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Oklahoma Water Resources Board

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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 and expanded in the 1970s. This annual measurement program has varied in size but has continued uninterrupted since its inception, primarily informing the allocation of water rights and enabling basic post-drought monitoring. USGS Principal Aquifers that have been historically monitored include the Ada-Vamoosa (since 1995), Arbuckle Simpson (since 1994), Blaine (since 1950), Central Oklahoma (since 1977), High Plains (since 1966), Rush Springs (since 1976), and Trinity (began 1981) aquifers. The Principal Aquifers within Oklahoma are shown in Figure 1.

In 2013, OWRB established the Groundwater Monitoring and Assessment Program (GMAP) to fully quantify the state's groundwater resources, characterize the ambient water quality, expand the water level network, and determine quality and quantity trends and conditions. GMAP serves as Oklahoma's primary contributor to the National Groundwater Monitoring Network (NGWMN).

Descriptions of Oklahoma's networks, their recent evolution, and interactions with the NGWMN are provided in the following sections ('Network Descriptions – Water Levels', 'Network Descriptions – Water Quality'). A summary of relevant grants and the history of OWRB as a data provider is included in the 'History & Status of Data Flows' section. To provide a comprehensive and accurate picture of OWRB's programs, both the network and grants sections will include work undertaken through this and other projects. Work specifically done for this project is discussed in the Project Summary section, with a breakout by objective. The final two sections will discuss problems encountered and the future of Oklahoma's networks.

Network Descriptions - Water Levels

To accomplish the GMAP goals, the spatial density in the annual water level network was significantly improved (one discrete quantity site per 50-100 km^2) with a total of about 842 sites, including 568 in Principal Aquifers. A smaller seasonal (triannual) discrete water level sub-network of about 251 sites (148 in Principal Aquifers) was implemented to recognize seasonality as well as changes due to climatic and water use drivers.

The combined annual and seasonal networks met the minimum spatial and temporal density recommendations of the NGWMN for a surveillance network in most aquifers but still suffered from data gaps in more spatially variable aquifers, such as the Arbuckle-Simpson aquifer (karst, high-use aquifer), or in aquifers where landowner access has been limited (e.g., Ada-Vamoosa, Edwards-Trinity System, Arbuckle-Simpson, and Rush Springs aquifers). The High Plains aquifer has always had relatively good landowner-mediated access but has mostly been limited to annual water level measurements due to the prevalence of irrigation wells with high seasonal use in the network.

The seasonal water level network did not meet the frequency recommendations of the NGWMN for a trend network of at least quarterly measurements and needed improvement. This was especially true in aquifers such as the Arbuckle Simpson, where seasonal sampling is not representative of the large variations inherent in a karst aquifer with heavy usage; the Edwards-Trinity system, which only had one long-term continuous water level monitoring site; the Rush Springs aquifer, which has both very high use and recharge; and the High Plains aquifer, with intense and seasonally variable usage. Year-to-year differences in the timing and extent of rainfall, recharge, and peak water use demands can severely bias measurements made only 1-3 times per year and miss the impacts of seasonal drawdowns.

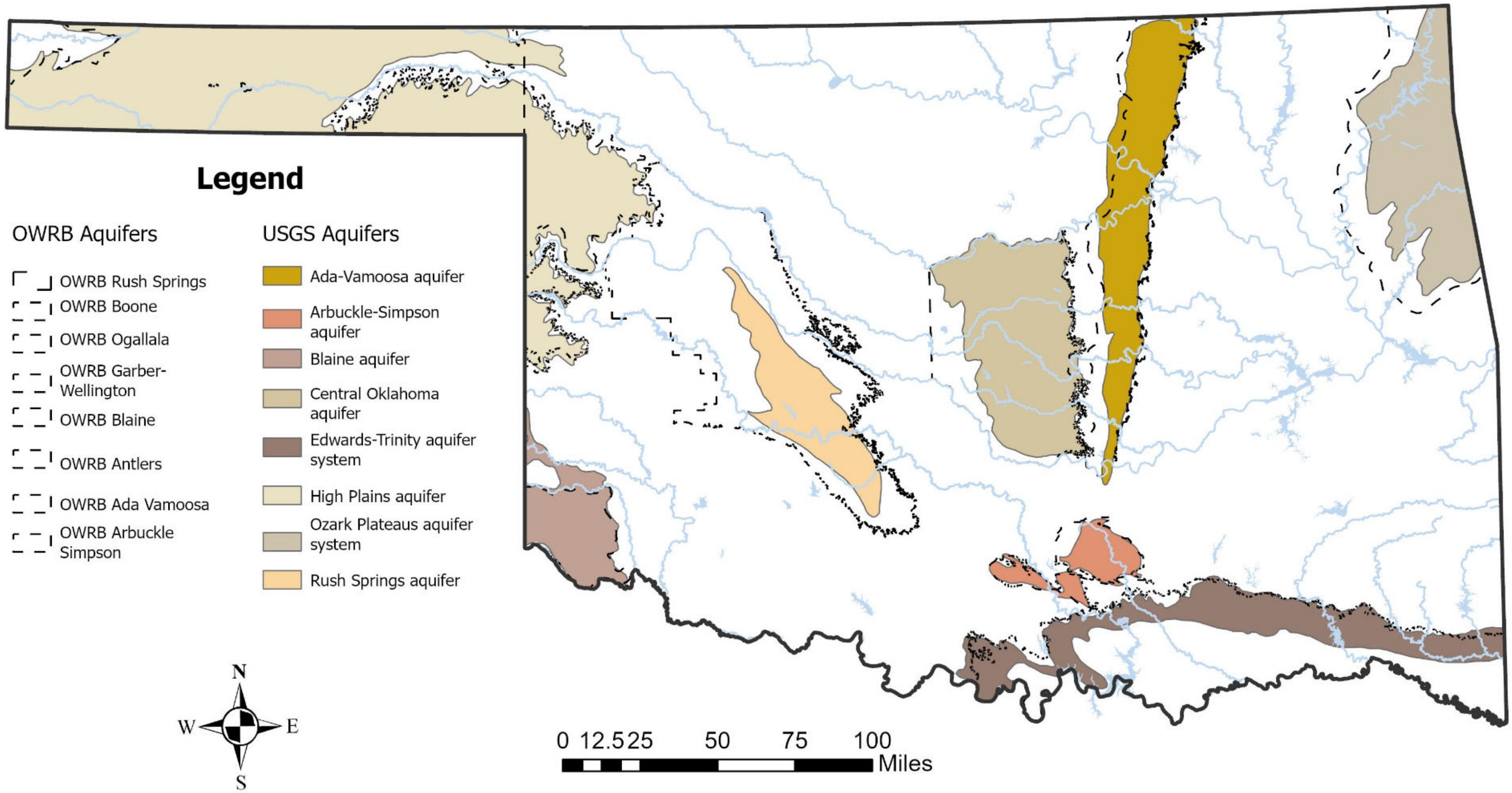

Figure 1: Principal Aquifer boundaries within Oklahoma are shown with USGS Aquifers (colored shapes with solid lines) and OWRB Aquifers boundaries (dashed lines). These differ significantly in some areas due to the USGS boundaries being limited to outcropped areas of each aquifer e.g., Rush Springs aquifer, and some of the OWRB boundaries being heavily influenced by political boundaries, e.g. the western edge of the Central Oklahoma aquifer.

To meet the temporal requirements of a trend network, the state's existing continuous recorder network was expanded in 2013 across the state's major aquifers (20 sites), except for the Edwards-Trinity System, where landowner participation remained limited. These sites were all equipped with hourly recording data loggers with data transferred through manual download. Despite this expansion, the continuous network did not meet the density goals of a trend network for either the NGWMN or Oklahoma's GMAP, especially in the High Plains (4 sites), Arbuckle-Simpson (3 sites), Rush Springs (2 sites), Ada-Vamoosa (3 sites), and the Edwards-Trinity System (1 site).

In 2020 (during the 2018 project), it was discovered that three of the water level trend wells, which were old 2" steel USGS monitoring wells, had degraded to the point that they no longer communicated properly with the aquifer and had to be decommissioned. All three of these wells were in the Oklahoma Panhandle region of the High Plains aquifer (one in each of Cimmaron, Texas, and Beaver counties), leaving that part of Oklahoma without a water level trend network that met both the spatial and temporal requirements of the NGWMN. This created a critical data gap in Oklahoma and regionally for the NGWMN, where the High Plains was otherwise better represented by other NGWMN partners. More importantly, it highlighted some of the major weaknesses of the historical OWRB water level networks, which have always hindered the inclusion of wells in long-term trend networks. These weaknesses included:

- An almost exclusive reliance upon private wells or land access with fluctuating landowner permissions and no regulatory framework to enforce monitoring.
- Most of the wells in Oklahoma, and many in these networks, lack construction and/or lithology information.
- Many of the wells have seasonally heavy uses which has also limited their inclusion in the trend network.
- Many more wells are unused/abandoned and, even if they have been long-term wells in our annual measurement programs, have mostly not been tested for connectivity to their aquifers until recently, as was the case of all the initial continuous sites in the OWRB networks.

To overcome these weaknesses, OWRB began a new expansion of the water level trend network with a more systematic approach to how wells are included in the network, incorporating upfront aquifer testing, a much wider effort at stakeholder engagement, and securing long-term access. This initiative began with the FY20 grant (this project) and continued with all additional state and NGWMN-funded work.

Through this FY20 NGWMN grant, OWRB first sought to fill a data gap in the water level network for the northern part of the Rush Springs aquifer by drilling three new wells with long-term access, good hydrologic connections, and detailed lithology and construction information. Other wells in the Rush Springs, High Plains, and Arbuckle Simpson aquifers would be subjected to aquifer testing and camera surveys to verify connectivity and provide missing construction metadata.

In 2021, OWRB performed a 20-year aquifer study update of the High Plains which included a large water level synoptic measurement (~430 wells) in place of its annual measurement (196 wells). This involved a large outreach effort with landowners, irrigators, and other stakeholders to both find temporary wells for the study and new wells for incorporation into the water level network as either discrete or continuous sites. Forty-two sites were initially identified (including 8 wells new to the network) that could serve as new continuous sites and additional wells have since been found. Through an NGWMN grant (FY21), 19 of these sites have been outfitted with continuous water level recorders and telemetry equipment.

Through additional state-funded work, all these sites have been fully surveyed, and undergone camera inspections and slug tests before inclusion in the network. The same work will be done with any other continuous data wells added to the OWRB network or NGWMN in the future.

Over the next few years, OWRB plans to evaluate coverage in each major aquifer and add continuous sites as needed, working with local stakeholders to improve long-term participation in our programs. The current coverage of the water level networks can be seen in Figure 2 which shows all OWRB wells and those already included in the NGWMN.

Network Descriptions - Water Quality

As part of GMAP, a statewide ambient water quality monitoring network was added in 2013 with a well-density goal of one quality site per 100-150 km^2, depending on the spatial extent of the aquifer. This expansion occurred during 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), 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 the spring of 2019, OWRB began implementing a trend water quality network composed of around 300 wells, approximately 190 of which were located within Principal Aquifers. Many of these wells originated from the baseline network. The GMAP sampling frequency was set at once every three years except for the High Plains aquifer, which was to be sampled once every five years, and the Arbuckle-Simpson aquifer, which was to be sampled annually. Each of the larger bedrock aquifers was split, with half of the wells for each aquifer being sampled one year and the remaining half the following year. All major alluvial and terrace aquifers were also to be sampled annually. This network design led to a variation in the exact number of wells sampled each year in the rotation, but it usually involved 190-260 wells.

