National Groundwater Monitoring Network

Minnesota Department of Natural Resources

Final Report

Cooperative Funding Agreements To Support National Groundwater Monitoring Network Data Providers

Fiscal Year 2017 Program Opportunity
Funding Opportunity G17AC00183

Attachment A

USGS National Ground-Water Monitoring Network Cooperative Agreement
Proposal Information Summary

1.	**Project Title:**	Minnesota Department of Natural Resources Groundwater Monitoring Data Sharing Partnership; Statewide Network, of Minnesota. Minnesota Department of Natural Resources will enable groundwater web services to be updated and connected with NGWMN to add Minnesota's principal aquifers to the NGWMN network.
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4.	**Amount Requested:**	$60,000
5.	**Proposed Start Date:**	August 1, 2017
6.	**Proposed Duration:**	12 Months (Ending October 1, 2018)
7.	**Data Provider Status:**	New Data Provider (Obj. 1)
8.	**Date of Final Report:**	12/17/2018

9. Objectives included in proposal:

Objective 1: Support to become a new data provider or expansion of services/sites by existing data providers.

Overview of Project
Minnesota Department of Natural Resources applied for Funding Opportunity G17AC00183 to become a first year data provider, providing groundwater level data to the USGS National Groundwater Monitoring Network.

Description of Agency
The Minnesota Department of Natural Resources is committed to the protection, preservation, management and sustainable utilization of Minnesota's natural and cultural heritage for current and future generations:

- Conserve and manage the state's natural resources
- Provide outdoor recreation opportunities
- Ensure commercial uses of natural resources function in a way that creates or maintains a sustainable quality of life.
- Work in collaboration with local partners to balance multiple interests and build strong relationships

The Minnesota Department of Natural Resources strives to integrate and sustain the interdependent values of a healthy environment, a thriving economy, and livable communities. DNR's integrated resource management strategy shares stewardship responsibility with citizens and partners to manage for diverse interests. DNR protects the state's natural heritage by conserving the diversity of natural lands, waters, and fish and wildlife that provide the foundation for Minnesota's recreational and natural resource-based economy (M.S. 84, M.S. 97A). DNR manages natural lands such as forests, wetlands, and native prairies; maintains healthy populations of fish and wildlife; and protects rare plant and animal communities throughout the state. DNR also manages the state's water resources, sustaining healthy waterways and ground water resources. DNR supports natural resource-based economies, ensuring the maximum long-term economic return and providing economic opportunities in a manner consistent with sound natural resource conservation and management principles.

The Purpose of Groundwater Level Monitoring
Since 1944, DNR has managed a statewide network of observation wells, also called Obwells. As the state's central groundwater level data resource, the purpose of monitoring these observation wells is to collect baseline data on groundwater level fluctuations and trends, and provide the data for public and professional use.

Well construction, aquifer and water level data from these wells is made accessible through a DNR web output (CGM or Cooperative Groundwater Monitoring). This data is most frequently used by DNR, state or educational institutions, professional consultants and other interested parties to assess groundwater resources, determine long term trends, interpret effects of groundwater use and climate, plan for water conservation, evaluate water conflicts, and manage groundwater resources responsibly. Soil and Water Conservation Districts and volunteers work cooperatively with DNR to measure groundwater levels monthly, providing valuable data on groundwater levels throughout the state.

National aquifers of Cambrian-Ordovician, lower cretaceous and upper carbonate aquifers are equipped with obwells with continuous monitor loggers installed.

DNR is currently working on a major database enhancement to incorporate a substantial amount of privately-collected groundwater level data in the state database. This data is sourced from Appropriation Permit groundwater sites, sites of which concern public/personal/economic

use of water in excess of 10,000 gallons/daily or 1 million gallons/annual. Such entities include municipalities, agricultural users, industrial and commercial use and others. This data will provide DNR with valuable information on the effect, if any, appropriation permit groundwater usage has on groundwater levels. These groundwater sites will not be classified as obwells and data quality coding will demarcate the source of the data.

Description of the Agency's existing monitoring networks
The Minnesota Department of Natural Resources groundwater monitoring network is extensive with a robust database to manage the ongoing collection of data. There is a total of **2,718** groundwater monitoring sites, a figure which increases monthly. The types of wells in the DNR database include:

1. **Observation wells**
    - Dedicated monitoring well, in most instances, for the purposes of groundwater level monitoring. The construction methods, aquifers of measure and locations are extremely diverse.
2. **Appropriation permit sites**
    - Well for the purposes of groundwater appropriations or a well monitoring groundwater appropriations for a permit/within the vicinity of groundwater appropriations.
3. **Wetland piezometers**
    - Hand driven observation wells with casings of 1.25 to 2 inch diameter, no deeper than 15 feet below land surface or 10 feet into mineral soil, for the purpose of measuring water levels in and below unstable soils (e.g. peat, muck).
4. **Other unclassified category wells**
    - Well that is not defined by the descriptions above, or may be a well designated for a special project. Check well remarks

