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Northrop Grumman Systems Corporation

Phase 2 On-Site Containment System Hydraulic Effectiveness Work Plan

August 14, 2012

Phase 2 On-Site Containment System Hydraulic Effectiveness Work Plan

Northrop Grumman Systems Corporation, Bethpage, New York
NYSDEC Site 1-30-003A
August 2012

1.0 Introduction

This Work Plan has been prepared by ARCADIS of New York, Inc. (ARCADIS) on behalf of the Northrop Grumman Systems Corporation (Northrop Grumman) and describes the approach for drilling one additional vertical profile boring (VPB) and for installing 4 additional monitoring wells at the Northrop Grumman facility in Bethpage, New York. This work is being conducted to further evaluate the effectiveness of the On-Site Containment (ONCT) System in preventing the off-site movement of volatile organic compound (VOC) impacted groundwater**.** Regional groundwater flow in the area of the Northrop Grumman facility is to the south/southeast, with a downward component, and is locally modified by pumping of public supply and remediation wells and discharge of water to recharge basins.

1.1 Background

The Northrop Grumman facility is located in the hamlet of Bethpage, Town of Oyster Bay in east-central Nassau County, Long Island, New York approximately 30 miles east of New York City (**Figure 1**). The facility at one time consisted of slightly more than 600 acres, of which 110 acres were owned by the US Navy (Navy) – a government owned-company operated (GOCO) facility. Beginning in the 1930s the Northrop Grumman facility (originally Grumman Aircraft Corporation) designed, tested, and built military aircraft, primarily for the Navy. Although the Navy owned a portion of the property, Northrop Grumman carried out site operations. Much of the facility has been sold and redeveloped over the ensuing years (**Figure 2).**

Because of the existence of on-site groundwater contamination and pursuant to the Operable Unit (OU) 2 Record of Decision (ROD) issued by the New York State Department of Environmental Conservation (NYSDEC), Northrop Grumman designed, constructed, and operates the ONCT system that consists of 5 deep remedial wells (Wells 1, 3, 17, 18, and 19 - see **Figure 2**) that pump continuously at a rate of 3,800 gallons per minute (gpm; 5.5 million gallons per day [MGD]). Water from the wells is treated by two air strippers and then discharged primarily to the Northrop Grumman south basins with anywhere from 100 to 400 gpm going to the adjacent Calpine Energy generating facility for energy generation and up to 700 gpm going to the Northrop Grumman west basins. The purpose of the ONCT system is to prevent on-site groundwater, impacted with VOCs, from moving off-site. Data collected and evaluated (multiple lines of evidence) since early 1999, during quarterly and annual sampling and reporting rounds, indicate that the ONCT system is meeting its objective of preventing off-site movement of VOC-impacted groundwater. Furthermore, a study required by the NYSDEC OU 2 ROD and carried out by Navy and Northrop Grumman resulted in a report entitled “Operable Unit 2 Groundwater Remedial System Hydraulic Effectiveness Evaluation” (2003) which came to the same conclusion on the ONCT system as the quarterly and annual reports.

Although all data analyses to date have concluded that the ONCT system is working as designed, it is recognized that the monitoring well network (that provides much of the data upon which conclusions about the ONCT system effectiveness in meeting remedial goals are based) can be enhanced to allow more confident conclusions to be reached.

1.2 Objectives

The objective of the work outlined in this Work Plan is to provide additional monitoring points to help in assessing the effectiveness of the ONCT system in containing on-site VOC- impacted groundwater. The work discussed herein is the second phase and additional VPBs and wells may be proposed through an addendum(s) to this Work Plan. The first phase of work was completed in accordance with a December 6, 2011 work plan that was approved by the New York State Department of Environmental Conservation (NYSDEC). ARCADIS understands that the Navy is also planning deep VPBs near the southern boundary of the Northrop Grumman facility and the work defined in this plan will be coordinated with the Navy to ensure consistency of drilling approach and to avoid duplication of efforts.

1.3 Scope

The scope of work consists of drilling, sampling of soil and groundwater, and analysis of groundwater samples for VOCs from a single VPB (VP-74) and the installing, developing, and sampling of 4 additional monitoring wells (**Figure 2**). VPB drilling will extend into the Raritan confining unit (RCU) to ensure that all transmissive zones, through which VOC-impacted groundwater could migrate, have been identified. The RCU identification protocol (Appendix A) will be followed to ensure a standardized approach to identifying this unit.

For monitoring well clusters, split spoon and geophysical data required to select the screen intervals for all wells proposed in a cluster will be collected from the deepest well in the cluster **(Table 2)**.

2.0 Field Activities-Vertical Profile Boring/Monitoring Wells

Table 1 contains the objectives for the proposed VPB drilling and well installation. **Table 2** provides the details of the proposed VPB drilling and sampling. **Table 3** summarizes the details of well construction and development and **Figure 3** is a generalized monitoring well construction diagram.

2.1 Sampling and Analysis

Sampling and laboratory protocols for the collection and analysis of water samples collected as part of this Work Plan and any subsequent addendum(s) will follow procedures detailed in the NYSDEC-approved OU2 Groundwater Monitoring Plan (ARCADIS 2001; 2006). Groundwater samples collected from VPs and monitoring wells will be submitted for laboratory analysis for the Target Compound List of VOCs.

2.2 Health and Safety Plan

The health and safety procedures, detailed in the Site-Specific Health and Safety Plan (ARCADIS 2011), will be followed for work carried out according to this Work Plan and any subsequent addendum(s) to it.

