FINAL TECHNICAL REPORT

AWARD NUMBER: G20AC00179

AGENCY: Maryland Department of Natural Resources, Maryland Geological Survey

PROJECT TITLE: Filling Gaps in Information and Performing Well Maintenance at Maryland NGWMN sites

CONTACT PERSON: Andrew Staley **TITLE**: Program Chief, Hydrogeology & Hydrology Program

ADDRESS: 2300 St. Paul Street, Baltimore, MD 21218

PHONE: (410) 260-8818

EMAIL: andrew.staley@maryland.gov

CONTACT PERSON 2: Richard A. Ortt **TITLE**: Acting Director, Maryland Geological Survey

ADDRESS: 2300 St. Paul Street, Baltimore, MD 21218

PHONE: (410) 554-5503

EMAIL: richard.ortt@maryland.gov

TERM COVERED: September 30, 2020, to September 29, 2022 (includes a no-cost extension of 1 year)

FINAL REPORT DATE: December 22, 2022

PROJECT SUMMARY: This was a two-year project (initial 1-year performance period with a 1-year no-cost extension). Objective 3 work was performed to update altitude and coordinate information using GPS/total station leveling surveying techniques. Objective 4 work included well-integrity testing in selected NGWMN wells to determine well-screen and open-hole hydraulic connection to the aquifer, to locate obstructions, to identify deterioration, and to assess the physical condition of the casings, joints, screens, and fracture openings. Tasks performed under Objective 4 included borehole camera surveys, well sounding, and slug testing.

DESCRIPTION OF WORK DONE TO SUPPORT THE NGWMN AS A DATA PROVIDER

A total of 112 National Ground-Water Monitoring Network wells were used for water-level data in Maryland when this project was initiated (fig. 1; app. A). The wells are measured and maintained as part of a cooperative agreement between the Maryland Geological Survey (MGS) and the United States Geological Survey (USGS) MD-DE-DC Baltimore Water Science Center. Ninety-one wells are in the Coastal Plain physiographic province, and 21 are in the fractured rock physiographic provinces.