The monitoring schedule and collection of data is a based on the type of well. Observation wells are DNR-installed or acquired wells, maintained by the DNR and measured by DNR or a monitoring partner under a recommended monitoring schedule. Appropriation Permit wells are wells used for water appropriation in excess of 10,000 gallons/daily or 1 million gallons/annual. These sites are measured by the permit holder itself with varying levels of DNR intervention. Wetland wells or piezometers are part of a federal, state, and local wetland protection effort to assess water saturation levels, restoration efforts or otherwise, the health of wetlands. There is particular interest in calcareous fen wells, hence the location of these wells, and these are generally measured by DNR staff. The category of Unclassified Well is sparsely used, often denoting a well that is not classified as either an Observation Well, Appropriation Permit Well or Wetland well, but water level data is stored with DNR. These may also denote a special project well with targeted monitoring and/or purpose-driven monitoring schedules.

Approximately **20-40** new observation wells are installed annually. As of November 2018, **1,086** observation wells are actively measured ***at least*** quarterly. (Typical measurement interval is 8 measurements annually) The oldest observation well (now sealed) with a groundwater level record was completed in **1896.** The oldest **actively** monitored well was completed in **1906.** The earliest groundwater level measurement dates back to **1932.** The longest actively measured obwell has water level records dating spanning from **1945 to current.**

As of December 17, 2018, there is a total of **418,895** hand measurements (field visits/inspections) and **22,726,111** corrected logger data points and **15,931,549** uncorrected logger data points. Note that DNR logs not only water levels but also water temperature,

separate from the aforementioned figure. There are **678** obwells equipped with data loggers with continuous time series groundwater level records.

The type of loggers DNR uses includes OTT/Orpheus Mini loggers with integrated barometric pressure sensors which are replacing In-Situ data loggers, both Rugged Baro-Trolls and Rugged/Level Trolls. DNR ensures that data delivered to the public web out is barometrically corrected, whether field visit or continuously monitored.

The Minnesota Department of Natural Resources is continuously installing and expanding the observation well network. Obwells are selected to address existing and future water supply needs and accordingly, the network is frequently evaluated for compatibility with the program's purpose.

Groundwater level data, measured from observation wells, is collected by Soil and Water Conservation District personnel under contract with DNR, DNR staff itself or other contracted entities. Most wells are measured once a month from June through November and twice during the months of March through May for a total of eight measurements annually. This measurement record documents the water levels during spring recharge, the period of summer appropriation, and expected reduction in use in the fall. Water levels are not collected in the winter when there is little recharge and water use is typically at its lowest levels. For sites where continuous monitoring devices are installed, quarterly field visits are prescribed to reference the logger data to the hand measurement to ensure logging accuracy and equipment function. All water levels reported to the DNR web output is reported as depth below measuring point elevation. Note that DNR is providing the NGWMN with water levels reported from ground surface, in alignment with the USGS preference.

Site Selection Criteria and Process
DNR has over 1,000 actively monitored observation well sites to select from, to provide to the USGS National Groundwater Monitoring Network.

In 2017, as a new data provider to the USGS National Groundwater Monitoring Network, DNR reviewed possible sites for network inclusion based on:

- Site is a dedicated Observation Well, or for the sole purpose of monitoring groundwater levels
- Site is monitored regularly by Soil and Water Conservation District staff or DNR staff
- Geographical position within national and local aquifers
- Meets spatial density requirements within national aquifers of interest
- Site read status, with preference for actively monitored sites
- Types of data provided with preference for sites that have both continuous and discrete data
- Status of wells connection to the aquifer with preference on wells with good connection or recent maintenance; good slug test results

Priority was placed on wells that have a period of record at least a minimum of 5 years.

To perform the site selection process:

1. Active groundwater sites (of observation well type) were queried from PostGreSQL Observation Well Database, with associated well construction, aquifer and period of record data
2. Classification of wells by Subnetwork and Monitoring Categories

    - Most observation wells are considered to be background subnetworks with a mix of trend and surveillance monitoring types.
        - Further analysis on groundwater level data may be considered to determine if there are suspected or documented change subnetworks
        - Most observation wells are "trend" monitored. There are some permit-required monitored observation wells which could be considered surveillance monitored wells, however, these have not been supplied to NGWMN as of yet.
3. **Spatial joins** with groundwater sites and their respective local/national aquifers were performed in ArcMap 10.4.1. This spatial join allowed wells to be appropriately spaced.
4. Review of well metadata, with focus on quality, reviewing construction and aquifer details (Ensuring the most up-to-date construction information/aquifer details were input, comparison between DNR Observation Well database and the County Well Index database)
5. Upload of select sites to the USGS NGWMN Well Registry

The selection of wells for USGS National Groundwater Monitoring Network inclusion was performed by a Hydrologist Supervisor.

Classify sites according to Subnetwork and Monitoring Categories as described in the NGWMN Framework document and Defining the Subnetwork and Defining Monitoring Categories tip sheets.