2.3 Pumping Test Protocol

A protocol for conducting a pumping test(s) will be developed in a future Work Plan addendum and the test(s) will be conducted once all VPBs and wells have been completed. The purpose of the pumping test(s) will be to obtain hydraulic information to use to further evaluate the effectiveness of the ONCT system in preventing the off-site movement of VOC-impacted groundwater. The test(s) will likely involve using pressure transducers to measure water-levels in select monitoring wells while turning one or more of the ONCT wells off and/or on.

2.4 Investigation Derived Waste

Investigation derived waste (IDW) produced during drilling and well development activities will be collected, containerized in 55-gallon drums, and temporarily stored at the Northrop Grumman facility before being characterized (as required by the disposal facility) and disposed off-site at an approved facility.

2.5 Decontamination

A decontamination pad will be located on Northrop Grumman property that will be used for the collection of all decontamination-generated fluids. These fluids will be collected and stored in drums, pending characterization sampling, and either discharged to the local Publically Owned Treatment works (POTW) or sent off-site for disposal.

2.6 Surveying

The locations of all VPBs and wells will be surveyed to the North American Datum (NAD) 1983 to the nearest 0.1 foot by a New York State (NYS) licensed surveyor along with the measuring point elevation of the wells to the nearest 0.01 foot.

2.7 Reporting

Following the drilling/sampling of the VPB, the installing/developing/sampling of the monitoring wells subject to this work plan, and following data validation, a basic data report will be submitted to NYSDEC. If needed, a work plan addendum may be prepared and submitted to the NYSDEC after this basic data report describing the objectives and details for additional VPBs and monitoring wells. The interpretative report will be prepared after all work (including the pumping test) is completed.

3.0 References

ARCADIS 2011a. Site Specific Health and Safety Plan, Northrop Grumman Systems Corporation, October 2011.

ARCADIS 2011b. On-Site Containment System Hydraulic Effectiveness Work Plan, Northrop Grumman Systems Corporation, Bethpage, New York, NYSDEC Site 1-30-003A, December 6, 2011.

ARCADIS G&M, Inc. 2006. Petition for Recommended Modifications to the Operable Unit 2 Groundwater Monitoring Plan, Northrop Grumman Corporation, Bethpage, New York. June 2006.

ARCADIS Geraghty & Miller, Inc. 2001. Operable Unit 2 Groundwater Monitoring Plan. Northrop Grumman Corporation, Bethpage, New York. May 11, 2001.

US Geological Survey 1989. Smolensky et al. Hydrologic Framework of Long Island, New York. Hydrologic Investigations Atlas. 1989

US Geological Survey. Buxton et al. Hydrogeologic Correlations for Selected Wells on Long Island, New York—A data base with retrieval program. US Geological Survey Water-Resources Investigations Report 86-4318.

Tables

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Table 1. Objectives for Proposed Wells and Vertical Profile Boring, Phase 2 ONCT System Hydraulic Effectiveness Evaluation, Operable Unit 2, Northrop Grumman Systems Corporation, Bethpage, New York.

Location	Action Planned	Shallow Monitoring Well	Intermediate Monitoring Well	Deep Monitoring Well	Deep 2 Monitoring Well	Deep 3 Monitoring Well	Objectives
Proposed VP/Wells							
GM-21	Install new monitoring well	EXISTING Well GM-21S	EXISTING Well GM-21I	EXISTING Well GM-21D	***PROPOSED Well GM-21D2***	--	1.) Objective of GM-21D2 is to collect additional geologic information and groundwater quality data that will provide additional horizontal and vertical characterization/delineation of VOCs in groundwater at the souther boundary of the NG site, between Wells 17 and 18, in the deep 2 zone. 2.) Monitoring WellGM-21D2 will be used to monitor groundwater quality and water levels at the southern boundary of the NG site. Table 2 provides proposed groundwater and split-spoon sampling intervals.
VP-74/ GM-74	Install and sample new VPB and install new monitoring wells	--	EXISTING Well GM-74I	EXISTING Well GM-74D	EXISTING Well GM-74D2	***PROPOSED Well GM-74D3***	1.) Objective of VP-74 is to collect additional geologic information and groundwater quality data that will provide additional horizontal and vertical characterization/delineation of VOCs in groundwater at the southern boundary of the NG site, near Well 18, to the base of the Magothy aquifer. 2.) Based on the results of VP-74, Monitoring Well GM-74D3 will be installed to monitor groundwater quality and water levels at the southern boundary of the NG site. Table 2 provides proposed groundwater and split-spoon sampling intervals.
GM-78	Install new monitoring wells	EXISTING Well GM-78S	EXISTING Well GM-78I	***PROPOSED Well GM-78D***	***PROPOSED Well GM-78D2***	--	1.) Objective of GM-78D and GM-78D2 is to collect additional geologic information and groundwater quality data that will provide additional horizontal and vertical characterization/delineation of VOCs in groundwater at the southwestern boundary of the NG site, near Well 17, in the deep and deep2 zones. 2.) Monitoring Wells GM-78D and GM-78D2 will be used to monitor groundwater quality and water levels at the southwestern boundary of the NG site. Table 2 provides proposed groundwater and split-spoon sampling intervals.

Notes

VPBs and deep, deep2, and deep3 monitoring wells will be drilled by mud rotary methodology. Shallow and intermediate wells will be drilled using hollow stem auger methodology.

