AWARD NUMBER: G19AC00183

AGENCY: Maryland Department of Natural Resources, Maryland Geological Survey

PROJECT TITLE: Performing Well Maintenance at MGS NGWMN sites

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FINAL REPORT DATE: October 14, 2021

PROJECT SUMMARY: This was a two-year project (initial 1-year performance period with 1-year no-cost extension) to do well maintenance (Objective 4). Work under Objective 4 consisted of well integrity investigations using 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 are used for water-level data in Maryland (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.

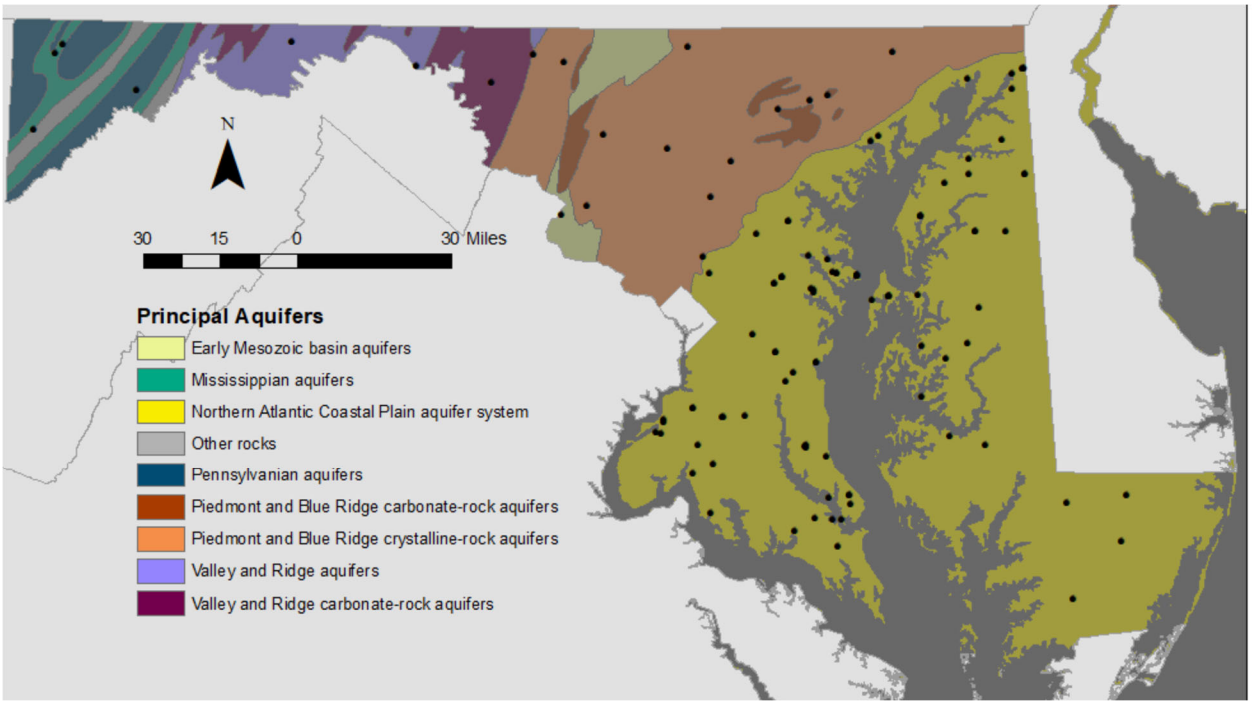

Figure 1. Map of NGWMN wells in Maryland

Tasks performed under this grant fell under Objective 4 (well maintenance). These 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 clogged screens and to establish a baseline for future comparison.

Objective 4 - Well Maintenance at MGS NGWMN Wells

Camera Surveys and Well-Depth Sounding

Forty-two camera surveys were tasked for the grant and we ultimately performed surveys on 42 wells during the course of the grant performance period (fig. 2; app. A). One of the wells in the proposed well list (QA Cg 69) was found to be inaccessible for the camera equipment. Therefore, we performed a camera survey on another deep well (QA Ef 29) in the Maryland NGWMN network.

