APPENDIX C

Select Site Investigation Reports (Provided on CD)

APPENDIX C.3

Borehole Geophysical Reports (Duoos, 2015)

BOREHOLE GEOPHYSICAL REPORT

MONITOR WELLS MW-33, MW-34, MW-35 AND MW-36
VASHON ISLAND LANDFILL
VASHON ISLAND, WASHINGTON

FOR

ASPECT CONSULTING, LLC
SEATTLE, WASHINGTON

MAY 2015

PHILIP H. DUOOS
GEOPHYSICAL CONSULTANT

May 7, 2015 Our Ref: 1133b-15

Mr. Bob Hanford
Aspect Consulting, LLC
401 Second Ave. S., Suite 201
Seattle, WA 98104

REPORT: Borehole Geophysical Logging
Monitor Wells MW-33, MW-34, MW-35 and MW-36
Vashon Island Landfill, Washington

Dear Mr. Hanford:

Attached are the plots of the geophysical well logging data for the four monitoring wells that I logged on April 20, 2015. The depths indicated on the logs are referenced to the tops of the PVC well casing. A page with details of the well construction is attached. EM conductivity and ground penetrating radar data were recorded in each hole.

EM Conductivity Logs

Conductivity data were obtained using a Mount Sopris MGX II Digital Console and EMP-2493 downhole probe. The earlier survey included obtaining Natural Gamma logs, but the natural gamma tool was not effective in this geologic environment (overburden materials) and the bentonite grout used in the construction of the wells also affected the natural gamma data.

EM conductivity measurements are similar to the resistivity tool but use EM induction and provides more meaningful data in shallow holes and can be run in PVC casing. EM data is used to measure changes in formation resistivity and porosity, water saturation, and fluid resistivity. Magnetic Susceptibility (Mag. Sus.) is also measured, and is useful in delineating ferrous mineralization. The EM response is zero near the borehole (to a radius of about 4 inches). The peak response is at a radius of about 11 inches, with significant response to a radius of about 36 inches. The conductivity and magnetic susceptibility logs are shown for each well. All of the logs were recorded while coming up the holes at speeds ranging from 16 to 18 feet per minute.

The EM conductivity response seems to respond well to the stratigraphy observed in the geologic logs. The shallower materials consisting of primarily sands and gravels are lower in conductivity. The deeper silt layers correlate to generally higher conductivities, with some silt layers showing much higher conductivity values. The fat clays observed in the geologic logs correlate very well to the higher conductivity values.

The EM response is adversely affected by the presence of the steel centralizers used for construction of some of the wells near the bottom of the wells, and is indicated by the high-magnitude and erratic response (MW-34, 35 and 36). However, the response is limited to a fairly narrow band at the centralizers. The EM logs also respond erratically to the debris layer encountered in MW-33 above 30 feet deep. In MW-34 a narrow anomaly is observed at about 180 feet deep and may be related to naturally occurring iron in the geologic materials.

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Ground Penetrating Radar Logs

Ground penetrating radar (GPR) data were also recorded in each of the four borings using a MALA ProEx System with the 250 MHz borehole GPR antenna. The antenna is 1.9 inches in diameter and 9.8 feet long and comprised of two sections, each about 5 feet long. The lower section houses the transmitting antenna, and the upper section the receiver.

The transmitter antenna outputs a pulse of electromagnetic energy to the ground. The energy pulse is reflected by geologic layers or objects near the borehole (in a 360 degree direction) back to the receiver. The presence of finer-grained materials such as silts and clays will severely limit the penetration of the GPR signal, while coarser-grained materials such as sands and gravels allow for greater penetration.

The GPR scans are shown with depth down the hole (below the top of the PVC casing) along the right, and the two-way arrival time for the GPR signal across the top. The GPR logs of the various wells show reasonable correlation with the geologic logs, although the change in the GPR signal will not precisely match the geologic logs depths due to the design of the antenna. The depth of the GPR signal is plotted at the midpoint of the two antennas. However, as soon as either antenna is in an area with silts or clays the signal will begin to degrade, so it is difficult to obtain a precise depth on the interface.

For example, at MW-34 the GPR reflective layer is very weak between the top of the hole and about 35 feet deep. The geologic log indicates sandy, silty till to a depth of about 28 feet. The 10-foot long antenna system also has limitations in detecting or resolving thin layers.

The moderate GPR reflective layer between about 35 feet to 105 feet deep correlates well with the sand layer noted in the geologic log. The absence of any noticeable GPR reflections below 105 feet deep correlates with the finer-grained materials noted in the geologic log. The high amplitude reflection in the GPR log between about 165 feet and 183 feet correlates fairly well with the sand layer noted in the geologic log. The higher amplitude reflection may also be related to the loss of materials during drilling in this zone.

The GPR system was first run in MW-34. Upon completion of the data recording, while bringing the GPR antenna up the hole, the gears on the depth encoder for the GPR system were damaged. Temporary field repairs were made, but the accuracy of the GPR depths for the remaining three holes was compromised. In MW-33 and MW-35 the total GPR depth to the bottom of the hole was shallower than the actual depth by 5 feet and 4 feet, respectively. In MW-36 the GPR depth to the bottom of the hole was deeper than the actual by 2 feet. No corrections were made to the GPR logs for this depth error.

LOG CORRECTIONS AND CALIBRATION

The EM tool was calibrated upon completion of logging each well using a calibration ring with known values. The EM tool is sensitive to temperature, so the tool is calibrated quickly upon completion of each hole after it has stabilized to the well fluid temperature. The tool is placed in the air resting on wooden tripods away from the ground and any metal objects. A minimum reading is taken, and a maximum reading is also recorded to provide a reference between wells. The minimum values (should be zero) ranged from -2.43 to 8.84 mS/m. The maximum values ranged from 452.9 to 461.2. The minimum value is within the margin of error taking into account the variation due to temperature, and no corrections to the EM data were made.

The GPR system has no calibration. The settings (primarily gains and length of record) are based on visual inspection of the record.

Please note that while tool checks and calibrations can help correlate the logs between wells, other conditions such as the variations in the volume of bentonite in the annulus (due to wash outs, drilling methods, etc.) and variations in well construction can also affect the logs.

The logs within this report are printed at a scale to fit on one page and scanned to make one PDF file. PDF images of the EM logs and the GPR logs are also provided as separate files, which allow a clearer image that can be expanded for viewing. In this report I have pointed out some of the major features of the geophysical logs and related them to possible geologic features in a general sense to help you in the interpretation of the logs. However, these geophysical logs should be viewed primarily as just another set of data to assist you in your geologic interpretation of the conditions at the site.

Please feel free to contact me with any questions or comments regarding this information. It was a pleasure to have worked with you on this interesting project.

Sincerely,

Philip H. Duoos
Geophysical Consultant

Attachments

State of Washington
Licensed Geologist
561
Philip H. Duoos

Well Construction Measurements

Geophysical Logging Depths are Referenced to Top of PVC Casing
Elevations based on drill log notes.
Depth error in GPR logs are noted as discussed in report.

