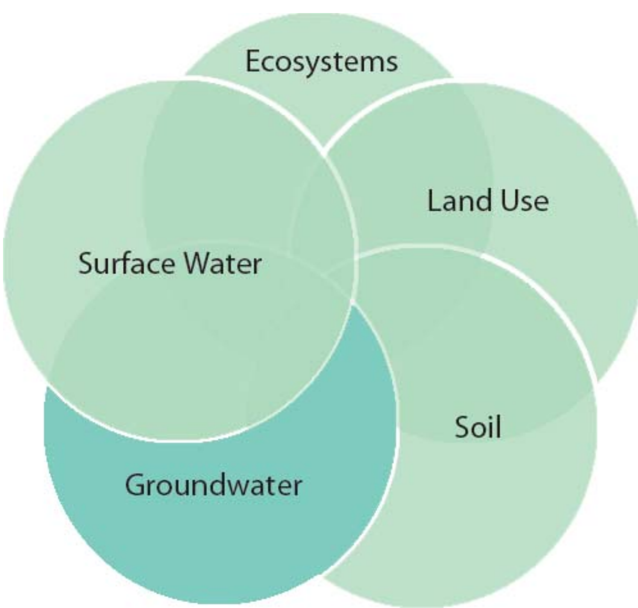
Minnesota Groundwater Level Monitoring Network—

Guidance Document for Network Development



Minnesota Department of Natural Resources

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Executive Summary

Minnesota's environmental and economic future depends on a continued and available supply of groundwater that is managed sustainably. The Minnesota Department of Natural Resources is responsible for managing the quantity of groundwater use through appropriation permits and monitoring water levels. Groundwater quantity estimates for management purposes depend on a historical record of water level measurements. However, the state's current groundwater level monitoring network does not provide adequate statewide groundwater quantity information because many areas and groundwater resources are unmonitored.

This Guidance Document outlines how Minnesota's current groundwater level monitoring network of approximately 750 wells should be expanded to approximately 7000 groundwater level monitoring wells to meet monitoring needs. This expansion is necessary because large areas in Minnesota are not adequately monitored. Many areas of Minnesota are underlain by multiple aquifers, all of which must be considered in developing the long-term network that will provide adequate resource data. A more complete and integrated network of groundwater level monitoring wells will provide stakeholders, local government officials, and groundwater resource managers with the information needed to:

- Understand the status of groundwater quantity throughout the state
- Formulate management responses to changing water levels
- Plan for the future based on current scientific data

This document is intended to provide the DNR with a guide to build the backbone network that will support the state's current and future groundwater level monitoring information needs. Network wells will become long-term assets used to fully understand, manage, and assess Minnesota's groundwater resources. As described in this document, this is an unprecedented expansion project that will vastly improve the understanding of Minnesota's groundwater resources. The envisioned expansion is a very significant undertaking, estimated to require 30 years to complete and cost $94.7 million. The continued operation and maintenance of the network assets as the network expands is also a significant undertaking, requiring on-going support to acquire, analyze, and interpret groundwater level data and to make the data readily available to a wide variety of users.

The Minnesota groundwater level network as it develops into the future is intended to meet information needs for sustainable management of water resources. The existing network, while limited, provides invaluable data for resource managers; the expanded network will provide greatly improved data resource to understand groundwater system response to change and provide the groundwater quantity data needed to make informed decisions to protect Minnesota's groundwater resource for the future.

Section 1: Introduction

This document is a guide for the continuation and further development of the Minnesota Department of Natural Resources' (DNR's) Groundwater Level Monitoring (GWLM) Network. Groundwater level data obtained from network wells provides an essential portion of the information needed to understand groundwater system change over time and effectively manage the resource.

Staff of the DNR's Division of Ecological and Water Resources formed the Groundwater Level Monitoring Work Group and their efforts are reflected in this document. Sections 1.1 through 1.4 reflect a common understanding of DNR staff in the Work Group. The subsections following set forth background information that was considered in the network design discussed in Section 2.

1.1 - Introduction

This document provides a guide for expanding the existing network of groundwater level monitoring wells to provide the information needed to effectively manage the groundwater resource. The network, operated and managed by the Minnesota Department of Natural Resources, provides groundwater level data from monitoring wells that is used in conjunction with climate, stream flow, lake level, and other hydrologic system data to accurately track trends over time in the hydrologic system, including groundwater quantity. These data describing the hydrologic condition of streams, lakes, aquifers are necessary for the long-term sustainable management of the state's water resources.

Measurement of water levels in wells is currently the only reliable technology to monitor changes in the quantity of groundwater. Adequate assessment of groundwater system trends depends on knowing water level changes over time measured in a sufficiently large network of wells. The wells measured must be sited in proper locations, installed to measure desired water-bearing zones (i.e., aquifers), and measured according to standard procedures.

The vision and mission statements for the DNR groundwater level monitoring network define what is hoped to be achieved over time to support the protection and management the groundwater resources of Minnesota. The goals and objectives are the blueprint for the ongoing and future network operation and development.

1.2 Vision

To assure long-term sustainable management of Minnesota's groundwater resources.

1.3 Mission Statement

Since there is no alternative technology to reliably measure groundwater levels other than through the use of wells, DNR will need to collect, analyze, and provide groundwater level data acquired from an expanded and integrated network of wells. The network will allow the DNR to assess the quantity of the groundwater resources and its response over time to natural and human-induced changes.

1.4 - Goals and Objectives

The following six goals with stated objectives were developed by the DNR Division of Ecological and Water Resources' Groundwater Level Monitoring Work Group:

> Goal 1: Develop and maintain a statewide, integrated long-term groundwater level monitoring well network.

Objectives:
- Continue and maintain the existing network.
- Complete network assessment and inventory
- Develop a long-range network plan to support resource management.
- Prepare a priority plan for adding wells to the network.
- Prepare a plan for removing non-functional wells from the network.
- Use wells owned or managed by others, as appropriate, to extend network coverage.
- Construct new wells where needed according to long-range and priority plans to extend network coverage.

Goal 2: Collect groundwater level measurements statewide.

Objectives:
- Collect regular, periodic groundwater level data statewide.
- Collect long-term data whenever possible.
- Collect data from well nests that measure different aquifers at the same location.
- Utilize electronic data collection and transfer methods when possible and appropriate.
- Establish agreements that allow access for measurements and maintenance.

Goal 3: Oversee data collection and maintain data collected through water appropriation permits and special studies.

Objectives:
- Consolidate groundwater level data generated by water appropriation permit requirements or special studies.
- Establish procedures and data review criteria for data acceptance into the GWLM Network database.
- Maintain all data for long-term access and analysis.

Goal 4: Maintain a statewide groundwater level data storehouse.

Objectives:
- Consolidate all groundwater level data for shared access through a single portal.
- Maintain all data for long-term access and analysis.
- Provide easy access to the data to meet both internal and external users needs.

Goal 5: Provide general interpretations of groundwater level data, including trends and fluctuations due to human impacts and natural influences.

Objectives:
- Enhance the existing web-based well hydrograph application for individual wells.
- Provide additional correlated data interpretation, such as precipitation time series data, lake level data, climate events, and water use data so that relationships to groundwater level changes can be investigated.
- Develop tools and applications for automated or semi-automated general data analysis.

- Develop criteria and techniques to portray the general resource status by aquifer and/or area for both short-term and long-term trends.
- Provide interpretations to the public and users in a form that is flexible and cost effec tive.

Goal 6: Provide data and technical assistance for in-depth technical analysis.

Objectives:

- Consolidate and maintain collected groundwater level data through a single portal in a form that provides the necessary data elements for detailed technical analysis.
- Assist users to access the data or provide customized database queries on request.
- Assure that internal and external users have access to all relevant data.
- Provide technical assistance and data interpretation.

1.5 - Groundwater: More than Just Aquifers

The current groundwater level monitoring network is designed to measure water levels in the more significant aquifers in Minnesota. However, to fully assess the status of the state's groundwater resource, the non-aquifer formations that convey water to, from, or between aquifers also need to be monitored.

Aquifers are the most well known among water-bearing geologic units of rock and sediment, although groundwater also occurs in geologic units that are not defined as aquifers. The sediment and rocks below the water table are saturated with groundwater; the more permeable formations that readily release water are defined as aquifers and can be used for a water supply. Less permeable formations tend to release water slowly and are generally not defined as aquifers or considered reliable water supplies. The less permeable sediments and rock can, however, transmit, over time, significant quantities of water to replenish aquifers.

Groundwater is actually a flow system that occurs within a three-dimensional geologic container of sediment and rock. The geologic container comprises many different geologic materials with varying properties and water saturates nearly the entire geologic container. Water moving from the land surface to aquifers beneath the land surface will move in and between both aquifers and non-aquifers on its path from recharge into the groundwater system to discharge from the groundwater system. Since water is essential for life, geologic materials that can supply water or are aquifers have been the focus of geologic mapping and monitoring. As aquifers are more intensively used for drinking water, industry, agriculture and other purposes, the replenishment of aquifers from non-aquifers requires more thorough understanding. In order to better quantify Minnesota's groundwater supply, the status or condition of non-aquifer units also need to be monitored and assessed. Therefore, both aquifer and non-aquifer groundwater monitoring sites need to be included in the GWLM Network.

1.6 - Historical and Background Information

Personnel from Minnesota's Department of Conservation, Division of Waters first began collecting groundwater level records in 1932. This network began as a modest collection of water level measurements from a small number of wells, and additional sites were added slowly during these early years. As of June 2010, the DNR Division of Ecological and Water Resources managed a cooperative network of approximately 750 groundwater-level groundwater level monitoring wells. In 1975, R. F. Norvitch of the

United States Geological Survey (USGS) described the beginnings of the first Federal water level measuring program:

> "Groundwater level monitoring [in Minnesota] began in 1942, on the farm owned by Irwin Kjelshus located in Brown County as part of a federally financed program for the collection of basic records. This and one other well in Morrison County were designated as Federal Index Wells. Water level data from the wells were sent monthly to the staff of the Water Resources Review."

The Norvitch report gave details of the USGS groundwater-level monitoring effort and represents one of the earlier descriptions of groundwater-level monitoring in Minnesota.

A 1993 DNR summary report outlined the progress of the Groundwater Level Monitoring Well Program. At that time, a total of 650 groundwater level monitoring wells were actively monitored and paper records were being organized and electronic records updated. An electronic database was transferred from the USGS to the Division's network server, where missing information was appended to file records and file updates were completed. Also, at that same, 20 new groundwater level monitoring wells were added to the network. DNR personnel on these improvements to the GWLMN were partly funded by the 1989 Minnesota Clean Water Act.

Under contract with DNR, Soil and Water Conservation Districts (SWCD) cooperators currently measure water levels monthly at most of the groundwater level monitoring wells and report the readings to DNR. Readings are also obtained from volunteers at several locations.

Most recently, DNR has produced two detailed and closely-related reports titled "Long-Term Protection of the State's Surface and Groundwater Resources January 2010" and "Groundwater: Plan to Develop a Groundwater Level Monitoring Network for the 11-County Metropolitan Area". Both of these documents outline and discuss the DNR's groundwater perspectives and policies, including the need for long-term groundwater level monitoring. These and other reports are relevant to and interconnected with this document.

1.7 - Current State of the Minnesota Groundwater-Level Monitoring Network

The current network provides groundwater-level data measured at approximately 750 wells distributed throughout the state. Most, but not all, counties have at least one GWLM Network well that is measured, and most of the wells are measured once per month. Figure 1 shows the distribution of measured and unmeasured groundwater-level monitoring wells in the network. These wells tend to be located in areas underlain by significant aquifers. Some counties do not have any measured wells in the network because the counties are not participating in the network, population levels are low, or because water resources are limited in those locations.

Over the decades of network operation, the DNR has collected water level measurements from as many as 1,639 groundwater-level monitoring wells. Wells that were formerly measured, but that are not currently measured are called unmeasured wells; the historical data from these 889 unmeasured wells are main

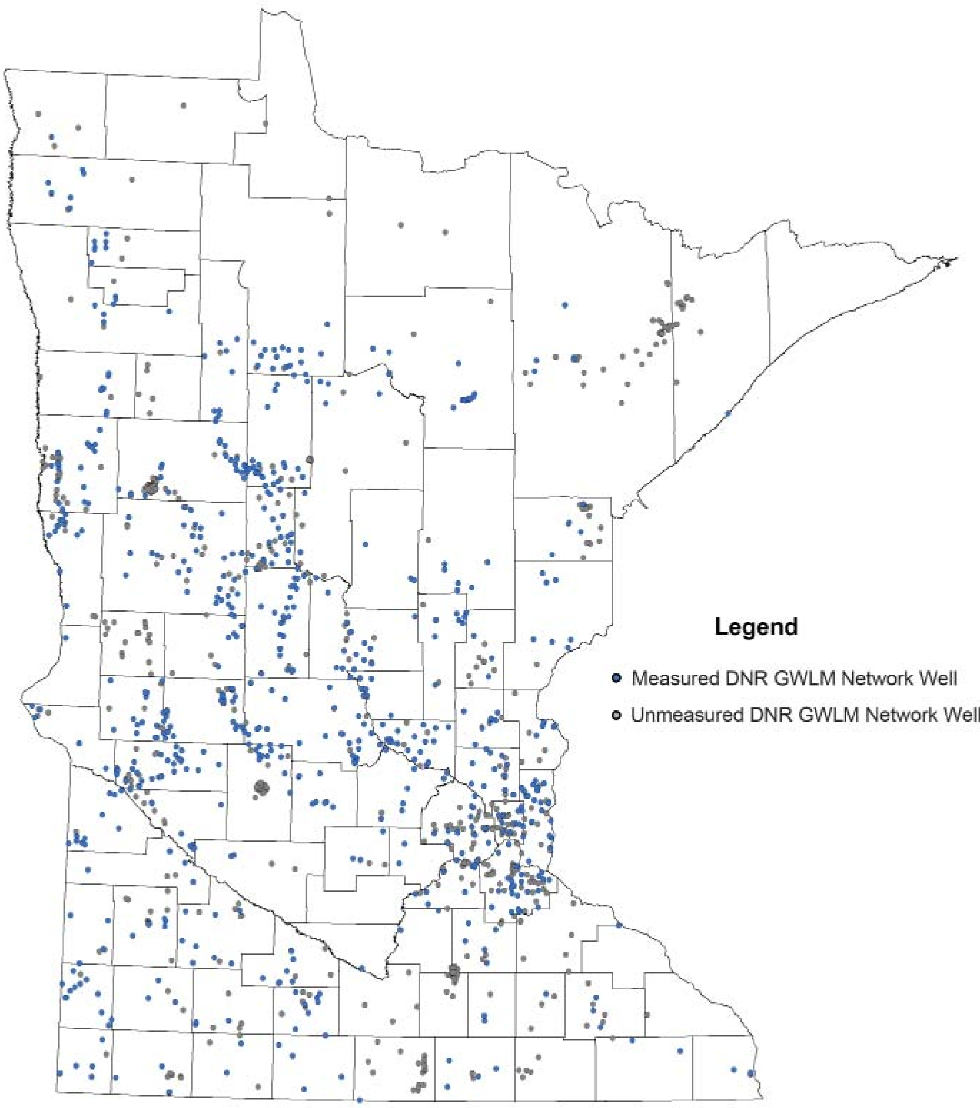

FIGURE 1. Map of measured and unmeasured DNR GWLM wells.

tained in a database. Wells at unmeasured sites may still exist but are not measured, they may be sealed and unmeasurable, or they may no longer exist. The reasons for not measuring wells include: the condition of the well degrades, access to the well changes, there is no local cooperator available to measure the well, or the well is pumped. When possible, pumped wells are not measured because the measured water level in a pumped well will not reflect the ambient aquifer water level, and may compromise the data.

The GWLM Network has been developed over decades with groundwater level monitoring wells added as the DNR gained access to each well. Typically, groundwater level monitoring wells were added to the network as a result of a groundwater inquiry or water use investigation. As a result, the current network consists of a patchwork of wells with varying purposes including: municipal supply wells, irrigation wells, monitoring wells, and private wells. Since the purposes vary, the construction of the wells also varies by depth, size, diameter, and aquifer monitored.

The GWLM Network includes wells that that were constructed at various times. These wells became part of the network at different times in the past, resulting in water level records of varying lengths. Table 1 shows the age profile of water level records with the corresponding number of wells in the network as of 2010. The length of well record is important because a long-term record contains the historic highs and lows that increase the data value. Most network wells have data records from 20-40 years. The network has relatively few groundwater-level monitoring wells with monitoring records longer than 40 years.

TABLE 1. Data record length profile of measured wells in the groundwater level monitoring well network

Years of Record	Number of Wells
0-10	121
10-20	116
20-30	255
30-40	173
40-50	53
>50	8
Total	726

The length of data record only indicates how long the wells have been measured; wells with long data records may have been constructed significantly earlier than the start of the data record. Some wells in the network were constructed many decades before becoming part of the network.

DNR Division of Ecological and Water Resources, supported through the state General Fund, is assessing the condition of all measured and unmeasured GWLM Network wells (Figure 2). The assessment includes locating the well with Global Positioning System (GPS) equipment, recording the well's elevation, taking site photographs, collecting physical well measurements and conducting hydraulic tests where appropriate. As of September 2010, the assessment of the GWLM Network wells has been completed in 63 of the 87 counties.

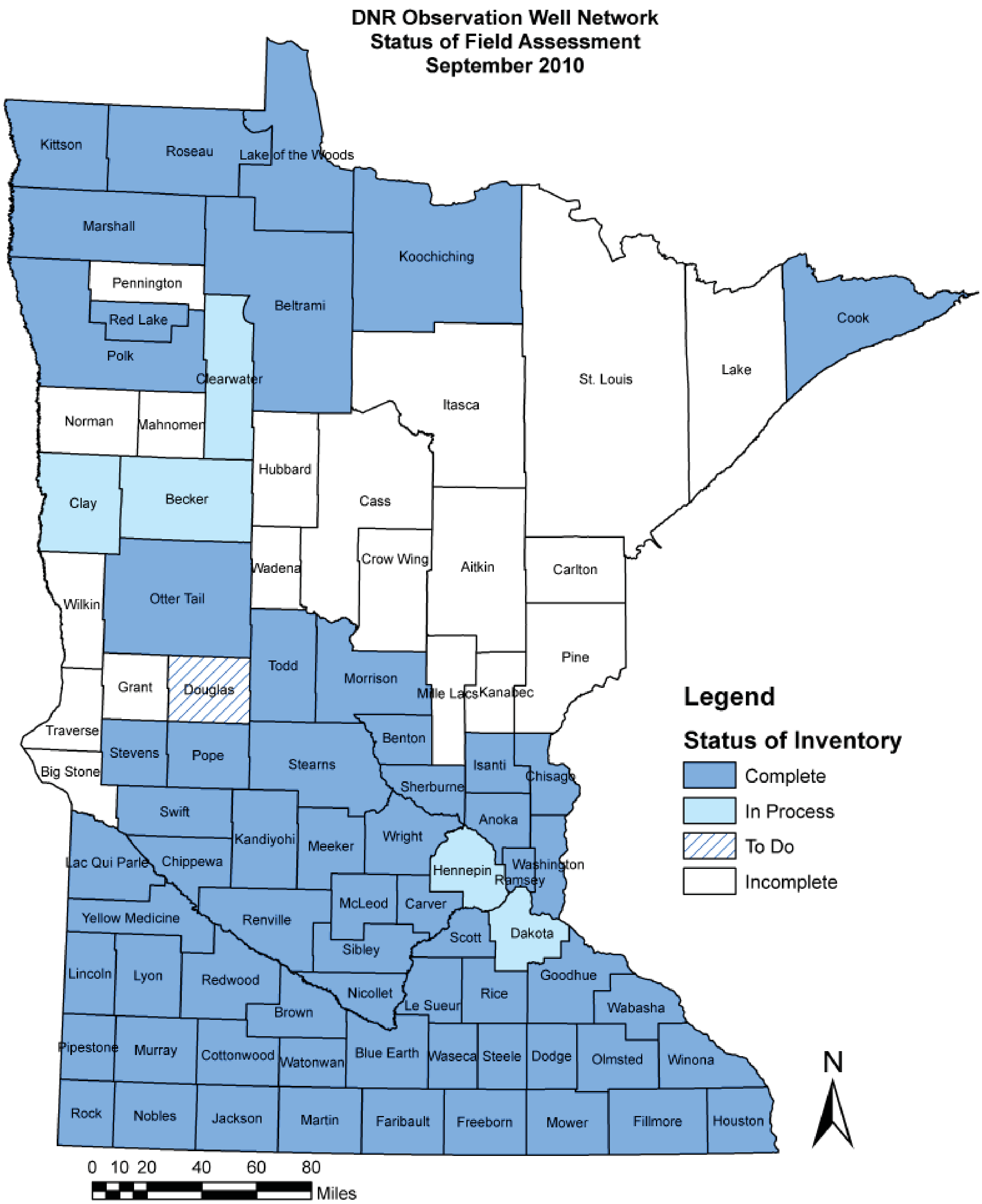

FIGURE 2. DNR status of field assessment.

Approximately 1,077 wells have been assessed, leaving approximately 562 wells remaining (Figure 2). Currently unmeasured wells are also included in the network assessment. The unmeasured wells are being revisited to verify records and to determine if it is possible to reactivate any wells with a new groundwater level monitoring well so that the continuity of water level records can be re-established. If the well is in poor condition, but the continuity of the long-term record is a priority, the well may be replaced. A copy of the Field Check List used for the groundwater level monitoring well assessment is included as Appendix 1. As part of the assessment process, a list of wells requiring maintenance has been created. The list includes specific items identified during the site visit that need attention or repair. The assessment is scheduled to be completed during 2011.

Most wells in the GWLM Network are located on private property and are privately owned. DNR staff are granted access to the well by the well owner through written or verbal access agreements. A process is underway to obtain updated written access agreements at all actively-measured groundwater-level monitoring well locations. A copy of an access agreement is included as Appendix 2. Experience has shown that basing a network mostly on private wells is difficult to operate because of the changes that disrupt access, such as ownership transfers and cancelled agreements. Establishing network wells on public property, when possible, is preferred since ownership is less likely to change.

Wells that are part of the network require ongoing maintenance. Over time, wells may be damaged or may not function properly. Wells need to be properly repaired and maintained if quality data are to be obtained. For privately-owned wells, the maintenance of those wells is the responsibility of the well owner. Network wells controlled by the DNR are maintained by the GWLM Network manager.

When the assessment described earlier or other information indicates that a GWLM Network well does not provide representative water levels, the GWLM Network manager evaluates the well condition and determines whether to redevelop, replace, or seal the well. Redevelopment of a well involves removing sediments, mineral scale, and biological slimes from the well. If the well does not respond to redevelopment, the well is sealed, and a replacement is considered by the GWLM Network manager based on the importance of that particular location. The decision to replace a well is based on the presence of other GWLM Network wells in the vicinity. Simple well replacements to a depth of about 50 feet can be accomplished by DNR Division of Ecological and Water Resources staff using the division's hollow stem auger drill rig (Figure 3).

FIGURE 3. Installing a shallow GWLM well using a hollow stem auger drill.

This drill rig is operated under the supervision of DNR Division of Ecological and Water Resources-licensed well drillers. For deeper groundwater level monitoring wells, registered water well drilling contractors are hired through a competitive bidding process (see Appendix 3).

Installation of wells is done following all safety requirements; Appendix 4 is a template for a drilling site safety plan. If the DNR determines that a private well needs to be replaced, the DNR will work to place the replacement well on appropriate public property. If no public property is available, replacement on the existing private land will be evaluated and if necessary an agreement with the property owner will be obtained. The property owner would be responsible for sealing the private well on their property if the DNR no longer uses the well as an GWLM Network well.

The approximately 750 groundwater-level monitoring wells in the GWLM Network may seem to provide adequate coverage (Figure 1). However, the map shown in Figure 1 tells an incomplete story; while an existing well may be indicated at a given location, this does not mean that all the aquifers in that location are adequately monitored.