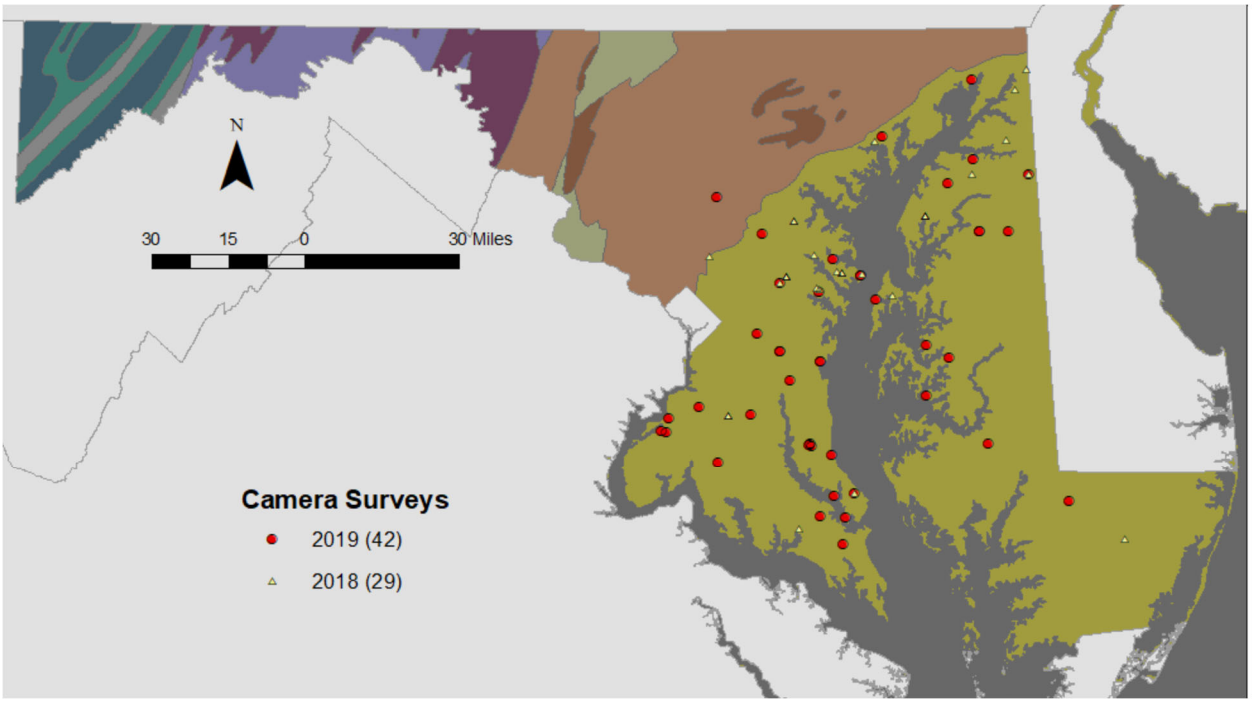

Figure 2. Map of NGWMN wells in Maryland that had camera surveys performed during 2018 and 2019 grant performance periods.

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 from the well (to the extent possible) 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 scaling, 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 28 NGWMN wells and ultimately performed 28 slug tests during the grant performance period (fig. 3; app. A). One of the wells in the proposed well list (QA Cg 69) was found to be inaccessible for the slug testing equipment. Therefore, we performed a slug test on another deep well (QA Ef 29) in the Maryland NGWMN network.