In 2017, the sites selected to provide data to the USGS NGWMN were predominantly:

- Subnetwork: Background
- Monitoring Category: Surveillance and Trend

As observation wells are dedicated groundwater level monitoring sites monitoring baseline or background groundwater levels, a majority of sites provided to the USGS NGWMN fall into "Background" subnetwork by default. Observation wells are generally not used as water supply sources, are sited in areas to avoid significant drawdown events and not situated near large surface bodies of water.

Observation wells, however, may meet the criteria of "Suspected Changes" and "Documented Changes," especially those of long-term monitoring. Revisions to the well registry subnetwork classification are ongoing as analysis is performed. Observation wells of "Documented Changes" are considered rare given the nature/purpose of observation wells.

Through review, observation wells were classed as either "Surveillance" or "Trend" monitoring categories. There are no "Special Studies Monitoring" wells included with the groundwater sites provided to USGS NGWMN. Observation wells are monitoring frequently by at least, 8 measurements annually, and in the subset of wells provided to the USGS NGWMN, supplemented with continuous data. Wells that were classed as "Surveillance" monitoring wells are generally situated closely to metropolitan centers.

Sites fulfill trend monitoring and surveillance monitoring needs. A majority of sites that can be classified as trend monitor sites will have periods of record at least a decade in length. Surveillance monitor sites are more common in high population areas and closer together in proximity. DNR research has been conducted with many groundwater sites and will be able to identify wells that meet the criteria for various subnetworks that of background conditions, suspected changes and documented changes.

For “Trend” sites, DNR will use database queries of PostgreSQL to focus on a site density of 1 to 8 sites per 1000 square miles in each Principal or Major aquifer. DNR has Nested wells has 214 active nested wells for consideration as “Trend” sites. Area and groundwater monitoring hydrologists will use NGWMN tip sheet criteria to classify sites appropriately for consideration for data sharing with NGWMN.

Surveillance sites can be referenced to a nearby trend site and with DNR’s extensive groundwater monitoring network, a density of 3 to 7 surveillance sites per trend site is possible to reflect local conditions within the aquifer. Area and groundwater monitoring hydrologists will use NGWMN tip sheet criteria to classify sites appropriately for consideration for data sharing with NGWMN. Hydrologist supervisors and division director may assist in identifying sites for data sharing with NGWMN.

In a relatively undeveloped aquifer water levels may vary less spatially, therefore fewer surveillance wells may be required. In a more developed aquifer water levels may be more spatially variable, so more surveillance sites may be required.

Provide required data elements for selected sites. Data is provided either in the Well Registry or through web services. The required data elements are listed and the source of data for each element is described in the Minimum Data Requirements tip sheet.

DNR has fully provided the minimum data elements, as described in the NGWMN “Minimum Data Elements Tip Sheet.”

Data elements are provided by 3 databases, which will be detailed later on in this document.

Data Elements provided by the Well Registry:

- Name of Agency that collects data
- Site Number
- Site Name
- Country
- State
- County
- Latitude (decimal degrees)
- Longitude (decimal degrees)
- Horizontal Datum
- Horizontal Location method
- Horizontal Location Accuracy
- National Aquifer Code
- Local Aquifer Code
- Type of site; Well/Spring
- Confinement Status; Confined/unconfined
- Well Depth
- Well Depth Units
- Land surface altitude with Metadata
- Land Surface Altitude
- Vertical Datum
- Altitude Units
- Altitude Accuracy

- Method of altitude measurement

Data Elements Provided by the County Well Index Database (Web Service Connection)

- Lithology
- Lithology ID
- Description of Lithology of the unit
- Observation Method
- Beginning depth of lithologic unit
- Ending depth of lithologic unit
- Well Depth
- Well Depth Units
- Beginning depth of Screen interval
- Beginning depth of Screen interval
- Screen depth unit of measure
- Screen interval material
- Casing interval
- Casing depth unit of measure
- Casing material

Provided by the Cooperative Groundwater Monitor Database (Web Service Connection)

- Date/Time of water-level measurement
- Depth to Water
- Water-level units
- Method of water-level measurement
- Accuracy of water-level measurement

The DNR Observation Well database already houses nearly all the necessary data elements in the "Minimum Requirements for Candidate Sites." Data that is not available is stored in either the linked County Well Index (MDH) or scanned paper records. Such data is readily available online through the DNR Cooperative Groundwater Monitor website and links to the County Well Index. Some areas of need may include altitude but this may be countered with the provision of Measure Point Elevations as recorded by DNR. Groundwater level coordinator will provide the necessary data elements to Information Technology staff when NGWMN data link is created.