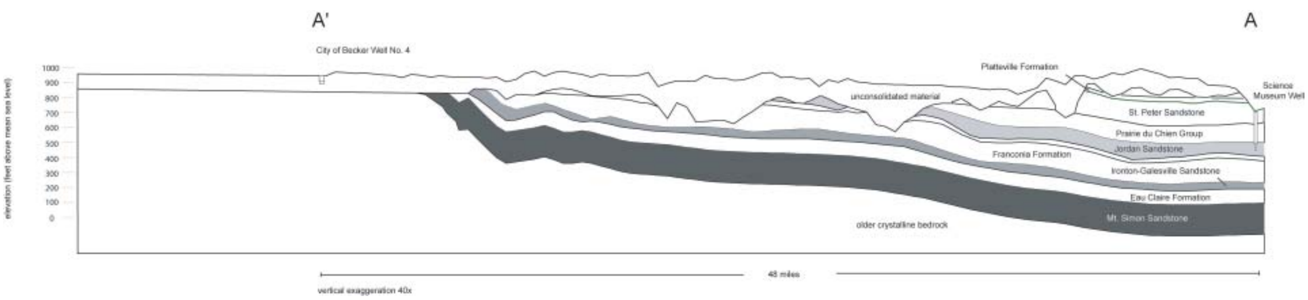

FIGURE 4a. Cross section from downtown St. Paul to the city of Becker showing multiple regional water supply aquifers.

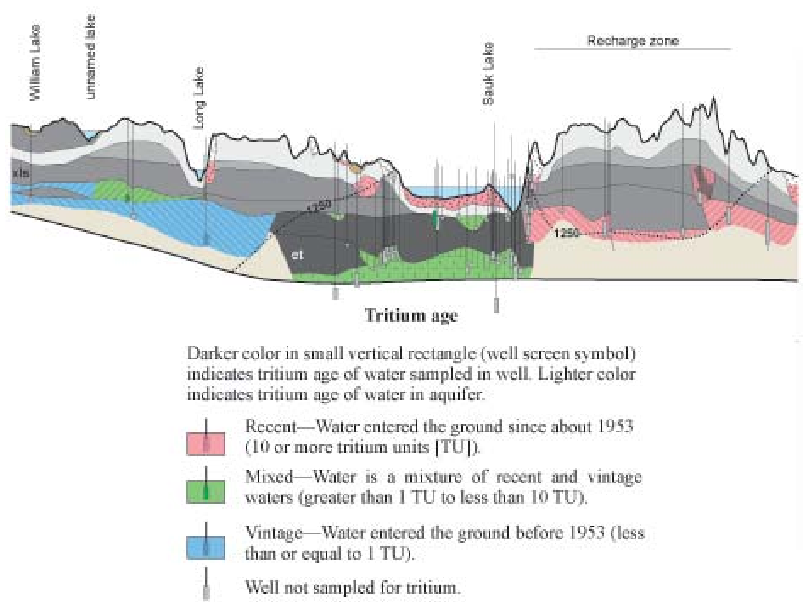

FIGURE 4b. Portion of cross section F-F' from the Todd County Geologic Atlas, Plate 8. The pink, green, and blue-colored units aquifers containing groundwater of different tritium age. The grays show the position of clay-rich sediments (till) in the subsurface. Lighter grays are more permeable.

The cross section example in Figure 4a of the northwestern portion of the Twin Cities metropolitan area shows how the major bedrock aquifers of southeastern Minnesota are continuous over regional areas. Some subsurface materials are less continuous, such as the Quaternary sediments that underlie most of the landscape of Minnesota. Minnesota's subsurface contains multiple layers of Quaternary sediment and more than one aquifer at a single location can be present at different depths. The aquifers within Quaternary sediments are less extensive than the bedrock aquifers in Figure 4a. Figure 4b shows a portion of northwestern Todd County. In this figure, sediments colored pink, green, and blue have been identified as aquifers and they illustrate how multiple aquifers can occur in one area but may not be continuous over larger areas. The statewide network design must understand and incorporate these variations in depth and continuity of groundwater resources to assure adequate monitoring. The mapping of Quaternary sediments and aquifers is incomplete in many parts of the state, and is ongoing as part of the County Geologic Atlas Program and other mapping investigations. As mapping proceeds, new information will guide future network development.

The following statewide well location and aquifer extent maps show the subsurface variability of aquifers in Minnesota and the existing monitoring well distribution within those aquifers. Figures 5a-5e shows the well locations for selected aquifers or aquifer groups. When the locations of measured wells from Figure 1 are presented according to aquifer or aquifer groups, unmonitored areas are revealed in the current GWLM Network. The greater the distance between wells, the more uncertainty exists about the actual water level in an aquifer. The uncertainty varies by depth and resource. The water table and shallow Quaternary settings have the most variation and therefore require more monitoring wells in an area. In contrast, water levels in wells in deeper regional bedrock aquifers are more predictable and thus require fewer monitoring sites per given area.

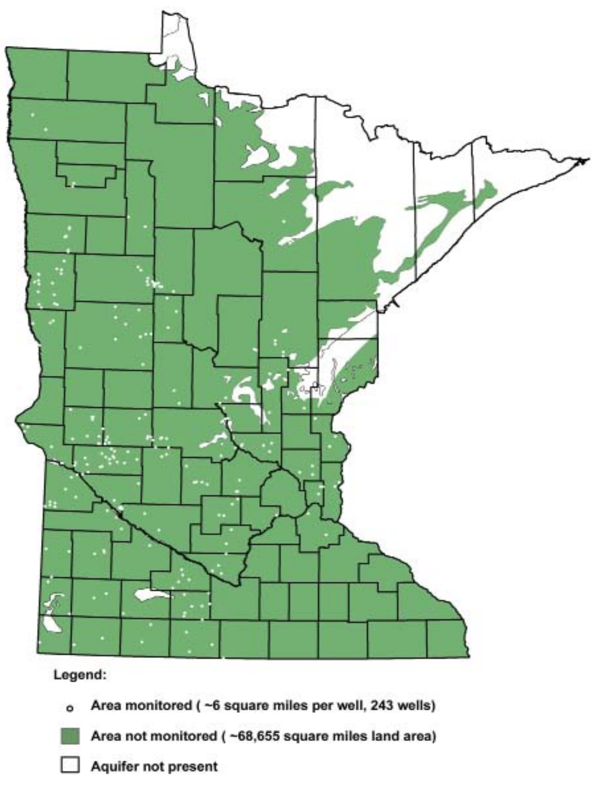

FIGURE 5a. Map of existing monitoring wells and potential extent of buried drift aquifers. The buried drift aquifers have not been completely mapped, and occur at multiple depths in many locations.

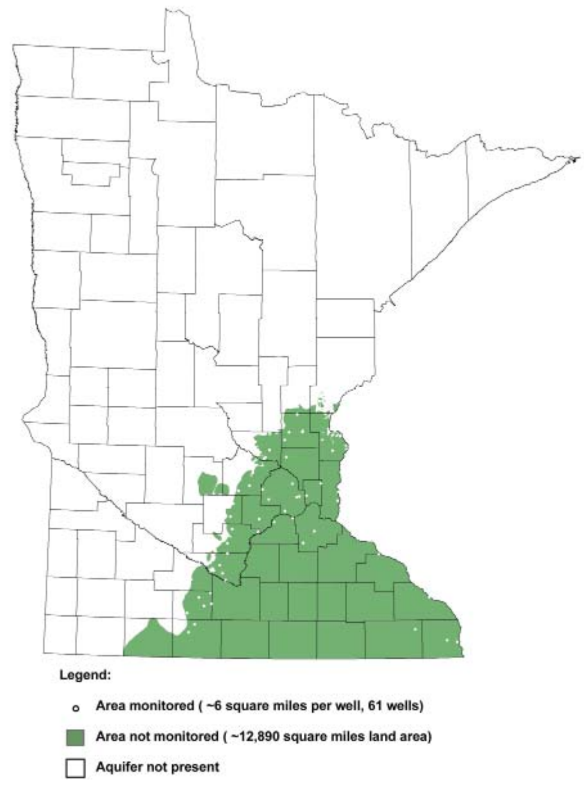

FIGURE 5b. Map of existing monitoring wells and the extent of the Mount Simon aquifer.

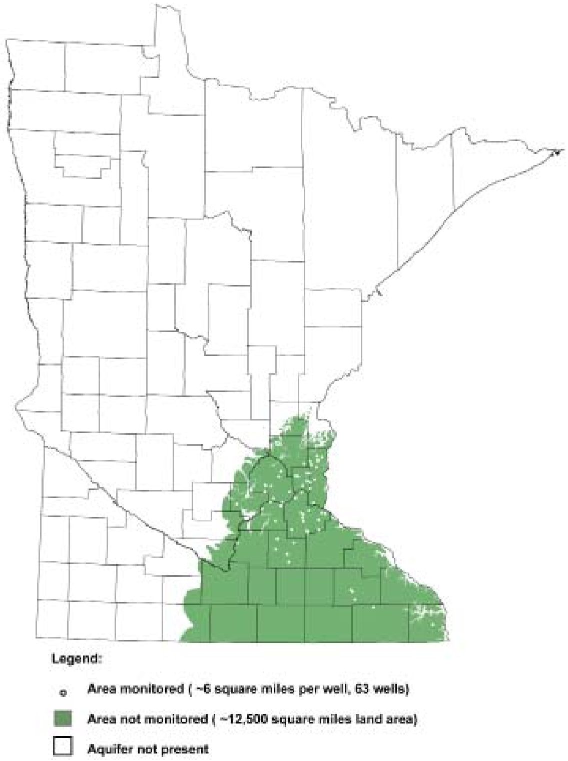

FIGURE 5c. Map of existing monitoring wells and the extent of the Prairie du Chien aquifer.

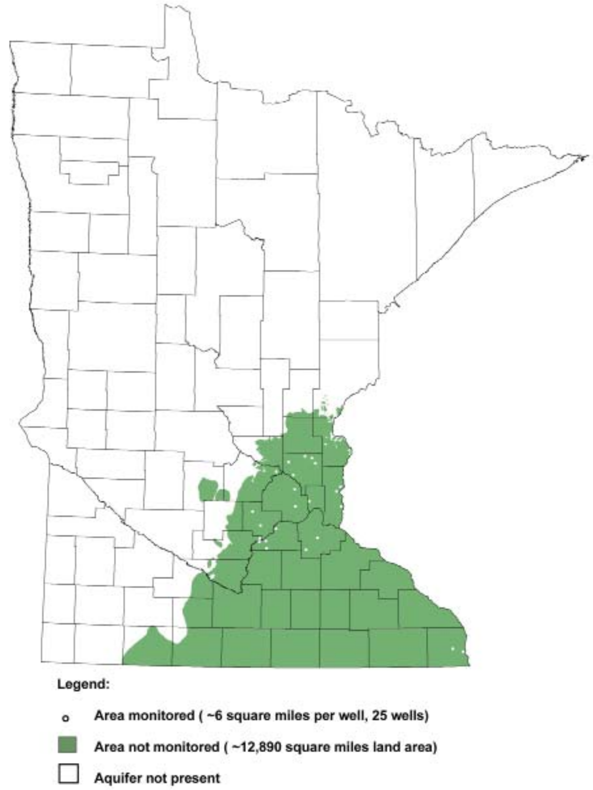

FIGURE 5d. Map of existing monitoring wells and the extent of the Tunnel City/Wonewoc aquifer.

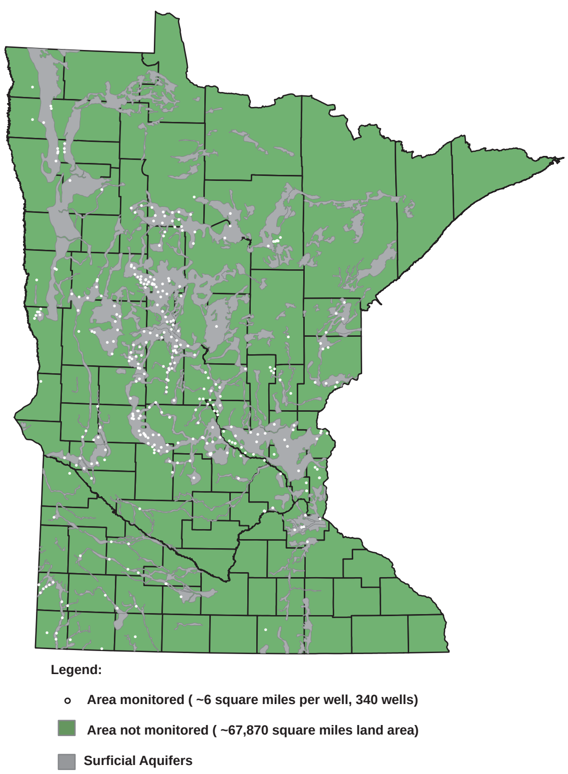

FIGURE 5e. Map of existing monitoring wells and the extent of the water table system. The extent of the water table system includes both aquifer and non-aquifer water table settings.

Additional network wells are brought into the network though accepting existing wells or installing new groundwater level monitoring wells. Policies and criteria for accepting existing wells or installing new wells into the network are included in Appendix 5. These policies and criteria are followed by the GWLM Network manager when evaluating a proposed existing well for inclusion in the network or when considering adding a new well to the network. The criteria include both technical and administrative criteria that are the basis for accepting existing wells or installing new wells. In the event a well is no longer needed as part of the network, related policies and criteria are considered for the removal of a well from the network.

Many aquifers throughout the state lack adequate groundwater level monitoring data. The extent and coverage of the current network show that there is a need for additional groundwater level monitoring wells to achieve long-term data goals that will help protect and manage the water resources of the state. A more detailed discussion of the network expansion is covered in Section 2. The initial network was built using a gathering of resources; the current network has been built and operated using limited funds. Recently, the need for additional groundwater level data has been recognized by citizen and Legislative advocates, and more funding has been allocated to begin needed expansion and improvement of the network.

1.8 - Review of State Groundwater Level Monitoring Networks in Other States

A review of groundwater level monitoring networks operated by other states was completed using information from public resources. During the review process it became clear that a fair comparison would be difficult because of variations in the reporting methods for individual state networks.

In 2007, a nationwide report was published that summarized states' monitoring efforts (Figure 6). In this report, the responding states provided answers to 24 questions including the number of wells, measurement frequency, and nature of that state's network(s). In that report, Minnesota ranked 18th out of the 36 states based on total number of wells. Minnesota's network ranks 15th among the 36 states based on well density.

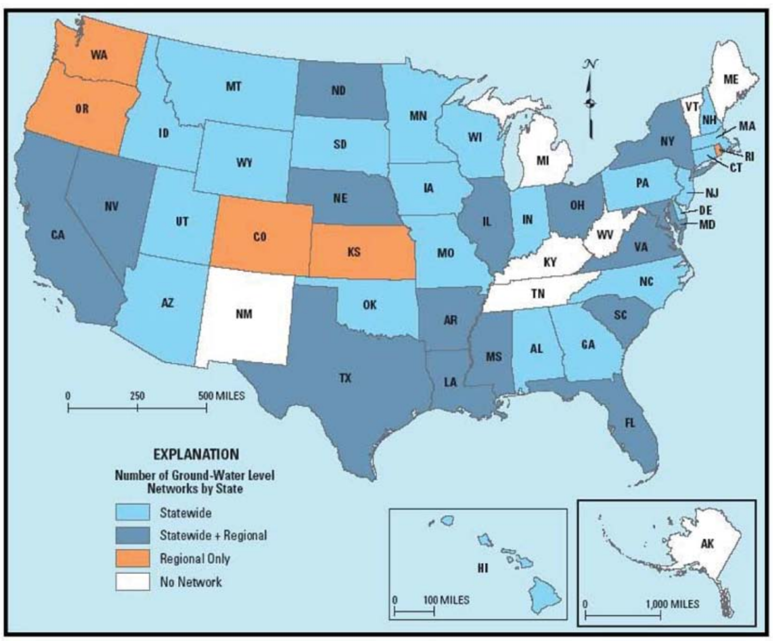

FIGURE 6. Summary of states' groundwater Level monitoring efforts (Association of American State Geologists, 2007).

Based on 42,916 groundwater level monitoring wells, California appears to lead all other states. California's well density is 0.4 wells per square mile. However, while California reported having 8,245 wells with a five-year or longer length of record, the survey results did not indicate how many of these wells have been measured monthly.

To make a valid comparison, the Minnesota groundwater level monitoring well network was compared to the other 29 states that measure water levels once a month. North and South Dakota ranked first and second, Florida was third, and Minnesota ranked fourth. Table 2 lists the states that responded to the survey question that asked the number of wells that are measured monthly. Not all states responded to this survey, so the information presented on this table may be incomplete.

TABLE 2. States that measure groundwater levels monthly.
[Data from Association of American Geologists, 2007].

Rank	State	Total Wells Measured	Total Wells with at Least 5 Years of Measurements
1	North Dakota	2547	2547
2	South Dakota	1639	1639
3	Florida	1310	953
4	Minnesota	675	675
5	Texas	500	460
6	North Carolina	247	
7	Washington	200	
8	Georgia	180	180
9	New Jersey	163	156
10	Wyoming	150	140
11	Missouri	101	70
12	Massachusetts	92	90
13	Arizona	90	40
14	Virginia	80	46
15	Ohio	77	70
16	Illinois	50	50
17	New York	50	37
18	Delaware	45	45
19	Maryland	43	
20	Indiana	40	40
21	Nevada	38	38
22	New Hampshire	27	26
23	Montana	25	25
24	Arkansas	24	20
25	Kansas	20	20
26	Alabama	18	18
27	Nebraska	12	12
28	Louisiana	8	8
29	Oregon	4	4

Source: Association of American State Geologists, 2007

1.9 - National Efforts to Guide Groundwater Level Monitoring

A national group of groundwater experts advises the federal government on water resource data issues. This group, known as the Advisory Committee on Water Information (ACWI), was originally formed by the Secretary of Interior under the Federal Advisory Committee Act; the ACWI formed a sub-group known as the Subcommittee on Groundwater (SOGW) that is working to develop and encourage implementation of a nationwide, long-term groundwater quantity and quality monitoring framework. This framework would provide information necessary at a national level for the planning, management, and development of groundwater supplies to meet current and future water needs, and ecosystem requirements.

In June of 2009, SOGW released the report “A National Framework for Groundwater Monitoring in the United States”. This document outlines the building of a National Ground-Water Monitoring Network (NGWMN) to include both groundwater levels and groundwater quality. More recently, Minnesota’s groundwater level monitoring wells located within southeast and south central Minnesota (including the Twin City Metropolitan Area) were selected by SOWG, as were wells from four other areas (Illinois-Indiana, Montana, New Jersey and Texas), for inclusion in a pilot project to implement a national network. The data acquired via the national network would be available through a national data portal that is currently under development.

1.10 - The Minnesota Groundwater Level Monitoring Network as Part of a Hydrologic Cycle Network of Networks

The current DNR GWLM Network includes about 750 wells that are measured manually. A small number of these wells are equipped with electronic data collection instruments that can obtain more frequent water level measurements. While the group of about 750 wells is considered the primary component of the network, the DNR network also includes related groups of wells or data collections that are also important components of the network. Examples of other network sources include data from wells that are no longer measured, wells and data required under conditions of DNR appropriation permits, and wells currently or historically part of special studies conducted by the DNR.

Minnesota’s GWLM Network does not operate in isolation. The DNR GWLM Network is part of a multi-agency approach in Minnesota that directly or indirectly measures groundwater levels. Other state agencies have established groundwater quality monitoring networks for specific purposes such as groundwater quality assessment and long-term trends. The collection of groundwater levels is part of groundwater sampling protocols for natural groundwater chemistry surveys, investigations related to contaminant releases, and research studies. The efficient collaboration and sharing of groundwater level monitoring efforts and assets among state agencies has been advanced by the development of on-line applications for improved data access and distribution. However, an ongoing challenge is the assembly of groundwater level data from multiple sources.

In addition to the DNR GWLM Network being part of efforts by groundwater quantity and quality monitoring organizations, the DNR Network can also be considered to be part of a larger “Hydrologic Cycle Network of Networks”. In concept, the “network of networks” includes the ongoing monitoring efforts by DNR, other state agencies, Federal agencies, and other organizations that track and measure water as it moves from atmosphere, to landscape, to subsurface, and back to the surface, eventually returning to the atmosphere. One example of this “hydrologic cycle network of networks” concept is the monthly DNR Hydrologic Conditions Report series. This report of DNR monitoring provides general information describing the hydrologic status of various water resources across Minnesota. The report compares monthly precipitation, stream flow, lake level and groundwater levels to historical values. The monthly reports are based on information generated by DNR through long term programs committed to recording and tracking the long term status of the state's water resources. The "network of network" concept provides a useful framework for integrating monitoring efforts for the entire hydrologic cycle across multiple organizational levels and geographic scales.

1.11 - Monitoring a Three-Dimensional System

As discussed in Section 1.5, the rock and sediment beneath the land surface, most of which is saturated with water, have varying properties that allow more or less water to move in or between those materials. In addition, the rock and sediment that are aquifers occur at different depths, thicknesses, and distributions. For example, the southeastern portions of Minnesota, including the Twin Cities Metropolitan Area, are fortunate in being underlain by multiple major water supply aquifers; in contrast, other parts of Minnesota have fewer or limited aquifers. Ongoing geologic mapping using digital geospatial technology is providing enhanced three-dimensional depictions of the occurrence of subsurface materials, including both aquifers and the materials that are not considered aquifers.

The groundwater flow system within the geologic framework is also three dimensional; groundwater level data are needed from wells in multiple locations and from wells drilled to varying depths to better understand the groundwater flow system. This three-dimensional information is critical to fully evaluate the movement of groundwater within aquifers, between aquifers, and from recharge areas to discharge areas. A well nest of two or more wells at a single location allows for water level measurements that indicate the hydraulic relationship between two depths; this is known as vertical gradient. Water levels from wells distributed laterally throughout an aquifer provide the data to establish the hydraulic relationship between wells at different locations or horizontal gradient. Both vertical and horizontal gradient data are needed to more fully understand groundwater flow and the impacts of water use and other changes on the groundwater system.

The existing network, as discussed in Section 1.7, has limitations in lateral and vertical data coverage. Due to the costs involved with well installation and management, the capability of the groundwater level monitoring network to collect water levels that adequately describe the three-dimensional groundwater flow system in Minnesota is limited. However, where possible, and with available funding, well nests and additional wells are installed at priority locations to improve lateral and vertical data coverage.

Section 2: Designing the Network and Allocating Wells Within the Network

The approximate number of wells distributed statewide and in varying aquifers to meet state groundwater level information needs is 7,000, a nearly ten-fold increase from the approximately 750 wells currently monitored. The additional wells will be placed according to a statewide design and installed over time to fulfill long-term groundwater level monitoring needs.

This section introduces the considerations involved in designing a backbone for the long-term Groundwater Level Monitoring Network. Some of the considerations include requirements for adequate coverage, including: number of wells, where they are drilled, how deep they are drilled, and how often they are measured. Adequate coverage at the appropriate locations will help resource managers better understand the response of the groundwater system over space and time; as a result, wells placed in a designed network will support the protection and management of water resources.

Following extensive internal review of the existing GWLM Network, the DNR Groundwater Level Monitoring Work Group determined that approximately 7,000 groundwater level monitoring wells are needed to establish long-term trend groundwater levels in Minnesota. This section also outlines the DNR's method of determining well density and distribution based on unit area and the allocation of the groundwater level monitoring well to the various depths with the state to meet long-term information needs.

2.1 - Well Density as a Design Element

Well density is defined as the number of wells per unit area. Groundwater level monitoring well density for a GWLM Network such as Minnesota's is not a predetermined number, but may vary considerably depending on the characteristics of a particular area or aquifer resource. The density of wells in an area should be considered flexible, depending upon the following factors:

- Aquifer characteristics: extent, productivity, recharge, leakage, discharge
- Surface water and groundwater interaction zones
- Topography and geology
- Special conditions, such as ecologically-sensitive areas, impacted waters, areas of concern, and other groundwater-related conditions that may be identified in the future.
- Intensity of use, existing water appropriations, and future potential use
- Appropriation permit requirements; potential impacts of use
- Population: water supply use or potential use
- Regional or local importance
- Area dependence on groundwater and alternate source availability

Figure 7 shows the general classes of groundwater level monitoring well network densities established by consensus of the GWLM Work Group. The density classes range from high densities to low densities depending on conditions in or affecting a single groundwater resource. Higher densities are needed, for example, where populations are more concentrated, commercial use is intense, and in locations of regional or local importance. Lower densities are appropriate for less populated areas, areas with lower use, and in locations where groundwater is not a major concern.

The well density ranges listed below are used in the following sections to support the well allocations by resource for the long-term network plan.