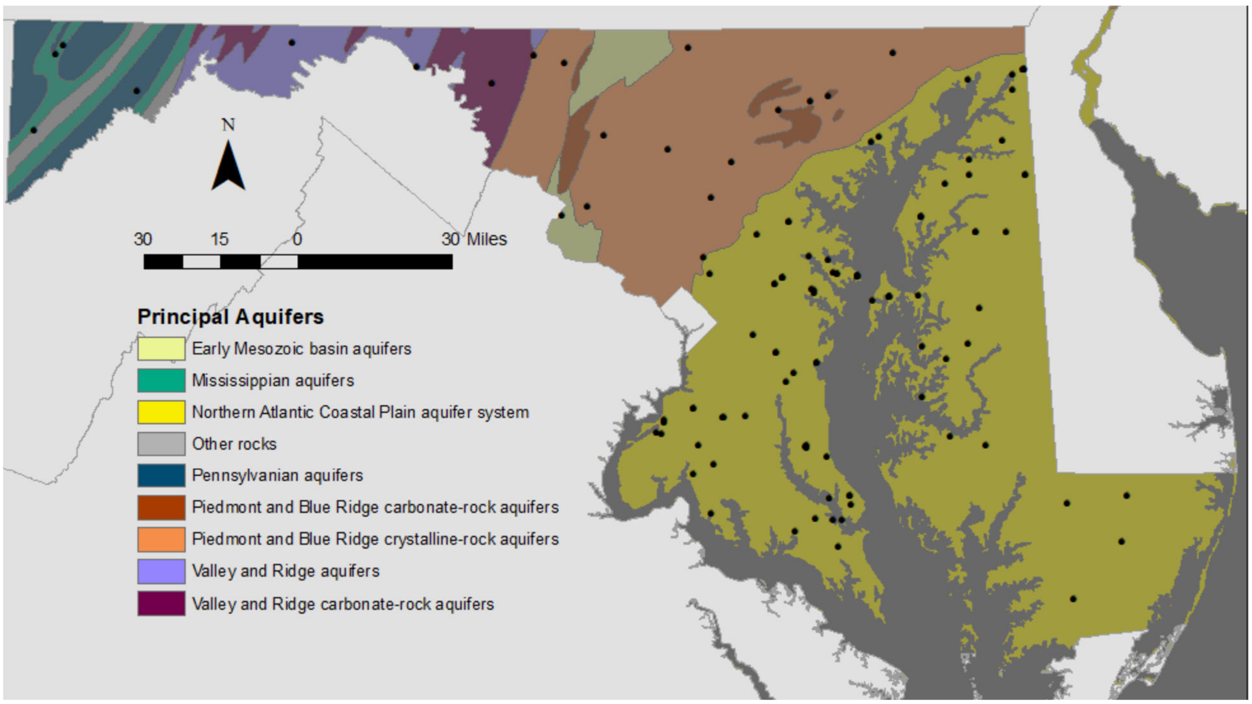

Figure 1. Map of NGWMN wells in Maryland

Tasks performed under this grant fell under Objective 3 (gap filling) and Objective 4 (well maintenance). Objective 3 tasks included GPS and total station elevation surveying to update altitude and coordinate information which were derived using the relatively inaccurate method of estimation from paper topographic quadrangles. Objective 4 tasks included performing borehole camera surveys to visually inspect wells and well depth measurements to identify sediment accumulation or obstructions; and performing slug tests to identify compromised well openings and to establish a baseline for future comparison.

Objective 3 - Filling gaps in information at Maryland NGWMN sites

GPS / Total Station Elevation Surveys

Four elevation surveys using GPS occupations or total station leveling to update data at NGWMN wells were tasked for the grant and we ultimately performed surveys on three of these wells during the grant performance period (fig. 2; app. A). One of the wells in the proposed well list (MO Cb

26) was found to be inaccessible to the survey equipment. No other wells in the Maryland NGWMN network were identified that needed updated elevation surveys. Therefore, additional slug testing was performed at wells in Anne Arundel County (AA Ad 90, AA Ad 102, and AA Bb 87) that were previously tested in 2018 in order to compensate for the loss of this tasked survey.