MW-33

Top of PVC Casing Elev: 359.3'
Ground Surface Elevation: 357.07'
Total Depth (below Top PVC): 139.1'
Measured GPR depth: 134.3'

MW-34

Top of PVC Casing Elev: 385.9'
Ground Surface Elevation: 383.26'
Total Depth (below Top PVC): 247.6'
Measured GPR depth: 247.3'

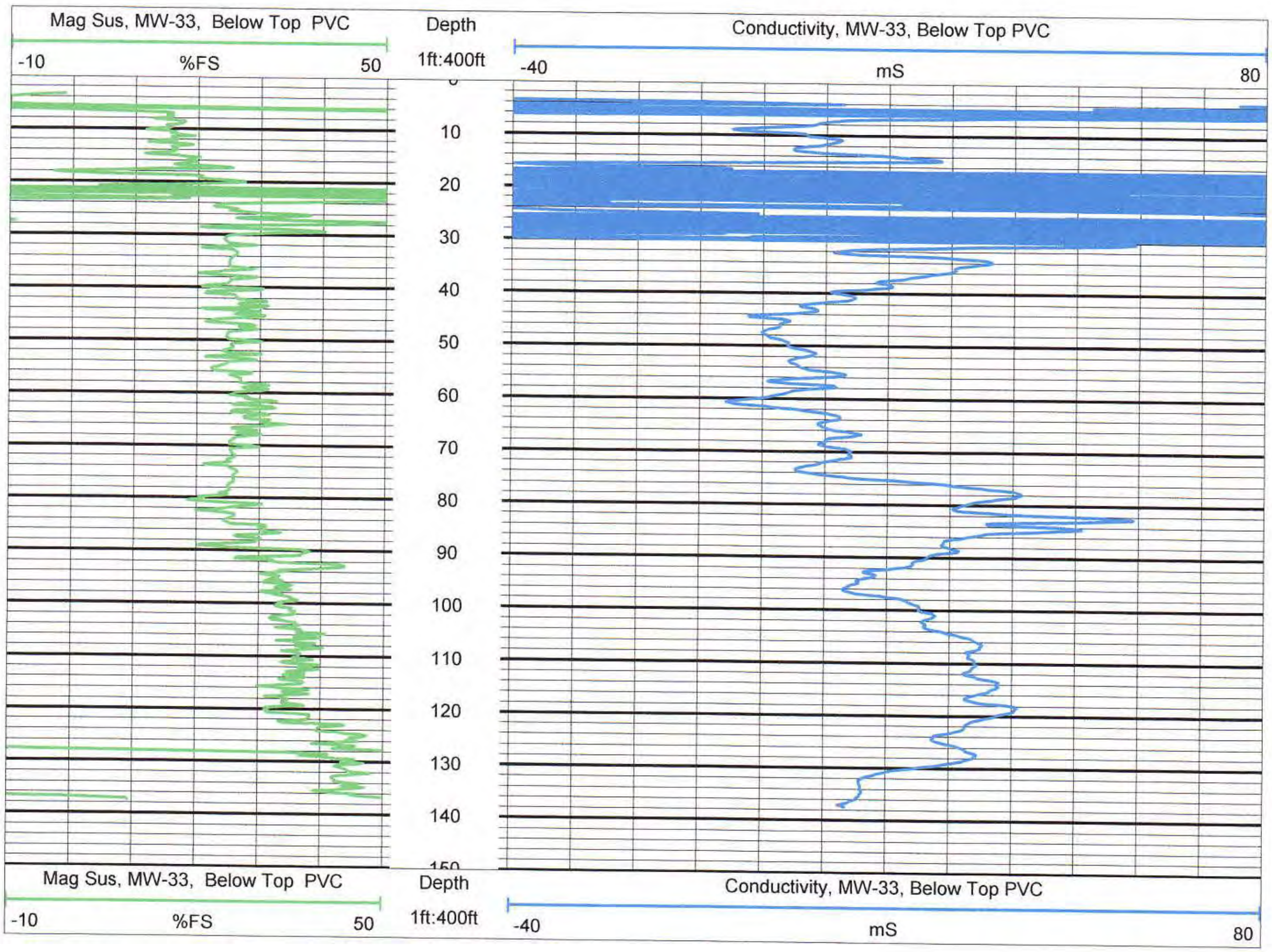
MW-35

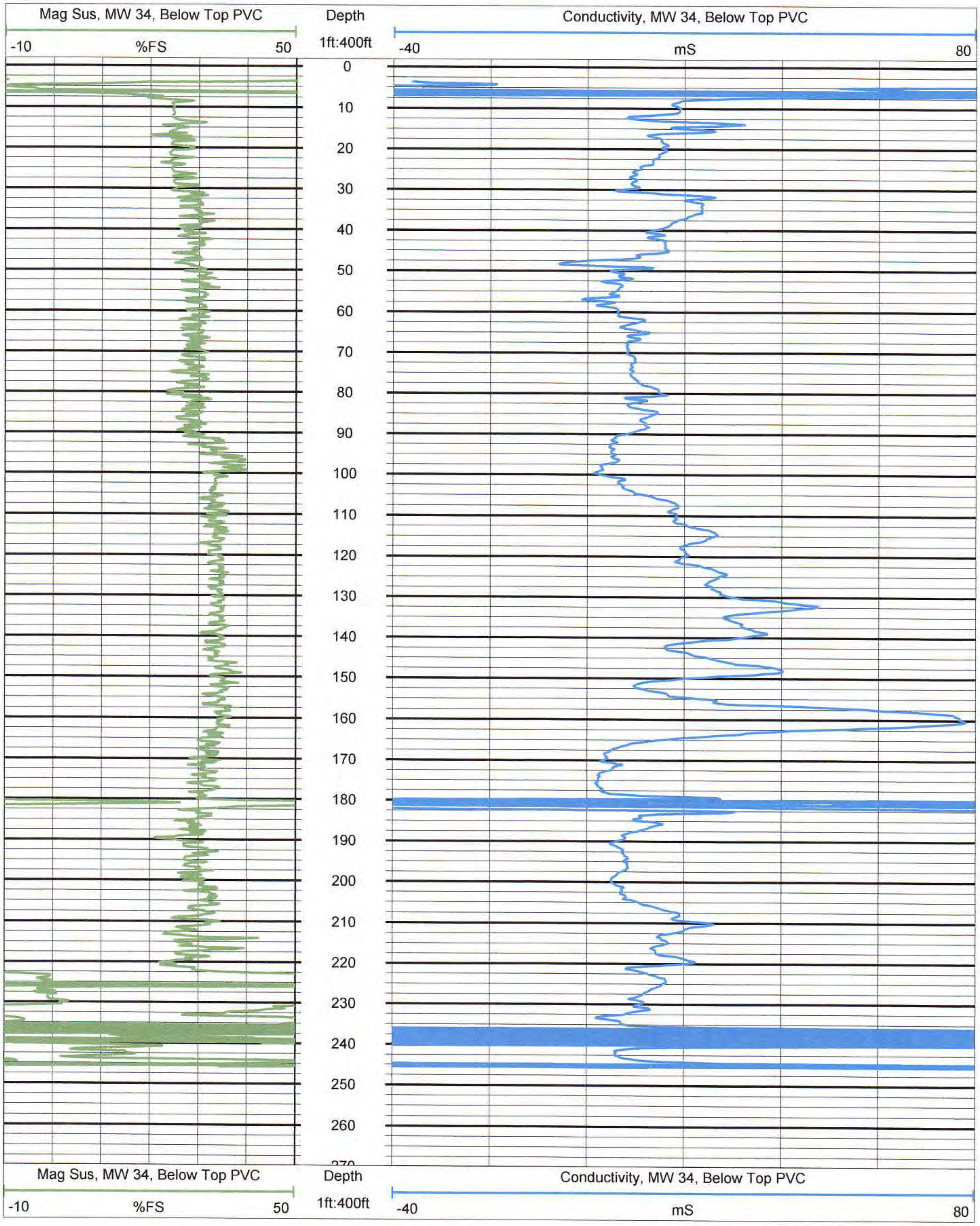
Top of PVC Casing Elev: 361.4'
Ground Surface Elevation: 358.75'
Total Depth (below Top PVC): 127.1'
Measured GPR depth: 122.8'