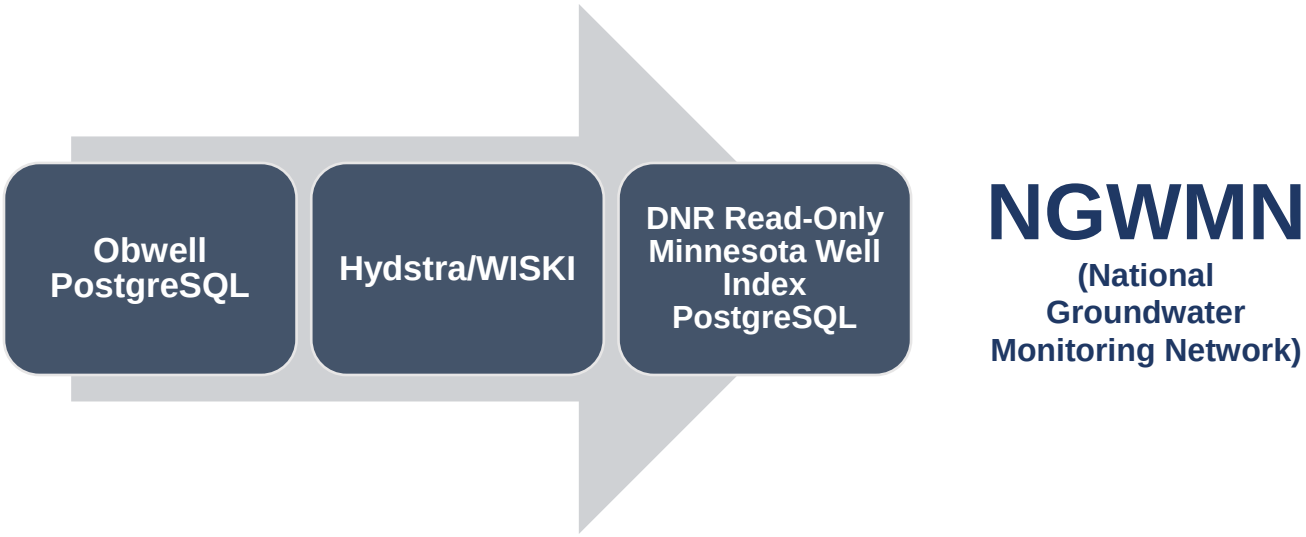
Provide data from agency databases to the NGWMN Portal by creating or repurposing existing web services.

DNR IT infrastructure is continually evolving. Groundwater levels are stored in 2 databases, one that primarily accepts and manages hand measurements and well metadata, while the other concerns time series continuous data, displaying output data and data corrections. The former is the PostGreSQL database while the latter is Hydstra/WISKI.

- DNR will work actively with IT staff in creating and maintaining a continuous flow of accurate and current groundwater level data to the NGWMN. With this data already available in Minnesota's Cooperative Groundwater Monitor, the vital component to the success of this task will be to ensure a link is created.
    - Groundwater level coordinator will establish sites and corresponding metadata into NGWMN portal.
    - Upon the establishment of data sites, MNIT or Minnesota Information Technology staff will establish a live link between DNR databases and the NGWMN network

How the Web Services Connections Operate

iv. IT Infrastructure.



Obwell = Input for discrete/continuous data
Hydstra/WISKI = Where continuous data is corrected, if needed
MWI = Definitive data source of well metadata (of the Minnesota Department of Health)
CGM = Minnesota Web Output for groundwater level data; connected with NGWMN

Note: There is no connection between the MWI and Obwell or Hydstra/WISKI
Obwell and Hydstra/WISKI are connected as data flows one-way from Obwell to WISKI, any data transformation in WISKI does not flow back to Obwell

Four Databases for storing groundwater level and well metadata:

- **Obwell PostgreSQL:** Public facing input for data entry, contracts and storage of discrete measurements/continuous logger files
- **Hydstra/WISKI:** Database for manipulating continuous groundwater level data
- **DNR Read-Only Minnesota Well Index, PostgreSQL**: Necessary for storage of well metadata, construction details and aquifer information. Managed by the Minnesota Department of Health, refreshed for DNR nightly.

Groundwater-level data is managed by the DNR and is stored in both direct DNR server, developed by the agency and a CITRIX cloud-based server, WISKI, which is a database succeeding Hydstra, a predecessor database.

WISKI has provided greater automation of data correction, analysis and tools to better manage groundwater level data. The conclusion of this database migration finished in June 2018. Well construction information is maintained by the Department of Natural Resources and Department of Health in the Minnesota Well Index, a web-based server linked with DNR with DNR retaining paper records.

DNR groundwater level data management system is managed by both PostgreSQL and WISKI. PostgreSQL is an open-source inter-relational database similar to Oracle. The database is stored on a server in the DNR's Central office in St. Paul, Minnesota. The reason for 2 asynchronous databases is due to the need for a data entry portal and database to manage and

manipulate continuous data. As WISKI does not have a public input for partners external to DNR to upload groundwater level data, the PostgreSQL data is necessary for public input and whereas continuous data cannot be manipulated in PostgreSQL, WISKI is necessary for this purpose. Uploading groundwater level data through PostgreSQL, either hand measurements or time series data is automated with a web-based application platform from PostgreSQL for Soil and Water Conservation Districts, DNR staff and water appropriation permit holders.