During early 2020, when sampling was temporarily put on hold due to COVID-19, the water quality networks were reassessed. It was determined that, along with maintaining the ongoing water level networks, the existing schedule was not feasible in the long term. The limited temporal density of data and the practice of splitting each bedrock aquifer over two different years, with no way to determine if changes occurred between sites or years, would also preclude the development of water quality trends.

The network is currently being redesigned with both surveillance and trend components in a similar fashion to the NGWMN. The surveillance component resembles the original trend design but with a lower monitoring frequency, which is still being determined but is likely to be every 4-10 years. This component will provide a conditional assessment and guide the trend network in spatial and parametric coverage. Wherever possible, sites already in existing networks will be maintained. The trend component is under development and will involve a much smaller number of sites (using continuous water level sites wherever possible) with aquifer-specific parametric coverage.

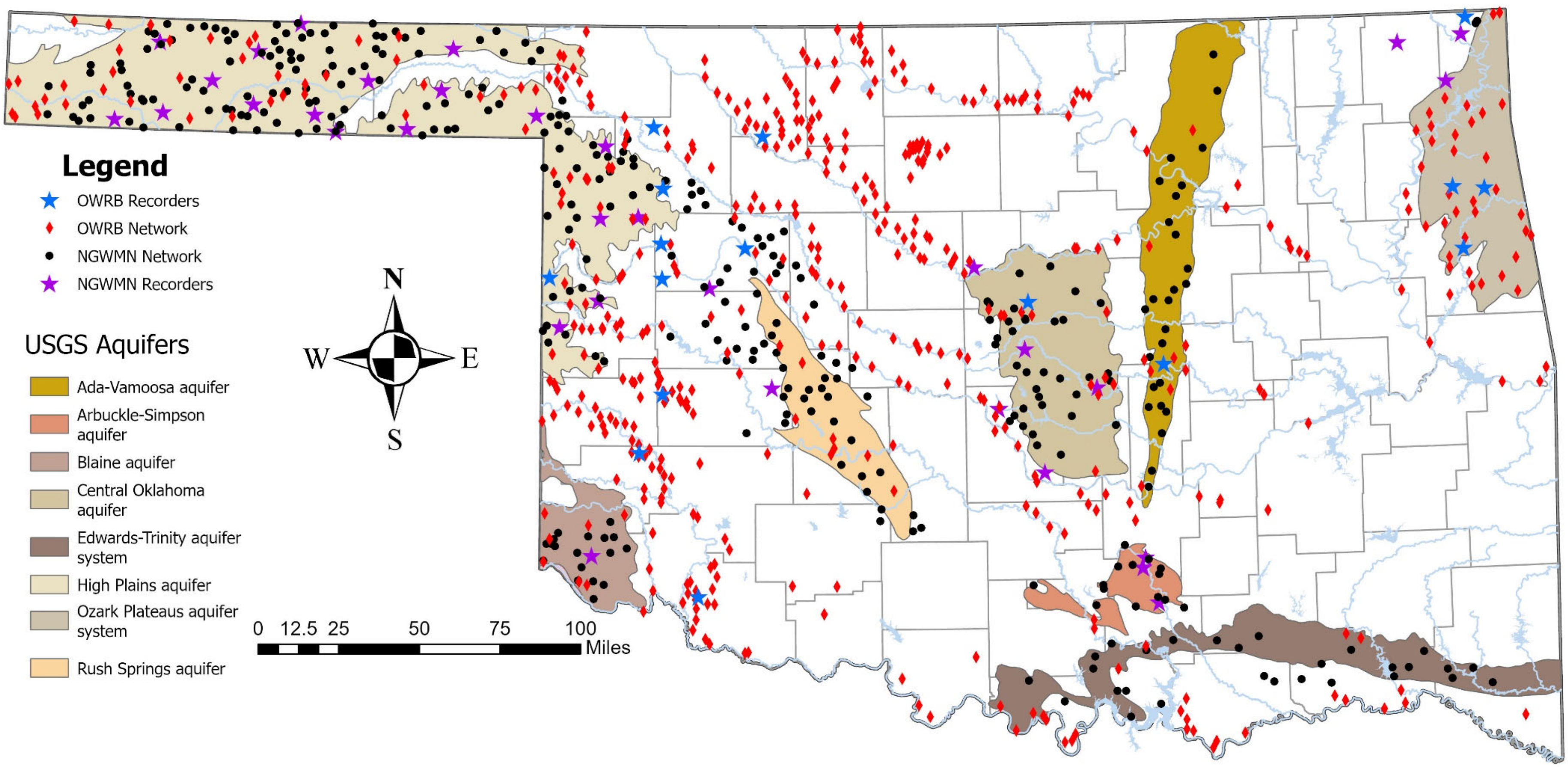

Figure *2*: Map of Oklahoma showing principal aquifers and all water level wells currently in the OWRB networks including alluvial ad terrace systems. Purple and blue stars indicate continuous water level sites in the NGWMN and OWRB networks respectively. Black circles and red diamonds indicate sites in the NGWMN and OWRB discrete water level networks respectively.

History & Status of Data Flows

The OWRB has been an NGWMN data provider since 2016, with six grants to date. These are summarized below and in Table 1. Additional details can be found in relevant project final reports available upon request from OWRB or the NGWMN.

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 OWRB's Oracle Well Drillers database.

In 2018 OWRB received a third grant, which initiated our use of camera surveys and aquifer tests to fill data gaps and ensure sites were properly connected to their aquifers. This grant also allowed for a significant expansion of our 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 were housed in the Ambient Water Quality Monitoring System (AWQMS), which was also in use by at least seven other states and roughly seventy tribes. AWQMS enforced WQX schema and data requirements that sufficiently met the minimum data requirements of the NGWMN for water level and water quality data.

Table 1: Summary of Oklahoma's NGWMN Grants

Year	Main Goals	Status
2016	New Data Provider to provide data from the continuous water level network.	Completed
2017-2018	Add sites to the NGWMN and create web services to connect continuous water level, construction, and lithology data from Aquarius and the Oklahoma Well Drillers Database.	Completed
2018-2019	Perform slug tests to ensure sites are properly connected to their aquifers and conduct camera surveys to fill well construction data gaps. Expand and improve the AWQMS database to facilitate groundwater data management and create web services for discrete water levels, water quality, construction, and lithology data.	Completed
2019-2020	Add 93 water level sites (55 in the High Plains) and 22 water quality sites (10 in the High Plains). Perform slug tests on 20 High Plains sites to ensure wells are properly connected to their aquifers and 9 camera surveys to fill well construction data gaps.	Completed
2020-2021	Perform quality control and add many new discrete water level and water quality sites to the well registry. Conduct slug tests to ensure sites are properly connected to their aquifers, and perform camera surveys to fill well construction data gaps. Drill three new wells to fill network gaps in the Rush Springs aquifer.	Completed - This Project
2021	This project seeks to fill critical gaps in the Trend Water Level Network in the Oklahoma portion of the High Plains aquifer by adding 19 new continuous water level sites.	Completed
2022	No grant.	N/A

However, the scope of construction and lithology information that AWQMS could store required expansion, and web services needed to be developed/improved to provide these data to the network. Additionally, although the database could store groundwater data, it was missing domains and domain values that made it feasible to manage groundwater data at the programmatic level, including information such as local and national aquifer designations and landowner information. These issues left users requiring additional databases and spreadsheets to operate programs.

Through the 2018 project, AWQMS underwent significant development to improve its ability to manage groundwater-related data. Development goals included creating or expanding numerous monitoring location (well/spring) data domains to provide storage for construction, lithology, and general informational data. Specific examples include new tables for screen information (depths, materials, sizes, etc.) and lithology (depths, material, descriptions, and observation method). These tables are accessible from each Monitoring Location page in the system and, to maintain system functioning, have been integrated with all data import and export tools.

The goals also included developing web services for water level, water quality, construction, and lithology data so that these can flow to the NGWMN. A crosswalk of web service domains was completed by the USGS staff in early December 2020. The improvements were released with versions 8.0 and 9.0 of AWQMS in 2021 and 2022, respectively. The initial release was to all states, tribes, and other users utilizing the cloud-based version of AWQMS. Shortly after, a second release was 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 was thus part of the initial release in 2021. This migration was mainly done to eliminate our reliance on state information technology services, which had previously caused large delays and poor resolution of problems with data flows to the NGWMN and database maintenance in general.

An additional benefit of working with Gold Systems (the developers of AWQMS and contractors with the EPA for WQX development) is that we were able to advise on other groundwater-related development of AWQMS as it was being performed through other projects. This included work done by other states and tribes and some funds from an OWRB-managed Exchange Network grant. 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, all of which are now searchable within AWQMS. Other metadata, such as landowner information, were also included in this process.

It is hoped that these improvements will make AWQMS an all-around 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.

With the releases of AWQMS 8 and 9, all OWRB sites in the NGWMN Well Registry were made visible, and discrete water quality and water level data began flowing to the network. AWQMS now serves to provide all lithologic and construction information for all water level and water quality sites in Oklahoma's network. These services are also available to all other states, tribes, and data networks that utilize AWQMS at no additional cost beyond their regular AWQMS maintenance fees.

Work continues to further improve AWQMS concerning groundwater data management through the review of the system and requests for improvements to Gold Systems, which tie the work into other projects as they are able. Additional domain values for the new groundwater-related domains can be freely added at the request of OWRB or any other users since the full expanse of these could not be determined by any one program during development. For instance, construction materials and lithology types may need to be expanded as the system comes into use in different areas or as new technologies are developed. Also, although the current list of local aquifers is extensive for each state, they may need further additions from relevant state and tribal users. OWRB was recently awarded a new Exchange

Network grant where one of the goals is to include the water level measurement point height as its domain and to allow that data to be published via API, significantly improving AWQMS as a tool for maintaining a groundwater program and utilizing the stored data in data collection apps such as Esri Survey123. This work has not yet been started but is expected to be completed early in 2025.

The 2019 grant prioritized work in the High Plains aquifer, but also involved work across the state. Specifically, new wells were added to both the water level (93 wells) and water quality (22 wells) networks; camera surveys were performed to fill gaps in construction details, and slug tests were performed to ensure wells were connected to their aquifers and determine hydraulic conductivities.

This 2020 grant (discussed more fully in later sections) also prioritizes adding new wells to the NGWMN, filling in metadata gaps, ensuring well-aquifer connectivity in various aquifers, and drilling a small number of wells in the Rush Springs aquifer, which has suffered from poor coverage in its central and northwestern sections.

In 2021, OWRB received a 1-year grant to expand the continuous water level trend network in the High Plains aquifer, purchasing and installing water level and telemetry equipment at 19 sites.

All grants are completed with this report closing out the FY20 grant, and the following report being completed for the FY21 grant.

Project Summary

This grant prioritized maintaining and expanding Oklahoma's contribution to the NGWMN. Maintenance activities under Objective 2, Part A, included site and metadata updates, provider page updates, and maintenance of web services for our continuous water level data. Expansion of the network under Objective 2, Part B, included adding 43 new water level sites and 10 new water quality sites from the Rush Springs and Arbuckle Simpson aquifers. These were some of the core wells in our program and complemented Oklahoma's existing coverage.

We also proposed to install three new monitoring wells that would serve as both water level and water quality sites in an area of the Rush Springs aquifer, particularly lacking suitable wells. A major goal of the drilling was to secure long-term access to well-maintained wells with good construction records. To this end, state-owned lands were to be targeted for drilling sites. At least one of the three wells was to be a trend water level site (continuous recorder).