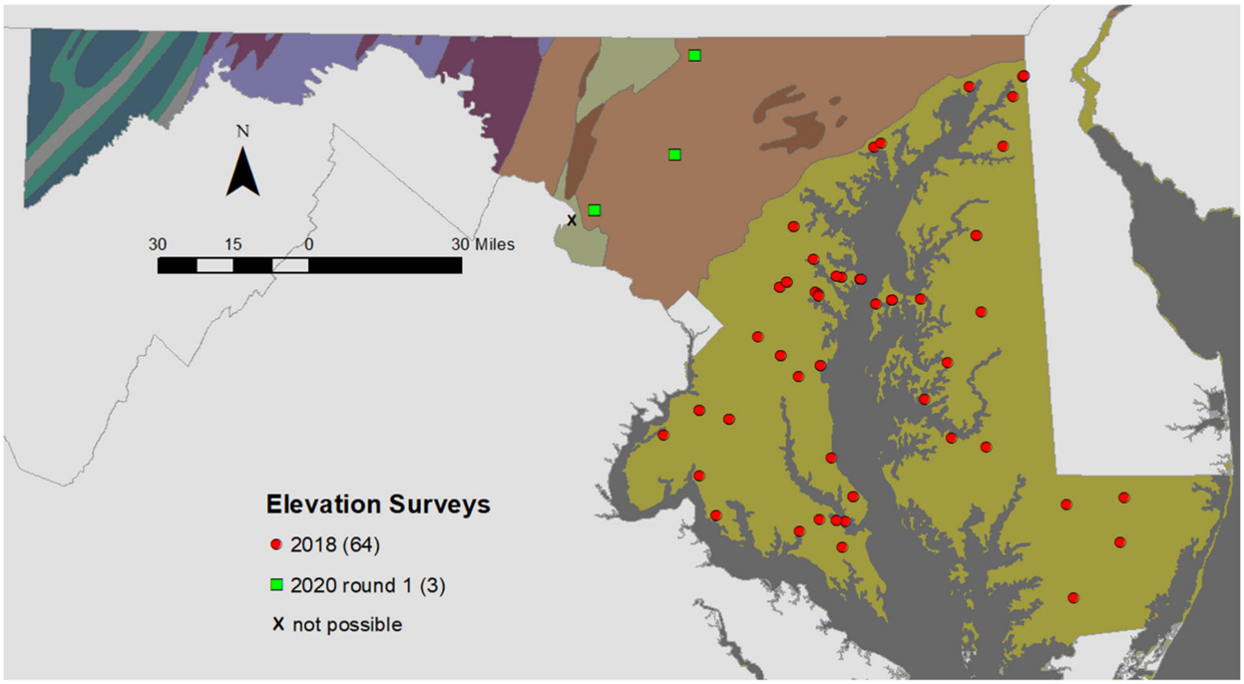

Figure 2. Map of NGWMN wells in Maryland that had elevation surveys performed during 2018 and 2020 round 1 grant performance periods.

Total station leveling surveys utilizing Global Positioning System (GPS) measurements were performed in order to increase the accuracy of altitude and latitude/longitude measurements at these observation wells. GPS measurements provide an accurate method for greatly improving altitude and location accuracy at measuring points, thus ensuring that measured groundwater levels are accurately referenced to land surface.

These wells were all located at sites that are too heavily forested to receive reliable satellite transmissions for a simple GPS occupation. For these sites we conducted a resection (free station) survey in which we established 3 temporary benchmarks in an adjacent cleared area, and then used a total station to level and locate the measuring point of the obscured well. At each temporary benchmark (backsight point), a dual frequency (L1/L2) GPS receiver with fixed-height range pole was set up and continuous GPS data were recorded. The total station was used to locate and triangulate among the benchmarks using laser and prism to determine relative position of the total station horizontally and vertically. Finally, a prism was held on the well measuring point (foresight point), and the total station was shot to the well site to determine its position horizontally and vertically. The GPS data from the benchmarks (backsight and foresight) was processed using the National Geodetic Survey's Online Positioning User Service (OPUS) to determine accurate orthometric heights and latitude/longitude (Rydlund and Densmore, 2012).

Objective 4 - Well Maintenance at Maryland NGWMN Wells

Camera Surveys and Well-Depth Sounding

Nineteen camera surveys were tasked for the grant and we ultimately performed surveys on 18 wells during the course of the grant performance period (fig. 3; app. A). Three of the wells in the proposed well list (BA Ce 21, GA Eb 78, and MO Cb 26) were found to be inaccessible for the camera equipment. Therefore, we performed a camera survey on two other wells (AA Ad 90 and AA Ad 102) in the Maryland NGWMN network.

