UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION III
1650 Arch Street
Philadelphia, Pennsylvania 19103-2029

March 4, 2008

Commander,
Radford Army Ammunition Plant
Attn: SJMRF-OP-EQ (Jim McKenna)
P.O. Box 2
Radford, VA 24141-0099

P.W. Holt
Environmental Manager
Alliant Techsystems, Inc.
Radford Army Ammunition Plant
P.O. Box 1
Radford, VA 24141-0100

Re: Radford Army Ammunition Plant, Va.
Master Work Plan Addendum 022
Review of the Army's RCRA Work Plan Addendum

Dear Mr. McKenna and Ms. Holt:

The U.S. Environmental Protection Agency (EPA) and the Virginia Department of Environmental Quality (VDEQ) have reviewed the U.S. Army's (Army's) December, 2007 submittal of the Final Work Plan Addendum 022 for Solid Waste Management Unit (SWMU) 45. Based upon our review, the Work Plan is approved, and in accordance with Part II. (E) (5) of RFAAP's Corrective Action Permit, it can now be considered final.

If you have any questions, please call me at 215-814-3413, or Jim Cutler at 804-698-4498. Thanks.

Sincerely,

William Geiger
RCRA Project Manager
General Operations Branch (3WC23)

cc: Jim Cutler, VDEQ

ATK
ALLIANT TECHSYSTEMS

Radford Army Ammunition Plant
Route 114, P.O. Box 1
Radford, VA 24143-0100
USA

January 4, 2008

Mr. William Geiger
RCRA General Operations Branch, Mail Code: 3WC23
Waste and Chemicals Management Division
U. S. Environmental Protection Agency, Region III
1650 Arch Street
Philadelphia, PA 19103-2029

Mr. James L. Cutler, Jr.
Virginia Department of Environmental Quality
629 East Main Street
Richmond, VA 24143-0100

Subject: With Certification, Radford Army Ammunition Plant,
Work Plan Addendum 022, Site Screening Process at Solid Waste Management Unit 45, Final December 2007
EPA ID# VA1 210020730

Dear Mr. Geiger and Mr. Cutler:

Enclosed is the certification for the subject document that wase sent to you on January 3, 2008. Also enclosed is a copy of the transmittal email message and response to comments.

Please coordinate with and provide any questions or comments to myself at (540) 639-8658, Jerry Redder of my staff (540) 639-7536 or Jim McKenna, ACO Staff (540) 639-8641.

Sincerely,

P.W. Holt, Environmental Manager
Alliant Techsystems Inc.

c: Durwood Willis
Virginia Department of Environmental Quality
P. O. Box 10009
Richmond, VA 23240-0009

E. A. Lohman
Virginia Department of Environmental Quality
West Central Regional Office
3019 Peters Creek Road
Roanoke, VA 24019

Rich Mendoza
U.S. Army Environmental Command
1 Rock Island Arsenal
Bldg 90, 3rd Floor, Room 30A
IMAE-CDN
Rock Island, Illinois 61299

08-815-1
JMcKenna

Tom Meyer
Corps of Engineers, Baltimore District
ATTN: CENAB-EN-HM
10 South Howard Street
Baltimore, MD 21201

bc:
Administrative File
J. McKenna, ACO Staff
Rob Davie-ACO Staff
M.A. Miano
P.W. Holt
J. J. Redder
Env. File

Coordination: J. McKenna
J. McKenna

MM Miano

08-815-1
JMcKenna

Concerning the following:

Radford Army Ammunition Plant
Work Plan Addendum 022,
Site Screening Process at Solid Waste Management Unit 45
Final December 2007

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fines and imprisonment for knowing violations.

SIGNATURE:
PRINTED NAME: Jon R. Drushal
TITLE: Lieutenant Colonel, US Army
Commanding

SIGNATURE:
PRINTED NAME: Kent Holiday
TITLE: Vice President and General Manager
ATK Energetics Systems

Greene, Anne

From: McKenna, Jim
Sent: Thursday, January 03, 2008 11:48 AM
To: Greene, Anne; beth lohman; dennis.druck@us.army.mil; durwood willis2; Geiger.William@epamail.epa.gov; Redder, Jerome; jim spencer; jlcutler@deq.virginia.gov; Mendoza, Richard R Mr CIV USA SA; Parks, Jeffrey N; Timothy.Leahy@shawgrp.com; Tina_Devine@URSCorp.com; Tom.Meyer@nab02.usace.army.mil
Subject: FW: WPA 022 - SSP at SWMU 45 (UNCLASSIFIED)
Importance: High
Attachments: WPA 022 RTC 10_29_07 RTC.pdf

Classification: **UNCLASSIFIED**
Caveats: NONE

All:

Note the contractor will ship the subject document with a copy of this email and attachment to the POCs and tracking numbers below.

Certification letter will follow from RFAAP under separate cover.

Immediately below are the POCs and respective Fed Ex tracking numbers for the WPA 022 - SWMU 45:

Will Geiger	7904 1675 5242	Paper Copy and CD
Jim Cutler	7914 6872 3685	Paper Copy and CD
Durwood Willis	7918 2576 8299	Paper Copy and CD
Tom Meyer	7992 4855 8600	CD
Rich Mendoza	7926 2474 9118	CD
Dennis Druck	7918 2581 1899	CD
Beth Lohman	7983 4369 3654	CD

Thank you for your support of the Radford AAP Installation Restoration Program.

Jim McKenna

Classification: **UNCLASSIFIED**
Caveats: NONE

Response to Comments (10/29/2007)
EPA and VDEQ Comments Received via e-mail (09/11/07)
Draft Work Plan Addendum 022, SSP Investigation for Solid Waste Management Unit 45, July 2007

GENERAL COMMENTS

Comment 1: Groundwater sampling is proposed at three existing site monitoring wells (45MW1, 45MW2, and 45MW3), but it does not appear that any of these wells are located downgradient of geophysical anomaly areas #4 and #5, as shown on Figure 1-15 (2007 Geophysical Survey – Geophysical Anomaly Areas). Groundwater flow direction at Solid Waste Management Unit (SWMU) 45 is reportedly to the north towards the New River (Section 1.2.5, Groundwater). None of the existing wells are located north of the anomalies identified on the eastern half of the site. Please revise the Work Plan Addendum to include an assessment of groundwater north of geophysical anomaly areas #4 and #5, or provide the justification for not assessing groundwater in this portion of the site.

> **RFAAP Response:** An additional monitoring well (45MW4) will be installed north and downgradient of anomalies #4 and #5 to evaluate potential releases to groundwater in this area of the site. Based on data from existing monitoring wells 45MW1, 45MW2, and 45MW3, the uppermost zone of groundwater occurs within overburden; however, if an insufficient water column is present within the overburden, then the monitoring well will be screened across the overburden and bedrock interface. Monitoring well 45MW4 will be installed with a 15 ft long screen so that the top of the screen is above the seasonally high water table.
>
> Air rotary drilling method will be used for installation of monitoring well 45MW4 given that well installation into bedrock may be required. A 6-inch diameter, roller bit will be used to drill within soil overburden and a 6-inch diameter, air hammer bit will be used to drill in bedrock. If unstable conditions are encountered in the borehole, then a 6-inch temporary casing will be set in the borehole to allow for boring completion and monitoring well installation. A minimum 8-inch diameter roller bit will be used in the overburden if temporary casing is required. The casing sections are fitted with auger couples to allow for incremental removal during well construction. Monitoring well 45MW4 will be constructed using 2-inch diameter (nominal), Schedule 40 polyvinyl chloride (PVC) threaded screen and riser pipe. A 0.010-inch screen slot size and No. 2 sand filter pack will be used to construct the wells.
>
> The work plan addendum will be revised to show the proposed monitoring well installation. Information on proposed drilling methods, and monitoring well construction information and specifications including: well diameter, screen and riser pipe material, screen slot size, filter pack material, bentonite seal, cement-bentonite grout, surface seal, protective casing, and surface completion details, will be added to work plan addendum. A proposed well construction diagram will also be included in the work plan addendum in addition to SOPs related to drilling, monitoring well installation, monitoring well development, and groundwater sampling.

Comment 2: The summary of the geophysical survey conducted in 2007 references "standing water . . . observed within a non-contiguous ditch" at the site. Photograph 8, provided in Appendix B, also shows a "water-filled depression" in the center of the site. The Work Plan Addendum does not appear to provide further detail on this site feature. Section 1.2.3 indicates that, "Storm water and precipitation will tend to infiltrate rather than run off . . . ." Photograph 8 does not appear to support these statements. Please revise the Work Plan Addendum to address whether the standing water observed at the site was the result of a recent precipitation event and to evaluate whether water from this depression warrants further assessment.

> **RFAAP Response:** Standing water observed in this approximate six foot wide, 15 foot long, and two foot deep area was likely the result of recent precipitation events. This depression area was likely the result of a previous test excavation conducted in the landfill area based on vegetative covered soil piles observed in adjacent areas. Sampling of this water for the SSP is not warranted given that it is not a surface water body draining the site and collection of a surface water sample from this area will not provide meaningful information to characterize releases to soil and groundwater at the site. The Work Plan Addendum will be revised accordingly to incorporate this additional information.

Comment 3: The proposed analyses for investigation-derived materials (IDM) presented in Table 1-4 (Handling and Disposal of Investigation-Derived Materials) do not correlate with those analyses summarized on Table 2-4 (Summary of Proposed Sample Identifiers, Depths, and Analytical Methods). For example, Table 1-4 indicates that excess soil from borings and test pits will be analyzed for the full toxicity characteristics leaching procedure (TCLP) analysis, corrosivity, paint filter liquids, and explosives. However, Table 2-4 indicates that soil IDM will be analyzed for volatile organic compounds (VOCs) instead of explosives. Additionally, Table 1-4 indicates that purge water will be analyzed for TCLP metals, but Table 2-4 does not mention this analysis. Please revise the Work Plan Addendum to consistently document the proposed analyses for the IDM.

> **RFAAP Response:** Table 2-4 will be revised to indicate IDM analyses for soil to include full TCLP, pH, Paint Filter, and Explosives and IDM analyses for water to include TCLP metals, COD, and pH.

Comment 4: The aerial photographs, provided as Figures 1-4 through 1-8, do not include north arrows as references for the figures' orientation. Please revise Figures 1-4 through 1-8 to include north arrows.

> **RFAAP Response:** Figures 1-4 through 1-8 will be revised to include north arrows.

SPECIFIC COMMENTS

Comment 5: Section 1.4.3, Installation Assessment – EPIC Aerial Photographic Analysis – USEPA 1992, Page 1-8: The second paragraph references photographs from 1954 and 1966; however, neither of these aerial photographs appears to have been included as a figure (although all of the other referenced photographs have been appended). The 1954 photograph is reported to have shown open storage of containers and a "small area of possible liquid." The 1966 photograph is reported to have shown a "possible trench and a dark-toned material." The locations of these historic features may be important to the current investigation if they represent potential source areas. Please revise the Work Plan Addendum to include the aerial photographs from 1954 and 1966, or provide justification for not including these two aerial photographs in the Work Plan Addendum as background information relevant to the current investigation.

Additionally, it appears that an additional figure, the aerial photograph from 1975, was included as Figure 1-7, but this figure was not described in Section 1.4.3. Please revise the Work Plan Addendum to provide a description of the aerial photograph from 1975 (Figure 1-7).

> **RFAAP Response:** The 1954 and 1966 aerial photographs that are referenced in the EPIC and USEPA Report are not available; however, the interpreted information referenced in the report text for 1954 and 1966 is shown on available EPIC markups of photographs from 1962 and 1971, respectively. Figures 1-5 (1962) and 1-6 (1971) will be modified to show the features identified by EPIC and described in the Work Plan Addendum text.
>
> Both of these areas were located within the geophysical survey area; however, geophysical anomalies were not identified in the area where open container storage was identified.
>
> The location of the "possible trench and dark toned material" is east of access road to SWMU 45 and within planned sample areas at geophysical anomaly 1 and areas to the north.
>
> One of the four discretionary sample locations proposed in the landfill area will be moved to the identified container storage area in the northwest corner of the study area to evaluate for potential releases. One surface soil sample (0 to 1 ft bgs, except for 0.5 to 1 ft bgs for VOCs) and one subsurface soil sample will be collected from this location for chemical analysis. The subsurface soil sample will be collected from a discrete depth interval of 4 to 5 ft bgs. Figure 1-17 will be modified accordingly.

Comment 6: Section 1.4.4, Geophysical Investigation – 2007, Post Survey Reconnaissance, Page 1-10: Five of the anomalies identified during the geophysical investigation were selected for further investigation during a site reconnaissance. Holes of varying depths and widths were dug at the five anomalies to confirm the results of the geophysical survey. The Work Plan Addendum does not include field documentation from this event. Although the information from this field event is summarized in Section 1.4.4, the field reports should also be appended as they likely provide further detail on the dimensions of the holes as well as the materials encountered in each hole. Please revise the Work Plan Addendum to include the field reports or logs from the post survey reconnaissance.

> **RFAAP Response:** A photographic log and information from the additional investigation will be provided in an Appendix D.

Comment 7: Section 1.5.2, Mechanisms of Contaminant Release, Page 1-11: Offsite surface water and sediment of the New River are identified as potentially affected media, yet surface water and sediment sampling have not been proposed in this Work Plan Addendum. The Work Plan Addendum should describe how these potentially affected media will be adequately characterized. Please revise the Work Plan Addendum to address this concern. Additional investigation of the New River surface water and sediment may be necessary, depending on the results of the proposed groundwater sampling.

> **RFAAP Response:** The following text will be added to Section 1.5.2 "While site groundwater discharge may be hydraulically connected to the New River, the completeness of this pathway is unknown. If site-related groundwater impacts are identified, an assessment of the potential impacts to the New River will be conducted via screening the groundwater data for COPCs against Virginia Water Quality Criteria and EPA Region III freshwater ecological screening values. If the screening indicates potential impacts to the New River at levels of concern, additional investigation of the nature and extent of impact to groundwater and/or the New River may be necessary."

Comment 8: Section 1.7.1, Test Pit Investigation and Soil Sampling, Page 1-13: Six test pits are proposed in those areas where anomalies were identified during the geophysical survey. Area #3, identified on Figure 1-15, is a relatively large area in comparison to the other anomalies but only one test pit (TP3) is proposed for this area (Figure 1-17). It is not clear that the southern portion of Area #3 will be adequately characterized with the currently proposed test pits and soil borings. Please revise the Work Plan Addendum to address how the southern portion of anomaly Area #3 (the area immediately northwest of monitoring well 45MW1) will be adequately characterized. An additional test pit or boring should be considered for this area.

> **RFAAP Response:** An additional test pit (TP7) will be completed in the southern part of this anomaly to further evaluate conditions and potential releases. One of the discretionary sample locations from the soil borings will be moved to this test pit given the higher release potential within this area, based on the geophysical survey and field observations than in other areas where anomalies were not identified. Please note that any excess material from the test pits (investigative derived material) will be appropriately containerized in 55-gallon DOT drums rather than a roll-off container. The final work plan (including Table 1-4) will be modified to incorporate these changes.

Comment 8A: Two soil samples are proposed for each of six planned test pits. Fifteen direct push soil borings are planned for locations depicted on Figure 1-17. Samples are proposed for those 4 locations where potential for a release are highest. However, this strategy could result in redundant sampling in grids with waste and test pits. I propose not sampling the test boring in the same grid space where a high potential of release is encountered in the test pit.

> **RFAAP Response:** Concur. Given that two samples are being collected from each test pit for chemical analysis, samples for chemical analysis will not be collected from borings completed in the same grid as a test pit. Borings in these areas will be used to evaluate the nature and extent of waste material, etc. through visual observations, field screening with a photoionization detector, etc.

Comment 9: Section 1.7.2, Direct Push Soil Borings, Page 1-14: Although 15 direct push borings will be installed, samples for chemical analysis will only be collected at four of these fifteen locations where the potential for a release is highest. While the rationale for this sampling strategy appears acceptable in an effort to both identify a release and conserve project resources, the Work Plan Addendum should include a contingency for additional samples should field observations suggest the potential for a release at more than four locations. Please revise the Work Plan Addendum to include a contingency for additional samples for chemical analysis if the potential for a release is suggested via visual observation or field screening results.

> **RFAAP Response:** To eliminate potential redundant samples and provide for more coverage of the site, soil samples for chemical analysis will not be collected from soil borings completed in the same grid area as test pits, as discussed in the response to Comment 8A. This will reduce the number of potential boring locations where samples may be collected from 15 to 9. Two of the four discretionary samples are proposed to be moved to specific locations where the potential for releases appears to be highest as described in the responses to Comments 5 and 8. The remaining two discretionary sample locations will be based on the conditions encountered in the nine borings to be completed in grid areas outside of the planned test pit locations. As a contingency, up to two sample locations (each location would include a surface and subsurface soil sample) may be selected from these nine boring locations if significant release potentials are identified by observations of waste material, field screening, etc. The Work Plan Addendum will be revised accordingly to incorporate these changes.

Comment 10: Table 2-4, Summary of Proposed Sample Identifiers, Depths, and Analytical Methods: Soil and groundwater samples will be analyzed for dioxins if evidence of burn material is observed at one or more test pit locations according to the SWMU 45 – Summary of Data Gap Analysis and Completion Plan table in Section 1.6.5 on page 1-12. Table 2-4 does not specify that soil and groundwater samples may be analyzed for dioxins, depending on site conditions. Please revise Table 2-4 to document that soil and groundwater samples may be analyzed for dioxins if evidence of burn material is encountered at one or more of the test pits.

> **RFAAP Response:** Note 1 provided on Table 2-4 will be revised to state "Up to 4 soil samples and 4 groundwater samples will be submitted for dioxin/furan analysis if burned material is encountered in test pit areas."

Comment 11: Appendix A, Standard Operating Procedures, SOP 30.1 Soil Sampling: Number 17 on Page 3 of the SOP for soil sampling indicates that borings will be abandoned in accordance with SOP 20.2. However, it appears that SOP 20.2 addresses well development and not well/boring abandonment. Please revise SOP 30.1 to address this discrepancy, and provide an appropriate SOP for boring/well abandonment procedures.

> **RFAAP Response:** The SOP 30.1 Number 17 on page 3 will be revised to state that borings will be abandoned in accordance with SOP 20.3. SOP 20.3 (Well and Boring Abandonment) will be included in Appendix A; this SOP will also be updated to incorporate the latest information included in ASTM standards, as appropriate.

MINOR COMMENTS

Comment 12: Section 1.6.4, Other, Page 1-12: This section provides an incorrect reference for the physical testing of site soils. It appears that the correct reference for this information is Section 1.7.2.1 (Physical Soil Testing) and not Section 1.7.4, as noted. Please revise the document to correct this editorial oversight.

> **RFAAP Response:** The reference in Section 1.6.4 will be revised to 1.7.2.1.

EPA Hydrogeologist General Comments:

Comment: Reliance on outdated standards should be discontinued. References to ASTM and other standards should include the latest versions. Work performed should be in accordance with SOP developed from the latest standards.

> **RFAAP Response:** SOPs included in this Work Plan Addendum and subsequent work plans will be updated as required to reflect updates to ASTM and other standards, as applicable.

Comment: Data quality objectives should be formulated and stated for groundwater on Table 2-3.

> **RFAAP Response:** Table 2-3 will be modified to include the following additional data quality objectives for Decision Rules and Parameters of Interest:
>
> - Hydraulic conductivity of screened intervals of monitoring wells.
> - Groundwater flow velocity.
> - Complete the site screening process (SSP) for groundwater sample results.
>
> The following data quality objectives for groundwater were included in Table 2-3 (and in the text of Section 2.3) of the Work Plan Addendum:
>
> - Principal Study Questions
>   - Have hazardous constituent concentration leaching from disposal material/waste to subsurface soil and/or groundwater above SSP criteria?
>   - Do hazardous constituent concentrations in soil and groundwater pose an unacceptable risk to human health and the environment?
> - Decision Inputs
>
>   Groundwater – tap water RBCs in the most recent USEPA Region III RBC table, Federal Maximum Contaminant Levels (MCLs), and Virginia Water Quality Standards in 9 VAC 25-260.
> - Study Boundaries
>
>   Parameters of Interest for groundwater: pH, specific conductance, dissolved oxygen, oxidation-reduction potential, and turbidity.
>
>   Depth to groundwater and groundwater flow direction.

Comment: The work plan addendum calls for soils sampling at various depths which are not supported by the master work plan. If the depths called for in the master work plan have been sampled previously, and the samples outlined in the work plan addendum are in addition to previously obtained samples, then this fact should be stated in the work plan addendum. The purpose for each sample location and media type should be outlined in the work plan addendum. The work plan should include justification and discussion of the reasons for selecting the locations for ground water monitoring wells and sample locations.

> **RFAAP Response:** As indicated in Section 1.6.2 of Work Plan Addendum (WPA) 022 for SWMU 45, soil chemical data have not been collected previously at the site and therefore, Section 2.7 of the WPA identified the proposed sampling locations, depths, and rationale based on the data gap analysis presented in Section 2.6. This is consistent with Section 5.29 of the Master Work Plan, which indicates that site-specific locations and depths for surface and subsurface soil samples will be identified in Work Plan Addenda. Also consistent with Section 5.2.9 of the Master Work Plan, depths for surface soil

samples proposed in WPA 022 are from 0 to 0.5 ft bgs, except for samples for analysis of volatile organic compounds, which will be collected from 0.5 to 1 ft bgs.

As discussed in Section 1.6.3 of WPA 022, three existing groundwater monitoring wells (45MW1, 45MW2, and 45MW3) were installed previously at the site in 1991 to evaluate potential releases to groundwater from the landfill area. The WPA proposed an additional round of groundwater samples from these monitoring wells to evaluate for potential releases and fill identified gaps based on the results of the geophysical survey, which indicated that well 45MW1 is appropriately positioned as an upgradient monitoring well and that wells 45MW2 and 45MW3 were appropriately positioned as downgradient wells of the main landfill area (geophysical anomalies 1, 2, and 3). As discussed in the response to Comment 1, an additional groundwater monitoring well (45MW4) will be installed in the eastern part of the site to evaluate potential releases to groundwater from the other major geophysical anomalies (4 and 5) identified by the surveys. The Work Plan Addendum will be revised to incorporate this additional information.

Comment: Data gap analysis included in Subsection 7.4 (page 7-2) does not include groundwater data gaps. Please revise.

RFAAP Response: Groundwater data gaps are included in Section 1.6.3 of the Work Plan Addendum. This section will be updated to include the additional information related to the data gap for evaluating groundwater releases in the eastern part of the site in the area of geophysical anomalies 3 and 4, and the planned installation of a fourth well (45MW4) in this area to fill the identified data gap.

Comment: All notes (including logs, and surveys) made during field activities should be included in the report.

RFAAP Response: Concur. A photographic log and information from the additional investigation due to the anomalies identified during the geophysical investigation will be provided in an Appendix D.

Comment: The reference list (4.0) does not include guidance for well/direct push abandonment, as the SOP for these procedures is not provided in the WPA.

RFAAP Response: SOP 20.3 (Well and Boring Abandonment) will be provided in Appendix A and referenced in Table 1-1 and in the Appendix A reference list. This SOP will be updated to include information from the latest ASTM standards, as appropriate.

Comment: Guidance for well abandonment (from which an SOP for monitoring well/direct push sampling point abandonment may be developed) includes: ASTM D6001-05, and ASTM D5299-99(2005).

RFAAP Response: SOP 20.3 (Well and Boring Abandonment) will be updated to incorporate information from the latest ASTM standards, as appropriate.

Response to Comments (10/29/2007)
EPA and VDEQ Comments Received via e-mail (09/11/07)
Draft Work Plan Addendum 022, SSP Investigation for Solid Waste Management Unit 45, July 2007

Comment: RAAP must obtain VADEQ approval for installation/use of direct push wells. This approval should be documented in the post-fieldwork submitted reports.

> **RFAAP Response:** Comment noted for future reference. Direct push groundwater sampling is not proposed for the site investigation. SOP 20.12 (Direct Push Groundwater Sampling) will be removed from Appendix A.

Geiger.William@epamail.epa.gov

12/07/2007 10:07 AM

To Tina_Devine@URSCorp.com

cc anne.greene@atk.com, dennis.druck@us.army.mil, "durwood willis2" <dhwillis@deq.virginia.gov>, "beth lohman" <ealohman@deq.state.va.us>, "Parks, Jeffrey N"

bcc

Subject Re: Revised RTC for SWMU 45 attached

EPA and VDEQ approve of Radford's response to our WPA 022 Comments.

William A. Geiger
USEPA Region III
1650 Arch Street
Philadelphia, PA 19103
(215)814-3413

Tina_Devine@URSCorp.com

11/09/2007 04:22 PM

To
<jim.mckenna@us.army.mil>

cc
<anne.greene@atk.com>, "beth lohman" <ealohman@deq.state.va.us>, <dennis.druck@us.army.mil>, "durwood willis2" <dhwillis@deq.virginia.gov>, William Geiger/R3/USEPA/US@EPA, <jerome.redder@atk.com>, <jlcutler@deq.virginia.gov>, "Mendoza, Rich" <richard.r.mendoza@us.army.mil>, "Parks, Jeffrey N" <Jeffrey.Parks@shawgrp.com>, <Timothy.Leahy@shawgrp.com>, <Tom.Meyer@nab02.usace.army.mil>

Subject
Revised RTC for SWMU 45 attached

Some of you may have already received this, but there was some trouble with the attachment so I am resending the RTCs. Let me know if anyone has trouble with it. Have a great weekend.

(See attached file: WPA 022 RTC 10_29_07 RTC.pdf)

Tina DeVine, P.E.
Project Engineer
URS Corporation
(804)474-5448

(See attached file: WPA 022 RTC 10_29_07 RTC.pdf)

WPA 022 RTC 10_29_07 RTC.pdf

"McKenna, Jim J Mr CIV USA AMC"
<jim.mckenna@us.army.mil>

11/05/2007 03:21 PM

To <anne.greene@atk.com>, "beth lohman" <ealohman@deq.state.va.us>, <dennis.druck@us.army.mil>, "durwood willis2"

cc

bcc

Subject Revised Response to Comment For WPA 022 - SWMU 45 SSP Workplan (UNCLASSIFIED)

Classification: **UNCLASSIFIED**
Caveats: NONE

All:

Attached are the subject response to comments from EPA and DEQ on WPA 22, SWMU 45 SSP.

Let me know if they are ok. If so then I will coordinate sending out the revised workplan.

Thanks.

Jim

Classification: **UNCLASSIFIED**
Caveats: NONE

Geiger.William@epamail.epa.gov

09/11/2007 09:56 AM

To jim spencer <james_o_spencer@urscorp.com>, "Parks, Jeffrey N" <Jeffrey.Parks@shawgrp.com>, Timothy.Leahy@shawgrp.com,

cc jlcutler@deq.virginia.gov, Cramer.Mike@epamail.epa.gov

bcc

Subject Draft Workplan 022 Comments

Guys, I've hastily put together some comments from Jim, Mike, and myself regarding Workplan Addendum 022, so that we have something to discuss at the meeting. I apologize if some are repetitive, but it will at least give us a starting point. Hopefully you haven't all left already for tomorrow.

GENERAL COMMENTS

1. Groundwater sampling is proposed at three existing site monitoring wells (45MW1, 45MW2, and 45MW3), but it does not appear that any of these wells are located downgradient of geophysical anomaly areas #4 and #5, as shown on Figure 1-15 (2007 Geophysical Survey – Geophysical Anomaly Areas). Groundwater flow direction at Solid Waste Management Unit (SWMU) 45 is reportedly to the north towards the New River (Section 1.2.5, Groundwater). None of the existing wells are located north of the anomalies identified on the eastern half of the site. Please revise the Work Plan Addendum to include an assessment of groundwater north of geophysical anomaly areas #4 and #5, or provide the justification for not assessing groundwater in this portion of the site.

2. The summary of the geophysical survey conducted in 2007 references “standing water . . . . observed within a non-contiguous ditch” at the site. Photograph 8, provided in Appendix B, also shows a “water-filled depression” in the center of the site. The Work Plan Addendum does not appear to provide further detail on this site feature. Section 1.2.3 indicates that, “Storm water and precipitation will tend to infiltrate rather than run off . . . .” Photograph 8 does not appear to support these statements. Please revise the Work Plan Addendum to address whether the standing water observed at the site was the result of a recent precipitation event and to evaluate whether water from this depression warrants further assessment.

3. The proposed analyses for investigation-derived materials (IDM) presented in Table 1-4 (Handling and Disposal of Investigation-Derived Materials) do not correlate with those analyses summarized on Table 2-4 (Summary of Proposed Sample Identifiers, Depths, and Analytical Methods). For example, Table 1-4 indicates that excess soil from borings and test pits will be analyzed for the full toxicity characteristics leaching procedure (TCLP) analysis, corrosivity, paint filter liquids, and explosives. However, Table 2-4 indicates that soil IDM will be analyzed for volatile organic compounds (VOCs) instead of explosives. Additionally, Table 1-4 indicates that purge water will be analyzed for TCLP metals, but Table 2-4 does not mention this analysis. Please revise the Work Plan Addendum to consistently document the proposed analyses for the IDM.