Very High	High	Moderate	Low	Very Low
10 per square mile	2 per square mile	1 every 5 square miles	1 per township (36 square miles)	10 for entire state land area (70,400 square miles)
Well density (ρ) and distribution values (d) discussed in Section 2.3				
ρ = 10+	ρ = 2	ρ = 0.2	ρ = 0.028	ρ = 0.00014
d = 0.1	d = 0.5	d = 5	d = 36	d = 7,040

Well Density Class Characteristics	
Very High	High intensity of use, known pumping impacts on other users or supplies, groundwater resources sensitive to change, high potential for impacts on area surface water resources, rapidly declining water levels.
High	High population, high existing or potential use, groundwater system less sensitive to change, possible overlapping well contribution areas, declining water levels and identified potential for pumping impacts
Moderate	A well-known and mapped aquifer with some existing pumping impacts, limited other problems or issues.
Low	A deep, regional confined system with low risk of use impact, low risk of high intensity use
Very Low	Small or limited yield, low population, low intensity of use, limited dependence on groundwater

FIGURE 7. Suggested groundwater level monitoring well density ranges for a single groundwater resource.

2.2 - Unit Areas as Network Design Elements

A unit area is the resource area that is used with well density discussed above to support the allocation of wells for a long-term groundwater monitoring network. Unit area is used in Section 2.1 as the denominator when calculating well density. More commonly-used unit area options are typically based on the following established boundaries:

- County – politically based
- Major basin/ watershed – topographically based
- Groundwater province – geologically based
- Aquifer extent – geologically based

In the context of designing a statewide groundwater level monitoring network, the commonly-used unit area options do not fit the needs of a network that monitors both near surface and deeper groundwater systems. Although familiar and convenient to use, a county-based boundary as a unit area is not a workable unit area for groundwater level monitoring because the extent of aquifers does not follow geopolitical boundaries. Basin/watershed boundaries are defined by topography and since water table elevation in most cases reflects the land surface topography, basin/watershed boundaries are appropriate unit areas for mapping the water table system. The deeper groundwater systems, however, commonly cross basin/watershed boundaries, and are not generally constrained by basin/watershed boundaries; deeper aquifers are geologically defined and are best represented by Groundwater Province and mapped aquifer extent (where known), which are not based on topography. With these considerations, unit area options based only on topography or only on geology or aquifer extent are incomplete, and application of one or the other as the single basis of network unit areas is problematic.

The long-term groundwater level monitoring network requires a flexible unit area that integrates surface conditions related to topography with subsurface conditions of deeper resources that are defined by geology. Figure 8 presents the criteria for unit areas for network development and the allocation of GWLM wells as defined by basin or watershed for near surface and shallow depths and by Groundwater Province (see Fig 14, Sec. 2.4) or aquifer extent for aquifers occurring at moderate or deep depths. The division between the two types of unit areas is defined at about 50 feet beneath the land surface and is identified as the “active hydrologic zone boundary”.

Unit Areas		Depth	Hydrologic System	Tritium Residence Time	Hydrologic Condition	Geologic Setting
State	State Subregion	Near Surface	Active	Recent	Usually unconfined	Alluvial systems, outwash, till, buried outwash, bedrock
Basin (12 State Basins)	Watershed (84 DNR Major Watersheds)	Shallow		Recent/Mixed		Outwash, till, buried outwash, bedrock
Active Hydrologic System Boundary - approximately 50' below land surface						
Groundwater Province	Aquifer Extent	Moderate	Deep	Mixed/Vintage	Typically confined	Outwash, till, buried outwash, bedrock
		Deep		Vintage		Till, buried outwash, bedrock

Figure 8. Criteria for defining unit areas.

Related criteria included in Figure 8 that will assist the proper selection of unit area are hydrologic system, tritium residence time, and hydrologic condition. Hydrologic system in this description refers to whether groundwater movement is relatively fast and complex with water actively moving between the surface and subsurface (active hydrologic system), or relatively slow with much less interaction between the surface and subsurface (deep hydrologic system). The active hydrologic system is common at the surface and to shallow depths. The deep hydrologic system is typical of groundwater systems at moderate or deep depths. Tritium residence time of groundwater samples, if data are available, may be used to support a selection of unit area by helping to define a hydrologic system.

Tritium values of 10 or more tritium units (TU), defined as Recent, are commonly observed in the active hydrologic system. Tritium values of less than 10 TU, defined as Mixed and Vintage, are commonly observed in the deep hydrologic system at moderate and deep depths, but Mixed values may also be observed at shallow depths. Tritium values equal to or less than 1 TU, defined as Vintage, are typical of the deep hydrologic system at deep depths. Groundwater with recent and mixed tritium age can be considered part of the active hydrologic system with unit area defined by basin or watershed. Groundwater with mixed and vintage tritium can be considered part of the deep hydrologic system with unit area defined by groundwater province or aquifer extent.

Hydrologic condition describes the groundwater system as either unconfined or confined, and is an additional criterion to assist selection of unit area. Unconfined hydrologic conditions occur at the water table. Confined conditions are typical of aquifers in the deep hydrologic system. The unit area for unconfined conditions is defined by basin/watershed while the unit area for confined conditions is most typically defined by groundwater province or aquifer extent.

Selection of the appropriate unit area to support development of the Minnesota GWLM network may require, in addition to the primary basis of unit area, the consideration of several additional criteria as discussed above. The selection of unit area is important in the discussion in Section 2.4, describing allocation of groundwater monitoring wells according to unit area and hydrologic system.

2.3 – Groundwater Level Monitoring Well Density and Distribution Within the Unit Area
The concept of well density was introduced in general in Section 2.1. Once the boundaries of the unit area have been decided (Section 2.2), the next step toward designing a statewide groundwater level monitoring network is to determine the number of wells per unit area. The following section presents the factors and criteria for determining how many wells per unit area or square mile are needed to adequately monitor the groundwater resource. The following section further explains the process used to establish the goal number of 7,000 wells for the state network.

Well density can be determined using the following equation:

Well Density as:

$\rho = w/A$ (groundwater level monitoring wells per square mile)

ρ (rho) is the well density

w is the number of groundwater level monitoring wells

A is the unit area in square miles

An alternative way to consider the number of wells needed for a statewide monitoring network is the area coverage per well, which is the inverse of well density. This is defined here as well distribution, and can be determined as follows:

Well Distribution is the inverse of density:

$1/\rho = d = A/w$ (square miles per groundwater level monitoring well)

d is the well distribution $= 1/\rho$

Density Class	Very High	High	Moderate	Low	Very Low
Area	10 per square mile or greater	2 per square mile	1 every 5 square miles	1 per township (36,000 square miles)	10 for entire state land area (70,400 square miles)
Density (ρ)	ρ = 10+	ρ = 2	ρ = 0.2	ρ = 0.028	ρ = 0.00014
Distribution (d)	d = 0.1	d = 0.5	d = 5	d = 36	d = 7,040

Figure 9. Suggested groundwater level monitoring well density ranges for a single groundwater resource with corresponding calculated density and distribution values. Density class characteristics were presented in Figure 7.

Figure 9 shows the calculated density and distribution values according to the density ranges presented in Figure 7 in Section 2.1. The calculated density and distribution values in Figure 9 are used in Table 3 to show the corresponding relationship between general density classes and specific density and distribution in the example.

Table 3 presents calculated density and distribution values for a constant 1,000 square mile unit area according to a range of wells from 1 to 500 GWLM wells. This shows the number of wells for a given unit area (1,000 square miles), but it does not address the actual ground-level placement of well nests or groups of wells, nor the allocation of wells to a specific aquifer. Both density and distribution values are useful, but for operation of the GWLM Network, the distribution value (d) is immediately practical since it indicates the number of square miles of a resource that the GWLM well might be considered to be monitoring. Larger distribution values may be suitable for area or regional data gathering, while smaller distribution values may be considered for more local or detailed data needs.

The right column in Table 3 shows how the calculated density and distribution values corresponds to the general density range classes from Figure 9. If the entire land area of Minnesota is considered the unit area, Minnesota's current GWLM well density is 0.010, as calculated by dividing the number of GWLM wells (750) by state land area (70,400 mi^2). The 70,400 square miles of land area is calculated from the area of the state (86,938 mi^2) minus the area of surface waters and wetlands (13,968 mi^2); this area represents the land area on which a well can actually be constructed (Land Management Information Center, 2011). The area to be monitored is the entire state area of 86,938 square miles because aquifers extend beneath surface water and wetlands. According to this calculation, Minnesota's current groundwater level monitoring network is in the Low Well Density Class.

Table 3. Examples of well distribution and density values by varying number of groundwater level monitoring wells in a unit area.

Unit Area A = Square Miles	GWLM Wells (w) w = A/d	Distribution Value d = 1/ρ	Density Value ρ = GWLM Wells per Square Mile	Well Density Class
1,000	1	1,000	0.001	Low
1,000	5	200	0.005	
1,000	10	100	0.01	
1,000	50	20	0.05	Moderate
1,000	100	10	0.1	
1,000	200	5	0.2	
1,000	300	3.3	0.3	
1,000	400	2.5	0.4	
1,000	500	2	0.5	

Table 4 shows three different well distribution and density value scenarios for two very different unit areas: statewide and a more local scale (Pope County). In this example, Pope County is used as the smaller unit area because it has existing wells that are part of the GWLM Network. For each unit area, the table shows the current number of GWLM Network wells compared to the long-term network buildout goal discussed previously and a theoretical network buildout goal of twice the long-term goal. Although the current well distribution and density values of the state and Pope County differ, for comparison purposes similar well distribution and density values are used for the proposed buildout and theoretical buildout scenarios. The current well density class range (see Figure 9) for both the statewide and Pope County unit area is within the Low range. The proposed statewide long-term network development to about 7,000 wells results in a well density class of Moderate; theoretical expansion of the statewide network to 14,000 does not change the well density class. Even at 14,000 wells the well density class range remains in the Moderate class.

Table 4. Examples of GWLM Network well distribution and density using Minnesota total land area and Pope County as unit areas.

Unit Area	Unit Area A = square miles	Number of GWLM Wells (w)	Well Distribution Value d = 1/ρ = A/w	Well Density Value ρ = w/A	Well Density Class Range (See Figure 7)
MN	70,400	approx. 750 (current)	93.9	0.01	Low
MN	70,400	7,000 (proposed build-out)	10.1	0.1	Moderate
MN	70,400	14,000 (theoretical)	5	0.2	Moderate
Pope County	670	26 (current)	25.8	0.04	Low
Pope County	670	67 (proposed build-out)	10	0.1	Moderate
Pope County	670	135 (theoretical)	5	0.2	Moderate

Pope County is included as an example in Table 4 because various network designs for the county were evaluated by the DNR's Groundwater Level Monitoring Work Group. The evaluation identified many of the difficulties in designing a GWLM network and ultimately assisted in developing the concepts presented in this document. The result of the Pope County evaluation showed a wide range of opinions of monitoring needs identified by DNR staff with an equally wide range of recommended groundwater level monitoring wells needed to adequately monitor the Pope County groundwater system. The differences were mainly due to differing monitoring goals, which very much affected the selection of the appropriate number of GWLM wells needed to adequately monitor multiple aquifers.

Through extensive evaluation, the DNR's Groundwater Level Monitoring Work Group has determined that a reasonable long-term build out for the backbone network should have a goal of approximately 7,000 GWLM wells. Evenly distributed across the state, this number of GWLM wells would result in a density of 0.1 and distribution of 10 or one GWLM well for every ten square miles. Putting these values into a public land survey perspective, using townships for unit areas, a long-term build out to 7,000 GWLM wells would provide three to four wells per township (36 square mile area) statewide. Seven thousand wells is a limited number when considering that the geologic framework and the groundwater system are three dimensional. Commonly, multiple aquifers underlie most areas of the state and most will need to be monitored for long-term trend data in most areas.

Because Minnesota's groundwater systems demonstrate great variations, with multiple aquifers at varying depths, this report recommends that statewide values for GWLM well densities should be considered as variable, ranging from 0.05 to 0.2, or a corresponding distribution value of one GWLM well per 20 to 5 square miles. This range will provide more operation and management flexibility to install and monitor needed wells based upon review of the specific hydrologic conditions and concerns for a particular unit area.

2.4 - Allocation of Groundwater Level Monitoring Wells

Groundwater level information needs, as discussed in Sections 1.7 and 2.3, can be satisfied by increasing the number of groundwater level monitoring wells in the backbone network from approximately 750 to 7,000. With the long-term build out goal identified, the long-range number of groundwater monitoring wells needs to be assigned to Minnesota's aquifers and groundwater systems at different depths to maximize information while limiting costs. This section describes the process of assigning network wells to aquifers and groundwater systems, a process that is called allocation. Allocation is defined here as:

> A plan to assign the appropriate numbers of GWLM wells among Minnesota's groundwater resources to acquire the necessary groundwater level data to describe the groundwater resource condition and trends.

This report recommends that the allocation of network wells to aquifers in groundwater systems should be based on a percentage method. After considering other groundwater network plans related to groundwater level monitoring needs, this report concludes that other network plans are too generalized and do not address the criteria for assigning new wells to Minnesota's varying aquifers and groundwater systems. Carefully evaluated and constructed well assignments are critical to providing the information needed by the network plan. No directly usable method was identified that could form the basis of the needed well allocation. Therefore, a new method has been developed that combines allocation methods for two different unit area concepts. One unit area concept is based on topography, which defines watersheds, and is applied to the shallow near surface systems (active hydrologic zone). The second unit area concept is based on aquifer extent and is applied to deeper aquifer systems. This approach has the benefit of organizing shallow wells around watersheds and deep wells around deeper aquifer systems.

The following discussion presents several examples of how the process of allocation and network development is intended to proceed at the state level. In order to develop a statewide backbone network that satisfies the state's current data needs, DNR staff will be responsible for reviewing available information needed to formulate a preliminary allocation plan based on the approach described in this document. Figures 10-13 show examples of the available information resources that will help DNR staff and others identify areas where backbone network development is needed.

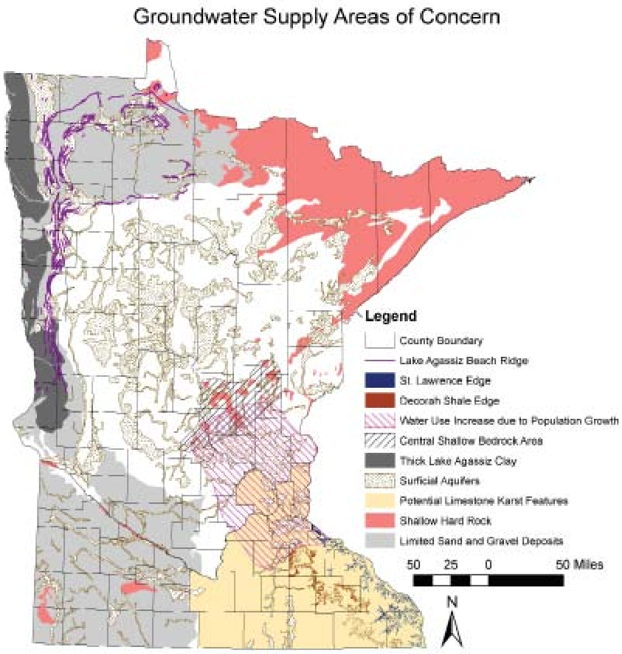

Figure 10. Groundwater Supply Areas of Concern. The Groundwater Supply Areas of Concern map identifies areas where geological and water use aspects lead to groundwater concerns.

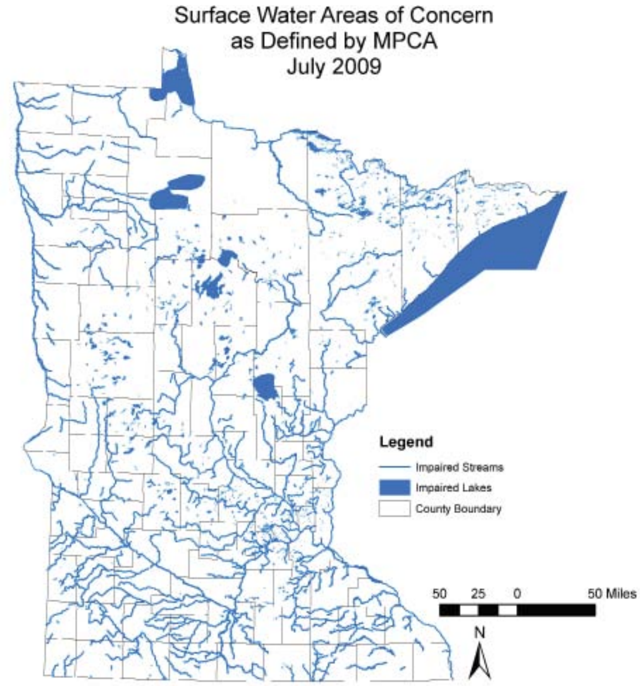

Figure 11. Surface Water Areas of Concern. The MPCA Surface Water Areas of Concern map identifies the location of impaired waters of the State.

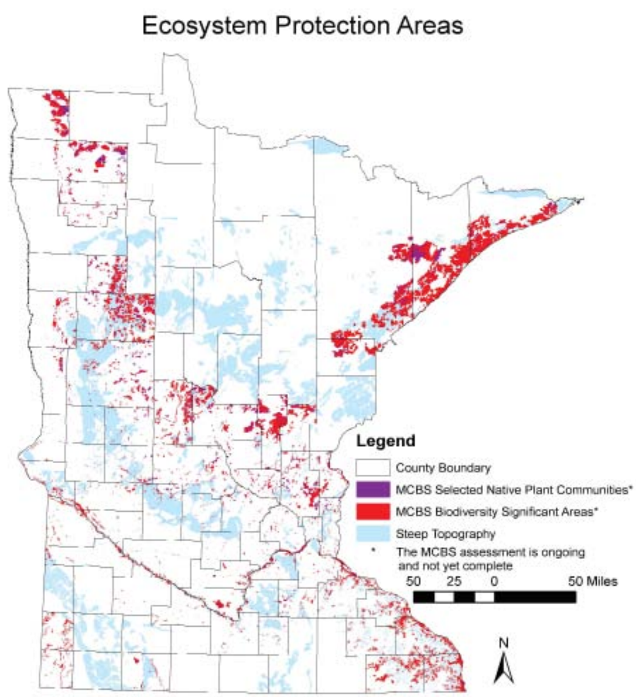

Figure 12. Ecosystem Protection Areas. The Ecosystem Protection Areas map identifies the areas in the state where the Minnesota County Biological Survey has located native plant communities and rare species. This survey is ongoing and has not been completed for the entire State.

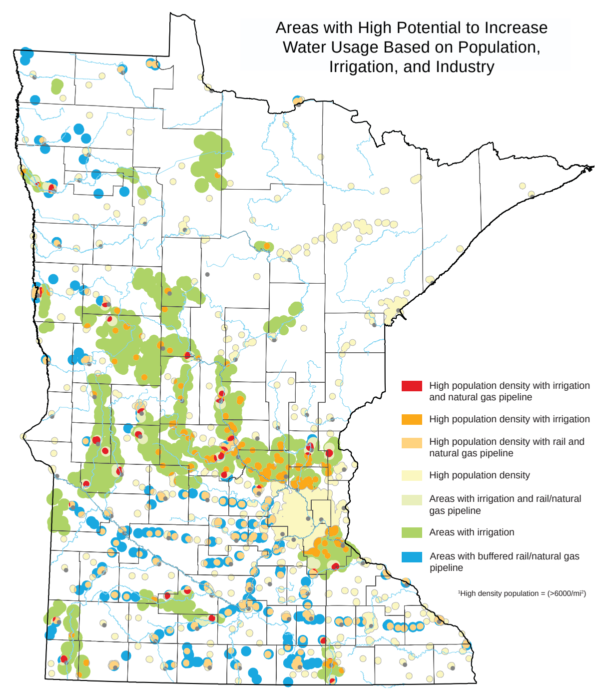

Figure 13. Optimum Density Rankings. The Optimum Density Ranking map shows areas with high potential to increase water usage, incorporating areas of high population density, irrigation areas, and location with good access to both transportation and natural gas.

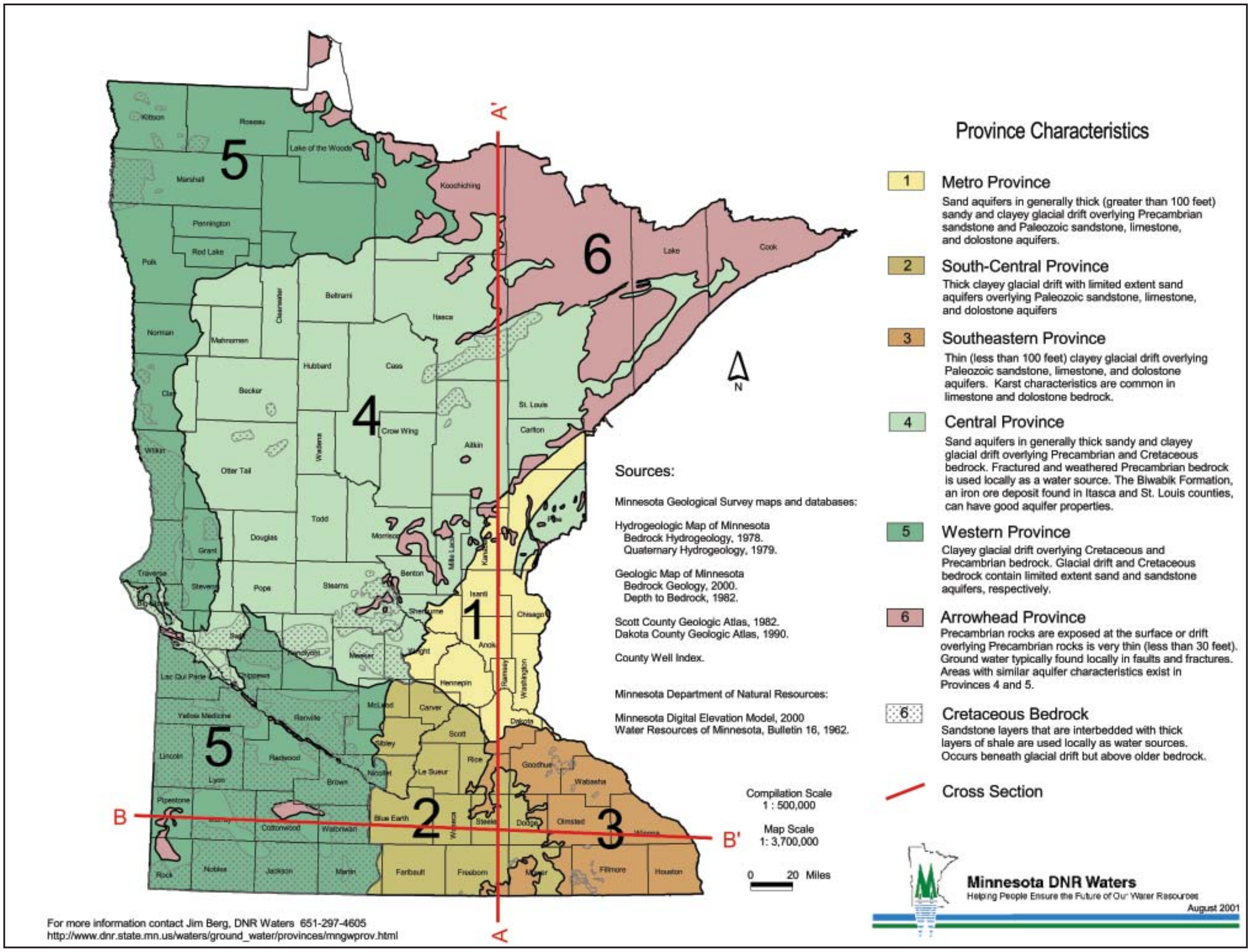

Figure 14. Map of the groundwater provinces.

Figure 14 shows the groundwater provinces map. This map is an important reference for the allocation process since it shows the major hydrologic regions within the state.

Table 5. Selected aquifer parameters for groundwater provinces.

