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"Oklahoma NGWMN Round III Final Report"

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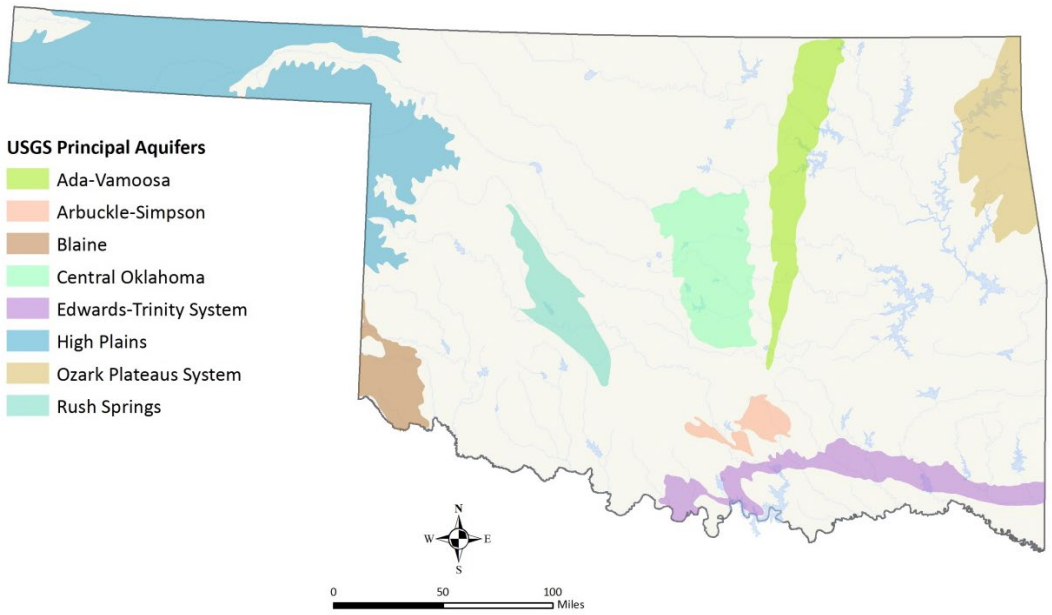
Background

The Oklahoma Water Resources Board (OWRB) has historically maintained an annual groundwater level measurement program which began in the 1950s with an expansion in the 1970s. This annual measurement program has varied in size but has continued uninterrupted since its inception, mainly informing drought monitoring in the state and allocation of water rights. USGS Principal Aquifers that have been historically monitored include the Ada-Vamoosa (began in 1995), Arbuckle Simpson (began 1994), Blaine (began 1950), Central Oklahoma (began 1977), High Plains (began 1966), Rush Springs (began 1976), and Trinity (began 1981) Aquifers. The Principal Aquifers within Oklahoma can be seen in Figure 1.



In 2013, OWRB established the Groundwater Monitoring and Assessment Program (GMAP) with the aim of fully quantifying the states groundwater resources, characterizing the ambient water quality, and determining quality and quantity trends. To this end, the spatial density in the annual water level trend network was significantly improved (one quantity site per 50-100 km^2) and the state's existing continuous recorder network was expanded across the state's major aquifers (33 sites) including all of the Principal Aquifers (20 sites). These are all equipped with hourly recording data loggers with data currently transferred through manual download. This frequency of data recording is sufficient to satisfy the NGWMN's minimum density goal of 1 site per 1,000 mi^2. A smaller seasonal water level trend sub-network measuring wells three times per year was also implemented to recognize seasonal changes, changes due to climate, and/or changes due to usage over time. Once the OWRB trend water level sites (manually measured three times per year) are added to the NGWMN, the density goals for the NGWMN trend network based on usage and development of the Principal Aquifers will be met. Likewise, when added, the OWRB's annual water level sites should be able to fulfill density goals for the NGWMN surveillance network.

