Establishing Alabama as a Data Provider to the U.S. Geological Survey National Groundwater Monitoring Network

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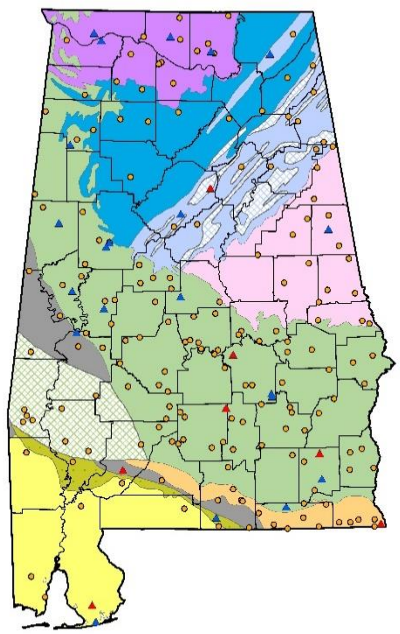
September 1, 2018, to August 31, 2020



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Geological Survey of Alabama Open-File Report 2011

November 25, 2020

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1.0 Background information

1.1 Description of Agency and Purpose of Monitoring

The Geological Survey of Alabama (GSA) has provided services and information to Alabama and its citizens as a natural resource data gathering and research agency since its establishment in 1848 (GSA, 2017). As part of its mission, the GSA explores and evaluates the mineral, water, energy, biological, and other natural resources of the State of Alabama, and conducts basic and applied research in these fields (GSA, 2017). Natural resource investigations of both groundwater and surface water began in 1898 when the GSA, in cooperation with the U.S. Geological Survey (USGS), began a systematic evaluation of the state's water resources (Johnston, 1933). For the past several decades, the GSA has published many reports related to both groundwater and surface water resources in Alabama.

The GSA Groundwater Assessment Program (GSA-GAP) has two ongoing monitoring programs: real-time and periodic. Collected data are made available to the public through an online portal and to other state agencies such as the Drought Monitoring and Impact Group (MIG) of the Alabama Drought Assessment and Planning Team (ADAPT). Semi-annual water levels collected for the periodic monitoring program are used to create snapshots for specific aquifers and/or locations that have demonstrated impacts due to pumping, land use, and/or drought stressors. These programs are detailed in *An Assessment of Groundwater Resources in Alabama, 2010-2016 (*GSA, 2018), which contains a detailed compilation of aquifer characteristics and groundwater wells monitored across the state. As described in the program design section of Appendix 2 of *A National Framework for Ground-Water Monitoring in the United States*, (Subcommittee on Ground Water (SOGW), 2013), Alabama utilizes the major regional aquifer physiography to delineate groundwater flow regimes across the state.

The GSA began systematically installing real-time monitoring equipment in wells throughout the state in 2010 to monitor and assess groundwater levels that provide data on groundwater responses to water use, land use changes, and natural stressors. The NGWMN is a national database of vetted groundwater quality data presented in the same format to facilitate scientific research and the discernment of large-scale groundwater patterns. Providing the GSA's groundwater monitoring network data in the USGS National Groundwater Monitoring Network (NGWMN) format to view readily alongside adjacent states may reveal regional aquifer conditions within the southeastern region of the United States. This knowledge has the potential to lead to a better understanding of groundwater conditions, support water management decisions, and provide insight about groundwater responses to climatic changes in the region.

1.2 Projects with NGWMN

The project summarized herein is the first project that the GSA has conducted for the USGS NGWMN. The contract period spanned two years under Award #G18AC00066, and work began September 1, 2018. This report represents the completion of the project, and documents work performed in accordance with the proposal guidelines (Hinson and others, 2018).

The Objective 1 task for the project, to select and classify Alabama wells for inclusion in the NGWMN has been performed. The Objective 1 project work included selecting appropriate sites that meet the goals of the NGWMN, classification of the sites, entering site information into the NGWMN database, and establishing web services with the USGS NGWMN data portal. All project work for the NGWMN was completed by August 31, 2020.

The Objective 2 tasks of providing persistent data services to the NGWMN and keeping those well records current, were completed during the second project year. The GSA-GAP staff prepared an interim progress report that was submitted to the USGS in September 2019.

This final written report documents the services performed for both Objectives 1 and 2, in fulfillment of the current contract for the USGS NGWMN.

2.0 Overview of work

The NGWMN is a national portal created and maintained by the USGS to establish an online network of selected wells that monitor groundwater conditions in principal aquifers across the country. The principal aquifers across the United States were first identified and described in the *Groundwater Atlas of the United States, Miller, 1990*, and Alabama has water-bearing strata in eight of these principal aquifers. The purpose of the national network is to facilitate better management and provide basic scientific research data of known quality on groundwater resources. The NGWMN serves data in a consistent format through a single national data portal from various sources of vetted data, which include measurements collected by various local, state and federal agencies. The frequency of water-level measurements is designed to discern seasonal fluctuation from longer term trends, particularly aquifer decline, in the aquifers. The premise for the national network design is based upon distinguishing the monitoring sites by the presence of observed anthropogenic effects on water levels. The category of background means little known anthropogenic affects are observed. The suspected changes category has some known or anticipated anthropogenic impact in water levels. The documented changes category has measured and recorded declines in water levels due to anthropogenic influence.

2.1 Existing monitoring networks

The GSA-GAP has been actively monitoring groundwater conditions in the state since the early 1950s through a network of observation wells. Initially, this network was operated in conjunction with the USGS; however, currently the GSA-GAP has full responsibility to maintain and operate the network of real-time groundwater wells. Unlike historical observations, which occurred on a periodic basis, the current network is a real-time network (water levels are recorded and reported in real-time to the GSA-GAP office) and updates are available daily via an online portal. Real-time data collection began in 2010, with the installation of the first equipment in some of the observation wells used for periodic monitoring. Since 2010, GSA has focused on expanding the network, which now includes 29 well sites to monitor daily water-level elevation changes across the state. Ten of the real-time wells are used to report groundwater level response to drought to various stakeholders throughout the state.

Using the classification and nomenclature for principal aquifers of the United States (USGS, 2013), the GSA-GAP real-time monitoring network includes eight of the major aquifer systems (see table 1). Hydrogeologic attributes of the various aquifers in the state of Alabama are described from north to south in the following sections. The complex geologic diversity in the state combined with shared state boundaries, demonstrates the need for careful assessment and water resource planning.

2.1.1 Mississippian aquifers

The Mississippian aquifer system in Alabama is comprised of karstic limestone (carbonate) aquifers that have complex and wide-ranging flow characteristics. The five wells with dedicated real-time equipment, located in this part of the state provide important trend water-level monitoring data to the NGWMN in an area of active groundwater withdrawal from the Alabama-Tennessee River (ATR) basin. Currently, this northern region of Alabama is experiencing unprecedented population growth spreading outward from the city of Huntsville, causing increasing competition for essential water resources, both in agricultural and residential land development. Accurate water-level data provides useful information for water-supply planning purposes.

2.1.2 Pennsylvanian aquifers

The well-indurated clastic sandstone formations forming the Pennsylvanian aquifers are not prolific water-bearing units in Alabama, and the fracture-dominated flow in these aquifers can create problematic water availability issues for shallow wells during extreme conditions, either flood or drought. As such, these aquifers are sensitive indicators of precipitation input and water-level elevation responses. Currently, there are two wells constructed in the Pennsylvanian aquifers of Alabama in which real-time monitoring have been installed. In this geographic region of the state, surface water reservoirs are the primary sources for water supply.

2.1.3 Valley and Ridge aquifers

The hydrologic regime of the Valley and Ridge aquifers in Alabama is fracture-flow dominated. Water flows predominantly within the dissolved fractures of folded and faulted carbonate units which form part of the Alabama-Coosa-Tallapoosa (ACT) River basin located in northeastern Alabama and northwestern Georgia. Water levels from these wells combined with nearby stream baseflow data can provide information on groundwater-surface water interactions in this transboundary region, essential for sustainable water resource planning. Currently, there are two wells constructed in the Valley and Ridge aquifers of Alabama, which have dedicated monitoring equipment to transmit real-time data.

2.1.4 Piedmont and Blue Ridge aquifers

The Piedmont and Blue Ridge aquifers of Alabama are not significant water-supply units; however, shear zones and other brittle fault zones can create pathways of considerable water transmissivity in these metamorphic and igneous rocks. These aquifers supply water in the ACT River basin in the eastern part of the state. Currently, there is one well constructed in the Piedmont and Blue Ridge aquifers of Alabama which has dedicated monitoring equipment to transmit real-time data. In this geographic region of the state, surface water reservoirs are the primary sources for water supply.

2.1.5 Mississippi embayment aquifer system

The Mississippi embayment aquifer system aquifer is a prolific water yielding system of confined and semi-confined aquifers which are comprised of thick layers of mud interbedded with some coarser sand facies. Confined aquifers occur in the western part of state near the boundary with Mississippi. Currently, there are two wells constructed in the Mississippi embayment aquifer system of Alabama which have dedicated monitoring equipment to transmit real-time data.

2.1.6 Southeastern Coastal Plain aquifer system

The Southeastern Coastal Plain aquifer is a regionally extensive and prolific water-yielding system of water-bearing strata comprised of a thick wedge of predominantly clastic sedimentary facies from sand to clay, interbedded with thin layers of carbonate strata. This thick hydrogeologic unit of Cretaceous to upper Miocene sediments underlies more than half of the State of Alabama. Groundwater is pumped from this aquifer system to provide essential water resources for public, domestic, and agricultural use. These wells provide important real-time monitoring locations useful to evaluate potential transboundary groundwater issues along Alabama’s western boundary with Mississippi through a surface and groundwater connection with the Tombigbee River. Currently, there are 12 wells constructed in the Southeastern Coastal Plain aquifer system of Alabama which have dedicated monitoring equipment to transmit real-time data.