As data is entered, both continuous and discrete data is reviewed by the groundwater level database manager. Discrete measurements are reviewed in a provisional table space prior to approval for formal entry into the formal hand measurements table in PostgreSQL and then, migrated to WISKI. Continuous data, if submitted by a reliable partner, is generally automatically accepted. If data is being submitted by a new user, data is reviewed prior to data entry by the groundwater level database manager, and then, is entered by the manager directly into the formal table space.

Paper copies and scanned records of field visits/groundwater level readings are stored and provide redundant (or qualitative support, if needed) backup where needed.

With regards to the migration of data from PostgreSQL to WISKI, discrete and continuous data is transferred in a vastly different manner. Discrete data is stored in the PostgreSQL database in an individual table, with a many-to-one relationship, called “OBS”. Continuous data is temporarily (not permanently, like hand measurements) stored in PostgreSQL in a many-to-one relationship table called “TIME_SERIES_MEASUREMENTS” for up to 2 months and then, manually deleted as slowdowns in data entry/migration can occur if excess data remains/input at all at once.

Separately each week, an ArcGIS shapefile is created from an export of the Observation Well Database.

Discrete data is migrated from PostgreSQL to WISKI using a trigger that detects:

1. Edits (modifying data in database with the same primary key)
2. Deletions (deletion of data with an existing primary key)
3. New data (creation of new data with the creation of a new primary key)

For discrete data, any data causing a trigger code will result in a nightly migration at 5:15pm to WISKI from PostgreSQL. Continuous data, on the other hand, upon input in PostgreSQL, is automatically migrated to WISKI at 20 past each hour.

WISKI stores DNR ground and surface water data in this database. This database is a time series or telemetry database management database that stores data in a similar manner to PostgreSQL, with multiple interlinked tables, but is housed in a CITRIX cloud. DNR uses this database to evaluate or correct ground and surface water data as well as the storage of site specific data.

Groundwater level data flows in one direction to the public (Simplified)

1. Groundwater level data (discrete/continuous or new well/changes to well metadata) is entered into PostgreSQL
2. Data migrates to WISKI
    a. Every four hours for well metadata
    b. Every day at 5:15pm for hand measurements
    c. Hourly for continuous data at the 20th minute

3. Data is processed and output to a publically accessible website, the Cooperative Groundwater Monitor (CGM) nightly
    a. Note that the CGM is a PostgreSQL database using AJAX data call prompts, and PERL library scripts to generate the interface
    b. CGM also links with the MWI to provide well construction/aquifer details (not a database link, rather a web referral link)

For each well, a hydrograph of all the water-level measurements is presented, along with date searchable water level measurements, historic changes and a link to the Minnesota Well Index providing construction and lithography details. Information from the well ID number, aquifer type to location details with UTM coordinates information is provided.

Security of these databases is strong. Whether inputting data or performing data corrections, only authorized personnel can perform actions affecting the entry, output or management of data. There are three tiers of user access/data manipulation offered in PostgreSQL.

- Basic users can enter data only and only to specific sites they have been assigned to, with sites being specific observation wells. These users may often comprise Soil and Water Conservation Districts who we work in conjunction with to collect groundwater level data.
- Technical Users may enter data for any groundwater monitor site, with these users generally being Department of Natural Resource employees.
- Super users are able to enter, manage and correct data. There is only 7 personnel with this level of access and these individuals are highly trained to review groundwater data and have substantial database management.

The internal PostgreSQL database is only accessible by IT staff at developer level and one Minnesota Department of Natural Resources employee with considerable database management experience. Total number of staff with access is 5, restricting the potential of unwarranted changes to data. Access is only granted through sufficient training and passing of security clearances.

Similarly, user access to the WISKI database is meritoriously based. Users are classed in similar tiers as the PostgreSQL database, from 1-3 ranking, with 3 indicative of the greatest database influence and 1 indicating entry-level access. Each user, notwithstanding account level, is established a specific account with user id tracking in place, and issued a revolving security token to ensure database security.

Information Technology developers involved with database maintenance include: Greg Massaro, Steve Lime, Wade Gillingham and Tom Hoyne. DNR staff involved with the groundwater level database management include Tim Quan. All the listed staff members have significant experience in database management. Greg Massaro has substantial experience in GIS with a computer science background, who was directly involved with creating the PostgreSQL-based database for DNR groundwater level data. Steve Lime specializes in remote sensing and developing web applications, and manages DNR websites. Wade Gillingham similarly has strong database management experience and manages WISKI for both the DNR and PCA. Tom Hoyne is a high level database administrator for Minnesota Information Technology at the Department of Natural Resources who manages the functioning of the PostgreSQL database. Tim Quan has considerable experience in managing databases and handles groundwater level wells for the DNR. All IT and DNR staff are available on an on call basis and it is anticipated that Greg Massaro and Steve Lime will be devoting their groundwater

database maintenance time to ensuring the link between DNR databases and the NGWMN output.

