Cover Page

Award Number: G21AC10405

New Mexico Bureau of Geology and Mineral Resources (NMBGMR), at New Mexico Tech

New Mexico Bureau of Geology and Mineral Resources Groundwater Level Monitoring Network Year 5

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Term of award: September 15, 2021 to September 14, 2022

Date: January 5, 2023

Major Goals 2021-2022:

To support persistent data services as an existing data provider for the National Groundwater Monitoring Network (NGWMN) by adding new sites, maintaining current sites, maintaining web services, keeping the site list up to date, keeping metadata current, and providing updates to the NGWMN Data Provider page for the New Mexico Bureau of Geology and Mineral Resources (NMBGMR).

To begin serving continuous monitoring data to the NGWMN portal and to develop a new endpoint that serves data to the NGWMN portal via the GroundwaterML2 (GWML2) XML format.

To purchase and install 21 pressure transducer data loggers and barometer data loggers at selected NGWMN sites, replacing equipment deployed beyond the manufacturer's warranty.

Project Summary:

New Mexico Bureau of Geology and Mineral Resources was awarded Grant No. G21AC10405 to support persistent data services, update the data service format, and purchase continuous monitoring equipment. The period of work is between September 15, 2021 and September 14, 2022. Work included selecting additional sites for network inclusion, obtaining construction information, maintaining existing NGWMN sites, keeping metadata current, and providing updates to the NGWMN Data Provider page for the NMBGMR. The format of data served was updated to the GroundwaterML2 (GWML2) XML schema and data services were expanded to include continuous monitoring data served to the NGWMN portal.

Work done to support the NGWMN as a data provider:

For the year 2021-2022, our team focused on Objective 2 (supporting persistent data services) and Objective 6 (purchase of continuous monitoring equipment).

For Objective 2A, our team consists of an IT Manager, Database Administrator, Software Engineer, Hydrogeological Data Manager, Program Manager, and Research Scientist. With U.S. Geological Survey funds, the Hydrogeology Data Manager worked with our in-house Aquifer Mapping Program (AMP) database to keep the NGWMN sites up to date. The Hydrogeology Data Manager executed Quality Assurance/Quality Control (QA/QC) procedures on all data, helped review all data and, working with the Research Scientist and Program Manager, determined any additional well site selections. The Research Scientist contacted well owners for prospective wells and compiled the final report. The Program Manager assisted with QA/QC procedures and reviewed the final report. Their time was supported by federal U.S. Geological Survey funding.

We added four new sites to the monitoring network this year (Table 1; Figure 1). We added and categorized two sites located in the Roswell Basin aquifer system (NM-00367 and NM-00643) (Table 1; Figure 1). The sites are not currently visible to the public through the NGWMN web portal as we have yet to confirm lithology and formation. These steps will be completed in the next year through the review of well logs and local geology. As soon as this information is complete, the sites will be made visible. We added two wells in the Rio Grande Aquifer system. We added, categorized, and turned “on” one site (EB-373), and we added an additional site not yet categorized (PC-020) (Table 1; Figure 1). We acquired construction data for one site added to the NGWMN in 2020 (NM-00037) using a 1,000 foot-length Laval Underground borehole camera (R-CAM 1000 TLE Level Wind). We undertook this data collection using internal NMBGMR funds. We categorized the site and turned it “on” in the NGWMN data portal.

Table 1. Updates to NGWMN sites

Point ID	Principal Aquifer	Well depth (ft)	Subnetwork	Monitoring Category	Monitoring Frequency	Action
EB-373	Rio Grande aquifer system	300	Known changes	Trend	Continuous	Added, categorized, turned “on”
NM-00367	Roswell Basin aquifer system	246	Known changes	Trend	Continuous	Added, categorized
NM-00037	Rio Grande aquifer system	518	Known changes	Trend	Continuous	Construction information added, categorized, turned “on”
NM-00643	Roswell Basin aquifer system	231	Known changes	Trend	Continuous	Added, categorized
PC-020	Rio Grande aquifer system	320	Not categorized	Not categorized	Continuous	Added

The IT Manager and Database Administrator provided persistent web services, backups, and database support. The Software Engineer insured correct data transfer from the AMP database to the NGWMN portal and periodically checked user load on the network. Their time was supported by federal U.S. Geological Survey funding. This team structure proved effective in maintaining a high quality standard of data submitted to the NGWMN.

Under Objective 2B (Occasional work need to upgrade services or add new services), the Software Engineer and Database Administrator updated the web service to provide data using GroundwaterML2 (GWML2) XML schema data standards (https://docs.ogc.org/is/19-013/19-013.html). The GWML2 documents are generated dynamically from the NMBGMR’s database using a combination of SQL and Python scripting.

The Software Engineer configured the Flask application to begin serving continuous monitoring data to the NGWMN Portal. Continuous water level monitoring data is collected using 10-meter range DI501 and DI801 TD-Diver pressure transducers made by Van Essen Instruments. The pressure transducers record water depth at least once every 12 hours. The Flask application is configured to serve one measurement per day to the NGWMN portal. If multiple measurements are collected on the same day, the minimum depth below-ground-surface (bgs) measurement is served to the NGWMN portal. The continuous depth-to-water measurements at each well site are