2.1.7 Floridan aquifer system

A small portion of the regionally extensive Floridan aquifer system is located in southern Alabama and provides valuable continuous water-level data to the NGWMN in an area of active groundwater withdrawals within the Apalachicola-Chattahoochee-Flint (ACF) River basin. These wells may provide data that could be used to characterize these areas of the NGWMN into a subnetwork of suspected changes. Currently, there are two real-time wells constructed in the Floridan aquifer system of Alabama.

2.1.8 Coastal lowlands and surficial aquifer system

The Coastal lowlands and surficial aquifer system in Alabama comprise a complex assemblage of interbedded clays and sands, and wells in this principal aquifer system are susceptible to impacts from hurricanes and large storm systems. Water-level data from these wells help scientists evaluate saltwater encroachment and climate change issues along the coast. Currently, there are three real-time wells constructed in the Coastal lowlands aquifer system of Alabama.

For the overall group of real-time wells, the total depths range from 40 feet below land surface (bls) in the Jackson County well (GSAL 071GG29001), constructed in the Fort Payne Chert, to the deepest well surface screened in the Nanafalia Formation at 2,070 feet bls located in Choctaw County (GSAL 023Z11002). The oldest period of record dates to 1936 in a Jefferson County well (GSAL 073L24004).

The other previously existing well network monitoring system used by GSA is the periodic well network, which incorporates water levels manually measured on a semi-annual basis by GSA-GAP staff. Typically, depth-to-water is measured during the spring and fall of each year to record the annual theoretical high and low levels. Most of these wells are privately owned, and many still have pumps installed even if the well is not being used. At the present time, the periodic monitoring network includes 468 wells across the state of Alabama. The periodic network contains 33 wells in the Mississippian aquifers, 48 wells in the Pennsylvanian aquifers, 42 wells in the Valley and Ridge aquifers, 39 wells in the Piedmont and Blue Ridge aquifers, 29 wells in the Mississippi Embayment aquifer system, 230 wells in the Southeastern Coastal Plain aquifer system, 13 wells in the Floridan aquifer system, and 34 wells in the Coastal Lowlands aquifer system.

3.0 Well site selection for the NGWMN

The purpose of the NGWMN is to provide a national overview of long-term trends across regional aquifer systems. As such, wells are selected to differentiate between the effects of short-term and long-term hydrologic stressors across the aquifers. As a newly established data provider to the NGWMN, the GSA-GAP staff selected wells from our current water-level monitoring programs to meet the requirements of the NGWMN after reviewing the criteria for inclusion into the USGS catalog.

The 29 wells in Alabama's real-time network were established as trend-monitoring wells, and the daily data are currently being served to the NGWMN program online at cida.usgs.gov/ngwmn. Water-level elevations are measured by pressure transducers and recorded on a data logger every two hours. These data are transmitted to a GSA-GAP dedicated computer each day, and the daily average for the trend monitoring well is served to the NGWMN portal every evening. The USGS utilizes two network categories, trend and surveillance wells, to indicate the frequency of monitoring in the NGWMN program.

3.1 Trend Well Network

Trend monitoring, as described in Section 4.5.1 of "A National Framework for Ground-Water Monitoring in the United States" (SOGW, 2013), is designed to look at long-term and seasonal water-levels at frequent measuring intervals for a limited number of wells across the state. The GSA-GAP staff selected trend wells from the state's real-time network, which derives water-level elevation data from eight of the nine aquifer systems identified in Alabama. The trend well locations are shown in figure 1.

3.2 Surveillance Well Network

Surveillance monitoring as described in Section 4.5.1 of "A National Framework for Ground-Water Monitoring in the United States" (SOGW, 2013), is designed to periodically "tie together" the trend monitoring well data, providing greater spatial coverage to fill in the gaps of the more frequent (but fewer sites) trend well measurements. The frequency of measurements made in Alabama's surveillance wells is semi-annual and provides an extensive snapshot of aquifer conditions.

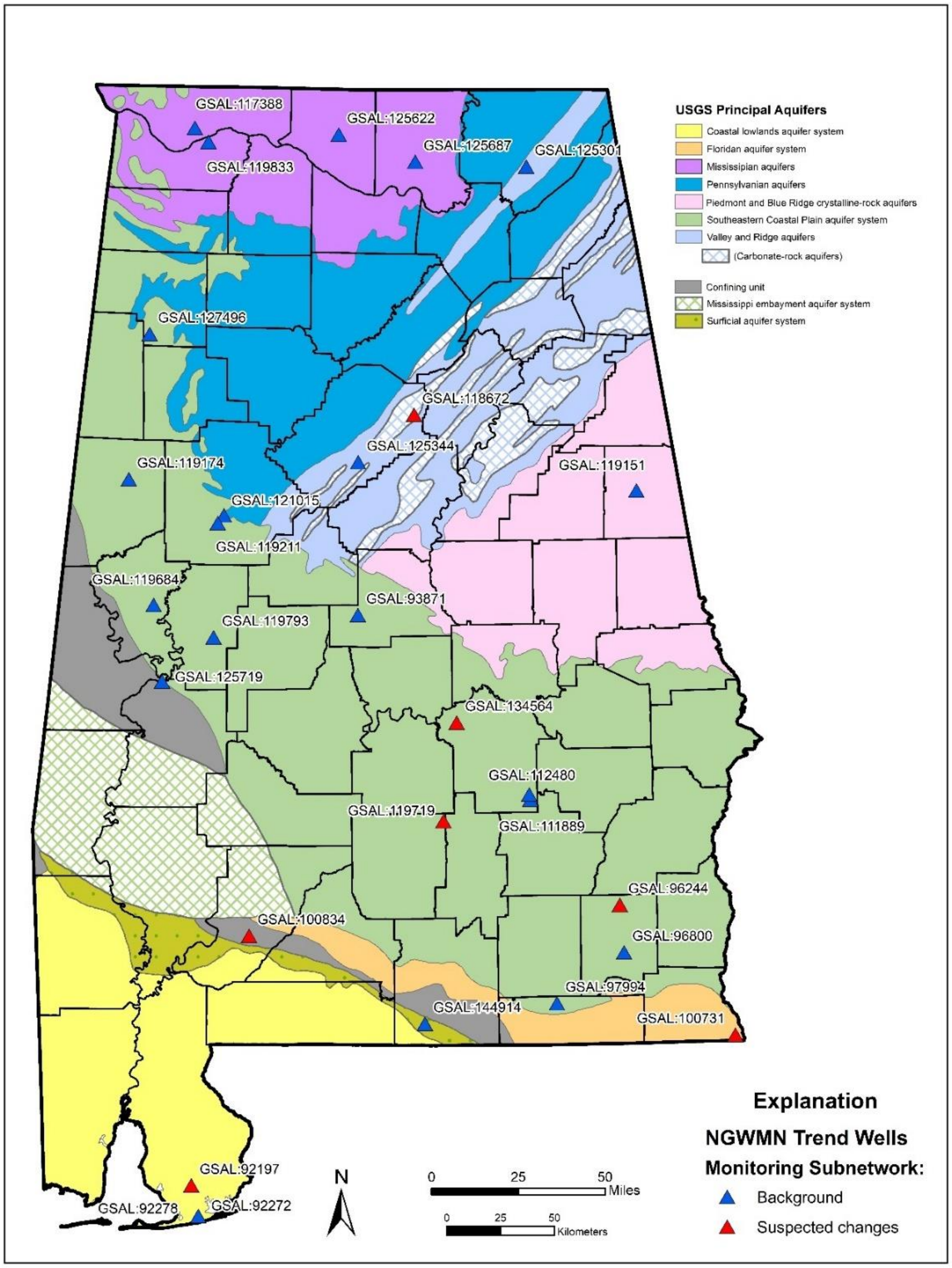

Figure 1. Location of NGWMN trend monitoring wells in Alabama.

The 468 periodic program wells in Alabama were thoroughly evaluated for potential inclusion into the USGS NGWMN surveillance well network. Wells were selected in order of usefulness and suitability of the water-level measurements as data points for inclusion in the national network. After screening out those wells that were deemed ineligible for the national network based on criteria discussed in following paragraphs, the remaining monitoring well candidates were ranked using a decision matrix of weighted factors for future inclusion into the USGS NGWMN.

The selection of periodic wells to be further evaluated for potential inclusion into the NGWMN surveillance network was a three-step process. In the first step, ineligible wells were eliminated from further consideration. In general, these eliminated wells either had access problems or did not have detailed lithologic or well construction data on record. In the graphical breakdown presented in Figure 2, a total of 104 wells were not eligible for the NGWMN due to a lack of minimum data requirements.

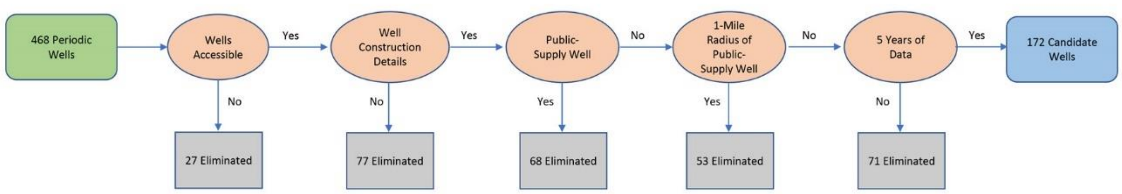

Figure 2. Selection criteria for surveillance NGWMN wells in Alabama.

As clearly stated in section 4.5.1 of “A National Framework for Ground-Water Monitoring in the United States” (SOGW, 2013), the monitoring wells selected for the network are most representative of *static* water levels. The GSA-GAP staff eliminated the public supply wells and periodic monitoring wells within a 1-mile radius of a public supply from further consideration as potential surveillance wells, due the possible drawdown effects of high capacity pumping. After removing the 121 wells within a conservative 1-mile radius of pumping influence as shown in figure 2, a total of 243 wells remained to be further evaluated for inclusion in the NGWMN.