Lastly, a statewide ambient water quality monitoring network was added where the well density goal was one quality site per 100-150 km^2 depending on the spatial extent of the aquifer. This expansion occurred throughout a baseline assessment period (2013-2018) where each aquifer was characterized in turn. These baseline evaluations were completed for the Ada-Vamoosa (2014), the Arbuckle Simpson (2015), the Central Oklahoma (2014), the southern non-Panhandle portion of the High Plains (2013), the Rush Springs (2013), the Trinity (2015), the High Plains Ogallala-Panhandle Region (2016), the Ozarks Plateaus (2017), and the Blaine (2019) aquifers.

In spring 2019 OWRB began implementing a trend water quality network composed of around 300 wells, of which approximately 190 are located within Principal Aquifers. Many of these wells originated from the baseline network. The GMAP sampling frequency is once every three years except for the High Plains aquifer which is sampled once every five years, and the Arbuckle-Simpson aquifer which is sampled annually (except in 2020 due to COVID-19 related delays). Data from this network derived from Principal Aquifers is being made available over time to the NGWMN. Although the Blaine aquifer was sampled for water quality in 2019 there are currently no plans to sample the Blaine in an ongoing manner. Also, at this current time there are no plans to re-sample the Ozarks Plateaus system, due to a lack of accessible wells.

The OWRB began the process of becoming a data provider to the NGWMN in January 2016 with a one-year grant to provide data from the continuous water level network. Through a Round II grant (2017-2018), the OWRB established a connection with the USGS data portal via web-services with continuous recorder water-level data housed and managed in Aquatic Informatics' Aquarius Time-Series software (Aquarius) and lithologic and well construction data housed in the OWRBs Oracle Well Drillers database. OWRB is currently providing daily average values from Aquarius for all 20 continuous sites in the network (see Task 3 for updates).

This 2018 grant has allowed significant expansion of OWRB capabilities as a data provider including the development of web-services to begin providing discrete water levels and water quality data to the network. Discrete water-level and water quality data are housed in the Ambient Water Quality Monitoring System (AWQMS) which is also in use by at least seven other states and roughly seventy tribes. AWQMS enforces WQX schema and data requirements that sufficiently meet the minimum data requirements of the NGWMN and can currently distribute both water level and water quality data via web-services (water quality and water level services were one combined service). However, the scope of construction and lithology information that AWQMS could store required expansion and web services needed to be developed to provide those data to the network.

OWRB also has a 2019 grant which prioritizes work in the High Plains Aquifer, specifically adding new wells, filling in gaps in construction details and performing slug tests. Our 2020 grant prioritizes adding new wells to the network, filling in metadata gaps, ensuring well-aquifer connectivity in various aquifers and drilling a small number of wells in the Rush Springs aquifer.

The scope of work for this project included:

Task 1) Developing the ability of AWQMS to house discrete groundwater data including critical metadata, lithology, and construction details. Connecting this database to the NGWMN by developing separate webservices for water levels, lithology, and construction details.

Task 2) Adding 200 water level and 120 water quality sites into the well registry with corresponding metadata. Selected sites were to be reviewed for data completeness (relative to minimum data element requirements) and then classified by sub-network prior to well registration.

Task 3) Continuing the existing relationship with OMES-IT to maintain the Aquarius database and support data services associated with continuous water level sites and their related well construction and lithology in the OWRBs Oracle Well Drillers database.

Task 4) Providing missing metadata for ten of the existing continuous water level sites that have missing or incomplete well construction information. This was to be accomplished through down hold camera surveys to inspect interior well conditions and locate screen/slotted intervals.

Task 5) Performing pump and or slug tests to evaluate connectivity between well screens/boreholes with the adjacent aquifer for the existing sites.

Task 1: AWQMS Development and Discrete Data flows

Through this project, AWQMS has undergone significant development towards improving its ability to manage groundwater related data. Development goals included creating or expanding numerous monitoring location (well/spring) data domains providing storage for construction, lithology, and general informational data. A few specific examples include new tables for screen information (depths, materials, sizes, etc.) and lithology (depths, material, descriptions, and observation method). These tables will be accessible from each Monitoring Location page in the system and, to maintain system functioning, have been integrated with all data import and export tools.