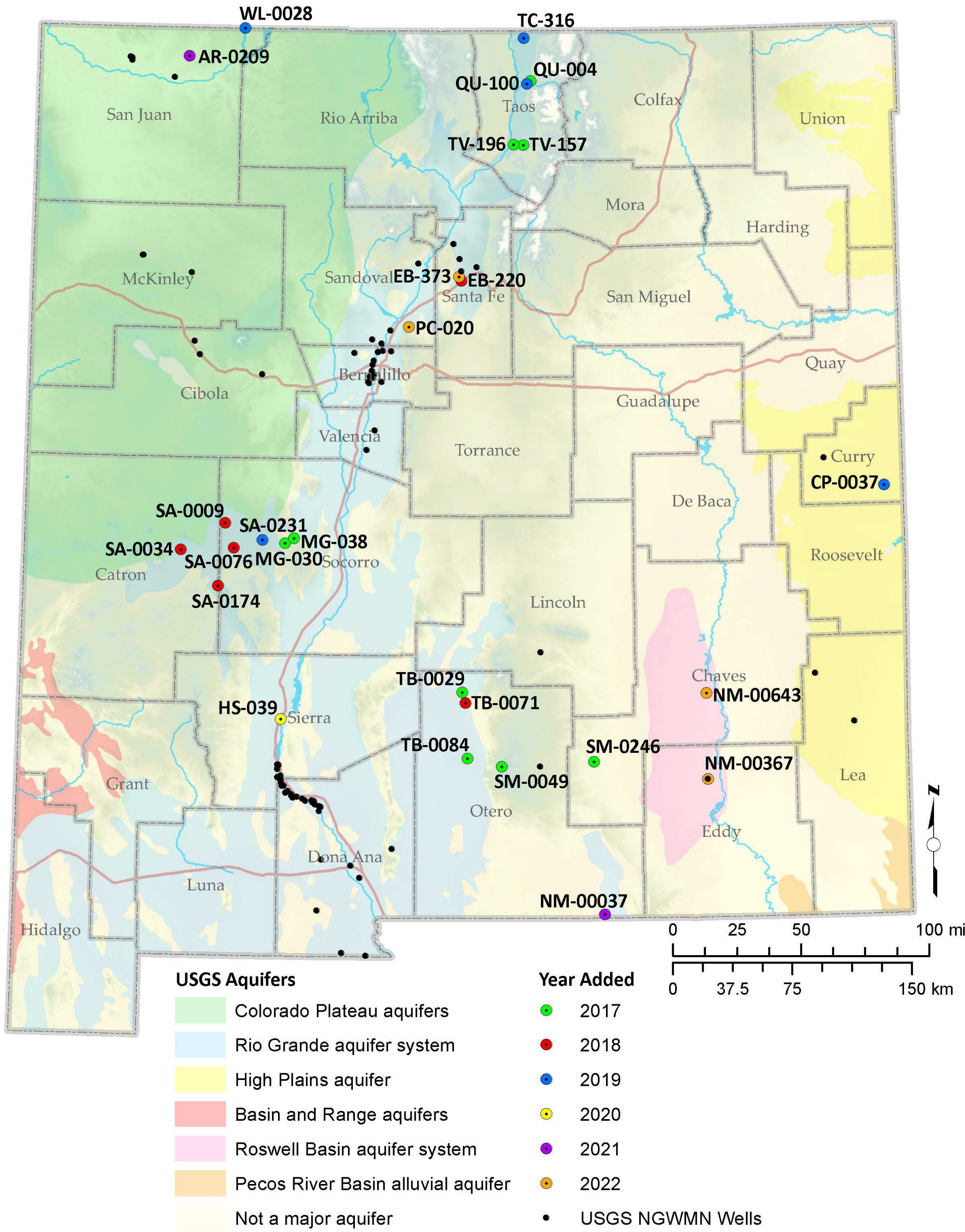

Figure 1. Principle aquifers, USGS NGWMN sites and NMBGMR sites selected for inclusion in the NGWMN in 2021-2022 (orange).

confirmed using manual measurements collected annually. The methods for collecting and processing continuous water level data, and for conducting QA/QC procedures are detailed in a technical report (Appendix A).

Under Objective 6 (Equipment Purchases), we purchased a total of 21 pressure transducers to replace aging equipment previously deployed as part of the NMBGMR's statewide Healy Collaborative Groundwater Monitoring Network. We purchased twelve DI801 TD-Diver Data Loggers with a range of 10 meters manufactured by Van Essen Instruments using federal U.S. Geological Survey funding. The purchased data loggers replaced equipment at selected sites (Table 2) likely to fail due to age. We also purchased nine D1800 Baro-Diver Data Loggers from Van Essen Instruments using in-kind matching funds to replace deployed barometers older than the manufacturer's warranty. Barometers are used to correct the TD-Diver pressure readings by removing atmospheric pressure to isolated static water pressure (see Appendix A for procedure details). Pressure transducers and barometers previously deployed in NGWMN wells that were still within the manufacturer's warranty period were not replaced. Therefore, in some wells pressure transducers were replaced while previously deployed barometers were not, and vice versa. The pressure transducer and barometer data is processed through in-house software to produce depth-to-water measurements confirmed by manual measurements (see Appendix A for the procedure details).

The Hydrogeological Data Manager purchased the equipment with time supported by in-kind matching funds. Two NMBGMR Hydrogeologists and a Hydrogeological Field Technician installed the equipment in the selected wells. In-kind matching funds supported their time and travel expenses. The Research Scientist documented the purchases and installations in the final report with time supported by federal U.S. Geological Survey funds.

We were unable to deploy a pressure transducer and barometer as planned in well SA-0076 located in the Rio Grande Aquifer system. The USGS New Mexico Water Science Center added site SA-0076 to the long term monitoring Climate Response Network (CRN) and installed continuous monitoring equipment. In order to use available resources more efficiently, we instead installed the pressure transducer and barometer in site AR-0209, a dedicated monitoring well located in the alluvial aquifer associated with the San Juan River in Northern New Mexico (Table 2; Figure 2). Due to this unexpected challenge, the monitoring equipment was installed in AR-0209 outside of the grant period using NMBGMR funds (installation occurred on November 30, 2022). Well SA-0076 will remain a manually measured groundwater monitoring site in the NGWMN in order to maintain data continuity, however, continuous data are now available from the USGS CRN.

The NMBGMR team continued to work closely with the USGS NM Water Science Center and the NM Office of the State Engineer. Together, we identified sites that overlap with existing monitoring efforts (i.e. SA-0076) so as to use resources more efficiently and avoid duplicating submissions to the NGWMN.