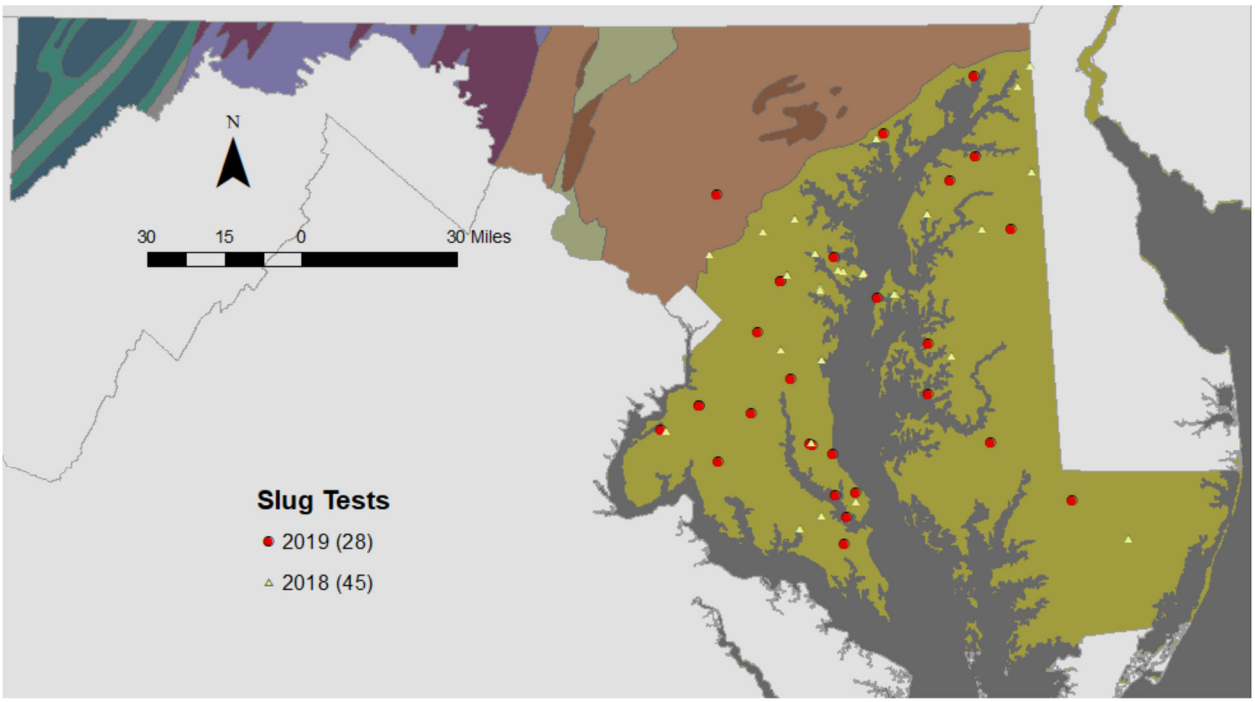

Figure 3. Map of NGWMN wells in Maryland that had slug tests performed during 2018 and 2019 grant performance periods.

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 will 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. 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, in order 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). Test data which exhibited oscillatory response were analyzed using the Butler (1998) solution for wells in a confined aquifer with high hydraulic conductivity which exhibit an inertial effect. Due to the large number of tests performed in this task and for the sake of consistency of analysis, 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 (well camera surveys) or redevelopment to clean out the screen openings and reestablish hydraulic connection of the well to the aquifer sediments (App. A). Data from all slug tests performed during this grant period will serve as an important 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 metadata 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 24.8 gigabytes of data from fieldwork during the grant performance period. This included many hours of well camera surveys, dozens of slug test data sets and analyses, 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 4 FIELDWORK

Through the course of the grant work, we found 14 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 Cc 102 – obstruction (concrete) wedged at casing joint; unable to remove
- AA Ce 133 – biofilm accumulation
- CA Db 47 – well filled with sediment above screen; potential collapse
- CA Db 65 – sediment accumulation, and encrustation on screens
- CA Dc 35 – sediment accumulation
- CH Be 73 – relatively new well; likely incomplete development
- CH Bg 12 – well filled with sediment above screen; potential collapse
- CH Cc 31 – clogged screens, heavy encrustation
- CH De 45 – biofilm accumulation
- HO Cd 79 – biofilm accumulation
- PG De 21 – unknown obstruction, biofilm accumulation
- QA Ea 27 – well filled with sediment above screen; potential collapse
- SM Df 71 – obstruction (2x4 wood piece) wedged at casing joint; unable to remove
- TA Cc 35 – unknown obstruction or blockage above expected total depth