NG Northrop Grumman Systems Corporation
VPB vertical profile boring
-- No proposed/existing well located at this depth.
VOCs volatile organic compounds

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Table 2. Proposed Vertical Profile Boring Drilling/Monitoring Well Sampling Details, Phase 2 ONCT System Hydraulic Effectiveness Evaluation, Operable Unit 2, Northrop Grumman Systems Corporation, Bethpage, New York.

Sample Location	Sampling Intervals (ft bls)	Split-Spoon Sampling Frequency (ft)	Estimated Screen Zone (ft bls)	Hydropunch Groundwater Sampling Frequency (ft)	Groundwater Laboratory Analysis [4]	Borehole Geophysical Logging
Proposed VPB/Well						
GM-21D2	Water Table[1] to 450	20	480 - 500	--	--	Gamma
	450 - End of Boring[3]	5		--	--	
VP-74/GM-74D3	Water Table[1] to 80	5	730 - 750	20	TCL VOC	Gamma
	80 - 400	20		20	TCL VOC	
	400 - 620	20		20	TCL VOC	
	620 - Raritan Clay[2]	5		20	TCL VOC	
	Raritan Clay - End of Boring[3]	Continuous		Sand Units Only	TCL VOC	
GM-78D/GM-78D2	Water Table[1] to 330	20	340 - 350 / 480 - 500	--	--	Gamma
	330 - 360	5		--	--	
	360 - 450	20		--	--	
	450 - End of Boring[3]	5		--	--	

Footnotes:

(1) Water table is approximately 50 ft bls.

(2) The Raritan Confining Unit is estimated to be at a depth of 650 ft bls.

(3) End of boring will be determined based on the anticipated depth of the well and the results of split spoon sampling. For proposed wells, split-spoon sampling frequency will be increased to 5 ft intervals near the anticipated depth of the well. For the VPB, split spoons and Hydropunch intervals may be modified based on the anticipated depth of the Raritan and local geologic conditions. The decision to terminate drilling of the VPB will be based on the Raritan Identification Protocol (Appendix A).

(4) Laboratory analysis of groundwater samples will be performed for the TCL List of VOCs using NYSDEC ASP 2000 Method OLM 4.2. VPB results will be obtained on a 24 hour TAT.

Definitions:

ONCT	On-Site Containment
ft bls	feet below land surface
VP	vertical profile boring
TAT	turnaround time
TCL	target compound list
VOC	volatile organic compound
NYSDEC	New York State Department of Environmental Conservation
ASP	Analytical Services Protocol

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Table 3. Summary of Proposed Monitoring Well Constuction Details, Phase 2 ONCT System Hydraulic Effectiveness Evaluation, Operable Unit 2, Northrop Grumman Systems Corporation, Bethpage, New York.

Well Identification	Nominal Borehole/ Well Diameter (in)	Drilling Method	Casing/ Screen Material	Screen Slot Size (in)	Screen Length (ft)	Well Development Method	Protective Casing Diameter/Type	Proposed Groundwater Sampling [3]
Proposed Wells [1]								
GM21D2	10 / 4	MR	Sch. 80 PVC/SS	0.02	20	AL/PS	12" FM	TCL VOCs
GM-74D3[2]	10 / 4	MR	Sch. 80 PVC/SS	0.02	20	AL/PS	12" FM	TCL VOCs
GM-78D	10 / 4	MR	Sch. 80 PVC/SS	0.02	20	AL/PS	12" FM	TCL VOCs
GM-78D2	10 / 4	MR	Sch. 80 PVC/SS	0.02	20	AL/PS	12" FM	TCL VOCs

Footnotes

(1) Total depth and screened interval of the monitoring well will be determined based upon proximal VPBs and split spoon and geophysical logging results. Well specifications may be modified further in the field based on site conditions.