Working with these federal and state entities ensures we ultimately achieve representative water level monitoring coverage throughout the state.

Table 2. Sites selected for continuous monitoring equipment.

Site Number	Principal Aquifer	Monitoring Category	Well Characteristics	Well depth (ft)	Equipment	Date of Installation
AR-0209 (SA-0076 replacement)	Not a major aquifer	Trend	Background	20	Pressure transducer; barometer	11/30/2022
CP-0037	High Plains Aquifer	Trend	Known changes	400	Pressure transducer	03/01/2022
EB-220	Rio Grande Aquifer System	Trend	Suspected/ Anticipated changes	161	Pressure transducer	04/05/2022
HS-039	Rio Grande Aquifer System	Trend	Background	27	Pressure transducer	03/22/2022
MG-038	Not a major aquifer	Trend	Known changes	135	Pressure transducer	05/24/2022
QU-004	Rio Grande Aquifer System	Trend	Background	500	Barometer	04/13/2022
QU-100	Rio Grande Aquifer System	Trend	Background	30	Pressure transducer; barometer	04/13/2022
SA-0009	Rio Grande Aquifer System	Trend	Background	297	Pressure transducer	02/23/2022
SA-0076	Rio Grande Aquifer System	Trend	Background	284	No equipment installed	None

Table 2., continued. Sites selected for continuous monitoring equipment

Site Number	Principal Aquifer	Monitoring category	Well characteristics	Well depth (ft)	Equipment	Date of Installation
SA-0231	Rio Grande Aquifer System	Trend	Background	30	Pressure transducer; barometer	02/21/2022
SM-0049	Not a major aquifer	Trend	Background	298	Barometer	01/19/2022
SM-0246	Not a major aquifer	Trend	Background	22	Barometer	01/19/2022
TB-0029	Rio Grande Aquifer System	Trend	Suspected/ Anticipated changes	724	Pressure transducer; barometer	01/20/2022
TB-0071	Rio Grande Aquifer System	Trend	Suspected/ Anticipated changes	651	Pressure transducer	01/20/2022
TC-316	Rio Grande Aquifer System	Trend	Suspected/ Anticipated changes	384	Barometer	04/13/2022
TV-157	Rio Grande Aquifer System	Trend	Suspected/ Anticipated changes	230	Pressure transducer	04/13/2022
TV-196	Rio Grande Aquifer System	Trend	Suspected/ Anticipated changes	450	Pressure transducer	04/13/2022
WL-0028	Colorado Plateaus Aquifers	Trend	Background	160	Barometer	02/09/2022

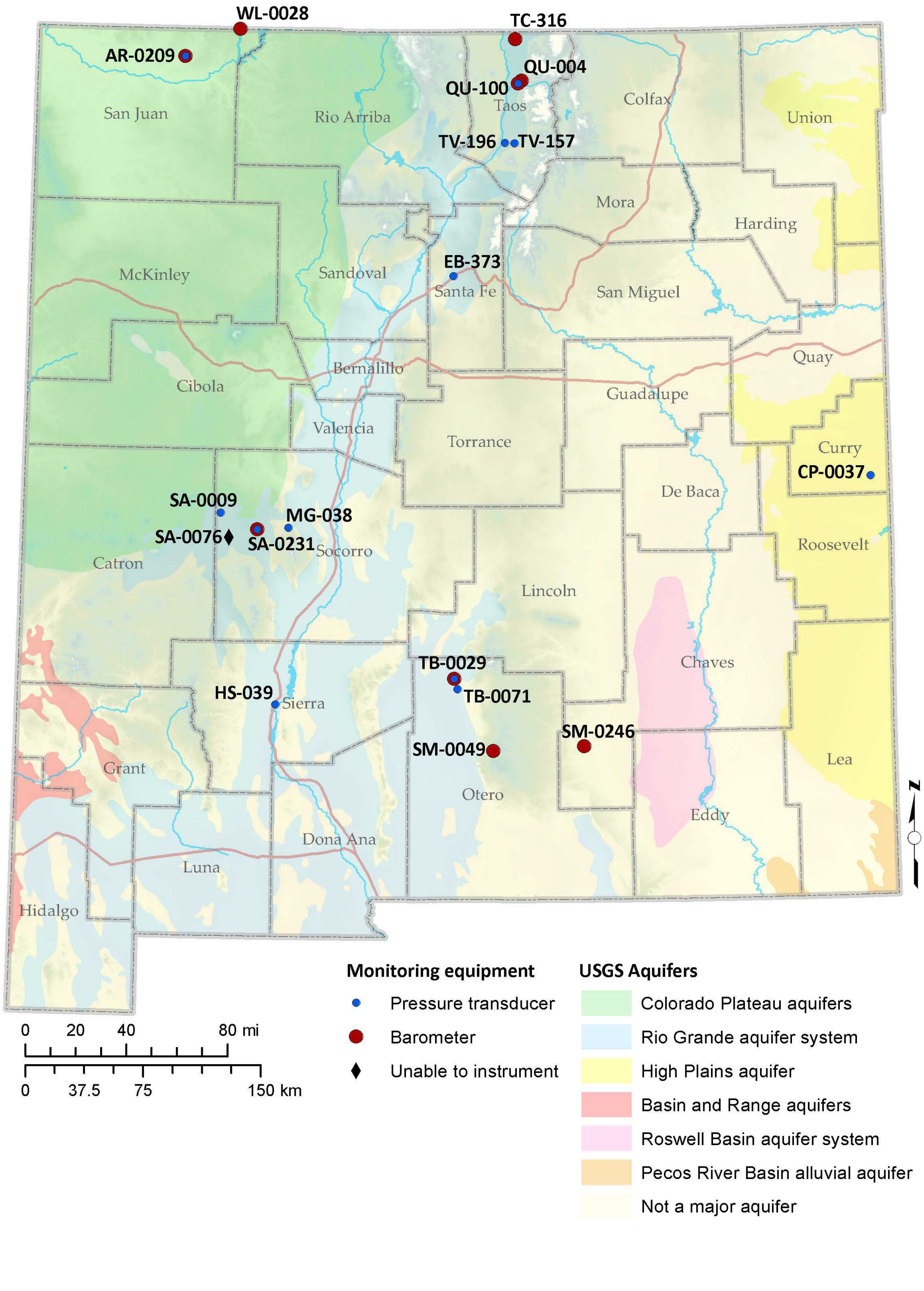

Figure 2. Principle aquifers and NMBGMR sites selected for pressure transducer (blue) and barometer (red) installation. Note well SA-0076 where we were unable to install equipment.