Goals also included development of webservices for water level & quality, construction, and lithology data so that these can flow to the NGWMN. Most of this development is complete although at the end of this project a few domain value lists still needed to be completed in the system. A crosswalk of webservice domains was completed by the USGS staff in early December 2020. Release of the new developments is expected to occur with version 8.0 of AWQMS in early 2021. The initial release will be to all states, tribes, and other users who utilize the cloud-based version of AWQMS. Shortly after, a second release will be made available to all states maintaining individual state hosted versions of AWQMS. In April 2020 OWRB successfully migrated its data to the cloud version of AWQMS and so will be part of the initial release in early 2021. At that time, all OWRB sites in the NGWMN Well Registry will be made visible and discrete water quality and water level data should begin to flow to the network. Once this work is completed, AWQMS will serve to provide all lithologic and construction information for all water level and all water quality sites in Oklahoma's network. These services will also be available to all other states, tribes, and data networks who utilize AWQMS at no additional cost to them other than their regular maintenance fees.

An additional benefit of working with Gold Systems (the developers of AWQMS) is that we were able to advise on other groundwater related development of AWQMS as it was being performed through other projects. As a result, we were able to make general improvements to groundwater data management within AWQMS. These improvements included integrating various domains into query tools such as screen intervals, well depths and well formation types. These are all now searchable within AWQMS. Other metadata such as landowner information were also included through this process. It is hoped that these improvements will make AWQMS an all-round better tool for groundwater data management, potentially increasing its utilization in this capacity with more states and tribes gaining access to this off the shelf mechanism of flowing data to the NGWMN.

Task 2: Addition of New Sites to the NGWMN

A major goal of this project was to add 200 water level and 120 water quality sites into the well registry with corresponding metadata. Selected sites were reviewed for data completeness (relative to minimum data element requirements) and then classified by sub-network prior to well registration. The selection and designation of sites was performed by Mark Belden prior to his retirement in March 2020 utilizing his experience of both the NGWMN requirements and his over 40 years' experience with Oklahoma's groundwater. All methods for site selection, field techniques, data quality assurance processes, and data storage outlined in OWRB's initial new data provider document (G16AC00020, submitted 3/2017) were adhered to while selecting and providing all additional sites for this grant.

All minimum data elements were met for all new wells. However, through the selection process there were many wells that were identified as having incomplete records for well construction details and lithology records. These wells have been included in the Well Registry under the 'Special' well types until manual work can be done to complete the well records. In the vast majority of cases, these well records are incomplete due to the incomplete filing of a well record by the well driller themselves, or because the well predates the requirement for a well log to be submitted for new well construction. In the case that a complete well log does not exist, long term water level data predating the implementation of GMAP, has previously been used to confirm the connectivity and representativeness of this well to the aquifer of interest. Most water quality sites have also been sampled during the statewide baseline period and shown to be representative of the aquifer specific water quality.

Future work planned to remedy these data gaps include slug testing and downhole camera work to investigate or confirm aquifer connectivity, casing, screen, and lithology details. Some of this work has already been approved through Round IV (2019) and Round V (2020) NGWMN grants (G19AC00273 and G20AC00385) through the USGS and is expected to take place over the next 1.5 years. Upon completion, these metadata will be updated in OWRB databases and therefore available to the USGS web services. Additional work will be carried out through state funded projects. No matter its source, all data updated to AWQMS for NGWMN wells will become available to the network through webservices.

Task 3: Support of Ongoing Data Services

OWRB's continuous data system is well established with continuous water level, lithology, and construction details flowing to the network via webservices. The development of the webservices was completed by the state's Office of Management and Enterprise Services (OMES) who provide most information technology related services to the state. This development has suffered from issues including poor responsiveness of OMES staff, inability to bill for work and timing of deliverables. Services were eventually established and these issues were documented in previous reports. At the time, OWRB had no choice but to contract with OMES who maintained the relevant systems and servers.

