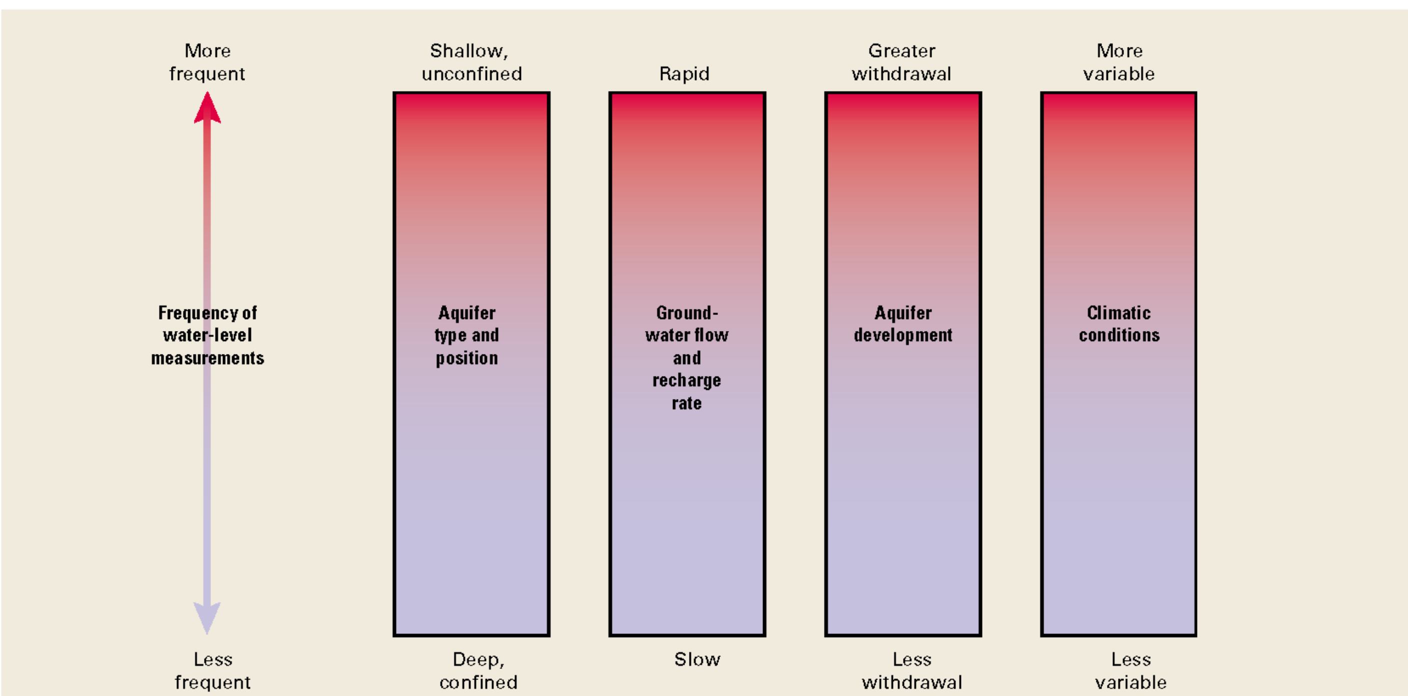


Figure 20: Common environmental factors that influence the choice of frequency of water-level measurements in observation wells (Taylor and Alley, 2001).

well in an area of agricultural irrigation where water levels fluctuate dramatically over the summer irrigation period. This data record is shown as recorded by a datalogger at high or continuous frequency, and as it was recorded through monthly hand readings as is the current standard for DNR observation wells. Hydrographs made from continuous data allow the best estimates of maximum and minimum water levels in the aquifers and can reveal the immediate impact of ground water withdrawals.

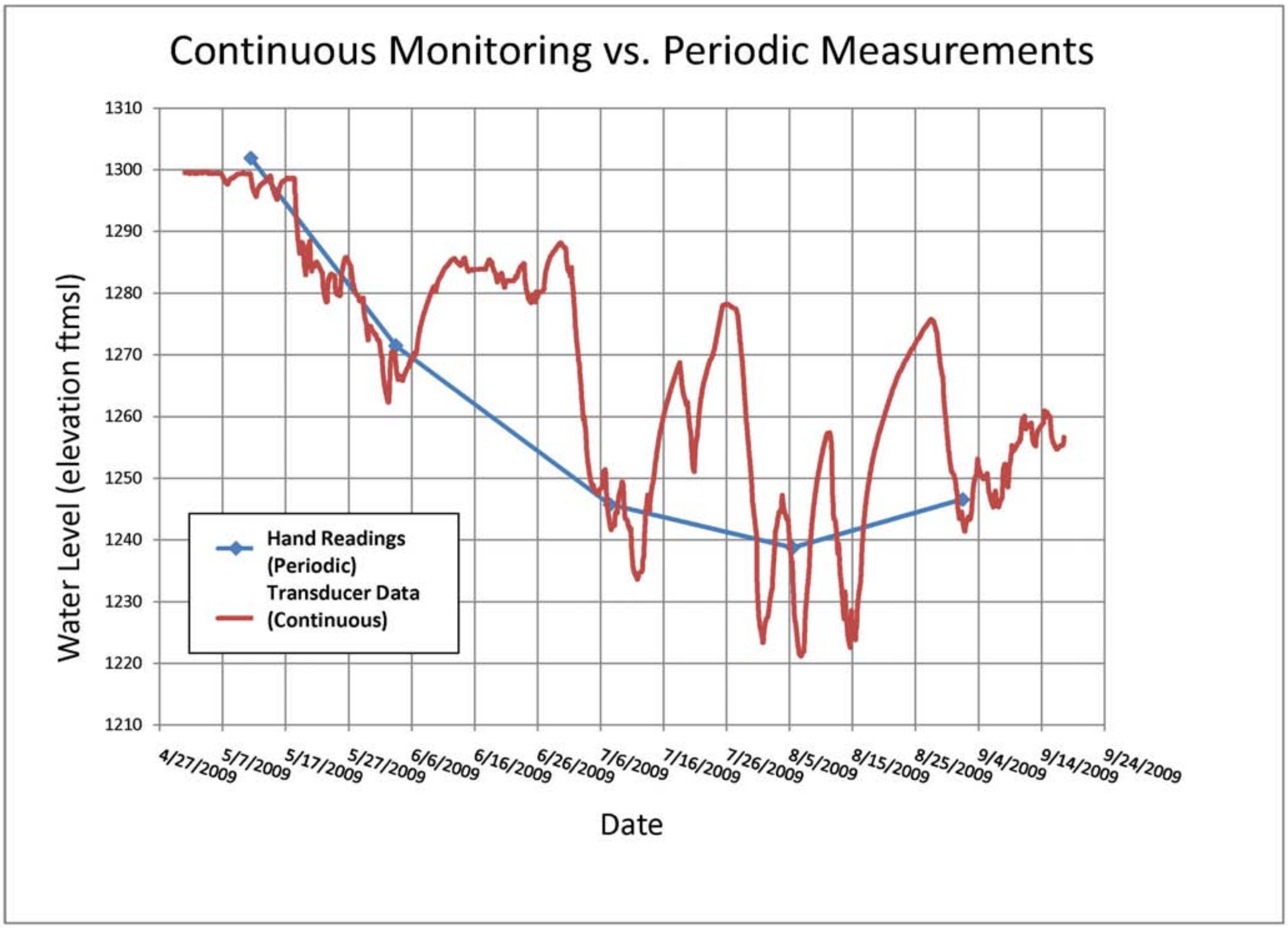


Figure 21: Observation well water levels presented as continuous transducer data recorded by a datalogger and as periodic (monthly) hand readings. This is a surficial aquifer well in Pope County.

DATA STANDARDS AND DATA MANAGEMENT

Data standards and data management routines have been determined by expert panels in more than one forum. This information is available to Minnesota's groundwater professionals and will be adapted to Minnesota's needs without need to repeat the whole effort. An example from the Advisory Committee on Water Information, Subcommittee on Ground Water (2009) is in the Appendix. Documents that will be adapted for Minnesota include guidance for:

- Standard practices to ensure comparability
- Access and data exchange
- Data entry and quality control tools, and
- Analysis tools

Software for Large Volume Data Management

Continuous, i.e. high frequency, monitoring is needed in the metropolitan area to understand system response to change. Assessment of groundwater recharge is only possible where high-frequency measurements of ground water levels are available (Lorenz and Delin, 2007). Staff resources will quickly be overmatched unless adequate software and network infrastructure are in place to manage the data.

High Frequency Data Collection

The software and network infrastructure should be designed to be scalable to a very large number of monitoring sites that comprise stressed subnetworks. The quality assurance and quality control processes for individual sites will benefit from using data from adjacent sites taken at equivalent frequency, meaning that ideally all sites would be sampled at similar frequencies. The data archiving methods will store data at lower or variable frequencies if appropriate, and the data download methods will permit users to request data at any desired frequency. Figure 22 is the data management and use schematic as envisioned in the National Framework.