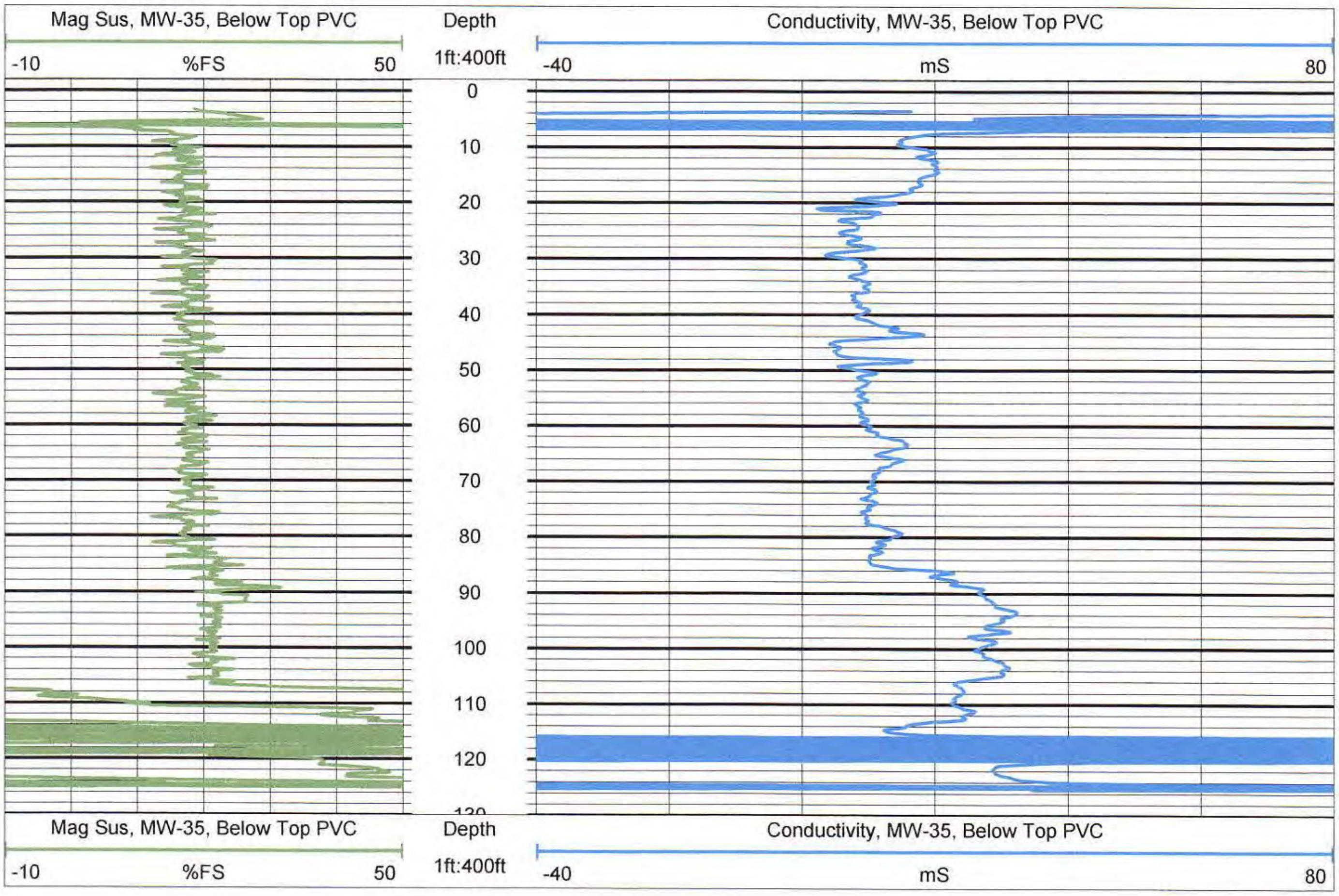
MW-36

Top of PVC Casing Elev: 378.0'
Ground Surface Elevation: 375.25'
Total Depth (below Top PVC): 166.8'
Measured GPR depth: 169.3'

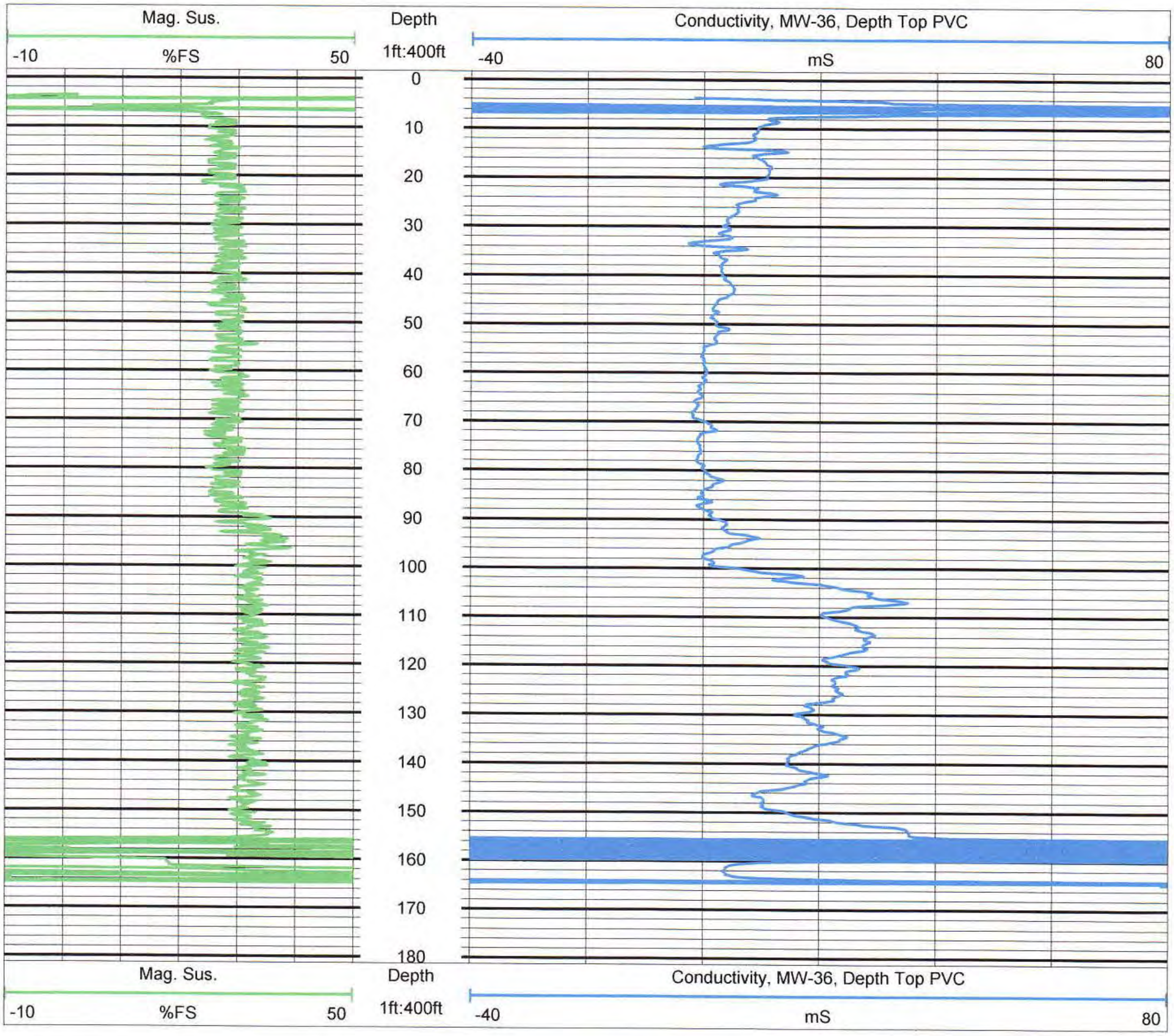
EM CONDUCTIVITY LOGS
(Magnetic Susceptibility and Conductivity)