The final part of the project aimed to assess the construction and connectivity of wells previously added to the NGWMN, including some wells with limited or no detail on construction or lithology but with significant water level records. These were predominantly oilfield supply wells that have been unused since entering Oklahoma's network and were prime candidates to evaluate through down-hole camera work to assess screened intervals and total depths through Objective 3 (Filling gaps in information at NGWMN sites). These wells were also candidates for work under Objective 4 (Well Maintenance) to evaluate connectivity to the aquifer through the performance of slug tests, to determine suitability of the sites for generating representative water level data.

Proposed Objectives and Tasks:

Objective 2, Part A: Support persistent data services from existing data providers

Tasks 2.1-2.3: Maintenance of the existing network and data services (federal/in-kind)

Objective 2, Part B Support persistent data services from existing data providers

Tasks 2.4-2.9: Addition of new sites to the NGWMN (federal)

Objective 3: Filling gaps in information at NGWMN sites

Tasks 3.1-3.5: Downhole camera evaluation of 25 High Plains, Rush Springs, or Central Oklahoman aquifer wells (federal/in-kind)

Tasks 3.6-3.9: Water Quality Sampling of 18 High Plains sites (in-kind work)

Objective 4: Well Maintenance

Tasks 4.1-4.5: Slug testing to assess well connectivity in 25 High Plains, Rush Springs, or Central Oklahoman aquifer wells (federal/in-kind)

Tasks 4.10-4.12: Water level measurements at 150 sites located in the High Plains aquifer (in-kind)

Objective 5: Well Drilling

Tasks 5.1-5.6: Drilling of three monitoring wells in the Rush Springs aquifer (federal/in-kind)

Task 5.7: Water Quality Sampling of 22 Rush Springs Wells (in-kind)

Project Objectives

Objective 2: Support persistent data services from existing data providers

Under Part A of Objective 2, all of Oklahoma's wells already in the NGWMN were reviewed, with updates made to well construction and lithology data as needed. (Task 2.1). Improved methodological and survey design descriptions were generated (Task 2.2). Maintenance of the web services for continuous data consisted of paying for one year of a license for Aquarius Time-Series software, which has been dedicated to web services for the NGWMN (Task 2.3). Although no in-kind match was required for this objective, we included one additional Aquarius license as an in-kind match. This license was used exclusively for editing and QA'ing data provided to the network. All additional licenses for this software, which were also used for data processing and management, were paid for through state resources. Discrete data web services were maintained as part of OWRB's routine use of the AWQMS database since the web services do not consume a license.

Additional maintenance work (already reported in the 2019 final report) was performed during this period to ensure ongoing connectivity of the continuous data to the NGWMN. This included code fixes to the web services to remedy an issue where hourly water level values were being reported instead of daily mean values.

Under Part B of this objective, we added 43 new water level sites and 10 new water quality sites to the NGWMN to complement Oklahoma's existing coverage (Tasks 2.4-2.9). The number of new wells by principal aquifer is summarized in Table 2, with details provided in Table A-1 and Figures 3-5.

Table 2: Summary of Sites Added to the NGWMN by Principal Aquifer and Network

Principal Aquifer	Water Level Sites	Water Quality Sites
Rush Springs	29	0
Arbuckle Simpson	14	10
Totals	43	10

Selected sites were reviewed for metadata completeness (relative to minimum data element requirements) and then classified by sub-network before well registration. The selection and designation of sites were performed by Chris Adams, utilizing his experience of the NGWMN requirements and previous descriptive work performed by Mark Belden, the previous Groundwater Monitoring Lead for OWRB. After classification, sites were uploaded to the NGWMN Well Registry. Water level and water quality Activities and Results data for these sites had already been migrated to the AWQMS database and thoroughly reviewed. Lithology and construction data for existing NGWMN sites had previously been fully integrated into the improved and expanded domains in the AWQMS database that were previously unavailable.

New sites had only been partially migrated and required remigration to account for the new data structures. Further, these data had been reviewed for comparison against previous iterations of the electronic data but not comprehensively reviewed against all other sources. Any data represented by codes, e.g., screen and casing materials, was transformed into fully worded values for ease of review. Data was then checked, well by well, against all available records including scans of the original hardcopy well completion reports and field notebooks from annual water level collections where some metadata had previously been updated. Any new updates or corrections were tracked, and the final data was then imported to AWQMS. Following the migration, data in AWQMS was rechecked for comparability to the corrected data files.

Once the well metadata was available in AWQMS it was intended that construction and lithology data would flow from it to the NGWMN. However, due to some issues with assigning the correct webservices to each well, data continued to flow from the Well Drillers database via OMES-created webservices until early 2023.

All minimum data elements were met for all new wells. However, some water level wells were identified as having incomplete records for well construction details and/or lithology records. These wells have been included in the Well Registry under the 'Special' well types until additional manual work can be done to complete the well records. In many 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. All water quality sites are required to have this information in the GMAP network and have also been sampled during the statewide baseline period and shown to be representative of the aquifer-specific water quality.

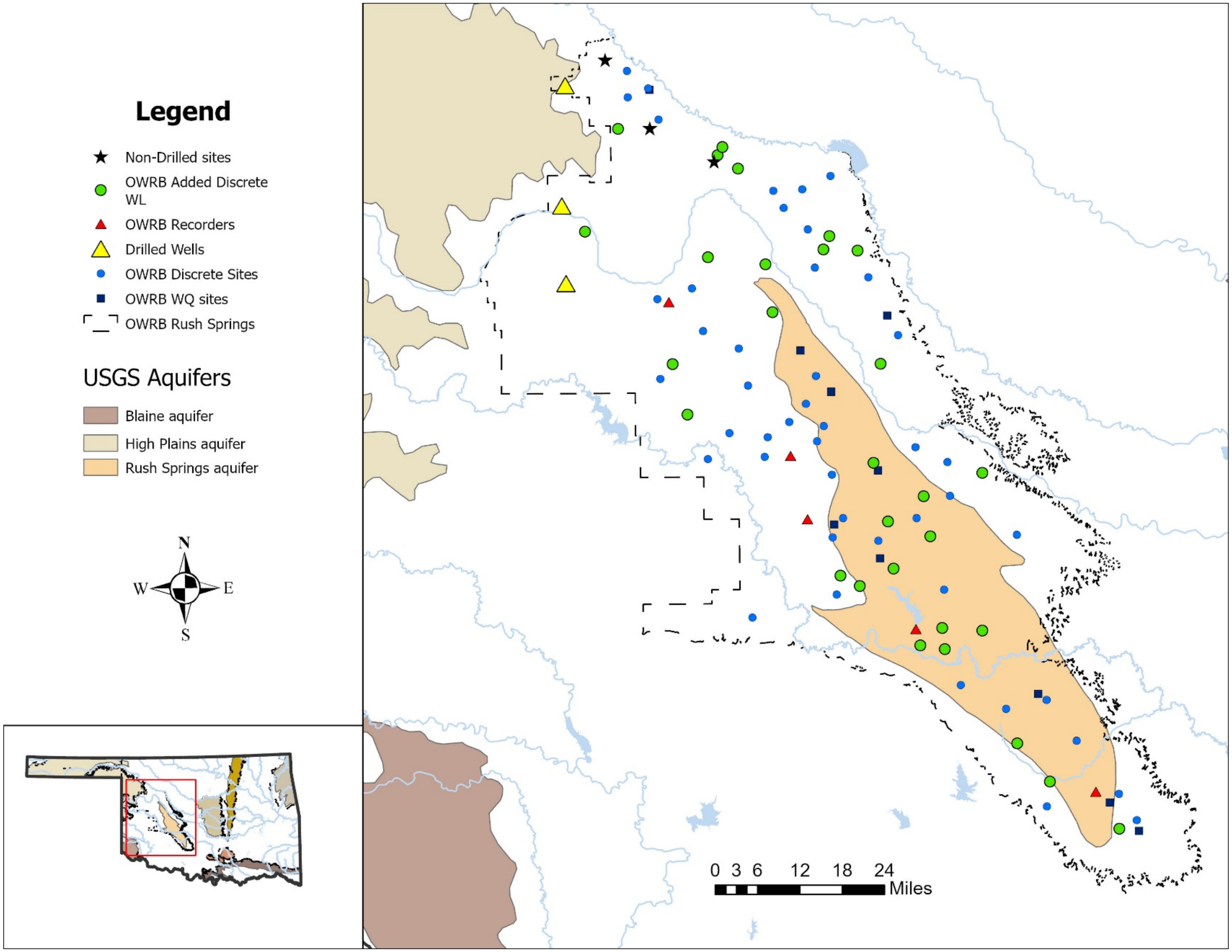

Figure 3: Map of the Rush Springs aquifer showing 46 OWRB discrete water level surveillance (blue circles), OWRB continuous recorders (5 red triangles), and OWRB water quality sites (navy blue squares). The 43 green circles are discrete water level sites that were added to the NGWMN through this proposal. The 3 yellow triangles are wells drilled under this proposal and the 3 black stars are sites that were originally proposed for the well drilling. As shown some sites are outside of the USGS Rush Springs boundary but they are still inside the OWRBs boundary of the aquifer (dotted line). The insert map shows where the main map is in relation to entire state of Oklahoma.

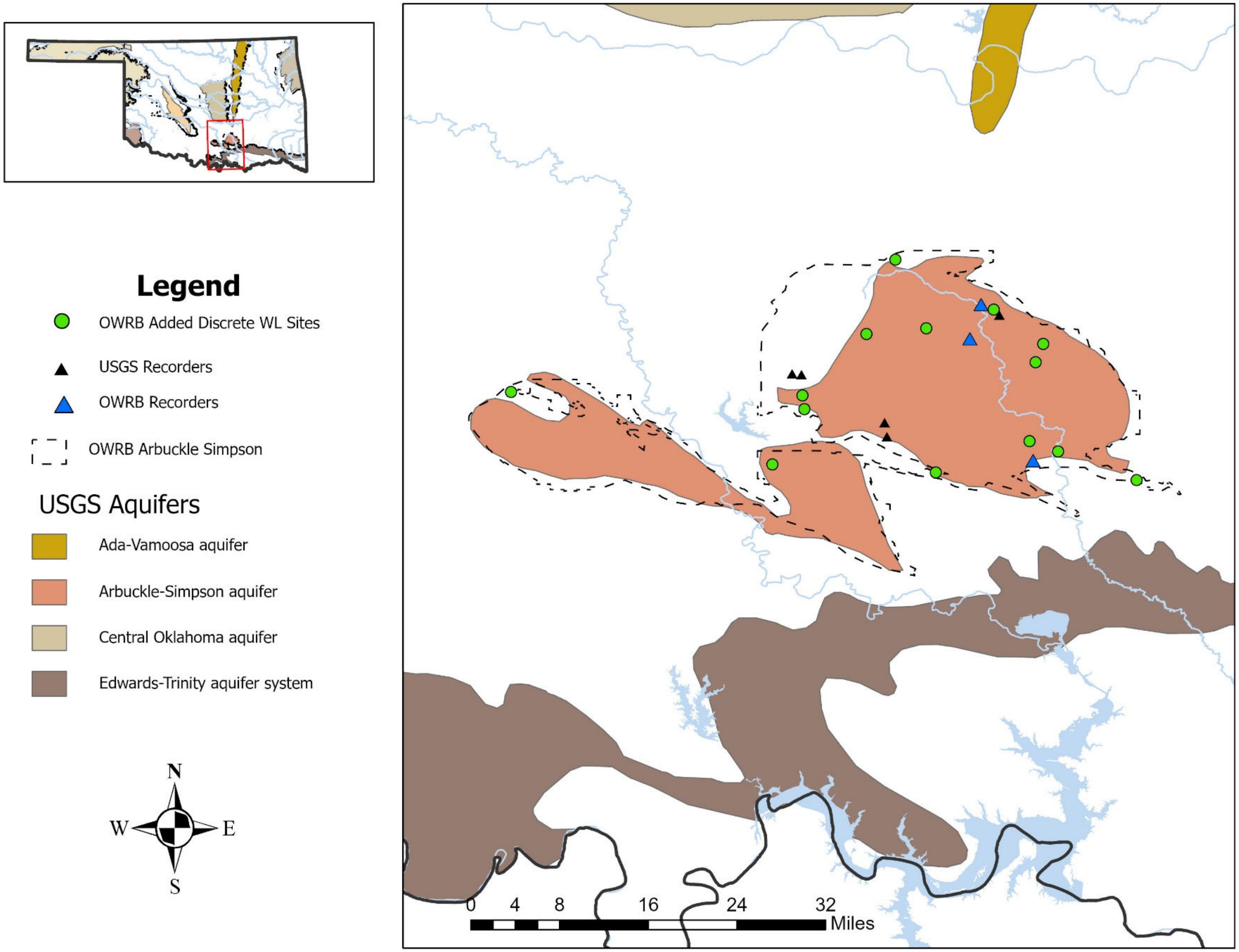

Figure 4: Map of the Arbuckle Simpson aquifer showing 3 OWRB continuous recorder sites (blue triangles), and 5 USGS continuous recorder sites (black triangles). The 14 green circles are OWRB discrete water level sites that were added as part of this proposal. As shown, there are some sites that are outside of the USGS Arbuckle Simpson boundary but are still within the OWRBs boundary for the aquifer (dotted line).