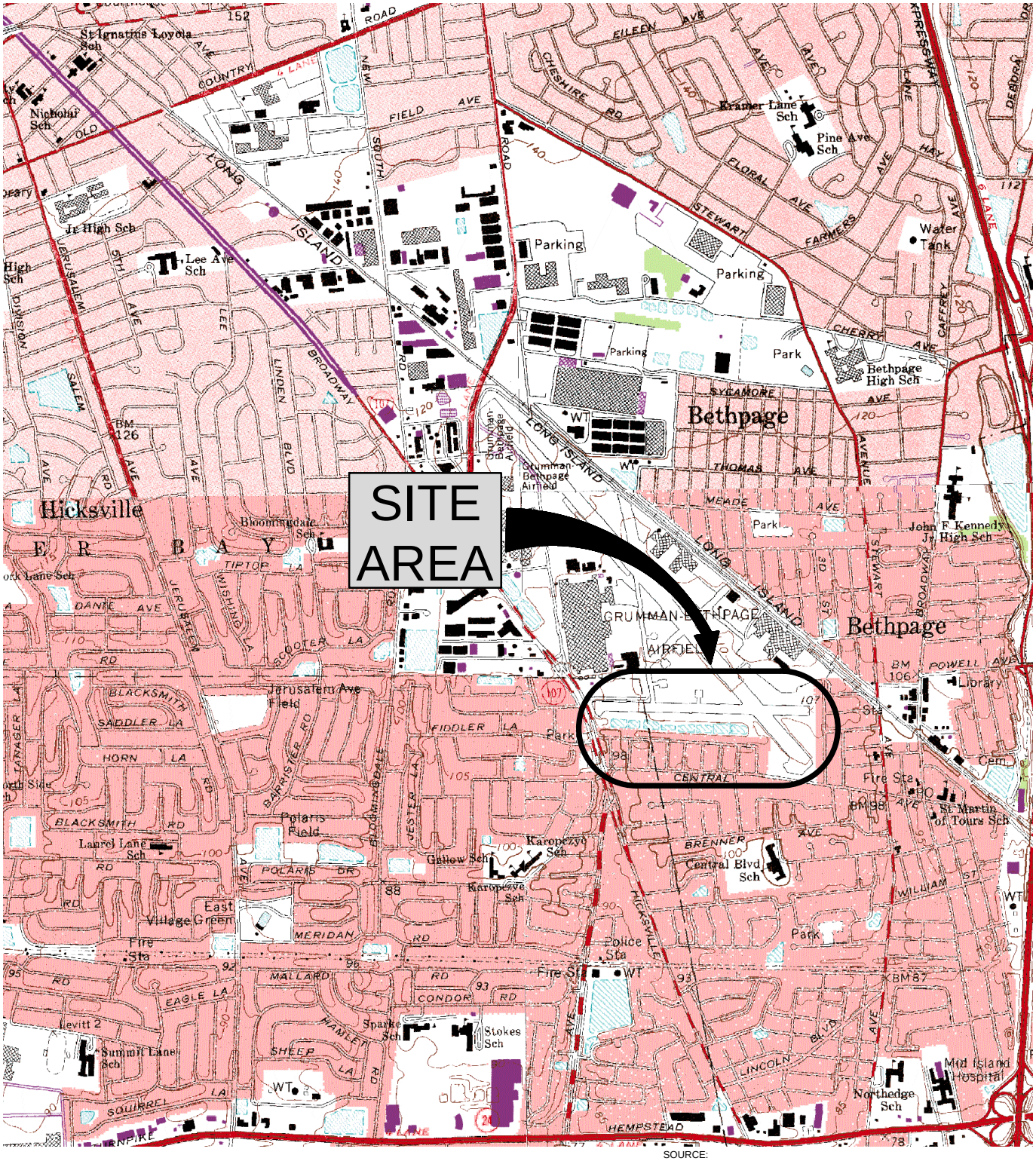
(2) Total depth and screened interval of the monitoring well will be determined upon completion of Vertical Profile Boring VP-74. Well specifications may be modified in the field based on site conditions.

(3) Wells will be sampled a minimum of 2 weeks after development is completed. Laboratory analysis of groundwater samples will be performed for the TCL List of VOCs using NYSDEC ASP 2000 Method OLM 4.2. Results will be obtained on a 2-week TAT.

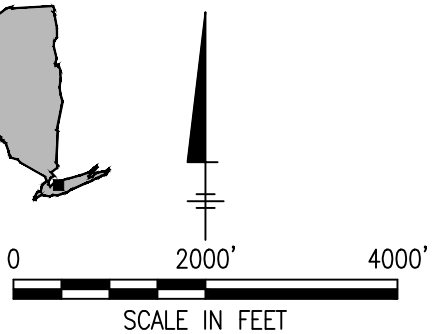
Definitions

ONCT	On-Site Containment System
SS	Stainless Steel wire-wrapped
PVC	Polyvinyl chloride
in	inches
ft	feet
FM	Flush Mount
AL/PS	Air Lift and/or Water Jetting Isolation Tool followed by Pump and Surge
PS	Pump and Surge
TAT	turnaround time
TCL VOCs	Target Compound List of Volatile Organic Compounds

Figures



SOURCE:
USGS 7.5 MIN. AMITYVILLE QUADRANGLE, AMITYVILLE, N.Y., 1994,
FREEPORT QUADRANGLE, FREEPORT, N.Y., 1994,
HICKSVILLE QUADRANGLE, HICKSVILLE, N.Y., 1967, PHOTOREVISED 1979,
HUNTINGTON QUADRANGLE, HUNTINGTON , N.Y., 1967, PHOTOREVISED 1979



