FINAL TECHNICAL REPORT

AWARD NUMBER: G20AC00383

AGENCY: Maryland Department of Natural Resources, Maryland Geological Survey

PROJECT TITLE: Performing Well Integrity Testing at Maryland NGWMN sites

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

FINAL REPORT DATE: March 24, 2023

PROJECT SUMMARY: This was a two-year project (initial 1-year performance period with a 1-year no-cost extension). Work was performed under Objective 4 and included borehole camera surveys, well sounding, and slug 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.

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.

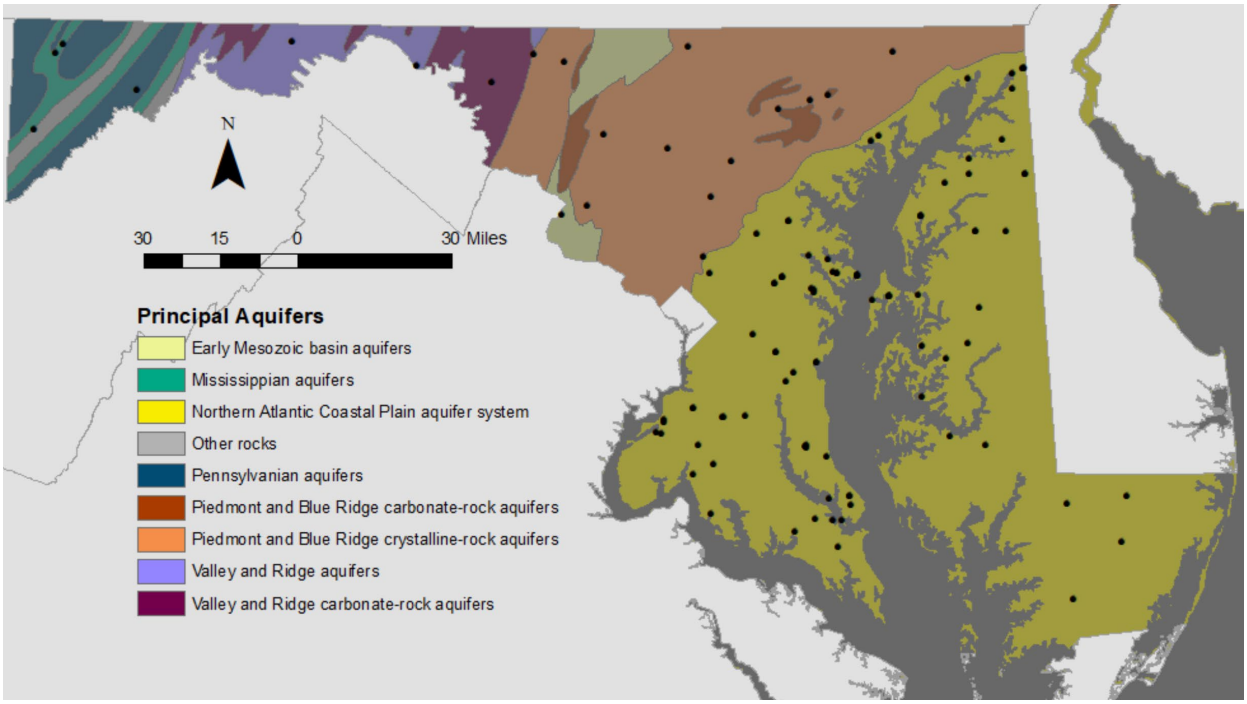

Figure 1. Map of NGWMN wells in Maryland

Tasks performed under this grant fell under Objective 4 (well maintenance). 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 of hydraulic properties.

Objective 4 - Well Maintenance at Maryland NGWMN Wells

Camera Surveys and Well-Depth Sounding

Six camera surveys were tasked for the grant and we ultimately performed surveys on all 6 wells during the course of the grant performance period (fig. 2; app. A). 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).