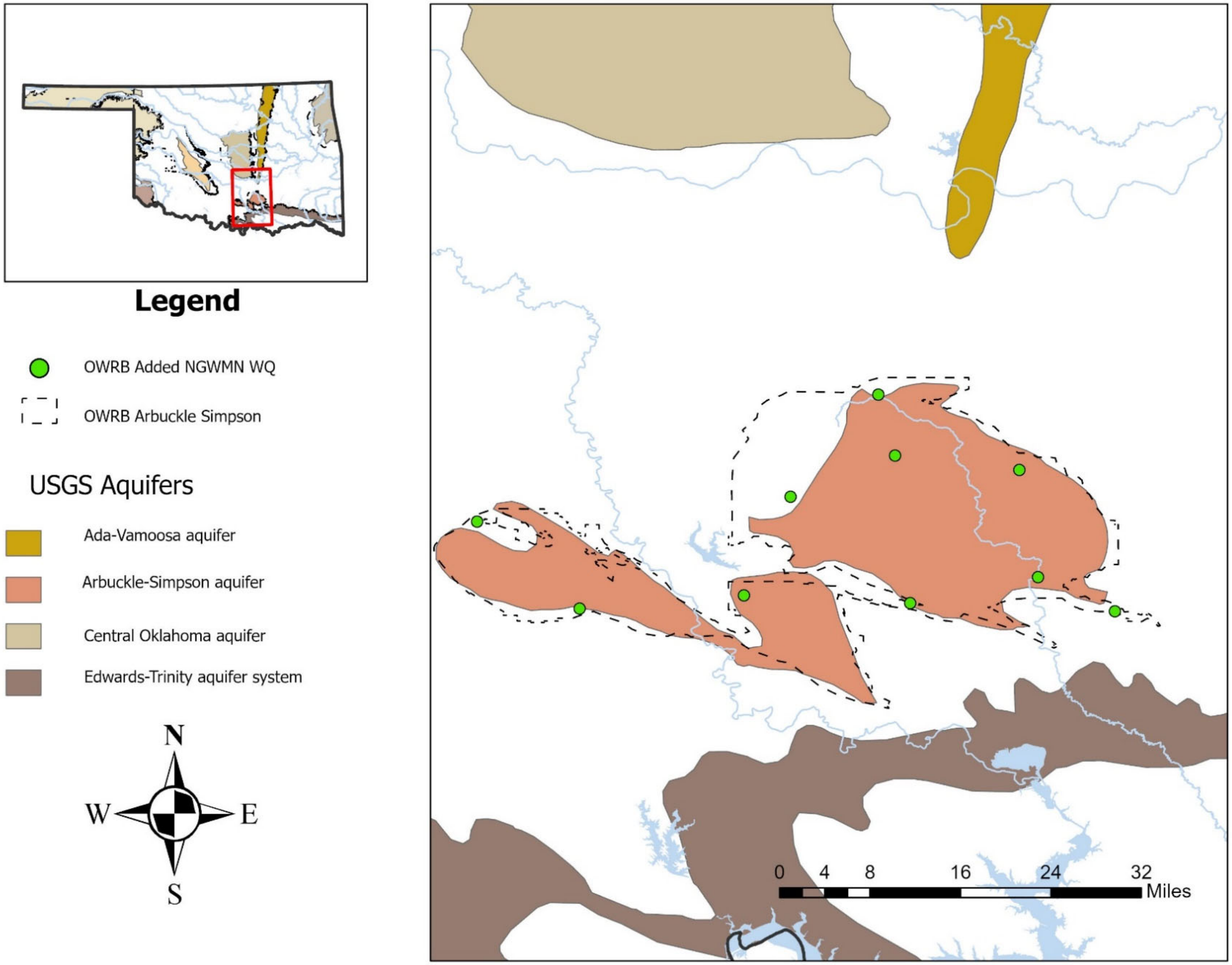

Figure 5: Map of the Arbuckle Simpson aquifer showing the 10 OWRB water quality sites (green circles) that were added to the NGWMN as part of this proposal. As shown, there are some sites that are outside of the USGS Arbuckle Simpson boundary but are still within the OWRB aquifer boundary (dotted line).

Since the end of the 2019 and 2020 projects, additional work to fill these metadata gaps has been completed through the additional state-funded work. No matter its source, all data updated to AWQMS for NGWMN wells will become available to the network through web services. As these data are updated in AWQMS the sites will be moved to the Surveillance or Trend well types in the NGWMN Well Registry.

Objective 3 & Objective 4: Filling gaps in information at NGWMN sites (Objective 3) & Well Maintenance (Objective 4)

During the project planning phase, we identified 39 old oilfield supply wells in the High Plains, Rush Springs, and Central Oklahoma aquifers. These wells had remained unused since entering Oklahoma's network but had been part of GMAP and previously added to the NGWMN. Although these wells possessed valuable long-term discrete water level data, they lacked detail on construction and lithology, with no corresponding well driller's log. With the exception of water level data, all but 5 wells had measured total depths (using steel tapes) and accurate GPS location and elevation information. All 39 were prime candidates for accessing screened intervals through down-hole camera work, funded under Objective 3. Since these wells had experienced many years with little to no pumping, they were also candidates for work under Objective 4 to evaluate connectivity to the aquifer through the performance of slug tests, determining the suitability of the sites for generating representative water level data.

Although all 39 wells would have benefited from this work, the initial intent was to prioritize 25 wells for camera surveys and aquifer tests during this project. Prioritization was initially based on the length and completeness of the water level records but was amended to include landowner permissions following the temporary loss of some permissions during the COVID-19 pandemic. Eventually, access to all wells was regranted for water level measurements.

Severe delays to this part of the project occurred due to limitations on fieldwork resulting from the COVID-19 pandemic. This affected both this project and the 2019 project. Camera surveys and aquifer tests were delayed when fieldwork had to be shut down for an extended period. When work was allowed to start back up, we incurred additional costs due to social distancing requirements, being limited to one person per vehicle, and restrictions on certain hotels being unavailable for accommodation, resulting in increased travel time. Shortened and/or canceled trips due to sickness also resulted in increased costs.

During this period, we also received a 2021 grant to install continuous water level recorders in the High Plains aquifer. These wells generally matched the 39 potential wells from this 2020 project in history and data availability, with many being similar old oil and gas wells. Initially, it was not intended to slug test and camera survey all these wells. However, given the history of issues with poor construction information and poor connectivity in some trend wells (discovered during this time), this was reconsidered. It was decided to survey and test every potential trend well before installing a continuous recorder. Some of the 2021 project wells were already due to be tested as part of this 2020 project and, due to delays in both projects from the pandemic, much of the testing work for both sets of wells was performed side by side. This was achieved by utilizing funds from the 2020 project along with additional state funds to cover the extra wells and the costs above what was expected due to the pandemic.

Ultimately, fifteen wells from the original 2020 project list and fifteen additional wells from the High Plains had camera surveys and slug tests performed. The remaining un-surveyed wells are still in the network providing discrete water level data and may potentially be further investigated at a later date.

The results of the camera surveys and slug tests are summarized below, with additional details for all wells investigated through Tasks 3 and 4 provided in Table 3 (original 2020 project wells), Table 4 (Additional High Plains wells), and Table A2 (un-surveyed 2020 wells (see Appendix)). All wells can be seen in Figure 6. The additional High Plains wells are reported here and will also be included in the 2021 project report for completeness.

Of the fifteen wells from the original 2020 list, eleven had good camera surveys and slug tests, providing clear construction details of the wells and reasonable estimations of hydraulic conductivity. Well 24822 was obstructed at 257 ft, with a reported total depth of 260 ft, but this obstruction had no impact on well integrity, connection to the aquifer, or water level measurements. This well had a telemetered water level recorder installed as part of the 2021 project and is included in the trend water level network.

Wells 9324 and 24961 underwent camera surveys and slug tests, but we were unable to determine screen placement and openings, and only an incomplete analysis of the data was possible. Despite this, partial analysis and historical water level records indicate good connectivity to the aquifer, and the wells remain in the water level surveillance program under the Special category.

Well 9314 demonstrated poor connectivity to the aquifer and has subsequently been dropped from the program.

The camera survey for well 24880 revealed a broken casing at 211.9 ft and a well collapse at 251.7 ft. Despite these issues, the well remains in the program but will undergo further investigation to evaluate the representativeness of water levels.

Eight of the fourteen additional High Plains wells underwent good camera surveys and fully completed slug tests. Well 24408 was obstructed at 139.8 ft in a 140 ft deep well, but this obstruction had no impact on well integrity, connection to the aquifer, or water level measurements.

Another four wells (3270, 23628, 120969, and 143209) had good camera surveys and completed field components of the slug tests. Unfortunately, hydraulic conductivities could not be estimated due to data loss before final analysis. However, preliminary inspection of the data and historic water levels indicated good connections with the aquifer. Each of these sites currently has telemetered water level recorders installed and is part of the trend water level network. Wells 120969 and 143209 are also water quality surveillance sites and are likely to become water quality trend sites. Each of these wells will undergo re-slug testing during a future maintenance trip.

Well 2066 was found to be poorly connected to the aquifer, with indications of possible blockages on the screen openings. This well would be a candidate for remedial work/cleaning in the future if other more suitable wells become unavailable.

Well 5385 was blocked by roots at 33 ft, preventing camera passage and slug testing. Historical water levels range from 27.86 ft to 31.1 ft. The well has currently been suspended from the network with the intent of investigating whether the historical water levels could be representative of that part of the aquifer or an artifact of the obstruction.

All construction data has been updated to AWQMS and is available to the NGWMN through web services.