NORTHROP GRUMMAN SYSTEMS CORPORATION
BETHPAGE, NEW YORK
OPERABLE UNIT 2

SITE LOCATION

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FIGURE
1

CITY:(Reqd) DIV/GROUP:(Reqd) DB:(Reqd) LD:(Opt) PIC:(Opt) PM:(Reqd) TM:(Opt) LYR:(Opt)ON=*;OFF=*REF*
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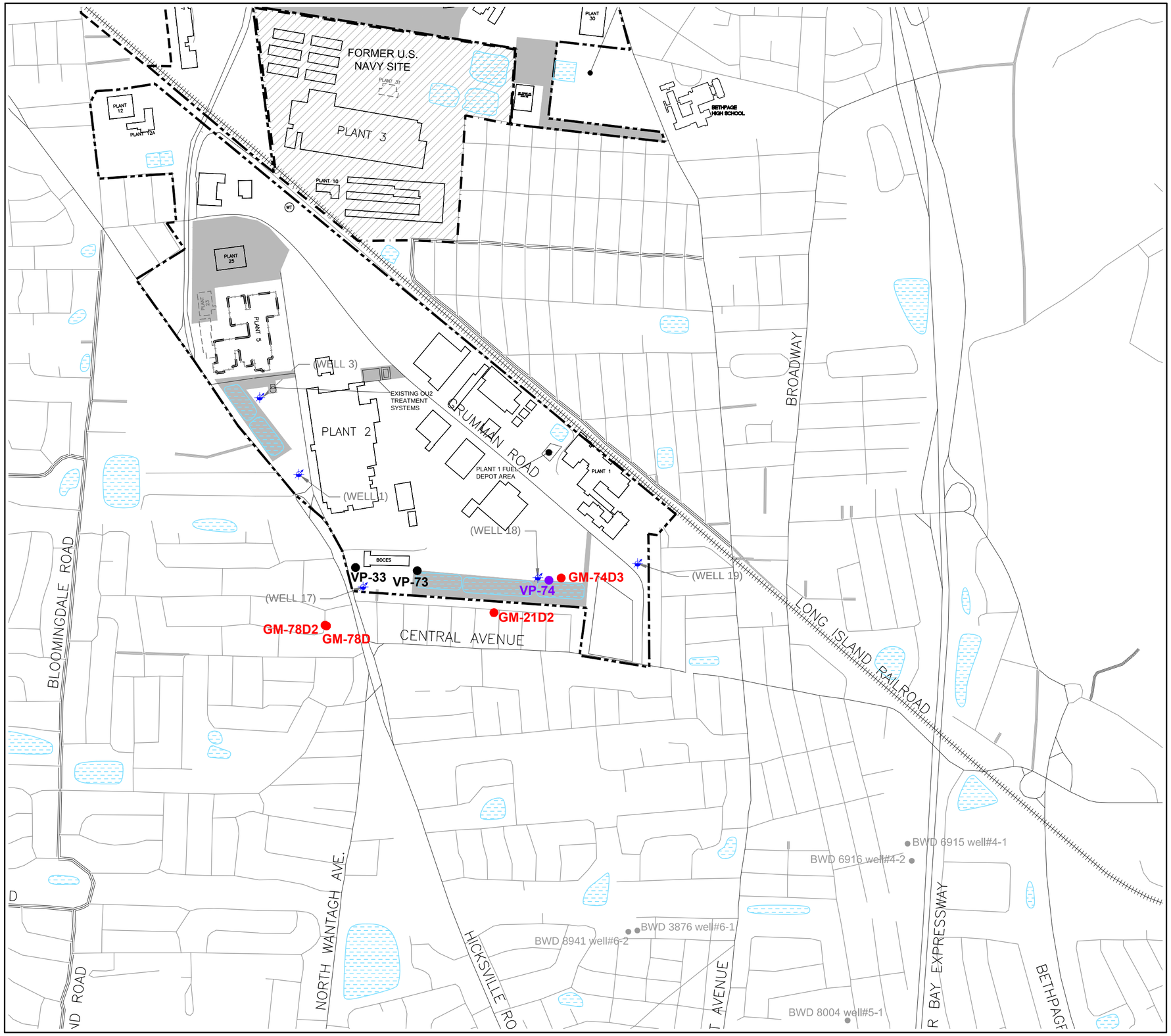
XREFS: IMAGES: PROJECTNAME: ----
AMITYVILLE.TIF
FREEPORT.TIF
HICKSVILLE.TIF
HUNTINGTON.TIF



0 800' 1600'

SCALE IN FEET

N

EXPLANATION

- PROPERTY BOUNDARY OF THE FORMER GRUMMAN AEROSPACE SITE
- PROPERTY BOUNDARY OF THE FORMER U.S. NAVY SITE
- LONG ISLAND RAILROAD
- NORTHROP GRUMMAN OWNED PROPERTY (AS OF 2003)
- FORMER U.S. NAVY OWNED PROPERTY
- RECHARGE BASIN
- OU-2 OPERABLE UNIT 2
- PUBLIC SUPPLY WELL
- OU-2 REMEDIAL WELL

NOTES:

1. NORTHROP GRUMMAN REMEDIAL WELLS 1, 3, 17, 18, AND 19 SCREENED IN DEEP 2 ZONE.
2. BETHPAGE WATER DISTRICT WELLS 6915 AND 6916 SCREENED IN DEEP 2 ZONE. BETHPAGE WATER DISTRICT WELLS 8004 AND 8941 SCREENED IN DEEP 3 ZONE.