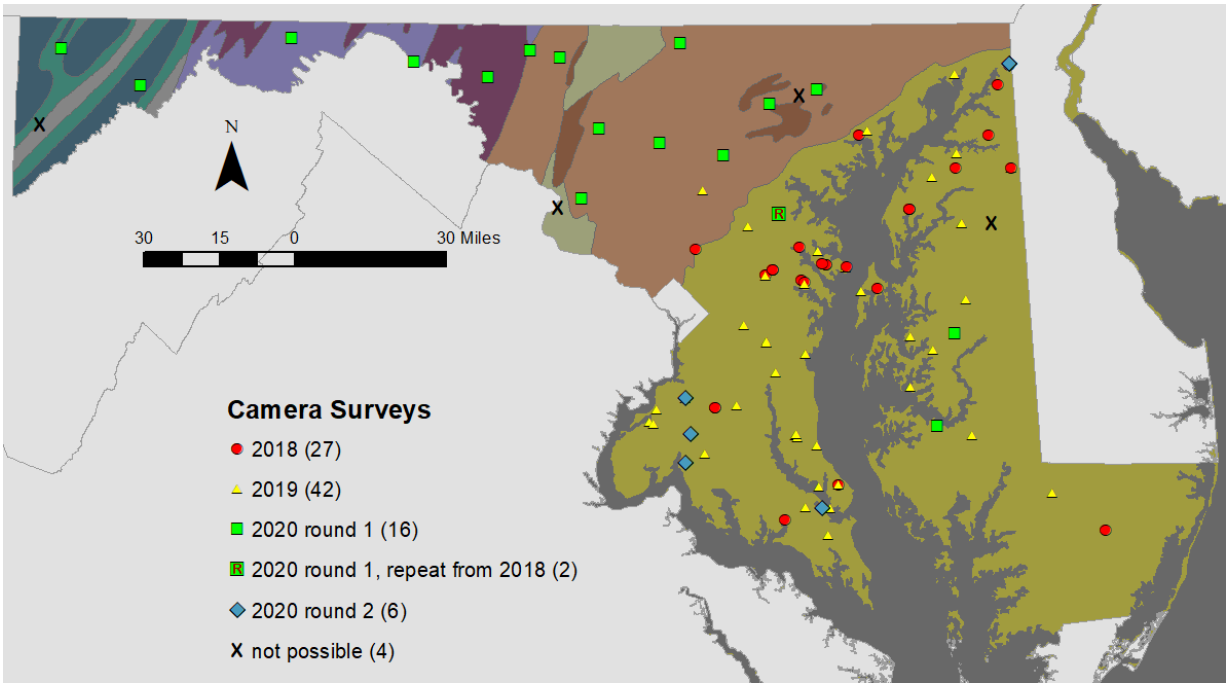

Figure 2. Map of NGWMN wells in Maryland that had camera surveys performed during 2018, 2019, 2020 round 1, and 2020 round 2 grant performance periods.

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. 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. Sounding was performed using a Solinst tag line with 1,500 ft cable. Well integrity could be compromised, and additional investigation may be warranted if sounded depth differs significantly from the reported depth of a well. A depth discrepancy in well WI Cg 20 indicates that sediment has infilled a portion of the screened interval in this well, and could indicate a potential casing collape.

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. 3; app. A). One of the wells in the proposed well list (BA

Ce 21) was found to be inaccessible for the slug testing equipment because the well cap was welded shut and the diameter of the measuring aperture was too small to insert the slug. Therefore, we performed a repeat slug test in three other wells (AA Cg 22, AA Cg 23, and AA Cg 24) 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.