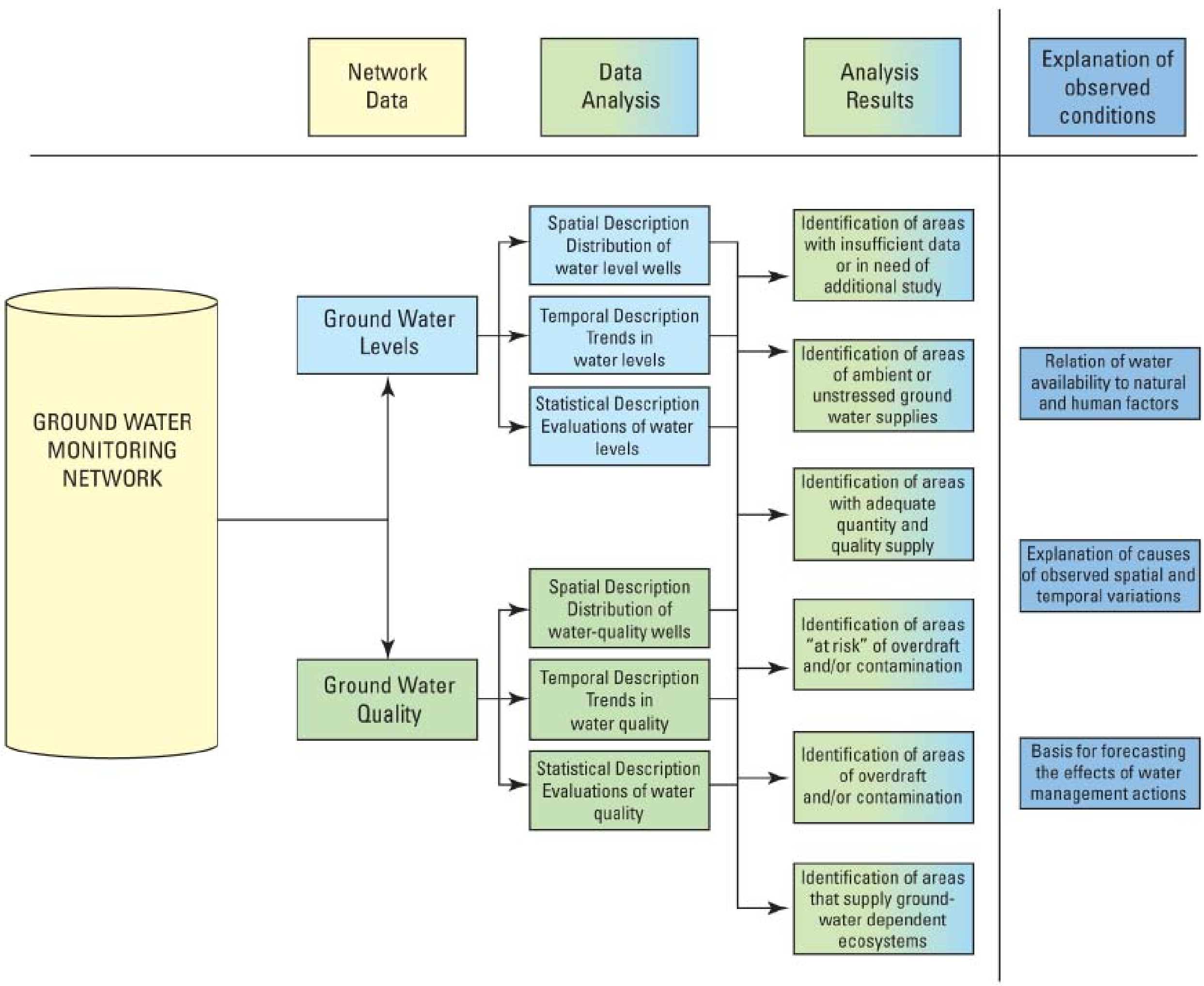


Figure 22: A water level monitoring network can support water quality subnetworks as part of the management system (Advisory Committee on Water Information, Subcommittee on Groundwater, 2009).

Cooperative implementation of the National Framework for Groundwater Monitoring in the United States will result in an improved DNR groundwater level monitoring network that will form the backbone of the regional groundwater level monitoring network for the metropolitan area. This backbone network will also provide opportunities for expanded monitoring of water chemistry. Minnesota will continue to focus on network enhancements while applying to be a pilot site for the first stages of national network development.

New monitoring locations will be recommended by a multi-agency coordination workgroup and any network improvements will focus on meeting both water quality and quantity monitoring needs. Existing and new subnetworks, to which other cooperators also contribute, will meet special monitoring study needs and will provide some of the existing wells that will be selected for regional monitoring. The anticipated workgroup work plan tasks correspond with actions required of partners in the national monitoring network:

Task 1: Evaluate potential monitoring points in the current DNR groundwater level monitoring network for inclusion in the backbone network. The Metropolitan Council's regional ground water model and/or a conceptual model of groundwater flow will provide context for these evaluations.

Task 2: Joint efforts of DNR, MDH, MDA, and MPCA will ensure whenever possible that locations will be useful for assessing water quality.

Task 3: Evaluate the chosen points to see if network coverage meets monitoring goals both for areas where pumping stresses are anticipated and in areas that are unstressed. Select wells of each type for trend monitoring in a stressed subnetwork and for background monitoring in an unstressed subnetwork.

Task 4: Evaluate the gaps in both the stressed and unstressed subnetworks and search for well owners or water users who may have the ability to monitor water levels and provide water level data meeting the standards of the backbone network. Provide appropriate technical assistance to make cooperation a mutually valuable undertaking.

Task 5: Prioritize instrumentation and maintenance needs and begin a program to address problems and carry out enhancements.

Task 6: Work with partners to structure a data portal to include analysis, storage, and retrieval of quality controlled and reviewed data. This essential task will require ongoing dedication of significant resources.

Task 7: Calculate cost to maintain the network indefinitely.

Metropolitan Area Groundwater Resource Issues

A groundwater model of the major aquifers in the seven-county Twin Cities area was developed for the Metropolitan Council's water supply planning efforts. The model is being used to predict the possibility of certain water supply-related problems in the future. Because the initial model calibration area included areas surrounding the seven county metropolitan area and because the geologic setting is quite similar, the Metropolitan Council's results can be extended, in a general sense, to the expanded (eleven county) metropolitan area and used to define the scope of new monitoring. Figures 23 and 24 show areas where aquifer levels may decline significantly over time and areas where surface water resources may be impacted by groundwater withdrawals.

Other known groundwater management-related issues are also being evaluated. In Figure 25, for example, locations of ground water dependent resources are shown. In many cases a stress on the ground water system can result in an adverse impact to the related surface water resource. The backbone network will assist managers with decisions aimed toward protection of valued ecosystems. Figure 26 shows the current understanding of several categories of vulnerability to contamination.

Current DNR Network Coverage

The statewide inventory and status assessment of wells in the existing DNR ground water level monitoring network was accelerated so that the results shown previously in Table 1 for the metropolitan area would be available for this report. The current network includes 177 actively monitored wells. Water level measurements are made monthly for at least 8 months per year. The distribution of active wells by aquifer is shown in Figures 27 through 30.

Assessing the Gaps in Coverage

Many wells in the existing DNR groundwater level monitoring network are 'Baseline' monitoring wells, intentionally located where they were (at least initially) not affected by short-term stresses. Monitoring of the condition of the major aquifers is a public responsibility, while monitoring of wells intended to track impacts of pumping is a responsibility to be shared more directly by the users. Once a baseline monitoring well begins to show pumping signatures from increased water use, a new, more distant well must then be installed to meet the baseline monitoring need.

To meet the need for accurately predicting the response to current and future stresses, additions to the network