Groundwater Province	Specific Capacity	Transmissivity (T) T = K*Thickness*7.48	Average Hydraulic Conductivity (K)	Comments
Province 6				
Glacial Drift	Variable	Variable	150 feet/day	Generally too thin for high capacity use
Precambrian Bedrock	<1 gpm/ft	<100 to 500 gpd/ft	0.1 feet/day	Highly dependent on fractures
Province 5				
Glacial Drift	<10 to >50 gpm/ft	< 20,000 to >100,000 gpd/ft	150 feet/day	Best yields in buried channel deposits
Cretaceous Bedrock	<1 to 17 gpm/ft	<200 to 30,000 gpd/ft	20 feet/day	
Precambrian Bedrock	<1 to 5 gpm/ft	<100 to 5000 gpd/ft	0.1 feet/day	Dependent on fractures
Province 4				
Surficial and Buried Aquifers	<10 to >40 gpm/ft	<10,000 to >80,000 gpd/ft	150 feet/day	
Cretaceous Bedrock	<1 to 17 gpm/ft	<200 to 30,000 gpd/ft	20 feet/day	
Precambrian Bedrock	<1 gpm/ft	<100 to 500 gpd/ft	0.1 feet/day	Dependent on fractures
Biwabik Iron Formation	<1 to 10 gpm/ft	<1000 to 20,000 gpd/ft	2 feet/day	
Province 3				
Glacial Drift	Variable	Variable	150 feet/day	Generally too thin for high capacity use
Upper Carbonate	5 to 90 gpm/ft	8000 to 175,000 gpd/ft	25 feet/day	
St. Peter	1 to 10 gpm/ft	2500 to 37,000 gpd/ft	10 feet/day	
Prairie du Chien-Jordan	3 to >100 gpm/ft	7000 to 250,000 gpd/ft	45 feet/day	
Tunnel City-Wonewoc	2 to 35 gpm/ft	4000 to 80,000 gpd/ft	25 feet/day	
Mt. Simon-Hinckley	1 to 33 gpm/ft	2000 to 70,000 gpd/ft	25 feet/day	
Province 2				
Glacial Drift	<10 to >30 gpm/ft	<10,000 to >50,000 gpd/ft	150 feet/day	Best yields in buried channel deposits
Upper Carbonate	5 to 90 gpm/ft	8000 to 175,000 gpd/ft	25 feet/day	
St. Peter	1 to 10 gpm/ft	2500 to 37,000 gpd/ft	10 feet/day	
Prairie du Chien-Jordan	3 to >100 gpm/ft	7000 to 250,000 gpd/ft	45 feet/day	
Tunnel City-Wonewoc	2 to 35 gpm/ft	4000 to 80,000 gpd/ft	25 feet/day	SC near low end in southern metro
Mt. Simon-Hinckley	1 to 33 gpm/ft	2000 to 70,000 gpd/ft	25 feet/day	
Province 1				
Surficial and Buried Aquifers	<10 to >40 gpm/ft	<10,000 to >80,000 gpd/ft	150 feet/day	
St. Peter	1 to 10 gpm/ft	2500 to 37,000 gpd/ft	10 feet/day	
Prairie du Chien-Jordan	3 to >100 gpm/ft	7000 to 250,000 gpd/ft	45 feet/day	
Tunnel City-Wonewoc	2 to 35 gpm/ft	4000 to 80,000 gpd/ft	25 feet/day	SC near low end in southern metro
Mt. Simon-Hinckley	1 to 33 gpm/ft	2000 to 70,000 gpd/ft	25 feet/day	

Table 5 shows the selected aquifer parameters for the groundwater provinces shown in Figure 14. The table presents a range of generalized estimates of aquifer characteristics for each of the groundwater provinces.

Figures 10-14 and Table 5 are based on recent data and offer information that is important to building a groundwater level monitoring network from a regional perspective. This information is sufficient to make some general recommendations regarding network development needs, but other information will be needed to address specific or problem areas. Water supply studies, municipal investigations, environmental studies, and other reports are all sources of more localized information on groundwater.

DNR staff will review all the available resource information to determine the appropriate unit area and the associated distribution value of the wells. Using that information, the preliminary goal number of wells to meet network needs is calculated by dividing unit area by the distribution value. Once the goal number of wells per unit area is determined, the preliminary allocation percentages are then used with the goal number to determine the allocation number of wells by groundwater resource.

Table 6 shows a simplified example of how the allocation of groundwater level monitoring wells could be accomplished for a unit area with three groundwater resources.

Table 6. Example allocation of GWLM wells to principal aquifers.

Hydrologic System	Unit Area (square miles)	Distribution Value (d)	Goal Number of GWLM Wells
	1000	10	100
	Groundwater Resource	Allocation %	Allocation Number of GWLM Wells
Active	Water Table	60%	60
Active or Deep	Buried Drift	30%	30
Deep	Bedrock	10%	10
		100%	100

The allocation number of network wells generated by this process should be reviewed and agreed upon by the DNR Groundwater Level Monitoring Work Group.

The allocation percentage should be adjusted to create the best possible utilization of the goal numbers for the unit area. In most areas, the active hydrologic system should receive the larger allocation of wells with a generally decreasing number of wells with depth, unless the unit area conditions observed suggest otherwise. The active hydrologic system should have a greater well density than the deep hydrologic system because the shallower resources are often the first to show responses to changing conditions and have greater spatial variability. Fewer wells are needed for deeper groundwater resources because they tend to respond more slowly, and have similar characteristics over larger distances, therefore granting more time for reaction and response to significant changes in water levels.

During the network development of the GWLMN, the concept of incremental development or iterative phases should become part of the development program. The construction of groundwater level monitoring wells, for each unit area, should occur over the course of two or more phases.

A period of time of at least several years is needed following initial well installations to allow for data collection and analysis. Subsequent iterative phases will then benefit and perhaps lead to redefining a suitable groundwater level monitoring well distribution and allocation. Table 7 demonstrates the same example used in Table 6 with consideration for existing GWLM wells and two phases of network development.

Table 7. Example allocation of GWLM wells with consideration for existing GWLM wells with two iterative phases of development

Unit Area (square miles)	Distribution Value (d)	Goal Number of GWLM Wells	Existing Number of GWLM Wells	Iterative Phase 1	Iterative Phase 2
1000	10	100	10	45	45
Groundwater Resource	**Allocation %**	**Allocation Number of GWLM wells**	**Existing Wells by Resource**	**New Wells by Resource**	
Water Table	60%	60	5	28	28
Buried Drift	30%	30	4	12	12
Bedrock	10%	10	1	5	5
	100%	100	10	45	45

Tables 6 and 7 are general examples that show the concept for determining the goal number of wells and then allocating them to groundwater resources. In addition, Table 7 shows the iterative process for network development that is an extension of Table 6. Neither table are meant to serve as examples for any specific area in Minnesota.

The next example uses the basic elements of Table 7 with Minnesota's six Groundwater Provinces as unit areas. Unit areas based on Groundwater Provinces are appropriate as an example because 1) they provide statewide coverage, 2) they are geologically defined, and 3) selected aquifers parameters have been organized by Groundwater Province and groundwater resource (Table 5). The Groundwater Provinces are based on geology, and not by watershed. The development of well allocation for the active hydrologic system, which is watershed based, has not yet been completed. The statewide goal number for the active hydrologic system needs to redistributed by watershed in the future.

Table 8 was created as a statewide estimate of the goal number of groundwater level monitoring wells based on Minnesota Groundwater Provinces (Figure 14 and Table 5) as the unit area. The development of Table 8 required assigning allocation percentages for each groundwater system by province. The estimate of the distribution value of GWLM wells per square mile for the provinces was selected to range from 10 to 20 square miles per well (Tables 3 and 4). The allocation percentages are based on review of conditions for the groundwater resources for each unit area. The groundwater resources shown in Table 8 according to province are generalized, and do not fully reflect the local complexities in the groundwater system. For example, some bedrock resources that are generally regarded in Table 8 as part of the deep system, may where shallow also be a part of the active hydrologic system, which in Table 8 is included in the water table system.

Table 8. Well numbers and allocation for Minnesota's groundwater provinces.

Groundwater Resources	Unit Area (A) (square miles)	Density (ρ) / Distribution (d)	Allocation %	Goal Number of GWLM Wells (w) / GWLM Wells
Province 1	**5349**	**0.10 / 10**		**(535)**
Water Table			40%	214
Buried Aquifers			15%	80
St. Peter			5%	27
Prairie du Chien-Jordan			25%	134
Tunnel City - Wonewoc			10%	53
Mt. Simon Hinckley			5%	27
Total			**100%**	**535**
Province 2	**3011**	**0.10 / 10**		**(301)**
Water Table			25%	75
Buried Aquifers			15%	45
Upper Carbonate			15%	45
St. Peter			5%	15
Prairie du Chien-Jordan			25%	75
Tunnel City - Wonewoc			10%	30
Mt. Simon-Hinckley			5%	15
Total			**100%**	**301**
Province 3	**7404**	**0.07 / 10**		**(740)**
Water Table			20%	148
Buried Aquifers			10%	74
Upper Carbonate			30%	222
St. Peter			10%	74
Prairie du Chien-Jordan			15%	111
Tunnel City - Wonewoc			10%	74
Mt. Simon-Hinckley			5%	37
Total			**100%**	**740**

Table 8. Well numbers and allocation for Minnesota's groundwater provinces. (continued)

Groundwater Resources	Unit Area (square miles)	Density (ρ) / Distribution (d)	Allocation %	Goal Number of GWLM Wells (w) / GWLM Wells
Province 4	**29985**	**0.15 / 15**		**(1999)**
Water Table			67%	1339
Buried Aquifers			27%	540
Cretaceous Bedrock			2%	40
Precambrian Bedrock			2%	40
Biwabik Iron Formation			2%	40
Total			**100%**	**1999**
Province 5	**26893**	**0.10 / 10**		**(2689)**
Water Table			65%	1748
Buried Aquifers			22%	592
Cretaceous Bedrock			10%	269
Precambrian Bedrock			3%	81
Total			**100%**	**2689**
Province 6	**11404**	**0.05 / 20**		**(570)**
Water Table			50%	285
Buried Aquifers			10%	57
Precambrian Bedrock			40%	228
Total			**100%**	**570**

Table 8 shows how approximately 7,000 groundwater level monitoring wells could be distributed and allocated to provide the needed long-term groundwater resource trend data. Section 3 will describe how to manage this network as it is developed. The well allocation in Table 8 is used in Section 4 to develop a cost estimate for network expansion over a period of 30 years.

Section 3: Network Operations

The projected network development is intended to fulfill groundwater level monitoring data needs for long-term trend monitoring. In addition to the phased installation of GWLM Network wells, operations capability will be built gradually. Upon completion of each well, the cycle of long-term water level monitoring of the backbone condition begins. This long-term monitoring cycle includes water level data collection, scientific analysis, sharing among government agencies, and distribution of groundwater level information for public use. This section discusses how water level measurements are acquired as electronic data, reviewed for accuracy, and processed for public distribution.

3.1 - Instrumentation

Historically, water levels were obtained manually. A person visited the well, lowered a measuring device to the water surface, read depth to water, and recorded the well number, the date and time, and the depth to water measurements. Some wells are now equipped with electronic equipment to automatically record measurements at specified intervals over a period of weeks to months. Regardless of new electronic devices, manual water level measurements are always needed to provide precision, confirmation, and backup measurements in case of equipment failure.

Manual water level measurements at DNR groundwater level monitoring wells are measured using steel surveyor's tapes (Figure 15). The steel tape method currently provides the most accurate and precise way of measuring water levels in wells. Other methods, such as electronic tapes or transducers may also be used, but each of those methods is confirmed periodically using a steel tape. The steel tape method provides a backup in case electronic methods fail. Each measurement requires a person who is trained to visit the GWLM well and measure the water level in the well. Personnel and travel costs have limited the frequency of manual water level readings to one reading per month. Increased deployment of electronic measurement equipment will increase measurement frequency while reducing personnel and travel costs. DNR policy and criteria documents regarding electronic instruments are included Appendices 5.4 and 5.5. Technical guidance for water level measurements are included in Appendix 6.

FIGURE 15. Common tools used for groundwater level monitoring (left to right): electronic tape, steel tape, data logger.

3.2 - Monitoring Length of Record and Continuity

Long-term water resources management efforts need long-term resource monitoring data that are collected in a time-series format. A series of measurements periodically on a regular schedule are called a time-series data set. Long-term time-series data are especially important for groundwater because groundwater levels may have a response lag of many years following climatic or pumping changes. For example, climate cycles in the Midwest occur over tens of years, so groundwater level monitoring data must also extend decades to track groundwater system response to climatic and other system changes.

While single water level measurements reported on well construction records are valuable, they are only one measurement in time. The value of the data increases as the length of water level records increases over time. Figure 15 shows how water level records increase in value to managers, researchers, and others who need groundwater level data.

FIGURE 15. Length of well record and its value for long-term trend analysis and resource management.

Data continuity is a critical element to the development of this network. It is important to obtain regular scheduled measurements so that significant changes or events are identified and not missed due to breaks in the data record.

3.3 – Monitoring Frequency

Monitoring frequency refers to how often groundwater level measurements are collected over time and recorded. Selection of a measurement frequency for a site will depend on the network and site, aquifer, purpose, intensity of use, site specific or local situations, and other factors. The frequency of measurement can vary depending on the particular purpose of the data being collected. For example, general groundwater system tracking at a GWLM Network site through multiple annual cycles may yield adequate information with monthly measurements. Daily or more frequent measurements may be required to track aquifer response in an area with heavy groundwater use. Recharge studies are an example of data needs that require high measurement frequencies to fully assess system response to recharge processes.

The frequency of water level measurements affects the value of the water level records. Figure 16 shows how greater frequency of water level measurements increases their value. The DNR's minimum criteria for inclusion of existing wells in the network should be water level measurements collected at least monthly. The decision to collect hourly or more frequent readings depends on the need for backbone data from a specific location.

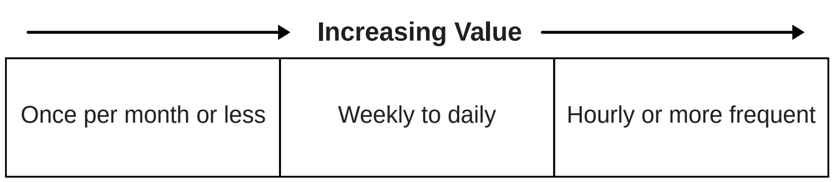

FIGURE 16. Frequency of measurement and its value for long-term trend analysis and resource management.

Most modern databases can handle large volumes of time-series data, thus reducing the limitations that previously hampered the collection of high-frequency data. As mentioned previously, most groundwater level network data is measured at a monthly frequency. If funding would allow, more frequent measurement would be desirable. At selected locations, pressure transducer data loggers are deployed in the DNR network of GWLM wells to record groundwater level measurements once every hour. Periodically, manual measurements are collected to provide water level reference data and to confirm the accuracy of the automated data collected by the pressure transducer. Based upon review of the collected pressure transducer data to date, hourly measurement frequency appears to be adequate for long term trend level monitoring purposes at sites with data logger instrumentation.

3.4 - Data Post-processing and Hydrographs

After being collected from the field, groundwater level data from data loggers undergoes post-processing, which is defined here as a series of data compilation steps where data files are checked for accuracy, configured, and prepared to be loaded into the database. After the data are loaded into the database, the user can evaluate a graph of the data. The manually-collected water level measurements are included as separate data values plotted with the pressure transducer data to verify the accuracy of the automated data.

During post-processing, it may be discovered that the old and new data sets may not perfectly match. If this should occur, DNR staff make changes to the data during post-processing, and the computer software tracks and records these changes. A supervisor then reviews the changes and validates (approves) the post processed data. The DNR saves both the unaltered data and corrected data sets.

Hydrographs are line charts of time-series water level data (Figure 17) that can illustrate and compress a large amount of data so it can be easily read, compared, and interpreted. A hydrograph provides a visual aid that is used during post-processing to assist joining recent data with older data.

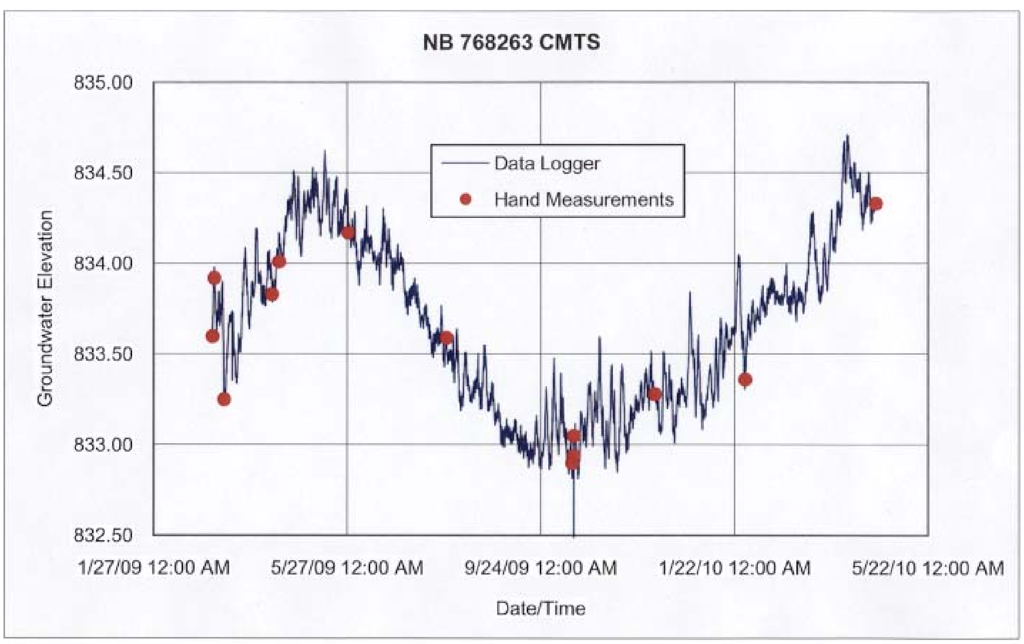

FIGURE 17. Hydrograph of water levels in a GWLM well with manual readings (shown as red points) and electronic data logger readings (blue continuous line).

3.5 - Data Uses and Limitations

The primary purpose of groundwater level monitoring is to protect the resource by informing and providing supporting scientific information for policy decisions and management actions. However, groundwater level information alone cannot prevent or solve problems. A statewide backbone network is extremely important because it provides information on resource trends, data for modeling, and assistance with problem identification. Efforts to address specific concerns will usually require that more detailed information be collected than can be obtained from the existing GWLM Network database. A typical example of addressing specific concers is when DNR responds to well interference complaints and resource conflicts; in such cases, more frequent monitoring may be required because the problem is local and needs additional monitoring to identify the issues and successfully resolve the problem.

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 better able to manage water use or prevent unintended impacts.

While the state GWLM Network as it currently exists provides valuable resource data, not all water level data needs have been met. Many times, monitoring sites may not be in the ideal locations or of sufficient density. Sometimes the available data is fragmentary, or only available for a few years. At many sites in the network the data record may be incomplete because measurements were only taken during the irrigation season. For many wells in the existing backbone network, measurements are only collected from March to October because winter conditions prevent site access. At some locations, the monitoring frequency may be inadequate; finally, data may be limited because wells at some monitoring sites are not properly maintained or need replacement.

3.6 - Database Management and Protocols

The DNR's groundwater level monitoring well database adheres to generally accepted industry standards as well as to the standards developed by the DNR's Management Information Services and the State of Minnesota Office of Enterprise Technology. The most recent version of the database uses an open source data system called PostgreSQL. Any changes to the database will be done so that they conform to State of Minnesota and industry standards.

The current database uses the Minnesota Department of Health's (MDH) Unique well numbering system as the primary key to identify specific wells. There is a secondary key in the database called the groundwater level monitoring well number, which is a well-specific number created by the DNR. It uses the widely used two digit Minnesota County code and a three digit incremental number. This well-specific identifier is useful as it immediately identifies the county in which the well is located; it is mostly used for internal DNR analysis.

The database provides the well location and well construction data and stores water level measurements associated with the well. Information about the database fields including the field attributes are specified in a database data dictionary which is available, but not included in this document.

3.7 - Data Availability and Access

Data from the groundwater level monitoring well network is currently available to anyone through the DNR's website. The information provided includes well location and construction information, aquifer designation, and all of the water level measurements for the well. A hydrograph for the well is also presented that includes a graph of precipitation data for the area near the well.

The data can be accessed by using a map on the DNR website to select a well location. The website also provides the option of choosing a well by MDH Unique number or the DNR groundwater level monitoring well number, if known. A list is presented of all measured and unmeasured wells in the groundwater level monitoring well database from which to choose. The data is also available directly from the DNR's groundwater level monitoring well database administrator.

The internet is currently the primary resource tool used by the DNR for providing groundwater level data and related resources to the public. Groundwater level monitoring well information with hydrographs and precipitation information are all currently available via the web at http://climate.umn.edu/ground_water_level/.

The DNR also produces interpretive products such as a monthly report of the State's hydrologic conditions. This report includes maps that provide general information on the status of water resources across the state. These interpretive reports provide recent information on the condition of principal components of the hydrologic cycle, including:

- Stream flow
- Groundwater
- Lake levels
- Precipitation and drought conditions

These reports can be found on the DNR's website at http://www.dnr.state.mn.us/current_conditions/hydro_conditions.html.

The monthly summary of groundwater conditions uses selected indicator wells located throughout the state with percentile ranking based on the last reported reading for the current month compared to all historical reported levels for that month. A version of the monthly summary conditions map showing groundwater levels and groundwater provinces (Figure 18) was included in the 2010 DNR Ecological and Water Resources Water Availability and Assessment Report.

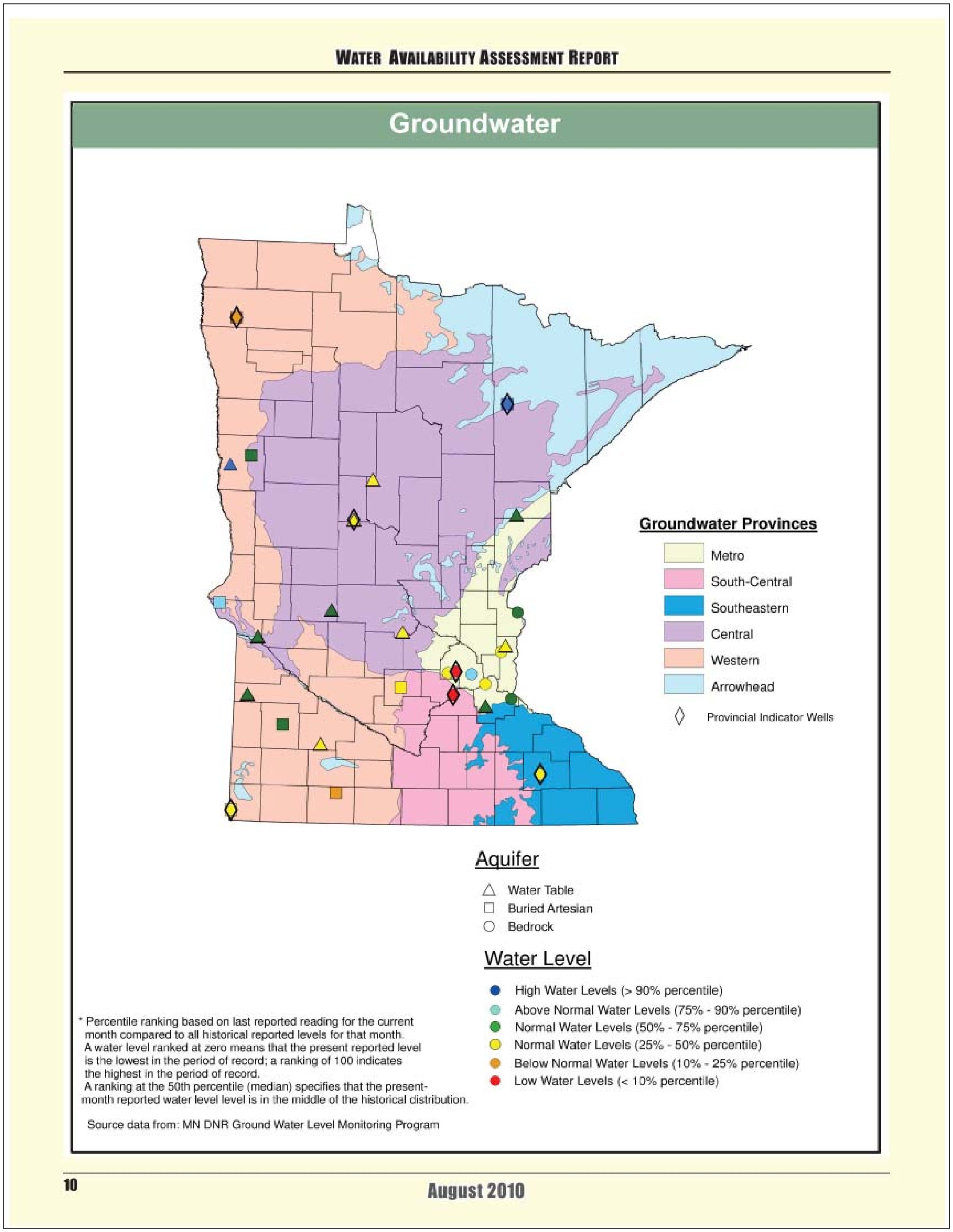

FIGURE 18. Groundwater level historical rankings.