The second step was a process of evaluation for the remaining 243 wells, whereby each of five factors were quantified and weighted, in relation to the network goals. During this evaluation process, 71 wells were identified that had less than 5 years of water-level data available. These 71 wells which were recently added to the periodic monitoring network will be considered for inclusion into the USGS NGWMN at a later time, after some reorganization of the GSA-GAP field sampling program. The remaining 172 candidate wells in Alabama's current periodic water-level monitoring program were ranked. As presented in table 2, the following factors were considered in order of importance to be included in the NGWMN, and a selection process of weighting the various factors:

- years of data;
- distance from public supply wells;
- proximity to other monitoring wells;
- distance from real-time wells; and
- proximity to stream gage

The method for the weighting process was to scan the entire range of data values for each of the above-listed factors, and then break the resulting dataset into groups that allowed for good spread in results and assign a weight, thus minimizing duplicate numbers. This provides a reasonable quantified approach to obtain a relative ranking of the wells for selection purposes. The numerical result is objective, but it is not an absolute measure.

The first factor 'years of data' allowed for a simple weighting scheme at 10-year intervals. Wells with 50 or more years of water-level measurements were assigned a weight of 1, 40 to 49 years of data yielded a weight of 2, and so forth.

The second factor 'distance from public supply wells' was evaluated numerically according to the methods described above.

The third factor of 'proximity to other monitoring wells' was evaluated geospatially using the locations in ArcGIS. A circle of 5-mile radius was created around each well, and the number of additional wells intercepted by this imaginary buffer were counted. The higher the count the higher the numeric ranking assigned, thus lowering the priority.

The fourth factor 'distance from real time wells' was measured as described above, with the intention of preventing too much redundancy in the monitoring dataset.

The fifth factor ‘proximity to stream gage’ worked in the opposite way of the previous factors which incorporated distance measurements. The closer a stream gage the lower the rank (resulting in a higher priority on the list such as number 1 or 2). Monitoring wells in close proximity to streams are valuable because these water-level measurements can quantify surface water/groundwater hydrologic communication, thus providing input about lag time in flow rates.

The third and final step of the process was to rank the wells as potential candidates for the NGWMN surveillance subnetwork. Listed in order of consideration, the following factors were weighted that *improved* the priority ranking for the well’s inclusion into the USGS NGWMN as a surveillance site.

1. Greater number of years of water-level elevation data;
2. Further distance from public supply well;
3. Number and proximity of monitoring wells within a 5-mile radius;
4. Further distance from an existing real-time well; and
5. Close proximity to a monitored stream gage.

Table 2 presents the overall rank of all the candidate surveillance wells, and it shows the factors used in the process of evaluation. For the most part, all the candidate wells are available for inclusion as surveillance wells in the NGWMN. The overall ranking primarily indicates spatial gaps in the current groundwater monitoring network. The wells selected for potential inclusion in the NGWMN would be included in the surveillance monitoring category.

After the candidate wells were ranked, they were sorted by aquifer (table 2), and the wells list was spatially arranged and color coded to match the relative physical location of the aquifers in Alabama from north to south, as depicted in figure 3. Subsequently, the candidate wells were ranked relative to those other well sites within the same aquifer system.

Although wells in the periodic network were evaluated for inclusion in the NGWMN as surveillance wells, potential candidate wells were not uploaded to the NGWMN portal during this project. This would have required an additional web services to be established between the GSA and USGS servers, because data collected from the periodic and real-time wells are stored in two separate databases on the GSA servers. Subnetwork classification of surveillance wells will be accomplished when they are uploaded to the NGWMN.

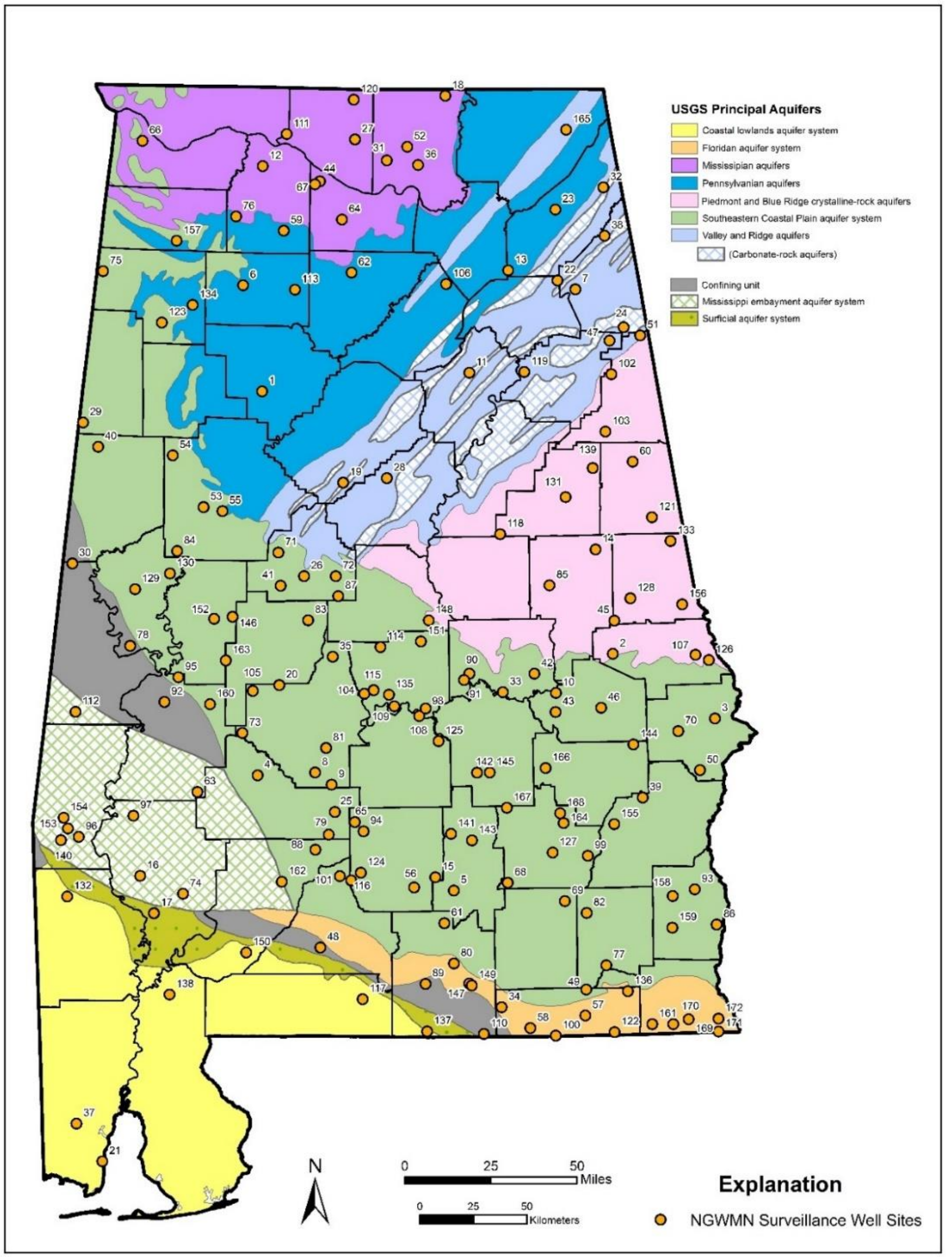

Figure 3. Location of NGWMN ranked surveillance well candidates in Alabama.

3.3 Assigning subnetworks and monitoring categories

Groundwater monitoring wells from both the trend and surveillance network were further evaluated for placement into the appropriate well classification subnetworks. These well classification subnetworks were defined as *background*, *suspected changes*, and *documented changes* in section 1.4.3 of “A National Framework for Ground-Water Monitoring in the United States” (SOGW, 2013). The delineation of these well classification subnetworks is based upon the anthropogenic effects on water levels due to land use and development on both groundwater recharge rates, and withdrawal due to pumping. The trend wells were classified into subnetworks, as listed in table 1 and locations displayed on figure 1. Nine trend wells used for drought monitoring in Alabama were classified as *background,* and one drought monitoring well in Houston County is classified as *suspected changes*. Surveillance wells will be classified into subnetworks when these wells are uploaded to the NGWMN portal.

3.3.a. Background Subnetwork

As defined by the USGS NGWMN, the *background* subnetwork includes monitoring sites that show minimal anthropogenic effects as measured from water-level elevations. At this time, 22 of the 29 GSA-GAP trend network wells are classified as background in the NGWMN water level database (see figure 1 and table 1). The spatial distribution of the background wells includes eight of the nine principal aquifers located in Alabama.

Hydrographs produced for the period of record for all the trend wells were examined, comparing the initial water-level elevations with current measurements. These hydrographs are presented in the *Assessment of groundwater resources in Alabama* report (GSA, 2018). Initial water-level measurements for most of the trend wells date back to the 1950s or 1960s, providing an average period of record of 60+ years. Water levels in most of the unconfined wells displayed wide seasonal fluctuation, indicating the significant contribution of water due to precipitation, recharging the aquifer systems. A wide range of water-level variation (on the order of tens of feet) is observable in many of the unconfined aquifer hydrographs. However, there is no clear trend of water level decline in these hydrographs examined for the period of record. Without a stringent linear regression statistical analysis of all water-level measurements in tandem with nearby precipitation stations, changes in water levels may be associated with natural seasonal hydrologic stressors.