4. The aerial photographs, provided as Figures 1-4 through 1-8, do not include north arrows as references for the figures’ orientation. Please revise Figures 1-4 through 1-8 to include north arrows.

SPECIFIC COMMENTS

5. Section 1.4.3, Installation Assessment – EPIC Aerial Photographic Analysis – USEPA 1992, Page 1-8: The second paragraph references photographs from 1954 and 1966; however, neither of these aerial photographs appears to have been included as a figure (although all of the other referenced photographs have been appended). The 1954 photograph is reported to have shown open storage of containers and a "small area of possible liquid." The 1966 photograph is reported to have shown a "possible trench and a dark-toned material." The locations of these historic features may be important to the current investigation if they represent potential source areas. Please revise the Work Plan Addendum to include the aerial photographs from 1954 and 1966, or provide justification for not including these two aerial photographs in the Work Plan Addendum as background information relevant to the current investigation.

Additionally, it appears that an additional figure, the aerial photograph from 1975, was included as Figure 1-7, but this figure was not described in Section 1.4.3. Please revise the Work Plan Addendum to provide a description of the aerial photograph from 1975 (Figure 1-7).

6. Section 1.4.4, Geophysical Investigation – 2007, Post Survey Reconnaissance, Page 1-10: Five of the anomalies identified during the geophysical investigation were selected for further investigation during a site reconnaissance. Holes of varying depths and widths were dug at the five anomalies to confirm the results of the geophysical survey. The Work Plan Addendum does not include field documentation from this event. Although the information from this field event is summarized in Section 1.4.4, the field reports should also be appended as they likely provide further detail on the dimensions of the holes as well as the materials encountered in each hole. Please revise the Work Plan Addendum to include the field reports or logs from the post survey reconnaissance.

7. Section 1.5.2, Mechanisms of Contaminant Release, Page 1-11: Offsite surface water and sediment of the New River are identified as potentially affected media, yet surface water and sediment sampling have not been proposed in this Work Plan Addendum. The Work Plan Addendum should describe how these potentially affected media will be adequately characterized. Please revise the Work Plan Addendum to address this concern. Additional investigation of the New River surface water and sediment may be necessary, depending on the results of the proposed groundwater sampling.

8. Section 1.7.1, Test Pit Investigation and Soil Sampling, Page 1-13: Six test pits are proposed in those areas where anomalies were identified during the geophysical survey. Area #3, identified on Figure 1-15, is a relatively large area in comparison to the other anomalies but only one test pit (TP3) is proposed for this area (Figure 1-17). It is not clear that the southern portion of Area #3 will be adequately characterized with the currently proposed test pits and soil borings. Please revise the Work Plan Addendum to address how the southern portion of anomaly Area #3 (the area immediately northwest of monitoring well 45MW1) will be adequately characterized. An additional test pit or boring should be considered for this area.

8A: Two soil samples are proposed for each of six planned test pits. Fifteen direct push soil borings are planned for locations depicted on Figure 1-17. Samples are proposed for those 4 locations where potential for a release are highest. However, this strategy could result in redundant sampling in grids with waste and test pits. I propose not sampling the test boring in the same grid space where a high potential of release is encountered in the test pit.

9. Section 1.7.2, Direct Push Soil Borings, Page 1-14: Although 15 direct push borings will be installed, samples for chemical analysis will only be collected at four of these fifteen locations where the potential for a release is highest. While the rationale for this sampling strategy appears acceptable in an effort to both identify a release and conserve project resources, the Work Plan Addendum should include a contingency for additional samples should field observations suggest the potential for a release at more than four locations. Please revise the Work Plan Addendum to include a contingency for additional samples for chemical analysis if the potential for a release is suggested via visual observation or field screening results.

10. Table 2-4, Summary of Proposed Sample Identifiers, Depths, and Analytical Methods: Soil and groundwater samples will be analyzed for dioxins if evidence of burn material is observed at one or more test pit locations according to the SWMU 45 – Summary of Data Gap Analysis and Completion Plan table in Section 1.6.5 on page 1-12. Table 2-4 does not specify that soil and groundwater samples may be analyzed for dioxins, depending on site conditions. Please revise Table 2-4 to document that soil and groundwater samples may be analyzed for dioxins if evidence of burn material is encountered at one or more of the test pits.

11. Appendix A, Standard Operating Procedures, SOP 30.1 Soil Sampling: Number 17 on Page 3 of the SOP for soil sampling indicates that borings will be abandoned in accordance with SOP 20.2. However, it appears that SOP 20.2 addresses well development and not well/boring abandonment. Please revise SOP 30.1 to address this discrepancy, and provide an appropriate SOP for boring/well abandonment procedures.

MINOR COMMENTS

12. Section 1.6.4, Other, Page 1-12: This section provides an incorrect reference for the physical testing of site soils. It appears that the correct reference for this information is Section 1.7.2.1 (Physical Soil Testing) and not Section 1.7.4, as noted. Please revise the document to correct this editorial oversight.

Mike's General Comments:

Reliance on outdated standards should be discontinued. References to ASTM and other standards should include the latest versions. Work performed should be in accordance with SOP developed from the latest standards.

Data quality objectives should be formulated and stated for ground water on table 2-3.

The work plan addendum calls for soils sampling at various depths which are not supported by the master work plan. If the depths called for in the master work plan have been sampled previously, and the samples outlined in the work plan addendum are in addition to previously obtained samples, then this fact should be stated in the work plan addendum. The purpose for each sample location and media type should be outlined in the work plan addendum.
The work plan should include justification and discussion of the reasons for selecting the locations for ground water monitoring wells and sample locations.

Data gap analysis included in Subsection 7.4 (page 7-2) does not include ground water data gaps. Please revise.

All notes (including logs, and surveys) made during field activities should be included in the report.

The reference list (4.0) does not include guidance for well/direct push abandonment, as the SOP for these procedures is not provided in the WPA.

Guidance for well abandonment (from which an SOP for monitoring well/direct push sampling point abandonment may be developed) includes: ASTM D6001-05, and ASTM D5299-99(2005).

RAAP must obtain VADEQ approval for installation/use of direct push wells. This approval should be documented in the post-fieldwork submitted reports.

William A. Geiger
USEPA Region III
1650 Arch Street
Philadelphia, PA 19103
(215)814-3413

ATK
ALLIANT TECHSYSTEMS

Radford Army Ammunition Plant
Route 114, P.O. Box 1
Radford, VA 24143-0100
USA

August 2, 2007

Mr. William Geiger
RCRA General Operations Branch, Mail Code: 3WC23
Waste and Chemicals Management Division
U. S. Environmental Protection Agency, Region III
1650 Arch Street
Philadelphia, PA 19103-2029

Subject: With Certification, Work Plan Addendum 022 Site Screening Process at Solid Waste Management Unit 45, July 2007
Radford Army Ammunition Plant Installation Action Plan
EPA ID# VA1 210020730

Dear Mr. Geiger:

Enclosed is the certification for the subject document that was sent to you on August 2, 2007.

Please coordinate with and provide any questions or comments to myself at (540) 639-8658, Jerry Redder of my staff (540) 639-7536 or Jim McKenna, ACO Staff (540) 639-8641.

Sincerely,

P.W. Holt

P.W. Holt, Environmental Manager
Alliant Techsystems Inc.

c: Jim Cutler
Virginia Department of Environmental Quality
P. O. Box 10009
Richmond, VA 23240-0009

Durwood Willis
Virginia Department of Environmental Quality
P. O. Box 10009
Richmond, VA 23240-0009

E. A. Lohman
Virginia Department of Environmental Quality
West Central Regional Office
3019 Peters Creek Road
Roanoke, VA 24019

Rich Mendoza
U.S. Army Environmental Command
1 Rock Island Arsenal
Bldg 90, 3rd Floor, Room 30A
IMAE-CDN
Rock Island, Illinois 61299

07-815-154
JMcKenna

Dennis Druck
U.S. Army Center for Health Promotion and Preventive Medicine
5158 Blackhawk Road, Attn: MCHB-TS-REH
Aberdeen Proving Ground, MD 21010-5403

Tom Meyer
Corps of Engineers, Baltimore District
ATTN: CENAB-EN-HM
10 South Howard Street
Baltimore, MD 21201

bc: Administrative File
J. McKenna, ACO Staff
P. W. Holt
J. J. Redder
Env. File

Coordination: J McKenna
J. McKenna
PW Holt for
M. A. Miano

07-815-154
JMcKenna

Concerning the following:

Work Plan Addendum 022
Site Screening Process at Solid Waste Management Unit 45
July 2007
Radford Army Ammunition Plant

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fines and imprisonment for knowing violations.

SIGNATURE:	
PRINTED NAME:	Jon K. Drushal
TITLE:	Lieutenant Colonel, US Army Commanding

SIGNATURE:	
PRINTED NAME:	Kent Holiday
TITLE:	Vice President and General Manager ATK Energetics Systems Division

07-815-154
JMcKenna

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

WORK PLAN ADDENDUM 022
Site Screening Process at Solid Waste Management Unit 45

FINAL
DECEMBER 2007

PREPARED BY:

URS

5540 Falmouth Street, Suite 201
Richmond, Virginia 23230
(804) 965-9000 main
(804) 965-9764 fax
CONTRACT NO. W9128F-04D-000
DELIVERY ORDER NO. DO-DA01

PREFACE

A two-stage approach has been developed to facilitate and streamline Resource Conservation and Recovery Act (RCRA) site investigations at Radford Army Ammunition Plant (RFAAP) pursuant to the Permit for Corrective Action and Waste Minimization (October, 2000). The approach consists of a single facility-wide Master Work Plan and multiple site-specific Work Plan Addenda.

The Master Work Plan provides comprehensive discussions of standard procedures, protocol, and methodologies that are to be followed during execution of field investigations at RCRA sites within the RFAAP. The Master Work Plan is a generic plan designed to streamline site-specific Work Plan Addenda development, review, and approval.

Each Work Plan Addendum describes the site-specific information for each RCRA site, providing detailed data on past site operations, potential chemicals of concern, sampling strategy, etc. Each addendum, through reference to the Master Work Plan, is developed as a concise document, focused on site-specific investigations.

THIS PAGE LEFT INTENTIONALLY BLANK

MASTER WORK PLAN ADDENDUM 022
RCRA SITE SCREENING PROCESS INVESTIGATION AT SWMU 45

TABLE OF CONTENTS

Section ***Page***

MASTER WORK PLAN ADDENDUM 022
RCRA SITE SCREENING PROCESS INVESTIGATION AT SWMU 45

TABLE OF CONTENTS
(CONTINUED)

MASTER WORK PLAN ADDENDUM 022
RCRA SITE SCREENING PROCESS INVESTIGATION AT SWMU 45

TABLE OF CONTENTS
(CONTINUED)

LIST OF FIGURES

LIST OF TABLES

MASTER WORK PLAN ADDENDUM 022
RCRA SITE SCREENING PROCESS INVESTIGATION AT SWMU 45

TABLE OF CONTENTS
(CONTINUED)

LIST OF APPENDICES

LIST OF ABBREVIATIONS AND ACRONYMS

ºC	Degrees Celsius
%	Percent
AES	Atomic Emission Spectroscopy
AOC	Area of Concern
ASTM	ASTM International
bgs	Below Ground Surface
BTAG	Biological Technical Assistance Group
$CaSO_4$	Calcium Sulfate
CFR	Code of Federal Regulations
CL	Sandy Clay
CLP	Contract Laboratory Program
cm/sec	Centimeter per second
CMS	Corrective Measures Study
CN	Cyanide
CNCl	Cyanogen Chloride
COD	Chemical Oxygen Demand
COPC	Chemical of Potential Concern
COPEC	Chemical of Potential Ecological Concern
COR	Contracting Officer’s Representative
CSM	Conceptual Site Model
DAF	Dilution Attenuation Factor
dBA	Decibels on the A-Weighted Scale
DOD	Department of Defense
DQO	Data Quality Objective
DNT	Dinitrotoluene
ECD	Electron Capture Detector
ELCD	Electrolytic Conductivity Detector
EPIC	Environmental Photographic Interpretation Center
ERIS	Environmental Restoration Information System
ESI	Electrospray Ionization
ft	Feet
ft/ft	Feet per foot
g	Gram
GC	Gas Chromatography
GM	Silty Gravel
GP	Gravel with Silt
GPS	Global Positioning System
HAZCOM	Hazard Communication
HBN	Health-Based Number
HCN	Hydrocyanic Acid
HHRA	Human Health Risk Assessment
HMX	Cyclo-1,3,5,7-tetramethylene 2,4,6,8-tetranitramine; Octogen
HPLC	High Performance Liquid Chromatography
HQ	Hazard Quotient
HSP	Health and Safety Plan
HSPA	Health and Safety Plan Addendum

LIST OF ABBREVIATIONS AND ACRONYMS
(CONTINUED)

HTRW	Hazardous, Toxic, and Radioactive Waste
I-RBC	Industrial Risk-Based Concentration
ICP	Inductively Coupled Plasma
ICP-MS	Inductively Coupled Plasma-Mass Spectrometry
IDM	Investigation-Derived Material
m/z	Mass-to-charge
MCL	Maximum Contaminant Level
MDC	Maximum Detected Concentration
MDL	Method Detection Limit
µL	Microliter
µm	Micrometer
mL	Milliliter
MHSP	Master Health and Safety Plan
mm	Millimeter
MMA	Main Manufacturing Area
MQAP	Master Quality Assurance Plan
MS	Mass Spectrometer
MS/MS	Tandem Mass Spectrometry
MS/MSD	Matrix Spike/Matrix Spike Duplicate
MSDS	Material Safety Data Sheet
msl	Mean Sea Level
MWP	Master Work Plan
NELAP	National Environmental Laboratory Accreditation Program
NFA	No Further Action
nm	Nanometer
OSHA	Occupational Safety and Health Administration
PAH	Polynuclear Aromatic Hydrocarbon
PCB	Polychlorinated Biphenyl
PETN	Pentaerythritol Tetranitrate
PID	Photoionization Detector
PM	Project Manager
ppb	Parts Per Billion
PPE	Personal Protective Equipment
ppm	Parts Per Million
ppq	Parts Per Quadrillion
PVC	Polyvinyl Chloride
QA	Quality Assurance
QC	Quality Control
QA/QC	Quality Assurance/Quality Control
QAP	Quality Assurance Plan
QAPA	Quality Assurance Plan Addendum
QSM	Quality Systems Manual
R	Rinse Blank
R-RBC	Residential Risk-Based Concentration
RBC	Risk-Based Concentration

LIST OF ABBREVIATIONS AND ACRONYMS
(CONTINUED)

RCRA	Resource Conservation and Recovery Act
RFA	RCRA Facility Assessment
RFAAP	Radford Army Ammunition Plant
RL	Reporting Limit
SB	Soil Boring
SD	Sediment
SHSO	Site Health and Safety Officer
SLERA	Screening Level Ecological Risk Assessment
SM	Silty Sand
SOP	Standard Operating Procedure
SOW	Statement of Work
SSL	Soil Screening Level
SSP	Site Screening Process
SVOC	Semi-volatile Organic Compound
SW	Surface Water
SWMU	Solid Waste Management Unit
T	Trip Blank
T-RBC	Tap Water Risk-Based Concentration
TAL	Target Analyte List
TCL	Target Compound List
TCLP	Toxicity Characteristic Leaching Procedure
TOC	Total Organic Carbon
TWA	Time Weighted Average
UCL	Upper Confidence Limit
UPL	Upper Prediction Limit
URS	URS Group, Inc.
USACE	United States Army Corps of Engineers
USATHAMA	United States Army Toxic and Hazardous Material Agency
USEPA	United States Environmental Protection Agency
UV	Ultraviolet
VDEQ	Virginia Department of Environmental Quality
VI	Verification Investigation
VOC	Volatile Organic Compound
VPDES	Virginia Pollution Discharge Elimination System
WPA	Work Plan Addendum

LIST OF ABBREVIATIONS AND ACRONYMS (CONTINUED)

THIS PAGE LEFT INTENTIONALLY BLANK

1.0 WORK PLAN ADDENDUM

In accordance with Contract Number W9128F-04D-000, Delivery Order DA01, URS Group, Inc. (URS) has been tasked by the United States Army Corps of Engineers (USACE), Baltimore District to perform a Resource Conservation and Recovery Act (RCRA) Site Screening Process (SSP) Investigation at Solid Waste Management Unit (SWMU) 45, Landfill No. 3, (the site) located in the Main Manufacturing Area (MMA) at the Radford Army Ammunition Plant (RFAAP), Radford, Virginia (Figure 1-1). The SSP Work Plan for this SWMU is presented as Work Plan Addendum (WPA) 022 to, and incorporates by reference, the elements of the RFAAP Master Work Plan (MWP) (URS 2003).

1.1 INTRODUCTION

The objectives of the SSP are to assess: 1) whether releases of hazardous substances, pollutants, contaminants, hazardous wastes, or hazardous constituents have occurred to the environment at the site, and 2) whether further investigation or action (i.e., risk assessment, RCRA Facility Investigation, interim action), or no further action (NFA) is appropriate at the site (USEPA 2001).

The SSP consists of the following steps (USEPA 2001):

- Performance of a desktop audit and site visit to develop the scope of the SSP Work Plan;
- Preparation of a SSP site-specific Work Plan;
- Performance of the field work in accordance with the approved SSP Work Plan;
- Evaluation of the SSP data and completion of pre-remedial risk screening; and
- Assessment of the need for further investigation, interim removal action, or preparation of a “No Further Action” Decision Document, per the RCRA Corrective Action permit based on the results of the SSP and risk screening.

The SSP risk screening for human health is comprised of the following five steps:

- Identification of chemicals of potential concern (COPCs) and cumulative risk screening;
- Chemical specific screening for lead and iron;
- Comparison to soil screening levels (SSLs) for the soil-to-groundwater migration pathway;
- Comparison to applicable relevant and appropriate requirements (ARARs); and
- Comparison to RFAAP background point estimates for metals.

Ecological risk screening for the SSP is comprised of the following elements: site reconnaissance, screening-level problem formulation, exposure assessment, ecological effects assessment, and risk calculation. The findings of this ecological risk screen are used as input to risk management decision-making for the site. The scientific/management decision point (SMDP) reached from the ecological risk screening concludes that one of the following statements is true:

- There is adequate information to conclude that ecological risks are negligible and therefore there is no need for further action at the SSA on the basis of ecological risk;
- The information is not adequate to make a decision at this point and further refinement of data is needed to augment the ecological risk screening; or

- The information collected and presented indicates that a more thorough assessment is warranted.

The proposed SSP field program is designed to meet the above project objectives. A geophysical survey has been conducted at the site as part of the work plan to assist in the delineation of the horizontal and vertical extent of landfill waste material and provide data on subsurface conditions at the site to guide SSP investigations.

This site-specific WPA provides the rationale and methods for planned field activities at SWMU 45 in support of the SSP investigation. Consistent with the MWP, this addendum is composed of the following sections:

- Section 1, WPA;
- Section 2, Quality Assurance Plan (QAP) Addendum (QAPA);
- Section 3, Health and Safety Plan (HSP) Addendum (HSPA); and
- Section 4, References.

This WPA references sections and Standard Operating Procedures (SOPs) contained in the MWP for the investigation at SWMU 45. Relevant SOPs are included in Appendix A of this WPA. The MWP will be kept on the site and referenced during field activities.

Table 1-1 lists the specific MWP investigative activities planned. The investigative activities performed as part of this WPA will be conducted in accordance with the MWP and the SOPs contained therein and included herein as Appendix A.

Changes to the approved WPA will be documented using the Work Plan Revision Form (Form E-1; Appendix E). Revisions must be reviewed and approved by the USACE Contracting Officer’s Representative (COR) and the RFAAP designee prior to implementation. Project personnel will be required to read this WPA and to sign and date a Worker Acknowledgement Form (Form E-2; Appendix E). The Site Health and Safety Officer (SHSO) will retain this form on the site during investigative activities. Appropriate health and safety precautions will be taken due to the potential for exposure to or handling of hazardous materials, energetics, and/or their degradation compounds.

Table 1-1

Applicable MWP Activities and Related SOPs

Subject	MWP Section	SOPs MWP Appendix A and Appendix A to WPA 022	
Installation Description	2.0		Not Applicable
Environmental Setting	3.0		Not Applicable
Documentation	4.3	10.1 10.2 10.3 10.4	Field Logbook Surface Water, Groundwater, and Soil/Sediment Field Logbooks Boring Logs Chain-of-Custody Form
Sample Management	5.1	50.1 50.2	Sample Labels Sample Packaging
Decontamination Requirements	5.12	80.1	Decontamination
Investigation-Derived Material	5.13	30.6 70.1	Containerized Material Investigation-Derived Material
Subsurface Investigation	5.2	20.1 20.2 20.3 20.4 20.7 20.8 20.11 30.1 30.2 30.7 30.9 40.1 40.2 90.1	Monitoring Well Installation Monitoring Well Development Well and Boring Abandonment Test Pits Resistivity and Electromagnetic Surveys Magnetic and Metal Detection Surveys Drilling Methods and Procedures Soil Sampling Groundwater Sampling Sampling Strategies Collection of Soil Samples by USEPA SW-846 Test Method 5035 for Volatile Organic Compounds Using Disposable Samplers Multi-parameter Water Quality Monitoring Instrument Water Level and Well Depth Measurements Photoionization Detector (HNu Model PI-101 and HW-101)
Drum Sampling	5.7	30.6	Containerized Material

THIS PAGE LEFT INTENTIONALLY BLANK

1.2 SITE BACKGROUND – ENVIRONMENTAL SETTING

1.2.1 Physiography

SWMU 45 comprises an approximate 3.4-acre study area located in the northwest section of the MMA at RFAAP (Figure 1-1) on the alluvial terrace south of the New River and east of calcium sulfate drying bed/disposal areas (SWMU 38 and area of concern [AOC] Q). The site is situated at approximately 1,700 to 1,710 feet (ft) above mean sea level (msl) and slopes slightly toward the north and the New River. SWMU 45 is topographically lower than areas to the south and topographically higher than areas to the north, east, and west (Figure 1-2). The RFAAP Installation perimeter fence is located between the site and the New River located approximately 200 ft north of the site. The land north of fence slopes steeply down to the New River, which is approximately 24 ft lower than SWMU 45.

The immediate SWMU 45 area consists of a pine plantation community with nearly complete vegetative cover. The area is characterized by tall stands of loblolly pine with understory species including wingstem, boxelder, foxtail, deer tongue, and immature sycamore. A security buffer zone approximately 40 ft wide is periodically cleared of tall vegetation (bush-hogged approximately once per year) inside the fence adjacent to the site. A site photographic log is included in Appendix B.

1.2.2 Tanks and Structures

Tanks or structures are not located in or near SWMU 45.

1.2.3 Surface Water

Based on topography, overland storm water flow that originates upgradient from the south will flow to the northeast through a well-defined drainage pathway along the railroad tracks separating the site from the main road. This storm water flows approximately 600 ft and discharges to the New River. The site is located within the 100-year floodplain of the New River (US HUD 1978).

Grading during construction of the Installation perimeter fence has created a slight topographic rise at the fence line that diverts storm water flows toward the northeast and southwest at the site. Storm water and precipitation will tend to infiltrate rather than runoff the site due to the areas flat topography, heavy vegetation, and a thick layer of organic matter on the ground surface. Although an approximate six foot wide, 15 foot long, and two foot deep area of standing water was observed during the geophysical investigation (see Section 1.4.4), the water accumulation was likely the result of recent precipitation events. This depression area was likely the result of a previous test excavation conducted in the landfill area based on vegetative covered soil piles observed in adjacent areas.

The New River flows northeast approximately 200 ft north-northwest of the site. Other surface water bodies, drainage ditches, manholes, catch basins, or flow paths do not appear to be present in the immediate SWMU 45 area.

1.2.4 Soil and Geology

SWMU 45 is underlain by Unison-Urban Land complex soil. This soil has moderate permeability and medium-to-strong acidity (IT 2001). Soil classification is not practical in urban land areas because the original soil has been physically altered or obscured. A typical profile of undisturbed Unison soil consists of a 15-inch thick surface layer of dark brown loam and a 43-inch thick subsoil of yellowish-red, sticky plastic clay underlain by a red sandy clay loam to a depth of 58 inches. In general, permeability is moderate in Unison soil, natural fertility is low, and organic matter content is low to moderate. *In situ* soil pH measurements of surface soil taken during a URS site reconnaissance in 2005 indicated nearly neutral pH of 6.6 to 6.7.

Subsurface conditions at the site were investigated as part of a facility-wide RCRA Verification Investigation (VI) conducted by Dames & Moore in 1991 and 1992. Three soil borings were completed for monitoring well installations (45MW1, 45MW2, and 45MW3) at the locations shown on Figure 1-2. Physical soil data for three soil samples collected from these borings are summarized in the following table.

Summary of VI Physical Soil Data (Dames & Moore, 1992)

Sample No.	Sample Depth (ft bgs)	Moisture (%)	Grain Size Distribution			Atterberg Limits (LL/PI)	USCS Classification
			Gravel (%)	Sand (%)	Fines (%)		
45MW1	10-12	13.6	6.2	69.4	24.4	Non plastic	SM
45MW2	5.5-6	9.2	0.0	89.7	10.3	Non plastic	SP-SM
45MW3	26-27	29.7	26.7	28.4	44.9	34/14	SC

Notes:
SM = silty sand, SP = poorly graded sand, SC = clayey sand.

Soil boring logs for 45MW1, 45MW2, and 45MW3 are included in Appendix C. Subsurface conditions encountered in the borings consisted of unconsolidated alluvial deposits, which generally become coarser with depth. Soil types encountered in the borings were primarily silty sand (SM) with sandy silt (ML) in surface soil, and silty sand/clayey sand with gravel (SM/SC) at depth. Boring 45MW2 was terminated at 26 ft bgs on top of bedrock. Bedrock was not encountered in the other two borings completed at the site. Carbonate bedrock of the Cambrian Elbrook Formation underlies the unconsolidated alluvial deposits at the site.

1.2.5 Groundwater

Three groundwater monitoring wells (45MW1, 45MW2, and 45MW3) were installed at the site in 1991 as part of a RCRA Verification Investigation (VI) conducted by Dames & Moore (Figure 1-2). Monitoring well construction data from the VI are summarized in the following table. The results of the VI indicated that an unconfined aquifer is present within unconsolidated alluvium above bedrock; groundwater is also present in underlying bedrock. Groundwater depths ranged from 18 to 23 ft bgs. The overall direction of groundwater flow in the alluvial floodplain is northward toward the New River.

VI - Monitoring Well Data (Dames & Moore, 1992)

Well	Total Depth (ft bgs)	Screened Interval (ft bgs)	Ground Surface Elevation (ft msl)	TOC Elevation (ft msl)	Depth to Water (ft from TOC)	Water Elevation (ft msl)	Geologic Unit Monitored
45MW1	27.5	17.3-27.3	1707.53	1709.70	25.00	1684.70	Alluvium
45MW2	24.8	14.8-24.8	1703.74	1706.17	21.21	1684.96	Alluvium
45MW3	30.0	20.0-30.0	1704.14	1706.52	21.42	1685.10	Alluvium

1.3 SITE BACKGROUND – HISTORY

A United States Environmental Protection Agency (USEPA) RCRA Facility Assessment (RFA) conducted at RFAAP identified SWMU 45, an inactive landfill (Landfill No. 3), as having the potential to release contaminants into the environment (USEPA 1987). The RFA described this landfill as having operated in the 1970s. Another report (USATHAMA 1984) described this landfill as the first known landfill at RFAAP, which operated between 1957 and 1961 (Dames & Moore 1992). The latter dates of operation appear to be more reliable based on recollections of plant personnel, the aerial photography, and apparent ages of pine trees planted after landfill operations ceased (Dames & Moore 1992).

Aerial photography from 1949 shows a cleared area with ground scarring in the area between but just south of existing site monitoring wells 45MW2 and 45MW3. An aerial photograph from 1962 does not show the ground scarring but shows a darker-tone and possibly disturbed area south of well 45MW2. An aerial photograph from 1971 did not show the 1949 or 1962 scarring patterns but did show a white-toned scarred area along the former access road approximately 100 ft north of existing site monitoring wells 45MW1.