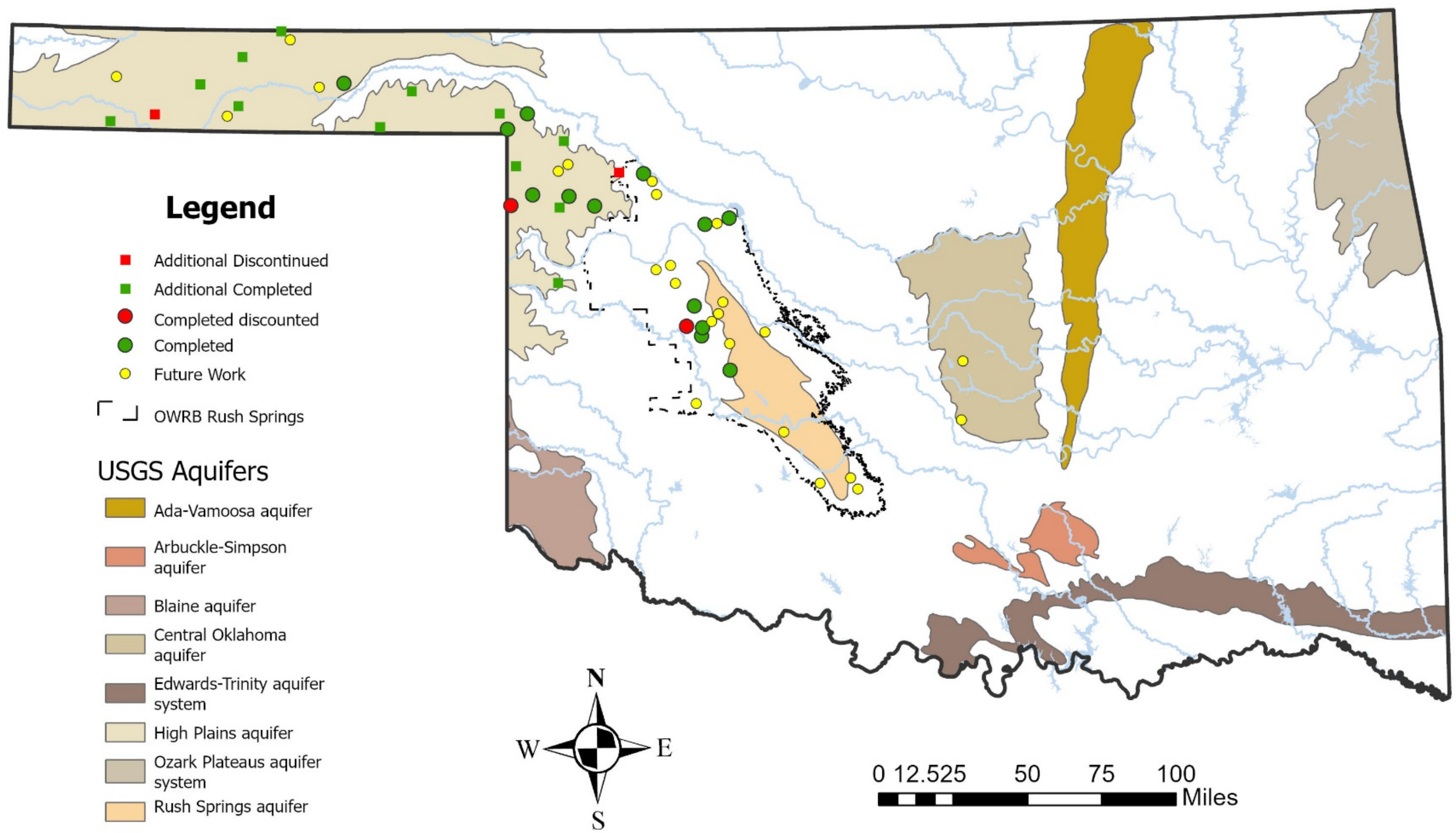

Figure 6: Map of Oklahoma showing the principal aquifers and completed slug test and camera work. The 13 green circles show sites with successfully completed slug test and camera surveys. The 12 green squares are successfully completed additional sites that were completed alongside the 2020 wells. Two wells from this project (red circles) and two additional wells (red squares) were surveyed but discontinued. There are 24 sites that remain un-surveyed but may potentially be further investigated (yellow circles).

The estimated hydraulic conductivities for all High Plains and Rush Springs wells were 3.9-323 ft day^{-1} and 0.7-30.1 ft day^{-1} respectively (see Table 3). Continuing efforts, previously reported in the 2019 final report, aimed at enhancing OWRB's expertise in aquifer testing and confidence in these results, will involve revisiting and reanalyzing 25% of all these wells over the next two years.

It was originally planned that in-kind activities contributing to objectives 3 and 4 would include two-thirds of the travel costs for the slug test and camera work. Discrete water level measurements at 150 High Plains wells, and water quality sampling in 18 High Plains wells was also planned.

As previously mentioned, work on this project was impacted by the COVID-19 pandemic with increased travel costs and additional staff time being spent on all field-related tasks which increased the in-kind contribution for travel. Twenty additional High Plains water level sites had also been added to the NGWMN either during grants or as they become available through the GMAP program. All 170 of these wells were measured in 2021 and the data was made available to the network. Twenty-six additional wells had water levels collected and remain in the GMAP program but not in the NGWMN. These wells will be added to the network as time allows giving 196 discrete water level sites in the NGWMN in the near future.

The eighteen High Plains water quality wells due to be sampled were sampled during 2021 along with 18 other wells distributed through the Oklahoma Panhandle region of the Ogallala (Figure 7). Except for two new wells, all these wells were originally sampled in 2016 as part of the baseline GMAP sampling. A number of these wells had not previously been added to the water quality surveillance network of the NGWMN and so have been added to the well registry and data made available through webservices. These additional 18 wells replaced some in-kind work planned under Objective 5 which included sampling in the Rush Springs aquifer (further discussed in the next section (Objective 5: Drilling new wells)). Information, including locations, networks, and years sampled can be found in the Appendix in Table A3.

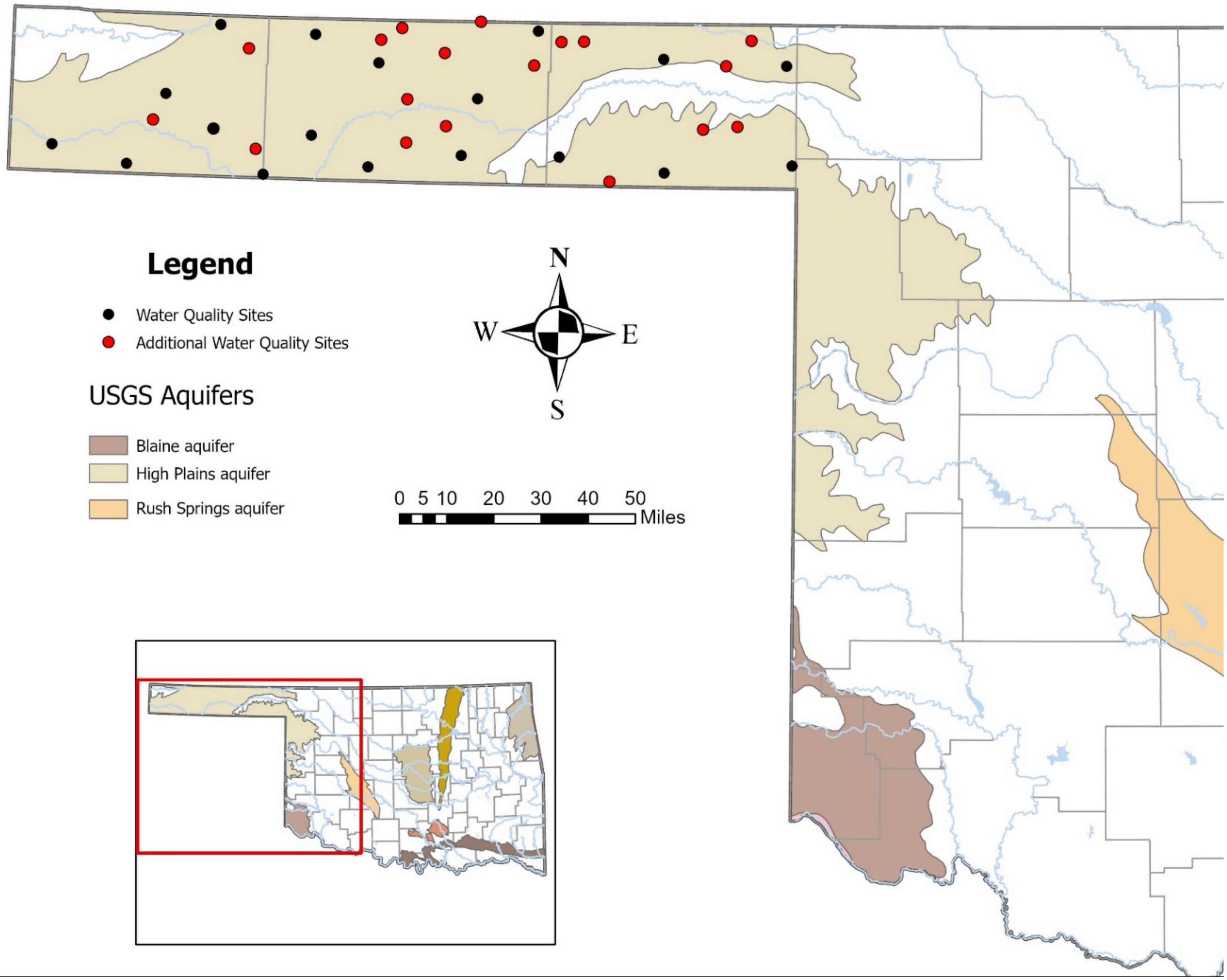

Figure 7: Map showing High Plains aquifer water quality sites that were sampled in 2021. Eighteen sites were originally proposed (black circles) with another 18 (red circles) being sampled and added to the NGWMN. These sites remain in the network as surveillance wells, but some are being investigated as potential water quality trend wells. Additional information can be found in Table A3.

Table 3: Status, network, and hydraulic conductivities and slug test outcomes for 2020 project wells.

Site ID	Well Name	Latitude	Longitude	Principal Aquifer	Well Depth (ft)	Monitoring Category	Status	Network	Work Completed	Test Date	K-Value Range (ft/day)	Surveillance Start	Trend Start
3348	MM3348	36.52111475	-99.9982561	High Plains	240	Surveillance	Discrete	WL	Both	7/13/2021	8.2-9.2	3/26/1980	
9240	MM9240	35.50541449	-98.8396133	Rush Springs	300	Surveillance	Discrete	WL	Both	7/28/2021	2-2.6	11/14/1990	
9243	MM9243	35.54603613	-98.8324107	Rush Springs	340	Surveillance	Discrete	WL	Both	7/12/2021	1.3-1.7	1/16/1991	
9290	X9290	36.08148015	-98.66619	Rush Springs	300	Surveillance	Discrete	WL	Both	7/12/2021	0.7-1	3/17/1980	
9314	MM9314	36.14780782	-99.9761532	High Plains	290	Surveillance	Discontinued	WL	Both	7/27/2021		2/5/1981	
9322	MM9322	36.19198363	-99.6287248	High Plains	421.7	Surveillance	Discrete	WL	Both	7/26/2021	8.6-18.7	1/29/1980	
9324	9324	36.20009063	-99.8444065	High Plains	UNK.	Surveillance	Discrete	WL	Both	7/27/2021		3/17/1981	
24822	Adams	36.74199281	-100.985944	High Plains	260	Trend	Recorder	WL	Both	8/2/2022	18.49-23.77	8/15/2016	9/14/2022
24880	MM24880	35.55509236	-98.9283725	Rush Springs	400	Surveillance	Discontinued	WL	Both	7/14/2021		1/16/1991	
24881	X24881	35.65260585	-98.8806621	Rush Springs	420	Surveillance	Discrete	WL	Both	7/28/2021	1.2-1.5	1/16/1991	
24961	MM24961	36.59704798	-99.8773479	High Plains	150	Surveillance	Discrete	WL	Both	7/13/2021		1/3/1989	
25661	MM25661	36.30083727	-99.1794028	Rush Springs	80	Surveillance	Discrete	WL	Both	7/3/2021	18.3-30.1	2/1/1989	
27649	MM27649	35.33808415	-98.6716316	Rush Springs	300	Surveillance	Discrete	WL	Both	7/21/2021	2.9-3.5	1/15/1991	
27665	MM27665	36.05204986	-98.8113569	Rush Springs	360	Surveillance	Discrete	WL	Both	7/12/2021	0.7-1.1	1/17/1989	
140808	Harmon	36.14596487	-99.4732699	High Plains	200	Trend	Recorder	WL	Both	8/25/2021	2.7-3.0	1/11/2012	11/21/2013
221261	Camargo	36.026944	-99.346397	Rush Springs	140	Trend	Drilled/Recorder	WL & WQ	Both	8/7/2023	Under Review	8/8/2023	8/7/2023
221266	Sharon	36.274249	-99.336162	Rush Springs	200	Trend	Drilled/Recorder	WL & WQ	Both	8/8/2023	Under Review	8/8/2023	8/8/2023
224227	Leedey	35.8673184	-99.336897	Rush Springs	280	Trend	Drilled/Recorder	WL & WQ	Future Work				

Table 4: Status, network, and hydraulic conductivities and slug test outcomes for additional High Plains wells.