Additionally, visual inspection during camera surveys and site visits have found certain wells to be:

- Collapsed (CA Db 47, CH Bg 12, QA Ea 27, SM Ce 43)
- Poorly developed (CH Be 73)
- Heavily encrusted, heavy sediment accumulation, or fouled with biofilm (AA Ce 133, CA Db 65, CA Dc 35, CH Cc 31, CH De 45, HO Cd 79, PG De 21)
- Obstructed by debris (AA Cc 102, PG De 21, SM Df 71, TA Cc 35)

EXPECTED CHANGES TO MARYLAND'S NGWMN WELL NETWORK

Based on the discovery of potential collapsed screens or casings that were discovered during camera surveys, we may have to abandon wells CA Db 47, CH Bg 12, QA Ea 27, and SM Ce 43 and drop

them from our network and from the NGWMN. Decisions on the fates of these wells will be discussed during a planned network evaluation analysis to be done jointly by MGS and USGS MD-DE-DC Baltimore Water Science staff in early 2022.

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**
AA Ad 90	391032076385902						
AA Ad 102	391032076385904						
AA Bb 87	390826076454802		☑				
AA Cc 89	390010076415703	☑		K = 55.21 ft/d			
AA Cc 102	390004076420001	☑	☑	K = 47.41 ft/d	Yes		concrete debris @ 350' bls
AA Cc 115	390103076402601						
AA Cc 116	390103076402602						
AA Cc 117	390103076402603						
AA Ce 117	390450076343402						
AA Ce 133	390410076302401	☑	☑	K = 3.20 ft/d	Yes	slow response	biofilm present in screen slots
AA Cf 98	390150076283003						
AA Cf 99	390150076283002						
AA Cf 137	390205076292702						
AA Cg 22	390123076241601						
AA Cg 23	390123076241602		☑				heavy encrustation and biofilm on screens
AA Cg 24	390123076241603		☑				
AA Cg 25	390127076240301						
AA De 1	385915076340401						
AA De 95	385853076333001						
AA De 206	385833076332801		☑				heavy encrustation on screens, unknown obstruction/blockage @ 846' bls
AA Fc 34	384833076415601		☑				
AA Fc 35	384833076415602		☑				
AA Fe 92	384644076331201		☑				biofilm present in screen slots
AA Fe 93	384644076331202		☑				
AL Ah 1	394024078273401						
AL Ca 20	393148079010601						
BA Ce 21	393102076341801						
BA Dc 444	392931076410301						

☑=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**
BA Ea 18	392045076512501						
CA Bb 23	384458076375501						
CA Bb 27	384333076394701	☑	☑	K = 17.0 ft/d			unknown obstruction @ 203' bls
CA Db 47	383239076354201	☑	☑	bad	Yes	No response	well filled with sediment above screen (below 393' bls)
CA Db 65	383216076351401	☑	☑	K = 1.71 ft/d	Yes	slow response	sediment buildup @ 39' bls, moderate encrustation on screens
CA Db 96	383244076354201		☑				
CA Dc 35	383050076305501	☑	☑	K = 1.45 ft/d	Yes	slow response	sediment buildup on top of casing reduction @ 745' bls
CA Fc 13	382343076302901	☑	☑	K = 117.8 ft/d			
CA Fd 51	382408076260401						
CA Fd 54	382407076260301	☑	☑	K = 48.3 ft/d			heavy encrustation on screens
CA Fd 85	382236076255401						
CA Gd 61	381956076275301	☑	☑	K = 8.36 ft/d			unknown metal debris @ 420' bls
CE Bf 58	393605075472302						
CE Bf 143	393612075472702						
CE Bf 144	393612075472701						
CE Bf 158	393509075495401						
CE Cd 52	393432075593602	☑	☑	K = 5.39 ft/d			
CE Ce 55	393241075500201						
CE Ee 29	392403075521801						
CH Bc 77	383644077055501						
CH Bc 81	383709077061002		☑				sediment buildup @ 528' bls
CH Be 72	383903076594301	☑	☑	K = 7.79 ft/d			
CH Be 73	383903076594302	☑		K = 0.43 ft/d	Yes	slow response	
CH Bf 134	383728076531701						
CH Bf 158	383732076531902						
CH Bg 12	383746076482901	☑	☑	K = 0.42 ft/d	Yes	poor slug test response	sediment filled casing above expected total depth - collapse?
CH Cc 31	383455077074401	☑	☑	K = 0.29 ft/d	Yes	slow response	clogged screens, heavy encrustation
CH Cc 34	383441077063901		☑				heavy encrustation on bottom screens, near total depth