1.4 PREVIOUS INVESTIGATIONS

1.4.1 RCRA Facility Assessment – USEPA 1987

An assessment was conducted at SWMU 45 to evaluate potential hazardous waste or hazardous chemical releases and implement corrective actions, as necessary. The assessment consisted of a preliminary review and evaluation of available site information, personnel interviews, and a visual inspection of the site. Environmental samples were not collected at SWMU 45 as part of the inspection. At the time of the RFA, the area identified by site personnel as the landfill was “indistinguishable from the surrounding area as a landfill site.” According to the RFA, the disposal unit began operation in the 1970s but was not active at the time of the visual site inspection conducted in 1986. Paper and refuse were reportedly placed in the landfill. No data indicated releases had been collected at the time of the RFA.

1.4.2 Verification Investigation – 1992

The results of a VI were reported by Dames & Moore in 1992. The objective of the VI was to evaluate whether toxic or hazardous contaminants were present and had the potential of migrating beyond the boundaries of the identified SWMUs (Dames & Moore 1992a).” The VI included a geophysical survey of an approximate 5-acre study area, and installation and sampling of three groundwater monitoring wells as described below.

Geophysical Survey

A geophysical survey was conducted in the SWMU 45 area as part of the VI to better delineate landfill and disposal boundaries at the site. The survey was conducted over the approximate 3.6-acre area shown on Figure 1-3. The reconnaissance-level geophysics survey was conducted using the EM-31 in conductivity mode and a proton magnetometer. For the initial survey, measurements were collected at intervals of 10 ft along seven parallel north-south lines placed 100 ft apart. The survey covered an area of 250 by 600 ft (Figure 1-3). Additional data were collected at intervals of 10 ft from line 2+00 East to 4+00 East and at intervals of five feet from 5+80 East to 6+20 East due to anomalous features detected that warranted further investigation. Figure 1-3 shows the summary interpretation of the geophysical data included in the Dames & Moore VI Report (1992) including three potential burial areas and a potential metallic object anomaly.

<u>Monitoring Well Installation and Groundwater Sampling</u>

Three groundwater monitoring wells were installed at the site to evaluate potential releases to groundwater from the identified landfill area including one upgradient well (45MW1) and two downgradient wells (45MW2 and 45MW3). These monitoring wells were installed to monitor the uppermost zone of groundwater present within unconsolidated alluvium.

Groundwater samples were collected site monitoring wells in November 1991 for analysis of volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), TCL explosives, Target Analyte List (TAL) metals, total organic carbon (TOC), total organic halogens (TOX), and pH. Sample results are summarized in Table 1-2 and compared to current EPA Region III adjusted tap water risk-based concentrations (T-RBCs). Bis(2-chloroethyl)ether and manganese were detected in the sample collected from downgradient well 45MW3 at concentrations above their adjusted T-RBCs. Manganese was also detected in the upgradient well 45MW1 sample at a concentration above its adjusted T-RBC.

1.4.3 Installation Assessment – EPIC Aerial Photographic Analysis – USEPA 1992

The Environmental Photographic Interpretation Center (EPIC), through the USEPA and U.S. Army Toxic and Hazardous Material Agency (USATHAMA), provided aerial photographic analysis of 42 known SWMUs at RFAAP (USEPA 1992). Aerial photographs from 1937 through 1986 were analyzed to identify features that may have represented sources of potential groundwater or surface water contamination at RFAAP.

Activity at SWMU 45 was first noted in aerial photography at this site in 1949, which included substantial clearing, possible fill activity, light-toned mounded material, and staining (USEPA 1992 and Figure 1-4). The site appeared to have been enlarged by clearing between 1949 and 1954 with access roads and open storage of containers visible in 1954; however, most of the site appeared to be in the early stages of revegetation (USEPA 1992). Additionally, a small area of possible liquid was reported visible near the containers seen in the 1954 photograph (USEPA 1992). The 1954 aerial photograph referenced in the report is not available, however the interpreted information referenced in the report text for 1954 is available on the EPIC markup of the photograph from 1962 (Figure 1-5). By 1962, the site appeared to be revegetating and evidence of mounded material and staining was absent (USEPA 1992 and Figure 1-5). In 1966, a possible trench and a dark-toned material were visible in the photograph (USEPA 1992). The 1966 aerial photograph referenced in the report is not available, however the interpreted information referenced in the report text for 1966 is available on the EPIC markup of the photograph from 1971 (Figure 1-6). By 1971, most of the area was revegetating except for a small ground scarred area (USEPA 1992 and Figure 1-6). By 1975, the site appears to be revegetated except for a small ground scarred (Figure 1-7). By 1986, the site appeared to be inactive and revegetating (USEPA 1992 and Figures 1-7 and 1-8).

1.4.4 Geophysical Investigation – 2007

As a part of this WPA, a geophysical investigation of the site area was conducted in April 2007 by ATS International, Inc. (ATS) under URS oversight. The scope of investigations is described in detail in the EPA and VDEQ approved geophysical investigation plan included in Appendix D.1. The investigation was performed once a 325 ft by 800 ft survey grid was placed at the site shown on Figure 1-9. There were three main elements of the geophysical investigation:

- Using electromagnetic induction (EM) to delineate the horizontal extent of fill material;
- Using two-dimensional electrical resistivity imaging (2D-ERI) to assess the vertical extent of fill material, assess the potential for leachate migration, and confirm the horizontal extent of fill material delineated by the EM survey; and
- Completing five targeted spectral analysis of surface waves (SASW) to corroborate the vertical extent of fill material and assess the depth to bedrock beneath the site;

Locations of the geophysical surveys are shown on Figure 1-9. Results of the geophysical survey were used to better delineate landfill boundaries at the site, provide data to guide the SSP investigation at the site, and confirm that existing monitoring wells 45MW1, 45MW2, and 45MW3 are appropriately positioned to detect potential releases to groundwater. A copy of the geophysical investigation report prepared by ATS is included in Appendix D.2 and a summary of their results and conclusions is presented below.

EM Survey Results

The purpose of the EM survey was to evaluate lateral changes in EM distribution that may indicate the presence of fill materials. Strong, localized contrasts in conductivity may indicate the presence of buried materials that differ from the natural materials. The quadrature component of the EM data provides apparent terrain conductivity, which is a weighted average of the conductivity through the depth of measurement beneath the instrument. High magnitude responses, either positive or negative, indicate high bulk conductivity in the materials under the instrument. The in-phase component of the EM data is the ratio of the secondary to primary magnetic field, and it is sensitive to the presence of highly conductive material such as shallow metal objects. It is generally considered the metal-detection mode of the EM investigation.

Figure 1-10 presents a contour map of quadrature component of EM data. Figure 1-11 presents a contour map of in-phase component of EM data. The quadrature component of the EM data revealed an area in the north central portion of the study area characterized by elevated conductivities relative to the majority of the site. While variations in conductivity is normal, the magnitude of observed conductivities is unlikely the result solely of variations in natural geologic conditions. In addition, although standing water was observed within a non-contiguous ditch in this portion of the site, it is unlikely that the size of the area of elevated conductivities is the result of higher groundwater saturation from the standing water. This zone of high conductivity in the north-central part of the surveyed area, northwest of well 45MW1 and between wells 45MW2 and 45MW3 appears to be coincident with the disturbed ground at the end of the site access road in the 1949 and 1964 aerial photographs.

The distribution of the in-phase EM data component is generally consistent with that of the quadrature component. A number of small in-phase anomalies are observed in the north central portion of the site, with additional correlated anomalies in other areas. One of these anomalies, located approximately 75 ft west of 45MW1, appeared to be coincident with an observed piece of sheet metal at the ground surface.

2D-ERI Survey Results

The resistivity imaging survey was conducted to collect cross-sectional resistivity data over areas of anomalous EM to delineate the vertical extent of potential fill materials. Figure 1-12 provides locations of electrodes for the five resistivity lines superimposed over the contour map of the quadrature component of the EM data. Figure 1-13 provides interpreted pseudo-section results for the five resistivity lines. The resistivity lines placed through the anomalous EM zones display low-resistivity zones in the shallow subsurface that correlate well with the lateral extents of the elevated EM zones. The low resistivity zones are generally characterized by lower values and greater depth than low resistivity features found elsewhere on the resistivity cross sections. Interpreted together, ATS concluded the EM and resistivity data suggest the presence of fill materials that may be as deep as 20 ft in some places.

SASW Survey Results

The purpose of the SASW survey was to corroborate the depth to bedrock and vertical extent of potential fill materials in the event that leachate was present beneath the fill that masked the vertical boundary with the natural materials. The SASW results are not of themselves conclusive, but are supportive of the above interpretations. Results of SASW profiles are provided on Figure 1-14. SASW profiles, which were placed in what was interpreted by ATS to be natural materials, display a relatively abrupt change from velocities of 500 to 700 ft per second to velocities of approximately 1,700 ft per second at approximately 5 to 7 ft in depth. Those SASW profiles placed in the shallow low-resistivity zones, interpreted to be potential fill materials, generally display low velocities to depths of 18 to 20 ft below grade where they increase suddenly to greater than 2,000 ft per second.

Investigation Uncertainties

It was noted by ATS that there are uncertainties associated with interpretations of the geophysical data. For example, the resistivity results from Line 3 are very similar to those of Line 2, but Line 3 is not mapped as passing through the zone of elevated EM. However, ATS noted these results are consistent with other studies they have conducted using these methodologies to map the lateral and vertical extent of fill. ATS also noted that it is generally not feasible, based on geophysical results, to determine the type of materials comprising the interpreted fill. Fill from displaced natural materials can display similar EM and resistivity signatures to those of municipal waste. However, ATS noted that there is no substantial evidence of leachate present at the site.

Post Survey Reconnaissance

URS completed a brief reconnaissance at the site after the geophysical survey was completed. Five of the anomalies identified in the EM survey were selected for further investigation to confirm the geophysical survey results and provide data to guide the follow-up SSP investigations at the site. Figure 1-15 depicts the five geophysical anomalies areas targeted for the reconnaissance. URS dug holes of varying depths and widths using a shovel.

Metal debris was identified at anomalies 1, 2, and 4. The debris included metal parts tags, pipes, pipe fittings, springs and bars as well as several unknown items. This debris was within 0 to 1 ft bgs, however, it appeared that more debris could have been uncovered if the excavations were expanded. Anomaly 1 could only be excavated to 1 ft depth due to hitting a hard cement-like layer. On review of the field information, the hard, dark colored heavy material observed at anomalies 1 and 3 may be slag material.

Clayey soil was encountered at anomalies 3 and 5, but no other materials or debris. While two distinct layers of soil were observed at anomaly 3, it was on a mound approximately 3 ft above a surrounding gulley so it may not have been dug deep enough to uncover any debris.

Other types of solid waste such as paper, cans, bottles, or plastic were not observed during the reconnaissance. The observations confirm metallic debris fill material at the locations identified in the EM survey. A photographic log of the further investigation of the five anomalies identified during the geophysical survey are provided in Appendix D.3.

1.5 CONCEPTUAL SITE MODEL (CSM)

1.5.1 Contaminant Sources

SWMU 45 is an inactive landfill area. Paper and municipal refuse were the only materials reportedly disposed of in SWMU 45. A thin layer of landfill material (small rubber pieces and paper) was encountered from 1 to 3 ft bgs in VI boring 45MW3. Metallic debris was observed at various locations in surface or near surface soil in the landfill area, where geophysical anomalies were identified in the 2007 geophysical survey.

1.5.2 Mechanisms of Contaminant Release

The site is located on an alluvial terrace approximately 200 ft south of the New River. Surface water bodies, drainage ditches, manholes, catch basins, or preferred drainage paths or features are not present at the site. Storm water is expected to infiltrate rather than runoff the site due to the site’s nearly flat topography, heavy vegetation, and a thick layer of organic matter in surface soil.

Groundwater is present at the site within unconsolidated alluvium and underlying bedrock at depths of approximately 18 to 23 ft bgs. The overall direction of groundwater flow in the alluvial floodplain is northward toward the New River. While site groundwater discharge may be hydraulically connected to the New River, the completeness of this pathway is unknown. If site-related groundwater impacts are identified, an assessment of the potential impacts to the New River will be conducted via screening the groundwater data for COPCs against Virginia Water Quality Criteria and EPA Region III freshwater ecological screening values. If the screening indicates potential impacts to the New River at levels of concern, additional investigation of the nature and extent of impact to groundwater and/or the New River may be necessary. Potentially affected media at the site include:

- Surface and subsurface soil via disposal of landfill material and debris;
- Subsurface soil via leaching of chemicals;
- Groundwater via leaching of chemicals; and
- Offsite surface water and sediment of the New River via groundwater discharge.

A CSM for SWMU 45 is presented on Figure 1-16.

1.5.3 Exposure Pathways

1.5.3.1 Human Receptors/Pathways

Although current and likely future land-use scenarios are limited to industrial operations, both residential and industrial scenarios will be evaluated in the SSP human health screening (USEPA 2001).

1.5.3.2 Ecological Receptors/Pathways

SWMU 45 is exclusively an upland habitat that lack wetland and significant drainage features. Therefore, soil represents the potential exposure medium for ecological receptors. A photographic log for the site is provided in Appendix B. Receptor categories and the species selected to represent the wildlife categories include: plant communities, soil invertebrate/microbial communities, omnivorous birds: American Robin (*Turdus migratorius*), carnivorous birds: Red-Tailed Hawk (*Buteo jamaicensis*), herbivorous animals: Meadow Vole (*Microtus pennsylvanicus*), omnivorous mammals: Red Fox (*Vulpes vulpes*); and carnivorous mammals: Short-Tailed Shrew (*Blarina brevicauda*). Refer to Table 1-3 for wildlife receptor profiles.

1.6 DATA GAP ANALYSIS

Data gaps identified for the SSP investigation are discussed in the following sections.

1.6.1 Landfill Area

Potential disposal and fill areas have been identified at the site by completion of geophysical surveys. Metallic objects and/or debris have been observed at the surface or near surface in several of the identified geophysical anomaly areas. During installation of 45MW3 as part of the VI, a thin layer of landfill material (small rubber pieces and paper was encountered from 1 to 3 ft bgs.

Further investigation of the identified potential fill areas is required to assess the nature of soil cover, fill material, and disposal. The following areas require further investigation:

- The apparent fill area between monitoring wells 45MW1, 45MW2, and 45MW3 (geophysical anomalies No. 2, 3, and 4 on Figure 1-15);
- Geophysical anomaly No. 1 located approximately 75 ft west of monitoring well 45MW1 (Figure 1-15); and
- Geophysical anomaly No. 5 located in the eastern part of the study area (Figure 1-15).

A combination of test pits and soil borings will be used to fill the identified data gaps as described in Section 1.7.1.

1.6.2 Soil

Soil chemical data has not been collected to evaluate potential commingling of waste with soil cover or potential releases to subsurface soil. Soil samples will be collected from surface soil and subsurface soil for analysis of a full suite of chemicals to fill the identified data gaps, as described in Section 1.7.2.

1.6.3 Groundwater

Three groundwater monitoring wells were installed at the site in 1991 to evaluate potential releases to groundwater in the landfill area. Groundwater samples have not been collected from the site since initial sampling of the monitoring wells in November 1991. In addition, groundwater samples were not analyzed for a full suite of chemicals during this sampling event. Also, there is a data gap for evaluating groundwater releases in the northeastern part of the site in the area of geophysical anomalies 4 and 5 (Figure 1-15). The lack of recent groundwater data, limited analytical parameters for groundwater, and the lack of a monitoring well in the northeastern part of the site represent data gaps. Installation of an additional well (45MW4) and a round of groundwater sampling for existing and newly installed wells will be conducted at the site for a full suite of chemicals to evaluate for potential releases and fill the identified data gaps, as described in Section 1.7.3.

1.6.4 Other

Limited physical testing of soil has been conducted for subsurface soil at SWMU 45, and therefore, physical testing of four representative soil samples is proposed to characterize physical and geotechnical properties of site soil, as described in Section 1.7.2.1.

Although standing water observed during the geophysical investigation in an approximate six foot wide, 15 foot long, and two foot deep area, the water accumulation was likely the result of recent precipitation events. Sampling of this water for the SSP is not warranted given that it is not a surface water body draining the site and collection of a surface water sample from this area will not provide meaningful information to characterize releases to soil and groundwater at the site.

1.6.5 Summary of Data Gaps

The data gap analysis completed for SWMU 45 identified data gaps for fill/landfill material, soil, groundwater, and site-wide soil characteristics as summarized in the following table. This table also summarizes the completion plan to fill the identified data gaps.

SWMU 45 - Summary of Data Gap Analysis and Completion Plan

DATA GAPS			COMPLETION PLAN
Item	**Physical**	**Chemical**	
Nature of Fill Material and Landfill Area	Test Pits and Soil Borings	See Soil Below.	Complete test pits and soil borings in identified potential fill areas
Soil	Surface Soil Samples	Chemical Data – VOCs, SVOCs, polychlorinated biphenyl (PCBs), pesticides, explosives, dioxin/furans*, metals, cyanide	Collect surface soil samples for chemical analysis in fill/landfill areas
	Subsurface Soil Samples	Chemical Data – VOCs, SVOCs, PCBs, pesticides, explosives, dioxin/furans*, metals, and cyanide	Collect subsurface soil samples from test pits and/or soil borings completed in fill/landfill areas for chemical analysis
Groundwater	Groundwater Samples	Chemical Data – VOCs, SVOCs, PCBs, pesticides, explosives, dioxin/furans*, perchlorate, metals, and cyanide	Sample existing groundwater monitoring wells 45MW1, 45MW2, and 45MW3. An additional well, 45MW4 will be installed and sampled.
Site-Wide Soil Characteristics	Physical / Geotechnical Properties	pH, total organic carbon, grain size, Atterberg Limits, and moisture content	Collect samples for geotechnical and physical property analysis.

Note: * If evidence of burned material (i.e., ash) is apparent at one or more test pit locations, then surface soil and subsurface soil samples from up to two locations and groundwater will be submitted for analysis of TCL dioxin/furans by SW-846 Method 8290.

1.7 PLANNED FIELD ACTIVITIES

The SWMU 45 SSP field program is designed to address the data gaps identified in Section 1.6 and meet the SSP objectives identified in Section 1.1. The selection of the investigation areas and soil sample locations followed SOP 30.7 (Sampling Strategies, included in Appendix A) using a combination of biased and systematic sampling technique to identify potential releases.

The MWP is referenced where routine activities will be performed in accordance with the MWP specifications, SOPs, and the Master Health and Safety Plan (MHSP; URS 2003). Variances to the specifications are documented in this WPA. Table 1-1 identifies the MWP SOPs that will be followed as part of the SSP for field documentation, subsurface investigation, sampling, field evaluations, sample management, data management, and management of investigative derived material (IDM), decontamination, and field monitoring. Copies of the SOPs identified in Table 1-1 are included in Appendix A.

1.7.1 Test Pit Investigation and Soil Sampling

Test pits will be excavated in each of the identified potential fill/waste areas to evaluate the nature and thickness of soil cover and underlying fill and/or waste material. Figure 1-17 shows the location of the seven planned test pits (TP1 through TP7).

Test pits will be completed using a rubber tire, backhoe excavator consistent with the procedures outlined in SOP 20.4. The dimensions and depth of test pits will be dependent on the conditions encountered at each location. Test pit logs and photographic documentation will be completed for each location. Samples from the test pit will be screened for the presence of VOCs using a photoionization detector (PID). Any excess soil and waste material excavated from the test pits will be placed into appropriate containers for offsite disposal as outlined as in Section 1.7.5. Completed test pits will backfilled with clean fill material and compacted.

Two soil samples will be collected at each test pit location for chemical analysis including a surface sample (“A” sample) and subsurface sample (“B” sample). Surface soil samples will be collected from 0 to 0.5 ft bgs, with the exception of VOC samples, which will be collected from 0.5 to 1 ft bgs. Subsurface soil samples will be collected from a depth interval immediately below any waste material encountered, or from 5 ft bgs if waste or fill material is not encountered at a location to assess near surface releases. Soil samples will be submitted for chemical analysis of the following parameters:

- TCL VOCs by SW-846 Method 8260B;
- TCL SVOCs by SW-846 Method 8270C (low level);
- TCL PCBs and TCL pesticides by SW-846 Methods 8082 and 8081A;
- Explosives by SW-846 Methods 8330 and 8332; and
- TAL inorganics by SW-846 Methods 6010/6020/7471A/9012B.

In addition, if evidence of burned material (i.e., ash) is apparent at one or more test pit locations, then surface soil and subsurface soil samples from up to two locations will be submitted for analysis of TCL dioxin/furans by SW-846 Method 8290.

Soil sample analysis will be conducted consistent with the requirements of the Master Quality Assurance Plan (MQAP) and Section 2.0 of this WPA. Sample management and analytical methods are discussed in detail in Sections 2.4 and 2.5 of this WPA, respectively.

1.7.2 Direct Push Soil Borings

Sixteen direct push soil borings (SB1 through SB16) will be completed at the locations shown on Figure 1-17 to supplement the test pit data and provide additional data on the nature and extent of fill/waste areas at the site. Borings will be completed to a minimum depth of 10 ft bgs to determine if waste is present or to a depth below fill/waste material if deeper. A four-foot, Geoprobe Macro-Core® sampling device will be used to collect soil samples continuously from each of the borings, as described in SOP 20.11 in Appendix A. Soil core samples will be screened with a PID for the presence of VOCs. Borings logs will be prepared as outlined in SOP 10.3 in Appendix A.

Given that two samples are being collected from each test pit for chemical analysis, samples for chemical analysis will not be collected from borings completed in the same grid as a test pit. Borings in these areas will be used to evaluate the nature and extent of waste material through visual observations and field screening with a photoionization detector. This will reduce the number of potential boring locations where samples for chemical analysis may be collected from 16 to 10. The remaining four discretionary sample locations will be based on the conditions encountered in the 10 borings to be completed in grid areas outside of the planned test pit locations. One of the four discretionary sample locations will be located in the identified container storage area in the northwest corner of the study area to evaluate for potential releases. As a contingency, up to two sample locations (each location would include a surface and subsurface soil sample) may be selected from these 10 boring locations if significant release potentials are identified by observations of waste material and field screening.

Samples for chemical analysis will be collected at four of the soil boring locations where the potential for a release is highest (i.e., fill/waste material is encountered or elevated PID readings). A surface sample ("A" sample) and subsurface sample ("B" sample) will be collected from each of the four boring locations selected. Surface soil samples will be collected from 0 to 0.5 ft bgs, with the exception of VOC samples, which will be collected from 0.5 to 1 ft bgs. Where fill/waste material is encountered, subsurface soil samples will be collected from a depth interval immediately below the waste material. Where fill/waste material is not encountered, subsurface soil samples will be collected from the interval of the highest PID reading or from 5 ft bgs if PID readings are not elevated substantially above ambient background. Soil samples will be submitted for chemical analysis of the same parameters as the test pit samples.

Soil sample analysis will be conducted consistent with the requirements of the MQAP and Section 2.0 of this WPA. Sample management and analytical methods are discussed in detail in Sections 2.4 and 2.5 of this WPA, respectively.

1.7.2.1 Physical Soil Testing

Four representative soil samples (including surface soil and subsurface soil) will be analyzed to characterize physical and geotechnical properties of site soil as outlined in Section 2.5.4:

- Grain-size analysis (ASTM International [ASTM] D 422);
- Atterberg limits (ASTM D 4318);
- Soil moisture content (ASTM D 2216);
- Total organic carbon (Walkley-Black Method); and
- pH (ASTM D 4972).

Physical soil data will be used for qualitative soil screening evaluations as outlined in the EPA SSP document (EPA 2001) including calculation of site-specific soil screening levels for migration to groundwater, as required.

1.7.3 Groundwater Investigation and Analysis

Potential releases to groundwater at the site will be evaluated by the installation of one groundwater-monitoring wells downgradient of the SWMU and the collection of groundwater samples from the newly installed monitoring wells and existing wells 45MW1, 45MW2, and 45MW3 for chemical analysis (Figure 1-17).

1.7.3.1 Monitoring Well Installation

One groundwater monitoring well (45MW4) will be installed in the portion of the site north and downgradient anomalies 4 and 5 as shown on Figure 1-17.   The exact location of 45MW4 will be dependant on field conditions and the results of the investigation of anomalies 4 and 5.

Based on data from existing monitoring wells 45MW1, 45MW2, and 45MW3, the uppermost zone of groundwater occurs within overburden; however, if an insufficient water column is present within the overburden, then the monitoring well will be screened across the overburden and bedrock interface.

Monitoring well 45MW4 will be installed with a 15 ft long screen so that the top of the screen is above the seasonally high water table.

Air rotary drilling method will be used for installation of monitoring well 45MW4 given that well installation into bedrock may be required. A 6-inch diameter, roller bit will be used to drill within soil overburden and a 6-inch diameter, air hammer bit will be used to drill in bedrock. If unstable conditions are encountered in the borehole, then a 6-inch temporary casing will be set in the borehole to allow for boring completion and monitoring well installation. A minimum 8-inch diameter roller bit will be used in the overburden if temporary casing is required. The casing sections are fitted with auger couples to allow for incremental removal during well construction. Monitoring well 45MW4 will be constructed using 2-inch diameter (nominal), Schedule 40 polyvinyl chloride (PVC) threaded screen and riser pipe. A 0.010-inch screen slot size and No. 2 sand filter pack will be used to construct the wells. The monitoring well completion depth is expected to be approximately 30 ft bgs. A monitoring well construction diagram showing the proposed construction and materials is shown in Appendix A on Figure 20-1b.

The air rotary drilling method will be used for installation of monitoring wells given that well installation into bedrock is anticipated. A 6-inch diameter, roller bit will be used to drill within soil overburden and a 6-inch diameter, air hammer bit will be used to drill in bedrock. If unstable conditions are encountered in the borehole, then a 6-inch temporary casing will be set in the borehole to allow for boring completion and monitoring well installation. A minimum 8-inch diameter roller bit will be used in the overburden if temporary casing is required. The casing sections are fitted with auger couples to allow for incremental removal during well construction. Monitoring wells will be installed consistent with the procedures outlined in Section 5.2 of the MWP and MWP SOPs 20.1 and 20.11 (Appendix A). Split-spoon samples will be collected at 5-foot intervals for the uppermost 10 ft of each well boring and at 10-ft intervals thereafter.

1.7.3.2 Groundwater Sampling

After installation and prior to sampling, monitoring wells will be developed consistent with SOP 20.2 (Appendix A) using a combination of surging, pumping (including low flow) to remove any accumulated solids, mobile particulates, and sediment accumulated within or in the vicinity of the newly installed monitoring well from drilling. Well development will continue until stabilization criteria in Section 3.3.1 of SOP 20.2 are achieved. Existing wells 45MW1, 45MW2, and 45MW3 will be inspected to verify their suitability for collecting representative background samples, and as necessary, these wells will be redeveloped if necessary to yield samples with low turbidity.

Groundwater sampling will occur no sooner than 14 days after completion of monitoring well development to allow sufficient time for well stabilization. Groundwater sampling will be conducted following the procedures outlined in SOP 30.2 (Appendix A). A single continuous set of static water levels will be collected from site monitoring wells prior to purging and sampling. Low flow sampling will be performed according to SOP 30.2 and the latest USEPA guidance. Water quality parameters pH, temperature, specific conductance, oxidation/reduction potential, dissolved oxygen, and turbidity will be measured using an in-line flow cell (SOP 40.1 in Appendix A) during purging and immediately before sample collection to document parameter stabilization and water quality parameters.

Groundwater samples will be collected from existing site monitoring wells 45MW1, 45MW2, and 45MW3 and newly installed 45MW4 to evaluate for potential releases to groundwater in the landfill area. Groundwater samples will be analyzed for the following parameters:

- TCL VOCs by SW-846 Method 8260B;
- TCL SVOCs by SW-846 Method 8270C (low level);

- TCL PCBs and TCL pesticides by SW-846 Methods 8082 and 8081A;
- Explosives by SW-846 Methods 8330 and 8332;
- Perchlorate by SW-846 Method 6850; and
- TAL inorganics (total fraction) by SW-846 Methods 6010/6020/7470A/9012B.

Groundwater samples also will be analyzed for TCL dioxin/furans analysis by SW-846 Method 8290, if soil samples are submitted for TCL dioxin/furan analysis, as described in Section 1.7.1.

Groundwater sample analysis will be performed consistent with the methods and requirements of the MQAP and Section 2.0 of the WPA. Sample management and analytical methods are discussed in detail in Sections 2.4 and 2.5 of this WPA, respectively.

1.7.3.3 Slug Tests

Rising head and falling head slug tests will be conducted in the existing wells (45MW1, 54MW2, and 45MW3) and newly installed monitoring well (45MW4) consistent with SOP 40.3 (Appendix A) to provide estimates of the hydraulic conductivity of the screened intervals of each well. Hydraulic conductivity data, physical test data, and groundwater elevation data will be used to estimate the rate of horizontal groundwater flow in the uppermost zone of groundwater at the site.

1.7.4 Surveying

Horizontal coordinates and ground surface elevations for test pits and soil borings will be obtained using a global positioning system (GPS) unit with submeter accuracy for horizontal measurements (+1 part per and million) and vertical measurements (+ 2 parts per million for vertical measurements).