Completed data collection:

As with our inaugural year (2017-2018), a variety of data collection and database maintenance tasks were performed. Field work was done to collect manual measurements using standardized methods. Field sheets and notebooks were copied or scanned upon return to the office and stored on the NMBGMR network server where they are backed-up daily. Within two weeks, quality checks were performed and the data was entered into the AMP database. All well locations, well construction information, and manual water level data are maintained in the AMP database and the data fields are aligned with those in the NGWMN database. We maintained a reliable database link between the AMP database and the NGWMN database. All efforts to provide data to the NGWMN complement the NMBGMR mission to provide water level data to the public.

The NMBGMR team consisted of a Hydrogeological Data Manager, a Program Manager, a Research Scientist, a Hydrogeological Field technician, two Hydrogeologists, a Software Engineer, a Database Manager, and an IT Manager. USGS funds supported selection and classifying of wells in the network, upgrading and expanding web services, the purchase of continuous monitoring equipment, and documentation of work in the final report.

Updates made to web services:

The database link between the AMP and NGWMN databases enables relevant data tables to relate directly to the NGWMN tables. This information smoothly relates to the data requirements in the NGWMN database. Web services were upgraded to provide continuous monitoring data and to provide all data in the GroundwaterML2 (GWML2) XML format. Three full-time staff are dedicated to providing support for core IT infrastructure for the NMBGMR. IT staff worked with the AMP team on the NGWMN thanks to financial support provided by the USGS.

Problems encountered in serving data to the NGWMN data portal:

None

Notice of changes in databases or web services that would impact future integration with data portal:

The AMP SQL database will undergo a major upgrade in January 2023. We anticipate minimal disruption of data flow to the NGWMN.

Conclusions:

The NMBGMR is successfully connected to the USGS NGWMN, and is now showing 23 sites on the USGS website and has a total of 27 sites serving data to the NGWMN portal. The NMBGMR will continue to grow and add new sites, as well as improve data quality at existing sites. We look forward to continuing to work with the USGS toward this important endeavor for a national coverage of groundwater monitoring.

APPENDIX A

Procedure for Collecting and Processing Continuous Depth-to-Water Data

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Jake Ross, Software Engineer II
Geoffrey Rawling, Senior Field Geologist

December 2022

CONTENTS

Background

At the New Mexico Bureau of Geology and Mineral Resources (the "Bureau"), we use continuous pressure transducers in open, non-pumping, monitoring wells to collect records of groundwater levels (referred to here as "water level"). We use the term "continuous" to refer to data collected at regular time intervals by instruments installed in wells. Continuous records of water levels fill in the hydrograph between manual measurements and they vastly improve our understanding of the hydrologic controls of an aquifer (Figure 1). These continuous hydrographs can help identify influences on an aquifer such as: seasonal variation, pumping, river stage, recharge influences and timing of recharge.

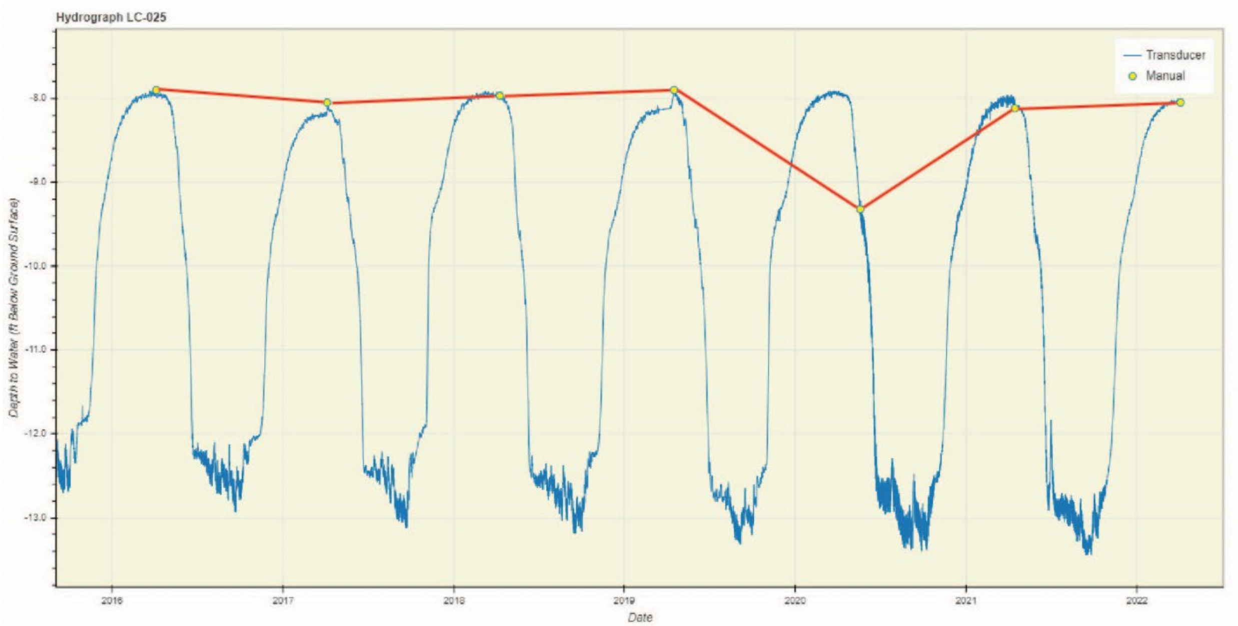

Figure 1. Example of a hydrograph that exhibits a strong seasonal trend. Without a continuous hydrograph the water levels in the well would appear static (as illustrated by the red line connecting the manual data measurements).