The original systems were designed to only allow web service calls for specific sites as they were added to the network. This has required work each time new sites were added to the well registry so that web service calls could penetrate the OMES/OWRB firewalls. This poor design choice was remedied by opening up the webservices and related servers/firewalls so that any site could be called by its ID without performing additional work each time a site was added.

To limit the needed involvement of OMES in future data flows, both Aquarius and AWQMS have been migrated to cloud based deployments over the course of this grant. The systems are now maintained by Aquatic Informatics (Aquarius) and Gold Systems (AWQMS) directly. Additional maintenance work was required from OMES to alter the target of the web service calls from the state hosted version of Aquarius to the cloud-based version. It was hoped that the move to the cloud version of Aquarius would remove many of the previous issues encountered when dealing with OMES.

During a routine quality assurance check of data flows made by USGS staff, it was noticed that some continuous water level data were missing from the NGWMN portal. This was found to be a naming issue with the characteristic (parameter name) in the Aquarius Time Series database not matching up with the web service call for a couple of sites. The issue was readily resolved and added in as a step in future quality assurance checks. However, during investigation of these issues, OWRB staff realized that the water level web services were not functioning properly, and that hourly data were being sent to the network instead of daily mean data. Moreover, the data were labeled with the same hourly timestamp. The original web services were constructed to pull the hourly water level data from Aquarius, calculate daily mean, and then provide that to the network when called. To the knowledge of staff currently working on the project, it is unclear why the OMES developers constructed them in that way when such a calculation is easily achieved in Aquarius and the Aquarius calculated daily mean data could have been pulled directly. OWRB now has calculated daily mean data series in Aquarius for each continuous data well and has a break-fix ticket in with OMES to repair the issue. The technicians working on the problem altered the web services code to pull the new daily mean data but are having issues deploying the code due to permissions issues on the servers. This issue has now been escalated to the senior administrative levels of OWRB and OMES and it is hoped a fix will soon be available. In case a fix is not achieved soon, OWRB staff have begun investigating if the NGWMN could utilize the API's inherent in Aquarius to pull the daily mean data directly. If this is possible, it would remove the last dependency on OMES. Although the lithology and construction part of the web services are currently working, that service will also

be moved over to AWQMS once those new web services are deployed in early 2021. The existing web services will remain as a backup in case needed.

Task 4: Provision of Missing Metadata

A downhole camera was purchased, and, over the course of this project, staff trained in its use. Downhole camera surveys were conducted on ten of the existing continuous water level sites that had missing or incomplete well construction information. Interior well conditions and location of screen/slotted intervals were noted. These data have been updated to OWRB's Well Drillers database and are available to the NGWMN through web services. These data will also be updated to AWQMS once the new updates are released so that data can be pulled from either system. Notable surveys include wells 9202 (Texhoma) and 9074 (Knowles), both of which are old USGS steel observation wells. These wells exhibited evidence of screen obstructions (rusting or calcification). In the case of Texhoma, there were two obstructions and the second of these prevented observations of the bottom of the last screen. These wells were also evaluated for connectivity to the aquifer and will be further discussed under Task 5. In the future, any continuous data wells added to the OWRB network or NGWMN with missing metadata will be surveyed prior to inclusion.

Task 5: Evaluation of Well-Aquifer Connectivity

During this project, three members of staff were sent for training in slug test methodology and trained in the use of Aqtesolv. Single well slug tests were performed on all recorder sites in the network during 2018-2020. Most wells performed as expected with four notable exceptions. Unfortunately, three of these are the High Plains Aquifer (Ogallala Panhandle) wells in the network: 9202 (Texhoma), 9074 (Knowles), and 9708 (Guymon). All three wells performed poorly during slug testing and demonstrated a lack of connectivity. The Guymon well was the only well that even partially recovered from the slug test and it took several hours to do so. All three wells will be made non-visible in the Well Registry until a course of action can be determined with the wells either being replaced or investigated for rehabilitation. It is currently unclear when the wells became so poorly connected to the aquifer, but the available time-series data are being investigated.