Horizontal coordinates and vertical elevations of each existing monitoring well will be resurveyed by Virginia licensed surveyor experienced working at RFAAP. Horizontal coordinates (northing and easting) will be surveyed using the North American Datum of 1983, Universal Transverse Mercator Zone 18, and vertical elevations will be surveyed using the National Geodetic Vertical Datum of 1988. At each monitoring well location, the ground surface elevation and elevation of the top of the inner well casing used for measuring water levels will be surveyed to the nearest 0.01 ft.

1.7.5 Investigation-Derived Material Handling and Disposal

Activities conducted during this investigation will comply with the relevant Occupational Safety and Health Administration (OSHA) and USEPA regulations regarding the identification, handling, and disposal of non-hazardous and hazardous investigation-derived material (IDM). Activities will be performed in accordance with the Installation safety rules, protocols, and SOP 70.1. Table 1-4 summarizes the suspected nature (hazardous versus non-hazardous) of the materials that will be generated during field investigative activities.

THIS PAGE LEFT INTENTIONALLY BLANK

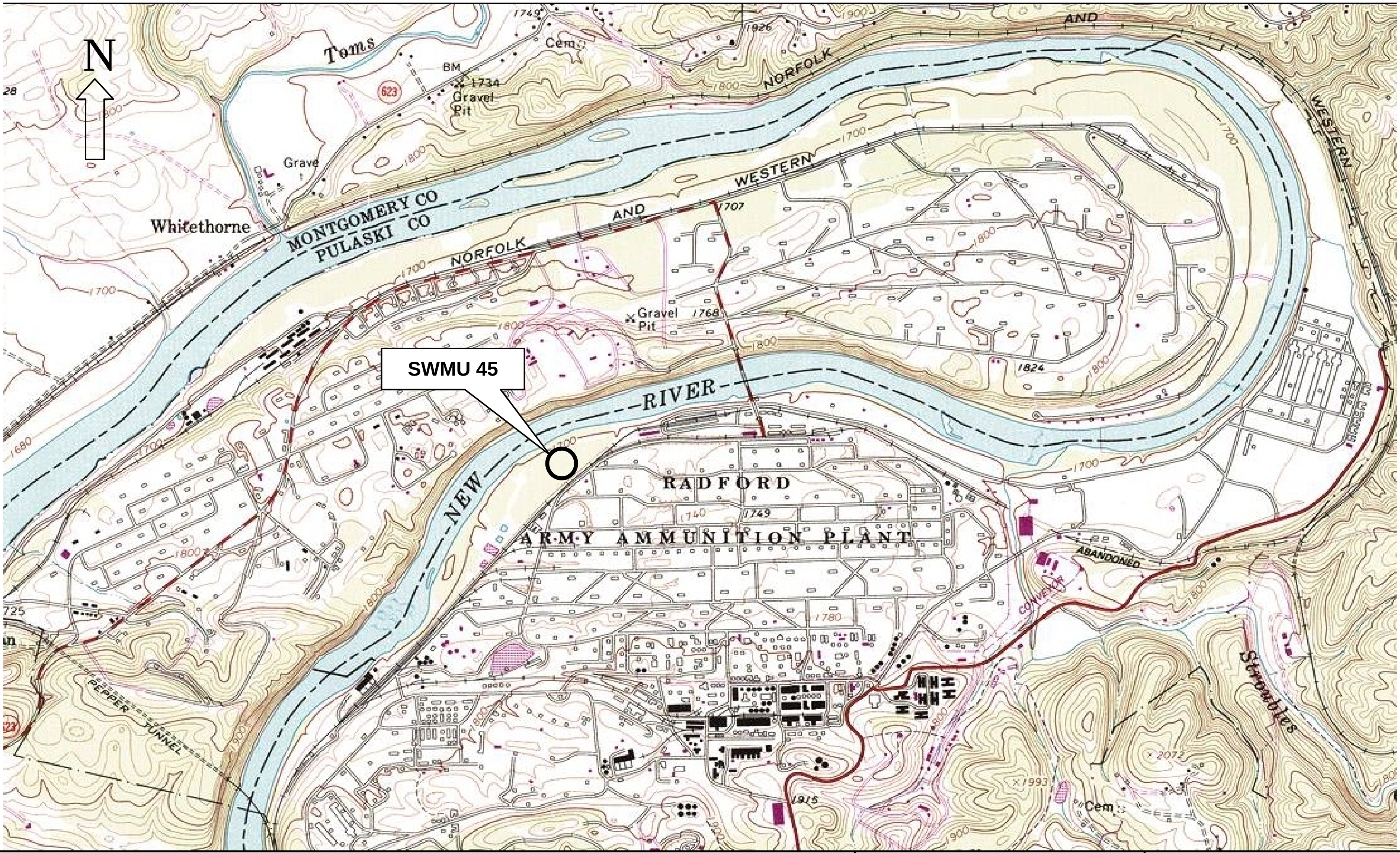


FIGURE 1-1

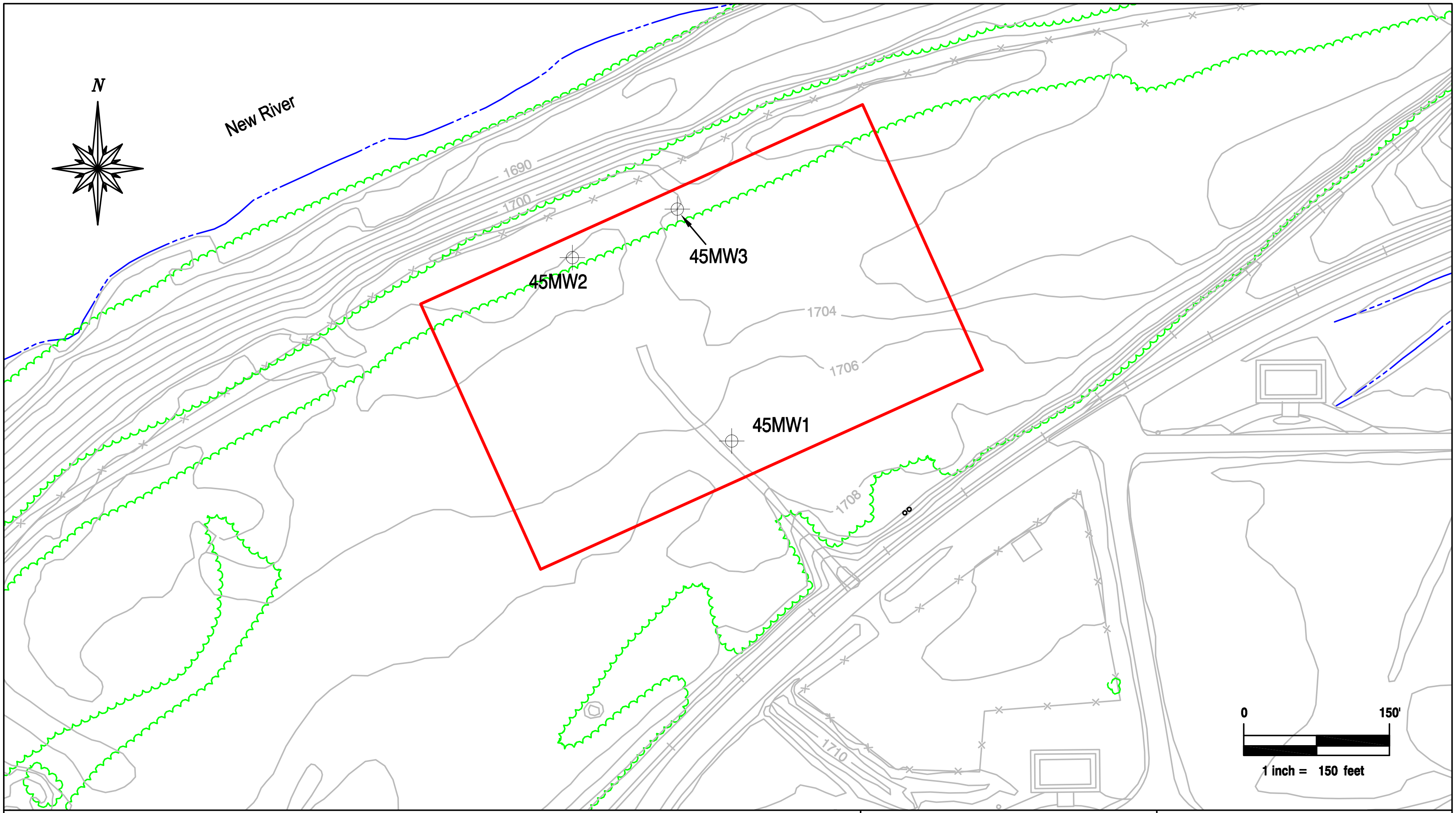
Site Location Map

MWP Addendum 022 –
SSP Investigation for SWMU 45
Radford Army Ammunition Plant
Radford, Virginia

Date: June 2007	URS Project #: 11656351
Prepared by: DBC	Approved by: JOS
Scale: *1" = 2000'*	File Name: Fig1-1 SiteLoc

URS

URS Group, Inc.
540 Falmouth Street
Suite 201
Richmond, Virginia 23230



Legend

⌖ Monitoring Well Location

— Topographic Contour

— Approximate Study Area

-x-x-x- Perimeter Fence

⌒⌒⌒ Vegetation

FIGURE 1-2

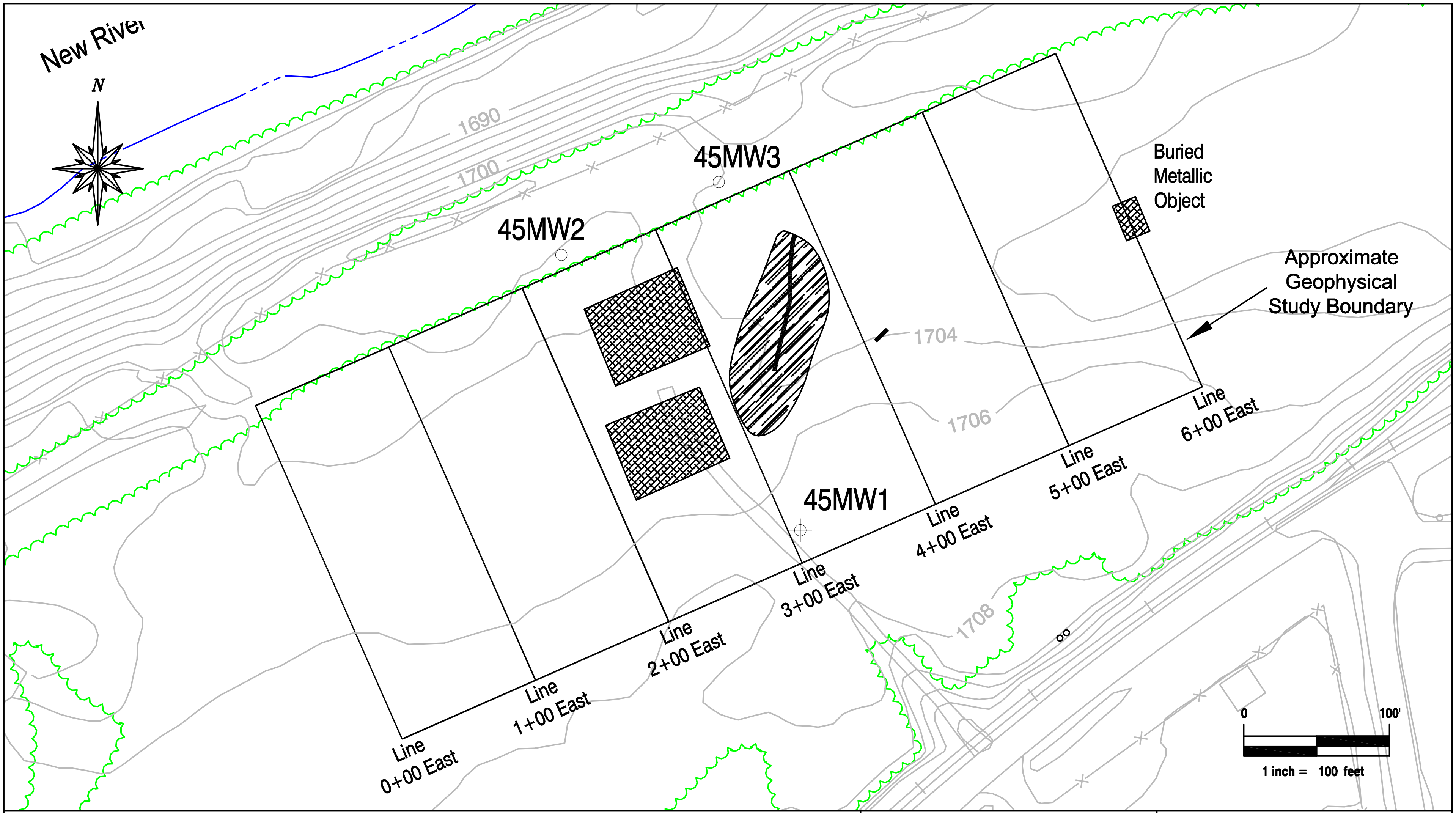
Site Topographic Map

Date: June 2007	URS Project #: 11656351
Prepared by: DBC	Approved by: JOS
Scale: 1" = 150'	File Name: Fig. 1-2 SiteTopo

MWP Addendum 022 -
SSP Investigation for SWMU 45
Radford Army Ammunition Plant
Radford, Virginia

URS

URS Group, Inc.
5540 Falmouth Street
Suite 201
Richmond, Virginia 23230



Legend

— Topographic Contour

⌖ Monitoring Well Location

▨ Non-Metallic Burial - Area B

▩ Metallic Burial - Area A

▬ Non-Contiguous Ditch

FIGURE 1-3

1992 VI Geophysical Survey Results

Date: June 2007	URS Project #: 11656351
Prepared by: DBC	Approved by: JOS
Scale: 1" = 100'	File Name: Fig. 1-3 '92 VI Geo

MWP Addendum 022 -
SSP Investigation for SWMU 45
Radford Army Ammunition Plant
Radford, Virginia

URS Group, Inc.
5540 Falmouth Street
Suite 201
Richmond, Virginia 23230

FIGURE 1-4

Aerial Photograph - 1949

Date: June 2007	URS Project #: 11656351
Prepared by: DBC	Approved by: JOS
Scale: *1" = ~265'*	File Name: Fig1-4 1949 Aerial

MWP Addendum 022 –
SSP Investigation for SWMU 45
Radford Army Ammunition Plant
Radford, Virginia

URS

URS Group, Inc.
540 Falmouth Street
Suite 201
Richmond, Virginia 23230

FIGURE 1-5

Aerial Photograph - 1962

Date: June 2007	URS Project #: 11656351
Prepared by: DBC	Approved by: JOS
Scale: *1" = ~225'*	File Name: Fig1-5 1962 Aerial

MWP Addendum 022 –
SSP Investigation for SWMU 45
Radford Army Ammunition Plant
Radford, Virginia

URS Group, Inc.
540 Falmouth Street
Suite 201
Richmond, Virginia 23230

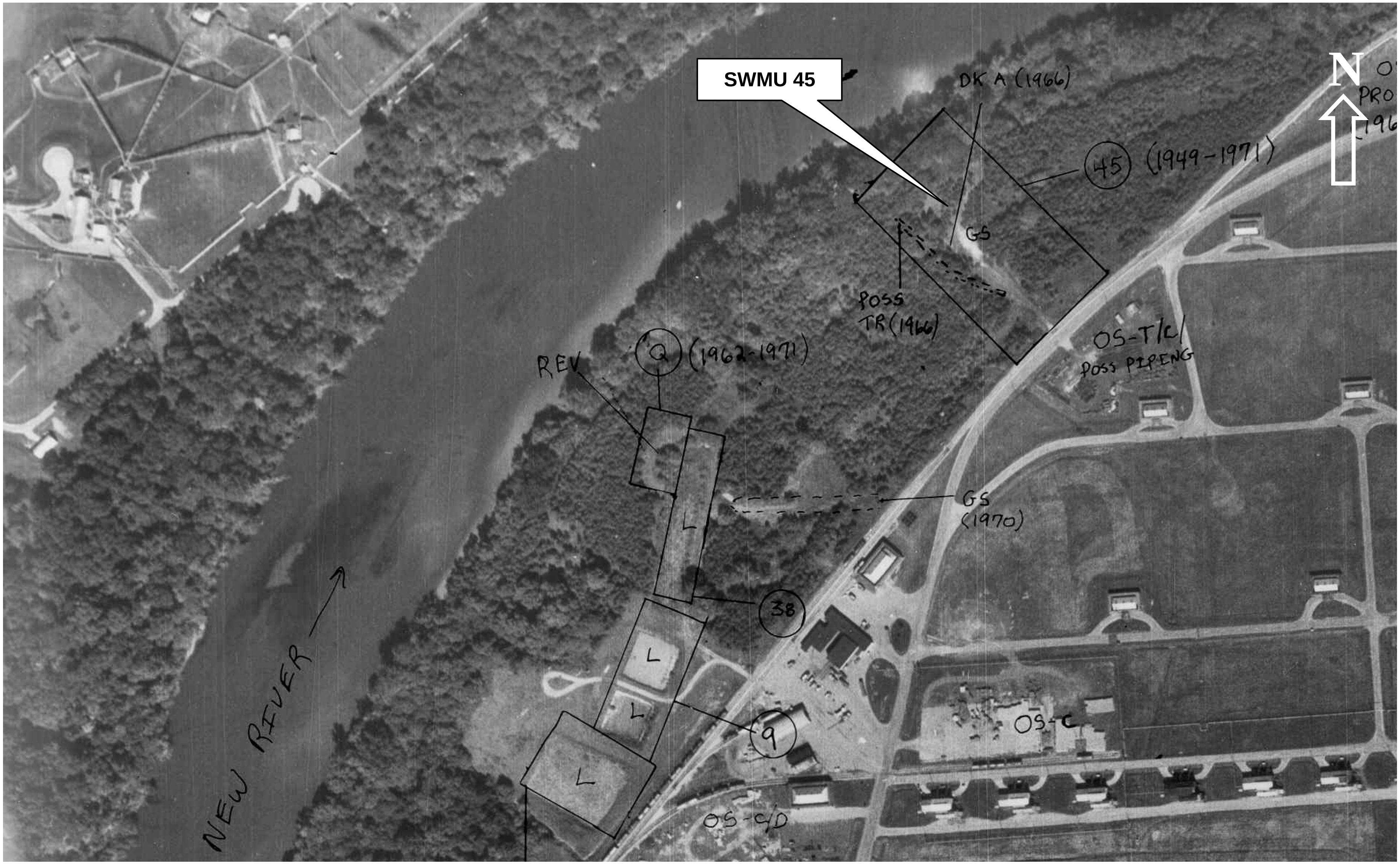


FIGURE 1-6

Aerial Photograph - 1971

Date: June 2007	URS Project #: 11656351
Prepared by: DBC	Approved by: JOS
Scale: *1" = ~230'*	File Name: Fig1-6 1971 Aerial

MWP Addendum 022 –
SSP Investigation for SWMU 45
Radford Army Ammunition Plant
Radford, Virginia

URS Group, Inc.
540 Falmouth Street
Suite 201
Richmond, Virginia 23230

FIGURE 1-7

Aerial Photograph - 1975

Date: June 2007	URS Project #: 11656351
Prepared by: DBC	Approved by: JOS
Scale: *1" = ~205'*	File Name: Fig1-7 1975 Aerial

MWP Addendum 022 –
SSP Investigation for SWMU 45
Radford Army Ammunition Plant
Radford, Virginia

URS

URS Group, Inc.
540 Falmouth Street
Suite 201
Richmond, Virginia 23230

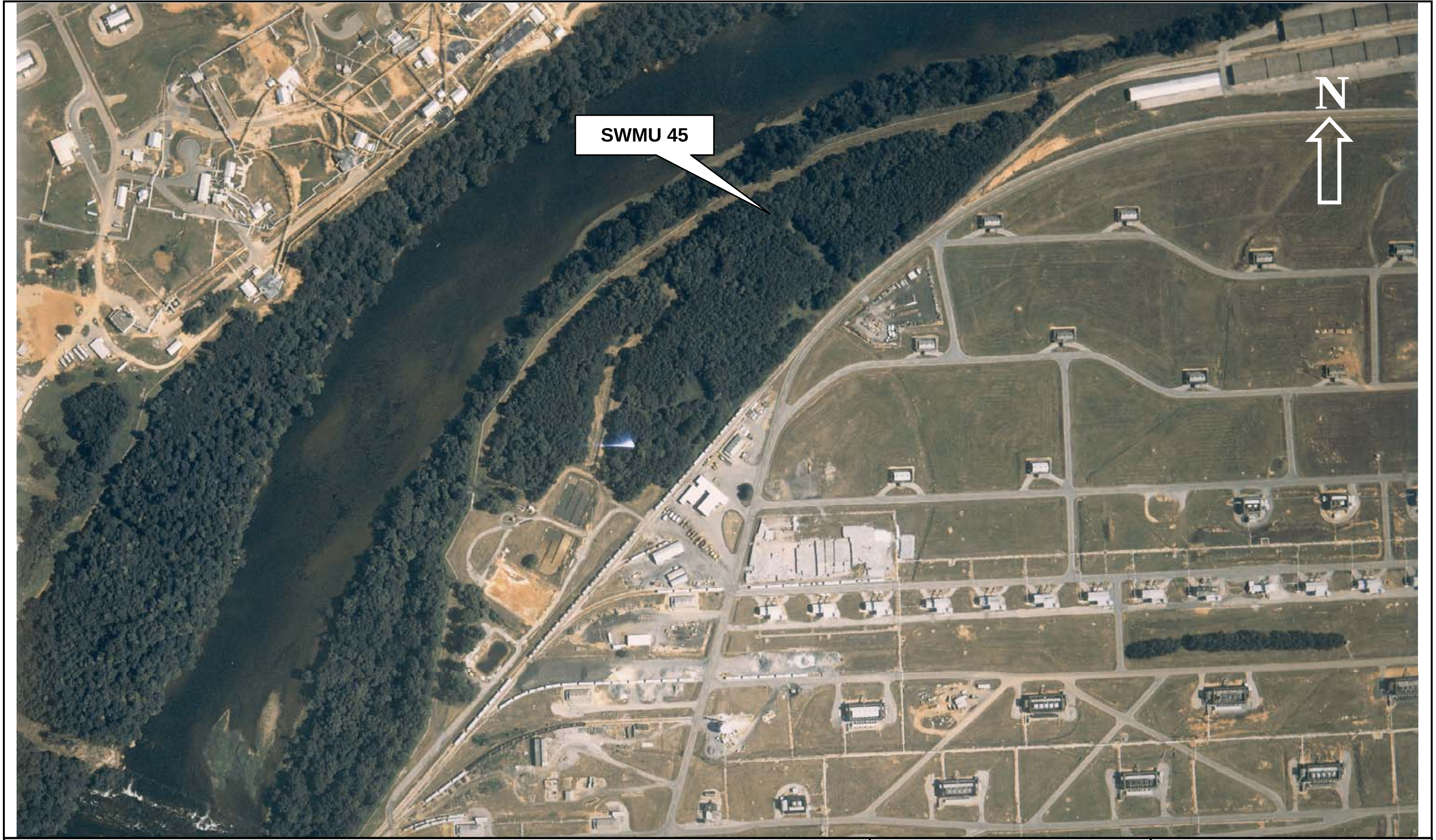


FIGURE 1-8

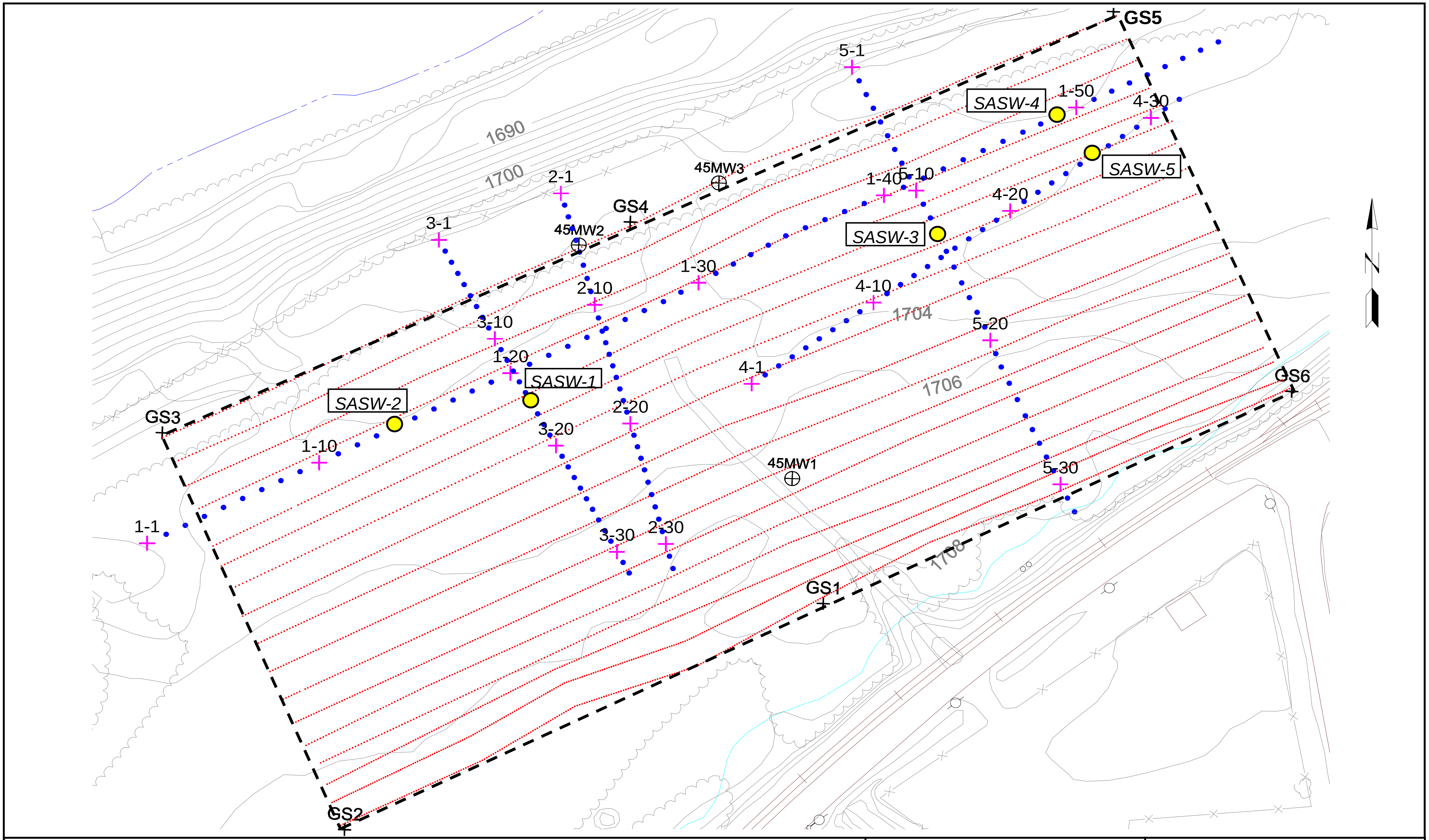
Aerial Photograph - 1986

MWP Addendum 022 –
SSP Investigation for SWMU 45
Radford Army Ammunition Plant
Radford, Virginia

Date: June 2007	URS Project #: 11656351
Prepared by: DBC	Approved by: JOS
Scale: *1" = ~230'*	File Name: Fig1-8 1986 Aerial

URS

URS Group, Inc.
540 Falmouth Street
Suite 201
Richmond, Virginia 23230



⋯ = *paths of EM traverses*

1-1 + • • = *locations of resistivity electrodes*

● = *location of SASW profile*

Scale: 1 inch = 105 feet

0 105 210
feet

Geophysical Survey Data provided by: **ATS International** Advanced Technical Services