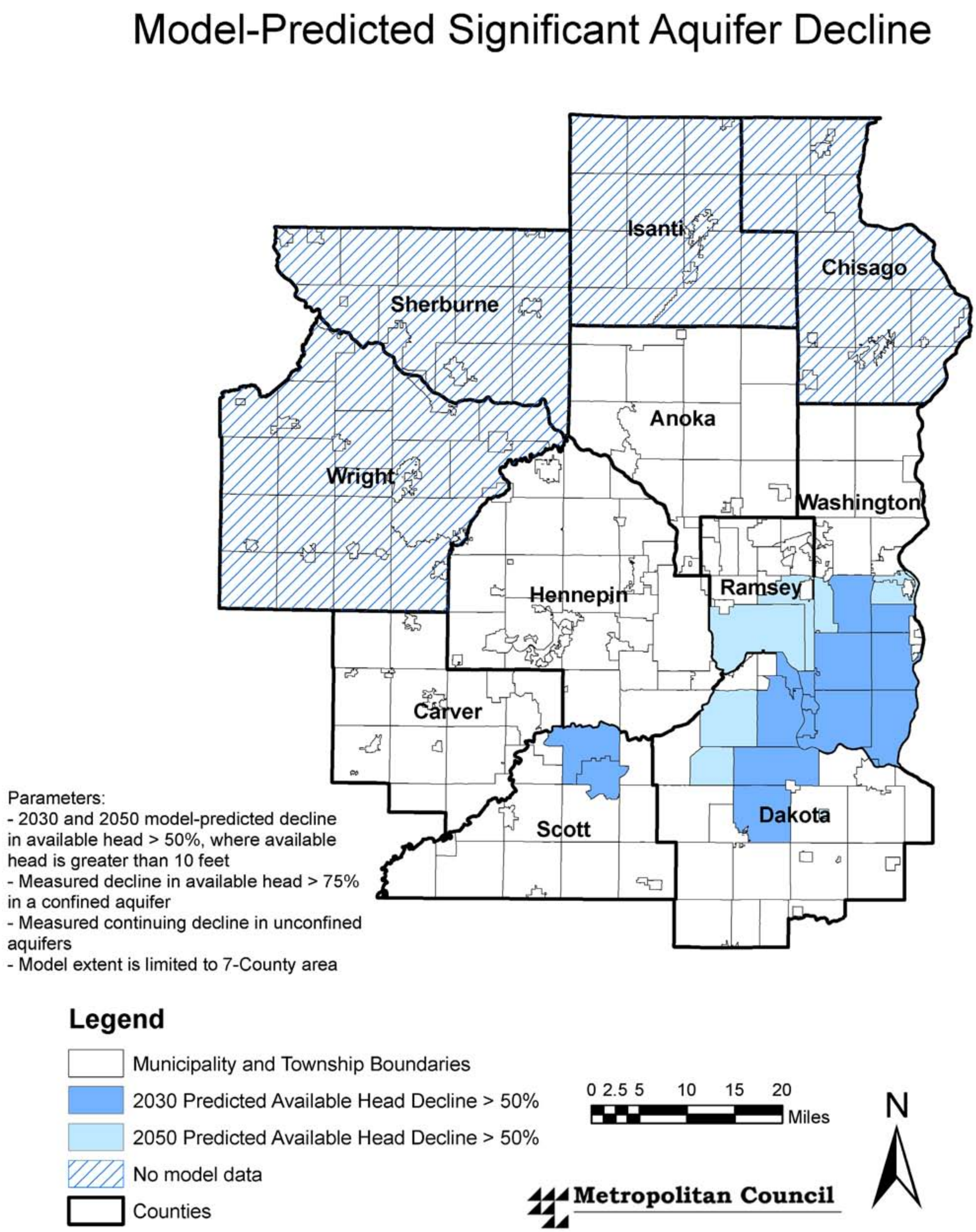


Figure 23: Areas where municipal pumping may cause significant aquifer decline as predicted by the Metro Model 2 (Data provided by the Metropolitan Council March 2009 Twin Cities Metropolitan Area Master Water Supply Plan, which has been provisionally approved by the Metropolitan Area Water Supply Advisory Committee. Model extent limited to 7-County Metropolitan Area).

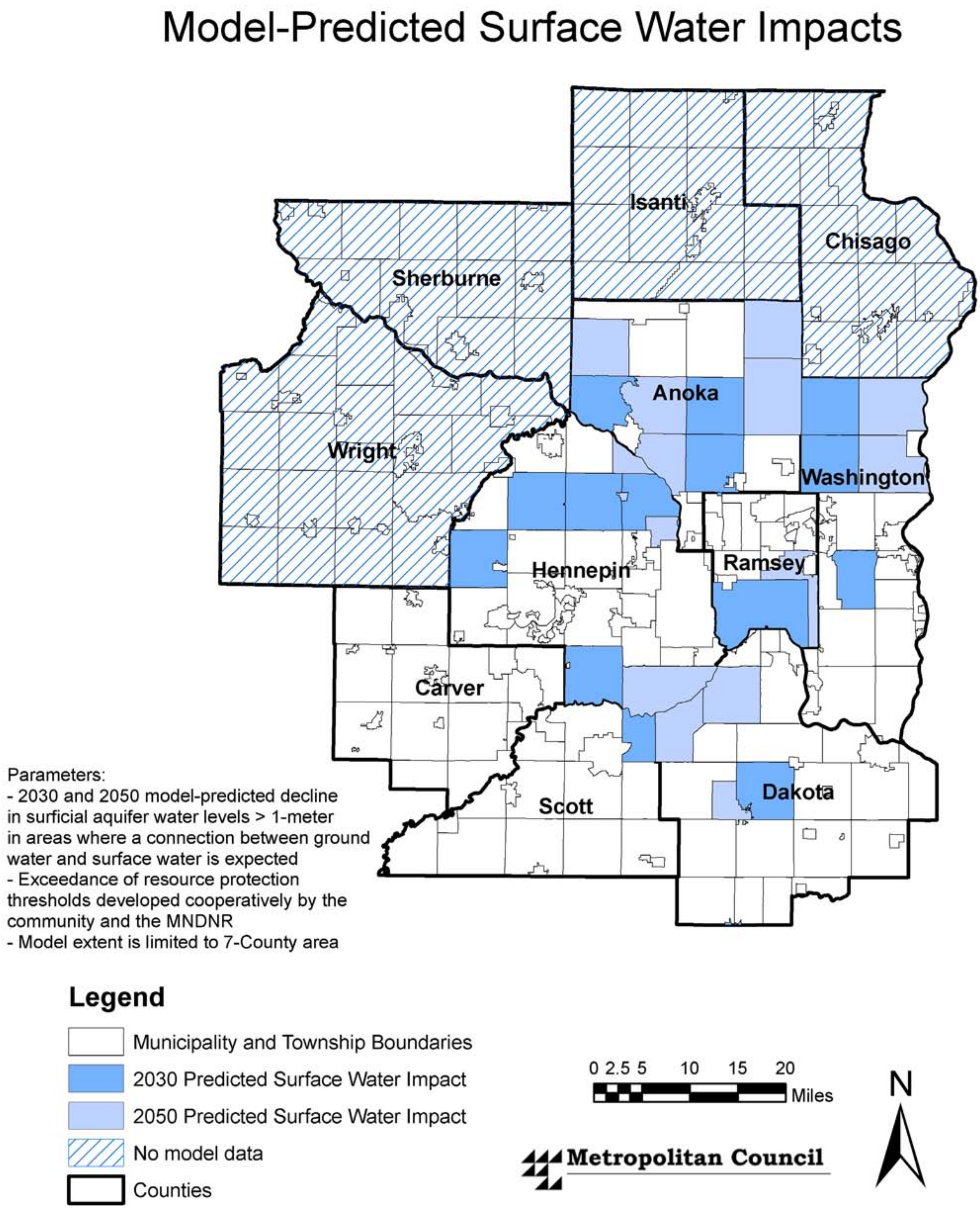


Figure 24: Areas where municipal pumping may adversely affect surface water as predicted by the Metro Model 2 (Data provided by the Metropolitan Council March 2009 Twin Cities Metropolitan Area Master Water Supply Plan, which has been provisionally approved by the Metropolitan Area Water Supply Advisory Committee. Model extent limited to 7-County Metropolitan Area).

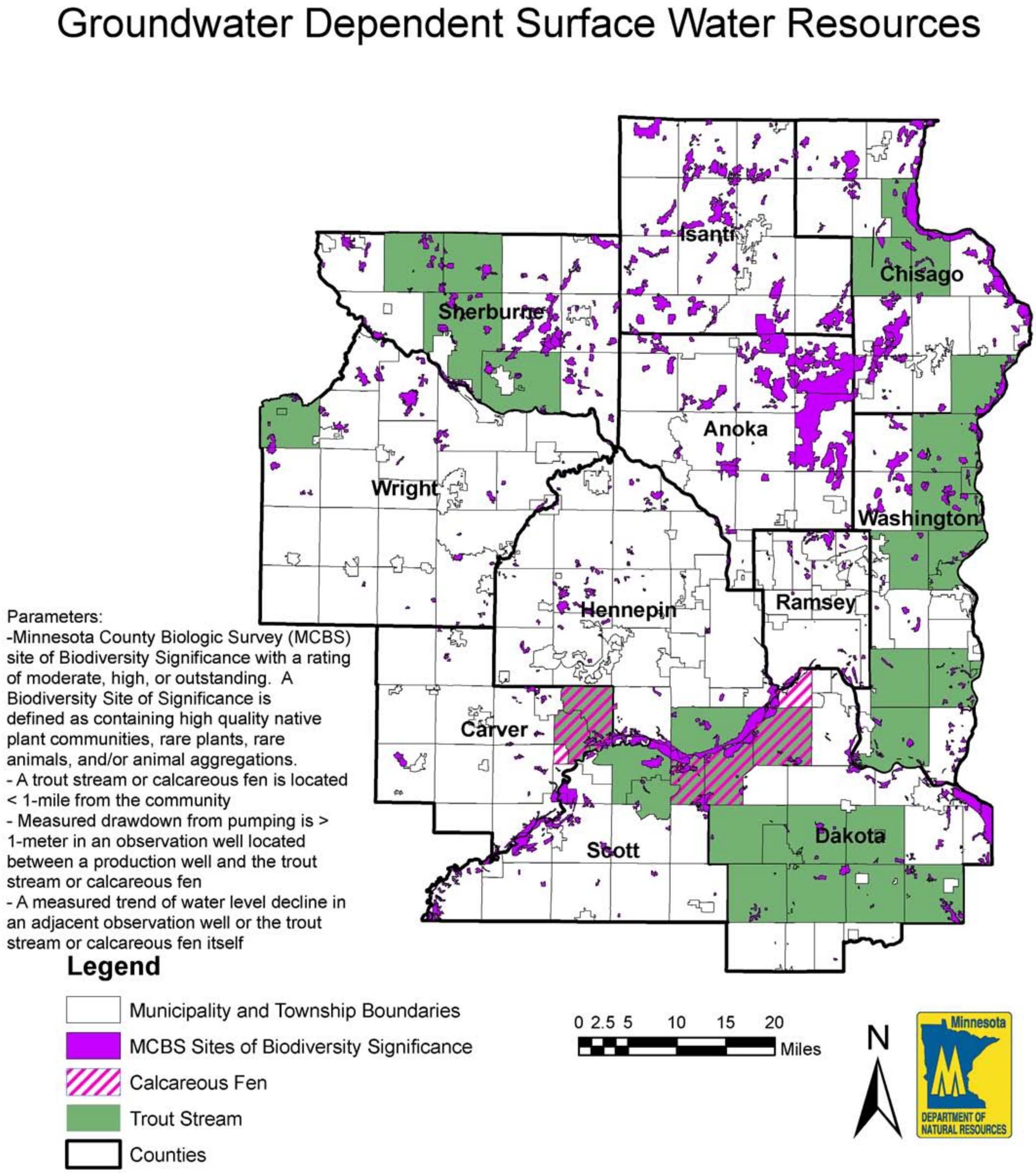


Figure 25: Areas where municipal pumping may adversely affect groundwater dependent surface water features.