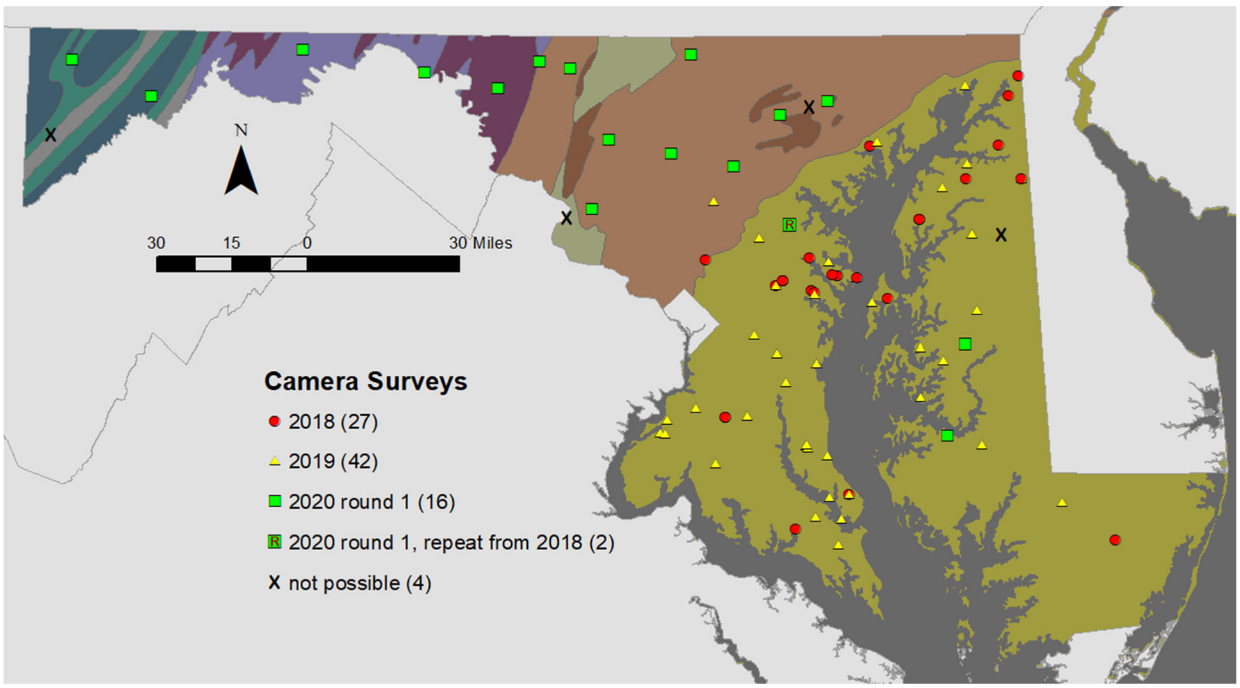

Figure 3. Map of NGWMN wells in Maryland that had camera surveys performed during 2018, 2019, and 2020 round 1 grant performance periods.

For the camera surveys, we used an Aries Explorer portable borehole camera, which is a high-resolution 1.75 inch diameter color video camera with adjustable LED lights, has rotating forward and side viewing capabilities, and has 1,200 feet of cable. Video from camera surveys was recorded to digital files via a portable USB drive connected to the camera unit. This video was analyzed (during the survey and later) to identify well casing and screen integrity, scaling, sediment accumulation, bacteria, and physical obstructions. Debris in wells that prevented the camera from reaching total depth was removed, if possible, from the well using a tag line with a treble hook attached to the end or a grappling device attached to wire line as described in USGS GWPD 6—"Recognizing and removing debris from a well" (Cunningham and Schalk, 2011).

Wells that exhibited significant encrustration, sedimentation, and blockage of screen openings were flagged and will be targeted for additional investigation (such as slug testing) or rehabilitation (debris removal, pumping, or redevelopment) at a future date beyond the performance period of this proposal. Wells with more serious problems such as sediment filling the casing above screens (indicating a collapsed screen or casing) were flagged for potential abandonment following a joint analysis by MGS and USGS Baltimore Water Science Center staff. Finally, well construction details (casing and screen diameter, materials, and intervals) were noted from the camera surveys and compared to the reported data. Any inconsistencies in well construction data were recorded to be corrected in the USGS NWIS database.

Well-depth measurements were performed in addition to the camera surveys. Well integrity could be compromised, and additional investigation may be warranted if sounded depth differs significantly from the reported depth of a well. Sounding was performed using a Solinst tag line with 1,500 ft cable.

Slug Tests

MGS was tasked to perform slug tests in 12 NGWMN wells and ultimately performed 14 slug tests during the grant performance period (fig. 4; app. A). One of the wells in the proposed well list (GA Eb 78) was found to be inaccessible for the slug testing equipment. Therefore, we performed a repeat slug test in three other wells (AA Ad 90, AA Ad 102, and AA Bb 87) in the Maryland NGWMN network that were previously tested in 2018. This repeat testing allowed us to determine hydraulic changes over the 4-year elapsed period of time.