FIGURE 1-9

2007 Geophysical Survey Area

Date: June 2007

URS Project #: 11656351

Prepared by: DBC

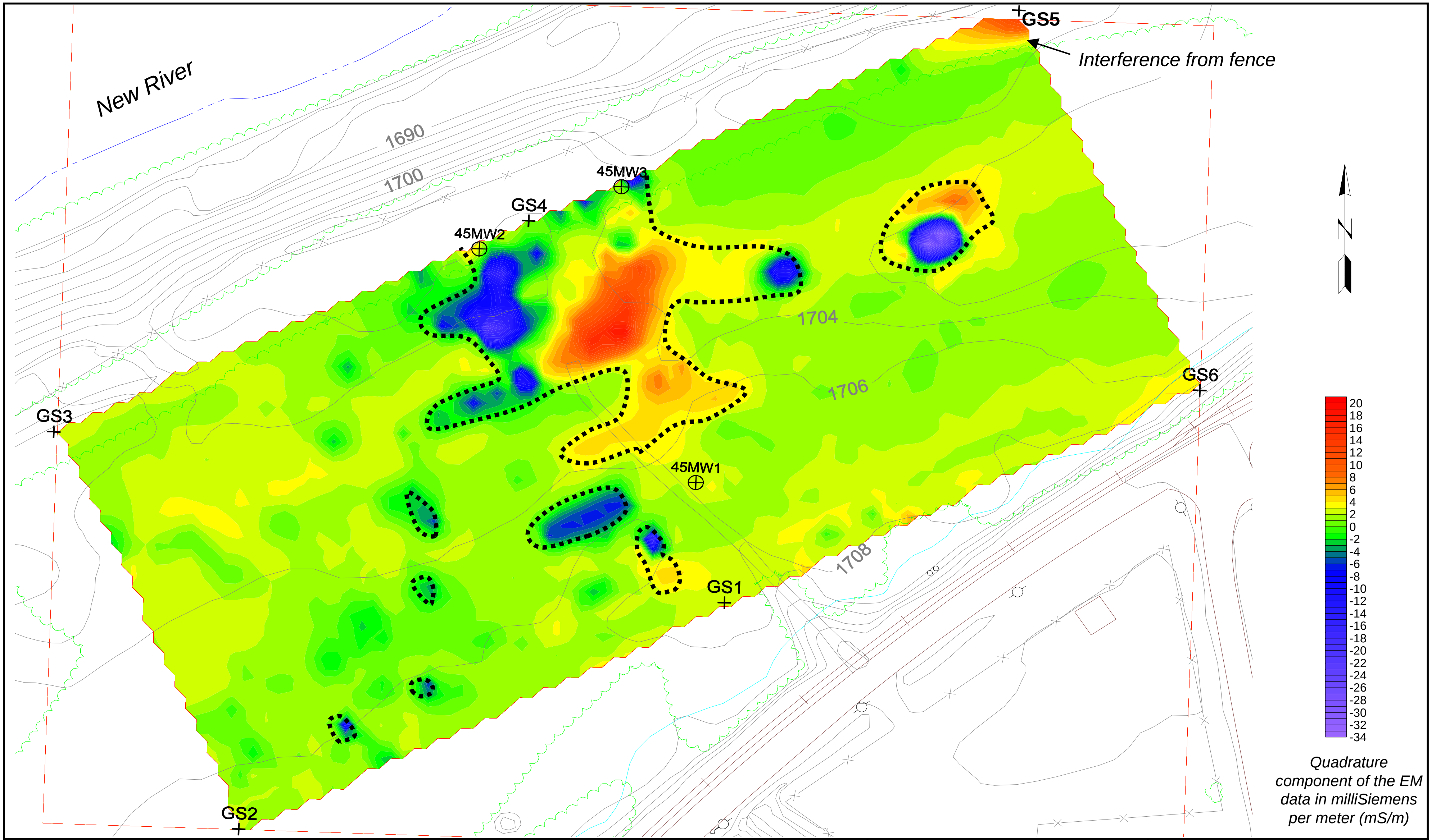
Approved by: JOS

Scale: *As Shown*

File Name: Fig1-12 Res.Results

MWP Addendum 022 –
SSP Investigation for SWMU 45
Radford Army Ammunition Plant
Radford, Virginia

URS
URS Group, Inc.
540 Falmouth Street
Suite 201
Richmond, Virginia 23230



◌ = Zones of high conductivity

Scale: 1 inch = 105 feet

0 105 210
feet

Geophysical Survey Data provided by: **ATS International** Advanced Technical Services

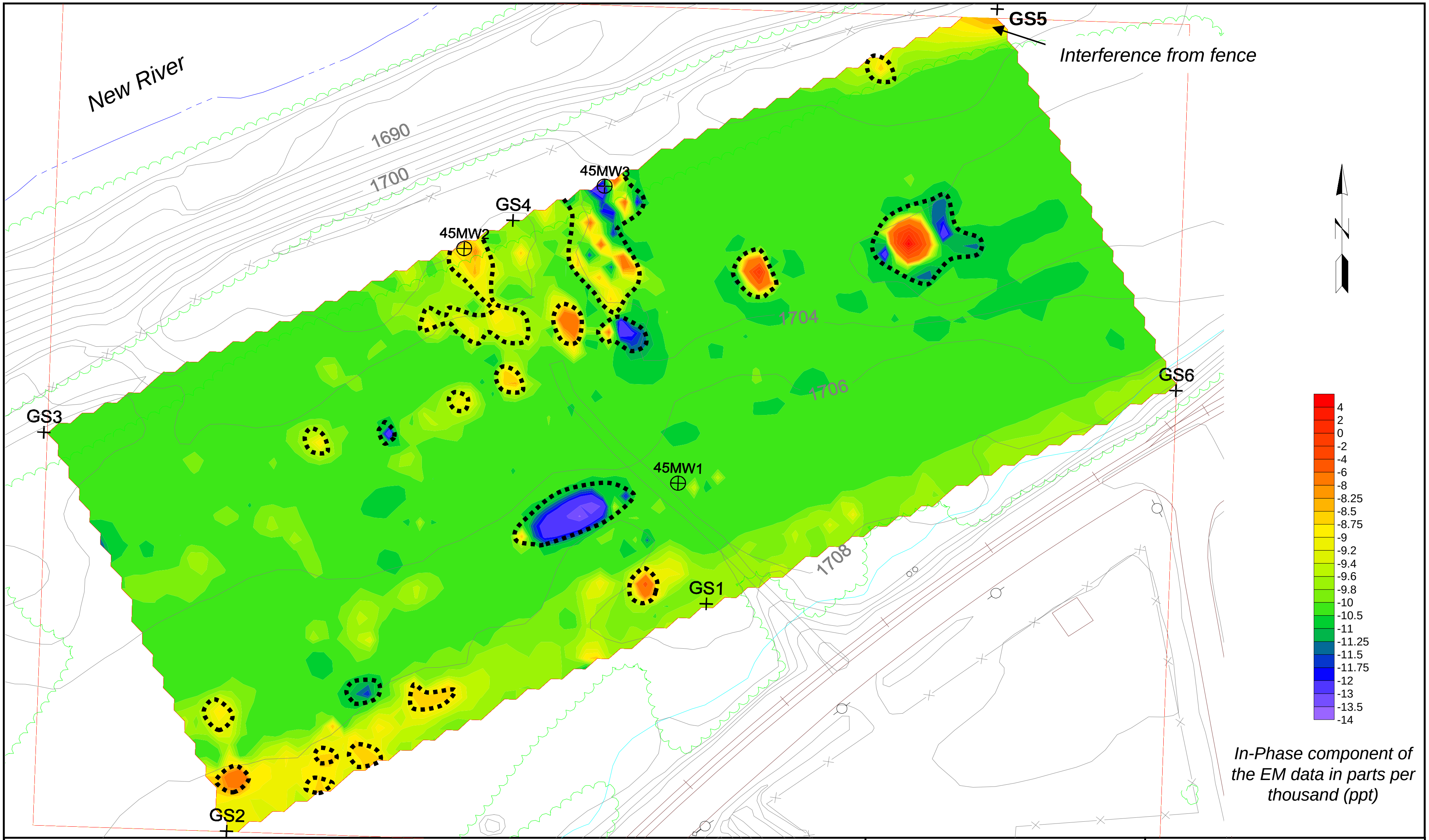
FIGURE 1-10

2007 Geophysical Survey - EM Data
Contour of Quadrature Component

Date: June 2007	URS Project #: 11656351
Prepared by: DBC	Approved by: JOS
Scale: *As Shown*	File Name: Fig1-12 Res.Results

MWP Addendum 022 –
SSP Investigation for SWMU 45
Radford Army Ammunition Plant
Radford, Virginia

URS
URS Group, Inc.
540 Falmouth Street
Suite 201
Richmond, Virginia 23230



In-Phase component of the EM data in parts per thousand (ppt)

◌ *= Zones of high conductivity*

Scale: 1 inch = 105 feet

0 *105* *210*
feet

Geophysical Survey Data provided by: ATS International Advanced Technical Services

FIGURE 1-11

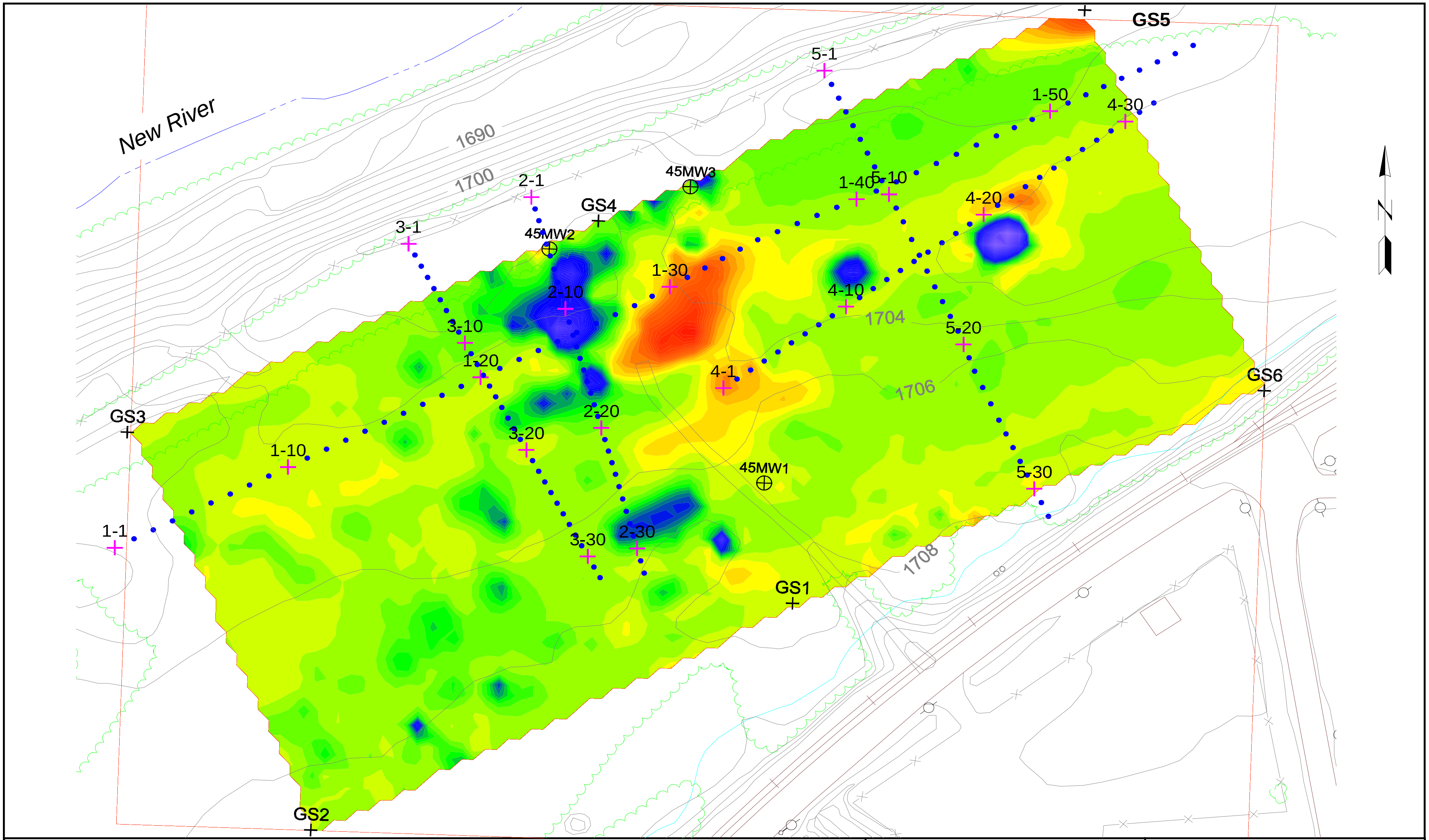
2007 Geophysical Survey - EM Data
Contour of In-Phase Component

Date: June 2007	URS Project #: 11656351
Prepared by: DBC	Approved by: JOS
Scale: *As Shown*	File Name: Fig1-12 Res.Results

MWP Addendum 022 –
SSP Investigation for SWMU 45
Radford Army Ammunition Plant
Radford, Virginia

URS

URS Group, Inc.
540 Falmouth Street
Suite 201
Richmond, Virginia 23230



1-1 + • • • = *locations of resistivity electrodes*

Scale: 1 inch = 105 feet

0 105 210
feet

Geophysical Survey Data provided by: **ATS International** Advanced Technical Services

FIGURE 1-12

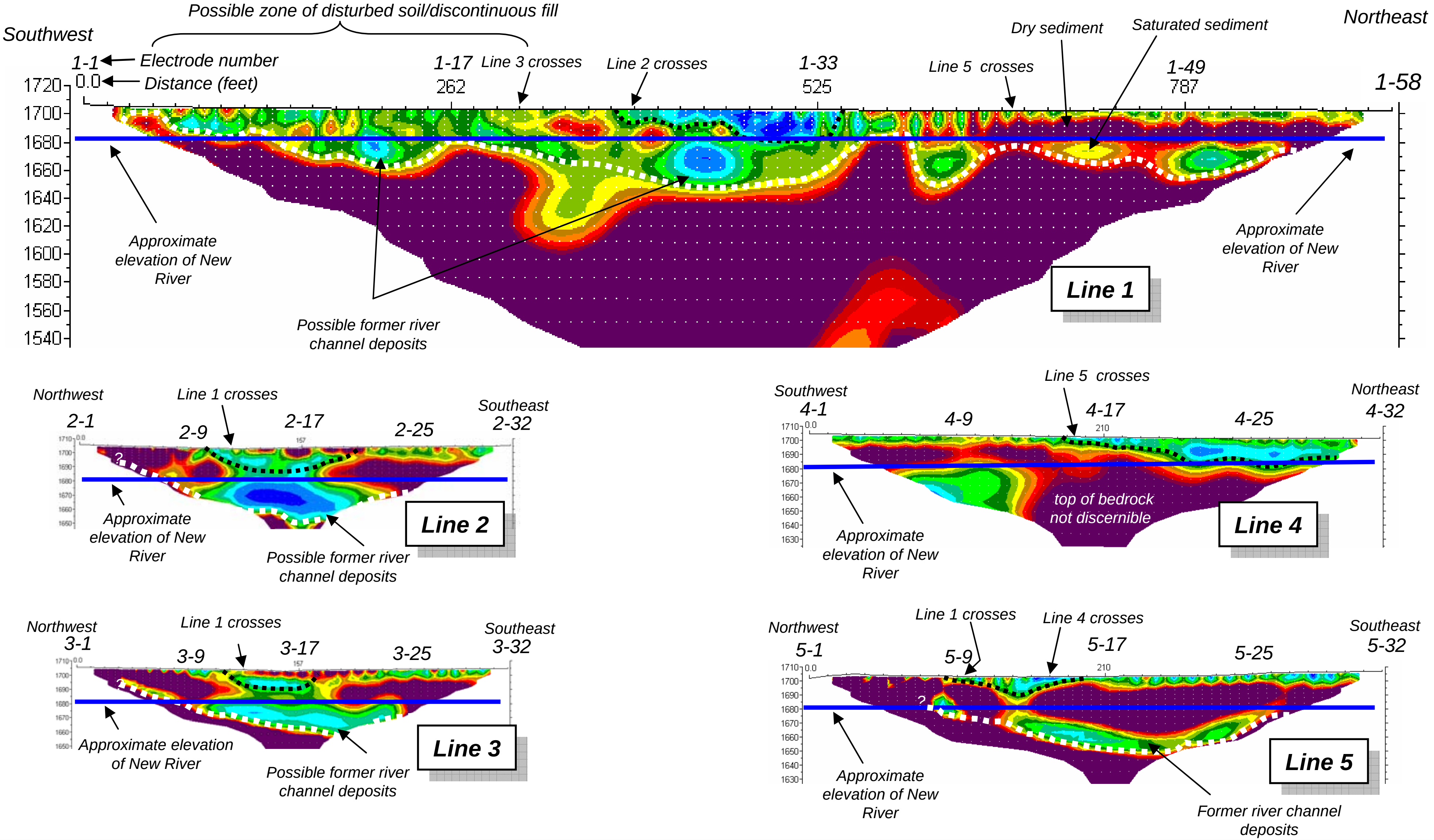
2007 Geophysical Survey - Location
of Resistivity Survey Lines

Date: June 2007	URS Project #: 11656351
Prepared by: DBC	Approved by: JOS
Scale: *As Shown*	File Name: Fig1-12 Res.Locs

MWP Addendum 022 –
SSP Investigation for SWMU 45
Radford Army Ammunition Plant
Radford, Virginia

URS

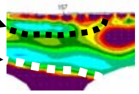
URS Group, Inc.
540 Falmouth Street
Suite 201
Richmond, Virginia 23230



Legend

Interpreted base of potential fill materials (black dotted line)

Interpreted top of bedrock (white dotted line)



Resistivity Scale in Ohm-meters

Distances and elevations are in feet
Cross-section Scale: 1 inch = 100 feet

Geophysical Survey Data provided by: ATS International Advanced Technical Services

FIGURE 1-13

2007 Geophysical Survey - Resistivity Results

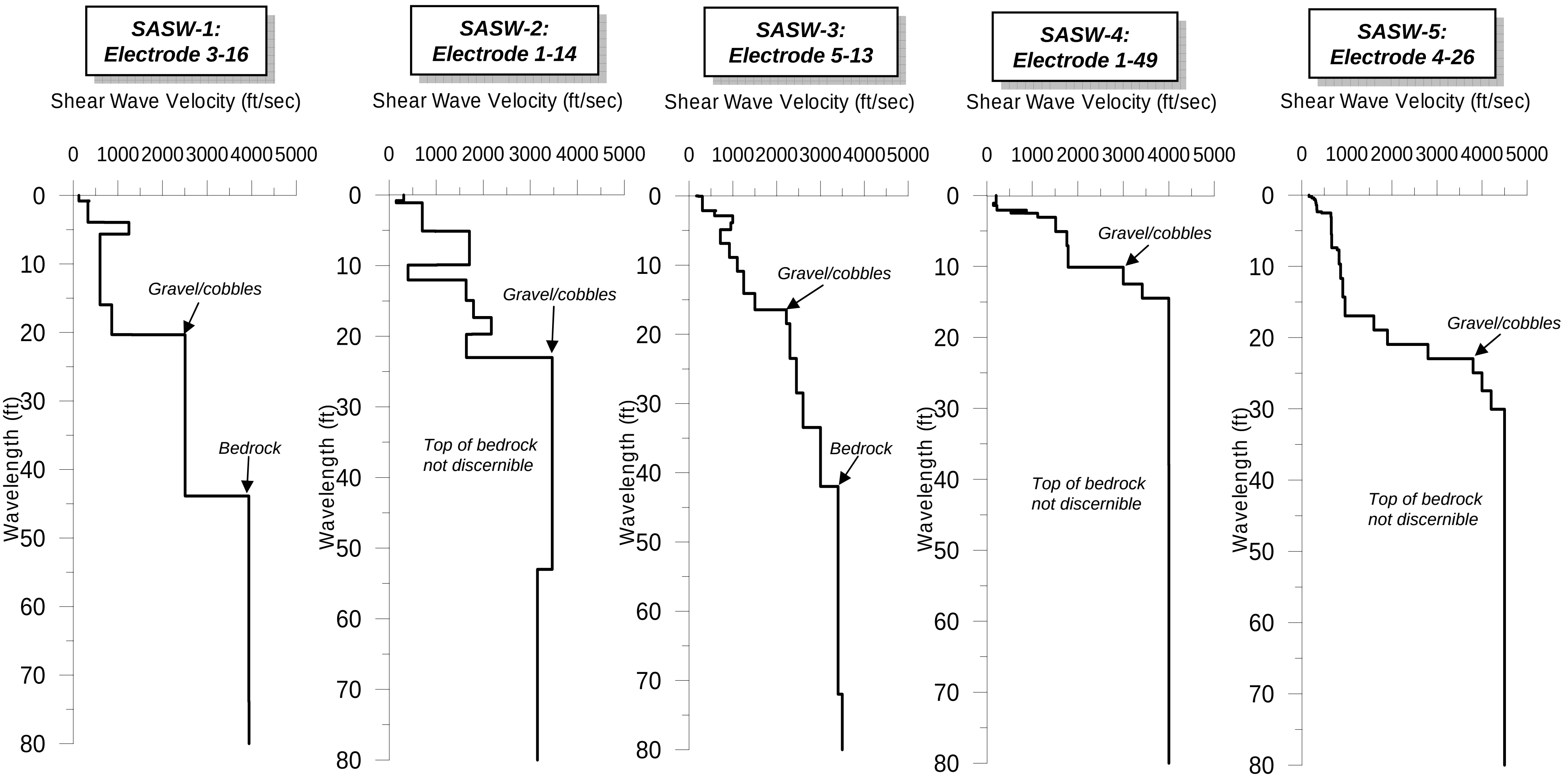
Date: June 2007	URS Project #: 11656351
Prepared by: DBC	Approved by: JOS
Scale: *As Shown*	File Name: Fig1-12 Res.Results

MWP Addendum 022 –
SSP Investigation for SWMU 45
Radford Army Ammunition Plant
Radford, Virginia

URS

URS Group, Inc.
540 Falmouth Street
Suite 201
Richmond, Virginia 23230

Results of the SASW Profiles



Geophysical Survey Data provided by: *ATS* International Advanced Technical Services

FIGURE 1-14

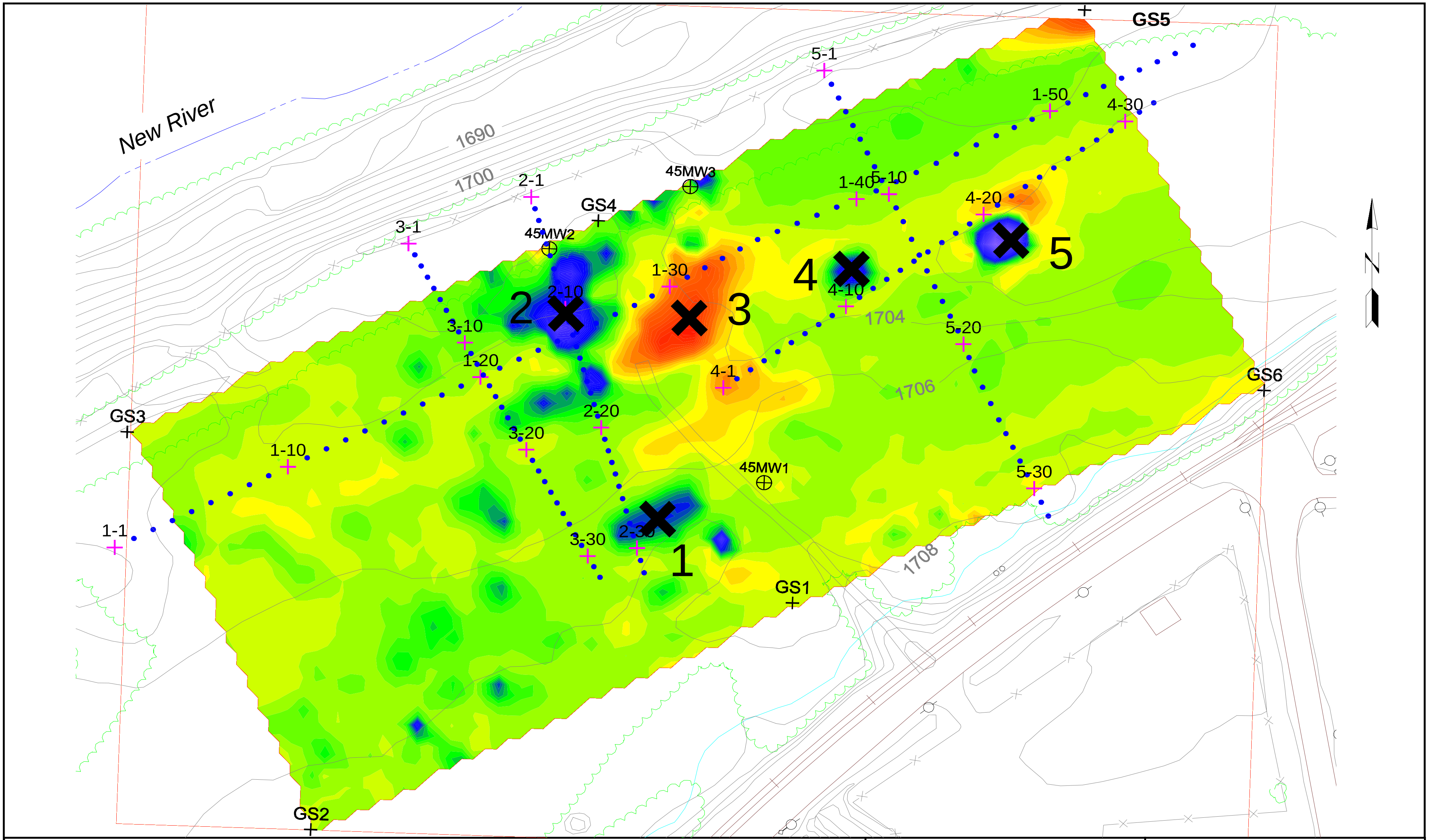
2007 Geophysical Survey - Results of SASW Profiles

Date: June 2007	URS Project #: 11656351
Prepared by: DBC	Approved by: JOS
Scale: *1" = 2000'*	File Name: Fig1-14 SASWResults

MWP Addendum 022 –
SSP Investigation for SWMU 45
Radford Army Ammunition Plant
Radford, Virginia

URS

URS Group, Inc.
540 Falmouth Street
Suite 201
Richmond, Virginia 23230



✖ = *anomaly area (#)*

1-1 + • • = *locations of resistivity electrodes*

Scale: 1 inch = 105 feet

0 *105 feet* *210*

Geophysical Survey Data provided by: **ATS International** Advanced Technical Services

FIGURE 1-15

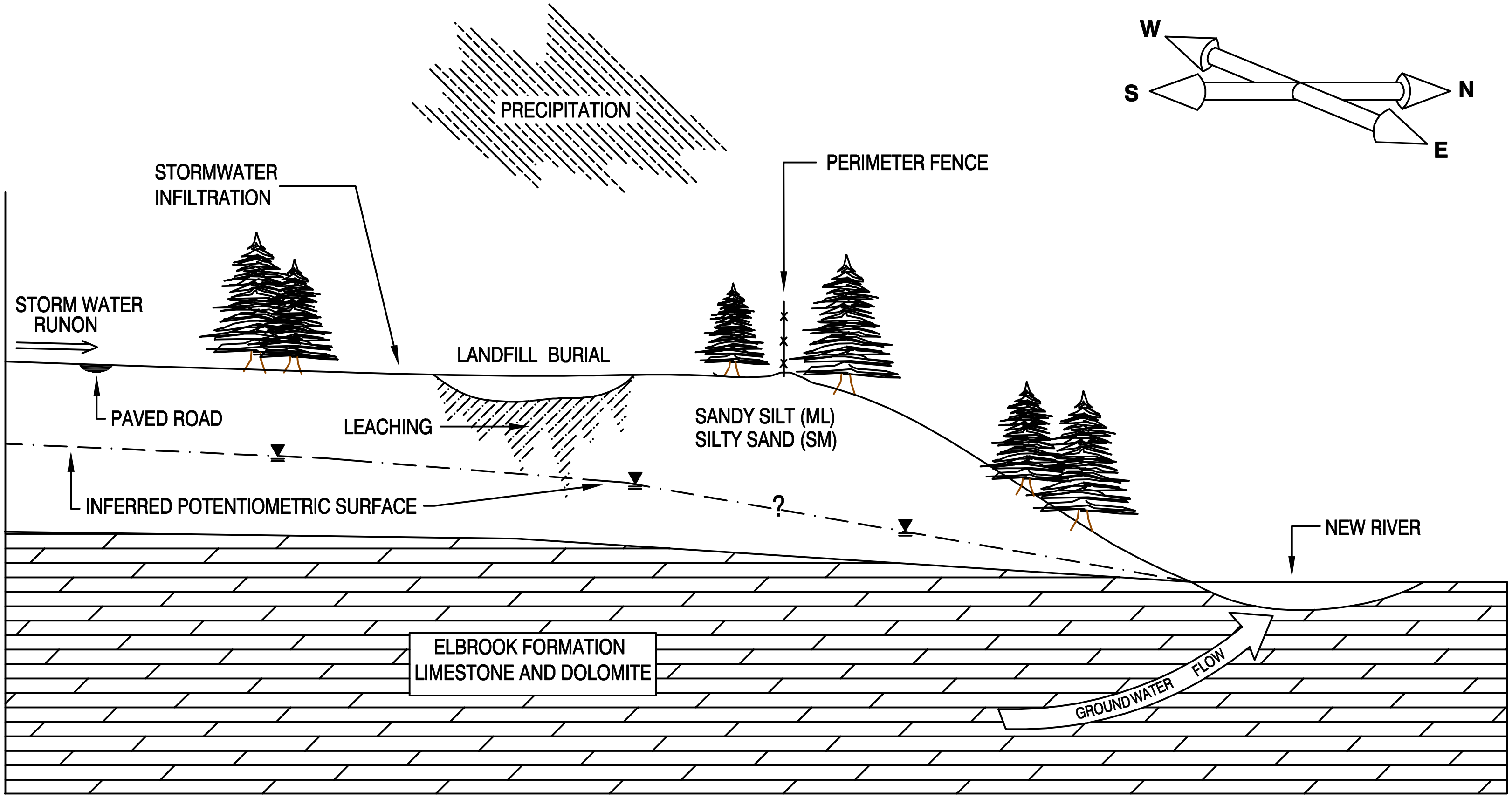
2007 Geophysical Survey –
Geophysical Anomaly Areas