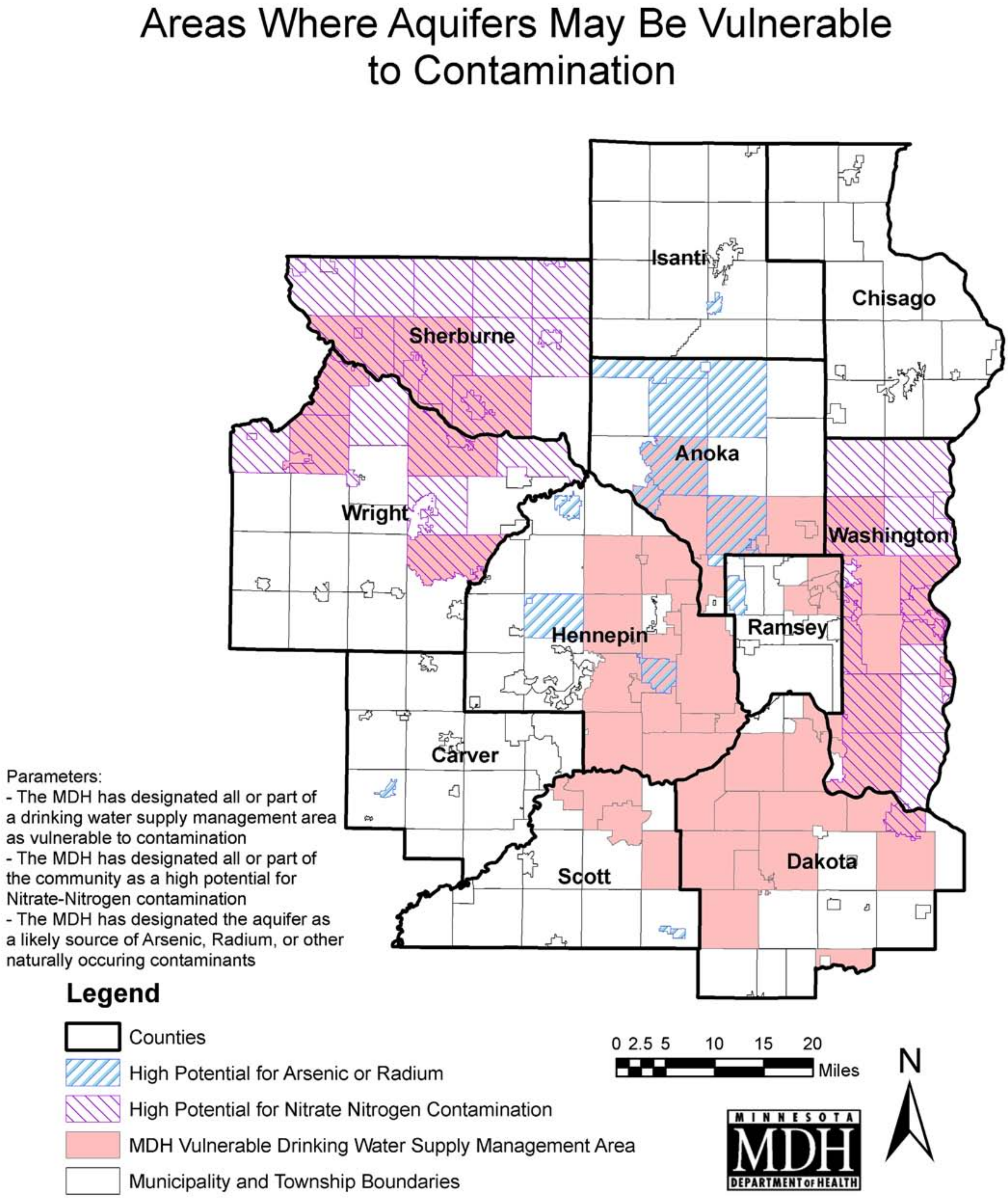


Figure 26: Areas where aquifers may be vulnerable to contamination (Source: MDH. Arsenic and Radium Data based on 2008 MDH Annual PWS Compliance Report. Nitrate-Nitrogen results restricted to Sherburne, Washington and Wright Counties based on available data).

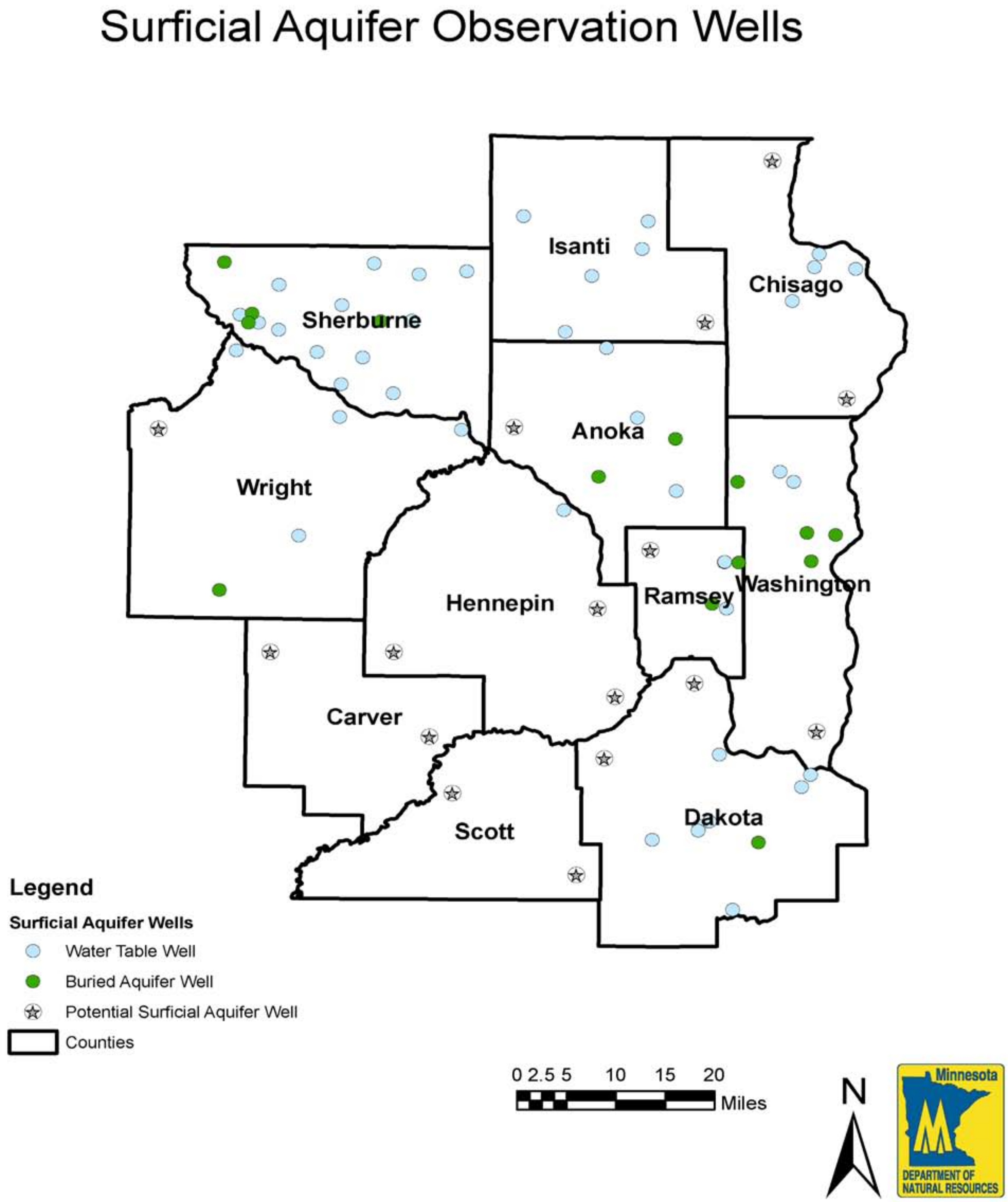


Figure 27: Active surficial aquifer observation well locations.