With regards to future advancements in the next 2-3 years, innovations to data accessibility to the public are expected. DNR is currently considering how best to consolidate the display of climate, groundwater and surface water onto a user-friendly display. As WISKI, is able to provide consistent formatting and is able to merge storage of highly diverse continuous data sets, how best to bring the data together with consideration to human factors and ergonomics through a web output is being studied.

The system of displaying the data itself is similarly a current topic of consideration as for whether DNR will utilize a current KISTERS web product, use database calls to connect data from WISKI to a new web platform or enhance our current web outputs (Cooperative Groundwater Monitoring/Cooperative Stream Gauging) to accommodate the greater database capabilities/data. The decision between the three options will be based on the system that can provide the best quality, efficiency of data updates and agility of changes when needed.

The retention of the CGM is believed to be beneficial to the facilitation and maintenance of a data link with the NGWMN website.

Originally, data was to be sourced from the WISKI database directly. WISKI is the authoritative source of discrete and continuous groundwater level data, and has some of the necessary metadata about groundwater sites to be supplied to the NGWMN. However, due to numerous technical faults with the implementation and operation of WISKI, it was determined that data should be sourced from the Cooperative Groundwater Monitor (CGM) Website itself where similar data transformations can be performed to meet NGWMN requirements.

To accomplish this task (web services connection), six new tables were created in the PostgreSQL database that houses data to be displayed on the CGM.

1. Daily Depth to Water
2. MV Construction Data
3. MV Logger Water Level Data
4. MV Manual Water Level Data
5. MV Stratigraphy Data
6. Wells

Operation of Data Transformations

Note: Essentially, all DNR groundwater sites with logger data are delivered to the NGWMN from the CGM.

- **a.** Only when a Minnesota groundwater site is added to the NGWMN well registry using the MDH Unique Number, which acts as the primary key, a database trigger in the CGM is activated and data is then sent daily at the end of the day to the NGWMN

1. Discrete and Continuous groundwater level data is entered by both internal DNR-employees and external (contracted) groundwater level professionals through a web application of the Observation Well Database (PostGreSQL)

2. Discrete groundwater level data is migrated to WISKI/Hydstra on a daily scheduled occurrence and continuous groundwater level data is migrated hourly.

3. Updates, including the addition of new groundwater monitoring sites and changes to metadata regarding current groundwater monitoring sites are done in the Observation Well Database. Data is also updated in the County Well Index, with changes reflected typically within a week of notification to the database administrator.
    a. Updates to well metadata is reflected in the NGWMN well registry OR well construction web services, generally within a week.
4. As of the current time, once data is migrated to WISKI/Hydstra, data is updated on the Cooperative Groundwater Monitoring (CGM) website nightly.
5. Once within the Cooperative Groundwater Monitoring website, for the National Groundwater Monitoring Network purposes, data from primary CGM tables goes into **six sub-tables.**

Six sub-tables for data transformations in CGM:

a. **Daily Depth to Water (Direct NGWMN Export Table)**
    i. This is a conversion of **hourly** continuous data to daily averaged continuous data.
        1. Daily Average Continuous Data from Measuring Point is converted into Daily Averaged Depth-to-Water, below ground surface in this table
    ii. This table has a “SET” and “UPDATE” execution query to automatically subtract the groundwater level elevations from the measuring point elevation, which, in turn, has had the “height above ground” or well protrusion height above ground subtracted from the elevation.
    iii. Continuous data is transferred from the table of “MV Logger Water Level Data” in hourly increments and calculated into daily averages. Originally, it was intended that Minnesota Department of Natural Resources exports this data to the NGWMN in original hourly format but to reduce the data storage burden on the NGWMN databases and after discussion with USGS staff, it was decided that DNR exports this data after a data transformation was performed.
        1. Daily averaged continuous data is calculated by:
            a. Determining that a daily average is only calculated when there are at least 24 hours of data in a day; once this is determined, a daily average is created. If there are fewer than 24 measurements in a continuous logger reading for any given day, no average is calculated for the day.

b. **MV Construction Data (Direct NGWMN Export Table)**
    i. This is a filter of the County Well Index well construction details, based on the Subset of NGWMN wells
    ii. The filter of NGWMN wells is created when there is a match between the “Wells” MDH Unique Number sub-table (below) and a match in the CWI wells construction table

c. **MV Logger Water Level Data (Temporary Storage Table)**
    i. Filter of continuous groundwater level data based on subset of NGWMN wells, sourced from Hydstra. Filter is activated when a well is selected for inclusion with NGWMN.
    ii. Continuous groundwater level data exported from Hydstra comes in the form of groundwater level elevations and is converted to Depth-to-

Water below measuring point in this table using “UPDATE” and “SET” execution scripts.

d. MV Manual Water Level Data (Direct NGWMN Export Table)

i. This is a filter of discrete (hand measured) groundwater level data based on the subset of NGWMN wells, sourced from Hydstra.

ii. Measuring points above ground

e. MV Stratigraphy Data (Direct NGWMN Export Table)

i. This is a filter of CWI well stratigraphy data based on the subset of NGWMN wells that exist in the “Wells” table

f. Wells (Direct NGWMN Export Table)

i. This is a table of groundwater sites, selected to be provided to the NGWMN, identified by MDH Unique Number (ID Number). This contains only the ID number, name of well and latitude and longitude coordinates.