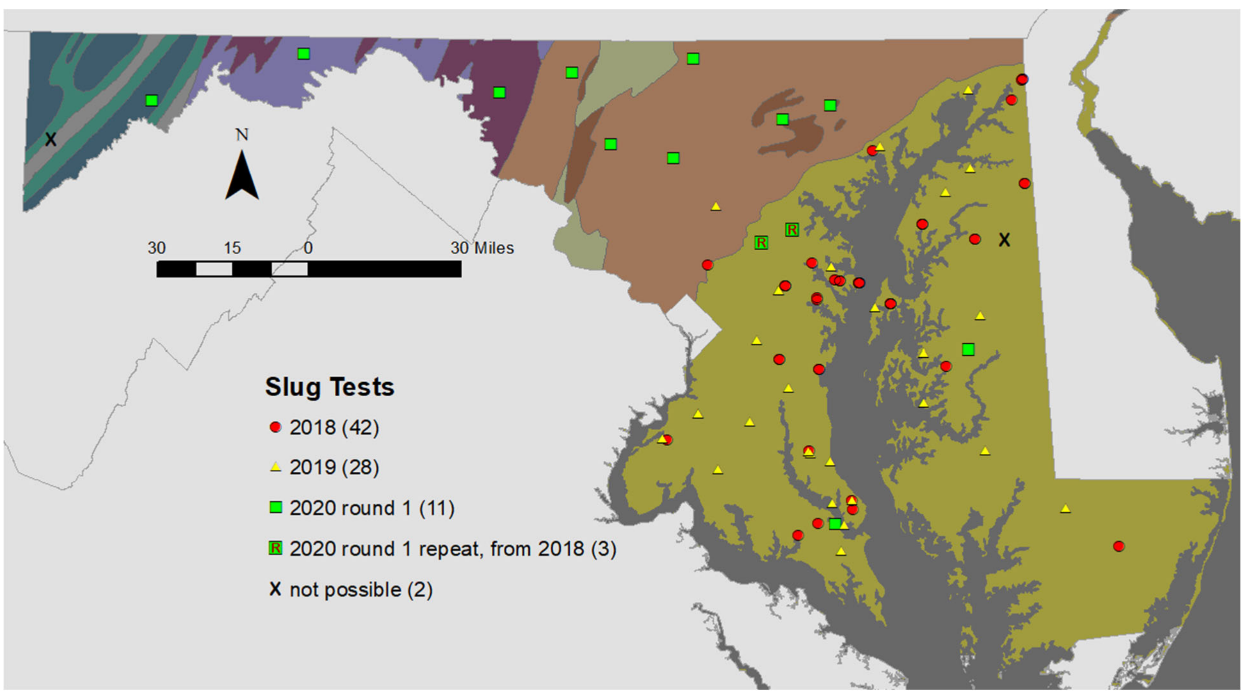

Figure 4. Map of NGWMN wells in Maryland that had slug tests performed during 2018, 2019, and 2020 round 1 grant performance periods.

We conducted slug tests using the procedures recommended in GWPD 17—"Conducting an Instantaneous Change in Head (Slug) Test with a Mechanical Slug and Submersible Pressure Transducer" (Cunningham and Schalk, 2011). For each test, a 15 psi In-Situ Level TROLL pressure transducer with vented cable was installed in the well below the level to which the slug was to be lowered. The transducer was set to collect data in “Fast Linear” mode, recording each data point every half second. A PVC slug able to displace water in the casing by at least 1 foot was lowered beneath the static water level and water level data were recorded. The water level was allowed to recover to pre-test static level, which was confirmed using a Heron Dipper-T electric water level tape. Following the recovery to static water level, the slug was removed and the water levels were recorded until water levels again reached pre-test static level. This slug-in/slug-out cycle was repeated, when possible, to collect a total of 2 slug-in datasets and 2 slug-out datasets.

Data collected from slug tests were analyzed using standard solutions such as Bouwer and Rice (1976) and Hvorslev (1951). The Butler (1998) solution was used for wells in a confined aquifer with high hydraulic conductivity which exhibited an inertial effect (oscillatory response). Due to the large number of tests performed in this task and for the sake of consistency of analysis and repeatable analyses in the future, slug test data were analyzed using AQTESOV software.