Site ID	Well Name	Latitude	Longitude	Principal Aquifer	Well Depth (ft)	Monitoring Category	Status	Network	Work Completed	Test Date	K-Value Range (ft/day)	Surveillance Start	Trend Start
349	Slapout	36.59763799	-100.0443163	High Plains	260	Trend	Recorder	WL	Both	8/2/2022	44.34-63.17	1/5/2015	11/28/2022
1886	Straight	36.99251545	-101.3697063	High Plains	300	Trend	Recorder	WL	Both	7/26/2022	3.922-14.42	5/24/2016	9/27/2022
3270	Fargo	36.46273715	-99.65699054	High Plains	258	Trend	Recorder	WL	Both	Revisit		1/12/2015	11/28/2022
9051	Elmwood	36.705586	-100.575557	High Plains	180	Trend	Recorder	WL	Both	8/30/2022	5.342-10.17	3/29/2021	1/19/2023
23628	Goodwell	36.62430676	-101.6233784	High Plains	370	Trend	Recorder	WL	Both	Reanalyze		1/7/2015	8/22/2023
24401	Conrad	36.53984808	-102.3947428	High Plains	140	Trend	Recorder	WL	Both	7/19/2022	37.66-47.86	8/10/2016	9/13/2022
24408	Eva	36.72797578	-101.8561648	High Plains	140	Trend	Recorder	WL	Both	8/2/2022	114.8-323	6/28/2016	8/29/2022
42791	Arnett	36.13864343	-99.68332698	High Plains	280	Trend	Recorder	WL & WQ	Both	8/31/2022	30.16-45.78	1/7/2015	9/12/2022
110093	Hough	36.86401465	-101.6031569	High Plains	380	Trend	Recorder	WL & WQ	Both	8/2/2022	44.34-63.17	3/30/2016	8/30/2022
120969	Shattuck	36.34029831	-99.94521124	High Plains	235	Trend	Recorder	WL & WQ	Both	Reanalyze		1/12/2015	7/25/2023
137270	Gray	36.52954748	-100.7653787	High Plains	420	Trend	Recorder	WL & WQ	Both	8/30/2022	21.15-25.58	3/9/2016	11/29/2022
143209	Roll	35.77029349	-99.6937825	High Plains	200	Trend	Recorder	WL & WQ	Both	Revisit		7/31/2013	11/28/2022
2066	Griggs	36.57737621	-102.1266013	High Plains	395	Surveillance	Discontinued	WL	Slug	7/19/2022		6/14/2016	
5385	X5385	36.30844249	-99.32381965	High Plains	70	Surveillance	Discontinued	WL	Camera	8/31/2022		1/31/1980	

Objective 5: Drilling new wells (Rush Springs)

Under objective 5 we proposed to install three new monitoring wells that would serve as both water level and water quality sites in the northwest of the Rush Springs aquifer, an area particularly lacking suitable wells for water quality and continuous water levels. A major goal of the drilling was to secure long-term access to well-maintained wells with good construction records. To this end, state-owned lands belonging to the Commissioners of the Land Office were originally targeted for drilling sites. Preliminary permissions for this work were received during the proposal phase of the project and it was hoped that such a partner would be able to provide uninterrupted long-term access.

Like much of the rest of the project, Objective 5 suffered delays of various natures. First, at the start of the pandemic when staff were transitioning from a full-time office to full-time remote work environment, much of the office related project tasks were disrupted. This delayed any start on planning and purchasing. Once we were able to start planning, work began on developing a statewide contract for well drilling so that the contract could serve both for wells drilled under this project, future funding opportunities, and future work planned with state funds in alluvial systems. The initial contract was based on an existing contract for monitoring well installation in place between the Oklahoma Corporation Commission and numerous well drillers. After encountering numerous issues trying to set up this contract involving the state's central purchasing and staff changes, it was decided to begin again with a more straightforward contract for just the three Rush Springs monitoring wells.

When we re-contacted the Commissioners of Land Office to determine the language for the agreements to install and access the monitoring wells, we discovered they would now only allow the monitoring wells to be installed if they could utilize them for stock wells. Since this would limit the well's use as continuous level trend wells, we decided to seek alternative sites in the same region of the aquifer. With a major priority of long-term access, we began investigating municipal sites, school districts, and other public institutions.

After developing a short list of suitable sites, field crews' ground-truthed locations, met with landowners and discussed future uses and benefits of these sites. High-accuracy GPS data was collected at each potential location to compare with aquifer maps and nearby lithologic drilling logs for suitability.

Eventually, we settled on two locations owned by school districts and a private site which had been granted long-term access to the Oklahoma Mesonet, one of our long-term partners in groundwater and environmental monitoring.

Bid request documents were made available to the public for bidding on 4/11/2023. Three drillers responded to the request with quotes. The winner of the bid was S&M Water Well Inc, out of Camargo, OK, and was awarded the contract for all three wells on 5/5/2023. We found the remaining two bids to be priced significantly above market rate even considering the general shortage of well drillers in Oklahoma.

All three wells were 4-inch PVC monitoring wells with factory-slotted PVC screens. Locations of the original planned and final well sites can be found in Figure 8 with information on network status found in Table 3. The wells have concrete well pads, protective bollards, and locking well caps. Figure 9 shows the completed 221266 (Sharon) well, with all three wells being similarly completed. Lithologies and construction details were recorded by both the well driller and OWRB geologists, have been entered into the AWQMS database, and are available to the NGWMN through webservices. Lithologies and construction can also be found in Tables 5-7 of this report. Figures A2-A6 include additional photos from the drilling at each site.

Well 221261 (Camargo) was drilled 05/30/2023 to a depth of 140 ft and screened from 110 to 140 ft in the Rush Springs Sandstone. The first attempt for this well was made to the south of the Mesonet station to allow for ease of access and connection to the Mesonet telemetry system. The drill lost circulation and drilling fluids were lost to the formation. An alternate drilling site, approximately 600 ft south of the original site was a success. Continuous water level equipment was installed and is being telemetered through In-situ telemetry services with the Mesonet system as a potential backup.

Well 221266 (Sharon) was drilled on 06/07/2023 to a depth of 200 ft and screened from 170 to 200 ft in the Rush Springs formation. This well is on the property of Sharon-Mutual Public Schools and we intended to have staff and students available during drilling for some educational opportunities. Unfortunately, the drilling could not occur until the school summer holidays began but we are developing an ongoing relationship to provide education resources and knowledge exchange activities during future sampling and measurement activities. Continuous water level equipment was installed and is being telemetered through In-situ telemetry services.

Well 224227 (Leedey) was drilled on 10/23/2023 to a depth of 280 ft and screened 200-280 ft in the Rush Springs formation. After initial site investigation by the well driller utilizing his knowledge of the area, we realized the geology in the area and depth to the relevant formations was likely much more variable than represented by the geological maps and available boring logs. We suspected the site would need to be drilled a lot deeper than originally expected and considered moving the site. However, during the reassessment of alternatives, it was decided to go ahead with this location. The City of Leedey has no surface water resources and has been reliant on purchased water for decades, partly due to the variable geology but also the lack of reliable water quantity and quality data in the area. The city showed significant interest in the possibilities of the project about assessing the development of an aquifer for long-term use. The first attempt at the well did not yield water down to bedrock but an alternate site, 1100 ft southeast of the original was a success. The additional costs for the deeper well were covered through state funds.

In-kind work included all the planning and contracting work associated with Objective 5 including travel and staff time for site visits. This contribution was increased due to changes in locations and staff. A direct contribution to well drilling costs was included but was increased due to the increased depth of well 224227. Further work was planned for sampling 22 Rush Springs water quality sites. Unfortunately, the anticipated sampling of the Rush Springs was postponed due to the pandemic and could not be sampled during the project period. As discussed earlier in this report, this work was replaced with the sampling of 18 additional High Plains sites. Additional water level recorders and telemetry equipment have also been included in the drilled wells. Sampling of the entire Rush Springs is expected to occur in 2024 or 2025. Data will be made available to the NGWMN as it is processed and entered into AWQMS.

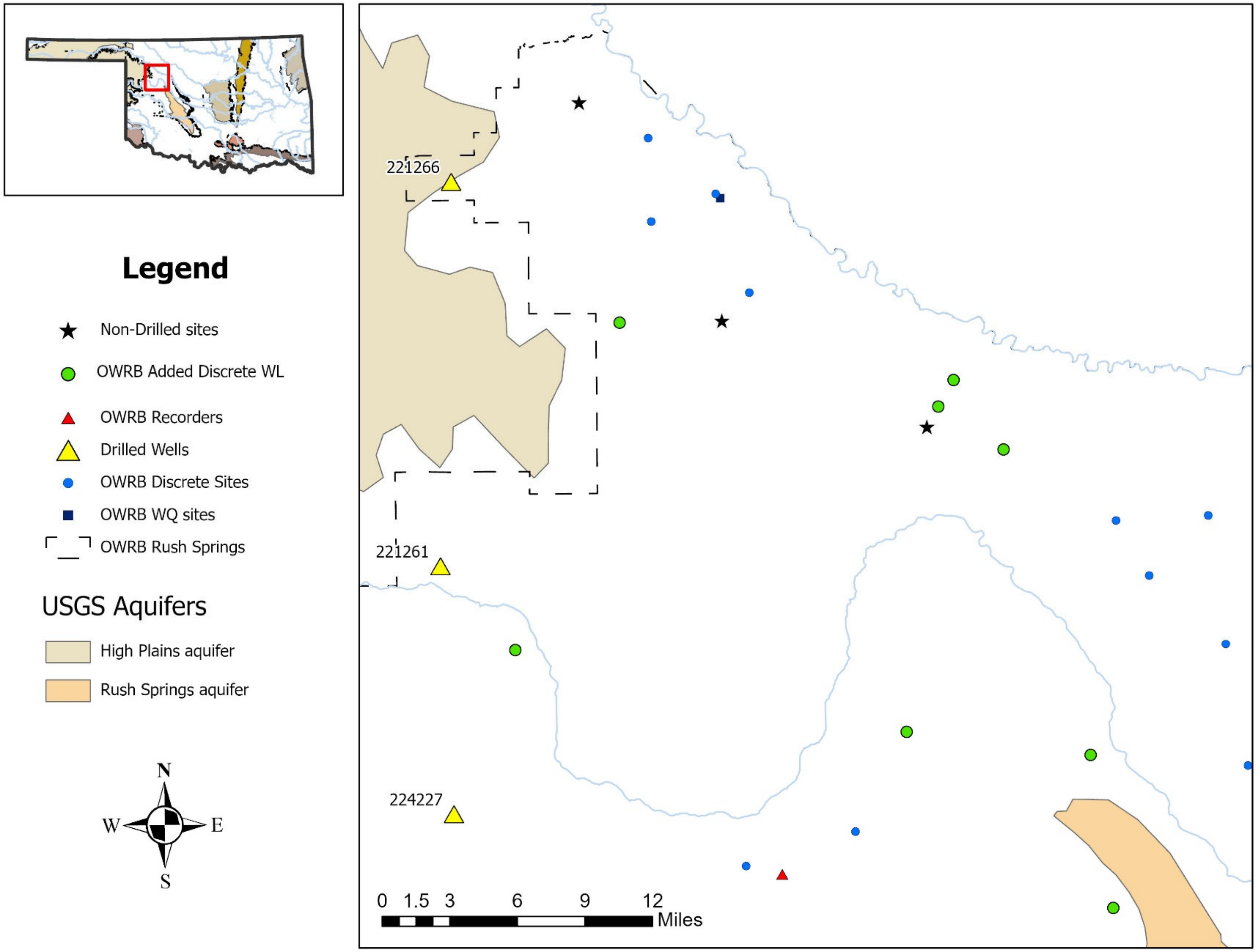

Figure 8: Map showing zoomed in portion of Figure 3 of the Rush Springs aquifer. This map is focused on the 3 continuous recorder sites that were drilled for the OWRB (yellow triangles). There are 3 sites that were proposed for drilling but for various reasons they were replaced by the completed drilled wells (black stars).