Mag Sus, MW-33, Below Top PVC
-10
%FS
50
Depth
1ft:400ft
Conductivity, MW-33, Below Top PVC
-40
mS
80
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150


Mag Sus, MW 34, Below Top PVC
-10
%FS
50
Depth
1ft:400ft
Conductivity, MW 34, Below Top PVC
-40
mS
80
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
260

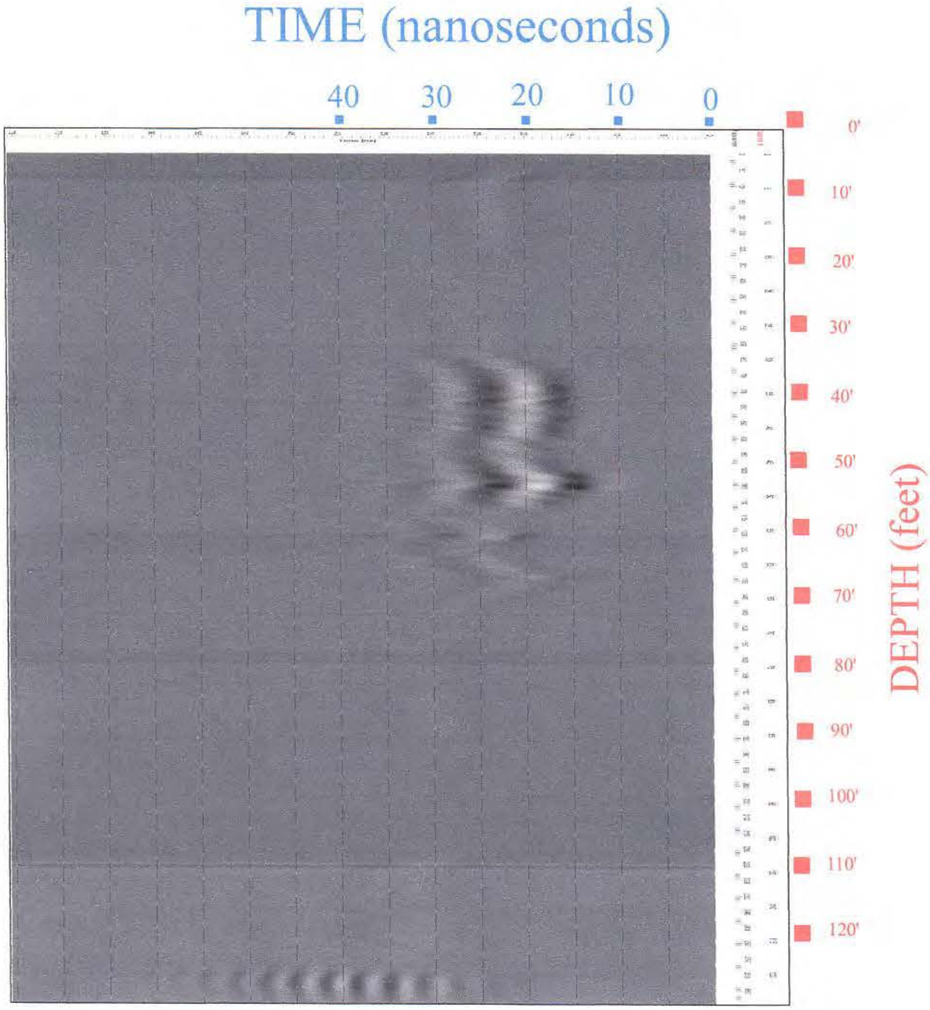


Mag Sus, MW-35, Below Top PVC
-10
%FS
50
Depth
1ft:400ft
Conductivity, MW-35, Below Top PVC
-40
mS
80
0
10
20
30
40
50
60
70
80
90
100
110
120
Mag Sus, MW-35, Below Top PVC
-10
%FS
50
Depth
1ft:400ft
Conductivity, MW-35, Below Top PVC
-40
mS
80



Mag. Sus.
-10
%FS
50
Depth
1ft:400ft
Conductivity, MW-36, Depth Top PVC
-40
mS
80
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
Mag. Sus.
-10
%FS
50
Depth
1ft:400ft
Conductivity, MW-36, Depth Top PVC
-40
mS
80

GROUND PENETRATING RADAR LOGS



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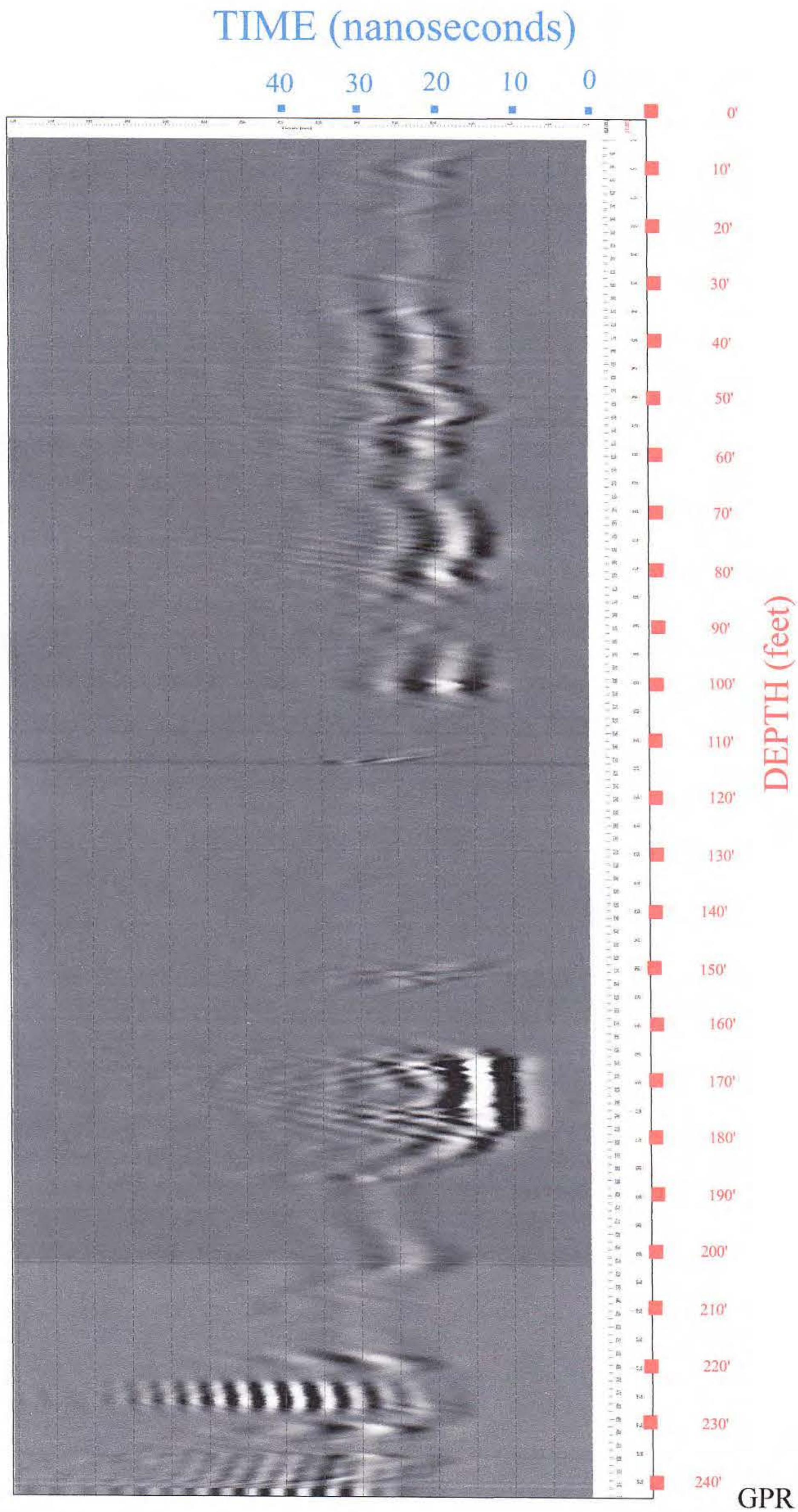
May 2015