3.3.b. Suspected Changes Subnetwork

The *suspected changes* subnetwork includes monitoring sites that provide data from principal aquifer systems that have water level changes anticipated due to anthropogenic influence. This subnetwork may be in areas where land-use changes are anticipated based on population growth and property development. At this time, seven wells of the trend network of GSA-GAP wells are currently listed in the *suspected changes* subnetwork, classified as having known or anticipated anthropogenic effects (see figure 1 and table 1). Six of the seven wells are located in the southern half of the state, below the Fall Line, and the seventh well, GSAL128672, is in Jefferson County. The principal aquifers with suspected changes in water levels due to anthropogenic influence include the Southeastern Coastal Plain and confining unit, Floridan, Coastal Lowland, and the Valley and Ridge formations. The GSA-GAP staff will continue to evaluate the water-level monitoring data to further distinguish long-term trends.

3.3.c. Documented Changes Subnetwork

The *documented changes* subnetwork includes monitoring wells that provide data from principal aquifer systems that have documented anthropogenic effects. At this time, the GSA-GAP staff have not placed any of Alabama’s wells, neither trend nor surveillance, into the subnetwork of *documented changes* as defined by the USGS NGWMN. As more data becomes available and reviewed, this determination could change.

4.0 Field techniques

Water-level data in the real-time network wells are measured continuously by pressure transducers and data loggers. The data is transmitted via the OTT intelligent top cap (ITC) technology to the GSA-GAP office computers via a 3G cellular network. Water levels are recorded every two hours by the pressure transducer, stored in the ITC datalogger and then transmitted via short messaging service (SMS) once a day to the GSA-GAP office. The GSA-GAP staff routinely review the water-level elevation data points for any possible errors due to slight variations in salinity and correct for local barometric pressure drops during extreme weather systems. Water-level elevations are averaged for the 24-hour period, and the daily mean value is served to the NGWMN portal, recorded as daily average trend monitoring data.

In the three Coastal lowlands aquifer system wells of the NGWMN, the GSA-GAP staff will attempt to assess the potential influence of salinity variation due to sea water. As part of this project, GSA-GAP staff replaced the existing pressure transducer probes with a dual probe that can effectively measure both salinity and water depth.

Water levels in the periodic program wells are measured manually by GSA staff using a steel tape and chalk. Field sampling methods are described in detail in the groundwater assessment report (GSA, 2018). A graphic overview of the sampling methodology is included on the GSA website, https://www.ogb.state.al.us/gsa/groundwater/periodic

5.0 Data management procedures

Real-time water-level data transmitted by SMS to the GSA office is received by OTT Hydras 3 software installed on a dedicated computer. Scripts written in the Hydra 3 software send both the two-hour raw data and daily average data to a dedicated hard drive for storage on a daily basis, and to the GSA server where the water-level data can be accessed for uploading to the NGWMN and GSA websites and be available for research purposes.

Periodic water-level data is tabulated and stored in Excel spreadsheets on the computer data server and uploaded to the GSA-GAP's RBDMS database. The data is copied and stored on a separate data back-up storage device each evening. The updated data is served daily to the USGS portal.

5.1 Minimum data elements

Criteria entered for wells selected for upload to the NGWMN registry include:

- Agency name;
- Unique site number and name;
- Location information including state, county, latitude and longitude with the horizontal datum and method used and accuracy;

- Altitude in specified units with the vertical reference datum and method used and accuracy;
- Well depth in specified units;
- The national aquifer designation and local aquifer name;
- The type of groundwater site and aquifer type;
- Whether the site is in a water level (WL) subnetwork and the WL system name from which the data is uploaded;
- Whether the well meets the criteria for WL baseline (five years of data), well type, well characteristics, well purpose and well purpose notes;
- Whether the well is part of the water quality (QW) subnetwork; and
- The URL to the specified data on the data provider's website.

5.2 Sites with missing data elements

Wells without adequate well construction information, from either the real-time or periodic networks, were removed from further consideration for the NGWMN. As shown in table 2, a total of 77 wells in the periodic network were eliminated from further consideration due to missing data elements. Moreover, 127 new wells have been recently added to GSA-GAP's periodic sampling program. Of these 127 additional new wells, many do not have complete construction detail or lack lithologic information and will not be eligible for inclusion into NGWMN in the future, even when the 5-year minimum data requirement is fulfilled.

5.3 Sites that do not meet NGWMN requirements

As discussed in section 4.5.1, page 32, of "*A National Framework for Ground-Water Monitoring in the United States*" (SOGW, 2013), public supply wells do not meet NGWMN requirements because water levels from these actively pumped wells are within the cone of depression influenced by nearby active groundwater withdrawal. As shown in Table 2, a total of 121 well sites were eliminated due to close proximity to a public supply well, defined as within a 1-mile radius of the pumping well.

- In addition, some private well sites (27) had problematic or inconsistent access issues and were removed from further evaluation for the NGWMN. The following attributes rendered groundwater wells ineligible for the NGWMN.wells with problematic access;

- wells with inadequate well construction information;
- public-supply wells that are actively pumped; or
- wells within a 1-mile radius of an active public-supply well.

6.0 Web services for the NGWMN

The GSA web services were developed using an existing ArcGIS Server. Pertinent well data was aggregated and extracted from the agency's two water databases via SQL queries. These SQL results were loaded into three empty tables in a new NGWMN geodatabase where each table represents a web service (water levels, construct data, and lithology). By using ArcGIS Pro, a new map was created from each of the tables and published to the ArcGIS Server as a new REST WFS web service. Each web service returns XML formatted data by passing a unique well identifier as a parameter in the URL. Data from these web services will be maintained from scheduled tasks that execute Python scripts to update the source data for each web service. At the time of this report, the tasks execute on a monthly schedule but have the flexibility to be at any query.

6.1 Water level service

Water levels for a well can be retrieved by accessing the water-level service and passing the unique site number as a URL parameter. In the following web service URL below, the USGS NGWMN Site Number 92278 is queried. When the matching record is accessed, an XML formatted document returning required elements is returned. The query and response shown below depicts a water-level record. A complete water-level measurement includes the date of measurement, depth-to-water, units, method for measuring, and the accuracy.

https://map.gsa.state.al.us/arcgis/services/NGWMN/**Water_Levels**/MapServer/WFSServer?&service=WFS&request=GetFeature&typename=NGWMN:Water_Level&outputFormat=GML3&filter=<ogc:Filter><ogc:PropertyIsEqualTo><ogc:PropertyName>Site_Number</ogc:PropertyName><ogc:Literal>**92278**</ogc:Literal></ogc:PropertyIsEqualTo></ogc:Filter>.

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     <NGWMN:OBJECTID>1461</NGWMN:OBJECTID>
     <NGWMN:Agency_Code>GSAL</NGWMN:Agency_Code>
     <NGWMN:Site_Number>92278</NGWMN:Site_Number>
     <NGWMN:Source_Site_ID>BAL-2</NGWMN:Source_Site_ID>
     <NGWMN:Date_of_Measurement>2011-05-24T00:00:00-06:00</NGWMN:Date_of_Measurement>
     <NGWMN:Depth_to_Water>8.359999656677246</NGWMN:Depth_to_Water>
     <NGWMN:Depth_to_Water_Units>ft</NGWMN:Depth_to_Water_Units>
     <NGWMN:Depth_to_Water_Method>Pressure Tranducer</NGWMN:Depth_to_Water_Method>
     <NGWMN:Depth_to_Water_Accuracy>0.01</NGWMN:Depth_to_Water_Accuracy>
     <NGWMN:Depth_to_Water_Accuracy_Units>ft</NGWMN:Depth_to_Water_Accuracy_Units>
   </NGWMN:Water_Level>
 </gml:featureMember>
```


6.2 Construction service

The construction service, which contains casing and screen information, can also be accessed via passing a unique site number inside the URL, as follows:

https://map.gsa.state.al.us/arcgis/services/NGWMN/**Construction**/MapServer/WFSServer?&service=WFS&request=GetFeature&typename=NGWMN:Construction&outputFormat=GML3&filter=<ogc:Filter><ogc:PropertyIsEqualTo><ogc:PropertyName>Site_Number</ogc:PropertyName><ogc:Literal>**92278**</ogc:Literal></ogc:PropertyIsEqualTo></ogc:Filter>.

For both casing and screen information, the web service returns tops, bottoms, diameters, construction materials, and units for each casing and screen respectively. The service also supplies well depth and well depth units. The features described by this query are illustrated as follows:

```
▼<gml:featureMember>
  ▼<NGWMN:Construction gml:id="Construction.7113">
     <NGWMN:OBJECTID>7113</NGWMN:OBJECTID>
     <NGWMN:Agency_Code>GSAL</NGWMN:Agency_Code>
     <NGWMN:Site_Number>92278</NGWMN:Site_Number>
     <NGWMN:Source_Site_ID>BAL-2</NGWMN:Source_Site_ID>
     <NGWMN:Well_Depth>130</NGWMN:Well_Depth>
     <NGWMN:Well_Depth_Units>ft</NGWMN:Well_Depth_Units>
     <NGWMN:Casing_Depth_Top>0</NGWMN:Casing_Depth_Top>
     <NGWMN:Casing_Depth_Top_Unit>ft</NGWMN:Casing_Depth_Top_Unit>
     <NGWMN:Casing_Depth_Bottom>100</NGWMN:Casing_Depth_Bottom>
     <NGWMN:Casing_Depth_Bottom_Unit>ft</NGWMN:Casing_Depth_Bottom_Unit>
     <NGWMN:Casing_Material/>
     <NGWMN:Casing_Diameter>4</NGWMN:Casing_Diameter>
     <NGWMN:Casing_Diameter_Unit>in</NGWMN:Casing_Diameter_Unit>
     <NGWMN:Screen_Depth_Top>100</NGWMN:Screen_Depth_Top>
     <NGWMN:Screen_Depth_Top_Unit>ft</NGWMN:Screen_Depth_Top_Unit>
     <NGWMN:Screen_Depth_Bottom>130</NGWMN:Screen_Depth_Bottom>
     <NGWMN:Screen_Depth_Bottom_Unit>ft</NGWMN:Screen_Depth_Bottom_Unit>
     <NGWMN:Screen_Material/>
     <NGWMN:Screen_Diameter>4</NGWMN:Screen_Diameter>
     <NGWMN:Screen_Diameter_Unit>in</NGWMN:Screen_Diameter_Unit>
   </NGWMN:Construction>
 </gml:featureMember>
```


6.3 Lithology service

Similar to the web services described in prior sections, lithologic information can be obtained by passing the same unique identifier from the previously mentioned services as a parameter to the web service URL, as follows:

https://map.gsa.state.al.us/arcgis/services/NGWMN/**Lithology**/MapServer/WFSServer?&service=WFS&request=GetFeature&typename=NGWMN:Lithology&outputFormat=GML3&filter=<ogc:Filter><ogc:PropertyIsEqualTo><ogc:PropertyName>Site_Number</ogc:PropertyName><ogc:Literal>**92278**</ogc:Literal></ogc:PropertyIsEqualTo></ogc:Filter>

The lithology web service provides the lithologic ID, description, top and bottom of the unit, and the observation method. All lithologic observations were determined from drilling records reviewed by geologists on staff in the GSA-GAP. Where necessary, these depths were correlated with available electrical logs. The features described by the lithologic query are illustrated as follows:

```
▼<gml:featureMember>
  ▼<NGWMN:Lithology gml:id="Lithology.7151">
     <NGWMN:OBJECTID>7151</NGWMN:OBJECTID>
     <NGWMN:Agency_Code>GSAL</NGWMN:Agency_Code>
     <NGWMN:Site_Number>92278</NGWMN:Site_Number>
     <NGWMN:Source_Site_ID>BAL-2</NGWMN:Source_Site_ID>
     <NGWMN:Lithology_ID>Tm</NGWMN:Lithology_ID>
     <NGWMN:Symbol_Lithology/>
     <NGWMN:Lithology_Description>Miocene Series undifferentiated</NGWMN:Lithology_Description>
     <NGWMN:Lithology_Depth_Top>80</NGWMN:Lithology_Depth_Top>
     <NGWMN:Lithology_Depth_Top_Unit>ft</NGWMN:Lithology_Depth_Top_Unit>
     <NGWMN:Lithology_Depth_Bottom>133</NGWMN:Lithology_Depth_Bottom>
     <NGWMN:Lithology_Depth_Bottom_Unit>ft</NGWMN:Lithology_Depth_Bottom_Unit>
     <NGWMN:Observation_Method/>
   </NGWMN:Lithology>
 </gml:featureMember>
```


7.0 References Cited

Geological Survey of Alabama, 2017, Geological Survey of Alabama, http://www.gsa.state.al.us, accessed October 16, 2017.

Geological Survey of Alabama, 2018, *Assessment of groundwater resources in Alabama, 2010-2016*: Geological Survey of Alabama Bulletin 186, 426 p.

Hinson, A.S., Moss, N.E. and St. Clair, Eric, 2018, *Inclusion of Alabama Groundwater Wells into the National Groundwater Monitoring Network*: Geological Survey of Alabama Proposal submitted to USGS for Contract #G18AC00066.

Johnston, W. D., Jr., 1933, Ground water in the Paleozoic rocks of northern Alabama: Alabama Geological Survey Special Report 16, 414 p.

Miller, J. A., 1990, *Ground water atlas of the United States Segment 6*: U.S. Geological Survey Hydrologic Investigations Atlas 730-G, 28 p.

Subcommittee on Ground Water of the Advisory Committee on Water Information (SOGW), 2013, *A national framework for ground-water monitoring in the United States*: Advisory Committee on Water Information, https://acwi.gov/sogw/ngwmn framework_report_july2013.pdf , 168 p.

U.S. Geological Survey, 2003, *Principal aquifers of the 48 conterminous United States, Hawaii, Puerto Rico, and the U.S. Virgin Islands*, https://water.usgs.gov/ogw/aquifer/map.html, accessed October 18, 2017.

APPENDIX. TABLES

Table 1. Geological Survey of Alabama trend wells in NGWMN registry

NGWMN Site ID	Site Name	County	Principal Aquifer	Local Aquifer Formation	Aquifer Type	Latitude	Longitude	Well Depth (ft.)	Well Classification subnetwork
GSAL:119833	COL-1 033H30001	Colbert County	Mississippian aquifers	Fort Payne	UNCONFINED	34.773148	-87.631206	265	Background
GSAL:125301	JAC-2 071GG29001	Jackson County	Mississippian aquifers	Fort Payne	UNCONFINED	34.667628	-86.022021	40	Background
GSAL:117388	LAU-1 077O33001	Lauderdale County	Mississippian aquifers	Fort Payne	UNCONFINED	34.831529	-87.700665	227	Suspected changes
GSAL:125622	LIM-4 083J05001	Limestone County	Mississippian aquifers	Fort Payne	UNCONFINED	34.80528	-86.97111	143	Background
GSAL:125687	MAD-2 089Q13001	Madison County	Mississippian aquifers	Fort Payne	UNCONFINED	34.690728	-86.583715	168	Suspected changes
GSAL:127496	MAR-1 093T32001	Marion County	Pennsylvanian aquifers	Pottsville	UNCONFINED	33.967959	-87.920665	444	Suspected changes
GSAL:121015	TUS-5 125EE23002	Tuscaloosa County	Pennsylvanian aquifers	Pottsville	UNCONFINED	33.211574	-87.543283	302	Suspected changes
GSAL:125344	JEF-1 073CC29001	Jefferson County	Valley and Ridge aquifers	Bangor	UNCONFINED	33.434966	-86.874071	140	Background
GSAL:118672	JEF-2 073L24004	Jefferson County	Valley and Ridge aquifers	Fort Payne	UNCONFINED	33.632934	-86.594805	186.5	Background
GSAL:119151	RAN-1 111K03002	Randolph County	Piedmont and Blue Ridge crystalline-rock aquifers	Wedowee Group	CONFINED	33.308262	-85.488146	300	Background
GSAL:93871	CHI-1 021O16004	Chilton County	Southeastern Coastal Plain aquifer system	Coker	UNCONFINED	32.795811	-86.876908	252.5	Background
GSAL:96800	DLE-1 045J30005	Dale County	Southeastern Coastal Plain aquifer system	Clayton	CONFINED	31.377226	-85.580462	453	Background
GSAL:96244	DLE-2 045C13001	Dale County	Southeastern Coastal Plain aquifer system	Nanafalia	UNCONFINED	31.5761	-85.59763	240	Background
GSAL:97994	GEN-1 061J11001	Geneva County	Southeastern Coastal Plain aquifer system	Nanafalia	CONFINED	31.16697	-85.91009	790	Background
GSAL:119684	GRE-3 063R33001	Greene County	Southeastern Coastal Plain aquifer system	Eutaw	CONFINED	32.835589	-87.889155	407	Background
GSAL:119793	HAL-1 065P16005	Hale County	Southeastern Coastal Plain aquifer system	Eutaw	UNCONFINED	32.701389	-87.591111	280	Suspected changes
GSAL:125719	MAG-1 091B24002	Marengo County	Southeastern Coastal Plain aquifer system	Eutaw	CONFINED	32.51552	-87.84453	900	Background
GSAL:134564	MTG-4 101K20013	Montgomery County	Southeastern Coastal Plain aquifer system	Gordo	CONFINED	32.34479	-86.3903	446	Background
GSAL:111889	MTG-6 101AA14001	Montgomery County	Southeastern Coastal Plain aquifer system	Ripley	UNCONFINED	32.020654	-86.030427	80	Background
GSAL:112480	MTG-7 101AA03001	Montgomery County	Southeastern Coastal Plain aquifer system	Eutaw	CONFINED	32.041782	-86.036319	1350	Background
GSAL:119174	PIC-5 107I32001	Pickens County	Southeastern Coastal Plain aquifer system	Gordo	UNCONFINED	33.359978	-88.018508	235	Suspected changes
GSAL:119211	TUS-4 125EE34001	Tuscaloosa County	Southeastern Coastal Plain aquifer system	Coker	UNCONFINED	33.179167	-87.573611	71	Background
GSAL:119719	CHO-1 023Z11002	Choctaw County	Mississippi embayment aquifer system	Nanafalia	CONFINED	31.93294	-86.45764	2070	Background
GSAL:100834	MON-1 099Z30001	Monroe County	Mississippi embayment aquifer system	Citronelle	UNCONFINED	31.45344	-87.40981	140	Background
GSAL:144914	COV-1 039AA04001	Covington County	Floridan aquifer system	Crystal River	UNCONFINED	31.08529	-86.55266	420	Background
GSAL:100731	HOU-1 069V28001	Houston County	Floridan aquifer system	Crystal River	UNCONFINED	31.025555	-85.044444	118	Suspected changes
GSAL:92278	BAL-2 003DDD11002	Baldwin County	Coastal lowlands aquifer system	Miocene	UNCONFINED	30.280253	-87.649846	130	Background
GSAL:92272	BAL-3 003DDD11001	Baldwin County	Coastal lowlands aquifer system	Miocene	UNCONFINED	30.280249	-87.649863	315	Background
GSAL:92197	BAL-5 003UU29001	Baldwin County	Coastal lowlands aquifer system	Miocene	UNCONFINED	30.407872	-87.684638	137	Background

Table 2. Rank of potential NGWMN surveillance well candidates by principal aquifers

GSAL_ID	County	Latitude	Longitude	Well Depth	Wells in Principal Aquifer	Principal aquifer	Years of data	Distance to public supply wells (miles)	Number of wells in 5 mi. radius	Distance to real time wells (miles)	Distance from stream gage (miles)	Sum of Weighted Factors Final	Rank	
													Overall Rank	Rank Within Principal Aquifer System
079F26001	Lawrence	34.667777	-87.3475	200		Mississipian aquifers	34	4.31	1	17.70	1.73	43	**12**	**1**
089B09002	Madison	34.963412	-86.414531	136		Mississipian aquifers	51	2.16	1	21.11	2.77	44	**18**	**2**
083I17001	Limestone	34.780833	-86.876944	117		Mississipian aquifers	51	6.08	1	5.61	3.65	48	**27**	**3**
089P14002	Madison	34.692222	-86.715278	195		Mississipian aquifers	51	1.20	1	6.55	0.95	49	**31**	**4**