Most of the monitoring wells targeted for slug testing have historical hydraulic data in the form of either constant-rate aquifer tests or specific capacity pump tests. We identified wells with slug-test data that show slow response (low hydraulic conductivity) or were anomalous considering prior hydraulic testing. These wells were flagged for further investigation or redevelopment to clean out the screen openings or open-hole intervals and reestablish hydraulic connection of the well to the aquifer sediments (App. A).

Repeat slug tests were performed in three wells using the exact same procedures and analysis as were used during the initial testing four years prior (2018). Results indicate that two of the wells (AA Ad 102 and AA Bb 87) had similar, but slightly lower hydraulic conductivity as found in the 2018 tests. One well (AA Ad 90) had a much lower hydraulic conductivity (7.28 ft/d in 2018 vs 0.08 ft/d in 2022). A well camera survey showed significant encrustation in the screened interval, and thus we recommend this well be further investigated to determine if the well screens can be swabbed or hydraulically redeveloped. It is hoped that in a similar way, data from all slug tests performed during this grant period will serve as an important interim baseline for future slug testing.

QUALITY ASSURANCE OF COLLECTED DATA

We conducted a rigorous and comprehensive Quality Control/Quality Assurance (QA/QC) check of the field data in both our internal database and the metadata to be submitted to the national systems (USGS NWIS and the NGWMN portal). Queries and sorting of the database were used to check for duplicate records, errors and omissions. The QA/QC process was valuable in two key ways: (1) the process forced a familiarity with the well data; and (2) the process revealed errors with regards to consistency in data nomenclature, measurement units, datums and text descriptors (e.g. lithology/hydrostratigraphic unit naming conventions) that otherwise may not have been noticed.

Maryland Geological Survey collected and/or generated 11.3 gigabytes of data from fieldwork during the grant performance period. This included many hours of well camera surveys, slug test data sets and analyses, gps and leveling data, and photographs of well heads. Data that were collected and compiled during the grant were archived on MGS servers and backed up regularly. The data will be transmitted to the USGS Baltimore MD-DE-DC Water Science Center to be entered into their monitoring well files, which will then be available for future analysis of the well network.

PROBLEMS ENCOUNTERED DURING OBJECTIVE 3 and 4 FIELDWORK

Fieldwork tasks were disrupted due to the COVID pandemic restrictions on fieldwork as well as staffing shortages that occurred during the grant period. For these reasons, MGS asked for, and USGS granted a 1-year no-cost extension to provide enough time to complete the grant tasks.

Through the course of this grant performance period, we found 4 wells with poor hydraulic response (flat-lining water levels with no recovery to static) or low hydraulic conductivity during slug tests, and noted the likely causes of the poor response:

- AA Ad 90 – encrustation on well screens
- BA Dc 444 – very few open fractures in rock through open interval (tight rock)
- CL Ad 47 – very few open fractures in rock through open interval (tight rock)
- FR Df 35 – very few open fractures in rock through open interval (tight rock)

Additionally, visual inspection during camera surveys and site visits found the following issues:

- Well caps rusted or welded shut, or otherwise inaccessible (BA Ce 21, GA Eb 78, MO Cb 26)
- Wells poorly developed or constructed in a tight and unyielding formation (BA Dc 444, BA Ea 18, CL Ad 47, FR Df 35)
- Heavily encrusted screens or heavy sediment accumulation (AA Ad 90, AA Ad 102, AL Ca 20)
- Well casings obstructed by debris (DO Ce 15)

EXPECTED CHANGES TO MARYLAND'S NGWMN WELL NETWORK

Based on the potential clogged screens or unproductive open intervals that were discovered during slug tests, we may have to either redevelop or abandon wells AA Ad 90, BA Dc 444, CL Ad 47, and FR Df 35 and possibly drop them from our network and from the NGWMN. Decisions on the fates of these wells will be discussed during an ongoing network evaluation analysis performed jointly by MGS and USGS MD-DE-DC Baltimore Water Science staff.

REFERENCES

Bouwer, Herman, and Rice, R.C., 1976. A slug test method for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells, Water Resources Research, vol. 12, no. 3, pp. 423-428.