Procedures and Analysis

Instrumentation

The Bureau typically deploys Van Essen TD-Divers (model # DI801) to record continuous pressure and temperature data at a fixed point in a well, beneath the water level. Van Essen Baro-Divers (model # DI800) report a continuous record of the atmospheric pressure and temperature at the top of a well. Moving forward we will refer to these instruments as 'Divers' and 'Baros' respectively. The Divers typically have a 10 meter range, a reported accuracy of 0.5 cmH_2O and a resolution of 0.06 cmH_2O (Figure 2). Baros have a range of 1.5 meters, a reported accuracy of 0.5 cmH_2O, and a fine resolution of 0.03 cm H_2O (Van Essen Instrumentation B.V., Delft, The Netherlands).

Pressure Transducer Instrumentation

For monitoring surveillance, background or trend groundwater levels in wells, the wells selected for monitoring must meet several criteria prior to instrumentation with a pressure transducer. First, we must have permission from the well owner to access their well and consent that the data collected at the well will be made publicly available. Second, we require that it is an 'open well,' or a well that is unequipped and does not have a pump installed, in order to record static water level trends free of pumping signals. Pumps or other equipment in a well also complicate our ability to safely install and remove instruments from the well.

We must next determine the optimal hanging depth or "hanging point" for the Diver in the well. The hanging point is the elevation in the well at which the diver will be suspended by cable or line. The optimal hanging point ensures the Diver stays submerged in water, but is not 'overpressurized' past the operating range of the Diver (10 meters of overlying water pressure). First we must measure the depth to water in the well to help determine the hanging point. Generally, we deploy Divers roughly halfway between the maximum pressure range of the diver and the water surface. For example, if the measured depth to water is 50 meters, we would hang a Diver (with a 10m range) on roughly 55 meters of line. This ensures that if the water level is dropping, there is at least 5 meters of water above the instrument, ensuring the instrument will remain submerged. If water levels are instead rising, the Diver will measure the rise in pressure up to its maximum range, allowing 5 meters of recovery, after which the Diver simply records the maximum pressure. We use a marine-grade Dyneema® line to hang the Divers. We selected this line because it is resistant to ultra-violet radiation (which can be an issue at the wellhead) and has almost no stretch, thereby ensuring the Diver remains at the intended depth.

Barometers are typically installed at the top of the well, hanging in the open casing near the well cap. Ideally, every well would have both a Baro and a Diver, the broad spatial extent of atmospheric pressure conditions allows the use of one Baro for a region containing multiple monitored wells. In general, a barometer record can be used within a 20 mile radius between wells at similar elevations.

In most instances, Divers and Baros are programed to record pressure and temperature every 12 hours; at 12 am and 12 pm. This allows us to capture any diurnal trends that may be present.

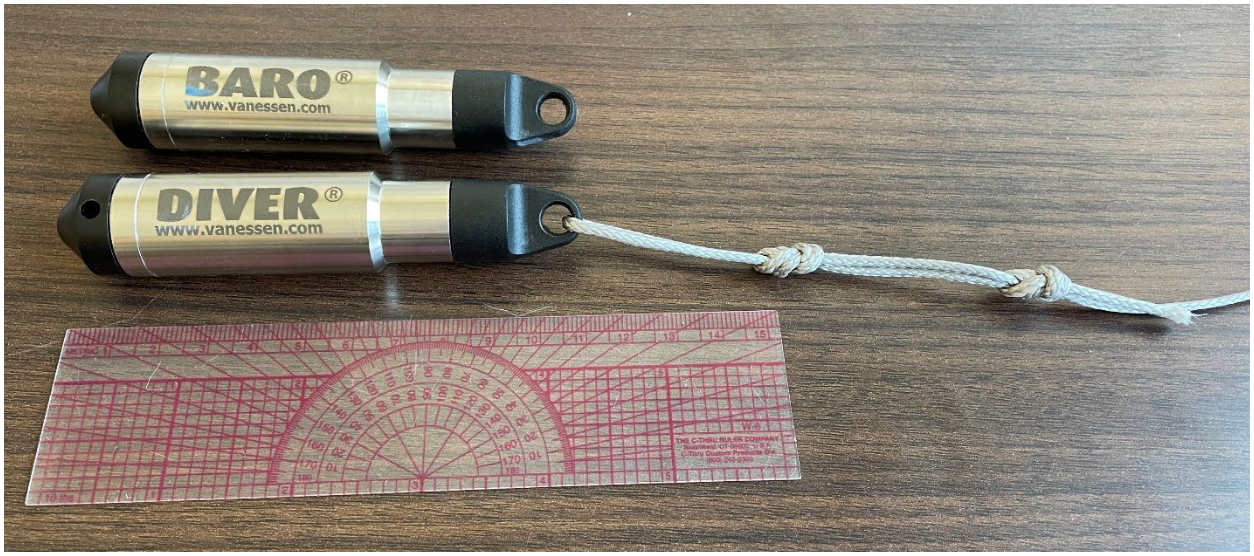

Figure 2. Example of a Diver and a Baro, as well as the Dyneema® line that is used to hang the instruments in the well.