PROPOSED ACTIVITIES

- VERTICAL PROFILE BORING (VPB)
- PROPOSED MONITORING WELL
- COMPLETED VPB

NORTHROP GRUMMAN SYSTEMS CORPORATION
BETHPAGE, NEW YORK
OPERABLE UNIT 2

PROPOSED MONITORING WELLS AND LOCATIONS

ALL COORDINATES REFERENCED TO NORTH AMERICAN DATUM 1983

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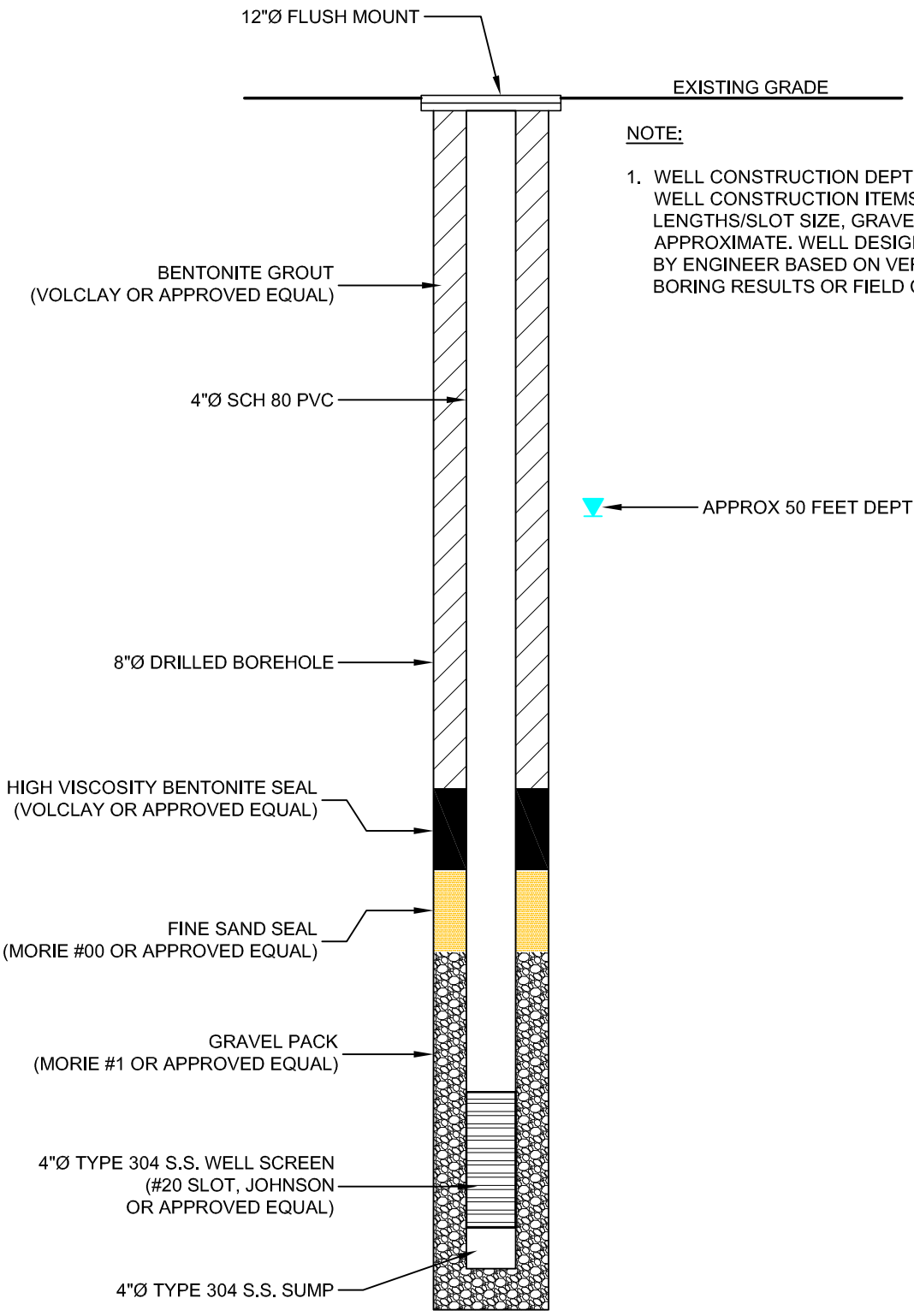
FIGURE 2



NOTE:

1. WELL CONSTRUCTION DEPTHS AND RELATED WELL CONSTRUCTION ITEMS (i.e., SCREEN LENGTHS/SLOT SIZE, GRAVEL PACK) ARE APPROXIMATE. WELL DESIGN WILL BE FINALIZED BY ENGINEER BASED ON VERTICAL PROFILE BORING RESULTS OR FIELD CONDITIONS.

DRAWING NOT TO SCALE

No.	Date	Revisions	By	Ckd

NORTHROP GRUMMAN SYSTEMS CORPORATION • BETHPAGE, NEW YORK

PHASE 2 ONCT DATA GAP INVESTIGATION

PROPOSED MONITORING WELL CONSTRUCTION DETAIL

ARCADIS Project No.
NY001496.0212.ONCB2

Date
JANUARY 2012

ARCADIS
2 HUNTINGTON QUADRANGLE
SUITE 1S10
MELVILLE, NY, 11747
TEL. 631.249.7600

DRAWING
3

CITY: DIV/GROUP: DB: LD: PIC: PM: TM: LYR:ON=*;OFF=*REF*
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Raritan Confining Unit Field Identification Protocol

(February 14, 2012 version)

Introduction

This protocol provides a standardized approach for field identification of the Raritan confining unit (RCU) (i.e., the hydrogeologic designation for the unnamed clay member of the Upper Cretaceous-age Raritan Formation on Long Island, New York). This protocol is intended as guidance for field geologists/scientists during oversight of drilling for selecting split-spoon sampling and Hydropunch groundwater sampling intervals and the depth to terminate borings. While this protocol was specifically prepared for field staff overseeing the drilling and sampling of deep boreholes that are part of the On-site Containment (ONCT) System evaluation program performed for Northrop Grumman Systems Corporation, in Bethpage, New York, this protocol will be useful to other investigators in confidently identifying this unit. This protocol is intended to be a flexible field guide that can be adjusted to fit site-specific field conditions based on the geologists/scientists experience. This protocol stresses the need to adequately identify: 1) the RCU and in so doing confirm that the transmissive Magothy aquifer, through which advective transport of impacted groundwater could occur, has been fully penetrated and 2) in the case of the ONCT system evaluation program, the vertical extent of volatile organic compound (VOC) contamination in groundwater. The RCU is generally identified as hard, solid clay of substantial thickness that severely restricts the exchange of groundwater (and by extension impacted groundwater) between the Magothy aquifer and the deeper Lloyd aquifer. Across Long Island, the large head differences measured between these two aquifers (at well clusters that screen both aquifers) is testament to the significant character of the RCU as a local and regional confining unit. For the purpose of this investigation, the RCU can be considered the bottom of the aquifer system.