GPR LOG
VASHON ISLAND LANDFILL
VASHON, WASHINGTON

MW-33



GPR LOG
VASHON ISLAND LANDFILL
VASHON, WASHINGTON

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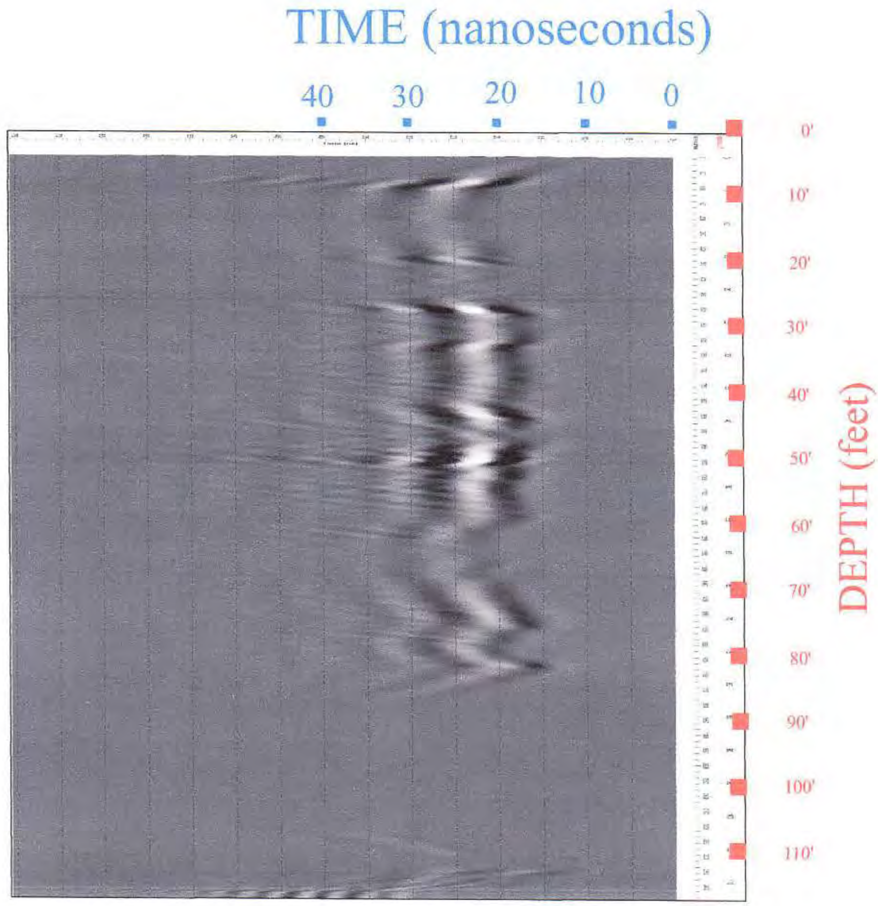
May 2015

MW-34



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May 2015

GPR LOG
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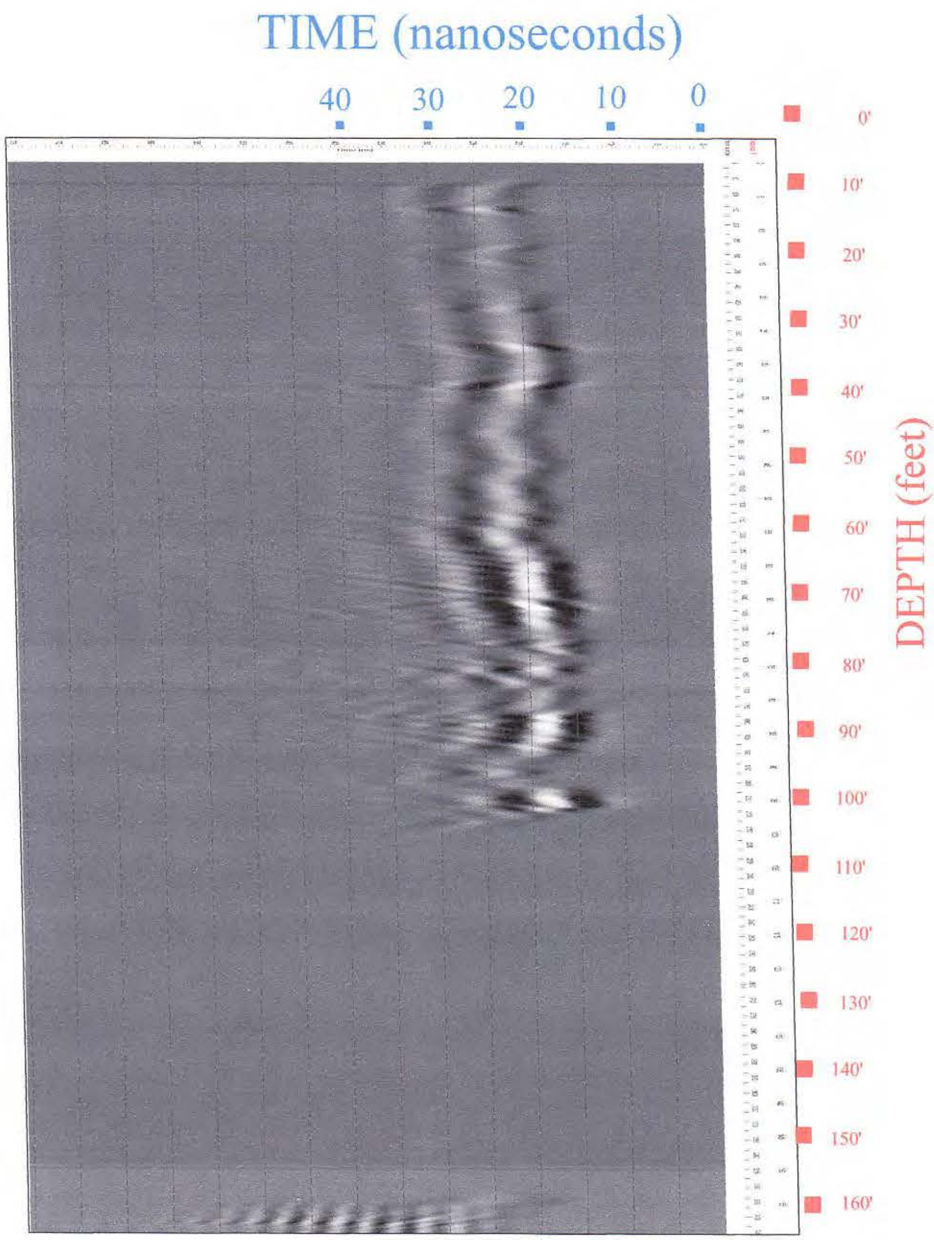
VASHON, WASHINGTON