Date: June 2007	URS Project #: 11656351
Prepared by: DBC	Approved by: JOS
Scale: *As Shown*	File Name: Fig1-15 Ano.Areas

MWP Addendum 022 –
SSP Investigation for SWMU 45
Radford Army Ammunition Plant
Radford, Virginia

URS

URS Group, Inc.
540 Falmouth Street
Suite 201
Richmond, Virginia 23230



CONCEPTUAL DRAWING - NO SCALE IMPLIED

FIGURE 1-16

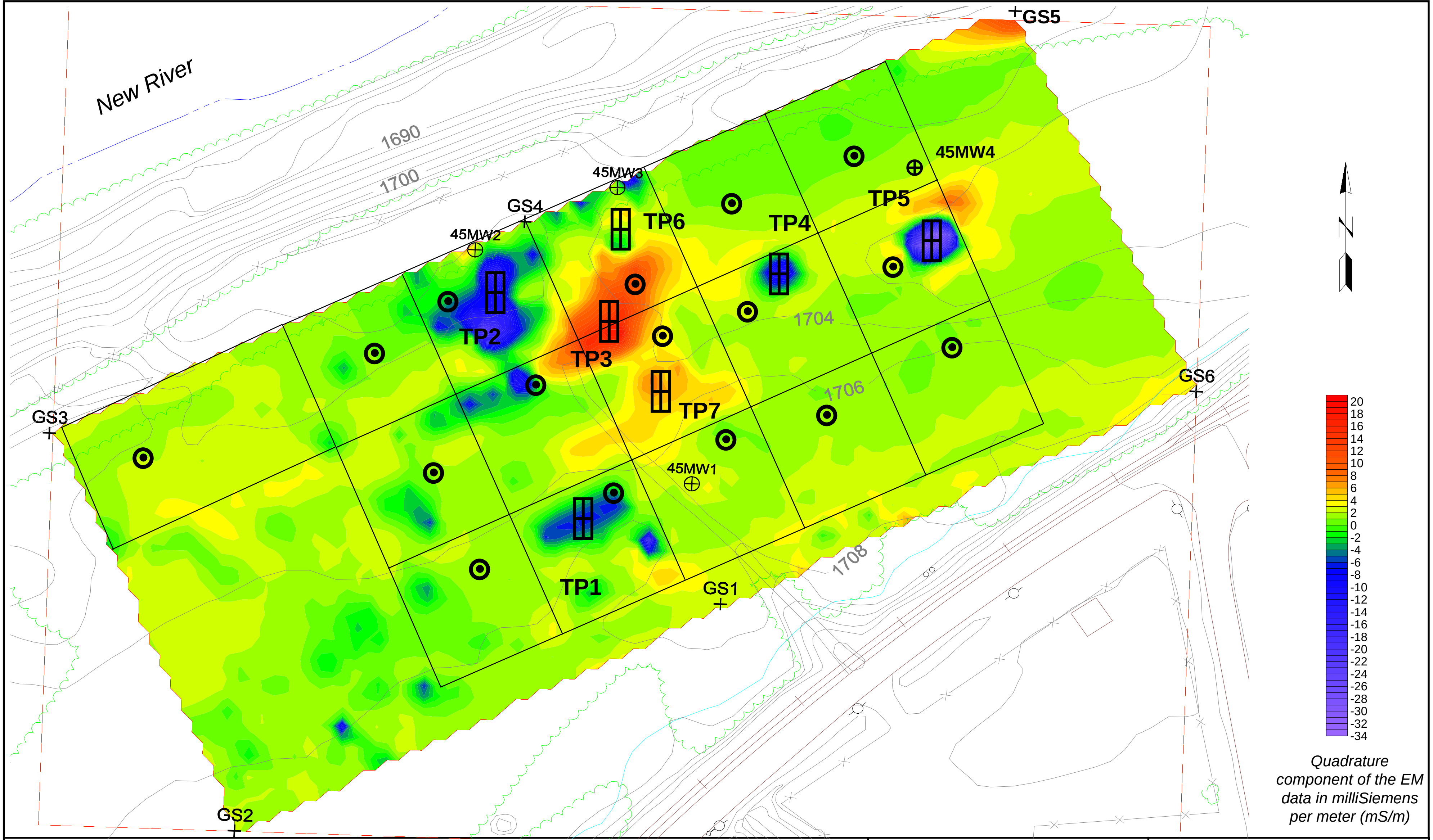
Conceptual Site Model

Date: June 2007	URS Project #: 11656351
Prepared by: DBC	Approved by: JOS
Scale: 1" = 150'	File Name: Fig. 1-16 Conc.Mod

MWP Addendum 022 -
SSP Investigation for SWMU 45
Radford Army Ammunition Plant
Radford, Virginia

URS

URS Group, Inc.
5540 Falmouth Street
Suite 201
Richmond, Virginia 23230



Quadrature component of the EM data in milliSiemens per meter (mS/m)

⊕ = *Monitoring Well*

◫ = *Test Pit Location*

◉ = *Direct Push Soil Sample Location*

Scale: 1 inch = 105 feet

0 105 210
feet

Geophysical Survey Data provided by: **ATS International** Advanced Technical Services

FIGURE 1-17
SSP Sample Locations

Date: June 2007	URS Project #: 11656351
Prepared by: DBC	Approved by: JOS
Scale: *As Shown*	File Name: Fig1-17 Sam.Locs

MWP Addendum 022 –
SSP Investigation for SWMU 45
Radford Army Ammunition Plant
Radford, Virginia

URS

URS Group, Inc.
540 Falmouth Street
Suite 201
Richmond, Virginia 23230

Table 1-2
Summary of Historical Analytical Groundwater Data for SWMU 45
Modified from Dames and Moore Verification Report Investigation (October 1992)
MWP Addendum 022 - SSP at SWMU 45
Radford Army Ammunition Plant, Radford, Virginia

Sample ID Field ID Sample Date Well Depth (feet) Matrix	CAS	C/N	Adjusted Tap Water RBC	MCL	45MW1 RDWC*1 11/8/1991 22 GW	45MW2 RDWC*2 11/8/1991 20 GW	45MW3 RDWC*3 11/7/1991 25 GW
TAL Metals (ug/L)							
Barium	7440-39-3	N	730	2,000	33.3	68.2	132
Calcium	7440-70-2	--	--	--	63,400	85,900	114,000
Iron	7439-89-6	N	2,555	--	141	<38.8	541
Lead[(1)]	7439-92-1	--	--	15	<1.26	<1.26	4.12
Magnesium	7439-95-4	--	--	--	25,200	30,800	36,000
Manganese	7439-96-5	N	73	--	681	3.47	98
Potassium	7440-09-7	--	--	--	1,460	<375	<375
Sodium	7440-23-5	--	--	--	50,800	4,530	10,900
Explosives (ug/L)							
None detected	--	--	--	--	ND	ND	ND
TCL VOCs (ug/L)							
Carbon Disulfide	75-15-0	N	104.3	--	0.737	<0.5	<0.5
Toluene	108-88-3	N	227.1	--	<0.5	1.27	<0.5
TCL SVOCs (ug/L							
Bis(2-chloroethyl)ether	111-44-4	C	0.00959	--	<1.9	<1.9	3.39
Total Unknown TICs	--	--	--	--	(3) 37	(1) 6	ND
Other (ug/L)							
Total Organic Carbon (TOC)	--	--	--	--	16,400	10,600	16,300
Total Organic Halogens (TOX)	--	--	--	--	80.4	104	66
pH (Standard Units)	12408-02-5	--	--	--	7.26	6.96	6.76

Notes:

CAS = Chemical Abstracts Service
ug/L = Microgram Per Liter
MDL = Method Detection Limit
RL = Reporting Limit
LQ = Laboratory Qualifier
VQ = Validation Qualifier
r = Reason Code
TIC = Tentatively Identified Compound
(#) # = (Number of TICs detected) Total concentration of all TICs
ND = Not Detected

RBC = USEPA Region III Risk-Based Concentration
(RBC) values from the April 6, 2007,
RBC Table and April 10, 2007, Alternate RBC Table
C/N = Carcinogenic/Non-carcinogenic per EPA RBC Table (April 2007)
MCL = Maximum Contaminant Level
(1) = Lead MCL value is an action level

☐ = Concentration above Tap Water RBC value

☐ = Concentration above MCL

THIS PAGE LEFT INTENTIONALLY BLANK

Table 1-3
Wildlife Profiles
MWP Addendum 022 - SSP at SWMU 45
Radford Army Ammunition Plant, Radford, Virginia

							Preliminary Assessment						Refined Assessment						
Representative Species			Composition of Diet [1] (%)				Minimum Body Weight [1]	Maximum Body Weight [1]	Maximum Food Ingestion Rate[2]	Maximum Substrate Ingestion Rate [1]		Maximum Water Ingestion Rate [3]	Average Body Weight [1]	Average Food Ingestion Rate [2]	Average Substrate Ingestion Rate [1]	Average Water Ingestion Rate [3]	Home Range (ha)	Proportion of Year Species Active	AUFs
Food-web Classification	**Common Name**	**Scientific Name**	**Plants (incl. fungi)**	**Inverte-brates**	**Small mammals**	**Fish**	**kg**	**kg**	**kg dw/day**	**% of dry intake**	**kg dry wt./day**	**L/day**	**kg**	**kg dw/day**	**kg dry wt./day**	**L/day**			**Study Area (1.38) hectares**
Birds																			
soil-probing invertivore	American robin	*Turdus migratorius*	62%	38%			0.0635	0.103	0.020	5%	0.001	0.013	0.077	0.016	0.0008	0.011	0.48	1	1
large carnivore	Red-tailed hawk	*Buteo jamaicensis*			100%		0.957	1.235	0.063	0%	0	0.068	1.134	0.059	0	0.064	250	1	0.0055
Mammals																			
small herbivore	Meadow vole	*Microtus pennsylvanicus*	100%				0.017	0.0524	0.010	2.4%	0.00024	0.0070	0.037	0.008	0.00019	0.0051	0.037	1	1
medium carnivore	Red fox	*Vulpes vulpes*	17%	4%	79%		2.95	7.04	0.342	2.8%	0.0096	0.573	4.53	0.238	0.0067	0.39	96	1	0.0144
small invertivore	Short-tailed shrew	*Blarina brevicauda*	14%	86%			0.0125	0.0225	0.003	10%	0.00031	0.0033	0.015	0.002	0.00021	0.0023	0.39	1	1

Notes:
kg = Kilogram
kg dw/day = Kilogram Dry-weight per Day
L/day = Liter per Day

[1] Wildlife Exposure Factors Handbook. U.S. Environmental Protection Agency (EPA). 1993. Office of Research and Development. 2 Volumes. EPA/600/R93/187a&b. December.

[2] Estimated food intake rate (kg [dw]/day) calculated as follows:
FI ((kg/day) = 0.0687 $Wt.^{0.882}$ for mammals (red fox and short-tailed shrew)
FI ((g/day) = 0.577 $Wt.^{0.727}$ for herbivores (meadow vole)
FI ((g/day) = 0.301 $Wt.^{0.751}$ for non-passerine birds (red-tailed hawk)
FI ((g/day) = 0.398 $Wt.^{0.850}$ for passerine birds (american robin)

[3] Estimated water intake rate (L/day) calculated as follows:
Birds: $WI=0.059Wt^{0.67}$(kg)
Mammals: $WI=0.099Wt^{0.90}$(kg)

The soil ingestion rate for the american robin set equal to 38% of the american woodcock value (0.34*10.4%=4%), based on a robin diet of 38% invertbrates.

THIS PAGE LEFT INTENTIONALLY BLANK

Table 1-4
Handling and Disposal of Investigation-Derived Materials
MWP Addendum 022 - SSP at SWMU 45
Radford Army Ammunition Plant, Radford, Virginia

Material	Description	Quantity	Action	Expected Nature of Material
Excess Soil from Borings and Test Pits	From 6 Test Pits and 15 Soil Borings	Approximately twenty-one 55-gallon drums	Full TCLP, Corrosivity, Paint Filter Liquids, and Explosives	Non-hazardous. Concentrations are not expected to exceed TCLP, or pH limits.
Well Purge Water and Decontamination Water	Aqueous IDM	Approximately four 55-gallon drums	TCLP Metals, COD, and pH	Non-hazardous. Concentrations are not expected to exceed treatment plant limits.
PPE	Miscellaneous IDM	Approximately two 55-gallon drums	Evaluate Soil and Water Results	Non-hazardous material. Will be disposed of with soil IDM.

Notes:
IDM = Investigation-Derived Material
TCLP = Toxicity Characteristics Leaching Procedure
COD = Chemical Oxygen Demand
PPE = Personal Protective Equipment and Clothing

2.0 QUALITY ASSURANCE PLAN ADDENDUM

2.1 INTRODUCTION

This QAPA establishes function-specific responsibilities and authorities to ensure data quality for investigative activities at RFAAP. The project objectives will be met through the execution of the SOPs included in the MWP and appended to this document. The applicable SOPs are referenced below. Specific QC requirements include development of Data Quality Objectives (DQOs), performance of internal QC checks, and execution of appropriate analytical procedures during investigative activities. This QAPA is designed to be used in conjunction with the MQAP. Table 2-1 provides a list of general QA measures that will be implemented as specified in the MQAP.

Table 2-1

Quality Assurance Measures Discussed in the MQAP

Quality Assurance Measure	Section in MQAP	SOP No. (MWP Appendix A and Appendix A of WPA 022)
Project Organization and Responsibilities	2.0	--
Lines of Authority	2.2	--
Chemical Data Measurements	3.2	--
Levels of Concern	3.3	--
Site Investigation	4.0/5.0	20.1, 20.2, 20.3, 20.4, 20.7, 20.8, 20.11, 30.1, 30.2, 30.6, 30.7, 30.9, 40.1, 40.2, 40.3, 50.1, 50.2, 70.1, 80.1
Documentation Requirements	5.6	10.1, 10.2, 10.3, 50.1
Chain-of-custody Requirements	5.7	10.4, 50.2
Calibration Procedures	7.0	90.1
Data Reduction, Validation, Reporting, and Management	9.0	--
Corrective Action	10.0	--
Quality Assessments	11.0	--

The distribution list for submittals associated with this SSP is defined in the Facility Permit (USEPA, 2000a). At least three copies of draft documents and three copies of the final plans, reports, notifications, or other documents submitted as part of the SSP for SWMUs 45 is to be submitted to the USEPA Regional Administrator, and shall be sent Certified Mail, Return Receipt Requested, overnight mail, or hand-carried to:

USEPA Region III
Federal Facilities Branch (3WC23)
1650 Arch Street
Philadelphia, Pennsylvania 19103-2029

In addition, one copy each such submission shall be sent to:

Commonwealth of Virginia
Department of Environmental Quality
Waste Division
629 East Main Street
Richmond, Virginia 23219

Commonwealth of Virginia
Department of Environmental Quality
West Central Regional Office
Executive Office Park, Suite D
5338 Peters Creek Road
Roanoke, VA 24109

Moreover, one or more copies of each such submission shall be sent to:

Tom Meyer
USACE, Baltimore District
ATTN: CENAB-EN-HM (10000-G)
10 South Howard Street
Baltimore, Maryland 21203

Rich Mendoza
U.S. Army Environmental Command
1 Rock Island Arsenal
Bldg 60, 3rd Fl, NW Wing, Room 320
(IMAE-CDN)
Rock Island, Illinois 61299

James McKenna
Radford Army Ammunition Plant
Route 114, Peppers Ferry Road
Building 220
Radford, Virginia 24141-0099

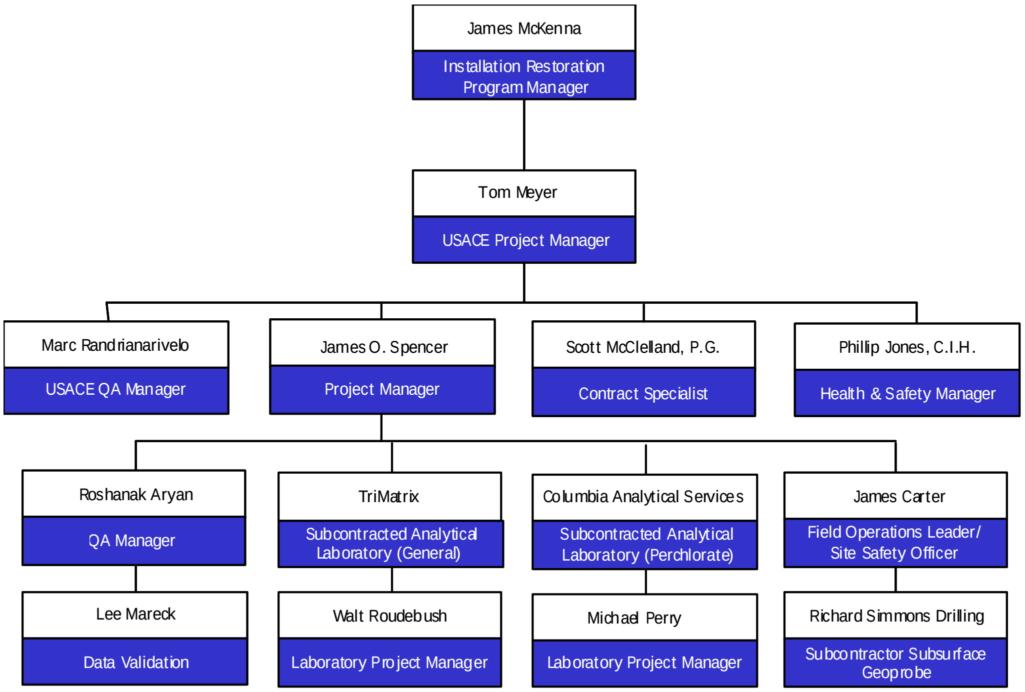
Dennis Druck
USACHPPM
5158 Blackhawk Road
ATTN: MCHB-TS-HER
Aberdeen Proving Ground, MD 21010-5403

2.2 PROJECT ORGANIZATION AND RESPONSIBILITIES

2.2.1 Contractor and Subcontractor Responsibilities

Contractor and subcontractor personnel requirements for implementing the technical, quality, and health and safety programs are described in Section 2.1 of the MQAP. Figure 2-1 presents the identification and the organization of project management personnel.

Figure 2-1
Project Organizational Chart



2.2.2 Key Points of Contact

Table 2-2 provides the names and points of contact for URS personnel and subcontractors.

The Project Manager (PM) is responsible for ensuring that activities are conducted in accordance with contractual specifications, the Statement of Work (SOW), and approved work plans. The PM will also provide technical coordination with the Installation’s designated counterpart. The PM is responsible for management of operations conducted for this project. In addition, the PM will ensure that personnel assigned the project, including subcontractors, will review the technical plans prior to initiation of each task associated with the project. The PM will monitor the project budget and schedule and will ensure availability of necessary personnel, equipment, subcontractors, and services. The PM will participate in the development of the field program, evaluation of data, reporting, and the development of conclusions and recommendations.

Table 2-2

Contractor and Subcontractor Key Points of Contact

Contractor	Key Point of Contact
Project Manager, James O Spencer Email: James_O_Spencer@URSCorp.com	URS Group, Inc. 5540 Falmouth Street, Suite 201 Richmond, Virginia 23230 Tel: 804.474.5420; Fax: 804.965.9764

Contractor	Key Point of Contact
Health and Safety Manager, Phillip Jones Email: Phillip_L_Jones@URSCorp.com	URS Group, Inc. 335 Commerce Drive, Suite 300 Fort Washington, Pennsylvania 19034 Tel: 215.367.2500; Fax: 215.367.1000
Quality Assurance Manager, Roshanak Aryan Email: Roshanak_Aryan@URSCorp.com	URS Group, Inc. 5540 Falmouth Street, Suite 201 Richmond, Virginia 23230 Tel: 804.474.5431; Fax: 804.965.9764
Data Validator, Lee Mareck Email: Lee_Mareck@URSCorp.com	URS Group, Inc. 5540 Falmouth Street, Suite 201 Richmond, Virginia 23230 Tel: 804.474.5444; Fax: 804.965.9764
Field Operations Leader and Site Health and Safety Officer, James Carter Email: James_Carter@URSCorp.com	URS Group, Inc. 5540 Falmouth Street, Suite 201 Richmond, Virginia 23230 Tel: 804.474.5419; Fax: 804.965.9764
Subcontractor	**Key Point of Contact**
Analytical Laboratory Services, General TriMatrix Laboratories, Inc. Email: RoudebushW@TriMatrixLabs.com	Walt Roudebush 5560 Corporate Exchange Court Grand Rapids, MI 49512 Tel: 616.975.4500; Fax: 616.940.4470
Columbia Analytical Services, Inc. Email: mperry@rochester.caslab.com	Michael Perry 1 Mustard St., Suite 250 Rochester, NY 14609 Tel: 585.288.5380; Fax: 585.288.8475
SGS Environmental Services, Inc. (SGS-Wilmington) Email: Heather.Patterson@sgs.com	Heather Patterson 5500 Business Drive Wilmington, NC 28405 Tel: 910.350.1903, Fax: 910.350.1557
Subsurface Drilling (Geoprobe®) Richard Simmons Drilling Email: RSDrilling@AOL.com	Richard Simmons Drilling 60 Drill Rig Drive Buchanan, Virginia 24066 Tel: 540.254.2289; Fax: 540.254.1268

The Field Operations Leader will provide management of the field activities during the fieldwork. The Field Operations Leader is responsible for ensuring that technical matters pertaining to the field-sampling program are addressed. They will participate extensively in data interpretation, report writing, and preparation of deliverables, and will ensure that work is being conducted as specified in the technical plans. In addition, the Field Operations Leader is responsible for field QA/QC procedures and for safety-related issues. Prior to initiation of field activities, the Field Operations Leader will conduct a field staff orientation and briefing to acquaint project personnel with the sites and assign field responsibilities.

The Health and Safety Manager will review and internally approve the HSPA that will be tailored to the specific needs of the project in the task specific addendum. In consultation with the PM, the Health and Safety Manager will ensure that an adequate level of personal protection exists for anticipated potential hazards for field personnel. On-site health and safety will be the responsibility of the SHSO who will work in coordination with the PM and the project Health and Safety Manager.

The QA Manager is responsible for ensuring that the QA procedures and objectives in the project-specific work plans are met, reviewing field and analytical data to ensure adherence to QA/QC procedures, and approving the quality of data prior to inclusion in associated reports. This may include the performance of field and laboratory audits during the investigation. In addition, the QA Manager will be responsible for the review, evaluation, and validation of analytical data for the project and will participate in interpreting and presenting analytical data. QC coordination is under the technical guidance of the QA Manager to direct the task leaders on a day-to-day or as-needed basis to ensure the application of QA/QC procedures.

The Data Validator is responsible for analytical data evaluation and review to provide information on analytical data limitations based on specific quality control criteria. Responsibilities of the Data Validator include establishing if data meet the project technical, quality control criteria, assessing the usability and extent of bias of data not meeting the specific technical, and quality criteria. The reviewer will establish a dialogue with the data users prior to and after review to answer questions, assist with interpretation, and to provide the validation reports.

The Contract Specialist is responsible for tracking funds for labor and materials procurement and oversight of the financial status of the project. Responsibilities include:

- Preparation of monthly cost reports and invoices;
- Administration of equipment rental, material purchases, and inventory of supplies;
- Administration and negotiation of subcontracts and interaction with the Administrative Contracting Officer and Procurement Contracting Officer on contract and subcontract issues; and
- Preparation of project manpower estimates and administration of contract documents.

2.3 QUALITY ASSURANCE OBJECTIVES

QA is defined as the overall system of activities for assuring the reliability of data produced. Section 2.1, of this WPA, references investigative, chemical, and regulatory measures associated with the QA Objectives of this project. Conformance with appended SOPs will ensure attainment of QA objectives. The system integrates the quality planning, assessment, and corrective actions of various groups in the organization to provide the independent QA program necessary to establish and maintain an effective system for collection and analysis of environmental samples and related activities. The program encompasses the generation of complete data with its subsequent review, validation, and documentation.

The DQO process is a strategic planning approach to ensure environmental data is of the appropriate type, quantity, and quality for decision-making. Project-specific DQOs are included in Table 2-3 for investigative activities. The overall QA objective is to develop and implement procedures for sample and data collection, shipment, evaluation, and reporting that will allow reviewers to assess whether the field and laboratory procedures meet the criteria and endpoints established in the DQOs. DQOs are qualitative and quantitative statements that outline the decision-making process and specify the data required to support corrective actions. DQOs specify the level of uncertainty that will be accepted in results derived from environmental data. *Guidance for the Data Quality Objectives Process* (USEPA 2000b), and *Guidance for Data Quality Objectives for Hazardous Waste Sites* (USEPA 2000c) formed the basis for the DQO process and development of RFAAP data quality criteria and performance specifications.

The objectives of the SSP are to assess: 1) whether releases of hazardous substances, pollutants, contaminants, hazardous wastes, or hazardous constituents have occurred to the environment at the site, and 2) whether further investigation or action (i.e., risk assessment, RCRA Facility Investigation, interim action), or no further action (NFA) is appropriate at the site.

The DQO process consists of the seven steps specified below.

1. **State the Problem:** Define the problem to focus the study. Specific activities conducted during this process step include (1) the identification of the planning team and the primary decision-maker, (2) the statement of the problem, and (3) the identification of available resources, constraints, and deadlines.

    a) The planning team consists of the RFAAP, USACE, USEPA, VDEQ, the RFAAP operating contractor, and URS; Relative to the implementation of this WPA, the primary decision-maker is RFAAP, in consultation with USACE, USEPA, VDEQ, the RFAAP operating contractor, and URS.

    b) The following project objectives have been identified:

        i) Assess whether releases of hazardous substances, pollutants, contaminants, hazardous wastes, or hazardous constituents have occurred to the environment at the site.

        ii) Complete human health and ecological SSP risk evaluations to assess whether further investigation or action (i.e., risk assessment, RCRA Facility Investigation, interim action), or NFA is appropriate at the site.

        iii) Reach a decision regarding future action at the site.

    c) The SSP project budget has been established, the project team has been identified, and a project schedule has been developed.

2. **Identify the Decision:** Define the decision statement that the study will attempt to resolve. Activities conducted during this step of the process involve (1) identification of the principal study question(s) and (2) definition of resultant alternative actions.

    a) Principal study questions include:

        i) What are the locations and nature of waste disposal areas at the site?

        ii) What is the thickness of soil cover in waste disposal areas?

        iii) Have materials/wastes disposed of at the site commingled with surface soil and are hazardous constituents present in surface soil at levels above human health and ecological SSP criteria?

    iv) Have hazardous constituents leached from waste material disposed at the site to underlying soil and/or groundwater at levels above background levels and human health risk SSP criteria?

    v) Do hazardous constituent concentrations in soil and groundwater pose an unacceptable risk to human health or the environment considering current and planned future land uses?

  b) The resultant alternative actions include:

    i) If completion of the release assessment, human health SSP risk evaluation, and ecological SSP risk evaluation indicate that NFA is appropriate at the site, then the SSP Report will present this information.

    ii) If it is concluded from human health and ecological SSP risk evaluations that further investigation or action is required at the site, then the SSP Report will present recommendations for additional investigations, further risk assessment, or other actions.

3. **Identify Inputs to the Decision**: Identify information inputs required for resolving the decision statement and assessing which inputs require environmental measures. This step of the process includes identification of the data that will be required to make the decision, identification of the information sources, identification of data required for establishment of study action levels, and confirmation of appropriate field sampling and analytical methods. The type of information that is needed to resolve the decision statement and the sources of this information include the following:

  a) Results of an examination of site use, operational history, environmental setting, land use, and groundwater use and characteristics.

  b) Details of a visual inspection of the site and site reconnaissance for ecological assessment.

  c) Test pit and boring data.

  d) Validated results of chemical and physical analyses performed on site soil and groundwater samples.

  e) Soil (human health) – residential RBCs, industrial RBCs, and soil to groundwater SSLs in the most recent version of the EPA Region III RBC table, lead action level, and RDA for iron.

  f) Groundwater – tap water RBCs in the most recent version of the EPA Region III RBC Table, Federal Maximum Contaminant Levels (MCLs), and Virginia Water Quality Standards in 9 VAC 25-260;

  g) Soil (ecological) – EPA ecological screening levels.

  h) Laboratory MDLs and RLs for TCL organics, explosives, perchlorate (groundwater), and TAL inorganics.