The DNR requires most holders of groundwater appropriation permits to provide water level data from pumping wells or associated monitoring wells. The water levels are collected by the permit holders and submitted to the DNR. The well and water level information are stored in a Microsoft Access® database. Access to this information is currently limited to Division of Ecological and Water Resources staff because of security concerns associated with public water supply wells. It is the intent of the Department to use this data for aquifer analysis and to assist the permit holders in managing the resource.

The DNR is moving to a more integrated website which will allow users to obtain data from the various water monitoring activities conducted by the department. These areas are stream flow, groundwater levels, and lake levels. Currently, a user must visit three different web sources to access each data set.

The vision for future web applications is full of opportunities. For example, the indicator well map could become an interactive map with links to related information fields. Irrigators and other high capacity water users could access a web based resource to assist with water management decisions, thus promoting better management practices to conserve Minnesota's groundwater resources.

A recognized need exists to improve shared access to water data across state agencies. Improved shared access will provide more data integration and allow for better access to the data by external users. The DNR/MPCA's Cooperative Stream Gaging Project is an example of joint management of a water resource database; this site provides access to near real-time and historical streamflow and water quality data. In time, the agencies plan to develop data systems that connect the data collected and stored by the various agencies so that it is accessible to the public. The idea of a data portal is attractive since it would allow will allow the different agencies to continue to collect and store the agency data and through the portal make the data available to anyone in a usable format. The startup and ongoing operation costs of such a portal are considerable and would require ongoing funding by multiple agencies to be successful.

Section 4: Estimated Cost to Develop a Statewide Backbone Groundwater Level Monitoring Network

The distribution of about 750 groundwater level monitoring wells in Minnesota's current measured network has limited coverage across the state (Section 1.7). The well distribution maps by aquifer discussed in that section and the evaluation of monitoring needs by resource presented in Section 2.4 supports the need for nearly 7,000 groundwater level monitoring wells in the backbone network for long-term trend monitoring. The long-range goal of about 7,000 groundwater level monitoring wells for the backbone network is nearly ten times the number of existing measured network wells. Given the scope of the network development that is needed, achieving the build-out goal for the backbone network will require a continuing investment over several decades. This section presents the cost estimate for this proposed network build-out to nearly 7,000 wells over a period of 30 years. The network build-out will vastly improve the state's ability to provide the necessary information to describe the quantity of groundwater in Minnesota, which will help ensure its availability and sustainability for future generations.

Table 8 in Section 2.4 presents the estimated long-range goal for the total number of GWLM wells needed by groundwater province to adequately monitor aquifers and groundwater resources in the backbone GWLM network. In Table 9, the estimated long-range goal for the total number of wells for the backbone network is summarized by aquifer or resource. Table 9 also summarizes the number of wells needed by resource to meet the long-range monitoring goal. If the number of existing wells in the backbone network is considered, a total of 6,078 additional wells are needed. The number of additional wells needed by resource in Table 9 was used in Table 10 to estimate the cost to construct the number of wells needed to meet the monitoring goal. Table 9 is organized by resource because there is a general cost variation to construct wells among the resources listed. For example, installing a well in a shallow water table resource is expected to cost less than installing a well in a deeper resource, such as the Mt. Simon Hinckley aquifer. Drilling costs can be expected to vary by groundwater resource based upon the drilling method used, number of sites to be drilled, drilling time required, fuel costs, type of construction materials, and other cost considerations.

Table 9. Statewide groundwater level monitoring well allocation by groundwater resource.

Groundwater Resource	Goal Number of Groundwater Level Monitoring Wells	Organized By	Percent of Statewide Buildout	Existing Number of Wells	Number of Wells Needed to Reach Goal Number
Water table	3,810	Watershed	55.7	341	3,469
Quaternary - Buried Aquifers	1,388	Varies	20.3	243	1,145
Cretaceous Bedrock	309	Province or Aquifer Extent (if mapped)	4.5	10	299
Upper Carbonate	267		3.9	6	261
St. Peter	116		1.7	5	111
Prairie du Chien-Jordan	320		4.7	6.3	257
Tunnel City - Wonewoc (formerly Franconia Ironton Galesville)	158		2.3	25	133
Mt. Simon Hinckley	79		1.2	61	18
Precambrian Bedrock	349		5.1	2	347
Biwabik Iron Formation	40		0.6	2	38
Total	**6,835**		**100%**	**758**	**6,078**

Table 10 shows that most of the wells needed for the statewide build-out are for monitoring the water table resource and Quaternary buried aquifers. Fewer wells are needed to complete the backbone network goal for bedrock aquifers. The water table and shallow Quaternary resources are assigned a greater proportion of wells because the shallower resources are often the first to respond to changing conditions and also have greater spatial variability (Section 2.4). Deeper groundwater resources, unless immediately affected by pumping stress, respond more slowly to change and tend to be more uniform over more extensive areas; therefore, fewer deeper wells are needed to meet the desired monitoring goal for the backbone network.

Table 10 was developed to show the cost estimate for a 30-year plan to achieve a backbone GWLM Network of about 7,000 wells. Under this plan approximately 1,015 wells would be built every five years or approximately 203 new groundwater level monitoring wells would be installed per year. The costs are based on 2010 cost estimates. The estimated cost for the first five years of network development, for the fiscal years 2011 to 2015, is $13,900,753 or approximately $2,800,000 per year.

Table 10. Minnesota groundwater level monitoring network build-out timeline and estimated cost (30-year plan).

Year	2010	2010-2015	2015-2020	2020-2025	2025-2030	2030-2035	2035-2040	Total Cost of Network Buildout	Operation End Maintenance Costs for Each Subsequent Year
Total Wells in Network	750 (existing)	1,765	2,780,	3795	4,810	5,825	6,840		
Drilling, Instrumentation, and Easements		$12,666,550	$12,666,550	$12,666,550	$12,666,550	$12,666,550	$12,666,550	$75,999,300	$300,000
Operations and Maintenance, Technical Support, and Quality control		$950,182	$1,652,145	$2,198,109	$2,744,073	$3,290,036	$3,680,000	$14,514,545	$736,000
Data Management, Groundwater Analysis, and Data Access		$284,022	$447,217	$610,413	$773,609	$936,804	$1,100,000	$4,152,065	$220,000
Total		$13,900,753	$14,765,913	$15,475,072	$16,184,231	$16,893, 391	$17,446,550	**$94,665,910**	$1,256,000

The costs in Table 10 include well installation and instrumentation, operations and maintenance, and data management and access. Well installation and instrumentation costs include those expenses to physically install monitoring sites. In addition to the drilling costs, each well includes the initial cost of a downloadable data logger and the cost of replacement after five years of operation. These well installation and instrumentation costs represent more than 90 percent of the expense to expand the existing network. Once installed, each site has additional ongoing expenses to periodically collect data, maintain the site for proper operation, and verify new data. As new sites are added to the network and greater volumes of data are generated, additional expenses for data management and access are incorporated into the cost estimate. The following lists, in general, the costs considered in the development of the Table 10 cost estimate for the network build-out:

Well installation and instrumentation

- Well drilling and construction
- Easements and site clearance
- Instrumentation with electronic water level recording equipment
- Agency staff oversight of drilling operations

Operations and maintenance, technical support, quality control

- Manual water level measurements
- Periodic down loading of electronic water level recording equipment
- Well inspections and maintenance
- Slug testing
- Equipment repair
- Verifying new data for accuracy
- Assisting data managers with data processing

Data management, groundwater level analysis, data access

- Post processing of downloaded data
- Barometric data correction
- Data upload into data base
- Data base management
- Provide data access to Web
- Analyze water level trends
- Respond to data requests and assist data users

Well installation costs can vary considerably depending on the depth of the well and other site considerations. A shallow well requires less time and lower-cost material to drill and construct than deep wells. For example, a shallow surficial sand aquifer well can be installed by a certified Minnesota water well contractor at a cost of about $5,000 while a deeper bedrock well can cost $70,000 or more. The DNR owns and operates water well drilling equipment and has trained personnel who are capable of installing water wells to a depth of about 50 feet at much lower cost. Based on anticipated depths of new wells to be installed for the network, the estimates presented in Table 10 are based on the use of DNR drilling equipment and crews of DNR staff. It is expected that DNR equipment and crews would install about 57 percent of the proposed network wells. The remaining 43 percent of the wells will require the use of more expensive equipment and materials suitable for wells of greater depth. The cost estimate for each well includes the cost of installing data logger instrumentation to measure water levels automatically. The cost of the data logger instrumentation is currently $750 per well.

Some expenses were intentionally not included in the cost calculation as they may be applicable to limited or specific sites. These expenses include borehole geophysical logging, water chemistry analysis or age-dating; monitoring well fees for water sampling; and easement or parcel purchase costs.

Advanced technology exists that can provide real-time data communication and well operational information via telemetry. This technology can send information via radio, cell phone, or by satellite. The cost of equipping one nested groundwater level monitoring well site with telemetry is currently estimated at about $15,000. Because of the cost, installation of telemetry capability was not included in the Table 10 expenses. This additional expense could be considered for high-priority sites where immediate data access is required and if additional funding were available.

The installation of more than 6,000 groundwater level monitoring wells for the statewide backbone network over a period of 30 years is a massive undertaking. The work will need to be prioritized and directed to logically build out from the existing network and link with specialized networks that are part of additional, permit-mandated monitoring locations or perhaps shorter-term investigations. The buildout priorities must also evaluate and acknowledge groundwater level data generated by other data collection efforts for other purposes. The primary focus of the buildout plan is, and should remain, long-term groundwater level data acquisition with the goal for the backbone network sites of minimum 30-year data records.

In addition to the logical extension from existing sites to areas currently unmonitored or under monitored, other priorities will guide future network development. Priorities may include sites that support long-term investigations or monitoring of groundwater management areas or, more generally, water resource management areas. Possible priority areas for this purpose could include the Buffalo aquifer near Moorhead, the Bonanza valley area east of Glenwood, the Pineland Sands Aquifer near Park Rapids, the Woodbury area, and the expansion of the northwest corridor between the Metro Area and St. Cloud. Other priority areas include portions of Minnesota undergoing development pressure with associated water needs, existing aquifer use areas that lack adequate backbone monitoring, and areas of significant hydrologic and ecologic importance that lack adequate backbone monitoring. Identification of priorities and the necessary design to meet identified priorities must be part of an ongoing review of existing network coverage as the backbone network develops over time. The review of priorities should also identify and address monitoring limitations in other parts of the hydrologic cycle such as stream flow, lake levels, and spring discharge.

The network development is a long-term, large-scale statewide effort resulting in new monitoring sites each year. The GWLM Network wells, while intended for primary use as part of the statewide backbone groundwater level monitoring network, will be constructed so others may use the wells to collect other types of data, including water quality data. This type of construction adds to the initial cost of a well, but allows greater flexibility for future use.

If the long-term buildout concept is funded, an initial development plan that covers at least two fiscal biennia will need to be developed in coordination with the annual or biennial work plans of the existing network. The long-term plan will also need to be developed in cooperation with existing monitoring efforts by state agencies, research institutions, and other stakeholders.

Coordination with network partners, data users, and stakeholders will require considerable investment in time. Some of these partners may be public organizations who may be approached with a request to install wells on their property. Installation of wells on public property is desirable since the land use is less likely to change and interfere with the operation of the well as a monitoring site. A good working relationship with partners and stakeholders and, over time, the delivery of desired data to those partners will be the key to the success of the network build-out.

Section 5: Recommendations

This section summarizes the recommendations identified in this document as needed to achieve the long-term goal of a fully realized statewide backbone groundwater level monitoring network. The realized statewide backbone network will provide greatly expanded data and the related interpretations needed to support sustainable management of the state's water resources.

5.1 Technical Recommendations

Expand the statewide backbone GWLM Network. This unprecedented network expansion from approximately 750 wells to 7,000 wells would increase the state's ability to understand, respond to, and plan for groundwater changes over time.

Install GWLM network wells with the intention of obtaining long-term records. The value of the data record increases with length of time. The backbone network should be developed over time to increase the number of wells with a data record of 20 years or more. Installed wells should be considered permanent and located to avoid disturbance.

Install at priority sites, if funding allows, electronic data loggers to collect near-continuous water level data. Near-continuous water level data has greater value but is more expensive to acquire and manage. Each GWLM Network well should be evaluated for installation of data logger equipment, such as wells located in priority resource management areas.

Install well nests to determine vertical hydraulic gradients. Installing two or more groundwater level monitoring wells to different depths at a single location allows better characterization of aquifer vertical hydraulic gradients and the potential for water movement between aquifers.

Organize groundwater level monitoring efforts based on watersheds for shallow groundwater systems and on aquifer extent for deep groundwater resources. Adopting the watershed as the organizational unit for monitoring the shallow groundwater system achieves a natural coordination between the shallow groundwater system and surface water monitoring. The deep groundwater resource would continue to be organized by aquifer or resource extent.

Incorporate active hydrologic zone concepts into the long-term network design. The active hydrologic zone is that portion of the groundwater system that readily interacts with surface water and closely tracks changes in precipitation. The long-term network design should include wells that monitor groundwater conditions in the active hydrologic zone and which are coordinated with surface water monitoring. Linking the two systems benefits understanding shallow groundwater systems and supports the development of ecologically-based watershed management.

Incorporate the well distribution and resource allocation method into the long-term network design. The method outlines the steps to determine groundwater level monitoring well needs by unit area and groundwater resource. The distribution and allocation method does not generate the final network design, but rather is intended to guide further discussions on specific network design at the regional and local level to meet specific monitoring needs.

Develop and operate the backbone GWLM Network as part of a network of networks. The backbone network should be considered a component of a more comprehensive network of networks devoted to monitoring the entire hydrologic cycle. As part of the network of networks, the backbone GWLM Network would more effectively share and coordinate groundwater monitoring efforts and assets.

Build out the backbone GWLM network in phases. The long-term development of the network should be approached as an iterative, phased process. A period of time is needed for data collection and analysis between phases. The data collected during each phase will inform the GWLM network development plan of subsequent phases.

The cost of both network build out and operation must be considered. The estimated build-out cost, while largely for the installation of new wells, must also include expenses for data collection, data management, data analysis, and monitoring site maintenance. On-going operation and maintenance costs will increase as the network is developed.

5.2 Implementation Recommendations

Build consensus among professionals and stakeholders. Share and discuss the guidelines in this document with internal and external groups of professionals. Use existing agency and stakeholder groups to inform the process of distributing and allocating groundwater level monitoring wells based on unit area and groundwater resource, and establish priorities for the build out process.

Develop a short-term implementation proposal. An initial, small-scale version of the 30-year plan should be developed, and if funded, implemented to evaluate and confirm the processes outlined in this document. Opportunities for collaborative network development and operation should be identified and pursued as part of the initial project implementation.

Develop a plan to build out the GWLM Network in phases. Each year the proposed plan would install approximately 210 new groundwater level monitoring wells. The network development is intended to be accomplished in iterative phases of approximately five years in length. The five-year period is intended to provide an opportunity to evaluate the network development process and make necessary adjustments to the plan for the next five-year phase.

Operate and maintain the GWLM Network for the long term. Sufficient funding support must be maintained to assure high-quality data are collected over many years. Long-term funding support must include the costs to repair or replace wells and equipment as needed.

Utilize the most efficient and effective methods to manage, analyze, interpret, and distribute the data. Expand current efforts to provide data to users online. Interactive web applications should be further developed to enhance interpretation, improve access, and increase usability of the data. It is expected that over time data delivery and electronic communication pathways will change; future network data operations should be flexible and adaptable to expected changes in electronic communications.

The statewide GWLM Network requires continuing commitment. Once the 30-year network build out project is complete, continuing funding for network operation and maintenance, as well as data management, analysis, distribution will be necessary.

Section 6: Conclusions

The primary purpose of the DNR GWLM Network development described in this guidance document is to assure long-term sustainable water supplies. This guidance document presents a plan for expanding the current groundwater level monitoring network to fulfill the need for more complete information on the condition of groundwater resources throughout the state. At present, the current groundwater level monitoring network is limited in the areas and resources monitored; it does not provide the information needed to adequately manage Minnesota's resources. While Minnesota's current network compares favorably to other states, there are large areas of the state and groundwater systems that are not adequately monitored.

The existing DNR GWLM Network includes about 750 wells distributed throughout the state, but the ability to adequately monitor the groundwater system with the current network is limited. The previous work by DNR staff summarized in this document concluded that a network goal of about 7,000 groundwater level monitoring wells is needed to meet long-term monitoring needs. This document describes a process of allocating network wells by groundwater province and groundwater resource, with more than half of the wells allocated to the water table and shallow groundwater resources. The remaining wells are allocated to deeper aquifer resources.

Building on the existing GWLM Network, and based on the long-term network goal, this document describes in general a network development plan spanning 30 years to completion. The installation of more than 6,000 groundwater level monitoring wells will cost approximately $94.7 million in 2010 dollars, including operations, maintenance, and data management. Ongoing operation and management cost for each subsequent year in 2010 dollars is estimated to be $1.23 million. Ongoing support from multiple stakeholders and a commitment to long-term funding will be needed to achieve the network development goal.

The long-term network development as conceived will provide expanded data from both the surficial and deeper resources to enhance understanding of the three-dimensional groundwater system. As a result, water resource managers will have much-improved information for:

- Understanding status and response to change of the groundwater water system,
- Formulating appropriate management responses to changing water levels,
- Planning for the future by making decisions based on scientific data.

Current and future groundwater quantity concerns include groundwater system response to climate change, increased water consumption, and changes in hydrologic and ecologic systems. The new organizational concept for groundwater level monitoring presented in this document incorporates both watershed and aquifer to better integrate and support other monitoring efforts, such as surface water monitoring. The scope of the GWLM Network expansion described in this document is unprecedented. The successful implementation of the network build-out is dependent on an ongoing and appropriate funding commitment.

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Glossary

Appropriation – Water consumption. In Minnesota, an water appropriation permit is required for withdrawal of 1 million gallons per year or 10,000 gallons per day.

Aquiclude – A saturated geologic unit that is not capable of transmitting significant quantities of water under ordinary hydraulic gradients.

Aquifer – A saturated permeable geologic unit that can transmit significant quantities of water under ordinary hydraulic gradients. Aquifers are broadly classified into two categories, unconfined and confined. When an aquifer is separated from the ground surface and atmosphere by a material of low permeability, the aquifer is confined.

Artesian Aquifer – When water levels in an aquifer exhibit pressure; e.g., when a well is installed in a confined aquifer and the water level in the well casing rises above the top of the aquifer due to pressure.

Aquitard – A less permeable geologic unit within a saturated stratigraphic sequence. These geologic units may be permeable enough to transmit modest quantities of water, but are not generally considered aquifers. Aquitards play significant roles in the study of regional groundwater flow, but are not productive enough to allow the completion of high yielding production wells.

Bedrock Aquifers – Bedrock aquifers are consolidated geologic rock units (bedrock) that have porosity and permeability such that they meet the definition of an aquifer (able to release water in quantities sufficient to supply reasonable amounts to wells). Water in these units is located in the spaces between the rock grains (such as sand grains) or in the fractures within the more solid rock.

Buried Aquifers – Subsurface aquifers comprised of glacially-deposited sands and gravels, over which a confining layer of clay or clay till was deposited. Their areal extent and hydraulic connections beneath the ground surface are often unknown.

Climate Change – Any change in global temperatures and precipitation over time due to natural variability or to human activities.

Confined Aquifer – An aquifer separated from the atmosphere by very slowly permeable sediment or rock (aquitard) called a confining layer. Water in these aquifers is under pressure and, in a well, the water level will rise above the top of the aquifer. See Unconfined Aquifer.

Data Logger – An instrument that records electronic data from an electronic sensor. Historically, data loggers were separate instruments externally connected to electronic sensors. Today, micro-technologies allow union of the sensor and data recorder into a single device.

Groundwater – Water located within the soils and rocks located beneath the surface of the earth.

GWLM – DNR acronym used generically for groundwater level monitoring, but sometimes referring to a specific work group.

Hydraulic Connection – A condition that exists between apparently separated units where water is either gained or lost to the other.

Hydraulic Conductivity (“K”) – Hydraulic conductivity is the rate at which water moves through material.

Hydraulic Gradient – The gradient or slope of a water table or piezometric surface.

Hydrograph – A time series graph showing changes in water level on the Y-axis versus time on the X-axis.

Hydrology – The scientific study of the properties, distribution, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.

MPCA – Minnesota Pollution Control Agency.

Network – A system of interrelated items.

Groundwater level monitoring well – A water well that is used is to measure water levels.

Obwell – A DNR internal informal reference that means the same as groundwater level monitoring well.

Pressure Transducer – An electronic sensor that measures pressure. Pressure transducers are placed in GWLM wells to measure water pressure which is then converted to water level in the well.

Recharge - Mechanisms of water inflow to the aquifer. Typical sources of recharge are precipitation, applied irrigation water, underflow from tributary basins and seepage from surface water bodies.

Specific Capacity – A hydrologic ratio determined by well discharge divided by water level drawdown during a pumping test. These measurements are made during a pumping test to determine the approximate well yield.

Surface Water – Water located at the earth’s surface, occurring as lakes, rivers, wetlands, and oceans.

Sustainability – The condition of where groundwater can be withdrawn from an aquifer without harming ecosystems, degrading water quality, or compromising the ability of future generations to meet their needs.

Transmissivity – The rate of flow of water through a vertical strip of aquifer which is one unit wide extending the full saturated depth of the aquifer and under a unit hydraulic gradient. Transmissivity is used characterize aquifer conditions.

Unconfined Aquifer – An aquifer in which the top of the saturated zone (the water table) is at atmospheric pressure.

Water Table – Water beneath the land surface occurs in two principal zones: the unsaturated zone and the saturated zone. The upper surface of the saturated zone is referred to as the water table.

Appendix 1

DNR OB Well
Field Check List

Date ____________________

DNR OB Well No. ____________________

Unique Well No. ____________________

County ____________________

		Yes	No	Notes
1	Well Site Found			
2	Well in place			
3	Well Type/Use			
4	Site Photographs			From a distance & close up + Misc.
5	Used metal detector			found: Yes maybe No
6	Nested Site			names:
7	Site Description			
8	Well condition	Good	Fair	Poor
9	Bollards			number material
10	Bollard condition	Good	Fair	Poor
11	Protective Casing			diameter
12	Reflective tape			
13	DNR OB ID Sticker			cross out phone add number
14	MN Unique Well ID Tag			
15	Well Cap	outer	inner	
16	Other Access	pitless	vent	
17	Lock			Condition: Good Fair Poor
18	Type of lock			key code color
19	Well Diameter			ID OD (circle)
20	Casing Material	Steel	PVC	
21	Stick up			slope flat hard soft
22	MP Marked at TOC			
23	Pump in well			submersible turbine
24	Decontaminate Steel Tape			
25	Well Depth from TOC			
26	Well bottom	Hard	soft	other
27	GPS: Trimble Garmin	N		E
28	Elevation	GL:		MP:
29	Depth to water from TOC solinst			time
30	Depth to water from TOC steel	H	C	D time
31	Slug tested			Fast Moderate Slow (circle)
32	data logger used			
33	data logger installed (long term)			
34	Decontaminate Steel Tape			
35	Well locked B4 leaving?			

Appendix 2

AGREEMENT FOR INSTALLATION, MAINTENANCE AND USE OF A TEST HOLE OR WATER LEVEL OBSERVATION WELL ON PRIVATE OR PUBLIC LAND

THIS AGREEMENT is entered into this ____ day of _______________ 20___, by John and Joan Smith, hereinafter referred to as the "Grantor", and by the State of Minnesota, acting by and through the Commissioner of Natural Resources, hereinafter referred to as the "Grantee".