Butler, J.J., Jr., 1998. The Design, Performance, and Analysis of Slug Tests, Lewis Publishers, Boca Raton, 252p.

Cunningham, W.L., and Schalk, C.W., comps., 2011, Groundwater technical procedures of the U.S. Geological Survey: U.S. Geological Survey Techniques and Methods 1–A1, 151 p.

Hvorslev, M.J., 1951. Time Lag and Soil Permeability in Ground-Water Observations, Bull. No. 36, Waterways Exper. Sta. Corps of Engrs, U.S. Army, Vicksburg, Mississippi, pp. 1-50.

Rydlund, P.H., Jr., and Densmore, B.K., 2012, Methods of practice and guidelines for using survey-grade global navigation satellite systems (GNSS) to establish vertical datum in the United States Geological Survey: U.S. Geological Survey Techniques and Methods, book 11, chap. D1, 102 p. with appendixes.

Schwarz, C.R., Snay, R.A., and Tomas Soler, 2009, Accuracy assessment of the National Geodetic Survey's OPUS-RS utility: GPS Solutions vol. 13, pp. 119-132.

		Objective 3	Objective 4					
Well Name	**USGS Site Number**	**GPS or Total Station Survey**	**Slug Test**	**Camera - Sounding**	**Hydraulic Conductivity from Slug Test**	**Problem identified**	**hydraulic problem identified**	**description of problem / (comments)**
AA Ad 90	391032076385902		✓	✓	K = 0.0829 ft/d	Yes	slow response	encrustation on screens (repeat test - dropped from 7.28 ft/d in 2018)
AA Ad 102	391032076385904		✓	✓	K = 20.09 ft/d	Yes		encrustation on screens (repeat test - 20.36 ft/d in 2018)
AA Bb 87	390826076454802		✓		K = 16.63 ft/d			(repeat test - 18.65 ft/d in 2018)
AA Cc 89	390010076415703							
AA Cc 102	390004076420001							
AA Cc 115	390103076402601							
AA Cc 116	390103076402602							
AA Cc 117	390103076402603							
AA Ce 117	390450076343402							
AA Ce 133	390410076302401							
AA Cf 98	390150076283003							
AA Cf 99	390150076283002							
AA Cf 137	390205076292702							
AA Cg 22	390123076241601							
AA Cg 23	390123076241602							
AA Cg 24	390123076241603							
AA Cg 25	390127076240301							
AA De 1	385915076340401							
AA De 95	385853076333001							
AA De 206	385833076332801							
AA Fc 34	384833076415601							
AA Fc 35	384833076415602							
AA Fe 92	384644076331201							
AA Fe 93	384644076331202							
AL Ah 1	394024078273401		☑	☑	K = 14.81 ft/d			
AL Ca 20	393148079010601		☑	☑	K = 142.2 ft/d	Yes		sediment accumulation (~20 ft)
BA Ce 21	393102076341801			☐		Yes		well cap can't be removed for survey (welded on)
BA Dc 444	392931076410301		☑	☑	K = 0.91 ft/d	Yes	slow response	few visible factures in open interval
BA Ea 18	392045076512501			☑		Yes		few visible factures in open interval
CA Bb 23	384458076375501							
CA Bb 27	384333076394701							

☑=tasked and completed ; ☐=tasked but not completed ; ✓=not tasked but completed

		Objective 3	Objective 4					
Well Name	USGS Site Number	GPS or Total Station Survey	Slug Test	Camera - Sounding	Hydraulic Conductivity from Slug Test	Problem identified	hydraulic problem identified	description of problem / (comments)
CA Db 47	383239076354201							
CA Db 65	383216076351401							
CA Db 96	383244076354201							
CA Dc 35	383050076305501							
CA Fc 13	382343076302901							
CA Fd 51	382408076260401							
CA Fd 54	382407076260301							
CA Fd 85	382236076255401							
CA Gd 61	381956076275301							
CE Bf 58	393605075472302							
CE Bf 143	393612075472702							
CE Bf 144	393612075472701							
CE Bf 158	393509075495401							
CE Cd 52	393432075593602							
CE Ce 55	393241075500201							
CE Ee 29	392403075521801							
CH Bc 77	383644077055501							
CH Bc 81	383709077061002							
CH Be 72	383903076594301							
CH Be 73	383903076594302							
CH Bf 134	383728076531701							
CH Bf 158	383732076531902							
CH Bg 12	383746076482901							
CH Cc 31	383455077074401							
CH Cc 34	383441077063901							
CH Ce 56	383251076583901							
CH De 45	382927076552301							
CH De 52	382752076593601							
CH Ee 16	382103076560201							
CL Ad 47	394008077005601	☑	☑	☑	K = 0.0028 ft/d	Yes	No response	few visible factures in open interval
CL Ec 75	392259077052401	☑	☑	☑	K = 1.07 ft/d			