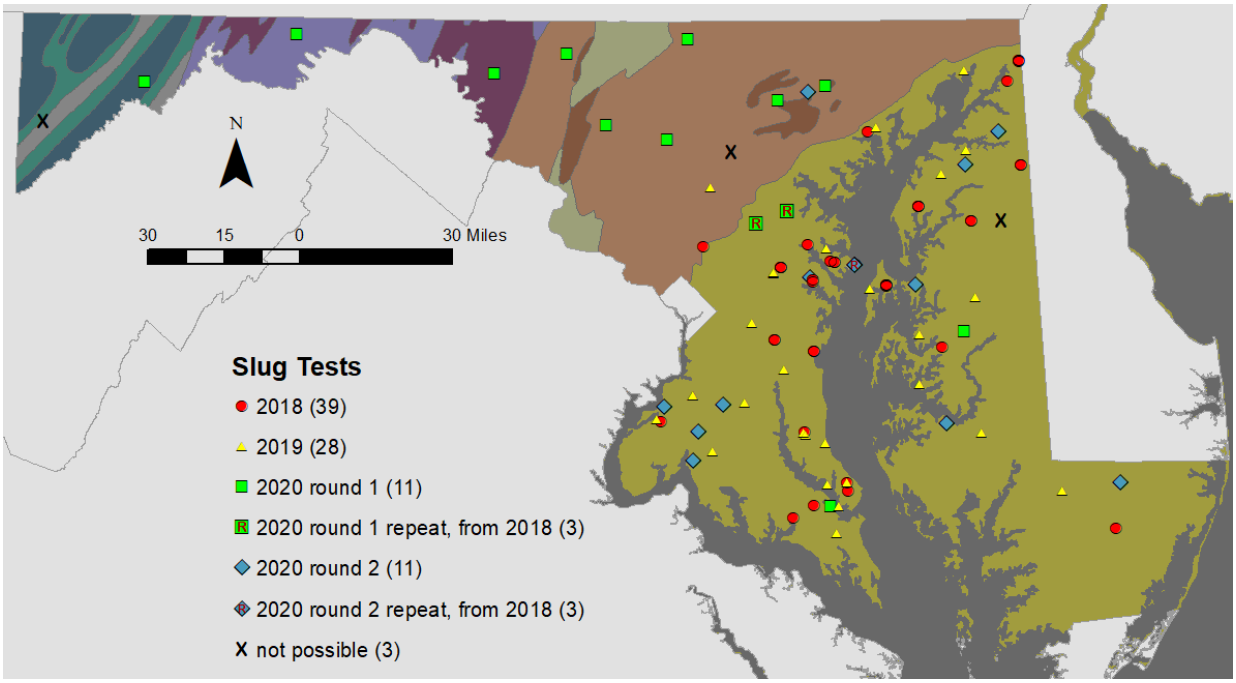

Figure 3. Map of NGWMN wells in Maryland that had slug tests performed during 2018, 2019, 2020 round 1, and 2020 round 2 grant performance periods.

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 Cg 22 and AA Cg 23) had very similar hydraulic conductivity values as found in the 2018 tests. One well (AA Cg 24) had a hydraulic conductivity that was significantly lower than that measured in 2018 (42.99 ft/d in 2018 vs 29.15 ft/d in 2022). It is unclear what has changed in the elapsed years in this well, but the decrease could be due to encrustration or biofouling of the screens and gravel pack. 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 generated 15.8 gigabytes of data from fieldwork during the grant performance period. This included many hours of well camera survey video files, slug test data sets and analyses, and field sheets for all tasks. 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 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:

- BA Ea 18 – very few open fractures in rock through open interval (tight rock)
- KE Be 43 – encrustation on screens
- QA Ec 1 – biofilm and sediment buildup in screens
- WI Cg 20 – sediment infill in screened interval

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

- CE Bf 144 – significant encrustation on screens and physical obstruction were noted

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 BA Ea 18, KE Be 43, QA Ec 1, and WI Cg 20 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

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Appendix A - List of Tasks Completed During Performance Period

		Objective 4					
Well Name	**USGS Site Number**	**Slug Test**	**Camera - Sounding**	**Hydraulic Conductivity from Slug Test**	**Problem identified**	**hydraulic problem identified**	**description of problem / (comments)**
AA Ad 90	391032076385902						
AA Ad 102	391032076385904						
AA Bb 87	390826076454802						
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	✓		K = 29.07 ft/d			(repeat test - 27.21 ft/d in 2018)
AA Cg 23	390123076241602	✓		K = 2.37 ft/d			(repeat test - 2.59 ft/d in 2018)
AA Cg 24	390123076241603	✓		K = 29.15 ft/d			(repeat test - 42.99 ft/d in 2018)
AA Cg 25	390127076240301						
AA De 1	385915076340401	☑		K = 36.5 ft/d			
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						
AL Ca 20	393148079010601						
BA Ce 21	393102076341801	☐			Yes		Well cap welded on - could not be removed for slug test
BA Dc 444	392931076410301						
BA Ea 18	392045076512501	☑		--	Yes	very slow response	Tight formation - sparse fractures