WITNESSETH:

WHEREAS, the Grantee desires to expand the observation well network throughout the state for the purpose of obtaining geologic and hydrologic information; and

WHEREAS, the Grantor is the owner of property, as described below, on which the Grantee has deter mined it would be beneficial to gather geological and hydrologic information; and

WHEREAS, the Commissioner of Natural Resources has the authority to conduct surveys, investigations, and studies of waters of the state in order to implement the Commissioner's duties under Minnesota Statutes 103G.121,

NOW THEREFORE, it is agreed between the parties hereto:
1. The Grantor, for and in consideration of the faithful performance by the Grantee of all covenants and conditions herein contained, hereby grants a perpetual Agreement to the Grantee to establish, operate and maintain an water level observation well on the following described premises in __________County, Minnesota to wit:

NW ¼, SE ¼, Se ¼ Sec __, T___, R__W

together with the right of ingress and egress over the following described premises to wit:

NW ¼, SE ¼, Se ¼ Sec__, T___N, R__W

as depicted on the map attached hereto and made a part thereof. Grantee agrees to use existing access roads whenever possible.

This Agreement is for the purpose of drilling or augering a test hole or water level observation well on the above described premises in accordance with M.S. 103I and for measuring the water level on a regular basis. The test hole will extend in the earth to depths which will enable the Grantee to obtain geologic and hydrologic information. If hydrologic conditions are favorable, casing will be installed and the test hole will become a water level observation well for the purpose of taking water level measure ments throughout the term of this Agreement. In addition to the hole as outlined above, the water level observation well will consist of the following physical characteristics and appurtenances, collective ly hereinafter called the "Structure": A 2 " diameter PVC casing extending approximately 3 feet above the land surface protected by a 6-inch steel protective casing.

2. Excavation and/or installation of the Structure shall begin within 30 days or at a mutually agree-able time after the effective date of this Agreement. The Structure shall be installed and main tained in a safe and workmanlike manner.

3. The Structure and all equipment and tools for the maintenance and use thereof placed in or upon said described property shall remain the property of the Grantee and shall be removed, filled and/or sealed by the Grantee at its own cost and expense within a reasonable time after the termination of this Agreement. Upon removal, filling and/or sealing of the Structure, the Grantee shall restore the above described premises as close as possible to the same state and condition existing prior to the excavation, and/or installation of the Structure and its appurtenances.

4. The Grantee agrees to cooperate, to the extent allowed by law, in the submittal of all claims for alleged loss, injuries, or damages to persons or property arising from the acts of the Grantee's employees, acting within the scope of their employment, or contractors in the excavation, installation, use, maintenance, and/or removal of said Structure, appurtenances, equipment and tools as authorized and limited by the Minnesota Torts Act, M. S. 3.736.

5. Results of the water level observations will be available to the Grantor.

6. This Agreement shall become effective when all signatures required have been obtained and shall continue in full force and effect until terminated by the Grantee at any time with 30 days' written notice. However, if the Structure prevents or in any way interferes with the Grantor, the Grantor's heirs, successors or assigns' ability to sell, finance, develop or otherwise use the premises for any purpose, the Grantor may terminate this Agreement by giving 60 days' written notice to the Grantee.

7. This Agreement shall run with the land and bind all of Grantor's successors, heirs and assigns.

8. To the best of Grantor's knowledge the vicinity of the proposed water level observation well is free from contamination.

9. The Grantee assumes no liability for any contamination or other damages that may have occurred on the property prior to the effective date of this Agreement.

10. Contamination which occurs after the construction of the water level observation well, and is introduced into the aquifer because of the existence of the water level observation well, will be the responsibility of the Grantee.

GRANTOR:
By:______________________________________Title:_________________________
By:______________________________________Title:_________________________

This instrument was drafted by:
Minnesota Department of Natural Resources
Division of Waters
500 Lafayette Road
St. Paul MN 55155-4032

May 2011 / File date

Appendix 3

Bid No.0000

SOLICITATION FOR CONTRACT WORK PRIME CONTRACTOR
SCHEDULE OF ITEMS

BIDS WILL BE AWARDED TO THE CONTRACTOR WHO SUBMITS THE LOWEST BID, MEETING ALL TERMS, CONDITIONS AND SPECIFICATIONS, FOR EACH LOCATION.

THIS IS A UNIT PRICE BID. ACTUAL QUANTITIES WILL BE MEASURED FOR PAYMENT. SUBMIT BID FOR ALL ITEMS. FAILURE TO DO SO WILL PRECLUDE CONSIDERATION OF THE BID. IN CASE OF ERROR IN THE EXTENSION OF PRICES, THE UNIT PRICE SHALL GOVERN. IN CASE OF ERROR IN SUMMATION, THE TOTAL OF THE CORRECTED BID AMOUNTS SHALL GOVERN.

Item No	Description – Dual Rotary Reverse Circulation (w/surface sampling every 5 ft) 4-inch diameter casing 1 of 2 in well nest Name of Location	Est Qty	Pay Unit	Unit Price	Amount Bid
1	Mobilization/demobilization	1	Job	$____________	$____________
2	Drill & Sample Hole (Unconsolidated material)	200	Foot	$____________	$____________
3	Drill & Sample Hole (Bedrock)	100	Foot	$____________	$____________
4	10” Steel Casing	200	Foot	$____________	$____________
5	4” Steel Casing	250	Foot	$____________	$____________
6	Grout (Furnish & Install)	3	Cu Yd	$____________	$____________
7	Develop 4” Well	1	Job	$____________	$____________
8	Protective outer casing w/locking cap (Furnish & Install)	1	Each	$____________	$____________
9	4” Diameter Protective Steel Posts (Furnish & Install)	3	Each	$____________	$____________
10	**Total: Dual Rotary Reverse Circulation Name of Location**				$____________

BY: ____
(Signature) *(Please Print Name)*

Title: ____

DATE: ______________________

Bid No.0000

SOLICITATION FOR CONTRACT WORK PRIME CONTRACTOR
SCHEDULE OF ITEMS

BIDS WILL BE AWARDED TO THE CONTRACTOR WHO SUBMITS THE LOWEST BID, MEETING ALL TERMS, CONDITIONS AND SPECIFICATIONS, FOR EACH LOCATION.

THIS IS A UNIT PRICE BID. ACTUAL QUANTITIES WILL BE MEASURED FOR PAYMENT. SUBMIT BID FOR ALL ITEMS. FAILURE TO DO SO WILL PRECLUDE CONSIDERATION OF THE BID. IN CASE OF ERROR IN THE EXTENSION OF PRICES, THE UNIT PRICE SHALL GOVERN. IN CASE OF ERROR IN SUMMATION, THE TOTAL OF THE CORRECTED BID AMOUNTS SHALL GOVERN.

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5	4” Steel Casing	250	Foot	$____________	$____________
6	Grout (Furnish & Install)	3	Cu Yd	$____________	$____________
7	Develop 4” Well	1	Job	$____________	$____________
8	Protective outer casing w/locking cap (Furnish & Install)	1	Each	$____________	$____________
9	4” Diameter Protective Steel Posts (Furnish & Install)	3	Each	$____________	$____________
10	**Total: Dual Rotary Reverse Circulation Name of Location**				$____________

BY: ____
(Signature) *(Please Print Name)*

Title: ____

DATE: ______________________

SPECIAL TERMS, CONDITIONS, AND SPECIFICATIONS
PROJECT SPECIFICATIONS

Bid 0000

DNR Central Region Observation Well Drilling Name of Project Locations

Scope of Work
The contractor will furnish all labor, tools, materials, equipment, and all else necessary to legally and correctly install and complete monitoring wells by dual rotary reverse circulation method and conventional mud rotary method, as specified (with surface sampling every 5 feet), and seal bore holes, if necessary. The contractor must be registered with the Minnesota Department of Health as a Well Contractor.

The project consists of installing a two-well monitoring nest at each location. Each nest will include a well completed in the Mt. Simon sandstone. The primary goal for drilling boreholes into the Mt Simon Sandstone is to complete a monitoring well at each location. The second goal is to learn the total thickness of the Mt. Simon Sandstone at each location by drilling to the base of the formation where feasible.

All contract work shall be completed on/or before the Project Completion Date of: September 30, 2010. Site locations are listed on page 33 of this document.

Location of the Monitoring Wells
Locations are as specified in this bid document. All work performed shall conform with the Water Well Construction Code, Minnesota Statutes, Chapter 1031, and Minnesota Rules, Chapter 4725, administered by the Minnesota Department of Health (MDH). The DNR Project Supervisor will state the exact location prior to the commencement of the actual drilling.

Quality of Work
The work to be done, as defined in this document, shall consist of furnishing all labor, tools, materials, equipment, and all else necessary to legally and correctly drill and seal bore holes, if necessary, and install and complete monitoring wells in the State of Minnesota. This includes any and all reports that may need to be filed with the MDH. Copies of any reports filed shall be sent to the appropriate MDH representative & and Project Supervisor.

Contractors' Licenses
All work pertaining to the drilling of bore holes and installation of well materials must be done by contractors licensed in accordance with the Water Well Construction Code as specified in Minnesota Statutes, Chapter 103-I.

Award
Contractors must provide a price for each itemized line for each location they are bidding. Bids will be awarded to the Contractor who submits the lowest bid, meeting all terms, conditions and specifications, for each well nest location as specified. The State reserves the right to make multiple awards on this contract if deemed to be in the best interest of the State. The State also reserves the right to reduce the number of locations awarded based on available funding at the time of the award.

Payments
The Contractor will be required to submit an itemized invoice for payment for each monitoring well which has been installed. In all instances the contractor shall recommend and bill the State using the lowest cost alternative for completing a service item. Invoices are to be sent to the Project Supervisor. Payment will not be made until borehole records have been submitted to the MDH and Project Supervisor receives copies. Separate payment requests can be made, to the Project Supervisor, for each monitoring well after the monitoring well has been installed and all other related work (geophysical logging, well development, site clean-up, and appropriate record submittal) has been completed.

Retainage
The State, in making partial payments, will retain five (5) percent of the duly approved value of the work performed under the contract documents until final completion and acceptance of work at each location by the Project Supervisor.

Coordination of Work
Within 7 days of receiving the Notice to Proceed the contractor shall prepare a work schedule. No work shall begin until the Project Supervisor has approved the work schedule. All work must be completed within 30 days of receiving approval by the Project Supervisor unless written permission has been received from the State allowing a later completion date. Failure to do so will result in work being giving to another Contractor unless delays were caused by unforeseeable conditions as discussed in the section "Changes". Once the project is started, work is to proceed on a continuous basis. Interruptions in finishing a project must be approved by the State. The State may stop work at any time and the Contractor will be paid for all work that has been completed prior to being asked to stop work.

Changes
The work shall be bid assuming some unknown difficulties of a nature typical for work of this type will be experienced. Changes to the contract time period or the contract amount will be considered only if conditions vary substantially from those likely to occur or are reasonably unforeseeable.

Drilling Permits, Licenses, and Permission to Drill
The Project Supervisor will obtain permission to drill. The Contractor will be responsible for obtaining any and all necessary State and local permits and licenses that may be required by law to perform the work defined in these specifications. Permits required by local authorities shall be secured and paid for by the Contractor. The Contractor is required to be licensed in accordance with the Water Well Construction Code. The Project Supervisor will notify Gopher-One-Call prior to drilling.

Drilling Mud
Only commercially prepared drilling mud shall be used. Natural clay from outside sources or recovered from previous well cuttings shall not be used. The use of organic mud will only be allowed with the prior approval of the Project Supervisor. Drilling mud shall be changed every 150 feet (or as appears necessary by DNR Project Supervisor) so that a more accurate description of the cuttings can be made.

Working Schedule
All drilling and other work for which there will be payment shall be done during the daylight hours of a 5-day work week (Monday through Friday), except as specified below. Unless approved by the Project Supervisor, no drilling shall be done on official state holidays or nonworking days. The Contractor and the Project Supervisor, at the beginning of the work, shall mutually agree on a schedule of work hours to be followed. If certain phases of work on a test hole must be continued into the hours of darkness, the Contractor shall provide sufficient lighting so that work may be carried out in a safe and efficient manner. If the schedule of work hours is to be changed, the Project Supervisor and the Contractor shall mutually agree to such change 24 hours in advance of such change.

General Bidding Instructions
The quantities shown here are estimates for bid tabulation. In all cases the State will pay the Contractor for the actual quantities used for work approved by the Project Supervisor. No bore hole will be started without additional permission from the Project Supervisor if the estimated cost for the bore hole will put the cost of work performed over the cost stated on the contract. Boreholes to be drilled under these specifications are to be used by the State in the investigation of stratigraphy and hydrology of sites in Minnesota. The anticipated drilling depth will generally be between 100 and 1000 feet. It may be necessary to install surface casing in the borehole to maintain circulation of drilling fluids or to control flowing conditions. Each borehole will have a protective casing/cap installed by Contractor.

Drilling Site
The drilling site is defined as the general location of the drilling, being an area no larger than 500' x 500'. More than one monitoring well may be installed at a site, or it may be necessary to reset the drill rig should an unexpected obstruction or other problem be encountered. The cost of relocating the drill rig within the drilling site will be paid as Idle Time. The Contractor shall provide all equipment and experienced personnel, including the specified drilling equipment; all tools, accessories, power, lighting; and all other items necessary to conduct efficient drilling operations. The Contractor shall arrive at the site with sufficient supplies, and well materials to complete the anticipated project in order not to delay the drilling. If it is anticipated that the project will require a surface casing, such materials shall be on-site at the start of the project. If the well/bore must be sealed/abandoned, the Contractor shall also have sufficient supplies and materials to complete this task.

The drill rig shall be in good condition and of sufficient capacity as to meet the drilling specifications outlined. In the event that the equipment, judged on the basis of work completed to date, is considered unsatisfactory, thus endangering performance under the contract, the DNR shall notify the Contractor of such in writing for corrective action.

General Health & Safety
The Contractor is solely responsible for the protection of property and the health and safety of its employees, subcontractors, suppliers, agents and others on or near the site, including health and safety matters related to the nature of the work and the potential for encountering hazardous substances in air, soil, leachate, and/or condensate during the work. The Contractor's personnel shall maintain safe working conditions, including the wearing of hard hats and steel-toed shoes. Hearing protection is also strongly encouraged.

Delays within contractor's control
Delays in drilling which cause idle time for the Owner (State of MN) shall be deducted from final payment by the State at the same rate as "Idle Time". These delays are those caused by inadequate supplies, failure to bring all equipment necessary to drill, install well materials and seal boreholes, or arrival at the drilling site after the predetermined time without reasonable cause. Only delays in excess of 30 minutes will be charged and idle time will be figured to the nearest quarter hour. Delays due to equipment breakdowns will be handled as described in "Equipment and Personnel to be furnished by Contractor".

Drilling Procedures
For each site the expected sequence is as follows. After setting surface casing, if needed, drilling is to proceed to a depth determined by the Owner, collecting samples as described in "Geologic Samples and Log". The borehole shall be sufficiently

straight and plumb to permit geophysical logging. During the drilling no sand, dirt, rock, old drilling cuttings, or any foreign materials shall be introduced into the borehole except with prior knowledge and consent of the Owner.

The Contractor shall make measurements of the amount of hole drilled or other factors for purposes of payment or testing with his own equipment in the presence of the Owner. In case of dispute or for any other purposes, the Owner will be entitled to make measurements at any time with its own equipment at no extra cost to the State. Explosives shall not be used in connection with any drilling operation except on specific prior written approval.

Geologic Samples and Record
Samples of the materials penetrated shall be collected at intervals of 5 feet, at changes in formation, and at depths determined by the Owner. The driller shall notify the Project Supervisor logging the test hole of such conditions to facilitate in evaluating changes in the formation. The driller shall carefully and accurately keep a log with descriptive notes of everything encountered by the drill and of all difficulties or unusual conditions met in drilling. Within 30 days after completion of the borehole, the invoice for the work and the DNR's copy of the Bore Hole Record and well construction shall be prepared and delivered to the Project Supervisor in accordance with Minnesota Rules, Chapter 4725.

Site Preparation and Clean-up
No fee will be paid to complete minor site preparation and clean up typical for work of this type. Changes to the contract amount will be considered only if conditions vary substantially from those typical for work of this type and must be approved by the Project Supervisor prior to the initiation of work.

Cuttings Containment, Final Clean Up and Restoration
The site shall be left free of waste materials; damaged areas restored, and with the ground surface restored to as near original condition prior to approval by project supervisor for final payment. To expedite the final clean up, the contractor should plan to provide an open container (dumpster or other similar container) for drilling fluid circulation and cuttings containment. Dug mud pits will not be suitable for any of these sites.

Damage to Facilities
The drilling site(s) chosen will be reasonably accessible and have reasonable maneuvering space for the Contractor's trucks and equipment. The Contractor shall be responsible for the cost of completing any repairs/replacement of any damaged structure, cover soils, vegetation, personal or real property caused by drilling activities both on and off the site. It is the responsibility of the Contractor to maintain the integrity of any site structure by taking appropriate measures to protect it from accidental damage, e.g., rutting. The Contractor shall immediately notify the Project Supervisor of any damage. The Project Supervisor will have the utilities located. If, upon inspection of the site, the Contractor determines that there is not sufficient cleared area for efficient operations, the Contractor shall notify the Project Supervisor who will arrange for an alternative site or for further site preparation.

Mobilization
Mobilization shall include moving all personnel, tools, equipment and vehicles to the site and removing the same from the site when drilling is completed. It shall also include the preparation of required submittals including the provision of insurance certificates and site preparation if any, setup, demobilization and final clean up and restoration. The Contractor shall arrive at the site with sufficient supplies to complete the anticipated project in order not to delay drilling. If it is anticipated that the project will require a surface casing, such materials shall be on-site at the start of the project.

Drilling
The price per foot of drilling shall include drilling, assisting in collection of geologic samples, recording a log of all materials and drilling conditions encountered, and filing a well log record.

Sealing Bore Hole
If a borehole cannot be completed as a monitoring well, upon completion of drilling and after the Project Supervisor has completed any testing deemed necessary, the borehole shall be sealed according to the Minnesota Rules, Chapter 4725. The quantity of grout required to seal a well will vary depending on type of formation. If the quantity of grout exceeds the well volume by 30 percent, the Project Supervisor must approve any further grout placement. While grouting in bedrock the Contractor shall be prepared to use stone aggregate to reduce the grout volume in accordance with Minnesota Rules, Chapter 5 4725.

Idle Time
During the progress of drilling operations under these specifications, it may be necessary for the Project Supervisor to perform work not directly involving drilling, such as geophysical logging that will require the services of the drilling crew and drilling equipment to stand idle during normal working hours. In such an event, the Owner shall request that the Contractor furnish such assistance and/or cease operations and shall state the anticipated extent or duration thereof. The Contractor shall promptly furnish such assistance and/or cease operations and shall receive reimbursement, therefore, according to the bid item for idle time. Idle time of the drilling crew and equipment, during normal working hours, not ordered by the Owner shall not be reimbursable under this contract. Also, time spent for circulation of drilling fluid for collecting samples or drill cuttings as called for under "Geologic Samples and Log" shall not be separately reimbursable; it is to be included in unit drilling cost. Idle time shall be figured to the nearest quarter hour.

Observation well locations Hennepin, Isanti and Anoka Counties

County	T R SEC QQ	Name	Owner	Nearest Intersection	Aquifer	Est. Well Depth
Isanti	35 25 33 NE NW	Crooked Road WMA	DNR/FAW	Dolphin St. NW, 285th Ave NW	Mt. Simon Sandstone	300
Isanti	35 25 33 NE NW	Crooked Road WMA	DNR/FAW	Dolphin St. NW, 285th Ave NW	Unconsolidated sand	100
Isanti	36 25 35 SE SE	Spectacle WMA	DNR/FAW	325th Ave NW, Helium St. NW	Mt. Simon Sandstone	350
Isanti	36 25 35 SE SE	Spectacle WMA	DNR/FAW	325th Ave NW, Helium St. NW	Unconsolidated sand	100
Isanti	37 24 2 SW SW	Stanchfield WMA	DNR/FAW	Flamingo St. NW, 413th Ave	Mt. Simon Sandstone	250
Isanti	37 24 2 SW SW	Stanchfield WMA	DNR/FAW	Flamingo St. NW, 413th Ave	Unconsolidated sand	60
Anoka	33 25 22 NE SW	Pickerel Lake WA	DNR/TAW	Jasper St., Old Viking Blvd NW	Mt. Simon Sandstone	400
Anoka	33 25 22 NE SW	Pickerel Lake WA	DNR/TAW	Jasper St., Old Viking Blvd NW	Unconsolidated sand	100
Hennepin	118 24 8 SW SW	Robina WMA	DNR/FAW	Lake Haughey Rd and Hwy 12	Mt. Simon Sandstone	600
Hennepin	118 24 8 SW SW	Robina WMA	DNR/FAW	Lake Haughey Rd and Hwy 12	Unconsolidated sand	100

Appendix 4

DOW SITE SPECIFIC DRILLING OPERATIONS SAFETY PLAN

Projected Date(s) of Field Work:

Site Address or Coordinates:

Approvals		
	Initials	Date
Prepared By		
Approved By		

☐ Site Map Attached

Work Planned at this site: LCCMR SC drilling and ob well installation. Site activities will include over-site of drilling procedures and sample collection. Follow-up site activities will include installation of long term water level monitoring equipment and water quality sample collection.

KEY CONTACTS

DNR Project Leader:	(project manager) ________	Phone:	Cell:	☐ CPR/F.Aid
Site Contact (WMA, etc.):	(on-site geologist) ____________	Phone:	Cell:	☐ CPR/F.Aid
Drilling Staff	Well Company drilling crew ______	Phone:	Cell:	☐ CPR/F.Aid
	______________________________	Phone:	Cell:	☐ CPR/F.Aid
	______________________________	Phone:	Cell:	☐ CPR/F.Aid
	______________________________	Phone:	Cell:	☐ CPR/F.Aid
	______________________________	Phone:	Cell:	☐ CPR/F.Aid

Other: Unit Supervisor Phone: Cell:

Administrator Phone:

Closest Emergency Medical Facility (Name):

Phone Number (general): Phone Number (emergency):

☐ Emergency Medical Facility Confirmed ☐ Map with Route to Hospital Attached

☐ 911 Service Confirmed

Police: 911 Fire: 911 Paramedic/Ambulance: 911

EMERGENCY PROCEDURES

Medical Emergencies

1. Remove injured or exposed person(s) from immediate danger if possible.
2. Evacuate other on-site personnel to a safe place in an upwind direction.
3. If serious injury or life-threatening condition exists, call 911 - Clearly describe location, injury and conditions to dispatcher/hospital. Designate a person to direct emergency equipment to the injured person(s).
4. Provide first aid if necessary. Be aware that shock is a threat for all persons at the site.
5. Call the DNR project leader and supervisor.
6. Immediately implement steps to prevent recurrence of the accident.

General Emergencies

In the case of fire, flood (uncontrolled flow of water), explosion, or other hazard, stop work, evacuate, and call the local police/fire department by calling 911 as appropriate.

Emergency Equipment Onsite
☐ First Aid Kit; ☐ Fire Extinguisher; ☐ Other: ____

PHYSICAL HAZARDS:

☐ Heat Stress	☐ Cold Stress	☐ Wet	☐ Noise
☐ Slip, Trip, & Fall	☐ Heavy Equipment	☐ Electrical Hazards	
☐ Underground Hazards: One Call Ticket # ____________		Date Called: ______________	
☐ Overhead Hazards	☐ Traffic	☐ Excavations/Trenching	☐ Confined Space

☐ Other: ____

SITE CONTROLS: Good Housekeeping measures minimize slip and fall hazards (and control erosion). Identified hazards should be flagged, fenced off or staked, etc. ____

____

PERSONAL PROTECTIVE EQUIPMENT – R = REQUIRED, A = HAVE AVAILABLE
Serious injuries and deaths have been **prevented** when people working near rigs have worn their protective gear.

_____ Eye Protection	_____ Safety Glasses	_______ Sun Protection
_____ Hard Hat	_____ Steel-Toed Boots	_______ Appropriate Clothing
_____ Traffic Safety Vest	_____ Hearing Protection	_______ Rain Gear

_____ Appropriate Gloves: Neoprene, safety grip; cloth/leather; Other _________________
Other: ____
Drillers will follow their own health and safety plans, copies of which must be provided to DNR, and provide their own personal protective equipment.

LIST OF POTENTIAL TOPICS FOR TAILGATE SAFETY MEETING
Drilling Contractor Staff are responsible for all activities related to drilling and drill rig setup and operation. At the tailgate safety meeting, the Drilling will brief DNR staff on critical safety features of the drill rig and point out hazards of working near a drill rig.