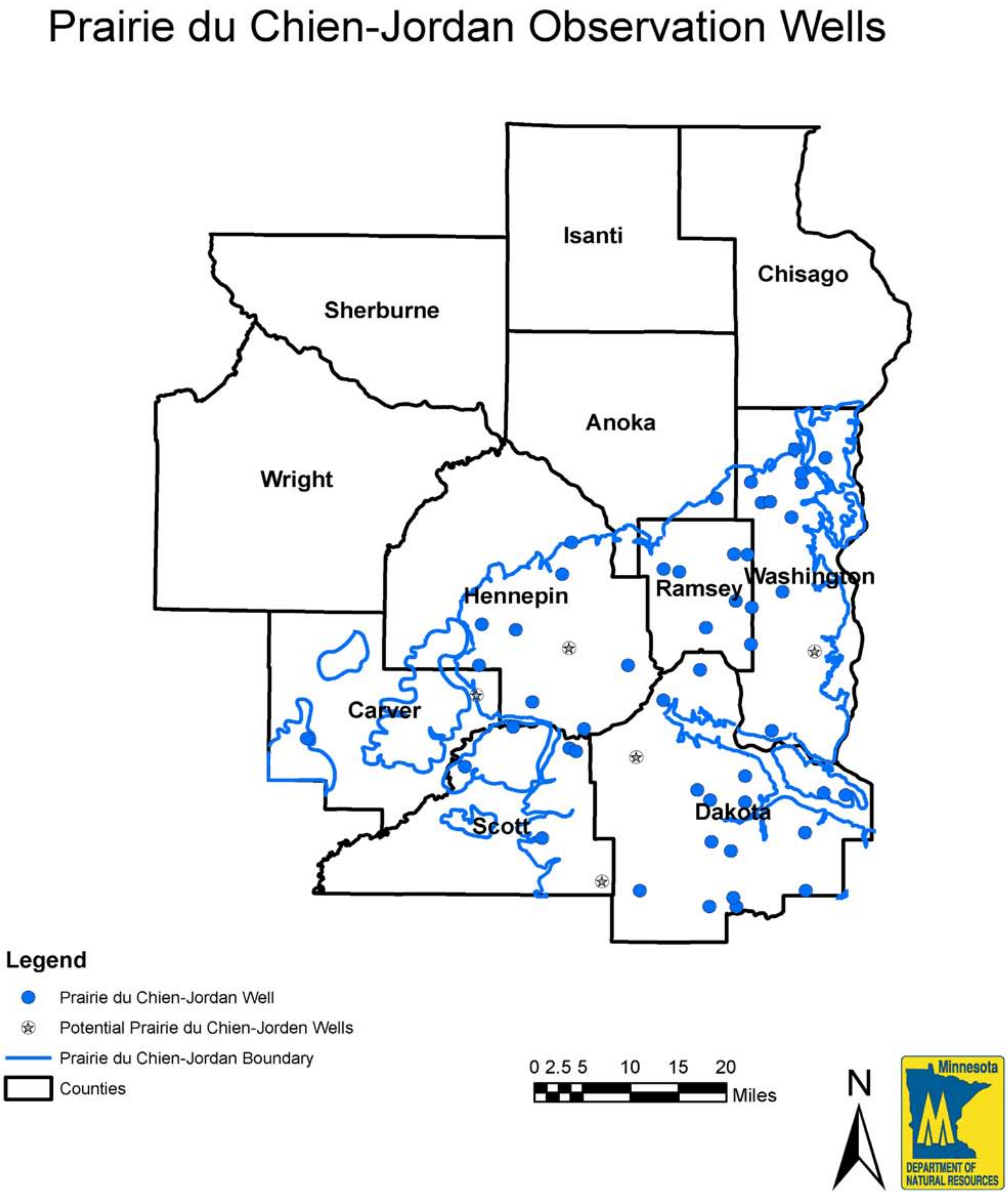


Figure 28: Active Prairie du Chien-Jordan observation well locations.

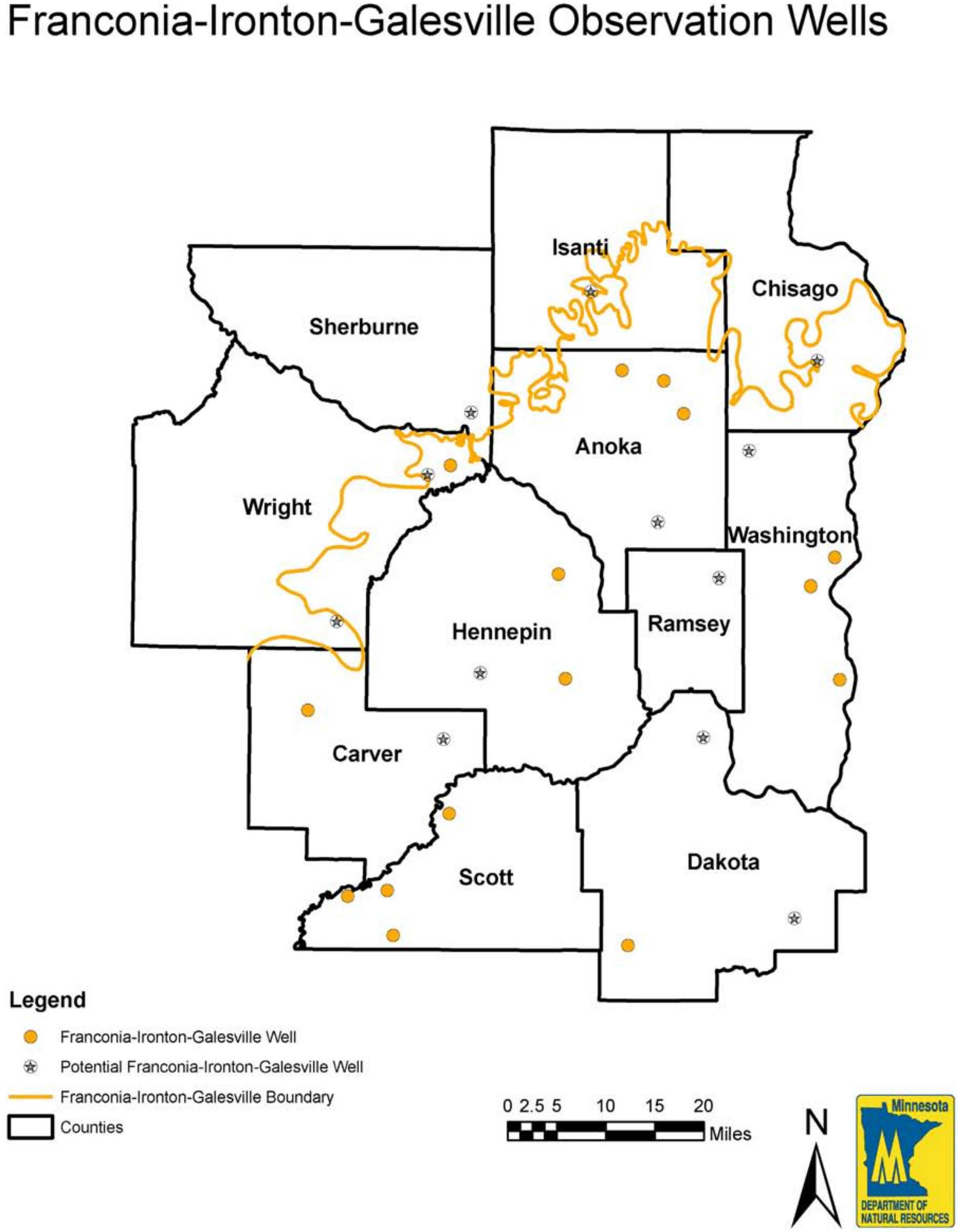


Figure 29: Active Franconia-Ironton-Galesville observation well locations.

Mt. Simon Observation Wells

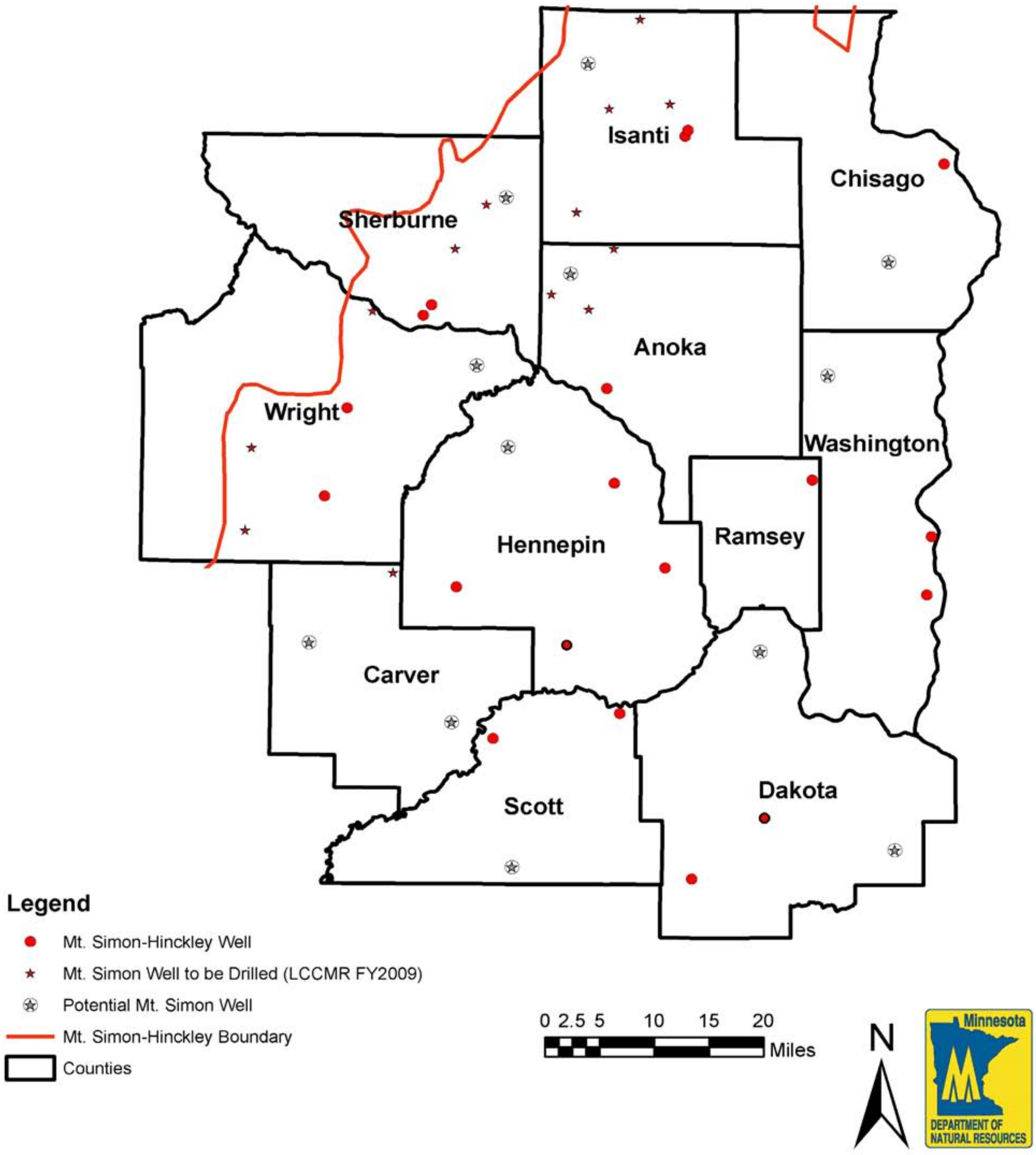


Figure 30: Active Mt. Simon observation well locations.