089R20006	Madison	34.672222	-86.55556	227		Mississipian aquifers	45	3.48	1	2.05	0.56	50	**36**	**5**
103B21001	Morgan	34.604166	-87.05611	340		Mississipian aquifers	55	5.42	2	14.58	4.73	52	**44**	**6**
089N27015	Madison	34.749312	-86.610412	144.5	**13**	Mississipian aquifers	34	1.66	1	4.31	0.85	55	**52**	**7**
103O10001	Morgan	34.442865	-86.943968	55.5		Mississipian aquifers	51	11.15	1	19.06	11.86	58	**64**	**8**
033E25001	Colbert	34.771006	-87.962011	414		Mississipian aquifers	34	3.07	3	14.88	4.36	59	**66**	**9**
103B20001	Morgan	34.591667	-87.081111	440		Mississipian aquifers	35	6.90	2	15.99	6.29	59	**67**	**10**
079T09001	Lawrence	34.455	-87.482222	54		Mississipian aquifers	34	13.53	2	22.78	12.62	62	**76**	**11**
083M12001	Limestone	34.803333	-87.225833	220		Mississipian aquifers	51	2.69	1	14.48	10.49	68	**111**	**12**
083A19001	Limestone	34.94843	-86.8829	128		Mississipian aquifers	51	3.45	1	11.06	13.97	71	**120**	**13**
127T26001	Walker	33.71806	-87.34689	55		Pennsylvanian aquifers	32	11.72	1	33.52	1.99	28	**1**	**1**
133G23001	Winston	34.16515	-87.445133	125		Pennsylvanian aquifers	26	10.90	1	32.06	5.93	38	**6**	**2**
049EE27001	De Kalb	34.225418	-86.100923	170		Pennsylvanian aquifers	31	6.98	1	30.80	5.11	44	**13**	**3**
049P25001	De Kalb	34.47979	-85.858	136		Pennsylvanian aquifers	32	10.83	1	15.97	5.92	46	**23**	**4**
079R35001	Lawrence	34.39567	-87.23959	120	**3**	Pennsylvanian aquifers	30	7.04	1	31.53	11.89	57	**59**	**5**
043I31001	Cullman	34.219399	-86.895148	111		Pennsylvanian aquifers	34	5.66	1	33.51	11.89	58	**62**	**6**
009E15001	Blount	34.169662	-86.415696	38		Pennsylvanian aquifers	31	2.40	1	37.16	12.67	68	**106**	**7**
133J28001	Winston	34.146817	-87.1821	115		Pennsylvanian aquifers	32	2.95	1	43.27	14.55	69	**113**	**8**
093M21001	Marion	34.080933	-87.70055	100.8		Pennsylvanian aquifers	34	4.60	1	16.78	15.89	78	**134**	**9**
019O26001	Cherokee	34.1425	-85.761666	187		Valley and Ridge aquifers	51	3.73	1	39.12	2.09	38	**7**	**1**
115L23001	St. Clair	33.795	-86.30166	177		Valley and Ridge carbonate-rock aquifers	51	4.28	1	20.24	3.85	42	**11**	**2**
073LL34001	Jefferson	33.33333	-86.938611	115		Valley and Ridge carbonate-rock aquifers	51	4.23	1	7.93	0.81	45	**19**	**3**
055B12001	Etowah	34.18083	-85.8515	42		Valley and Ridge aquifers	31	4.48	1	34.93	5.62	46	**22**	**4**
019V19001	Cherokee	33.98017	-85.51979	90		Valley and Ridge carbonate-rock aquifers	34	4.02	1	46.34	7.85	46	**24**	**5**
117J26001	Shelby	33.352222	-86.719444	120	**12**	Valley and Ridge aquifers	51	2.22	1	10.60	3.92	48	**28**	**6**
049J29001	De Kalb	34.571068	-85.61274	302		Valley and Ridge aquifers	53	2.92	1	24.25	5.38	49	**32**	**7**
019F05001	Cherokee	34.366666	-85.609722	318		Valley and Ridge aquifers	51	3.44	2	31.36	6.76	51	**38**	**8**
015I04001	Calhoun	33.92432	-85.59234	121		Valley and Ridge aquifers	51	1.79	1	42.87	9.66	53	**47**	**9**
029B36001	Cleburne	33.944279	-85.436448	45		Valley and Ridge aquifers	34	8.12	1	43.93	13.05	55	**51**	**10**
015N20001	Calhoun	33.79648	-86.02401	180		Valley and Ridge aquifers	34	6.03	2	34.74	14.05	71	**119**	**11**
071N33001	Jackson	34.815833	-85.798611	72.25		Valley and Ridge aquifers	44	3.72	1	16.30	24.60	102	**165**	**12**
081G25001	Lee	32.603747	-85.596396	30		Piedmont and Blue Ridge crystalline-rock aquifers	34	6.64	1	46.49	1.67	29	**2**	**1**
123A29001	Tallapoosa	33.0446	-85.676	78		Piedmont and Blue Ridge crystalline-rock aquifers	31	8.98	1	21.18	5.99	44	**14**	**2**
017W06001	Chambers	32.743438	-85.586863	36		Piedmont and Blue Ridge crystalline-rock aquifers	34	5.71	1	39.34	8.02	53	**45**	**3**
111C34001	Randolph	33.412795	-85.48384	315		Piedmont and Blue Ridge crystalline-rock aquifers	34	3.22	1	7.21	5.18	57	**60**	**4**
123L13001	Tallapoosa	32.895792	-85.908277	53.7		Piedmont and Blue Ridge crystalline-rock aquifers	34	1.38	1	37.43	11.22	64	**85**	**5**
029H27001	Cleburne	33.7825	-85.584939	200		Piedmont and Blue Ridge crystalline-rock aquifers	34	1.63	2	33.15	11.76	67	**102**	**6**
029S17001	Cleburne	33.540877	-85.618556	46.5		Piedmont and Blue Ridge crystalline-rock aquifers	34	1.15	1	17.71	8.27	67	**103**	**7**
081K36001	Lee	32.59441	-85.18488	70	**16**	Piedmont and Blue Ridge crystalline-rock aquifers	34	6.14	2	52.25	17.55	68	**107**	**8**
027V17001	Clay	33.11314	-86.15292	191		Piedmont and Blue Ridge crystalline-rock aquifers	51	4.80	3	40.78	15.13	70	**118**	**9**
111O22001	Randolph	33.177207	-85.391503	21.5		Piedmont and Blue Ridge crystalline-rock aquifers	34	1.05	1	10.62	10.72	72	**121**	**10**
081O10001	Lee	32.57129	-85.11943	190		Piedmont and Blue Ridge crystalline-rock aquifers	34	5.21	2	55.12	18.59	73	**126**	**11**

Table 2. Rank of potential NGWMN surveillance well candidates by principal aquifers

GSAL_ID	County	Latitude	Longitude	Well Depth	Wells in Principal Aquifer	Principal aquifer	Years of data	Distance to public supply wells (miles)	Number of wells in 5 mi. radius	Distance to real time wells (miles)	Distance from stream gage (miles)	Sum of Weighted Factors Final	Rank: Overall Rank	Rank: Rank Within Principal Aquifer System
017N01001	Chambers	32.836609	-85.505056	65		Piedmont and Blue Ridge crystalline-rock aquifers	34	1.19	1	32.51	15.23	74	**128**	**12**
027I21001	Clay	33.26681	-85.82312	255		Piedmont and Blue Ridge crystalline-rock aquifers	51	3.80	1	19.59	14.22	76	**131**	**13**
017B14001	Chambers	33.07597	-85.30033	47		Piedmont and Blue Ridge crystalline-rock aquifers	34	4.76	1	19.35	15.38	78	**133**	**14**
027G10001	Clay	33.38795	-85.68517	68		Piedmont and Blue Ridge crystalline-rock aquifers	34	7.88	3	12.65	15.88	80	**139**	**15**
017Q16001	Chambers	32.807971	-85.247305	23		Piedmont and Blue Ridge crystalline-rock aquifers	34	3.86	1	37.20	22.50	90	**156**	**16**
025PP04001	Clarke	31.514208	-87.870687	350	1	Surficial aquifer system	37	3.80	1	27.52	2.96	44	**17**	**1**
113L02001	Russell	32.324444	-85.093888	350		Southeastern Coastal Plain aquifer system	52	3.15	1	58.55	4.66	35	**3**	**1**
131H15002	Wilcox	32.098333	-87.363056	30		Southeastern Coastal Plain aquifer system	36	4.53	1	40.24	2.16	36	**4**	**2**
041S06001	Crenshaw	31.611111	-86.394444	291		Southeastern Coastal Plain aquifer system	52	3.90	2	35.41	1.22	36	**5**	**3**
047GG09001	Dallas	32.110604	-87.078282	1260		Southeastern Coastal Plain aquifer system	53	10.38	2	43.39	7.86	39	**8**	**4**
047HH31001	Dallas	32.059527	-86.996526	60		Southeastern Coastal Plain aquifer system	37	9.70	1	40.58	6.06	40	**9**	**5**
087I20001	Macon	32.441847	-85.881816	240		Southeastern Coastal Plain aquifer system	37	2.70	1	29.01	1.09	41	**10**	**6**
013T18001	Butler	31.667732	-86.485416	429		Southeastern Coastal Plain aquifer system	37	9.56	1	36.15	6.89	44	**15**	**7**
047H03001	Dallas	32.4791	-87.25674	500		Southeastern Coastal Plain aquifer system	52	6.93	1	24.79	4.86	45	**20**	**8**
131T08001	Wilcox	31.944338	-86.980547	61		Southeastern Coastal Plain aquifer system	36	4.84	1	42.21	6.32	46	**25**	**9**
007O25001	Bibb	32.93905	-87.13411	404		Southeastern Coastal Plain aquifer system	36	1.42	1	17.91	0.35	47	**26**	**10**