Tailgate Safety Briefings
Work for the day should not be started until hazards have been identified discussed. Following is a list of topics to review as appropriate.

- Is everyone wearing proper personal protective equipment? Clothing is snug, jewelry and watches will not snag?
- Are vehicles and machinery in good operating condition? (pre-drilling walk-around completed?)
- Is everyone aware of the safety plan and know what to do in case of an accident?
- Are fire extinguishers present? Are they of the appropriate size and type? Are they in good working condition?
- Is any fuel on the site properly stored?
- Do the conditions require "no smoking"? (and do the drillers observe that caution?)
- Is the work area organized? Would DNR be completely embarrassed if the media stopped by for pictures?
- Has staff been told to 'pick up after themselves' during drilling operations?
- Are any trip hazards present?
- Are all "shut down" devices on the drill rig installed and in good working condition?
- Are tools clean and in good working condition?
- Do the site conditions warrant wheel chocks for vehicles (drill rig/water truck)?
- Is there a working (charged) cell phone on site? Is there cell phone service? Failing that, is an emergency communication source available?
- Have employees been trained in first aid and CPR?
- Is there a properly stocked first aid kit available on-site and in every vehicle?
- Are overhead power lines or any other utility lines present in the area? A minimum distance of fifty or more feet should be observed when setting up in the vicinity of overhead lines. Has the power utility been onsite to install protective measures?
- Have all underground utilities been identified?
- Is there a danger of being struck by other moving vehicles?
- Is there a danger because of possible soil instability due to steep slopes, etc.?
- Is there poison ivy in the area, wild parsnip? Can staff identify these poisonous plants? Hornet nest or bee hives?
- Is there a danger of lightning strikes? This subject must be addressed regardless of time of year or current weather conditions.

TAILGATE SAFETY MEETING DOCUMENTATION FORM

Date:

Site Location:

Lead By:

Name (printed)	Signature

MAP TO HOSPITAL

(copy map and route from mapping program and paste in so it will print out with the safety plan – verify from personal knowledge of drilling site that the program is actually giving you something useful)

Appendix 5.1

Policy and criteria for accepting existing wells into the MN GWLM 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 Division, Department of Natural Resources, Division of Waters, depending on circumstances.

Background

From time to time, an existing well is no longer used by its owner. The reasons that a well is no longer used include the following: the completion of a study, re-purposing of a site property from one function to another, a change of land ownership, and possibly other reasons. 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. The 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 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.

Specific Criteria:

Technical Criteria

1. The existing network should be reviewed to identify a specific need. For example, the well fills a gap that exists in the network or an existing well is no longer functioning properly and needs replacing.
2. The existing well should connect with an aquifer of sufficient extent and thickness to have an economic or resource value for a significant area.
3. 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.
4. Wells that are proposed for ownership transfer to DNR Waters should be less than 25 years old and less than six inches in diameter. Proposed wells must meet the requirements of the Minnesota Well Code at the time of transfer.
5. Proposed wells for inclusion in the Network should be at least two inches in diameter to accommodate measurement devices.
6. 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.
7. 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.
8. 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.
9. Pumping and/or slug tests should be conducted to demonstrate functionality of the well.
10. The condition and safety of the proposed well must be field-verified. The field verification step should also check well location and use, and the presence of pumps or other equipment in the well.
11. 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

12. 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.
13. 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.
14. 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).
15. 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.

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

17. 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 their review and concurrence. The documentation should be kept in the GWLM Network well file and in the remarks section of the GWLM Network database.

Appendix 5.2

Policy and criteria for installing new wells to add to the MN GWLM Network

This policy applies to:

Drilling or installing new wells for use in the Minnesota Ground Water Level Monitoring (GWLM) Network. The ownership of the well is expected to be with the State of Minnesota, Department of Natural Resources, Division of Waters (DNR Waters).

Background

When the funding is available, new wells are installed by DNR Waters to add to the GWLM Network. The well is typically located in an area that is under-represented in the existing Network, is placed in an aquifer that was previously not measured, or is associated with a study being conducted in a particular area. DNR Waters will maintain the new well and properly abandon it when it is no longer needed.

Each proposed new well location should be carefully reviewed and a review memo and recommendation prepared. The review should be conducted by the Ground Water Monitoring Well Coordinator and should address the criteria (as outlined below) used to determine if a location would be acceptable for a new well. The documentation should be kept in the GWLM Network well file and in the remarks section of the GWLM Network database.

General Policy

The Division of Waters will install new wells to add to the GWLM Network to improve the quality and quantity of ground water data. These wells would be installed in areas or aquifers that have an insufficient number of GWLM Network wells.

General Criteria

A proposed new well *must* meet the following criteria:

- Must fulfill a monitoring need.
- Must be constructed to be in connection with the aquifer.
- Must be intended for long-term measurement.
- Must meet requirements of the Minnesota Well Code.

Likewise, a proposed new well *should* meet the following criteria:

- Should monitor a known aquifer or system.
- Should be located on public land, preferably State of Minnesota owned property.
- Should be part of a well nest installed in the various aquifers at the location.

Specific Criteria

1. The existing network should be reviewed to identify a specific need. For example, specific needs may include gaps that exist in the network or replacing an existing well that is no longer functioning properly. The location should be within an area identified in long-range or priority plans developed by DNR Waters.
2. The new well should be constructed to connect with an aquifer of sufficient extent and thickness to have an economic or resource value for a significant area.
3. 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.
4. New wells should be at least two inches in diameter to accommodate measurement devices.
5. New wells will be installed in accordance with all appropriate well installation regulations.
6. Installation procedures for the well shall include proper development before incorporating the well into the network.
7. Upon completion and development, a single-well pump test shall be conducted to determine well hydraulic characteristics.
8. An access arrangement will be approved between the property owner (including those sites owned by units within the DNR) and DNR Waters to allow long-term access to the well location for monitoring and maintenance (as defined in the Access Agreement).

Appendix 5.3

Policy and criteria for removing wells from the MN GWLM Network

This policy applies to

Removing existing wells from the Minnesota Ground Water Level Monitoring (GWLM) Network. The well may or may not be owned by the State of Minnesota, Department of Natural Resources, Division of Waters.

Background

Occasionally, a well in the GWLM Network is no longer measured, but has not been sealed. The well might not be measured because the well has been damaged and is no longer a functioning well, tests have indicated that the well is no longer connected to the aquifer, the use of the property has changed, or the property owner does not allow DNR staff on the property.

The well may have been installed by the DNR for either the obwell network or for a special project. It may have been installed for a project by another entity (e.g., the USGS) and use of the well was acquired by the DNR. The well may be an old water supply well or it could be an active water supply or irrigation well. The DNR may or may not own the property where the well is located.

If a well is no longer measured and is not in use for another purpose, it is not considered an active well by the Minnesota Department of Health (MDH) and according to Minnesota well code (Minnesota Statute 103I.301) the well must be sealed.

General Policy

The Division of Waters will seal wells and remove the site from the GWLM Network if they are no longer measured as a part of the GWLM Network and are not used by another entity.

If a well is owned by but is no longer actively measured by DNR Waters, it must be sealed by the DNR Waters in accordance with MDH well code and regulations.

If the well is owned by another entity and is not in use by that entity, the well owner must be notified that the well is no longer in use by the DNR and it should be sealed.

If another entity wishes to continue measuring a well owned by the DNR, the ownership of the well will be transferred to that entity and that entity will be responsible for the maintenance and eventual sealing of the well.

General Criteria

An existing well will be removed from the Network if:

- The well is no longer actively measured but is owned by the DNR.
- The property owner does not want the well on their property.
- Tests indicate that the well is no longer accurately measuring aquifer water levels.
- The well is redundant and is duplicating water level data from a nearby well.
- Well is damaged and can no longer function as a monitoring well.
- Well is damaged and is a threat to human health or the environment.

If the well was acquired from another entity (such as the USGS) and the DNR has actively measured the well for a period of time (at least five years), the DNR will accept responsibility for maintenance and sealing of the well unless other arrangements have been made.

Specific Criteria

Technical Criteria

A GWLM Network well will be sealed and removed from the Network if any of the following criteria are met and the well is owned (specifically or implicitly) by the DNR:

1. A well has been damaged beyond repair.
2. A well is no longer actively measured because it is in a location which does not fit into the needs of the GWLM Network.
3. A well is no longer effectively measuring the aquifer. This maybe indicated by a very slow to no response to a slug test or some other test.
4. Water levels have changed dramatically for no apparent reason. This may indicate the well casing has failed and water from a different part of the subsurface is entering the well.
5. A well is a flowing well with no way to consistently measure the water level.
6. A well has been damaged by the elements and the integrity of the well is in question.
7. The well is located close to another well which is measuring the same aquifer. Generally, the newer well should be retained in the Network as it is expected to have a longer remaining life span.
8. Property owner no longer wants the well on the property.
9. Property owner will not allow DNR or its contractors on the property to measure the well.

Administrative Criteria

1. If the well is sealed by the DNR, the well will be sealed in accordance with MDH well sealing requirements.
2. If the well is sealed for the DNR by a contractor, the well must be sealed in accordance with MDH well sealing requirements.
3. If the well was acquired from another entity and the DNR has actively measured the well for more than five (5) years, the DNR will continue or provide maintenance and will seal the well when necessary unless another agreement has been made.
4. When the well is sealed, the well sealing records must be kept by DNR with other data from the well.
5. If the well is owned by another entity, that entity must be notified by the DNR that the well will no longer be measured as a part of the GWLM Network and if the owner is not using the well, that the owner should seal the well in accordance with MDH well sealing requirements.

6. If the DNR plans to seal an obwell and is not certain that other entities measure the well, a warning sticker will be placed on the well stating the well will be sealed in six months (specify date on label) and if the measuring entity has concerns, it must contact the DNR within the six months. The DNR's Area and Regional Hydrologist and the local Soil and Water Conservation District and/or Waters.
7. Management District should be contacted at least 60 days before the well is sealed. If these individuals or organizations are measuring the well, arrangements must be made to outline the responsibility of the other individual or organization related to the maintenance and ownership of the well.
8. If the DNR finds a well that was formerly used as a DNR obwell, is no longer measured, and appears to not be actively used, the DNR will notify both the property/well owner and the MDH about the well and indicate that the well does not appear to be in use.

Appendix 5.4

Policy and Criteria for Installation and Use of Electronic Data Logging and Telemetry in the MN GWLM Network

This policy applies to:

The installation and use of electronic water level sensors (transducers), electronic data loggers, and telemetry equipment for automatically recording water levels in wells and automatically or semi-automatically acquiring the recorded electronic data for the Minnesota Ground Water Level Monitoring (GWLM) Network. The MN GWLM Network is operated by the State of Minnesota Department of Natural Resources, Division of Waters (DNR Waters).

Background

Electronic water level measurement and data logging

Water levels in ground water monitoring wells rise and fall in response to variations in long-term climate, seasonal recharge, weather events, pumping from the aquifer or related resource, and other hydrologic system changes. The water level changes in the well are measured periodically to track the response of the ground water system to those variations. Generally, water levels in Network wells are measured once a month from April to November and are not measured the other months.

The data are manually recorded and later provided to the Network database. In order to obtain accurate measurements to 0.01 foot, the preferred traditional equipment for the MN GWLM Network is a specially constructed steel tape. Currently, wells are measured manually once a month by SWCD staff. The SWCDs are paid a set amount per well measurement.

Electronic sensors called transducers can respond to water pressure changes that can be interpreted as water level changes. The electronic signal can be stored in another electronic device called a data logger for later retrieval. Transducers and data loggers are standard technology and have been used for many years by DNR Waters staff, especially for aquifer tests and special studies. They have not, however, been used for routine measurement of GWLM Network wells mainly because of cost. Newer designs have features (size, data capacity, data download procedures, required routine service) that may be more cost effective than manual measurements in certain locations. In this document, unless otherwise stated, datalogger means an integrated transducer and datalogger system.

Telemetry

Telemetry means remote communication and data acquisition by telephone lines, cell phones, radio, or satellite systems. Telemetry from sites instrumented with the necessary electronics is not new in Minnesota. The technology is used at about 150 stream gages in Minnesota (see Appendix A). The USGS uses telemetry at selected ground water level monitoring locations in Minnesota.

For the MN GWLM Network, using telemetry would allow remotely evaluating the status of the monitoring sites and downloading the water level measurements without traveling to the location. After the downloaded data is reviewed, it would be transferred to the GWLM database. Optimally, the data can be acquired and provided to users in near real time.

General Policy

Use of Transducers and Dataloggers

To reduce the costs of manual measurements, provide for more frequent measurements, and increase data management efficiency; the use of electronics for measuring and recording water levels in the MN GWLM Network should be employed. The dataloggers should be installed when and where it is cost effective and their use should be expanded over time. The long-term goal is to instrument all suitable Network wells with dataloggers.

Use of Telemetry

The purpose of telemetry is to reduce costs of manual measurements, provide for more frequent measurements, increase data management efficiency, and make data more immediately available; the use of telemetry in the GWLM Network should be considered at priority sites when and where it is cost effective. The use of telemetry may be expanded over time. DNR Waters should work with other agencies to install telemetry sites if such sites will improve information about the resource and there is sufficient support between the agencies.

General Criteria

Transducer and Datalogger Equipment

Transducer and datalogger equipment should be placed in all suitable obwells in the Network. Unsuitable wells are typically irrigation wells or other actively pumped wells or wells with limited access. This equipment should not be placed into actively pumping wells because of the potential for damage to the transducer, datalogger, or the pump. Adding electronic monitoring equipment to unsuitable wells should be assessed on a well-by-well basis.

Currently, there are a limited number of dedicated transducers and dataloggers installed in the Network. As funding becomes available dedicated Network dataloggers will be purchased and installed. The factors that need to be considered when evaluating where the dataloggers should be installed include the following:

- Wells in areas that currently or historically have had ground water supply issues, (i.e., Brooten/Belgrade or the Buffalo Aquifer area) should be given priority consideration. This would be a continuation or expansion of the existing practice to deploy dataloggers in areas requiring close observation because of water supply issues, drought, well interference, and resource conflicts. There are generally 10 to 20 dataloggers deployed for such purposes at any time.
- At the county level, factors to consider include:
    - Distances between obwells – wells that are far apart are better suited to have dataloggers. The amount of travel time and travel expense is reduced if someone visits the well

quarterly rather than monthly.
    - Local support – participation by SWCD, watershed districts, area hydrologists, local agencies, etc. A goal is to establish partnerships for downloading data and conducting site checks.
    - Nested well systems -- if a monitoring location is a nested well cluster, all of the wells in the nest should be instrumented.
- Ability for DNR personnel to visit the wells on a timely basis to download the datalogger and ensure equipment is functioning properly.

Details about the transducer equipment requirements and data collection are presented in Appendix B.

Telemetry Equipment

At this time, DNR Waters is not actively pursuing adding telemetry to any of the new or existing wells in the network. Because of the cost of installation, the on-going maintenance required for a telemetry system, and the relatively slow change in ground water levels, the use of telemetry for communicating ground water levels is not considered a priority use of limited resources.

5.4 - Appendix A

Minnesota Cooperative Stream Gaging Program

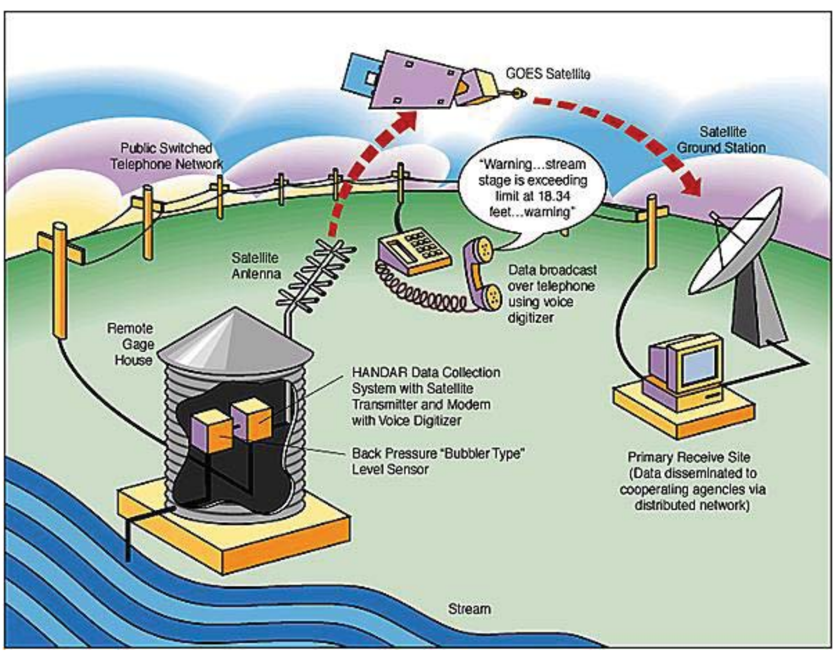
Telemetry Overview for Stream Gaging

The diagram below gives a general outline of how the Minnesota Cooperative Stream Gaging Program telemetry system is organized. There are two common ways to remotely communicate with the data loggers: telephone and satellite. Other options include cell phone and radio communication.

First, the telephone line, which is hooked up by the telephone company and is maintained just like any residential phone line. Program personal can call the logger, make programming changes, and get a measurement reading. With certain loggers, the phone can also be used as a warning if certain criteria are exceeded as shown in the diagram. This method can sometimes be difficult in more remote areas where a phone network can be far away from the site.

The second type of telemetry is through a Geostationary Operational Environmental Satellite (GOES). Like other forms of satellite communication, this allows a direct real-time feed of information from the logger to a computer. For flood warning gages, data is routed directly into the data system where it is analyzed by the software and then immediately put onto the website and stored in the database. The equipment required for this arrangement is a Data Collection Platform (DCP) transmitter, which is attached to an antenna on location. This transmitter is then able to communicate with the GOES satellite, which relays the data to a ground station and routes the data to an assigned computer. This method does not depend on remoteness of the site, but does require a relatively open space to transmit a satellite signal from the DCP to the satellite.

One of the biggest benefits of real time access to data is accurate and prompt response to changing situations in the field. Another benefit is efficiency: saving time and expense on data downloading visits, and the ability to check current conditions and equipment status when planning a site visit.



5.4 - Appendix B

Transducer and datalogger equipment requirements

The transducer and datalogger equipment must be able to measure ground water levels and temperature. They need to be a self-contained unit, which must include the transducer, the datalogger, the power supply, and the ability to be easily downloaded in the field. If possible, they should all be from the same manufacturer so there is consistency in the equipment and downloading software. The dataloggers should be able to withstand the conditions of the well they are installed, which include temperature and water pressures. Prior to installation, the expected range of the water levels needs to be considered. Initially, it is expected that a datalogger with a pressure range of 15 feet will be sufficient for most of the network wells. However, the record of each well needs to be examined prior to datalogger installation to insure that the resolution of the datalogger is appropriate to the conditions of that particular well.

Because these dataloggers are typically non-vented units, meaning that they do not take atmospheric barometric changes into account when recording the water level, a barometric datalogger will also need to be installed. This type of datalogger will allow the barometric changes to be removed from the water level data. A barometric data logger covers a 20-mile radius from the barometric logger location. The barometric datalogger can be installed in one of the obwells in the area, along with the water level datalogger. The barometric datalogger should be downloaded at the same time as the nearby water level dataloggers. The water levels from the surrounding wells can be compensated to reflect the change to due barometric changes. It is estimated six or eight barometric data loggers are needed for complete coverage of the state.

Transducer and datalogger data collection

In general, the dataloggers should measure ground water levels on an hourly basis and should be downloaded on a quarterly basis. This schedule can be revised to match the requirements for a particular area but daily readings should be the minimum measurement interval. DNR field staff will download the dataloggers. At this time, it is expected that the DNR water monitoring and survey unit personnel will download and the dataloggers while they are in the area conducting other monitoring. If needed, the field staff will also provide certain operational maintenance required by the equipment.

During the transition from manual measurements to electronic measurements with dataloggers, a local agency may be contacted and encouraged to take responsibility for routine downloads of the dataloggers in their area. If they are interested in participating, DNR staff would provide training and on-going support.

Appendix 5.5

Policy and Criteria for
Vibrating Wire Transducer Use and Installation in Wells of the MN GWLM Network

This policy applies to

The installation and use of vibrating wire technology (vibe wires) in wells in the Minnesota Ground Water Level Monitoring (GWLM) Network. The network is the responsibility of and managed by the State of Minnesota, Department of Natural Resources, Division of Waters (DNR Waters).

Background

DNR Waters first identified vibrating wire (vibe wire) technology for possible application in ground water level monitoring wells of the GWLM Network in 1999, when a need developed for instrumentation that could be permanently emplaced in a well that was due to be sealed. Vibe wires are commonly used in engineering applications that require emplaced or buried instrumentation with long-term stability and reliability. A vibe wire is designed to measure fluid pressures such as ground water elevations when buried directly in embankments, fills, etc. Appendix A presents a description of how vibrating wire technology works.

Vibe wire installations in Minnesota

Since 1999, 33 vibe wire installations at nine sites have been emplaced and are currently in use in sealed wells in Minnesota. Most of the installations are located in the Twin Cities metropolitan area. There are three in Minneapolis, three in St. Paul, four in Brooklyn Park, three in Caledonia (Houston County), three in Cambridge, three in Savage, three in Afton, one in Bayport, and nine in Castle Rock (Chub Lake study area).

As typified by these installations, vibe wire transducers were typically installed in deep wells (greater than 200 feet deep) that were being sealed by the well owner. The wells were being sealed for a number of reasons, including reduction of liability from a well no longer in use or redevelopment of a property. Because the number of deep observation wells in the state is limited, having the ability to continue monitoring these wells extends the period of record for the well, thereby increasing the data's value over the long term.

Vibe wire transducers do need to be sealed in place to be used. They can be used to measure water levels in open hole wells on a temporary or permanent basis. Vibe wires have been used in a number of open hole wells in the Twin Cities metropolitan area in association with various ground water studies.

Vibe wire data collection

Currently, none of the wells in which vibe wire are installed have dedicated dataloggers associated with them. At these locations, measurements are collected monthly using a data logger and a computer. The data is collected and the values recorded in a field book. This information is added to an Excel spreadsheet, which contains the initial ground water levels and the height of the measuring point above ground surface. The water level is calculated by subtracting the reading from the initial water level and multiplying it by a factor of 1 or –1 to adjust for the sign of the reading. These values are then entered into the GWLM Network database.

Dedicated dataloggers could be added to any of the current or future vibe wires. The limiting factor for having a datalogger at a well is the ability to house the datalogger at the ground surface. The vibe wire manufacturer has a number of different datalogger systems, all of which would require housing at or near the wellhead.

When a dedicated data logger is installed, the water levels should be collected on a daily basis and the data should be downloaded on a quarterly basis. The data collection rate and period between downloads can be varied as needed.

The DNR in cooperation with the USGS formerly established a telemetry system for collecting data from the Chub Lake vibe wires. Measurements were collected hourly and then transmitted to the USGS, which processed and presented the data as part of the USGS's real-time groundwater level network.

The water level data collected from these sites are currently stored in the Obwell database and are accessible through the Ground Water Level Data Retrieval page on the DNR website. The available Chub Lake data is available on the USGS groundwater website

<u>Experience and issues with vibe wire installations in Minnesota to date</u>

1. Experience with installing a vibe wire transducer as part of well sealing procedures has shown that a high level of care is needed to avoid damage to the transducer during emplacement, especially as these installations are in deep wells, typically at a depth of hundreds of feet. Handling the transducer cable itself during installation can be difficult and the transducer or cable can be damaged during sand pack or grout placement.
2. Once sealed, an independent method check of vibe wire transducer data is not possible. The measurements reflect relative change from the time of installation but it is difficult to establish accuracy, precision, or error. For some sites, relative change following installation may be acceptable.

General Policy

To maintain or improve the water level data of deep aquifers in Minnesota, DNR Waters will install vibe wires in select wells that are being sealed and that match the general criteria for site selection and installation as outlined in this document.

General Criteria
Site selection and installation

Site selection criteria
The current installed vibe wire transducers were emplaced in wells that were previously being monitored by DNR Waters for ground water levels, except for the Chub Lake wells. The vibe wire transducers were installed because the well owner planned to seal the well and vibe wire technology was the only way available which allowed data collection to continue at these locations. Because vibe wire transducers are permanently sealed into the well and do not allow access for calibration or servicing, vibe wire transducers should be considered only if no other option is available and continuation of the data record is a high priority.