The 2019 NGWMN grant prioritizes work in the High Plains region and OWRB is actively seeking wells that could either act as replacements for the existing wells or as new wells to expand the continuous (and discrete) network in this critical aquifer. Additionally, OWRB has recently begun a twenty-year update of the High Plains aquifer with a synoptic measurement due to take place in March 2021. The total number of target wells for the update will be more than 500 with 375 in the Panhandle region. This includes OWRBs annual and seasonal networks plus many new wells or wells previously dropped from the network due to being in excess of the desired spatial density. It is hoped that this pool will yield suitable wells for inclusion in the continuous network. We are also reaching out to many landowners and other stakeholders in the region to build upon existing partnerships to gain new sites. OWRB hope to add at least three continuous sites to the network but the greatest hurdle may be the high proportion of

active irrigation wells in that part of the state. Those wells lend themselves to water quality work and annual water level measurements, but are a problem for locating continuous sites.

Additional Information

Over the last twelve months there have been significant changes in both project and administrative staff at OWRB and our representatives for the NGWMN have changed. Mark Belden and Kyle Mattingly have both left OWRB with Chris Adams and Margarita Mendivelso replacing them as Groundwater Monitoring Coordinator and Groundwater Data Manager respectively. Margarita also replaced Sarah Yepez as the Groundwater Quality Assurance Manager. Chris Adams and Margarita Mendivelso will act as joint project managers for the remaining 2019 and 2020 NGWMN projects.

Additional project staff changes include Jet Stine replacing Chris Adams as OWRB Data and Quality Assurance Manager. LeAnna Kilhoffer moved internally from being the NGWMN projects GIS specialist and being replaced by Anthony Huey.

To provide ongoing resilience in the levels of staff knowledge, Anthony Huey, Zachary McKinney (another new Groundwater Environmental Specialist), and other agency level data management staff are being trained in all parts of the data management required for Oklahoma's participation in the NGWMN program.

Administrative staff changes include the OWRB Financial Manager, Leslie Nance, who oversaw all billing and project finances. Kelly Marsh recently replaced her with regard to project related finances for all USGS grants.

Summary

Updates and development of AWQMS is almost complete with deployment of the new updates expected in early 2021 with the release of AWQMS 8. This should not only allow Oklahoma to flow discrete water quality and water level data to the NGWMN but hopefully several other states and tribes as well.

Under Task 2 Oklahoma successfully added a few hundred sites to the network but they will only be made visible with the AWQMS updates.

The maintenance of existing connections under Task 3 suffered from continued issues related to delays with OMES, specifically the continuous water level data being provided as hourly data with a daily timestamp. It is hoped that these issues can soon be resolved but, as a backup, work is continuing to limit the involvement of OMES in all future data flows. This work has already seen successes with both Aquarius and AWQMS being moved to cloud-based systems during this grant period.

Tasks 4 and 5 identified a small number of wells that need either replacing or rehabilitation. These options will be investigated over the first half of 2021. If replacement wells can be identified, they will be added to the network ASAP. Future work will ensure that new

continuous wells are performing well and have all available metadata before inclusion in the networks.

Many staffing changes have occurred at OWRB over the last year and, although this has provided many challenges, we are hopeful that it can provide new opportunities as well. Specifically, we will be working more closely with our Planning and Management Division to coordinate data flows, collaborate on technical work, and make our data as available as possible. We will also be looking to expand our continuous water level network and begin connecting our existing sites with telemetry. We will also be reaching out to the NGWMN to see if we might be able to better align Oklahoma's programs with the long-term goals and priorities of the network.