4. **Define the Boundaries:** Define decision statement spatial and temporal boundaries. This step specifies (1) the spatial boundary, (2) the target population characteristics, applicable geographic areas and associated homogeneous characteristics, and (3) the constraints on sample collection.
   a) Physical boundaries of SWMUs 45 will be defined within the scope of the SSP by combining site historical data, previous site investigation findings, test pit data, soil boring data, and results of the geophysical survey, and site reconnaissance completed for this WPA;

   b) The media that will be investigated include surface soil, subsurface soil, waste, and groundwater within the SWMU area; and

   c) Practical constraints that could interfere with sampling include weather, site vegetation, boring refusal on site debris, and equipment access to test pit and boring locations.

5. **Develop a Decision Rule:** Define (1) the parameters of interest, (2) the action levels, and (3) develop a decision rule.

   a) Parameters of interest include:

      i) TCL VOCs, TCL SVOCs, TCL PCBs, TCL pesticides, explosives (including nitroglycerin and PETN), TCL dioxin/furans, perchlorate (groundwater), TAL metals (including cyanide), and chemical oxygen demand (COD);

      ii) Physical soil characteristics including: grain size analysis, Atterberg Limits, moisture content, TOC, soil bulk density, and pH;

      iii) Thickness of soil cover over fill/waste material, thickness and type of waste material;

      iv) Depth to groundwater in existing site monitoring wells;

      v) Groundwater characteristics and quality.

   b) Action levels include:

      i) Action levels for risk screening include USEPA Region III RBCs, USEPA Region III Draft BTAG screening levels, USEPA soil migration to groundwater SSLs, USEPA MCLs, Virginia State Water Control Board Water Quality Criteria, as well as the background soil metals constituent concentrations as reported in the Facility-Wide Background Study Report;

      ii) In accordance with USEPA Region III guidance, RBCs for non-carcinogenic constituents will be adjusted downward to an HQ of 0.1 to ensure that chemicals with additive effects are not prematurely eliminated during screening; and

      iii) MDLs and RLs, as specified herein, will ensure that data quality is sufficient for its intended use. The selected laboratories are within the CLP network, the proposed laboratories have been validated by USACE for the selected SW-846 Test Methods, and it is assumed that sources of analytical errors will be small and known.

c) Decision rules include:

    i) Constituents of potential concern will be identified by comparing maximum detected concentrations (or a 95% Upper Confidence Limit (UCL) if appropriate) to established action levels in order to decide the need for further evaluation, investigation, or response action;

    ii) Analytical laboratory decision rules are presented in this QAPA and the laboratory QAPs. These include specific action levels and decision rules based on accuracy and precision;

    iii) If boring refusal is encountered at less than the expected depth, then the boring will be offset five feet and advanced to the depth of previous refusal prior to collection of additional samples; and

    iv) Results of site activities will be used to refine the site conceptual model and will be used in the SSP evaluation.

6. **Specify Acceptable Limits on Decision Errors:** Specify the decision-maker's tolerable limits on decision errors. This step includes identification of (1) parameter range of interest, (2) decision errors, and (3) potential parameter values and probability tolerance for decision errors.

    a) MDLs and RLs are established for each analyte within the suite of parameters sought. MDLs and RLs below the action levels will ensure the data meet the DQOs. The contract laboratory will provide a CLP-like raw data package (Level IV). Data validation will be conducted based on this QAPA, the MQAP, the Department of Defense (DOD) Quality Systems Manual (QSM), and relevant USEPA Region III guidance.

    b) The main baseline condition decision error is to decide that the true mean concentration of a site-related contaminant does not exceed the action level for further study when in fact the mean concentration exceeds the action level and further action is needed (Type I, false rejection). Conversely, consequences of incorrectly deciding that the true mean concentration of a site-related contaminant is above the action level when in fact the mean concentration is below the action level include spending un-necessary resources to study further or remediate a site with insignificant risk (Type II, false acceptance).

    c) Information from previous studies and physical features of each area was used to develop a field sampling plan design that allows for a low probability of decision error.

7. **Optimize Data Design:** Identify data collection activities commensurate with data quality specifications. This final step in the process consists of (1) reviewing DQO outputs and existing environmental data, (2) developing data collection and design alternatives, and (3) documentation of operational details and theoretical assumptions.

    a) DQO outputs will be reviewed based on the data collection activities; the validity of the data could be verified if necessary based on the review;

    b) Data collection is based upon site-specific characteristics and the end use of the data; and

    c) This addendum contains the proposed sampling design program based on the DQOs. Project documentation will be implemented in accordance with the MWP.

Table 2-3

Summary of Project Data Quality Objectives

DQO Element	Project DQO Summary
Problem Statement	• Assess whether releases of hazardous substances, pollutants, contaminants, hazardous wastes, or hazardous constituents have occurred to the environment at the site. • Complete human health and ecological SSP risk evaluations to assess whether further investigation or action (i.e., risk assessment, RCRA Facility Investigation, interim action), or NFA is appropriate at the site. • Reach a decision regarding future action at the site.
Identify Decision/Study Question	Principal Study Questions • What are the locations of disposal areas at the site? • Have wastes disposed of at the site commingled with surface soil? • Are hazardous constituent concentrations in surface soil at levels above SSP criteria? • Have hazardous constituents leached from disposed material/waste to subsurface soil and/or groundwater at levels above SSP criteria? • Do hazardous constituent concentrations in soil and groundwater pose an unacceptable risk to human health and the environment? Resultant Alternative Actions • If completion of the release assessment, human health SSP risk evaluation, and ecological SSP risk evaluation indicate that no further action is appropriate at the site, then the SSP Report will present this information. • If it is concluded from human health and ecological SSP risk evaluations that further investigation or action is required at the site, then the SSP Report will present recommendations for additional investigations, further risk assessment, or other actions.

DQO Element	Project DQO Summary
Decision Inputs	• Results of an examination of site use, operational history, environmental setting, land use, and groundwater use and characteristics. • Details of a visual inspection of the site and site reconnaissance for ecological assessment. • Test pit, boring, and groundwater data. • Validated results of chemical and physical analyses performed on site soil and groundwater samples. • Soil (human health) – residential RBCs, industrial RBCs, and soil to groundwater SSL in the most recent version of the EPA Region III RBC table, lead action level, and recommended daily allowance (RDA) for iron. • Groundwater– tap water RBCs in the most recent version of the EPA Region III RBC Table, Federal Maximum Contaminant Levels (MCLs), and Virginia Water Quality Standards in 9 VAC 25-260. • Soil (ecological) – EPA ecological screening levels. • Laboratory MDLs and RLs for TCL organics, explosives, perchlorate (groundwater), and TAL inorganics.
Study Boundaries	• Physical boundaries of the site are defined within the scope of the SSP by combining site historical data, previous site investigation findings, soil boring information, and results of the geophysical survey and site reconnaissance completed for this WPA. • The media that will be investigated include surface soil, subsurface soil, waste, and groundwater within the site area. • Practical constraints that could interfere with sampling include weather, site vegetation, boring refusal on site debris, and equipment access to test pit and boring locations.

DQO Element	Project DQO Summary
Decision Rule	Parameters of Interest • TCL organics, TAL inorganics, explosives, and perchlorate (groundwater) • Groundwater: pH, specific conductance, dissolved oxygen, oxidation-reduction potential, and turbidity. • Physical soil: grain size, Atterberg limits, TOC, moisture content, and pH. • Depth to groundwater and groundwater flow direction. • Hydraulic conductivity of screened intervals of monitoring wells. • Groundwater flow velocity. Action Levels • Action levels for identification of COPCs include: EPA Region III RBCs, EPA Region III ecological screening levels, MCLs, Virginia Water Quality Criteria, and RFAAP background estimates for soil. • Laboratory MDLs and RLs. Low-level analytical methods have been selected to provide for the lowest achievable MDLs and RLs that, where possible, will achieve human health and ecological risk screening levels. Decision Rules • COPCs will be identified by comparing maximum detected concentrations to established risk-based screening levels in order to decide the need for further evaluation, investigation, or response action. • Complete the site screening process (SSP) for groundwater sample results. • Analytical laboratory decision rules are presented in the FLA QAP and associated laboratory QAP. These include specific action levels and decision rules based on accuracy and precision. • Results of site activities will be used to refine site conceptual models and assist in reaching decisions on future actions at sites.

DQO Element	Project DQO Summary
Tolerable Limits on Decision Errors	• MDLs and RLs are established for each analyte within the suite of parameters sought and low-level analytical methods have been selected to provide for the lowest achievable MDLs that will achieve human health and ecological risk screening levels, when possible. The contract laboratory will provide a CLP-like data package for data validation. Data validation will be conducted based on the MWP QAP, EPA national functional guidelines, and EPA Region III modifications to the national functional guidelines. • The main baseline condition decision error is to decide that the true mean concentration of a site-related contaminant does not exceed the action level for further study when in fact the mean concentration exceeds the action level and further action is needed (Type I, false rejection). Conversely, consequences of incorrectly deciding that the true mean concentration of a site-related contaminant is above the action level when in fact the mean concentration is below the action level include spending un-necessary resources to study further or remediate a site with insignificant risk (Type II, false acceptance). • Information from previous studies, physical features of the site area, and the geophysical survey conducted for this WPA were used to develop a field sampling plan design that allows for a low probability of decision error.
Optimize the Design for Obtaining Data	• DQO outputs will be reviewed based on the data collection activities; the validity of the data could be verified if necessary based on the review; • Data collection is based upon site-specific characteristics and the end use of the data; and • This addendum contains the proposed sampling design program based on the DQOs. Project documentation will be implemented in accordance with the MWP.

2.4 SAMPLE MANAGEMENT

Sample management objectives will be met through adherence to the sample identification procedures (identification convention), documentation requirements, and chain-of-custody procedures in the MWP.

2.4.1 Number and Type

Table 2-4 provides an itemization of the sample identifiers, sample depths (if applicable), and analytical parameters for environmental samples proposed during this investigation.

2.4.2 Sample Container, Preservation Method, and Holding Time Requirements

Table 2-5 identifies analytical parameters, container and preservation requirements, and holding times.

2.4.3 Sample Identification

Sample identification will consist of an alphanumeric designation related to the sampling location, media type, and sequential order according to the sampling event. The identification number will not exceed thirty-two characters for entry into Environmental Restoration Information System (ERIS). Samples will be coded in the following order to ensure a unique identification.

- **Site Location Code**: The first two characters will be the SWMU number (i.e., 45 for SWMU 45).

- **Sample/Media Type:** The next two characters will be the sample/media types. In this case, the characters will be TP for test pits, SB for soil borings, and GW for groundwater.

- **Sampling Location Number:** The next one or two characters will be the number of the sampling location (e.g., 3, 4, 5).

- **Sample Depth:** Surface samples (0 to 1 ft bgs) will be designated with an "A" after the boring number. The sample collected from intermediate depths of the boring, or from below waste/fill materials, will be designated with a "B" following the boring number. Samples collected from above groundwater or boring refusal, at the base of the boring will be designated with a "C."

- **Duplicate:** Duplicate samples will be identified with a "Dup" designation followed by a numeric designation corresponding to the sequence of duplicates collected (e.g., Dup-1). A record of the sample that corresponds to the duplicate will be kept in the field logbook. In this manner, duplicates will be submitted as blind duplicates, eliminating the potential for laboratory bias in analysis.

Sample Identification Examples:

1) A surface soil sample collected at a depth of 0 to 1 ft bgs at boring location four at SWMU 45 would be identified as sample 45SB4A (for SWMU 45, soil boring four, and "A" which stands for surface soil at that location).
2) QC Samples: QC samples will be identified by date (month, day, year), followed by QC sample type, and sequential order number at one digit. The QC sample types include Matrix Spike, Matrix Spike Duplicate (MS/MSD), Rinse Blank (R), and Trip Blank (T).

2.4.4 Documentation

SOPs 10.1 and 10.2 in Appendix A and Section 9.8 of the MQAP specify documentation protocols.

2.5 ANALYTICAL PROCEDURES

Laboratory analytical services will be subcontracted to the following laboratories:

- TriMatrix Laboratories Inc. – TCL VOCs, TCL SVOCs, TCL PCBs, TCL pesticides, explosives, TAL inorganics, TOC, and waste characterization analysis;

- Columbia Analytical Services Inc. – perchlorate analysis; and

- SGS Analytical Services – TCL dioxin/furans if required.

Analytical methods and procedures that will be used for the SSP to be conducted at SWMU 45 are discussed in the following sections. MDLs and RLs for these methods are presented in Tables 2-6 through 2-12.

Table 2-4
Summary of Proposed Sample Identifiers, Depths, and Analytical Methods
MWP Addendum 022 - SSP at SWMU 45
Radford Army Ammunition Plant, Radford, Virginia

		Chemical Analysis												Physical Analysis				
Sample ID	Depth (ft bgs)	TAL Metals/CV Mercury/Cyanide (Unfiltered) SW-846 Method 6010B/7471A/9012A	Pesticides/PCBs SW-846 Method 8081A/8082	VOCs SW-846 Method 8260B	SVOCs SW-846 Method 8270C	Perchlorate SW-846 Method 6850	Explosives/Nitroglycerin/ PETN SW-846 Method 8330m/8332	Dioxin/Furans SW-846 Method 8290 (1)	TCLP Full List	TCLP Metals	Chemical Oxygen Demand EPA Method 410.4	pH (corrosivity) SW-846 Method 9040B	Paint Filter Test SW-846 Method 9095	Grain Size ASTM D422	Atterburg Limits ASTM D4318	Moisture Content ASTM D2216	Total Organic Carbon Walkley-Black	pH ASTM D4972
Soil																		
Test Pits (1)																		
45TP1A	0-1	X	X	X	X		X							X	X	X	X	X
45TP1B	5-6*	X	X	X	X		X							X	X	X	X	X
45TP2A	0-1	X	X	X	X		X											
45TP2B	5-6*	X	X	X	X		X											
45TP3A	0-1	X	X	X	X		X							X	X	X	X	X
45TP3B	5-6*	X	X	X	X		X							X	X	X	X	X
45TP4A	0-1	X	X	X	X		X											
45TP4B	5-6*	X	X	X	X		X											
45TP5A	0-1	X	X	X	X		X											
45TP5B	5-6*	X	X	X	X		X											
45TP6A	0-1	X	X	X	X		X											
45TP6B	5-6*	X	X	X	X		X											
45TP7A	0-1	X	X	X	X		X											
45TP7B	5-6*	X	X	X	X		X											
Soil Borings(2)																		
45SB/SC1A	0-1	X	X	X	X		X											
45SB/SC1B	5-6*	X	X	X	X		X											
45SB/SC2A	0-1	X	X	X	X		X											
45SB/SC2B	5-6*	X	X	X	X		X											
45SB/SC3A	0-1	X	X	X	X		X											
45SB/SC3B	5-6*	X	X	X	X		X											
45SB/SC4A	0-1	X	X	X	X		X											
45SB/SC4B	5-6*	X	X	X	X		X											
45SB/SC5A	0-1	X	X	X	X		X											
45SB/SC5B	5-6*	X	X	X	X		X											
45SB/SC6A	0-1	X	X	X	X		X											
45SB/SC6B	5-6*	X	X	X	X		X											
45SB/SC7A	0-1	X	X	X	X		X											
45SB/SC7B	5-6*	X	X	X	X		X											
45SB/SC8A	0-1	X	X	X	X		X											
45SB/SC8B	5-6*	X	X	X	X		X											
45SB/SC9A	0-1	X	X	X	X		X											
45SB/SC9B	5-6*	X	X	X	X		X											
45SB/SC10A	0-1	X	X	X	X		X											
45SB/SC10B	5-6*	X	X	X	X		X											

Table 2-4
Summary of Proposed Sample Identifiers, Depths, and Analytical Methods
MWP Addendum 022 - SSP at SWMU 45
Radford Army Ammunition Plant, Radford, Virginia

		Chemical Analysis												Physical Analysis				
Sample ID	**Depth (ft bgs)**	**TAL Metals/CV Mercury/Cyanide (Unfiltered) SW-846 Method 6010B/7471A/9012A**	**Pesticides/PCBs SW-846 Method 8081A/8082**	**VOCs SW-846 Method 8260B**	**SVOCs SW-846 Method 8270C**	**Perchlorate SW-846 Method 6850**	**Explosives/Nitroglycerin/ PETN SW-846 Method 8330m/8332**	**Dioxin/Furans SW-846 Method 8290$^{(1)}$**	**TCLP Full List**	**TCLP Metals**	**Chemical Oxygen Demand EPA Method 410.4**	**pH (corrosivity) SW-846 Method 9040B**	**Paint Filter Test SW-846 Method 9095**	**Grain Size ASTM D422**	**Atterburg Limits ASTM D4318**	**Moisture Content ASTM D2216**	**Total Organic Carbon Walkley-Black**	**pH ASTM D4972**
Soil Borings$^{(2)}$																		
45SB/SC11A	0-1	X	X	X	X		X											
45SB/SC11B	5-6*	X	X	X	X		X											
45SB/SC12A	0-1	X	X	X	X		X											
45SB/SC12B	5-6*	X	X	X	X		X											
45SB/SC13A	0-1	X	X	X	X		X											
45SB/SC13B	5-6*	X	X	X	X		X											
45SB/SC14A	0-1	X	X	X	X		X											
45SB/SC14B	5-6*	X	X	X	X		X											
45SB/SC15A	0-1	X	X	X	X		X											
45SB/SC15B	5-6*	X	X	X	X		X											
45SB/SC16A	0-1	X	X	X	X		X											
45SB/SC16B	5-6*	X	X	X	X		X											
DUP-1	TBD	X	X	X	X		X											
DUP-2	TBD	X	X	X	X		X											
MS/MSD	TBD	X	X	X	X		X											
MS/MSD	TBD	X	X	X	X		X											
Aqueous																		
EQB1	TBD	X	X	X	X		X											
EQB2	TBD	X	X	X	X		X											
Water																		
Groundwater																		
45MW1	22	X	X	X	X	X	X											
45MW2	21	X	X	X	X	X	X											
45MW3	25	X	X	X	X	X	X											
45MW4	TBD	X	X	X	X	X	X											
DUP-3	N/A	X	X	X	X	X	X											
MS/MSD	N/A	X	X	X	X	X	X											
EQB3	N/A	X	X	X	X	X	X											
IDM																		
45IDM-SOIL	N/A						X		X			X	X					
45IDM-WATER	N/A									X	X	X						

Notes:
USEPA = U.S. Environmental Protection Agency
* = Subsurface sample depth subject to field conditions. Samples will be collected from below waste or from 5 to 6 ft bgs if waste is not present.
(1) = Up to 4 soil samples and 4 groundwater samples will be submitted for dioxin/furan analysis if burned material is encountered in test pit areas.
(2) = Chemical samples will be collected from 4 of 15 boring locations. Specific locations and depths of subsurface samples will be determined based on field conditions.
VOC = Volatile Organic Compound
SVOC = Semivolatile Organic Compound
PCB = Polychlorinated Biphenyl
PETN = Pentaerythritol Tetranitrate

Table 2-5
Summary of Sample Container, Preservation Method, and Holding Time Requirements
MWP Addendum 022 - SSP at SWMU 45
Radford Army Ammunition Plant, Radford, Virginia

PARAMETER	SAMPLE CONTAINER		PRESERVATION METHODS	HOLDING TIMES
	Quantity	Type		
SOLID SAMPLES				
TCL Volatile Organic Compounds	3	5-gram Encore samplers, zero headspace	Cool to 4 ± 2 °C; sodium bisulfate (low level), methanol (high level)	Must be analyzed within 48 hours or transferred to soil purge vial with preservative within 48 hours for analysis within 14 days
TCL Semivolatile Organic Compounds	1	500-mL wide-mouth glass container, Teflon$^{®}$-lined cap	Cool to 4 ± 2 °C	Extraction: 14 days Analysis: 40 days
TCL Pesticides	1	250-mL wide-mouth glass container, Teflon$^{®}$-lined cap	Cool to 4 ± 2 ºC	Extraction: 14 days Analysis: 40 days
TCL PCBs	1	250-mL wide-mouth glass container, Teflon$^{®}$-lined cap	Cool to 4 ± 2 ºC	Extraction: 14 days Analysis: 40 days
Explosives/Nitroglycerin/PETN	1	250-mL wide-mouth glass container, Teflon$^{®}$-lined cap	Cool to 4 ± 2 °C	Extraction: 14 days Analysis: 40 days
TAL Metals	1	250-mL wide mouth polyethylene container, Teflon$^{®}$-lined cap	Cool to 4 ± 2 °C	Metals: 6 months Mercury: 28 days
TCL Dioxin/Furans	1	250-mL wide-mouth glass container, Teflon$^{®}$-lined cap	Cool to 4 ± 2 ºC	Extraction: 14 days Analysis: 40 days
Total Organic Carbon (TOC)	1	4 Oz glass container, Teflon$^{®}$-lined cap	Cool to 4 ± 2 ºC	Analysis: 28 days
SOLID WASTE CHARACTERIZATION				
TCLP VOCs	1	125-mL wide-mouth glass vial, Teflon$^{®}$-lined cap	Cool to 4 ± 2ºC	Leaching: 14 days Analysis: 14 days
TCLP SVOCs (8270C, 8081A, & 8151A)	2	500-mL wide-mouth glass container, Teflon$^{®}$-lined cap	Cool to 4 ± 2 °C	Leaching: 14 days Extraction: 7 days Analysis: 40 days
TCLP Metals	1	250-mL wide-mouth polyethylene container, Teflon$^{®}$-lined cap	Cool to 4 ± 2 °C	Leaching: 6 months Analysis: 6 months Mercury analysis: 28 days
Explosives	1	250-mL wide-mouth glass container, Teflon$^{®}$-lined cap	Cool to 4 ± 2 °C	Extraction: 14 days Analysis: 40 days
Corrosivity, Paint Filter	1	250-mL wide-mouth glass container, Teflon$^{®}$-lined cap	Cool to 4 ± 2 °C	Corrosivity: 7 days Paint Filter: --
AQUEOUS SAMPLES				
TCL Volatile Organic Compounds	3	40-mL, glass vials, Teflon$^{®}$-lined septum cap, zero headspace	HCl to pH < 2, Cool to 4 ± 2ºC	14 days
TCL Semivolatile Organic Compounds	2	1-liter, narrow-mouth amber glass, Teflon$^{®}$-lined cap	Cool to 4 ± 2 °C	Extraction: 7 days Analysis: 40 days
TCL Pesticides	2	1-liter, narrow-mouth amber glass, Teflon$^{®}$-lined cap	Cool to 4 ± 2 °C	Extraction: 7 days Analysis: 40 days
TCL PCBs	2	1-liter, narrow-mouth amber glass, Teflon$^{®}$-lined cap	Cool to 4 ± 2 °C	Extraction: 7 days Analysis: 40 days
Explosives/Nitroglycerin/PETN	2	1-liter, narrow-mouth amber glass, Teflon$^{®}$-lined cap	Cool to 4 ± 2 °C	Extraction: 7 days Analysis: 40 days
TCL Dioxin/Furans	2	1-liter, narrow-mouth amber glass, Teflon$^{®}$-lined cap	Cool to 4 ± 2 °C	Extraction: 7 days Analysis: 40 days
Unflitered TAL Metals	1	500-mL, polyethylene container	HNO_3 to pH<2, Cool to 4 ± 2 °C	ICP: 6 months Mercury: 28 days
Perchlorate	1	125-mL, polyethylene container	Cool to 4 ± 2 °C	28 days
AQUEOUS WASTE CHARACTERIZATION				
TCLP Metals	1	500-ml, polyethylene container	Cool to 4 ± 2 °C	Leaching: 6 months Analysis: 6 months Mercury analysis: 28 days
Corrosivity	1	125-mL, polyethylene container	Cool to 4 ± 2 °C	7 days
Chemical Oxygen Demand (COD)	1	250-mL, polyethylene container	H_2SO_4 to pH<2, Cool to 4 ± 2 °C	28 days

Notes:

VOC = Volatile Organic Compound
SVOC = Semivolatile Organic Compound
TCLP = Toxicity Characteristic Leaching Procedure
COD = Chemical Oxygen Demand
PETN = Pentawrythritol Tetranitrate

TAL = Target Analyte List
TCL = Target Compound List
mL = milliliter
g = gram
ICP = Inductively Coupled Plasma

HNO_3 = Nitric Acid
H_2SO_4 = Sulfuric Acid
HCl = Hydrochloric Acid
°C = Degrees Celsius

Table 2-6
Summary of Analyte Detection Limits and Reporting Limits
TCL VOCs (by EPA Method 8260)
Soil and Water Samples
MWP Addendum 022 - SSP at SWMU 45
Radford Army Ammunition Plant, Radford, Virginia