Wells that are to be sealed and that have not been previously measured by DNR Waters should be considered for vibe wire installation if the well is located so that it fills a gap in the GWLM Network. This gap maybe related to the physical location or the aquifer that could be measured. In these instances, the well will need to be assessed as outlined in the Policy and Criteria for Accepting Existing Sites document.

Independent method check requirement
When possible, existing vibe wire sites shall be paired with a comparable site to obtain an independent method check of water level. This assures that the data collected are of high quality and identifies any instrument drift or failure.

Vibe wire resolution
When the vibe wires are installed in deep wells, the initial water pressure will typically be high. Because of the high initial water pressure, the range of pressures that the vibe wire can measure must be large to prevent damage to the vibe wire. This reduces the ability of the transducer to measure small changes in water levels.

For example, a vibe wire installed in a four inch well with 235 feet of head will have a pressure of 102 PSI exerted upon it. To insure that this pressure does not damage the vibe wire, the vibe wire will have a resolution of approximately six feet. Thus the water level may change six feet before the vibe wire will measure a change. This equipment resolution must be taken into account when selecting a site for vibe wire installation. The resolution must be noted in the data record and the users should be advised.

Vibe wire installation

A complete description of the steps and procedures for installing vibe wires is presented in Appendix B.

There is no technical limit to the number of vibe wires that could be installed in a well. Generally, the casing size dictates the number of vibe wires installed. The smaller the casing size, the fewer wires that should be installed because it is more likely that the tremie pipe used to place the sealing grout will damage the vibe wires during the installation/abandonment activities.

In many of the existing vibe wire installations in the GWLM Network, multiple wires have been placed in the same aquifer. This was to provide redundancy in case one of the instruments failed. In some wells there maybe multiple zones of ground water flow through the formation. In these locations, multiple vibe wires might be installed to collect data on the different zones.

A Minnesota Well Code variance is required for vibe wire installation. Sealing vibe wires into a borehole presents a challenge to the Minnesota Well Code as it is a relatively new technique and therefore it is not addressed in the code. The Minnesota Health Department (MDH) has been very cooperative in reviewing plans for each proposed installation and has issued variances, which allow them to address their concerns regarding proper installation. The DNR has installed vibe wires at a number of locations in the state and the MDH has provided a variance for each installation. The DNR will need a variance for any additional vibe wire installation and the well sealing activities will not begin before the variance is approved by the MDH.

The ownership of the sealed well with the installed vibe wires does not transfer to the DNR. An access agreement will be developed between the DNR and the land owner for access to the site to collect water levels.

Vibe wire abandonment

While no vibe wires have been abandoned, it maybe necessary to end the use of the vibe wires. The reasons to end measuring the vibe wires might include failure of the equipment, changes in land use, or DNR Waters no longer has well access. Unless otherwise directed by the MDH, the wires shall be cut off at the top of the grout and a minimum four inches of concrete shall be placed over the cut wires. The MDH shall be notified in the change of status of the well.

APPENDIX A
How Vibrating Wire Transducers Work

How vibrating wire transducers work

Vibe wire technology (vibe wires) has been around for many years, having evolved from engineering application where strain gages were buried in embankments or placed within structures. This long history has proven them to be stable and operative over many years of service, a necessary feature if they are going to be used in a sealed-well situation.

The vibrating wire unit consists of a pressure transducer containing the actual vibrating wire and a multi-wire cable that connects the transducer to the controlling and reading apparatus. This latter apparatus can be a data logger, a single readout device, or a computer with appropriate software.

Figure 1 schematically represents the pressure transducer. The heart of this device is the vibrating wire. Steel piano wire is secured, at the cable end, to the body of the transducer; the other end is welded to the center of a pressure sensitive diaphragm. The diaphragm has access to the pore water pressure through a porous filter. An electronic coil assembly is located near the midpoint of and close to the wire. This coil, upon receiving electronic signals from the control apparatus on the other end of the cable, electronically “plucks” the wire. This is accomplished when the activated coil varies the magnetic field, causing the gage wire to vibrate at its resonant frequency. While the wire vibrates, the coil picks up the vibrating signal and transmits it back via the cable to the reading apparatus where it is processed.

Pressure changes on the diaphragm change the tension in the gage wire, causing the wire to vibrate at a different frequency just as a plucked guitar string changes pitch as it is tightened or loosened. At the time of manufacture, each vibe wire transducer is calibrated for its resonant frequencies over a range of pressures.

When vibe wires are placed into an actual application, they are initialized for the ambient water level pressure at that time. Readings taken at a later date reflect the change from that initial water level.

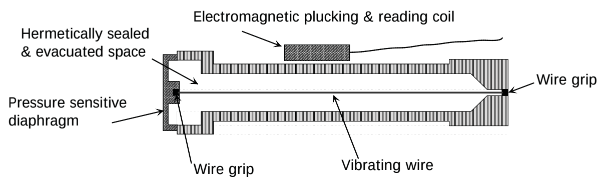


Figure 1. Schematic of vibrating wire transducer.

Appendix B
Specific procedures for vibe wire installation

Installation of the vibe wires transducers
The vibe wire transducer will be placed within a column of sand in that selected section of the borehole. The sand column is isolated within the borehole by neat cement grout below (if necessary) and above The sand column will extend at least five feet below the transducer and five feet above it.

A well variance from the Minnesota Department of Health (MDH) must be obtained prior sealing any vibe wire(s) in a well.

Figure 1 presents a diagram of a typical multiple vibe wire installation. A single vibe wire install would have a similar design. Multiple vibe wires may also be placed in a single aquifer as shown in Figure 2.

Placing the vibe wires requires the following steps:

- If the vibe wire is to be installed near or above the bottom of the well and there is no need to place grout in the bottom of the well, sand should be placed from the bottom of the hole to the level of the first (or deepest) vibe wire depth.
- If grout is necessary in the bottom portion of the well, it should be pumped into the borehole up to the point representing the bottom of the sand column, in which the first vibe wire is to be employed. That grout is allowed to set up solid.
- If the grout is installed, then at least five feet of sand will be placed from the top of the solid grout to the depth of the vibe wire.
- The vibe wire transducer is placed in a cloth bag that is then filled with sand. This gives the transducer weight to help it settle into the well and it protects the transducer from damage during the installation of the sand.
- Holding on to the cable, the vibe wire is suspended in the borehole at the desired depth.
- The vibe wire is calibrated, zeroed, and secured to prevent movement during the remaining work on site.
- Sand is placed into the borehole using a tremie pipe (to avoid abrasion of the vibe wire cables), where the sand will surround the transducer and rise to the planned depth, at least five feet above the vibe wire.
- After the sand has settled, neat cement grout is pumped into the borehole via a tremie pipe.
- If multiple vibe wires are being installed, grout is tremied to the depth of bottom of the next sand layer and allowed to set. The sand and vibe wire at the next interval above will be installed as outlined above. If the distance between the vibe wires is large, (100--150 feet or more), consider placing a five to ten foot cap of grout on the sand, allow that to set up, and then place the remaining grout. This

prevents the excessive pressure of a large column of grout from forcing cement into the sand and ruining the transducer. This continues until the last vibe wire is installed.

- If there is only one vibe wire to be installed, after the sand has settled, neat cement grout is pumped into the borehole via a tremie pipe. If the column of grout to be placed is quite large (100--150 feet or more), consider placing a five to ten foot cap of grout on the sand, allow that to set up, and then place the remaining grout. This prevents the excessive pressure of a large column of grout from forcing cement into the sand and ruining the transducer.

Vibe Wire Calibration

1. Prior to going into the field attach the vibe wire to a datalogger and insure that the transducer works. The pressure and temperature readings should register on the datalogger. If both readings are not present or do not seem correct, there may be a problem with the transducer. Contact the manufacturer for assistance.

2. At the site, unreel the vibe wire and mark every 100 feet on the wire using electrical tape. Mark the final installation depth as well.

3. Open the end of the transducer and fill the space with distilled water. This aids saturation of transducer.

4. Place transducer in bag and fill with sand. Place sand bag and transducer into bucket of water until ready for installation.

5. Measure depth to static water level (SWL) in the well.

6. Measuring from transducer, mark a point on vibe wire cable equal to SWL.

7. Mark a point on the vibe wire cable, e.g. (SWL+15 ft) to suspend the transducer 10 to 15 feet below the SLW.

8. Place transducer into borehole and suspend in 5--10 feet of water for 20--30 minutes (to allow sensor temperature to equilibrate with water temp; this also aids saturation of the transducer).

9. Pull transducer up until it is out of water.

10. Using supplied Linear Gage Factor, set a “field zero”. Identify this config file as “PreInstall” plus a site identifier.

11. Lower transducer into water down to first mark (e.g., SWL+15 ft) and obtain a reading: is it –15.0?

12. Continue to lower transducer to its proper borehole position; take a reading – is it equal to the transducer depth minus the SWL? Configure transducer as normal, getting a new zero reading. Save this new configuration file according to standard naming conventions. The naming convention for vibe wires is:

> The well's MDH Unique number_the transducer's serial number_the depth of the transducer. For example the name for obwell 62041 which is located in the Ironton-Galesville aquifer on the University of Minnesota St. Paul campus would be: 249803_55218_752 (unique number_transducer serial number_depth of transducer).

13. After the well has been sealed and the vibe wires are activated, staff will return to the site with appropriate survey equipment to determine the ground elevation at the site.

In some installations the vibe wires are installed at different depths within a thicker sand layer in a single aquifer. The procedures and installation steps would be the same for such an installation as outlined above. This installation style could be used to provide redundancy in the equipment to provide long-term data collection in the event one of the vibe wires failed or was damaged during installation. A diagram of such an installation is presented in Figure 2.

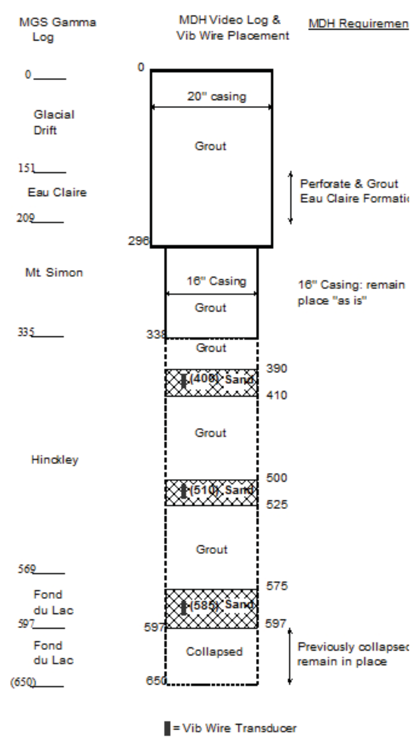


Figure 1. Placement of Vibe Wire Transducers in borehole or well

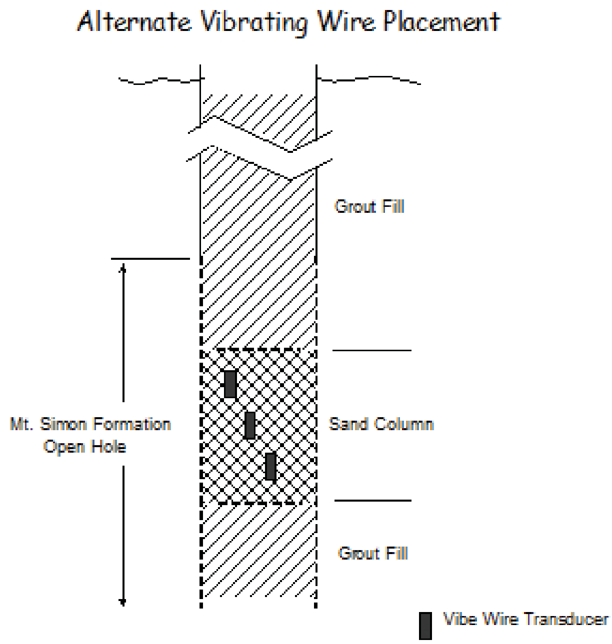


Figure 2. Alternative Placement of Vibe Wire Transducers in borehole or well

Appendix 6.1

DNR Waters Groundwater Level Monitoring Program
Technical Guide
July 14, 2010

Well Construction Methods and Materials

All well construction shall be done in accordance to the current rules and regulations. A qualified professional geologist (PG) should be on-site to supervise all field activities from mobilization through site cleanup. The role of an onsite geologist is multi-faceted; the range of duties varies from a project representative available to answer visitor and stakeholder questions, scientifically observing and recording hydrogeological aspects, and project manager providing on-site recommendations and comments during various stages of drilling and construction.

Numerous drilling methods are available to install obwells. In Minnesota, mud rotary drilling methods are the most common. However, there are a variety of technologies available that offer a variety of options depending upon the geologic conditions and depths anticipated. The selection of drilling methods and materials can be somewhat flexible and can be based upon the borehole depth, aquifer conditions, and other factors as indicated in Table 1:

Table 1 – Well Depth, Methods, and Materials

Observation Well Depth	Drilling Method	Well Diameter	Casing Material
Shallow (< 50 feet)	Hollow Stem Auger, Mud Rotary, Rotary Sonic	2 to 4 inch	PVC or Steel
Mid Drift (50-150 feet)	Hollow Stem Auger, Cable Tool, Mud Rotary, Rotary Sonic, Dual Rotary	2 to 4 inch	Steel
Basal Drift (150 -350 +feet)	Cable Tool, Mud Rotary, Dual Rotary, Rotary Sonic	4 inch or larger	Steel
Bedrock (variable feet)	Cable Tool, Mud Rotary, Dual Rotary, Rotary Sonic	4 inch or larger	Steel

Other drilling methods are also available. However, sample quality and geophysical logging requirements are also very important considerations when selecting the best drilling method. Steel well casing is the preferred material for deeper well installations due to the strength of the materials during well construction, and according to the well code steel casing is required for wells over 50 feet deep and in bedrock in Minnesota.
While a two-inch diameter observation well is often an industry standard for pizeometers, future needs that involve larger monitoring and collection devices should also be considered.

Generally speaking, larger diameter wells are more suitable for collecting water quality samples and for accommodating the variety of devices including pumps; smaller diameter well casings limit the size of instruments that can be installed. Historically, multiple-size well casings have been used for deep drilling by reducing the casing diameter with depth. Also, larger diameter wells generally accommodate and can respond more favorably to well maintenance procedures.

Once the well has been installed, well development procedures are conducted to clear the well of construction fluids and solids. During this development, well contractors make an estimate of specific capacity or well yield by measuring static level, rate of water withdrawal and water level drawdown. Recovery or the rate of water level rise within the well following well development can provide useful hydraulic information.

Each well should be protected. Three steel bollards should surround the well equally distant and 2 feet from the well. Additionally, an outer protective casing should be installed and fitted with a lockable cap. Each well should be completed with a water-tight well cap.

Above ground level well finishing measurements include the following:

Obwell	2 feet above ground level
Pro-top	3 feet above ground level
Bollards	4 feet above ground level

Bidding contracts should include site restoration as a project requirement, including removal of cuttings and other debris and site grading the site to re-establish the original surfaces. Reseeding is generally not done by the drilling contractors, due to the issue of introducing unknown species to the landscape. It is important to review the site restoration aspects with the land managers and other stakeholders so that everyone knows what to expect. Final site closure procedures for the contractor should include re-grading the surface to original slope and drainage, generally smoothing the ruts and bumps. A final site inspection should be conducted during site closure prior to approving final payments.

Appendix 6.2

DNR Waters Groundwater Level Monitoring Program
Technical Guide
July 14, 2010

Observation Well Siting
The process of siting an observation well refers to determining the most suitable observation well location. This technical guide will describe how to proceed with a site review and mark an intended drilling site. This process deserves attention to the following details; mistakes made here can be hazardous, upsetting and costly.

Siting practices have changed over time. Many years ago, small diameter pizeometers were installed by a federal government agency to conduct groundwater investigations. These wells were generally 1.25 inch steel pipe fitted with drive point screens. A smaller drill rig could easily drive into a road right-of-way (ditch) and quickly drill and install a well to the water table (< 30 feet). These wells did not require permission. Unfortunately, many of these wells have simply vanished. Information from site inspections suggests that many were snapped off at ground level by being bent-over, suggesting they were either accidentally hit or intentionally pushed over.

The best observation well locations are near entrances or field approaches to open spaces where impacts to the land can be minimized and the well can be easily seen. For most drilling equipment, about one-quarter acre of open space is adequate to move in, set up and do the drilling and construction work. Publically owned land should be used for observation well sites. Public lands provide a greater likelihood that that the well will stay in place allowing for long-term data collection. Currently, the well siting process is less often placing obwells on private land, unless it is absolutely necessary.
Listed below are a few examples of publicly-owned properties: Wildlife Management Areas, Lake Accesses, Parks, Landfills, Offices, Schools, Garages, Storage areas, and Undeveloped lots.
Once an observation well site or sites that show good potential are selected for consideration, an office review followed by a site visit is needed confirm that the site conforms to the following site details:

- **Ownership**
  Confirm that the ownership status will remain unchanged for the forseeable future and that a complete written access agreement and associated documents are provided, if applicable.
- **Property boundaries**
  Confirm that the site is located within the intended property boundaries. Review property resources and attempt to locate property corners and lines near intended well sites. Positioning of observation well sites needs to consider the current well construction and set back rules. The size of the work area should include consideration of the personnel and equipment anticipated.
- **Well Location**
  The actual spot where the borehole is drilled is marked with a white stake and flagging prior to the utility locate. This location may be refined based upon site conditions and comments from the drilling crew based upon moving their equipment to do the work. The location should be in plain sight and easily seen during entry to the location. Observation wells should not be hidden from plain sight where vandalism could more easily be done. Each site should be clearly marked with a six-foot high white flagged pole as a marker for each intended borehole location. A white marker is the accepted utility indicator for an intended excavation.

- **Target potential**

  Existing information resources need to be reviewed to confirm that the desired target formations are present. A contingency plan should be in place to identify alternate targets, should the targeted formation not be present. This is mainly an issue for glacial targets where formational variations can occur over short distances.

- **Site conditions**

  Utilities must be located and marked prior to beginning work. However, completing a utility clearance is not a guarantee that the location is safe to drill. Other potential hazards may be present that are not covered by a standard utility check. Review of the site history may reveal potential unknown obstacles. This includes former buildings, tile lines and privately own utilities. Drilling contractors are required to contact "Gopher One Call" to have utilities located at least 48 hours prior to beginning drilling.

- **Site Safety**

  Site Safety plans must be prepared for each drilling site. Each plan needs to identify potential hazards and clearly indicate emergency response plans. Weather can often affect outdoor work; close attention needs to be paid at any time of the year. Depending on the season, various animals, insects, and vermin may be present or on the prowl. Dress appropriately, and be aware of your surroundings in case you encounter unexpected visits from animals.

- **Neighbors & Visitors**

  Maintaining good public relations is a must. If a site has neighbors, make an extra effort to talk to them and inform them about the project. Be sure to plan for visitors by having extra safety equipment (e.g., hard hats and safety vests) available onsite for curious people. Sometimes visitors can provide local information that can help hydrologists better understand the history of the site. If a high volume of visitors is expected, fence off a safety zone; however curious they may be, visitors should never be allowed near active on-site equipment. When appropriate, publishing a press release prior to siting events and start of drilling operations can encourage positive relations with the public and program efforts.

As Murphy's Law suggests, it's often the unexpected situation or unplanned-for problem that often happens. The site should be thoroughly walked and inspected. The preparation of site maps using air photos and hand sketch drawings are helpful tools for communication purposes. Detailed site photographs taken from similar perspectives before, during and after construction procedures can provide important documentation of the changes made before and after well construction.

Appendix 6.3

DNR Waters Groundwater Level Monitoring Program
Technical Guide

Measuring Water Levels in DNR Observation Wells

A. Steel (Wetted) Tape Method

1. Determine where the "Measuring Point" (MP) is located on the well. In most cases this will be the top of the free-standing casing. However, there may be circumstances where the MP will be an access plug located elsewhere. Irrigation, or other high capacity, wells often have a plug near the base of the turbine or have an access tube angling off from the turbine base. If in doubt about the location of the MP, do one of two things: check the height of the MP described on the data sheet, it may lead you to the proper location or, call the Obwell Program in St. Paul for clarification.

2. Attaching a weight to the end of the steel tape is optional and should never be done in situations where the well contains any obstructions, including submersible pumps, pitless adapters or turbines.

3. Wipe the steel tape dry and then coat the end with carpenter's chalk. To do this, unreel a portion of tape (5 ft is usually sufficient) and, while holding the reel in one hand, press the chalk against the numbered side of the tape and pull it along toward the free end until the unreeled tape is coated with the light blue chalk.

4. Lower the chalked tape into the well until some of the chalked portion is in water. Continue lowering slowly until a whole-foot mark on the tape is exactly at the measuring point. Record this measurement on the data sheet as "Tape Held". Do not allow the tape to fall past this chosen "hold"; to do so would result in an erroneous reading.

5. Reel up the tape and carefully read the measurement (to the closest hundredth of a foot, 0.00') at the point where the chalk becomes wet and turns to a dark blue color. This is the "Wetted Length" measurement and should be recorded on the data sheet.

6. Subtract the Wetted Length from the Tape Held and record the result on the data sheet as "Depth Below Measuring Point".

Additional Notes:
Refer to past readings to determine where to "hold" the tape in order that the wetted length falls within the chalked portion of the tape.

Use the same Measuring Point for all subsequent water level measurements. If this becomes a problem, contact the Obwell Program in St. Paul.

Use the "Comments" column to report anything that may have affected the water level such as a nearby pumping well, irrigation, drainage of nearby water body, standing water, damage to well, etc. If the well has been damaged, contact the Obwell program as soon as possible.

B. Electronic Tape Method

1. Determine where the “Measuring Point” (MP) is located on the well. In most cases this will be the top of the free-standing casing. However, there may be circumstances where the MP will be an access plug located elsewhere. Irrigation, or other high capacity, wells often have a plug near the base of the turbine or have an access tube angling off from the turbine base. Note in some irrigation or pumping wells the access point may not be large enough to accept an electronic tape. In these situations a steel tape must be used.

If in doubt about the location of the MP, check the height of the MP described on the data sheet, it may lead you to the proper location.

2. Turn the meter on and check that it is functioning. There is usually a test button on the side of the device. When you press it the meter should ring. If it does not, check that the meter is turned on, the sensitivity is turned up (usually a knob on the side of the meter) and that the battery is good.

3. Wipe the steel tape dry and then coat the end with carpenter’s chalk. To do this, unreel a portion of tape (5 ft is usually sufficient) and, while holding the reel in one hand, press the chalk against the numbered side of the tape and pull it along toward the free end until the unreeled tape is coated with the light blue chalk.

For unrestricted wells like obwells, which do not have pitless adapters and submersible pumps with all the associated wiring, an electronic tape is preferable. Ease of operation and ease of recording are the main advantage. The electronic tape we typically use is the Solinst brand but is affectionately called an “M” scope. The electronic tapes have two wires encapsulated and insulated in a plastic sheath or flat scaled tape on the Solinst. The tape is terminated at 0.5” by 7.5” stainless steel sensing element. Approximately 3 inches from the tip of the element is a 0.22 by 0.94 window /opening in the center of which protrudes an electrode. Of the two wires in the tape one is connected to the electrode and the other is connected to the probe. The two wires are electrically isolated from each other until the probe is immersed in water. When the contact is made a this ringing sound will be heard, providing the meter is turned on, the battery is good, and the sensitivity is sufficiently turned up. Dissolved minerals in water is what makes water conductive – soaps, acids, salts all make water conductive to electrical current.

Having the meter turned on and the sensitivity turned up is important for two reasons other than readings. One, the probe is not designed for deep immersion which can force water under the insulating layers and around the probes wiring and cause it to fail, usually at a later date for no apparent reason when you have driven 3 hours to measure a well. The second reason is in case DTW is being measured in a well with a submersible pump. If one is checking DTW without the meter on and set, the probe could and has been lowered to the pickup area of the pump, and if the pump is running or turns on, then the probe is in danger of being ripped off the end of the cable to be ingested by the pump. Sometimes just an obstruction or the wiring or drop-pipe for the pump can cause a problem.

When there is oil in the well from oil drip lubricators on larger above-ground pumps (suspect this with irrigation wells) it is usually best to first use a steel to measure a well and check for oil. At least you know you will get a reading and a steel tape is easier to clean. When submersed through oil the electronic sensor will not work properly when it finally contacts the water since the oil coating is non-conductive and acts like an insulator.