should also be designed to monitor stresses on the aquifer system and monitoring wells should be located in the following types of hydrogeologic settings:

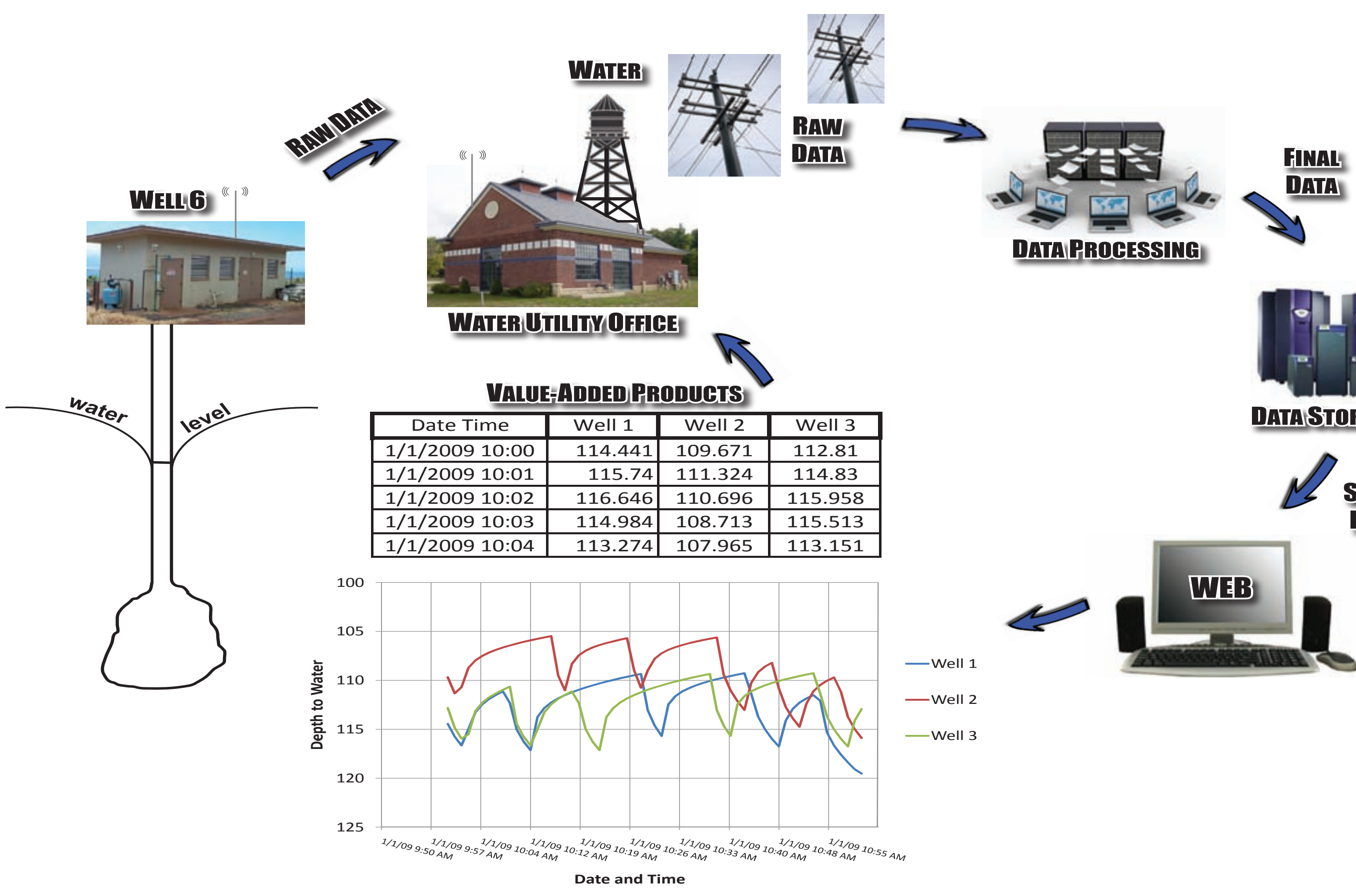
- Along rivers (including river levels).
- At perched lakes (lake level and groundwater level below).
- Near high capacity production wells
- At the water table in recharge/infiltration areas.
- In or near sensitive ecosystems.
- Across and within confining units.
- At the edges of confining units (in buried bedrock valleys).
- Along, or across, or within, faults or fault zones.

Coordination with goals of all partners needed to ensure the network gets the most possible information from the fewest wells. Spring and streamflow monitoring for assessment of aquifer discharge flux must be included in this analysis. The distribution of permitted users indicates areas of ongoing aquifer stress; population growth forecasts can predict future areas of aquifer stress.

Gaining Support and Acceptance of Monitoring Partners

Among groundwater users there is a range of management approaches and expertise. It will be important to reach out to major water users. Local governments, in particular, can be invaluable partners in the collection of water level monitoring data and are in a unique position to be able to plan for sustainability of their own drinking water supply once adequate data are available. Information about aquifer systems, groundwater level monitoring and groundwater - surface water interaction must be readily available to local decision makers.

Many water supply systems already measure water level information as part of day-to-day well-field management, but do not store or analyze it. In the future, cooperators in the metropolitan area's ground water level monitoring program would upload it to the data portal (Figure 30) so it can be accessed and used by other groundwater managers. After quality control and analysis, the information would be available to the cooperator at any time. The ground water level monitoring program must be prepared to provide technical assistance with development of local monitoring plans in coordination with appropriation permit requirements.



Date Time	Well 1	Well 2	Well 3
1/1/2009 10:00	114.441	109.671	112.81
1/1/2009 10:01	115.74	111.324	114.83
1/1/2009 10:02	116.646	110.696	115.958
1/1/2009 10:03	114.984	108.713	115.513
1/1/2009 10:04	113.274	107.965	113.151

Figure 31: Schematic of data flow from raw SCADA data to end usable product.

FUNDING NEEDS

Public investment is required at all levels of government. Private investment is required of users of large quantities of water, where the definition of 'large' may vary based on the hydrogeologic setting, total demand, and other resources or ecosystem services at risk. Monitoring networks gain value as length of record grows. Dedicated, predictable funding levels will allow the network to function as intended and provide value commensurate with the investment.

Network infrastructure needs

Well construction, maintenance and sealing will be ongoing activities. New well installations for the backbone network must meet construction standards intended to maximize useful life. Locations must be chosen with the intention to maintain the well nest indefinitely, meaning that permanent easements or purchase of small parcels will be necessary.

Current maintenance needs for existing DNR ground water level monitoring wells include sealing wells that do not meet current standards, are redundant or that need replacement due to age.

Technology needs

Technology that allows data from groupings of wells (nests) to transmit data as one station together can add efficiency. A Wi-Fi based network, for example, is a cost effective means of collecting data. One has been built by the Saint Anthony Falls Hydraulic Laboratory for the Minnehaha Watershed District. Cell phone data transmission is practical in the metropolitan area.

Sophisticated and very efficient data input procedures must be at the forefront of database development for the data coming in from backbone network wells, for time-series data submitted by subnetworks, and for data submitted by water appropriation permit holders. Quality assurance and quality control procedures for data coming from stress monitoring will require significantly more robust procedures than are currently in place.

An accessible internet portal must be developed. The best current model for this type of portal exists for stream gaging data. Automated products derived from network data can be linked to local web pages so that members of the public can view and use information from specific subnetworks or monitoring locations as needed. This information can also be linked to available water quality and well information, further enhancing data availability.

Funding model

This report is required to develop a cost-basis for network establishment, operation and maintenance for an indefinite network existence and to estimate this cost in cents per gallon of groundwater used in the metropolitan area.

Water Use Estimate

The average number of gallons of water used annually in the metropolitan area over the past four years (Figure 2) has grown to approximately 140 billion gallons.

Network Cost Estimates

Best estimates encompassing all network expenses are shown in Table 1, repeated on the facing page. The assumptions made in developing the costs estimates are given below.

The expectation is that the metropolitan area's real-time backbone monitoring needs would likely be met by about 60 sites, some of which will be located in the major aquifers outside the metropolitan area. A total of approximately 180 wells will be monitored in this way and the data will be available almost immediately from the web portal.