MW-35



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May 2015

GPR LOG
VASHON ISLAND LANDFILL
VASHON, WASHINGTON

MW-36

BOREHOLE GEOPHYSICAL REPORT

MONITOR WELLS MW-7, MW-19 & MW-27
VASHON ISLAND LANDFILL
VASHON, WASHINGTON

FOR

ASPECT CONSULTING, LLC
SEATTLE, WASHINGTON

FEBRUARY 18, 2015

PHILIP H. DUOOS
GEOPHYSICAL CONSULTANT

February 18, 2015 Our Ref: 1133-15

Mr. Bob Hanford
Aspect Consulting, LLC
401 Second Ave. S., Suite 201
Seattle, WA 98104

REPORT: Borehole Geophysical Logging
Monitor Wells MW-7, MW-19 and MW-27
Vashon Island Landfill, Washington

Dear Mr. Hanford:

Attached are the plots of the geophysical well logging data for the three monitoring wells that I logged on February 5, 2015. The depths indicated on the logs are referenced to the tops of the PVC well casing. Wells MW-7 and MW-19 have 2-inch diameter casing, and MW-27 has 4-inch diameter casing. Additional details of the well construction are attached.

The data were obtained using a Mount Sopris MGX II Digital Console with the following Mount Sopris tools:

Natural Gamma (NG) – Tool 2PGA-1000, measures the naturally occurring radioactivity of the formations adjacent to the borehole using a .875" diameter x 3" long sodium-iodide scintillation crystal. The measured values represent the number of gamma ray counts per second (CPS). The higher the CPS, the more radiation at that location. Natural gamma is generally used as a shale or clay indicator and quantifier. The primary substance that produces gamma rays in sedimentary rocks and soils is Potassium 40. Potassium 40, along with Thorium and Uranium are usually found in highest concentrations in clays and shales. Some igneous rocks (and the sand and gravel derived from them) can also contain Potassium 40. The natural gamma log has a radius of investigation of about 12 inches.

Electromagnetic Induction Logging (EM) – Tool EMP-2493, EM conductivity measurements are similar to the resistivity tool but use EM induction and provides more meaningful data in shallow holes and can be run in PVC casing. Is used to measure changes in formation resistivity and porosity, water saturation, and fluid resistivity. Magnetic Susceptibility (Mag. Sus.) is also measured, and is useful in delineating ferrous mineralization. The EM response is zero near the borehole (to a radius of about 4 inches). The peak response is at a radius of about 11 inches, with significant response to a radius of about 36 inches.

The natural gamma (NG) and conductivity (cond) and magnetic susceptibility (mag) logs are shown. All of the logs were recorded while coming up the holes. The NG logs were logged at speeds ranging from 14 to 15 feet per minute. The EM tool (cond. and mag) was run at 16 to 18 feet per minute.

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LOG CORRECTIONS AND CALIBRATION

The natural gamma logs are corrected from the tool's count per second (CPS) rate to the standard API Unit using a factor of 1.19 for this tool. A minor correction was also made to account for the water in the larger diameter well for MW-27. A correction is not necessary for PVC casing, or for water in the smaller 2-inch diameter wells. The natural gamma response is shown using the typical 3-point moving average filter. The EM logs are not filtered.

The natural gamma tool is calibrated after manufacture. No field calibrations are possible with this tool. The EM tool was calibrated upon completion of logging each well using a calibration ring with known values. The EM tool is sensitive to temperature, so the tool is calibrated quickly upon completion of each hole after it has stabilized to the well fluid temperature. The tool is placed in the air resting on wooden tripods away from the ground and any metal objects. A minimum reading is taken, and a maximum reading is also recorded to provide a reference between wells. The minimum values ranged from -20.5 to -15.7 mS/m. The maximum values ranged from 455.1 to 457.9 mS/m. The minimum value is set at zero, and a DC shift to the EM data is made.

Please note that while tool checks and calibrations can help correlate the logs between wells, other conditions such as the variations in the volume of bentonite in the annulus (due to wash outs, drilling methods, etc.) and variations in well construction can also affect the logs.

COMMENTS ON GEOPHYSICAL LOGS

The logs within this report are printed at a scale to fit on one page. PDF images of the logs to a larger scale are attached as separate files, and these larger versions also show the geologic logs provided by the driller. The geologic log depths are assumed to be relative to the ground surface, and have been corrected to match the top of PVC casing reference used for the geophysical logs.

The natural gamma logs do not seem to be a reliable indicator of the presence of silt or clay at the site. This is not uncommon in wells that are in overburden materials. The presence of the bentonite grout used to fill the annulus of the wells also adversely affects the natural gamma response. This can be observed in the screened intervals where the annulus was filled with sand showing a lower natural gamma response, especially in MW-19 and MW-27.

The natural gamma response is overall much higher in MW-27, which has a 4-inch casing. The driller's logs do not note the size of the drill, but MW-27 may have a larger annulus than the other two wells (2-inch casing), which would contain a larger volume of bentonite. Bentonite can also vary in its effects on the natural gamma response depending on the source of the material. MW-27 was drilled at a much later date than the other wells.

The EM conductivity response seems to respond well to the stratigraphy observed in the geologic log. The shallower materials consisting of primarily sands and gravels are lower in conductivity. The deeper silt layers correlate to generally higher conductivities, with some silt layers showing much higher conductivity values. The fat clays observed in the geologic log correlates very well to the higher conductivity values.

The EM response is adversely affected by the presence of the steel centralizers used for construction of the wells, and is indicated by the high-magnitude and erratic response. However, the response is limited to a fairly narrow band at the centralizers. Wells MW-7 and MW-19 have centralizers throughout, while in MW-27 the centralizers are limited to the screened portion of the well.

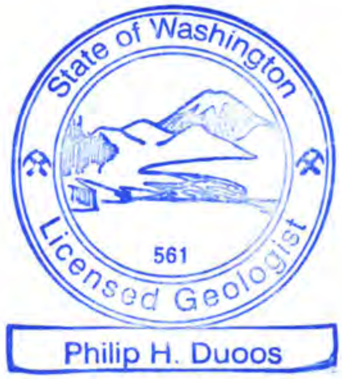
The EM conductivity logging data seem to correlate generally well with the geologic logs. The natural gamma may provide some limited information depending on the individual wells. In this report I have pointed out some of the major features of the geophysical logs and related them to possible geologic features in a general sense to help you in the interpretation of the logs. However, these geophysical logs should be viewed primarily as just another set of data to assist you in your geologic interpretation of the conditions at the site.