Figure 9: Well 221266 installed at Sharon Oklahoma, 06/07/2023.

Table 5: Well ID 221261, drilled 5/30/2023, with well lithology by depth, saturation and well screen location. See link for driller's log: https://www.owrb.ok.gov/wd/reporting/printreport.php?siteid=221261

Lithology Description Camargo Site				
Material	**Encountered**		**Saturated**	**Well Screen 110'-140'**
	From (ft.)	**To (ft.)**		
Topsoil	0	5	N	N
Sand - Fine to coarse grained	5	25	N	N
Sand - Fine to coarse grained with some pebble clasts	25	50	N	N
Sand - Fine to coarse grained with clay clasts	50	60	N	N
Sand - Fine to coarse with gravel	60	70	N	N
Red Sandy Clay	70	85	N	N
Red Sandy Clay with gypsum	85	100	N	N
Red Sandstone- fine grained, friable	100	106	Y	N
Gypsum	106	109	Y	N
Red Sandstone- fine grained with interbedded gypsum	109	140	Y	Y

Table 6: Well ID 221266, drilled 6/7/2023, with well lithology by depth, saturation and well screen location. See link for driller's log: https://www.owrb.ok.gov/wd/reporting/printreport.php?siteid=221266

Lithology Description Sharon Site				
Material	**Encountered**		**Saturated**	**Well Screen 170'-200'**
	From (ft.)	**To (ft.)**		
Topsoil	0	5	N	N
Sand - Fine to coarse grained	5	10	N	N
Clay	10	12	N	N
Sand - Fine to coarse grained	12	40	N	N
Red Clay	40	50	N	N
Red Very Fine-Grained Sandstone	50	60	N	N
Red Sandstone-Very Fine grained (RS-dry)	60	66	N	N
Red Sandstone- Very fine grained, (RS-wet)	66	70	N	N
Shale-Red	70	77	N	N
Rush Springs-Sandstone-very fine, red	77	80	N	N
Clay-red	80	90	N	N
Rush Springs-Sandstone-very fine, red	90	92	N	N
Clay	92	115	N	N
Rush Springs	115	117	N	N
Clay	117	124	N	N
Sandstone	124	130	N	N
Rush Springs	130	135	N	N
Sandstone	135	137	N	N
Clay	137	155	N	N
Clay Rush Springs	155	165	N	N
Rush Springs	165	168	Y	N
Clay Rush Springs	168	172	Y	N
Rush Springs	172	180	Y	Y
Clay	180	185	Y	Y
Rush Springs	185	188	Y	Y
Clay	188	190	Y	Y
Rush Springs Clay	190	200	Y	Y

Table 7: Well ID 224227, drilled 10/23/2023, with well lithology by depth, saturation and well screen location. See link for driller's log: https://www.owrb.ok.gov/wd/reporting/printreport.php?siteid=224227

Lithology Description Leedey Site				
Material	**Encountered**		**Saturated**	**Well Screen 200'-280'**
	From (ft.)	To (ft.)		
Topsoil	0	30	N	N
Clay/Shale	30	95	N	N
Sandstone	95	110	N	N
Gypsum	110	111	N	N
Clay and Shale	111	115	N	N
Sandstone	115	143	N	N
Gypsum	143	145	N	N
Clay/Sandstone	145	147	N	N
Gypsum	147	150	N	N
Sandstone	150	170	N	N
Gypsum	170	175	N	N
Sandstone	175	195	N	N
Clay	195	205	Y	Y
Rush Springs	205	210	Y	Y
Clay/Shale	210	225	Y	Y
Rush Springs	225	229	Y	Y
Clay/Sandstone	229	232	Y	Y
Rush Springs	232	239	Y	Y
Clay/Sandstone	239	255	Y	Y
Rush Springs	255	259	Y	Y
Clay/Sandstone	259	275	Y	Y
Rush Springs	275	280	Y	Y

Additional Information & Problems Encountered

As previously reported in the Final Report for the 2018 and 2019 grants there have been significant changes in the OWRB project and administrative staff during this project with some additional changes to be reported.

Mark Belden left OWRB with Chris Adams replacing him as Groundwater Monitoring Coordinator in 2020. Numerous other positions have been filled and refilled since this project first began in 2020 resulting in staff shortages for extended periods. The current structure of the group can be seen in the Appendix in Figure A1.

A significant period of work was impacted by the COVID-19 pandemic with reductions in field work capacity through 2020 and 2021. These included periods of complete shutdown during the early part of 2020 while OWRB developed procedures to allow field work to take place with reasonable precautions. Once field work could resume, staffing shortages were encountered when staff became infected or exposed with several periods where all field staff were quarantined.

Drilling of wells was impacted through the pandemic mainly through issues related to purchasing procedures, pandemic-related disruptions to office work, loss of original landowner permissions, and general shortages of well drilling capacity in Oklahoma.

Work on USGS projects was prioritized throughout the pandemic so all project work was completed. Additionally, state data generating programs related to the NGWMN were given a secondary priority and so data intended to be collected for inclusion in the network was also generated including water level measurements across the entire network. Statewide water levels were collected annually with all continuous water level data flows maintained. Water Quality work was focused on the High Plains aquifer with additional sites added to the original baseline characterization.

Summary & Future

Under Task 2, Oklahoma successfully added 43 new water level sites and 10 new water quality sites from the Rush Springs and Arbuckle Simpson aquifers to the NGWMN. These were some of the core wells in our program and complemented Oklahoma's existing coverage. Eighteen additional High Plains water quality sites were also added to the NGWMN. Camera surveys and aquifer tests performed under Objectives 3 and 4 helped fill metadata gaps across many wells. As previously found in the 2019 project, some wells were shown to be in poor condition or poorly connected to the aquifer of interest. This continues to highlight the importance of performing those types of checks whenever possible. Under Objective 5, three new wells were drilled and added to the water level and water quality networks. These wells fill critical data gaps in the Rush Springs aquifer.

The Oklahoma networks have been changing over recent years but also becoming more in line with the design of the NGWMN itself. The number of continuous water level data sites has been expanded, particularly in the High Plains aquifer with additional state-funded expansions planned during 2024 and 2025. An emphasis has been placed on data quality with an improved review of all data and a detailed upfront investigation of all sites before they are added to the networks. Fifty percent of all continuous data is now being telemetered leaving more time for review and analysis. The remaining sites are planned to move to telemetry during the summer and fall of 2024.

Many staffing changes have occurred at OWRB over the last five years and, although this has provided many challenges, we are hopeful that it can provide new opportunities as well. Specifically, we are working more closely with other OWRB sections and the Oklahoma State University Water Science Center to coordinate groundwater and surface water data flows, collaborate on technical work, and make our data as available as possible. We are seeking partnerships and input into our water quality network as we redesign to become both a conditional and trend program.

OWRB has no current NGWMN grants but we plan to seek additional funding to help maintain and improve the network as needed. An emphasis will likely be placed on maintaining and improving the current network which has been shown to be vulnerable to attrition from loss of landowner access and wells being poorly maintained and/or losing connection to their aquifers.

Appendix

Table A1: Objective 2 Part A wells added to the NGWMN in the water level and/or water quality networks.

National Aquifer Name	OWRB Site ID	Latitude	Longitude	Network
Rush Springs	106606	36.182276826	-99.203091250	Water Level
Rush Springs	131363	35.927152972	-98.599981073	Water Level
Rush Springs	19912	35.91711822	-98.978442085	Water Level
Rush Springs	19943	35.971779743	-99.287594065	Water Level
Rush Springs	20143	36.126571146	-98.951214014	Water Level
Rush Springs	23373	35.930721404	-98.686738427	Water Level
Rush Springs	62017	35.901147762	-98.833408354	Water Level
Rush Springs	103714	36.098347640	-98.899631508	Water Level
Rush Springs	85982	35.802891668	-98.816520843	Water Level
Rush Springs	146980	35.593582306	-99.033674589	Water Level
Rush Springs	20728	35.259305727	-98.653447161	Water Level
Rush Springs	5066	35.466888046	-98.293787432	Water Level
Rush Springs	3471	34.909465867	-98.217074409	Water Level
Rush Springs	3548	35.113849916	-98.456132977	Water Level
Rush Springs	3572	35.142439833	-98.299829029	Water Level
Rush Springs	3899	35.272654608	-98.519977498	Water Level
Rush Springs	4101	35.369974669	-98.532432361	Water Level
Rush Springs	9147	35.337999362	-98.426738091	Water Level
Rush Springs	9156	35.420933644	-98.442326983	Water Level
Rush Springs	21771	34.829292018	-98.137583134	Water Level
Rush Springs	4627	34.730259069	-97.966719413	Water Level
Rush Springs	4858	35.694306708	-98.546153997	Water Level
Rush Springs	30563	35.957719943	-98.671257265	Water Level
Rush Springs	30566	36.143393389	-98.938910125	Water Level
Rush Springs	138843	35.698150741	-99.06965078	Water Level
Rush Springs	3530	35.105242872	-98.394786771	Water Level
Rush Springs	9133	35.149131417	-98.400679465	Water Level
Rush Springs	9160	35.490353876	-98.567345041	Water Level
Rush Springs	29995	35.237726885	-98.605503379	Water Level
Arbuckle-Simpson	9638	34.588721887	-96.686923001	Water Level
Arbuckle-Simpson	12773	34.654127362	-96.815229659	Water Level
Arbuckle-Simpson	13741	34.417457950	-96.640319667	Water Level
Arbuckle-Simpson	26070	34.520596296	-96.631951578	Water Level
Arbuckle-Simpson	70487	34.366733689	-96.500363961	Water Level
Arbuckle-Simpson	85190	34.544123178	-96.622344604	Water Level
Arbuckle-Simpson	85191	34.564382013	-96.774549842	Water Level
Arbuckle-Simpson	86266	34.47693022	-96.936364779	Water Level
Arbuckle-Simpson	91510	34.404186398	-96.602712478	Water Level
Arbuckle-Simpson	93805	34.557287307	-96.852680217	Water Level
Arbuckle-Simpson	97279	34.377005041	-96.762341870	Water Level
Arbuckle-Simpson	99982	34.459113358	-96.933884411	Water Level
Arbuckle-Simpson	102726	34.481667513	-97.316260685	Water Level
Arbuckle-Simpson	137656	34.387057649	-96.975250852	Water Level
Arbuckle-Simpson	70487	34.366733689	-96.500363961	Water Quality
Arbuckle-Simpson	97279	34.377005041	-96.762341870	Water Quality
Arbuckle-Simpson	102726	34.481667513	-97.316260685	Water Quality
Arbuckle-Simpson	137656	34.387057649	-96.975250852	Water Quality
Arbuckle-Simpson	101354	34.370074146	-97.185145596	Water Quality
Arbuckle-Simpson	13744	34.410453500	-96.598949658	Water Quality
Arbuckle-Simpson	109810	34.547627677	-96.622705896	Water Quality
Arbuckle-Simpson	151683	34.565840142	-96.78175719	Water Quality
Arbuckle-Simpson	23565	34.513207953	-96.91534098	Water Quality
Arbuckle-Simpson	37183	34.644253584	-96.80310104	Water Quality

Table A2: Status and network for wells to be camera surveyed or slug tested through future work.