Description of Web Services Used or Installed for the NGWMN

The CGM web output uses Perl Scripts to provide services for the client-side applications to consume. Perl Scripts are the transmission for data flowing from the Observation Well database and WISKI to the CGM. MapServer takes well location information and creates the Map displays. When a site is searched for or filtered, “AJAX” is used to identify the site in the database. CGM essentially relies on only a couple of services - a sites service that provides metadata for all CGM sites (Perl Scripts) and then a site detail service that allows access to time series information. Finally, a publishing service called “GetCapabilities” is utilized for outputting Excel and CSV data when data is downloaded.

Using the same scripts, data is then transferred to the USGS NGWMN in XML format for consumption. XML files are created and issued to the NGWMN by means of a “GetCapabilities” service request that combines daily averaged logger data, manual water level data, stratigraphy data and construction data into 1 combined XML export to NGWMN. This reduces the data transit time and data processing needed.

Finally, the output is in Geography Markup language (GML). GML (an XML profile) is standard with the OGC service standards. This is also what USGS has already been consuming from DNR Obwell-based WFS for many years.

Data from the CGM is migrated to the NGWMN on a nightly basis. In the case where a new site is established, the site needs to be established in the CGM first and then, well metadata uploaded to the NGWMN Well Registry. Wells in the CGM are fetched to NGWMN based on concurrent site establishment. Technically, the entirety of CGM groundwater level data could be exported to NGWMN with this data service in place, however, a safe guard of concurrent site establishment in both CGM and NGWMN prevents the overload of data being transmitted.

DNR groundwater level website, the Cooperative Groundwater Monitor (CGM) has set a standard as to what DNR can provide to the public. The CGM is improved on a continuous basis. A connection between the CGM and NGWMN site will be established and maintained with the successful outcome of this grant. The CGM already fulfills nearly all NGWMN web services requirements. With substantial information on groundwater level details, searchable by site, water level data distinguished by hand measurement and logger data and construction details, the public has unencumbered access to significant quality data. Furthermore, groundwater level data is downloadable by site from the CGM in both CSV and Excel format.

DNR CGM meets nearly all these requirements found on the “Tip Sheet on Developing Web Services for the Network” below

DNR has set-up separate services for:

- Water Levels
- Lithology
- Construction (screens and casings)
- Data is publicly accessible (no authentication required)

DNR has provided capacity to:

- Allow for wells to be searchable by the unique site_no used in the well registry
    - All wells provided to NGWMN are identified by the Minnesota Unique Well Number. This is a unique number assigned to each well in the State (regardless of type) by the MDH. These wells also have an associated DNR-specific identification number that identifies the county where the well is located and sequence of adoption into the network.
- DNR has returned all the minimum data elements (see Minimum Data Elements Tip Sheet)
- There are no sites that do not meet requirements in Table 4.5.1.1 and/or 4.5.2.1 of the Framework Document.

Finances and Performance

Of the $60,000 USGS NGWMN award for Objective 1. 2017, DNR spent $9,113.73 of that amount and $50,886.27 is to be returned to USGS. The efficient use of funds is noteworthy and attributable to the skills of DNR IT staff, good communication between IT staff and the groundwater level database manager and the scripts that were pre-written by the DNR IT staff and groundwater level database manager in partnership.

Note that albeit, DNR IT staff were able to leverage some of the NGWMN Pilot web service scripts last used in 2011, the entirety of the data transmission scripts were redesigned to accommodate the change in web connections, particularly to accommodate the enormously greater amount of metadata flowing to NGWMN.

Brief description of DNR field practices:

Conducting Groundwater Level Measurement using Steel Tape

The steel tape DNR typically uses is made by a company called Lufkin and can only be purchased in large batches by special order, with the longest tape length being 500 feet.

- The tape is ¼ inch wide tempered steel with raised letters. Raised letters provides ease of reading and the improved ability to hold chalk. Steel tapes are considerable in weight thus accordingly, DNR protocol dictates the correct tape for the wells to be measured be used by thorough research of the well prior to measurement. Distance to water and well depth are considered during pre-measurement research.

1. Determine where "Measuring Point" (MP) is located on the well, generally indicated by a demarcation. Typically, 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 question 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 to the proper location or, call the Groundwater Level Database Manager in St. Paul for clarification.

    a. 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.
2. Chalk enough tape to exceed the expected DTW with 5 feet typically sufficient. Tapes often get wet above the water level, e.g. due to condensation in the well casing. If this is not noticed and dried off, the next reading could be impaired, and additionally, make it more difficult to re-chalk as a wet tape will not hold the chalk effectively.
    - Cold weather is usually the most difficult time to use a steel tape because color change is less evident when the water on the tape freezes and the freezing water is hard to remove from the tape. When possible, take two tapes along when it is below freezing and leave one on the dash to dry while the other is used. 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.
3. 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.
4. 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.
5. Subtract the Wetted Length from the Tape Held and record the result on the data sheet as "Depth Below Measuring Point".
    a. 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. Data accuracy to the 0.01 foot is possible with this method of measurement.