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

		Objective 4					
Well Name	**USGS Site Number**	**Slug Test**	**Camera - Sounding**	**Hydraulic Conductivity from Slug Test**	**Problem identified**	**hydraulic problem identified**	**description of problem / (comments)**
CA Bb 23	384458076375501						
CA Bb 27	384333076394701						
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		☑		Yes		encrustion on screens and physical obstruction
CE Bf 158	393509075495401						
CE Cd 52	393432075593602						
CE Ce 55	393241075500201						
CE Ee 29	392403075521801	☑		K = 70.38 ft/d			
CH Bc 77	383644077055501						
CH Bc 81	383709077061002	☑		K = 11.29 ft/d			
CH Be 72	383903076594301						
CH Be 73	383903076594302		☑				
CH Bf 134	383728076531701						
CH Bf 158	383732076531902	☑		K = 18.33 ft/d			
CH Bg 12	383746076482901						
CH Cc 31	383455077074401						
CH Cc 34	383441077063901						
CH Ce 56	383251076583901	☑	☑	K = 5.12 ft/d			
CH De 45	382927076552301						

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

		Objective 4					
Well Name	**USGS Site Number**	**Slug Test**	**Camera - Sounding**	**Hydraulic Conductivity from Slug Test**	**Problem identified**	**hydraulic problem identified**	**description of problem / (comments)**
CH De 52	382752076593601	☑	☑	K = 6.99 ft/d			
CH Ee 16	382103076560201						
CL Ad 47	394008077005601						
CL Ec 75	392259077052401						
DO Ce 15	383408076042402	☑		K = 28.79 ft/d			
DO Cf 36	383225075565002						
FR Bd 96	393733077274801						
FR Df 35	392517077190401						
GA Bc 1	393749079190301						
GA Bc 62	393908079173601						
GA Eb 78	392439079231801						
HA Bd 31	393902076160001						
HA Ca 23	393158076302601						
HA Ec 46	392408076210101						
HA Ed 49	392455076192103						
HO Cd 79	391445076555101						
KE Ae 71	392053075592901						
KE Bc 185	391650076050402						
KE Be 43	391823075594701	☑		--	Yes	very slow response	encrustion on screens
KE Bg 33	391815075472101						
KE Bg 34	391815075472102						
KE Cb 97	391124076101001						
KE Cb 100	391124076101004						
KE Cb 103	391124076101005						
MO Cb 26	391142077280601						
MO Cc 14	391314077224201						
MO Eh 20	390434076573002						
PG Bc 16	390151076561501						
PG De 21	385130076465501						

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

		Objective 4					
Well Name	**USGS Site Number**	**Slug Test**	**Camera - Sounding**	**Hydraulic Conductivity from Slug Test**	**Problem identified**	**hydraulic problem identified**	**description of problem / (comments)**
QA Cf 77	390845075582301						
QA Cf 78	390845075582302						
QA Cg 69	390839075515001						
QA Ea 27	385718076205501						
QA Eb 110	385751076171603						
QA Eb 111	385751076171601						
QA Eb 112	385751076171602						
QA Eb 113	385748076172001						
QA Ec 1	385756076105301	☑		--	Yes	very slow response	biofilm and sediment
QA Ef 29	385534075573601						
SM Ce 43	382012076332901						
SM Dd 50	381807076380001						
SM Df 71	381527076283101						
SM Df 88	381955076293901		☑				
SO Cf 2	380616075380701						
TA Cc 35	384923076100601						
TA Cc 53	384946076002201						
TA Cd 57	384709076050301						
TA Dc 54	384052076101201						
WA Be 2	393638078001301						
WA Bk 25	393851077343001						
WA Ci 82	393402077434201						
WI Ce 327	382220075392301						
WI Cg 20	382329075263701	☑		--	Yes	no response	sediment in screened interval
WO Cc 3	381543075273802						
wells tasked		12	6				
wells done		14	6				

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