Raritan Confining Unit and Magothy Aquifer Lithology and Depositional Environments

Both the RCU and overlying Magothy aquifer are the “hydrogeologic equivalents” of the Raritan Formation clay member and Matawan Group – Magothy Formation, undifferentiated, respectively. They are both Upper Cretaceous age units whose depositional origin is continental in nature (generally thought to be an environment of streams and coalescing deltas). The deposits in each unit include gravel, sand, silt, and clay. The differentiation between the units is not easily made based on mineral or sand type identification methods (both units generally contain quartzose sands with pyrite, iron oxide concretions and lignite common) but rather is more readily made from a hydrogeologic perspective based on grain size relative to the percent occurrence of that grain size within the unit. That is, a clay lense sample from the Magothy aquifer may look extremely similar to a clay sample from the Raritan clay, however, from an overall percent occurrence of clay encountered within the two units, clay is significantly more abundant in the RCU (with extensive lateral continuity). Color of deposits may also be used to assist in unit identification (gray clay and pink/red clay from Magothy and Raritan, respectively) however; it is by no means definitive. A more common and reasonably reliable field method of differentiation is to observe the transition of deposits encountered in the vertical sequence. Although the Magothy is characterized primarily by fine to medium sand, silt, and clay lenses, typically the basal zone exhibits a marked increase in grain size to the extent that the basal Magothy horizon is identified by it coarse sand, gravel, to even cobble size deposits. These coarse deposits typically rest directly on the erosional or non-depositional unconformity that separates the two units. The unconformity marks a vast change in the depositional environment, from very high energy (coarse deposits) to much lower energy levels (clay). The transition from the basal gravel zone is typically abrupt and the clay of the Raritan is encountered directly beneath the gravel zone however, the basal gravel zone has been noted to not always be present. Encountering

this sequence of deposits, used in conjunction with all other available information and interpretations has commonly been used to mark this hydrologic unit boundary across Long Island.

Procedures for Implementing the Protocol

The following are procedures for identification and characterization of the RCU and a framework for field staff to make decisions. As described in the preceding section, the mineralogy, grain size, color, etc. of the Magothy aquifer and RCU are not easily distinguishable when comparing single samples from each unit. More importantly for the purposes of these investigations, the existence, thickness, and continuity of clays encountered is most important rather than the ability to differentiate the deposits based on age or geologic name. The focus should be on identifying the transition through the coarse basal Magothy horizon into the fine clay deposits of the Raritan. Most certainly, geophysical logs of such deep borings are invaluable in also identifying a sharp transition zone and correlating lateral features.

1. Review applicable literature

a. Review Smolensky and others (1989)-"Hydrologic Framework of Long Island, New York" and specifically Sheet 2 of 3- the map showing the "Altitude of the Upper Surface of the Raritan Confining Unit" to obtain an initial indication of the expected altitude of the top of the RCU at a planned drilling location(s) by locating the proposed borehole(s) to be drilled on this map. For convenience in the field during drilling oversight, use a topographic map of the area or a nearby surveyed elevation to convert the expected RCU altitude to a depth in feet below land surface.

b. Review Buxton and others (1989)-"Hydrogeologic Correlations for Selected Wells on Long Island, New York-A data base with retrieval program" which is the companion publication to the Smolensky report referenced above and contains the basic data on which that report was based. Look in the Buxton report for wells near the planned drilling location(s) to obtain more site specific information to refine the expected depth to the RCU.

c. Review data from Vertical Profile Boring VP-73R, which was completed in January 2012 as part of the ONCT System evaluation program, which reached and penetrated into the RCU. The boring was advanced approximately 25 to 30 feet below the expected unit contact elevation, and the RCU deposits were characterized as light gray to red solid clay. Immediately overlying the clay was a horizon of sub-round to round quartz pebbles. A gamma log confirmed the abrupt change in deposit type.

d. Review data from other recently completed borings that have penetrated the RCU in the general area.

2. Drilling and split-spoon sampling

a. Communicate the objective of the borehole to the driller before commencing drilling and maintain communication throughout the borehole drilling to obtain his observations on material being penetrated by the drill bit. Ask him to tell you when he is drilling in sand or gravel and when he believes the borehole is penetrating clay or silt. Periodically note the drilling fluid pressure (if using a fluid based drilling technique and the rig has such a gage) as pressure increases may indicate penetration of a low permeability layer such as silt or clay.

b. While drilling through the Magothy aquifer, examine and describe split-spoon samples (according to ARCADIS' Standard Operating Procedure for Soils) for evidence of the RCU based on the descriptions given above for these units. If drilling is carried out using drilling fluid, note any color changes in the fluid that might indicate that the RCU has been reached. Generally, the Magothy tends to be gray with some white, but the RCU tends to be red, brownish-red, and pink. The red to brownish-red RCU frequently contains very thin white layers, which collectively can produce a pinkish color in the drilling fluid once the RCU has been penetrated.

c. Be aware that the basal zone of the Magothy aquifer is typified by coarse sand and gravel, and small cobbles have even been encountered in this horizon. The basal Magothy coarse zone may be tens of feet thick and at some locations may be up to 75 to 100 feet thick however, it is not always present. This horizon is reflective of a high energy environment and many times will stand in stark contrast to the fine sediment of the low energy environment of the underlying RCU.