☑=tasked and completed ; ☐=tasked but not completed ; ✓=not tasked but completed

		Objective 3	Objective 4					
Well Name	**USGS Site Number**	**GPS or Total Station Survey**	**Slug Test**	**Camera - Sounding**	**Hydraulic Conductivity from Slug Test**	**Problem identified**	**hydraulic problem identified**	**description of problem / (comments)**
DO Ce 15	383408076042402			☑		Yes		physical obstruction (bricks) at ~260 ft
DO Cf 36	383225075565002							
FR Bd 96	393733077274801		☑	☑	K = 2.177 ft/d			
FR Df 35	392517077190401		☑	☑	K = 0.836	Yes	Very slow response	few visible factures in open interval
GA Bc 1	393749079190301			☑				
GA Bc 62	393908079173601							
GA Eb 78	392439079231801		☐	☐		Yes		Well cap cannot be removed for slug test or survey (rusted bolts)
HA Bd 31	393902076160001							
HA Ca 23	393158076302601		☑	☑	K = 2.809 ft/d			
HA Ec 46	392408076210101							
HA Ed 49	392455076192103							
HO Cd 79	391445076555101							
KE Ae 71	392053075592901							
KE Bc 185	391650076050402							
KE Be 43	391823075594701							
KE Bg 33	391815075472101							
KE Bg 34	391815075472102							
KE Cb 97	391124076101001							
KE Cb 100	391124076101004							
KE Cb 103	391124076101005							
MO Cb 26	391142077280601	☐		☐		Yes		Well head inaccessible (casing elevated 11 ft above land surface)
MO Cc 14	391314077224201	☑		☑				
MO Eh 20	390434076573002							
PG Bc 16	390151076561501							
PG De 21	385130076465501							
QA Cf 77	390845075582301							
QA Cf 78	390845075582302							
QA Cg 69	390839075515001							
QA Ea 27	385718076205501							
QA Eb 110	385751076171603							
QA Eb 111	385751076171601							

☑=tasked and completed ; ☐=tasked but not completed ; ✓=not tasked but completed

		Objective 3	Objective 4					
Well Name	USGS Site Number	GPS or Total Station Survey	Slug Test	Camera - Sounding	Hydraulic Conductivity from Slug Test	Problem identified	hydraulic problem identified	description of problem / (comments)
QA Eb 112	385751076171602							
QA Eb 113	385748076172001							
QA Ec 1	385756076105301							
QA Ef 29	385534075573601							
SM Ce 43	382012076332901							
SM Dd 50	381807076380001							
SM Df 71	381527076283101							
SM Df 88	381955076293901		☑		K = 79 ft/d			
SO Cf 2	380616075380701							
TA Cc 35	384923076100601							
TA Cc 53	384946076002201		☑	☑	K = 20.93 ft/d			
TA Cd 57	384709076050301							
TA Dc 54	384052076101201							
WA Be 2	393638078001301			☑				
WA Bk 25	393851077343001			☑				
WA Ci 82	393402077434201		☑	☑	K = 57.8 ft/d			
WI Ce 327	382220075392301							
WI Cg 20	382329075263701							
WO Cc 3	381543075273802							
wells tasked		4	12	19				
wells done		3	14	18				

☑=tasked and completed ; ☐=tasked but not completed ; ✓=not tasked but completed