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		Objective 4					
Well Name	**USGS Site Number**	**Slug Test**	**Camera - Sounding**	**Hydraulic Conductivity from Slug Test**	**Problem identified**	**hydraulic problem identified**	**description of problem**
CH Ce 56	383251076583901						
CH De 45	382927076552301	☑	☑	K = 1.20 ft/d	Yes	slow response	biofilm
CH De 52	382752076593601						
CH Ee 16	382103076560201						
CL Ad 47	394008077005601						
CL Ec 75	392259077052401						
DO Ce 15	383408076042402						
DO Cf 36	383225075565002	☑	☑	K = 2.81 ft/d			
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	☑	☑	K = 68.1 ft/d			biofilm
HO Cd 79	391445076555101	☑	☑	K = 0.50 ft/d	Yes	very slow response	biofilm
KE Ae 71	392053075592901	☑	☑	K = 2.64 ft/d			
KE Bc 185	391650076050402	☑	☑	K = 118 ft/d			
KE Be 43	391823075594701						
KE Bg 33	391815075472101		☑				residual drillling mud in screens, piece of casing sticking out @554' bls
KE Bg 34	391815075472102						
KE Cb 97	391124076101001						
KE Cb 100	391124076101004						
KE Cb 103	391124076101005						
MO Cb 26	391142077280601						
MO Cc 14	391314077224201						

☑=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**
MO Eh 20	390434076573002						
PG Bc 16	390151076561501						
PG De 21	385130076465501	☑	☑	K = 0.19 ft/d	Yes		unkown obstruction @ 147' bls, biofilm accumulation
QA Cf 77	390845075582301		☑				
QA Cf 78	390845075582302		☑				
QA Cg 69	390839075515001	☐	☐				
QA Ea 27	385718076205501	☑	☑	K = 0.36 ft/d	Yes		sediment filled casing (244' bls) above expected total depth - collapse?
QA Eb 110	385751076171603						
QA Eb 111	385751076171601						
QA Eb 112	385751076171602						
QA Eb 113	385748076172001						
QA Ec 1	385756076105301						
QA Ef 29	385534075573601	✓	✓	K = 0.05 ft/d		*undersized slug	significant casing corrosion
SM Ce 43	382012076332901		☑		Yes		sediment fill @ 415' bls, unable to survey well screens
SM Dd 50	381807076380001						
SM Df 71	381527076283101	☑	☑	K = 0.07 ft/d	Yes		obstruction (2x4 wood piece) wedged at casing joint
SM Df 88	381955076293901						
SO Cf 2	380616075380701						
TA Cc 35	384923076100601	☑	☑	K = 0.05 ft/d	Yes		unknown obstruction/blockage @ 49' bls above expected depth
TA Cc 53	384946076002201						
TA Cd 57	384709076050301		☑				camera got stuck on top of outer rim of casing reduction @ 258' bls
TA Dc 54	384052076101201	☑	☑	K = 1.49 ft/d			bolt in casing @ 251' bls prevented camera from going deeper
WA Be 2	393638078001301						
WA Bk 25	393851077343001						
WA Ci 82	393402077434201						
WI Ce 327	382220075392301	☑	☑	K = 2.60 ft/d			
WI Cg 20	382329075263701						
WO Cc 3	381543075273802						

☑=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**
wells tasked		28	42				
wells done		28	42				