Electronic Tape Method

The DTW meter DNR typically uses is the Solinst brand. The electronic DTW meters 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 chime will sound, providing the meter is turned on, the battery is good, and the sensitivity is sufficiently turned up.

Note: Dissolved minerals in water 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. 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. An obstruction or the wiring or drop-pipe for the pump can cause a problem.

Instructions for Recording Measurements with Electric Tape:

1. Before each field trip, calibrate the tape. Do not adjust the sensitivity dial after calibration, keep turned on.
2. Locate the well and the measuring point.
3. If there is a black mark or indicated cut, use that point every time.
    a. If there is no mark, use the north side of the well casing.
4. The measuring point may be the top of the inner casing (if there is one), the top of the casing (if no inner casing), the top of a vent pipe, or the top of the access port.
5. Using calibrated tape, check that it is working and clean.
6. Lower tape down the well
7. When light comes on and/or you hear the chime or the needle of the meter moves, stop and take measurement
8. Take measurement by holding tape to the measuring point (see photo below)
9. Record this value as the hold.
10. Repeat measurement to ensure measurement technique consistency. A reading is verified if:
    a. 2 measurements are within 0.02' of each other. Note if conditions are changing during inspection; if one cannot get the same value in relatively the same timespan (e.g. five minutes) stay for a 5-15 minutes longer to capture this change as thoroughly as possible.

Data Management Practices

Groundwater data is actively reviewed for completeness, accuracy and detail, if necessary. The groundwater level coordinator plays a forefront role in data review activities as well as DNR staff who play significant roles in quality checks and peer-review.

Provisional Data Submissions

The stage of provisional data submission occurs when data is first input into the PostgreSQL database through the web application input. DNR staff and Soil and Water Conservation District partners may enter observations, which may come in the form of hand measurements and continuous time series data.

Data Evaluation

- Hand Measurements are checked for quality; comparisons between tape held and wetted length are considered
- Time of measurements must be accurate to the minute.
- Measurement times before 7:00am CST and times after 6:00pm CST may result in further inquiry.
- Depth to water is compared with historic measurements. If depth to water is greater than 10 feet from last monthly measurement or differing significantly from previous year's measurement of the same month, inquiry may be initiated.
- Measurement values are quality checked for tape held and wetted length.
- Comments are required where there are extenuating circumstances preventing "normal" read status or otherwise, the collection of a measurement. Some of these conditions may include a flowing well, ice or unreadable due to obstacles that impede the collection of a measurement. Values for these conditions are not to be recorded thus not to skew the hydrograph.
- Comments also required for special circumstances that may describe unusual water level trends such as exceptionally high or low water from historic records.

Data Entry into Database

Once groundwater level measurements have been reviewed for data quality, data is stored in the PostgreSQL database as an approved observation and data is copied over to the Hydstra database, and output onto the CGM within 24 hours.

Time Series Data is similarly quality checked, albeit in a different manner.

- Logger/pressure transducer installed are programmed to take hourly water level readings
- Hand measurements are taken with either a steel tape, or an electronic tape from a known measuring point to calibrate the logger in the field, if needed
- Logger data is downloaded quarterly and hand measurements, typically using Electric Tapes, are performed at time of logger download to ensure logger data accuracy and inspect for electronic drift
- Data from loggers come in the form of CSV files and are uploaded to Observation Well Database web input and then imported to Hydstra on an hourly basis.
- Groundwater level coordinator will review the logger data and ensure all measurements entered Hydstra and values are correctly recorded in CSV with depth to water, both non and barometrically-corrected correctly categorized, water temperature in Celsius and air temperature, if any.
    - Corrupted files are further investigated for errors and partners notified.
- All data corrections are handled in Hydstra.

Types of Data Collected by Loggers include:

- Depth to Water from MP Baro Correct (feet) – Corrected; the file with corrections
- Water Temperature (degrees Celsius) – Corrected; removed spikes and coded 25-Quality unknown

Steps to Correcting Data

1. Confirm that all data is accounted for (Review of data starts at end of archive and end of record should be same for all data types)
2. Trace reference time series data with hand measurements
3. Check for any signs of electronic drift
    1. Dates and amounts drifted are specified and accurate, and notes recorded
    2. Drift corrections are reasonable when identifying logger resets and site visits
    3. All hand measurements are addressed with comments
    4. Field sheets or notes are reviewed to ensure extenuating circumstances affecting groundwater level measurements are accounted for
4. Check quality codes based off of delta drift and spikes are examined, and removed, if necessary
5. Adjust DST/CST needs as specified by the data manager
6. Data is peer-reviewed once corrections are concluded.