Please feel free to contact me with any questions or comments regarding this information. It was a pleasure to have worked with you on this interesting project.

Sincerely,

Philip H. Duoos
Geophysical Consultant

Attachments



Well Construction Measurements

Geophysical Logging Depths are Referenced to Top of PVC Casing
Elevations based on drill log notes.
Elevations for MW-7 and MW-19 referenced to top of slab.
Reference Elevation for MW-27 is to top of PVC as per drill log.

MW-7

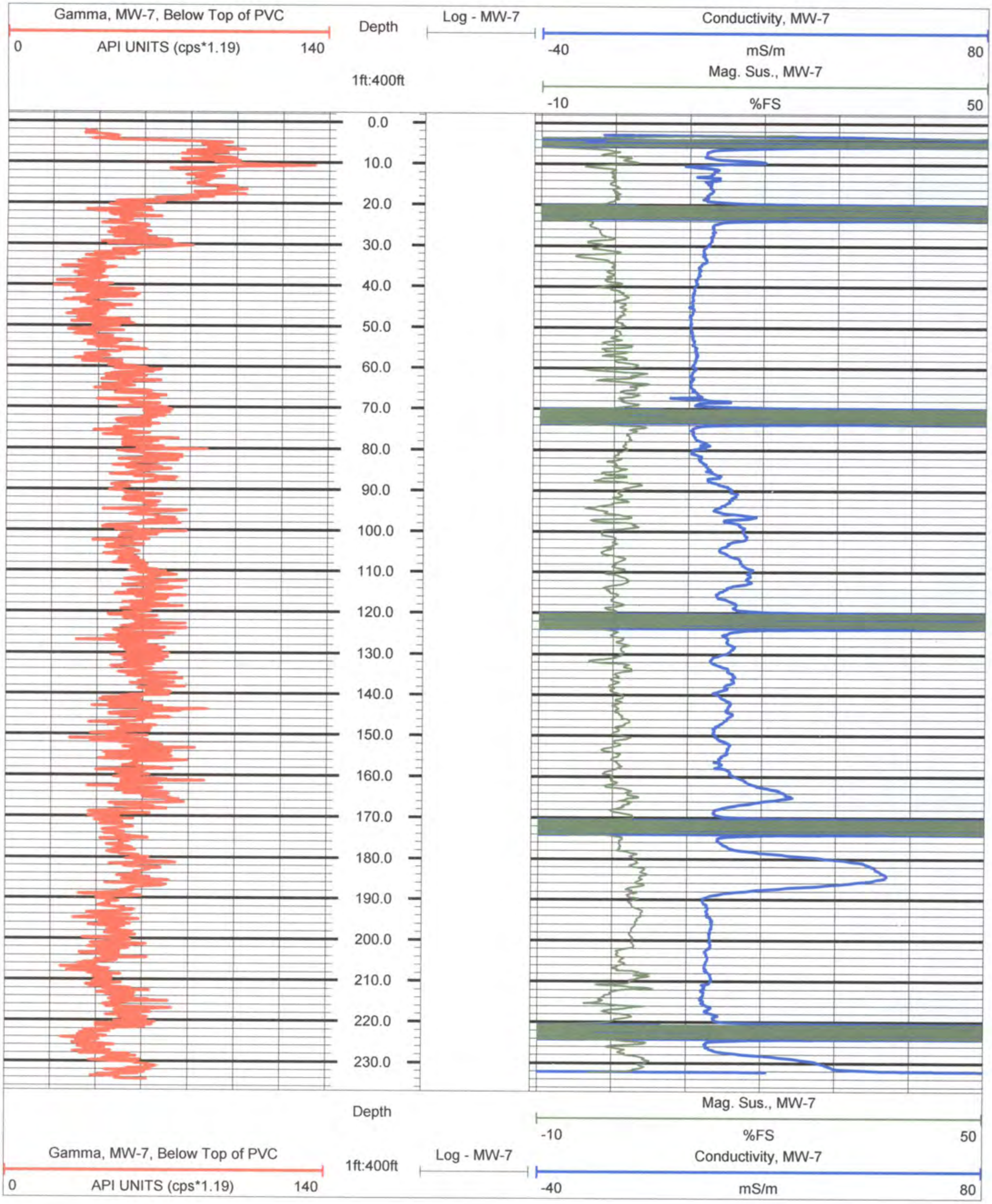
2-inch diameter Schedule 40 PVC Casing
Top of PVC Casing: 2.12' above top of slab, TOC Elev. = 373.22 feet
Top of slab (371.1' elev.) is 0.2' above ground surface

MW-19

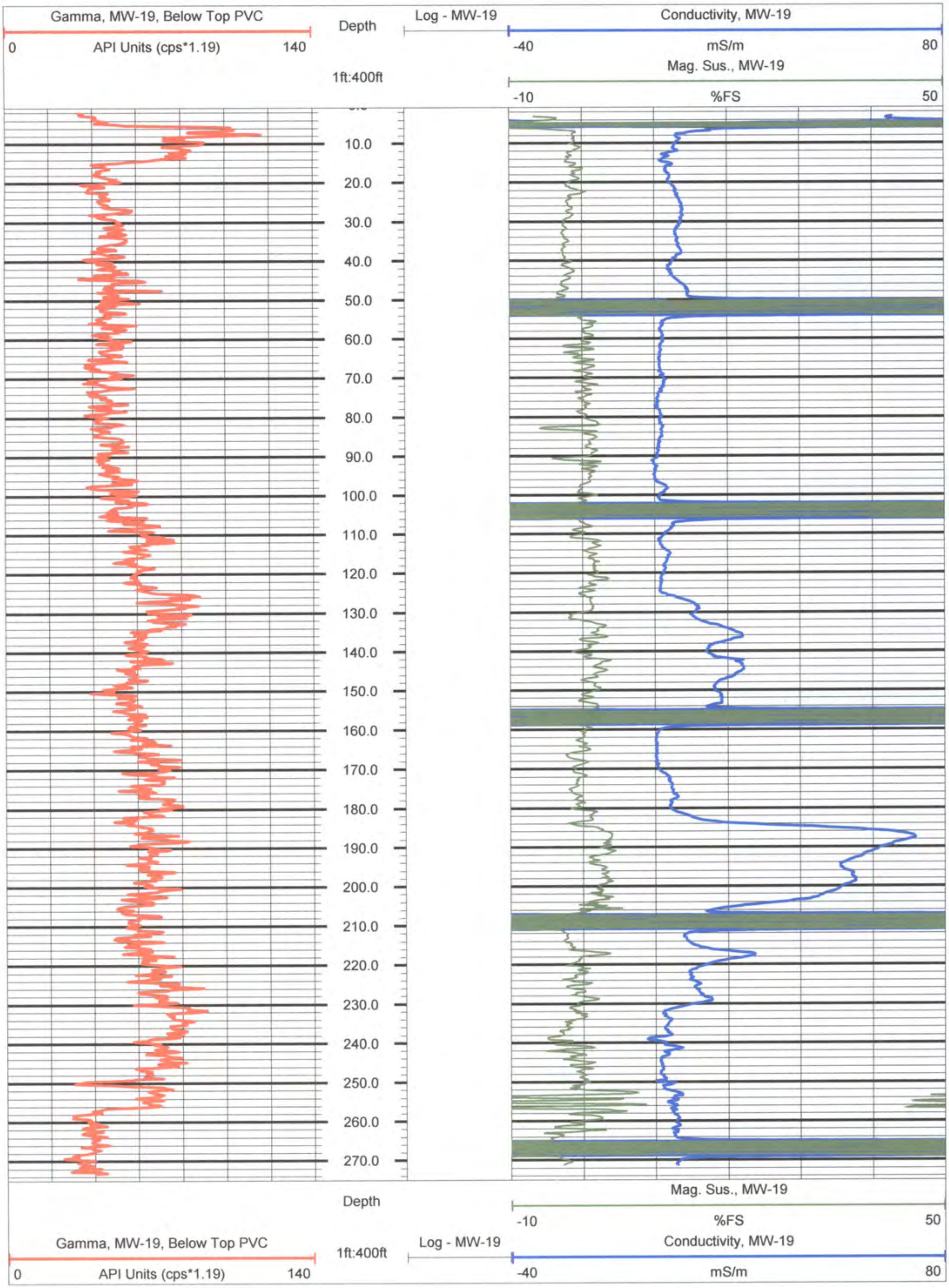
2-inch diameter Schedule 40 PVC Casing
Top of PVC Casing: 2.21' above top of slab, TOC Elev. = 402.81 feet
Top of slab (400.6' elev.) is at ground surface