Site ID	Well Name	Latitude	Longitude	Principal Aquifer	Well Depth (ft)	Monitoring Category	Status	Network	Surveillance Start
2231	2231	36.75905557	-102.365094	High Plains	152	Surveillance	Discrete	WL	1/25/1967
9029	MM9029	35.52169379	-98.4610197	Rush Springs	238	Surveillance	Discrete	WL	2/22/1989
9191	MM9191	34.80219224	-97.9653518	Rush Springs	197	Surveillance	Discrete	WL	3/21/1990
9212	X9212	35.67089909	-98.7085853	Rush Springs	225	Surveillance	Discrete	WL	1/24/1990
9225	9225	35.5765907	-98.7775181	Rush Springs	360	Surveillance	Discrete	WL	3/20/1990
9235	9235	35.61327153	-98.73496	Rush Springs	300	Surveillance	Discrete	WL	1/16/1991
9244	X9244	35.46753761	-98.6719796	Rush Springs	440	Surveillance	Discrete	WL	1/15/1991
9249	MM9249	35.76511711	-98.9920851	Rush Springs	360	Surveillance	Discrete	WL	1/16/1991
9262	MM9262	35.07316552	-97.2997498	Central Oklahoma	220	Surveillance	Discrete	WL	9/18/1981
9271	MM9271	35.3615132	-97.2819208	Central Oklahoma	100	Surveillance	Discrete	WL	3/30/1979
9274	MM9274	34.77837079	-98.146038	Rush Springs	UNK.	Surveillance	Discrete	WL	3/15/1983
9289	MM9289	36.05461548	-98.7382994	Rush Springs	400	Surveillance	Discrete	WL	3/29/1979
9308	MM9308	35.83181871	-99.1064243	Rush Springs	405	Surveillance	Discrete	WL	3/21/1990
9309	MM9309	35.85337139	-99.0195781	Rush Springs	400	Surveillance	Discrete	WL	1/25/1990
9353	X9353	36.31528024	-99.691352	High Plains	193	Surveillance	Discrete	WL	1/31/1980
9364	9364	36.34858773	-99.6316816	High Plains	182	Surveillance	Discrete	WL	1/31/1980
9427	MM9427	34.74673642	-97.9226879	Rush Springs	180	Surveillance	Discrete	WL	3/26/1979
24814	MM24814	36.95079599	-101.316197	High Plains	280	Surveillance	Discrete	WL	1/23/1991
25659	MM25659	36.20090934	-99.1002886	Rush Springs	180	Surveillance	Discrete	WL	2/1/1989
25660	25660	36.26458086	-99.1260358	Rush Springs	180	Surveillance	Discrete	WL	2/1/1989
27648	MM27648	35.17536756	-98.8745025	Rush Springs	305	Surveillance	Discrete	WL	1/15/1991
27653	MM27653	35.03131634	-98.3562644	Rush Springs	135	Surveillance	Discrete	WL	3/14/1990
27670	MM27670	36.72197341	-101.136411	High Plains	300	Surveillance	Discrete	WL	1/13/1992
39407	MM39407	36.57395972	-101.690542	High Plains	443	Surveillance	Discrete	WL	1/19/2010

Table A3: Locations, well depths, networks, and years sampled for 36 High Plains water quality wells. Where relevant, water level surveillance and trend start dates given for reference.

Site ID	Well Name	Latitude	Longitude	Principal Aquifer	Well Depth (ft)	WQ Network	Years sampled	WL Network	WL Surveillance Start	WL Trend Start
1074	OGLLP-394	36.62067	-101.49143	High Plains	475	Surveillance	2016 & 2021			
1724	OGLLP-458	36.86651	-101.00863	High Plains	562	Surveillance	2016 & 2021			
4247	4247	36.54468	-100.50597	High Plains	320	Surveillance	2021			
5596	OGLLP-228	36.58185	-102.83969	High Plains	100	Surveillance	2016 & 2021	Surveillance	6/22/2016	
5634	OGLLP-070	36.87417	-100.27409	High Plains	320	Surveillance	2016 & 2021			
9219	OGLLP-187	36.64638	-102.22702	High Plains	407	Surveillance	2016 & 2021			
25493	OGLLP-184	36.66786	-102.45829	High Plains	249	Surveillance	2016 & 2021			
33708	OGLLP-076	36.94007	-100.90699	High Plains	280	Surveillance	2016 & 2021	Surveillance	8/16/2016	
33768	Hardesty	36.58564	-101.28035	High Plains	280	Potential Trend	2016 & 2021	Trend	1/6/2000	9/27/2022
45549	OGLLP-011	36.87698	-100.0434	High Plains	210	Surveillance	2016 & 2021			
52226	OGLLP-233	36.96565	-102.21194	High Plains	335	Surveillance	2016 & 2021			
58046	Forgan	36.89332	-100.51298	High Plains	160	Potential Trend	2016 & 2021	Trend	5/23/2016	8/28/2022
76401	OGLLP-390	36.67429	-101.33997	High Plains	491	Surveillance	2016 & 2021			
77649	OGLLP-388	36.97206	-100.9959	High Plains	640	Surveillance	2016 & 2021			
79548	OGLLP-071	36.57081	-100.01729	High Plains	175	Surveillance	2016 & 2021			
88196	OGLLP-409	36.51139	-102.03257	High Plains	431	Surveillance	2016 & 2021	Surveillance	1/15/2008	
91052	OGLLP-021	36.67916	-100.35946	High Plains	140	Surveillance	2016 & 2021	Surveillance	2/22/2016	
108847	OGLLP-369	36.94515	-101.84772	High Plains	433	Surveillance	2016 & 2021			
110093	Hough	36.86401	-101.60316	High Plains	380	Potential Trend	2016 & 2021	Trend	3/30/2016	8/30/2022
110941	110941	36.95361	-100.17806	High Plains	65	Surveillance	2021			
112100	OGLLP-441	36.63545	-101.85293	High Plains	228	Surveillance	2016 & 2021	Surveillance	8/30/2016	
113896	OGLLP-403	36.76088	-101.22275	High Plains	425	Surveillance	2016 & 2021	Surveillance	5/24/2016	
114386	OGLLP-049	36.68867	-100.22819	High Plains	168	Surveillance	2016 & 2021	Surveillance	5/23/2016	
120319	OGLLP-008	36.94289	-100.82012	High Plains	320	Surveillance	2016 & 2021	Surveillance	8/29/2016	
124829	OGLLP-208	36.53032	-102.55351	High Plains	262	Surveillance	2016 & 2021			
135142	OGLLP-218	36.74892	-102.41388	High Plains	265	Surveillance	2016 & 2021	Surveillance	6/21/2016	
137590	OGLLP-411	36.75494	-101.49069	High Plains	260	Surveillance	2016 & 2021	Surveillance	5/24/2016	
140592	OGLLP-028	36.58728	-100.90632	High Plains	180	Surveillance	2016 & 2021	Surveillance	2/22/2016	
141557	OGLLP-447	36.54336	-101.63397	High Plains	220	Surveillance	2016 & 2021	Surveillance	8/9/2016	
143670	OGLLP-380	36.99702	-101.21607	High Plains	696	Surveillance	2016 & 2021			
146758	OGLLP-020	36.51492	-100.71224	High Plains	300	Surveillance	2016 & 2021			
154632	OGLLP-407	36.89847	-101.35151	High Plains	662	Surveillance	2016 & 2021			
160331	OGLLP-199	36.58842	-102.06437	High Plains	437	Surveillance	2016 & 2021			
161298	OGLLP-368	36.97264	-101.51716	High Plains	576	Surveillance	2016 & 2021			
164896	OGLLP-189	36.89646	-102.10171	High Plains	380	Surveillance	2016 & 2021			
190646	190646	36.93465	-101.59603	High Plains	460	Surveillance	2021			

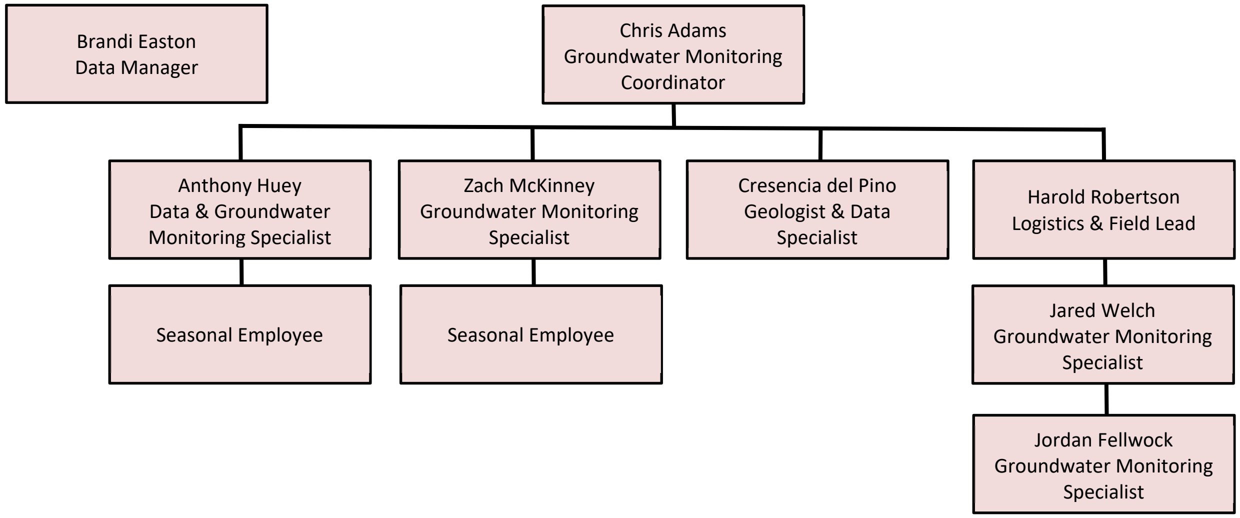

Figure A1: Organizational structure and roles of OWRB Groundwater Monitoring staff 2023-2024

Figure A2: Well ID 221266 Sharon site, drilled 6/7/2023

Figure A3: Well ID 221261 Camargo, drilled 5/30/2023

Figure A4: Initial Camargo site near Mesonet station, drilled 5/30/2023

Figure A5: Initial Leedey site location which was later abandoned, drilled 10/23/2023

Figure A6: Well ID 224227, Leedey site, drilled 10/23/2023