All other wells in the backbone water level monitoring network within the metropolitan area should be monitored with automated water level measuring devices. The conversion should commence immediately and be completed in 4 years.

This assessment is based on the existence of a subnetwork of additional, permit-mandated, monitoring locations. The burden of permit-required monitoring will be significantly lighter when data input, analysis and reporting are accomplished through the state's new comprehensive groundwater level monitoring database.

Deferred well maintenance will be carried out during the first four years. Wells in the current DNR ground water level monitoring network that prove to be unsuitable for the backbone network will be sealed or turned over to cooperators. Some wells will have to be replaced if maintenance does not restore function. Routine maintenance will be part of normal operations of the backbone network.

To improve understanding of stratigraphy and aquifer and aquitard characteristics, all newly constructed wells will be logged with borehole geophysical methods (gamma, caliper, temperature, fluid resistivity and flowmeter logs). Where interpretation of aquifer characteristics would be aided, a subset of existing wells should be logged.

Water chemistry sampling of a basic set of analytes must be carried out at well installation and repeated at set intervals as informed by network goals and an analysis of the initial water quality dataset.

Future well installations will include land acquisition or permanent easements. The backbone network must not suffer from abandonments forced by landowner decisions.

Under current fee structures, monitoring well fees must be paid to MDH or the local authority so that network wells may be sampled.

Database development and creation of an internet portal to other data sources whether the interface for technical users is on a commercial platform or on a state-developed platform, should be accelerated, with completion within four years. Database development and creation includes data entry via web interface, email, or upload; automatic data processing and QA/QC routines; data analysis tools; web-based display and retrieval of data; and the ability to serve the data to cooperator's web sites in the cooperator's desired formats. Ongoing system maintenance will be required.

Advanced data analysis routines to include derivation of aquifer characteristics from time series data will be created and added to the suite of available tools.

Cost in Cents per Gallon

Total estimated costs for build-out of the network over four years total $8,861,150 million dollars.

$8,861,750.00 /4 years = $2,215,437.50 per year

$2,215,437.50 per year / 140 billion gallons per year= $0.00001582 per gallon =

0.0000001582 cents per gallon, or

$15.82 per million gallons.

Disclaimer:

The recommendations in this plan will need to be adjusted in the future because of

- Constantly evolving management needs
- Constantly evolving technology
- Constantly evolving human-built environment
- Constantly evolving understanding of the aquifer system

Establishment and maintenance of a backbone groundwater level monitoring network is the best insurance that groundwater managers will have, in large part, the data needed to face the decisions of the future, whatever they may turn out to be.

Table 1: Costs for the Creation, Maintenance, and Operation of a Groundwater Level Monitoring Network for the 11-County Metropolitan Area.

	Year 1	Year 2	Year 3	Year 4	Total Development	Subsequent Years
Total Wells in Backbone Network	80	175	270	380	380	380
Backbone Network Establishment: Well Drilling, Easements, Instrumentation, Operation and Maintenance	$ 1,083,400	$ 1,310,750	$ 1,440,600	$ 1,627,000	$ 5,461,750	$ 627,000
Technical Support / Quality Control / Groundwater Analysis	$ 350,000	$ 350,000	$ 350,000	$ 350,000	$ 1,400,000	$ 105,000
Data Management and Access through Web Portal	$ 500,000	$ 500,000	$ 500,000	$ 500,000	$ 2,000,000	$ 93,000
	$ 1,933,400	$ 2,160,750	$ 2,290,600	$ 2,477,000	$ 8,861,750	$ 825,000
Dollars per Million Gallons	$ 13.81	$ 15.43	$ 16.36	$ 17.69	$ 15.82	$ 5.89
Cents per Gallon	0.001381	0.001543	0.001636	0.001769	0.001582	0.000589

Notes: All values 2009 dollars

By the end of the fourth year of network build-out, the backbone network will consist of 60 nests for which data are transmitted real time (approx. 3 wells per nest) and 200 monitoring wells with dataloggers

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The Ground Water Level Monitoring Work Group within DNR Waters has begun the process of drafting guidance documents for the ground water level monitoring network. Completed drafts address the following topics:

- Network Goals and Objectives
- Policy and Criteria for Accepting Existing Wells into the Network
- Policy and Criteria for Installing New Wells to add to the Network
- Policy and Criteria for Removing Wells from the Network
- Policy and Criteria for Installation and Use of Electronic Data Logging and Telemetry in the Network
- Policy and Criteria for Vibrating Wire Transducer Use and Installation in Wells of the Network
- Field Practices for Ground Water Data Collection

The drafts were developed to serve the most immediate operational needs of the current network. The intention is that all will become components of a fully developed guidance document.

Presented as examples below *Policy and Criteria for Accepting Existing Wells into the Network* and *Field Practices for Ground Water Data Collection*.

Policy and criteria for accepting existing wells into the Network

This policy applies to:

Accepting existing wells from other entities into the Minnesota Ground Water Level Monitoring (GWLM) Network. Ownership of the well may or may not be transferred to the State of Minnesota, Department of Natural Resources, Division of Waters, depending on circumstances.

Background

From time to time existing wells may become available for use as monitoring wells. In most cases, the well is no longer being used by the owner. The reasons that a well is no longer used include: the completion of a study, reuse of a site, or a change of land ownership, among others. Rather than seal the well, and possibly incur considerable expense, the owner of the existing well may approach DNR Waters and propose that the well become part of the GWLM Network. The actual ownership of the well may or may not be transferred to DNR Waters. Potential wells for inclusion in the network may also be identified in other ways, such as surveys of unused or abandoned wells by local governments. Historically, most of the wells in the current network were added to the network through formal or informal access obtained from other entities. In some cases DNR accepted formal ownership of the well from another entity.

Adding an existing well to the Network may be very beneficial in terms of adding valuable data to the network without the expense of actual installation. Existing wells that are added to the Network by access agreement have ownership and future responsibility retained by another entity. However, if the ownership of the well is transferred to DNR, the transfer brings with it a commitment by DNR Waters to maintain the site and, when no longer needed, to seal the well. Potential costs to seal a well can be considerable.

General Policy:

The Division of Waters will add existing wells to the GWLM Network to improve the quality and quantity of ground water data and to reduce the cost of installing new wells.

General Criteria:

An existing well proposed to be added to the Network:

- Must fulfill a monitoring need;
- Should monitor a known aquifer or system;
- Must be in connection with the aquifer;
- Must be intended for long-term measurement;
- Must meet requirements of the Minnesota Well Code.

Technical Criteria

- The existing network should be reviewed to identify a specific need. For example, the well fills a gap that exists in the network or the well can replace an existing network well that is no longer functioning properly and needs to be replaced.
- The existing well should connect with an aquifer of sufficient extent and thickness to have an economic or resource value for a significant area.
- Other ground water level monitoring networks should be reviewed so the proposed well is not a duplicate of an existing operational well. The proposed well should also support complementary hydrologic cycle networks such as climate and surface water.
- Wells that are proposed for ownership transfer to

DNR Waters should be less than 25 years old and less than 6 inches in diameter. Proposed wells must meet the requirements of the Minnesota Well Code at the time of transfer.

- Proposed wells for inclusion in the Network should be at least 2 inches in diameter to accommodate measurement devices.

- GWLM Network wells should not be used for pumping. If the proposed well is used for pumping, the effects of the pumping shall be considered prior to accepting the well into the Network.

- The well must have proper documentation including a well log and/or other construction data that adequately describes the physical setting and construction of the well.

- Geophysical and video logs should be conducted on all proposed wells to verify the condition of the well and confirm the geology of the area in which the well is installed.

- Pumping and/or slug tests should be conducted to demonstrate functionality of the well.

- The condition and safety of the proposed well must be field-verified. The field verification step should also check location, use, pumps, or other equipment in the well.

- Any well that is open to multiple aquifers cannot be accepted into the Network unless provisions have been made to properly refit the well for single aquifer use.

Administrative Criteria

- The record of ownership of each well proposed for inclusion in the Network should be confirmed. Whether the well is added to the Network by access agreement or transfer, an access agreement or transfer agreement, respectively, will need to be concluded with the well owner.

- If the proposed well for transfer is not an actively used well, any pumps or structures in the well should be removed prior to accepting the well for transfer into the GWLM Network. This work should be conducted by the previous/existing owner of the well prior to the DNR Waters using the well as part of the Network.

- For wells that are added to the Network by access agreement, an access arrangement shall be approved between the property owner and the DNR Waters to allow long-term access to the well location for monitoring and maintenance (as defined in the Access Agreement).

- Existing wells that are proposed for addition to the DNR Waters GWLM Network shall have identification tags and impact protection installed as needed to meet Minnesota Well Code Requirements prior to accepting the well into the Network.

If a well is unsuitable for adding to GWLM Network, the information about the well should be stored for possible future review and reconsideration.

- Each proposed addition to the Network should be carefully reviewed and a review memo and recommendation prepared. The review should be conducted by the Groundwater Monitoring Well Coordinator and should address the criteria (as outlined above) used to determine if a well should be accepted into the GWLM Network as an observation well. The recommendation will be submitted to the Ground Water and Hydrogeology Supervisor for review and concurrance. The documentation should be kept in the GWLM Network well file and in the remarks section of the GWLM Network database.