Field Data Logger Methodology

Typically, wells with Divers installed are visited once per year, at which time we collect a manual water level measurement, and download the pressure and temperature data from the Baro and Diver. Measurement protocols developed by the U.S. Geological Survey are used to manually measure water levels in wells using an electric tape or a graduated steel tape to obtain repeat measurements within 0.02 ft (Cunningham and Schalk, 2011). If water level measurements are not repeatable within 0.02 ft, notes are made and entered into database suggesting that these measurements were of lower data quality. This may happen for various reasons, such as when the well is pumping, recovering, or a nearby site is being pumped. Following the data download, we assess the health of the data logger. The reliability of the device decreases dramatically once the Diver's battery drops below 75%, necessitating unit replacement. Additionally, we conduct a cursory evaluation of the data. First, we evaluate if the hanging point is still suitable. By examining the downloaded hydrograph, we can determine if the Diver remained within the acceptable depth and pressure range, with the goal that it remained beneath the water surface and did not get submerged past the acceptable range. If the water level is dropping or rising, we may modify the hanging point to ensure the Diver remains at the optimal depth as the water level changes. We have found that pressure readings may begin to drift as the instruments age (Figure 3). We perform a quick field check of the data by calculating the change in water level between the previous manual measurements, and the first and last Diver measurements. If the measured change in water level agrees between the two measurement methods we know the Diver is working properly. If we believe the instrument has started to drift, we will replace the installed unit with a new Diver.

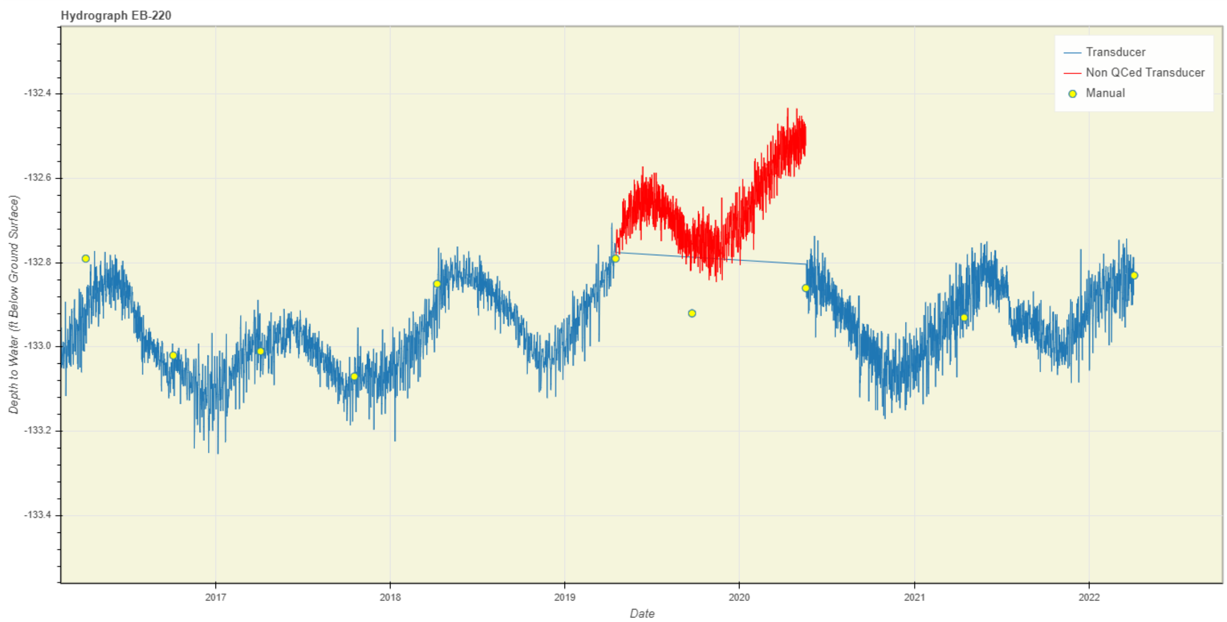

Figure 3. In this example, it appears the datalogger began drifting after being downloaded in April, 2019 (see red section of hydrgraph). In May, 2020 the datalogger was replaced when it was determined the instrument was beginning to fail. Manual measurements are noted with the yellow points.

Data Processing and Procedures

Once we return to the office, the Diver and Baro data are backed up and loaded into our main Diver Office database on the Bureau network. Diver Office is the main software package provided by Van Essen that acts as a database and can perform barometric compensations. A pressure transducer in a well measures total pressure, which consists of both the pressure of water above the diver and the barometric pressure of the atmosphere. Therefore, barometric compensation is required to accurately determine the true change in water level recorded by a pressure transducer. To perform a barometric compensation, the user must first select which Baro file was recorded closest to the Diver file that is being barometrically compensated. The software takes the atmospheric pressure recorded by a Baro and subtracts it from the total pressure recorded by the Diver in the well. The calculation also accounts for water temperature in order to convert pressure readings to water head that is equal to the depth of water above the pressure transducer. Once the records have been compensated, they are exported as CSV files containing a record of the 'Water column above diver' or diver pressure head and temperature.