d. Once the borehole reaches a depth close (30 feet above) to the anticipated depth of the surface of the RCU based on the literature, increase the split-spoon sampling frequency to every 5 feet. After the first spoon sample suggestive of the RCU (see above section "**Raritan Confining Unit and Magothy Aquifer Lithology and Depositional Environments"** for RCU descriptions) is observed increase split-spoon sampling frequency to continuous over the following 10-foot interval. If this 10-foot interval is predominately clay diagnostic of the RCU, the borehole can be terminated pending further characterization as described below in 3b. If this 10-foot interval is not predominately clay diagnostic of the RCU (i.e., clay diagnostic of the Magothy or predominately sand), then a decision should be made, with office project management staff, to either conduct continuous split-spoon sampling over an additional 10-foot interval or revert to split-spoon sampling at a 5-foot interval until a sample suggestive of the RCU is observed and then return to continuous split-spoon sampling. Once a 10-foot interval of predominately clay diagnostic of the RCU is penetrated, the borehole can be terminated, pending further characterization as described below in 3b.

e. If during split-spoon sampling it is no longer possible to advance the split spoon (i.e., refusal is reached-decided in the field with driller input) then the driller will be instructed to complete drilling of the borehole to the full depth of what would have been the 10-foot split-spooned interval and then steps 2f through 3b will be carried out. If the geophysical logging indicates that the portion of the 10 foot interval that was not split-spooned is predominately clay then the borehole can be terminated. However, if the geophysical logging indicates that the portion of the 10 foot interval that was not split-spooned is not predominately clay then a decision should be made, with office project management staff, to either attempt to conduct split-spoon sampling over an additional 10 foot interval or terminate the borehole.

f. Once the drilling has been terminated (i.e., the RCU has been penetrated a minimum of 10 ft), if using a fluid based drilling system, request the driller to slowly re-drill the last 10-foot interval to ensure that any swelling of the clay into the borehole is overcome and the borehole remains open to its full drilled diameter. Also, ask the driller to continue to circulate the drilling fluid until all entrained sediment has reached the fluid pit and settled out to the extent practical to help ensure that the borehole remains open to its full drilled depth so that geophysical logging can be effectively carried out.

3. Geophysical logging

a. Have the driller pull the rods from the borehole and then proceed with geophysical logging of the borehole, including a gamma ray log. However, if there are concerns about borehole stability the gamma ray log may be run inside the rods.

b. Review the split-spoon geologic descriptions and compare to the gamma ray log to confirm that the RCU has been reached and is predominately clay and, if confirmed, then drilling can be considered terminated.

4. **VOC groundwater sampling**

a. If the 10-foot continuously split-spooned sample interval is predominately clay diagnostic of the RCU but contains sand zones of a foot or more in thickness then an attempt should be made to collect a water quality sample from each of those sand zones with a Hydropunch sampler or equivalent device. All water samples collected as part of this protocol will be analyzed for VOCs by a fixed location laboratory on a 24-hour turnaround basis. It is recognized that since each Hydropunch water quality sampling attempt will be made prior to collecting the next split-spoon sample, there is no guarantee that the Hydropunch sampling attempt will be in a sand zone. Therefore, the attempt may not be successful in obtaining water. Regardless, the attempt should be made. If a sample is obtained and is free of VOCs or multiple samples are obtained and all or the deepest sample are free of VOCs, then the borehole drilling will be terminated after the 10 feet of continuous split spoon sampling is completed, and above steps 2f through 3b should be carried out.

   If water quality samples cannot be obtained, then a decision should be made, with office project management staff, whether to split-spoon sample an additional 10 feet and attempt to collect water quality samples from any sand zones or to terminate the borehole. One logistical issue that will need to be resolved is that VOC results will not be immediately available and so decisions to temporarily suspend drilling or continue will have to be made based on when in the work day the water quality sample is collected, when the VOC results will be available, and what other tasks the driller may be able to do while waiting for analytical results so that standby time can be minimized.

b. If the water quality sampling and analysis of the only sand zone or the deepest sand zone in the RCU contains elevated levels of Total VOCs (i.e., 100 micrograms per liter [ug/l] or greater) then continuous split-spoon sampling over a second 10-foot interval should be carried out. If this 10-foot interval is predominately clay, diagnostic of the RCU, then terminate drilling of the borehole and follow steps 2f through 3b above.

c. If the second 10-foot continuously split-spooned sample interval is predominately clay diagnostic of the RCU but contains sand zones of a foot or more in thickness then an attempt should be made to collect a water quality sample from each sand zone, with a Hydropunch sampler or equivalent device. If all samples or the deepest sample are free of VOCs then the borehole drilling will be terminated after the additional 10 feet of continuous split-spoon sampling is completed and above steps 2f through 3b should then be carried out.

d. If the water quality sampling of the only or the deepest sand zone in the second split-spooned interval of the RCU contains elevated levels of VOCs, then a decision will be made, with office project management staff, on whether to continue drilling/sampling or to terminate the borehole. When the borehole is terminated the above steps 2f through 3b should be carried out.

The rationale for the VOC sampling protocol is that 10 feet (or more) of relatively solid clay or clay with sand layers with no VOC detections (or no detections in the deepest sample) are sufficient evidence that the bottom of the transmissive zones of the Magothy or similar zones in the RCU have been identified and penetrated.