Field Practices for Ground Water Data Collection

These draft field practices are based on 'Field Practices for Ground-Water Data Collection', June 2009, Advisory Committee on Water Information, Subcommittee on Ground Water and on standard practices established for DNR and MPCA hydrologists.

Quality data depend on high quality consistent field data collection procedures. Important elements to ensure data quality include:

- Training of all staff who are involved in data collection

- Pre-visit field site review and preparation procedure

- Standard listing of data elements that must be recorded

- Standard procedure to prepare for water level measurements at the field site

- Water-level collection and data recording procedures

Field-sampling procedures must take these elements into account in order to ensure that:

- Water levels are being taken at the correct location, from the correct well at that location, and at the proper time

- Water-level data are recorded and transmitted accurately

- Information recorded during measurements contains all of the information needed to normalize and compare analysis results

- Measures are taken to ensure the accuracy of the result

This document sets most of the minimum standards for successful field work for the backbone network. Elements of the water-level measurement aspects of subnetwork data acquisition programs should also be defined in a written set of procedures specific to the subnetwork data collection goals.

Training

Training of staff is necessary prior to field collection of ground-water levels to ensure consistent data quality. This document and other ground water level network guidance documents can serve as the fundamental basis for that training. Appropriate training includes formal training classes through universities, professional associations, or vendors and hands-on field experience through mentoring, on-site (on the job), and follow-up training to ensure that data are being collected consistently and correctly. Example training goals include:

- Field Safety
- How to establish where the proper measuring point is.
- How to measure water-levels with different types of network-standard equipment, including electric and steel tapes.
- How to measure water levels with pressure transducers and how to ensure that the pressure transducer readings are verified with direct measurements.
- How to maintain datalogger equipment and to ensure that accurate measurements are recorded at the correct intervals.
- How to store and decontaminate field equipment.
- How to record field data and take appropriate notes about site conditions.
- How to transfer field data and notes to permanent database and file archive.

Pre-visit Field Site Review and Preparation Procedure

Preparation for water-level measurements includes the gathering of equipment and supplies. A checklist of the equipment and supplies needed for each measurement trip will help the measurer avoid delays and prevent the collection of invalid measurements.

Equipment that will be used to collect continuous water levels should be calibrated and tested before deployment to ensure accuracy.

Decontamination and calibration of steel and electric tapes should be conducted as near in time as practical to field measurement. A record of decontamination and calibration should be maintained for all equipment.

Standard data sheets for recording water-level measurements will include all appropriate data fields (such as: well unique number, site name, date, time, water level below measurement point, land surface correction, elevation of measurement point, etc.

A recommended list of equipment and materials for miscellaneous water-level measurements follows: a suitable map (optionally, an aerial photograph and a town plat/lot number map), compass or handheld global positioning system (GPS), site form for recording site information, water-level measurement form, steel tape (graduated in feet, tenths, and hundredths of feet) optionally with an attached weight made of brass, steel or iron, a solid cake of blue carpenters chalk, clean rags, an electric water-level measurement tape, pen andpencil, adjustable wrenches, allen wrenches, pipe wrenches, hammer, socket set, or other tools needed for well access, a bottle of sodium-hypochlorite for disinfection, and latex-free vinyl gloves.

Copies of data sheets from prior site visits are very useful when determining the approximate depth to water to determine length of steel tape to be chalked.

Minimum Data Elements

Each water-level measurement site has inherent data elements that need to be verified and recorded, preferably prior to water-level measurements. The person making the water-level measurement should check to ensure minimum data elements are available prior to conducting measurements to ensure that it is accurate and up to date when in the field. Corrections and updates to the information should be made prior to measurement.

The ASTM has a recommended list of minimum data elements for inclusion in a ground-water level network as does the USGS, USEPA, and other regional and State agencies.

Onsite Preparation

The following activities are carried out in preparation for a water level measurement:

- Site verification. This can be accomplished in several ways including having made a previous visit to the site, comparing the site to a known grid reference using GPS equipment, comparing photographs of the listed site to the actual site, or identifying the site by a physical label on the wellhead or identifying sign.
- Equipment decontamination. Equipment must be decontaminated between water-level collections to prevent cross contamination between wells.
- Site condition notations. These include the date and time of day, weather conditions (rain, snow, etc.), measurement-point condition, damage, deterioration

- and any other factors that could affect the results of the current water-level measurement or future measurements.
- Site access. This may include access to the property (gate opening, etc.) and opening the cap or shelter that encloses the well.
- Use site reference materials to verify the measuring point for each measurement.

Water-Level Measurements

Numerous technical procedures have been written to describe the procedures to use when measuring water levels, either manually or with recorders designed to automatically measure water levels on a continuous basis. Procedures from USEPA, USGS, and ASTM, among others, exist. Because these technical procedures do not appreciably vary in terms of the quality of data that would result, the following sections refer to the technical procedures already documented by these organizations.

All measurements should be recorded either on a field computing device or on network standard paper forms. If electronic recording of measurements is chosen, all information required on the paper form also should be enterable electronically. Electronic files should be downloaded when returning from the field and archived as a method for retaining original field measurements. Field measurements recorded on paper should be electronically entered into available databases shortly after returning from the field. Paper forms should be scanned and archived appropriately. No original documents are to be returned to the field.

Manual Water-Level Measurements

All manual water-level measurements should be designed to have repeatable and accurate methods of determining the elevation of the water-level surface. Manual water-level measurements can be made by use of several methods; the most common are the graduated steel or wetted tape method and the electric-tape method.

The method chosen at a given site will depend on site conditions and well construction.

Automated Water-Level Measurements

Automated water-level measurements are made so that a continuous (or near-continuous) record of water levels can be made with minimal human intervention. Automated (continuous or near-continuous) water-level measurements can be made with pressure transducers and other technologies. Regardless of the method of measurement, care should be taken to ensure that the entire expected range of water levels can be measured with the device at the expected accuracy.

After the water-level recorder is placed in a well, the resulting measurements are compared to manual water-level measurements to create a calibrated record of water levels. Documentation should be maintained to ensure accurate measurements, including date/time of calibration; the type, serial number, and range of measurement device; and what units are being measured. A field copy of the necessary calibration and equipment information should be taken to the field each visit.

Minimum Data Standards

The following section outlines various standards to which water-level measurements should adhere, to ensure consistent data quality. Various types of water-level measurements can be made and the standards vary with the type of equipment used to make the measurements.

Manual Water-Level Measurements

Several manual water-level measurements should be made in short succession to ensure the measurement is accurate to within at least 0.02 ft between consecutive measurements. For electric-tape measurements, the USGS recommends that at least three measurements be made, with two consecutive measurements within 0.02 ft. Some methods of manual measurement (at flowing wells, for example) will not have that level of repeatability. Regardless of the method of measurement, all measurements should be recorded. The accuracy of the water-level measurements (based on the repeatability of the measurements) should be documented.

Automated Water-Level Measurements

The accuracy of automated (continuous) water-level measurements should be at least 0.02 ft. Instrument drift and faulty instrumentation can affect the accuracy of the data collected.

The frequency at which the water-level recorder should be visited should be based on the stability of the transducer, the storage limitations of the recording device, and knowledge of the expected hydrograph of the aquifer. Field visits at intervals of 6-8 weeks should be sufficient until the requirements of the individual site are determined. Regardless of the measurement device, measurements should be made often enough that the recording devices onsite will not run out of room in memory to store data and so that the accuracy of the measurements is not compromised through excessive drift or range of water level. A large annual drawdown/recharge cycle would necessitate additional visits to allow resetting the transducer for different seasons or during climatic extremes. Real-time (or near-real-time) telemetry can also be added to the well; a stable well displaying real-time data may be visited much less frequently than other wells.

Instrument drift corrections, calibration corrections, and datum corrections all can affect the accuracy of measurements and should be applied after downloading the data.

Data Handling and Management

Extreme importance must be placed on documentation of field and office procedures to ensure that the quality of the data is maintained. This section covers some specific data handling and management procedures.

Electronic Entry of Data

The first step in processing water-level data is entry of the measured data (measured or computed values associated with a specific instantaneous date and time), field data, and related information into an electronic database and/or processing system.

Verification and Editing of Data

Data must be checked carefully and verified against field notes or records before being used in further analysis. Suspicious values may require investigation. Individual values that might be incorrect are compared to field measurements or to known extremes of record. Prior to editing, original unit values should be archived; a copy of the original data file should be edited, and this copy should also be archived upon completion of editing. Various issues can arise in water level data sets, including errors with times and dates and instrument drift or datum errors. Current procedures in place for entry of data into the joint MPCA/DNR Hydstra data system will be drawn upon for guidance.

Field-measurement data includes discrete water-level measurements, well-construction data, and miscellaneous field notes. Field-measurement and related data usually are entered into the electronic system in the office, although some data can be entered on portable field computers. Various computations and comparisons should be made to ensure accuracy of the data and consistency of the information

Arithmetic errors, transcription errors, and logic errors (such as depth of well less than depth to water), should all be checked and corrected before final entry into the database. All data should be entered into the database with the same significant digits as recorded in the field. Calculated values should be rounded to the significant digits recorded in the field notes. Measuring point elevations should be a permanent datum maintained as accurately as possible throughout the lifetime of the observation well. Surveying or leveling should be performed periodically to ensure that corrections can be made to adjust for movement of the datum.

Original paper records should not be modified, deleted or erased, or returned to the field because this increases the chance they will get damaged or lost. Scanning and archiving of notes recorded on paper notes should be done so that all editing of errors, instrument or time drift corrections, and such can be recreated if necessary.