075Q18001	Lamar	33.58054	-88.24761	34		Southeastern Coastal Plain aquifer system	36	9.91	1	30.06	9.45	49	**29**	**11**
051U15001	Elmore	32.446681	-86.14543	135		Southeastern Coastal Plain aquifer system	37	2.96	1	15.94	2.94	50	**33**	**12**
047C29001	Dallas	32.59902	-86.9911	300		Southeastern Coastal Plain aquifer system	43	5.06	1	15.10	5.22	50	**35**	**13**
005F29002	Barbour	31.995556	-85.457778	1423		Southeastern Coastal Plain aquifer system	52	7.00	1	30.04	9.65	51	**39**	**14**
107D24001	Pickens	33.479434	-88.170445	65		Southeastern Coastal Plain aquifer system	52	6.05	1	33.63	8.26	51	**40**	**15**
007W11001	Bibb	32.89854	-87.25116	175		Southeastern Coastal Plain aquifer system	36	5.32	1	22.88	7.10	52	**41**	**16**
051N19001	Elmore	32.523611	-85.98777	88		Southeastern Coastal Plain aquifer system	37	5.99	1	26.55	7.31	52	**42**	**17**
087N19002	Macon	32.361201	-85.884239	180		Southeastern Coastal Plain aquifer system	37	5.07	1	23.74	6.15	52	**43**	**18**
087P16001	Macon	32.376766	-85.65811	100		Southeastern Coastal Plain aquifer system	37	4.48	2	31.99	7.27	53	**46**	**19**
061C33001	Geneva	31.188889	-85.748056	127		Southeastern Coastal Plain aquifer system	37	2.59	1	9.71	2.97	54	**49**	**20**
113X13001	Russell	32.1075	-85.172777	1120		Southeastern Coastal Plain aquifer system	45	1.99	1	44.32	9.46	54	**50**	**21**
125FF13001	Tuscaloosa	33.22831	-87.6387	109		Southeastern Coastal Plain aquifer system	34	3.02	2	5.07	2.86	55	**53**	**22**
125E33001	Tuscaloosa	33.44603	-87.79504	195		Southeastern Coastal Plain aquifer system	51	5.80	1	21.75	8.92	55	**54**	**23**
125EE23001	Tuscaloosa	33.212269	-87.543772	61		Southeastern Coastal Plain aquifer system	34	4.08	1	0.06	2.83	56	**55**	**24**
013S31001	Butler	31.625232	-86.590028	400		Southeastern Coastal Plain aquifer system	37	7.26	1	37.25	11.13	56	**56**	**25**
039C22001	Covington	31.473526	-86.442027	672		Southeastern Coastal Plain aquifer system	53	3.80	1	27.53	8.69	57	**61**	**26**
013E29001	Butler	31.901431	-86.881655	165		Southeastern Coastal Plain aquifer system	52	7.66	2	41.98	12.81	58	**65**	**27**
109T26001	Pike	31.642437	-86.12905	346		Southeastern Coastal Plain aquifer system	54	2.95	1	26.69	8.62	59	**68**	**28**
031A21002	Coffee	31.56312	-85.84837	260			37	1.61	2	14.81	4.38	60	**69**	**29**
113M19008	Russell	32.273333	-85.277222	465		Southeastern Coastal Plain aquifer system	37	8.29	1	47.26	15.65	60	**70**	**30**
007L22001	Bibb	33.038223	-87.262837	176		Southeastern Coastal Plain aquifer system	52	3.50	2	20.17	9.81	60	**71**	**31**
007Q33001	Bibb	32.938909	-86.975629	100		Southeastern Coastal Plain aquifer system	36	5.83	1	11.41	9.53	61	**72**	**32**
047S14001	Dallas	32.27674	-87.43958	1120		Southeastern Coastal Plain aquifer system	36	10.75	1	28.82	12.34	61	**73**	**33**
093H06001	Marion	34.21996	-88.15553	98		Southeastern Coastal Plain aquifer system	51	9.79	1	24.63	12.31	61	**75**	**34**
045N28001	Dale	31.290183	-85.647933	355		Southeastern Coastal Plain aquifer system	37	2.77	2	7.20	4.26	62	**77**	**35**
131GG12001	Wilcox	31.848611	-87.011111	380		Southeastern Coastal Plain aquifer system	31	2.06	1	35.95	10.75	63	**79**	**36**
047AA01001	Dallas	32.214286	-87.023702	800		Southeastern Coastal Plain aquifer system	37	6.00	1	38.14	13.16	63	**81**	**37**
045E09006	Dale	31.512124	-85.741848	290		Southeastern Coastal Plain aquifer system	51	4.23	2	9.58	6.19	63	**82**	**38**
105F31001	Perry	32.75312	-87.11389	40		Southeastern Coastal Plain aquifer system	51	10.96	1	14.10	13.01	63	**83**	**39**

Table 2. Rank of potential NGWMN surveillance well candidates by principal aquifers

GSAL_ID	County	Latitude	Longitude	Well Depth	Wells in Principal Aquifer	Principal aquifer	Years of data	Distance to public supply wells (miles)	Number of wells in 5 mi. radius	Distance to real time wells (miles)	Distance from stream gage (miles)	Sum of Weighted Factors Final	Rank	
													Overall Rank	Rank Within Principal Aquifer System
125SS22001	Tuscaloosa	33.04269	-87.76966	446	84	Southeastern Coastal Plain aquifer system	52	2.47	1	14.75	9.06	63	**84**	**40**
067P26002	Henry	31.455278	-85.103611	500		Southeastern Coastal Plain aquifer system	37	3.89	1	28.68	11.95	64	**86**	**41**
007T27001	Bibb	32.854701	-86.963713	143		Southeastern Coastal Plain aquifer system	52	8.81	1	6.48	11.82	64	**87**	**42**
099B32001	Monroe	31.785077	-87.076883	380		Southeastern Coastal Plain aquifer system	52	7.56	1	30.11	14.59	64	**88**	**43**
051R24001	Elmore	32.525912	-86.311248	137		Southeastern Coastal Plain aquifer system	37	1.45	2	13.30	6.13	65	**90**	**44**
051R35001	Elmore	32.499167	-86.338055	142		Southeastern Coastal Plain aquifer system	37	1.06	2	11.06	7.30	65	**91**	**45**
067J02001	Henry	31.605556	-85.208333	302		Southeastern Coastal Plain aquifer system	54	2.96	3	23.05	8.61	65	**93**	**46**
013F03001	Butler	31.862695	-86.839132	110		Southeastern Coastal Plain aquifer system	36	10.05	2	42.37	16.35	66	**94**	**47**
091A23002	Marengo	32.510353	-87.758804	800		Southeastern Coastal Plain aquifer system	36	1.77	1	5.02	7.05	66	**95**	**48**
085B21001	Lowndes	32.347939	-86.561653	400		Southeastern Coastal Plain aquifer system	37	3.57	2	10.02	9.97	66	**98**	**49**
109O15001	Pike	31.753409	-85.732944	565		Southeastern Coastal Plain aquifer system	37	5.21	1	14.59	11.35	66	**99**	**50**
035E10002	Conecuh	31.67381	-86.95628	193		Southeastern Coastal Plain aquifer system	54	12.81	2	30.75	17.69	66	**101**	**51**
001N23001	Autauga	32.443056	-86.833888	260		Southeastern Coastal Plain aquifer system	37	2.42	3	24.43	8.76	67	**104**	**52**
047G09001	Dallas	32.454505	-87.388501	450		Southeastern Coastal Plain aquifer system	37	5.95	1	20.71	12.22	67	**105**	**53**
001T11001	Autauga	32.38	-86.529444	400		Southeastern Coastal Plain aquifer system	37	4.05	3	8.49	7.40	68	**108**	**54**
001U05001	Autauga	32.389725	-86.684878	200		Southeastern Coastal Plain aquifer system	37	1.52	3	17.50	7.44	68	**109**	**55**
001E10006	Autauga	32.63968	-86.75374	170		Southeastern Coastal Plain aquifer system	37	1.59	2	12.93	9.56	70	**114**	**56**
001O08001	Autauga	32.45777	-86.7875	120		Southeastern Coastal Plain aquifer system	37	2.62	4	23.86	9.29	70	**115**	**57**
013P18003	Butler	31.65551	-86.90018	16		Southeastern Coastal Plain aquifer system	37	9.34	3	33.12	15.42	70	**116**	**58**
093T24001	Marion	34.00575	-87.855633	69		Southeastern Coastal Plain aquifer system	51	2.32	1	6.95	10.36	72	**123**	**59**
013P03003	Butler	31.687967	-86.852771	320		Southeastern Coastal Plain aquifer system	52	7.35	2	36.60	16.59	72	**124**	**60**
085J28001	Lowndes	32.242116	-86.466207	440		Southeastern Coastal Plain aquifer system	52	2.79	1	8.35	10.74	72	**125**	**61**
109Q12001	Pike	31.768579	-85.90619	565		Southeastern Coastal Plain aquifer system	54	2.57	1	18.84	13.99	73	**127**	**62**
063Q15001	Greene	32.880265	-87.978209	550		Southeastern Coastal Plain aquifer system	37	2.35	1	6.02	10.54	74	**129**	**63**
063J29001	Greene	32.947744	-87.804442	560		Southeastern Coastal Plain aquifer system	36	4.36	2	9.16	10.94	75	**130**	**64**