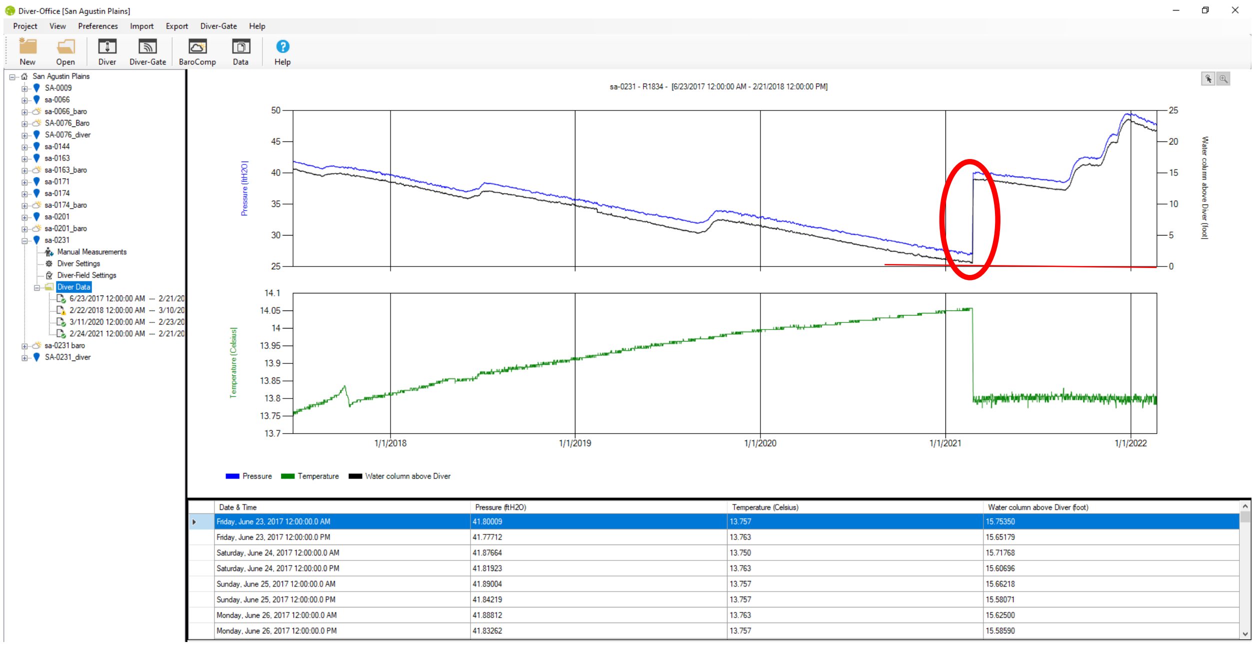

Figure 4. This shows the Diver Office graphic user interface (GUI). On the left, you can see all of the Divers and Barometers in a given geographic region. The graph shows how the hanging point was adjusted in early 2021 because the 'Water column above Diver' (the black line) had nearly dropped to zero. As result of the water level almost dropping below the elevation that the Diver was hanging, the hanging point was lowered as to keep the diver submerged.

Traditionally, the data are next brought into Microsoft Excel and a researcher would manually convert the compensated pressure head data to a Depth to Water (DTW) measurement using the following equation (1):

DTW(ft) = Hanging Point(ft) - Diver Pressure Head(ft) (1)

This method requires that the 'Hanging Point' of the pressure transducer remains exactly the same following each download. In practice, however, this measurement frequently shifts by a few centimeters after each re-installation, which introduces complexity when removing the offset manually. Additionally, as data files grow larger they become increasingly cumbersome to manage and access effectively. To improve this process, application development staff with the Bureau developed a python application called 'Wellpy'. Wellpy is a simple GUI tool designed to address the issues the New Mexico Bureau of Geology faces when handling and processing growing quantities of data. Wellpy is an open source project hosted at https://github.com/NMBGMR/Wellpy.

To use Wellpy for visualizing and correcting the continuous data, the CSV files generated by Diver Office are first imported into Wellpy via a standard file explorer window. The program extracts the measurements and necessary metadata from the CSV file, then for a given well automatically loads all existing manual water level measurements, and previously processed pressure data entered in our database (Figure 5).

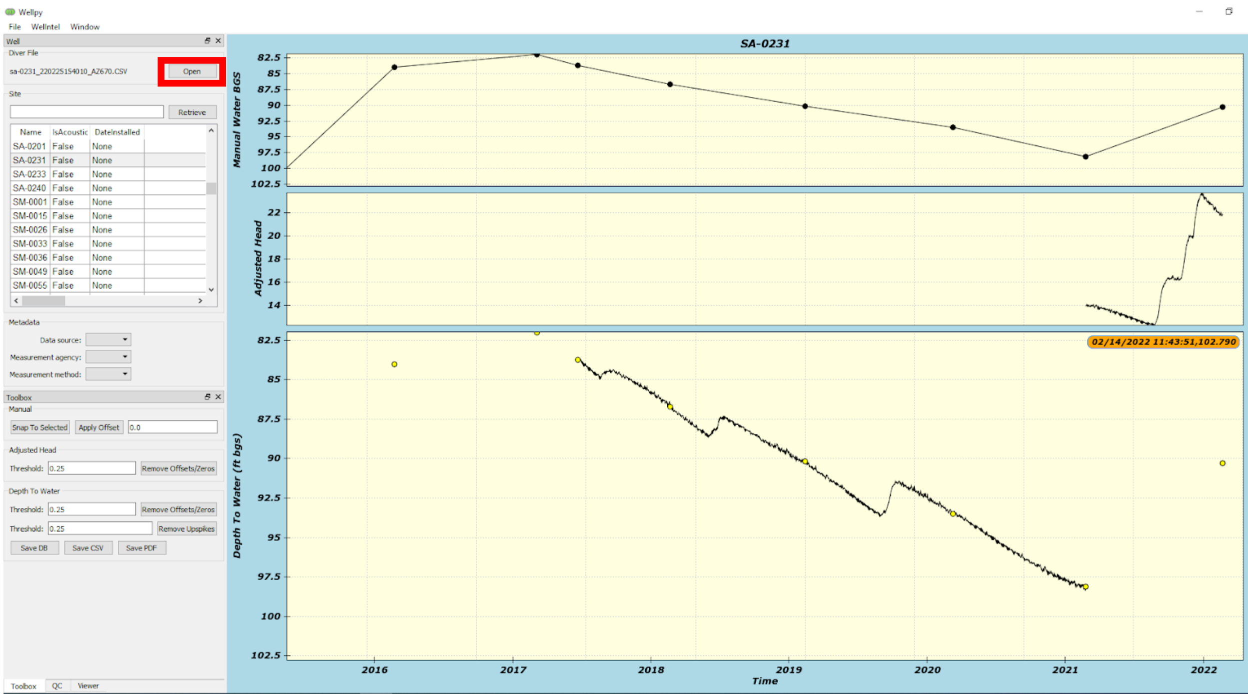

Figure 5. After Diver data has been barometrically compensated and exported using Diver Office the .CSV file is loaded into Wellpy. Existing manual measurements for the given well are displayed in the top graph. The new data that was just imported into Wellpy is displayed in the middle graph. The previously processed continuous data and manual measurements are plotted in the bottom graph.