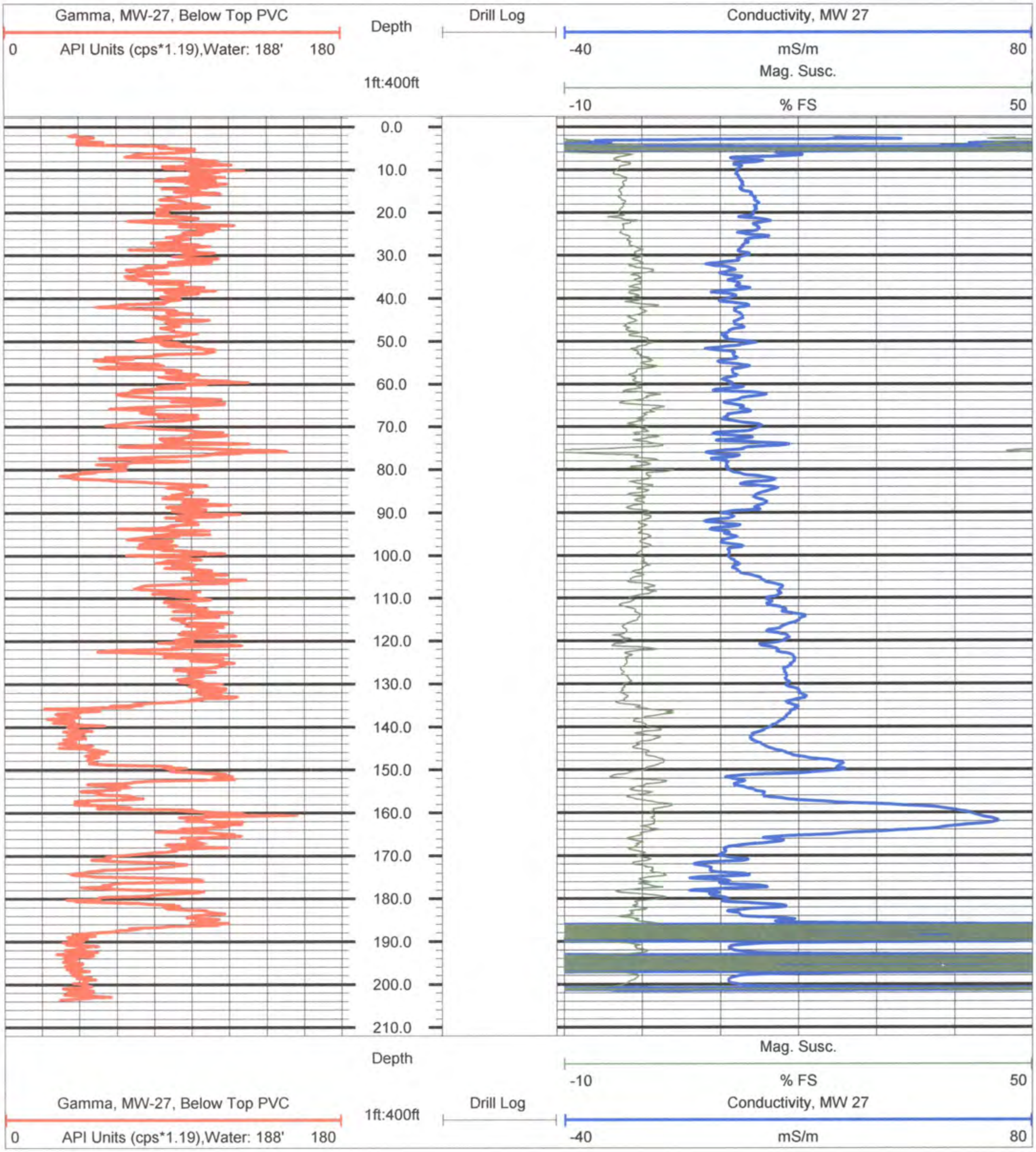
MW-27

4-inch diameter Schedule 80 PVC Casing
Top of PVC Casing: 2.31' above top of slab, TOC Elev. = 383.06 feet
Top of slab (380.75' elev.) is 0.25' above ground surface.
Water at about 188' below TOC, minor Nat. Gamma correction made for water (4-in. well only)



Gamma, MW-7, Below Top of PVC
0
API UNITS (cps*1.19)
140
Depth
1ft:400ft
Log - MW-7
Conductivity, MW-7
-40
mS/m
80
Mag. Sus., MW-7
-10
%FS
50
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
110.0
120.0
130.0
140.0
150.0
160.0
170.0
180.0
190.0
200.0
210.0
220.0
230.0
Depth
Mag. Sus., MW-7
-10
%FS
50
Gamma, MW-7, Below Top of PVC
1ft:400ft
Log - MW-7
Conductivity, MW-7
0
API UNITS (cps*1.19)
140
-40
mS/m
80


Gamma, MW-19, Below Top PVC
0
API Units (cps*1.19)
140
Depth
1ft:400ft
Log - MW-19
Conductivity, MW-19
-40
mS/m
80
Mag. Sus., MW-19
-10
%FS
50
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
110.0
120.0
130.0
140.0
150.0
160.0
170.0
180.0
190.0
200.0
210.0
220.0
230.0
240.0
250.0
260.0
270.0
Depth
Mag. Sus., MW-19
-10
%FS
50
Gamma, MW-19, Below Top PVC
0
API Units (cps*1.19)
140
1ft:400ft
Log - MW-19
Conductivity, MW-19
-40
mS/m
80


Gamma, MW-27, Below Top PVC
0 API Units (cps*1.19),Water: 188' 180
Depth
1ft:400ft
Drill Log
Conductivity, MW 27
-40 mS/m 80
Mag. Susc.
-10 % FS 50
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
110.0
120.0
130.0
140.0
150.0
160.0
170.0
180.0
190.0
200.0
210.0
Depth
Mag. Susc.
-10 % FS 50
Gamma, MW-27, Below Top PVC
1ft:400ft
Drill Log
Conductivity, MW 27
0 API Units (cps*1.19),Water: 188' 180
-40 mS/m 80