001O13001	Autauga	32.438306	-86.711554	180		Southeastern Coastal Plain aquifer system	37	1.92	5	19.85	9.03	79	**135**	**65**
041I12001	Crenshaw	31.85064	-86.406871	170		Southeastern Coastal Plain aquifer system	37	6.33	2	25.02	17.57	80	**141**	**66**
101X17001	Montgomery	32.107761	-86.276573	970		Southeastern Coastal Plain aquifer system	37	1.76	2	14.81	13.81	80	**142**	**67**
041H24001	Crenshaw	31.822603	-86.303856	182		Southeastern Coastal Plain aquifer system	52	4.27	2	21.07	16.72	80	**143**	**68**
011G01001	Bullock	32.22041	-85.50058	540		Southeastern Coastal Plain aquifer system	37	5.31	2	33.73	18.38	81	**144**	**69**
101X13001	Montgomery	32.10824	-86.21382	18		Southeastern Coastal Plain aquifer system	37	3.68	2	11.37	14.60	81	**145**	**70**
065I29001	Hale	32.766598	-87.490575	130		Southeastern Coastal Plain aquifer system	50	7.17	1	7.38	17.53	81	**146**	**71**
021R36001	Chilton	32.751399	-86.512051	48		Southeastern Coastal Plain aquifer system	34	6.29	1	21.45	18.11	82	**148**	**72**
001G03006	Autauga	32.66278	-86.55185	460		Southeastern Coastal Plain aquifer system	37	3.40	1	21.03	19.23	84	**151**	**73**
065J28001	Hale	32.757972	-87.58255	100		Southeastern Coastal Plain aquifer system	51	3.69	1	3.93	15.11	84	**152**	**74**
005P36001	Barbour	31.885661	-85.600657	181		Southeastern Coastal Plain aquifer system	52	3.48	1	21.33	20.12	87	**155**	**75**
059O22001	Franklin	34.351158	-87.783811	37.4		Southeastern Coastal Plain aquifer system	34	7.52	3	26.44	20.55	91	**157**	**76**
067K15001	Henry	31.578611	-85.316944	280		Southeastern Coastal Plain aquifer system	37	1.92	4	16.55	15.25	91	**158**	**77**
067N34002	Henry	31.445232	-85.321546	560		Southeastern Coastal Plain aquifer system	37	1.49	1	16.00	18.48	92	**159**	**78**
091I32001	Marengo	32.397301	-87.600955	1000		Southeastern Coastal Plain aquifer system	38	1.60	1	16.39	18.33	92	**160**	**79**
105L31001	Perry	32.58221	-87.52332	200		Southeastern Coastal Plain aquifer system	37	4.74	3	9.11	19.31	98	**163**	**80**
109D33001	Pike	31.89247	-85.85079	190		Southeastern Coastal Plain aquifer system	37	3.20	4	13.76	20.90	102	**164**	**81**
011N10001	Bullock	32.125125	-85.936783	925		Southeastern Coastal Plain aquifer system	52	4.38	2	8.19	22.48	103	**166**	**82**
109G02001	Pike	31.959111	-86.130636	180		Southeastern Coastal Plain aquifer system	54	5.36	1	7.25	25.94	103	**167**	**83**
109D17001	Pike	31.93365	-85.86719	192		Southeastern Coastal Plain aquifer system	37	4.20	3	11.30	23.87	104	**168**	**84**

Table 2. Rank of potential NGWMN surveillance well candidates by principal aquifers

GSAL_ID	County	Latitude	Longitude	Well Depth	Wells in Principal Aquifer	Principal aquifer	Years of data	Distance to public supply wells (miles)	Number of wells in 5 mi. radius	Distance to real time wells (miles)	Distance from stream gage (miles)	Sum of Weighted Factors Final	Rank: Overall Rank	Rank: Rank Within Principal Aquifer System
025EE11001	Clarke	31.671321	-87.9399	200		Mississippi embayment aquifer system	37	9.28	1	34.68	6.95	44	**16**	**1**
091GG10001	Marengo	32.027032	-87.660599	160		Mississippi embayment aquifer system	51	11.33	2	35.33	12.35	58	**63**	**2**
025JJ12001	Clarke	31.597417	-87.728071	140		Mississippi embayment aquifer system	40	6.63	1	21.23	10.44	61	**74**	**3**
023CC14004	Choctaw	31.833133	-88.2453	370		Mississippi embayment aquifer system	37	4.15	2	14.25	8.57	66	**96**	**4**
025H16001	Clarke	31.924744	-87.975925	250	**10**	Mississippi embayment aquifer system	37	9.84	2	28.30	12.72	66	**97**	**5**
119HH15001	Sumter	32.360433	-88.268333	180		Mississippi embayment aquifer system	51	7.40	1	26.96	15.27	68	**112**	**6**
023BB24006	Choctaw	31.8183	-88.3327	40		Mississippi embayment aquifer system	37	1.98	2	10.78	12.66	80	**140**	**7**
023CC04003	Choctaw	31.867733	-88.2989	270		Mississippi embayment aquifer system	52	1.96	4	10.35	12.52	84	**153**	**8**
023X20001	Choctaw	31.913267	-88.320938	200		Mississippi embayment aquifer system	36	3.23	2	8.14	15.54	85	**154**	**9**
099O23001	Monroe	31.649709	-87.242035	800		Mississippi embayment aquifer system	36	1.39	2	16.75	18.43	95	**162**	**10**
119B10001	Sumter	32.9857	-88.292983	693		Confining unit	37	4.26	1	25.65	4.54	49	**30**	**1**
035T27001	Conecuh	31.372387	-87.051642	259		Confining unit	31	1.66	1	21.88	4.96	54	**48**	**2**
063EE09001	Greene	32.641419	-87.999974	700	**6**	Confining unit	37	8.51	1	12.55	10.87	62	**78**	**3**
039Q22001	Covington	31.218056	-86.535833	275		Confining unit	36	6.14	1	9.20	8.88	65	**89**	**4**
091G31005	Marengo	32.405789	-87.827213	1000		Confining unit	37	5.69	1	7.63	8.47	65	**92**	**5**
039DD33003	Covington	31.00569	-86.251302	285		Confining unit	39	4.32	1	18.69	11.61	68	**110**	**6**
061H29001	Geneva	31.117778	-86.163611	290		Floridan aquifer system	37	2.77	1	15.40	3.84	50	**34**	**1**
061Q04001	Geneva	31.079444	-85.754167	220		Floridan aquifer system	39	3.92	2	11.03	5.80	56	**57**	**2**
061T27001	Geneva	31.028611	-86.024167	230		Floridan aquifer system	39	5.66	1	11.68	7.25	56	**58**	**3**
039L19004	Covington	31.30379	-86.39622	170		Floridan aquifer system	36	3.89	1	17.67	8.30	63	**80**	**4**
061X23001	Geneva	30.995833	-85.899722	260		Floridan aquifer system	39	1.75	4	11.80	4.20	66	**100**	**5**
061AA19002	Geneva	31.00805	-85.612	150		Floridan aquifer system	39	6.08	1	20.78	14.43	72	**122**	**6**
061B03001	Geneva	31.1798	-85.544019	365	**14**	Floridan aquifer system	37	2.85	4	13.77	11.94	79	**136**	**7**
039S23001	Covington	31.218611	-86.321389	272		Floridan aquifer system	54	2.69	2	16.49	15.08	81	**147**	**8**
039S24003	Covington	31.210556	-86.309167	220		Floridan aquifer system	39	2.24	2	16.81	14.18	83	**149**	**9**
069R26002	Houston	31.039678	-85.427143	180		Floridan aquifer system	26	7.14	2	22.72	22.74	94	**161**	**10**
069T16002	Houston	31.058056	-85.248333	125		Floridan aquifer system	39	2.95	2	12.30	29.10	113	**169**	**11**
069S27001	Houston	31.03834	-85.324194	150		Floridan aquifer system	39	1.87	2	16.62	27.01	115	**170**	**12**
069X14001	Houston	31.003889	-85.103611	140		Floridan aquifer system	39	6.60	2	3.82	38.07	117	**171**	**13**
069U14001	Houston	31.058611	-85.102222	300		Floridan aquifer system	39	3.71	2	4.12	35.94	119	**172**	**14**
097MM06004	Mobile	30.465633	-88.112467	90		Coastal lowlands aquifer system	52	6.47	1	25.84	4.77	45	**21**	**1**
097GG12009	Mobile	30.623611	-88.240555	139		Coastal lowlands aquifer system	53	2.32	1	36.32	7.37	50	**37**	**2**
053Q10001	Escambia	31.154389	-86.844584	203		Coastal lowlands aquifer system	39	2.03	1	17.94	11.83	70	**117**	**3**
129H17001	Washington	31.581205	-88.298883	270	**8**	Coastal lowlands aquifer system	52	1.30	1	25.97	15.72	76	**132**	**4**
039AA26002	Covington	31.017698	-86.529409	380		Coastal lowlands aquifer system	39	4.85	2	4.85	10.72	79	**137**	**5**
003G05002	Baldwin	31.17191	-87.79105	250		Coastal lowlands aquifer system	53	2.63	1	29.73	17.47	79	**138**	**6**
099GG36001	Monroe	31.350456	-87.416078	175		Coastal lowlands aquifer system	34	2.29	1	7.10	15.45	84	**150**	**7**

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