The program then allows the user to select a manually measured DTW to process the data with. Because we collect a manual DTW measurement every time we download the Diver, there is a manual measurement bounding each continuous time series that we process. By selecting a manual DTW measurement and triggering the 'Snap to selected' button (Figure 6), we are giving the program a value to calculate an artificial hanging point with the following equation (2):

$$\text{Calculated Hanging Point(ft)} = \text{Manual DTW(ft)} + \text{Diver Pressure Head(ft)} \quad (2).$$

We have a significantly higher confidence in the precision and repeatability of a manual DTW measurement compared to a measured hanging point. Measured hanging points can be shifted up or down if there is a slight changes to how the string is routed as it goes back into the well. These slight changes introduce error into the calculation and time series typically won't correctly line up making them less reliable. Once the calculated hanging point is determined, the program applies equation 3 to the time series data to convert Diver pressure head to DTW over the entire time series (Figure 6).

$$\text{Time series DTW(ft)} = \text{Calculated Hanging Point(ft)} - \text{Diver Pressure Head(ft)} \quad (3)$$

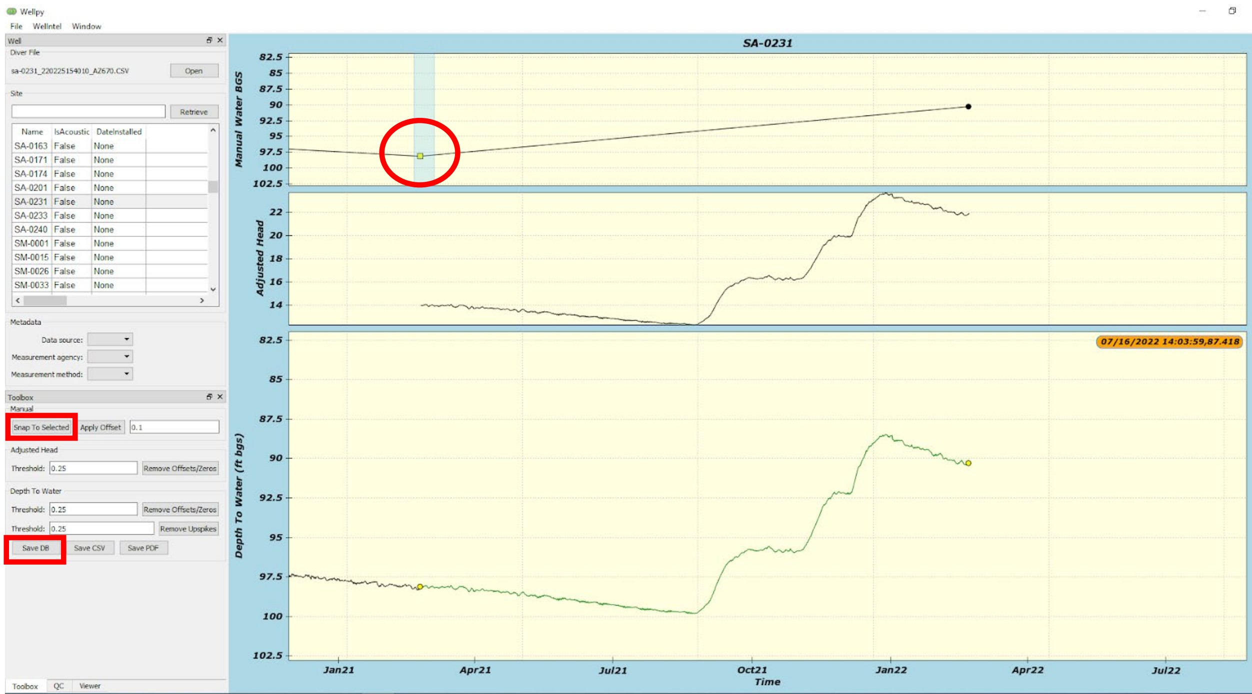

Figure 6. In the top graph, a manual measurement is selected to be used as the 'calculated hanging point'. When the 'Snap to Selected' button is clicked the pressure data in the second graph is processed and the data is then displayed as 'Depth to Water' in the bottom graph in green. When we are satisfied with the fit the 'Save DB' button saves the time series to our database.

This method of data adjustment using Wellpy has been very helpful in the early detection of drifting data loggers. If both manually measured DTW measurements that bound the time series have a high Data Quality classification (steel tape or electric tape measurements within two hundredths of a foot), but the graph does not pass through both measurements, we can be reasonably certain there is a problem with the data logger or the barometer it was compensated with (Figure 3). If this is the case, we do not upload the data to our database and the Diver is replaced when we next visit the site. If the continuous DTW measurements appear hydrologically sound and pass through both manual DTW measurements, the time series is uploaded to our database as provisional data until a quality review is complete.

Quality Control Process

Once the time series has been uploaded and marked as provisional, a hydrogeologist at the Bureau reviews the data, or conducts data quality control (QC) review. This colleague is tasked with ensuring the hydrographs make hydrologic sense, confirming the continuous time series data match the manual measurements, helping catch any other problems with the data that may occur. This colleague is not involved in the collection or processing of the manual and continuous data, and therefore can provide an independent assessment of the results. Possible drifting of transducers, mismatch of manual and continuous measurements, "spikes" or other clearly unusual or "non-natural" appearing aspects of the data are flagged for further review by the original analyst. When the hydrograph has been approved the data can be released to the public. Data are marked as "approved" in the database and then can be shared publicly via API, through sites like the USGS National Groundwater Monitoring Network, or the NM Bureau of Geology webmap (http://maps.nmt.edu).

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Van Essen Instrumentation B.V., Delft, The Netherlands, https://www.vanessen.com/products/data-loggers/baro-diver/