		Laboratory-Specific Method Detection and Reporting Limits				USEPA MCLs	USEPA Region III Risk-Based Concentrations									USEPA Region III BTAG Screening Levels		
		Soil		Water			Tap Water			Soil Industrial			Soil Residential					
Compound	CAS Number	MDL mg/kg	Reporting Limit mg/kg	MDL µg/L	Reporting Limit µg/L	MCL µg/L	C/N	RBC µg/L	Adjusted RBC µg/L	C/N	RBC mg/kg	Adjusted RBC mg/kg	C/N	RBC mg/kg	Adjusted RBC mg/kg	Aqueous Fresh Water µg/L	Soil mg/kg	Sediment mg/kg
1,1,1-Trichloroethane	71-55-6	0.00041	0.005	0.150	1.0	--	N	1.7E+03	1.7E+02	N	2.9E+05	2.9E+04	N	2.2E+04	2.2E+03	1.1E+01	3.0E-01	3.0E-02
1,1,2,2-Tetrachloroethane	79-34-5	0.00030	0.005	0.120	1.0	--	C	5.3E-02	5.3E-02	C	1.4E+01	1.4E+01	C	3.2E+00	3.2E+00	6.1E+02	3.0E-01	1.4E+00
1,1,2-Trichloro-1,2,2-trifluoroethane	76-13-1	0.00033	0.005	0.150	1.0	--	N	5.9E+04	5.9E+03	N	3.1E+07	3.1E+06	N	2.3E+06	2.3E+05	--	--	--
1,1,2-Trichloroethane	79-00-5	0.00038	0.005	0.110	1.0	--	C	1.9E-01	1.9E-01	C	5.0E+01	5.0E+01	C	1.1E+01	1.1E+01	1.2E+03	3.0E-01	1.2E+00
1,1-Dichloroethane	75-34-3	0.00050	0.005	0.160	1.0	--	N	9.0E+02	9.0E+01	N	2.0E+05	2.0E+04	N	1.6E+04	1.6E+03	4.7E+01	3.0E-01	--
1,1-Dichloroethene	75-35-4	0.00049	0.005	0.130	1.0	--	N	3.5E+02	3.5E+01	N	5.1E+04	5.1E+03	N	3.9E+03	3.9E+02	2.5E+01	--	3.1E-02
1,2,3-Trichlorobenzene	87-61-6	0.00635	0.020	0.320	1.0	--	--	--	--	--	--	--	--	--	--	8.0E+00	1.0E-01	8.6E-01
1,2,4-Trichlorobenzene	120-82-1	0.00039	0.005	0.360	2.0	7.0E+01	N	6.1E+01	6.1E+00	N	1.0E+04	1.0E+03	N	7.8E+02	7.8E+01	2.4E+01	1.0E-01	2.1E+00
1,2-Dibromo-3-chloropropane	96-12-8	0.00066	0.010	0.590	5.0	--	C	2.0E-04	2.0E-04	C	3.6E+00	3.6E+00	C	2.0E-01	2.0E-01	--	--	--
1,2-Dibromoethane	106-93-4	0.00018	0.005	0.086	1.0	--	C	5.3E-03	5.3E-03	C	1.4E+00	1.4E+00	C	3.2E-01	3.2E-01	--	5.0E+00	--
1,2-Dichlorobenzene	95-50-1	0.00017	0.005	0.290	1.0	--	N	2.7E+02	2.7E+01	N	9.2E+04	9.2E+03	N	7.0E+03	7.0E+02	7.0E-01	1.0E-01	1.7E-02
1,2-Dichloroethane	107-06-2	0.00014	0.005	0.086	1.0	--	C	1.2E-01	1.2E-01	C	3.1E+01	3.1E+01	C	7.0E+00	7.0E+00	1.0E+02	8.7E+02	--
1,2-Dichloropropane	78-87-5	0.00029	0.005	0.170	1.0	5.0E+00	C	1.6E-01	1.6E-01	C	4.2E+01	4.2E+01	C	9.4E+00	9.4E+00	--	3.0E-01	--
1,3-Dichlorobenzene	541-73-1	0.00009	0.005	0.150	1.0	--	N	1.8E+01	1.8E+00	N	3.1E+03	3.1E+02	N	2.3E+02	2.3E+01	1.5E+02	--	4.4E+00
1,4-Dichlorobenzene	106-46-7	0.00017	0.005	0.260	1.0	--	C	4.7E-01	4.7E-01	C	1.2E+02	1.2E+02	C	2.7E+01	2.7E+01	2.6E+01	1.0E-01	6.0E-01
1,4-Dioxane	123-91-1	0.01000	0.050	13.100	50	--	C	6.1E+00	6.1E+00	C	2.6E+02	2.6E+02	C	5.8E+01	5.8E+01	--	--	--
2-Butanone	78-93-3	0.00290	0.020	0.570	10	--	N	7.0E+03	7.0E+02	N	6.1E+05	6.1E+04	N	4.7E+04	4.7E+03	1.4E+04	--	--
2-Hexanone	591-78-6	0.00070	0.010	0.400	10	--	--	--	--	--	--	--	--	--	--	9.9E+01	--	--
4-Methyl-2-pentanone	108-10-1	0.00064	0.010	0.190	10	--	N	6.3E+03	6.3E+02	--	--	--	--	--	--	1.7E+02	1.0E+02	--
Acetone	67-64-1	0.00500	0.020	1.100	20	--	N	5.5E+03	5.5E+02	N	9.2E+05	9.2E+04	N	7.0E+04	7.0E+03	1.5E+03	--	--
Benzene	71-43-2	0.00020	0.005	0.065	1.0	5.0E+00	C	3.4E-01	3.4E-01	C	5.2E+01	5.2E+01	C	1.2E+01	1.2E+01	3.7E+02	1.0E-01	--
Bromochloromethane	74-97-5	0.00425	0.020	0.134	1.0	--	--	--	--	--	--	--	--	--	--	--	3.0E+02	--
Bromodichloromethane	75-27-4	0.00028	0.005	0.110	1.0	8.0E+01	C	1.7E-01	1.7E-01	C	4.6E+01	4.6E+01	C	1.0E+01	1.0E+01	--	4.5E+02	--
Bromoform	75-25-2	0.00011	0.005	0.150	1.0	8.0E+01	C	8.5E+00	8.5E+00	C	3.6E+02	3.6E+02	C	8.1E+01	8.1E+01	3.2E+02	--	6.5E-01
Bromomethane	74-83-9	0.00031	0.005	0.250	1.0	--	N	8.5E+00	8.5E-01	N	1.4E+03	1.4E+02	N	1.1E+02	1.1E+01	--	--	--
Carbon disulfide	75-15-0	0.00029	0.005	0.210	5.0	--	N	1.0E+03	1.0E+02	N	1.0E+05	1.0E+04	N	7.8E+03	7.8E+02	9.2E-01	--	8.5E-04
Carbon tetrachloride	56-23-5	0.00036	0.005	0.081	1.0	5.0E+00	C	1.6E-01	1.6E-01	C	2.2E+01	2.2E+01	C	4.9E+00	4.9E+00	1.3E+01	3.0E-01	6.4E-02
Chlorobenzene	108-90-7	0.00006	0.005	0.110	1.0	1.0E+02	N	9.0E+01	9.0E+00	N	2.0E+04	2.0E+03	N	1.6E+03	1.6E+02	1.3E+00	1.0E-01	8.4E-03
Chloroethane	75-00-3	0.00530	0.020	0.160	1.0	--	C	3.6E+00	3.6E+00	C	9.9E+02	9.9E+02	C	2.2E+02	2.2E+02	--	--	--
Chloroform	67-66-3	0.00026	0.005	0.170	1.0	8.0E+01	C	1.5E-01	1.5E-01	N	1.0E+04	1.0E+03	N	7.8E+02	7.8E+01	1.8E+00	3.0E-01	--
Chloromethane	74-87-3	0.00018	0.005	0.180	1.0	--	N	1.9E+02	1.9E+01	--	--	--	--	--	--	--	--	--
cis-1,2-Dichloroethene	156-59-2	0.00022	0.005	0.160	1.0	7.0E+01	N	6.1E+01	6.1E+00	N	1.0E+04	1.0E+03	N	7.8E+02	7.8E+01	--	3.0E-01	--
cis-1,3-Dichloropropene[1]	10061-01-5	0.00026	0.005	0.072	1.0	5.0E+00	C	4.4E-01	4.4E-01	C	2.9E+01	2.9E+01	C	6.4E+00	6.4E+00	--	3.0E-01	--
Cyclohexane	110-82-7	0.00022	0.010	0.160	5.0	--	N	1.2E+04	1.2E+03	--	--	--	--	--	--	--	--	--
Dibromochloromethane	124-48-1	0.00008	0.005	0.130	1.0	6.0E+01	C	1.3E-01	1.3E-01	C	3.4E+01	3.4E+01	C	7.6E+00	7.6E+00	--	--	--
Dichlorodifluoromethane	75-71-8	0.00036	0.005	0.190	1.0	--	N	3.5E+02	3.5E+01	N	2.0E+05	2.0E+04	N	1.6E+04	1.6E+03	--	--	--
Ethylbenzene	100-41-4	0.00013	0.005	0.110	1.0	7.0E+02	N	1.3E+03	1.3E+02	N	1.0E+05	1.0E+04	N	7.8E+03	7.8E+02	9.0E+01	1.0E-01	1.1E+00
Isopropylbenzene	98-82-8	0.00024	0.005	0.078	1.0	--	N	6.6E+02	6.6E+01	N	1.0E+05	1.0E+04	N	7.8E+03	7.8E+02	2.6E+00	--	8.6E-02
Methyl acetate	79-20-9	0.00037	0.020	0.390	10	--	N	6.1E+03	6.1E+02	N	1.0E+06	1.0E+05	N	7.8E+04	7.8E+03	--	--	--
methyl tert-Butyl ether	1634-04-4	0.00025	0.005	0.074	1.0	--	C	2.6E+00	2.6E+00	C	7.2E+02	7.2E+02	C	1.6E+02	1.6E+02	1.1E+04	--	--
Methylcyclohexane	108-87-2	0.00032	0.010	0.180	5.0	--	N	6.3E+03	6.3E+02	--	--	--	--	--	--	--	--	--
Methylene chloride	75-09-2	0.00320	0.020	0.210	5.0	--	C	4.1E+00	4.1E+00	C	3.8E+02	3.8E+02	C	8.5E+01	8.5E+01	9.8E+01	3.0E-01	--
Styrene	100-42-5	0.00005	0.005	0.043	1.0	1.0E+02	N	1.6E+03	1.6E+02	N	2.0E+05	2.0E+04	N	1.6E+04	1.6E+03	7.2E+01	1.0E-01	5.6E-01
Tetrachloroethene	127-18-4	0.00016	0.005	0.130	1.0	5.0E+00	C	1.0E-01	1.0E-01	C	5.3E+00	5.3E+00	C	1.2E+00	1.2E+00	1.1E+02	3.0E-01	4.7E-01
Toluene	108-88-3	0.00040	0.005	0.260	1.0	1.0E+03	N	2.3E+03	2.3E+02	N	8.2E+04	8.2E+03	N	6.3E+03	6.3E+02	2.0E+00	1.0E-01	--
trans-1,2-Dichloroethene	156-60-5	0.00016	0.005	0.150	1.0	1.0E+02	N	1.1E+02	1.1E+01	N	2.0E+04	2.0E+03	N	1.6E+03	1.6E+02	9.7E+02	3.0E-01	1.1E+00
trans-1,3-Dichloropropene[1]	10061-02-6	0.00028	0.005	0.087	1.0	--	C	4.4E-01	4.4E-01	C	2.9E+01	2.9E+01	C	6.4E+00	6.4E+00	--	3.0E-01	--
Trichloroethene	79-01-6	0.00013	0.005	0.140	1.0	5.0E+00	C	2.6E-02	2.6E-02	C	7.2E+00	7.2E+00	C	1.6E+00	1.6E+00	2.1E+01	3.0E-01	9.7E-02
Trichlorofluoromethane	75-69-4	0.00038	0.005	0.160	1.0	--	N	1.3E+03	1.3E+02	N	3.1E+05	3.1E+04	N	2.3E+04	2.3E+03	--	--	--
Vinyl Chloride[2]	75-01-4	0.00013	0.005	0.150	1.0	2.0E+00	C	1.5E-02	1.5E-02	--	--	--	C	9.0E-02	9.0E-02	9.3E+02	3.0E-01	--
Xylenes	1330-20-7	0.00025	0.005	0.250	3.0	1.0E+04	N	2.1E+02	2.1E+01	N	2.0E+05	2.0E+04	N	1.6E+04	1.6E+03	1.3E+01	1.0E-01	--

Table 2-6
Summary of Analyte Detection Limits and Reporting Limits
TCL VOCs (by EPA Method 8260)
Soil and Water Samples
MWP Addendum 022 - SSP at SWMU 45
Radford Army Ammunition Plant, Radford, Virginia

Notes:

CAS = Chemical Abstract Service
mg/kg = Milligram Per kilogram
µg/L = Microgram Per liter
TCL = Target Compound List
VOC = Volatile Organic Compound
MDL = Method Detection Limit
RL = Reporting Limit
Method Detection and Reporting Limits Provided by TriMatrix
-- = No Risk Criteria Available
MCL = Maximum Contaminant Level
BTAG = Biological Technical Assistance Group
    Soil - BTAG Screening Draft Values, 1995
    Water - BTAG Freshwater Screening Values, 2004
    Sediment - BTAG Sediment Screening Values, 2004

RBC = USEPA Region III Risk-Based Concentration
    (RBC) values from the April 6, 2007,
    RBC Table and April 10, 2007, Alternate RBC Table
Adjusted RBCs = a Hazard Quotient (HQ) of 0.1 applied to non-carcinogens
C/N = Carcinogenic/Noncarcinogenic status per EPA RBC Table (April 2007)
C = Carcinogenic
C!/N= Carcinogenic RBC/Non-carcinogenic Adjusted RBC taken from Alternate RBC table; see USEPA Region III guidance
N = Non-Carcinogenic
[1] = RBC value is for 1,3-Dichloropropene
[2] = RBCs presented are for early-life, except industrial soil RBC, which is for adult

▨ = Reporting limit was not low enough to meet screening criteria - but MDL does

Table 2-7
Summary of Analyte Detection Limits and Reporting Limits
TCL SVOCs (by EPA Method 8270C)
Soil and Water Samples
MWP Addendum 022 - SSP at SWMU 45
Radford Army Ammunition Plant, Radford, Virginia

		Laboratory-Specific Method Detection and Reporting Limits				USEPA MCLs	USEPA Region III Risk-Based Concentrations									USEPA Region III BTAG Screening Levels		
		Soil		Water			Tap Water			Soil Industrial			Soil Residential			Aqueous Fresh Water	Soil	Sediment
	CAS Number	MDL	Reporting Limit	MDL	Reporting Limit	MCL		RBC	Adjusted RBC		RBC	Adjusted RBC		RBC	Adjusted RBC			
Compound		mg/kg	mg/kg	µg/L	µg/L	µg/L	C/N	µg/L	µg/L	C/N	mg/kg	mg/kg	C/N	mg/kg	mg/kg	µg/L	mg/kg	mg/kg
1,1'-Biphenyl	92-52-4	0.0042	0.17	0.024	5.0	--	N	3.0E+02	3.0E+01	N	5.1E+04	5.1E+03	N	3.9E+03	3.9E+02	1.4E+01	--	1.2E+00
1,2,4,5-Tetrachlorobenzene	95-94-3	0.0008	0.17	0.025	5.0	--	N	1.1E+01	1.1E+00	N	3.1E+02	3.1E+01	N	2.3E+01	2.3E+00	3.0E+00	1.0E-01	1.1E+00
2,2'-oxybis(1-Chloropropane)	108-60-1	0.0043	0.17	0.047	5.0	--	C	2.6E-01	2.6E-01	C	4.1E+01	4.1E+01	C	9.1E+00	9.1E+00	--	--	--
2,4,5-Trichlorophenol	95-95-4	0.0033	0.17	0.030	5.0	--	N	3.7E+03	3.7E+02	N	1.0E+05	1.0E+04	N	7.8E+03	7.8E+02	--	1.0E-01	--
2,4,6-Trichlorophenol	88-06-2	0.0032	0.17	0.025	5.0	--	C	6.1E+00	6.1E+00	C	2.6E+02	2.6E+02	C	5.8E+01	5.8E+01	4.9E+00	1.0E-01	2.1E-01
2,4-Dichlorophenol	120-83-2	0.0035	0.17	0.022	5.0	--	N	1.1E+02	1.1E+01	N	3.1E+03	3.1E+02	N	2.3E+02	2.3E+01	1.1E+01	1.0E-01	1.2E-01
2,4-Dimethylphenol	105-67-9	0.0099	0.17	0.540	5.0	--	N	7.3E+02	7.3E+01	N	2.0E+04	2.0E+03	N	1.6E+03	1.6E+02	--	1.0E-01	2.9E-02
2,4-Dinitrophenol	51-28-5	0.0052	0.33	0.210	5.0	--	N	7.3E+01	7.3E+00	N	2.0E+03	2.0E+02	N	1.6E+02	1.6E+01	--	1.0E-01	--
2,4-Dinitrotoluene	121-14-2	0.0037	0.17	0.036	5.0	--	N	7.3E+01	7.3E+00	N	2.0E+03	2.0E+02	N	1.6E+02	1.6E+01	4.4E+01	--	4.2E-02
2,6-Dinitrotoluene	606-20-2	0.0013	0.17	0.075	5.0	--	N	3.7E+01	3.7E+00	N	1.0E+03	1.0E+02	N	7.8E+01	7.8E+00	8.1E+01	--	--
2-Chloronaphthalene	91-58-7	0.0025	0.17	0.012	5.0	--	N	4.9E+02	4.9E+01	N	8.2E+04	8.2E+03	N	6.3E+03	6.3E+02	--	--	--
2-Chlorophenol	95-57-8	0.0038	0.17	0.028	5.0	--	N	3.0E+01	3.0E+00	N	5.1E+03	5.1E+02	N	3.9E+02	3.9E+01	2.4E+01	1.0E-01	3.1E-02
2-Methylnaphthalene	91-57-6	0.0031	0.17	0.022	5.0	--	N	2.4E+01	2.4E+00	N	4.1E+03	4.1E+02	N	3.1E+02	3.1E+01	4.7E+00	--	2.0E-02
2-Methylphenol	95-48-7	0.0048	0.17	0.450	5.0	--	N	1.8E+03	1.8E+02	N	5.1E+04	5.1E+03	N	3.9E+03	3.9E+02	1.3E+01	1.0E-01	--
2-Nitroaniline	88-74-4	0.0046	0.17	0.280	5.0	--	--	--	--	--	--	--	--	--	--	--	--	--
2-Nitrophenol	88-75-5	0.0056	0.17	0.038	5.0	--	--	--	--	--	--	--	--	--	--	1.9E+03	--	--
3,3'-Dichlorobenzidine	91-94-1	0.0550	0.17	0.048	5.0	--	C	1.5E-01	1.5E-01	C	6.4E+00	6.4E+00	C	1.4E+00	1.4E+00	4.5E+00	--	1.3E-01
3-Nitroaniline	99-09-2	0.0120	0.17	0.710	5.0	--	--	--	--	--	--	--	--	--	--	--	--	--
4,6-Dinitro-2-methylphenol	534-52-1	0.0045	0.17	0.240	5.0	--	--	--	--	--	--	--	--	--	--	--	--	--
4-Bromophenyl-phenylether	101-55-3	0.0034	0.17	0.039	5.0	--	--	--	--	--	--	--	--	--	--	1.5E+00	--	1.2E+00
4-Chloro-3-Methylphenol	59-50-7	0.0052	0.17	0.024	5.0	--	--	--	--	--	--	--	--	--	--	--	--	--
4-Chloroaniline	106-47-8	0.0014	0.17	0.930	5.0	--	N	1.5E+02	1.5E+01	N	4.1E+03	4.1E+02	N	3.1E+02	3.1E+01	2.3E+02	--	--
4-Chlorophenyl-phenylether	7005-72-3	0.0049	0.17	0.029	5.0	--	--	--	--	--	--	--	--	--	--	--	--	0.0E+00
4-Methylphenol	106-44-5	0.0064	0.17	0.380	5.0	--	N	1.8E+02	1.8E+01	N	5.1E+03	5.1E+02	N	3.9E+02	3.9E+01	5.4E+02	1.0E-01	6.7E-01
4-Nitroaniline	100-01-6	0.0072	0.17	0.450	5.0	--	--	--	--	--	--	--	--	--	--	--	--	--
4-Nitrophenol	100-02-7	0.0055	0.33	0.440	5.0	--	--	--	--	--	--	--	--	--	--	6.0E+01	1.0E-01	--
Acenaphthene	83-32-9	0.0041	0.17	0.021	5.0	--	N	3.7E+02	3.7E+01	N	6.1E+04	6.1E+03	N	4.7E+03	4.7E+02	5.8E+00	1.0E-01	6.7E-03
Acenaphthylene [1]	208-96-8	0.0036	0.17	0.038	5.0	--	N	1.8E+02	1.8E+01	N	3.1E+04	3.1E+03	N	2.3E+03	2.3E+02	--	1.0E-01	5.9E-03
Acetophenone	98-86-2	0.0052	0.17	0.033	5.0	--	N	6.1E+02	6.1E+01	N	1.0E+05	1.0E+04	N	7.8E+03	7.8E+02	--	--	--
Anthracene	120-12-7	0.0046	0.17	0.030	5.0	--	N	1.8E+03	1.8E+02	N	3.1E+05	3.1E+04	N	2.3E+04	2.3E+03	1.2E-02	1.0E-01	5.7E-02
Atrazine	1912-24-9	0.0069	0.17	0.087	5.0	3.0E+00	C	3.0E-01	3.0E-01	C	1.3E+01	1.3E+01	C	2.9E+00	2.9E+00	1.8E+00	--	6.6E-03
Benzaldehyde	100-52-7	0.0084	0.17	0.056	5.0	--	N	3.7E+03	3.7E+02	N	1.0E+05	1.0E+04	N	7.8E+03	7.8E+02	--	--	--
Benzo(a)anthracene	56-55-3	0.0030	0.17	0.058	5.0	--	C	3.0E-02	3.0E-02	C	3.9E+00	3.9E+00	C	2.2E-01	2.2E-01	1.8E-02	1.0E-01	1.1E-01
Benzo(a)pyrene	50-32-8	0.0057	0.17	0.031	5.0	2.0E-01	C	3.0E-03	3.0E-03	C	3.9E-01	3.9E-01	C	2.2E-02	2.2E-02	1.5E-02	1.0E-01	1.5E-01
Benzo(b)fluoranthene	205-99-2	0.0098	0.17	0.038	5.0	--	C	3.0E-02	3.0E-02	C	3.9E+00	3.9E+00	C	2.2E-01	2.2E-01	--	1.0E-01	--
Benzo(g,h,i)perylene [1]	191-24-2	0.0087	0.17	0.030	5.0	--	N	1.8E+02	1.8E+01	N	3.1E+04	3.1E+03	N	2.3E+03	2.3E+02	--	1.0E-01	1.7E-01
Benzo(k)fluoranthene	207-08-9	0.0022	0.17	0.048	5.0	--	C	3.0E-01	3.0E-01	C	3.9E+01	3.9E+01	C	2.2E+00	2.2E+00	--	1.0E-01	2.4E-01
Bis(2-chloroethoxy)methane	111-91-1	0.0031	0.17	0.022	5.0	--	--	--	--	--	--	--	--	--	--	--	--	--
Bis(2-chloroethyl)ether	111-44-4	0.0048	0.17	0.039	5.0	--	C	9.6E-03	9.6E-03	C	2.6E+00	2.6E+00	C	5.8E-01	5.8E-01	--	--	--
Bis(2-ethylhexyl)phthalate	117-81-7	0.0041	0.17	0.500	5.0	6.0E+00	C	4.8E+00	4.8E+00	C	2.0E+02	2.0E+02	C	4.6E+01	4.6E+01	1.6E+01	--	1.8E-01
Butylbenzylphthalate	85-68-7	0.0047	0.17	0.760	5.0	--	N	7.3E+03	7.3E+02	N	2.0E+05	2.0E+04	N	1.6E+04	1.6E+03	1.9E+01	--	1.1E+01
Caprolactam	105-60-2	0.0130	0.33	0.770	5.0	--	N	1.8E+04	1.8E+03	N	5.1E+05	5.1E+04	N	3.9E+04	3.9E+03	--	--	--
Carbazole	86-74-8	0.0061	0.17	0.032	5.0	--	C	3.3E+00	3.3E+00	C	1.4E+02	1.4E+02	C	3.2E+01	3.2E+01	--	--	--
Chrysene	218-01-9	0.0028	0.17	0.030	5.0	--	C	3.0E+00	3.0E+00	C	3.9E+02	3.9E+02	C	2.2E+01	2.2E+01	--	1.0E-01	1.7E-01
Dibenz(a,h)anthracene	53-70-3	0.0059	0.17	0.019	5.0	--	C	3.0E-03	3.0E-03	C	3.9E-01	3.9E-01	C	2.2E-02	2.2E-02	--	1.0E-01	3.3E-02
Dibenzofuran	132-64-9	0.0032	0.17	0.014	5.0	--	--	--	--	--	--	--	--	--	--	3.7E+00	--	4.2E-01
Diethylphthalate	84-66-2	0.0034	0.17	0.052	5.0	--	N	2.9E+04	2.9E+03	N	8.2E+05	8.2E+04	N	6.3E+04	6.3E+03	2.1E+02	--	6.0E-01
Dimethylphthalate	131-11-3	0.0036	0.17	0.020	5.0	--	--	--	--	--	--	--	--	--	--	--	--	--
Di-n-butylphthalate	84-74-2	0.0088	0.17	0.810	5.0	--	N	3.7E+03	3.7E+02	N	1.0E+05	1.0E+04	N	7.8E+03	7.8E+02	1.9E+01	--	6.5E+00
Di-n-octylphthalate	117-84-0	0.0038	0.17	0.041	5.0	--	--	--	--	--	--	--	--	--	--	2.2E+01	--	--
Fluoranthene	206-44-0	0.0028	0.17	0.033	5.0	--	N	1.5E+03	1.5E+02	N	4.1E+04	4.1E+03	N	3.1E+03	3.1E+02	4.0E-02	1.0E-01	4.2E-01

Table 2-7
Summary of Analyte Detection Limits and Reporting Limits
TCL SVOCs (by EPA Method 8270C)
Soil and Water Samples
MWP Addendum 022 - SSP at SWMU 45
Radford Army Ammunition Plant, Radford, Virginia

		Laboratory-Specific Method Detection and Reporting Limits				USEPA MCLs	USEPA Region III Risk-Based Concentrations									USEPA Region III BTAG Screening Levels		
		Soil		Water			Tap Water			Soil Industrial			Soil Residential					
Compound	CAS Number	MDL	Reporting Limit	MDL	Reporting Limit	MCL	C/N	RBC	Adjusted RBC	C/N	RBC	Adjusted RBC	C/N	RBC	Adjusted RBC	Aqueous Fresh Water	Soil	Sediment
		mg/kg	mg/kg	µg/L	µg/L	µg/L		µg/L	µg/L		mg/kg	mg/kg		mg/kg	mg/kg	µg/L	mg/kg	mg/kg
Fluorene	86-73-7	0.0051	0.17	0.027	5.0	--	N	2.4E+02	2.4E+01	N	4.1E+04	4.1E+03	N	3.1E+03	3.1E+02	3.0E+00	1.0E-01	7.7E-02
Hexachlorobenzene	118-74-1	0.0047	0.17	0.033	5.0	1.0E+00	C	4.2E-02	4.2E-02	C	1.8E+00	1.8E+00	C	4.0E-01	4.0E-01	3.0E-04	--	2.0E-02
Hexachlorobutadiene	87-68-3	0.0039	0.17	0.015	5.0	--	C!/N	8.6E-01	7.3E-01	C!/N	3.7E+01	2.0E+01	C!/N	8.2E+00	1.6E+00	1.3E+00	--	--
Hexachlorocyclopentadiene	77-47-4	0.0038	0.17	0.240	5.0	5.0E+01	N	2.2E+02	2.2E+01	N	6.1E+03	6.1E+02	N	4.7E+02	4.7E+01	--	--	--
Hexachloroethane	67-72-1	0.0051	0.17	0.029	5.0	--	C!/N	4.8E+00	3.7E+00	C!/N	2.0E+02	1.0E+02	C!/N	4.6E+01	7.8E+00	1.2E+01	--	1.0E+00
Indeno(1,2,3-cd)pyrene	193-39-5	0.0039	0.17	0.021	5.0	--	C	3.0E-02	3.0E-02	C	3.9E+00	3.9E+00	C	2.2E-01	2.2E-01	--	1.0E-01	1.7E-02
Isophorone	78-59-1	0.0024	0.17	0.025	5.0	--	C	7.0E+01	7.0E+01	C	3.0E+03	3.0E+03	C	6.7E+02	6.7E+02	--	--	--
Naphthalene	91-20-3	0.0032	0.17	0.022	5.0	--	N	6.5E+00	6.5E-01	N	2.0E+04	2.0E+03	N	1.6E+03	1.6E+02	1.1E+00	1.0E-01	1.8E-01
Nitrobenzene	98-95-3	0.0048	0.17	0.053	5.0	--	N	3.5E+00	3.5E-01	N	5.1E+02	5.1E+01	N	3.9E+01	3.9E+00	--	--	--
N-Nitrosodi-n-propylamine	621-64-7	0.0042	0.17	0.037	5.0	--	C	9.6E-03	9.6E-03	C	4.1E-01	4.1E-01	C	9.1E-02	9.1E-02	--	--	--
N-Nitrosodiphenylamine	86-30-6	0.0048	0.17	0.037	5.0	--	C	1.4E+01	1.4E+01	C	5.8E+02	5.8E+02	C	1.3E+02	1.3E+02	2.1E+02	--	2.7E+00
Pentachlorophenol	87-86-5	0.0044	0.33	0.061	5.0	1.0E+00	C	5.6E-01	5.6E-01	C	2.4E+01	2.4E+01	C	5.3E+00	5.3E+00	5.0E-01	1.0E-01	5.0E-01
Phenanthrene [1]	85-01-8	0.0028	0.17	0.033	5.0	--	N	1.8E+02	1.8E+01	N	3.1E+04	3.1E+03	N	2.3E+03	2.3E+02	4.0E-01	1.0E-01	2.0E-01
Phenol	108-95-2	0.0060	0.17	0.055	5.0	--	N	1.1E+04	1.1E+03	N	3.1E+05	3.1E+04	N	2.3E+04	2.3E+03	4.0E+00	1.0E-01	4.2E-01
Pyrene	129-00-0	0.0032	0.17	0.044	5.0	--	N	1.8E+02	1.8E+01	N	3.1E+04	3.1E+03	N	2.3E+03	2.3E+02	2.5E-02	1.0E-01	2.0E-01

Notes:

CAS = Chemical Abstract Service
mg/kg = Milligram Per kilogram
µg/L = Microgram Per liter
TCL = Target Compound List
VOC = Volatile Organic Compound
MDL = Method Detection Limit
RL = Reporting Limit
Method Detection and Reporting Limits Provided by TriMatrix
-- = No Risk Criteria Available
MCL = Maximum Contaminant Level
BTAG = Biological Technical Assistance Group
Soil - BTAG Screening Draft Values, 1995
Water - BTAG Freshwater Screening Values, 2004
Sediment - BTAG Sediment Screening Values, 2004

RBC = USEPA Region III Risk-Based Concentration
(RBC) values from the April 6, 2007,
RBC Table and April 10, 2007, Alternate RBC Table
Adjusted RBCs = a Hazard Quotient (HQ) of 0.1 applied to non-carcinogens
C/N = Carcinogenic/Noncarcinogenic status per EPA RBC Table (April 2007)
C = Carcinogenic
C!/N= Carcinogenic RBC/Non-carcinogenic Adjusted RBC taken from Alternate RBC table; see USEPA Region III guidance
N = Non-Carcinogenic
[1] = RBC value for pyrene was used for these compounds

▨ = Reporting limit was not low enough to meet screening criteria - but MDL does

Table 2-8
Summary of Analyte Detection Limits and Reporting Limits
TCL Pesticides (EPA Method 8081A) and Herbicides (EPA Method 8151A)
Soil and Water Samples
MWP Addendum 022 - SSP at SWMU 45
Radford Army Ammunition Plant, Radford, Virginia

		Laboratory-Specific Method Detection and Reporting Limits				USEPA MCLs	USEPA Region III Risk-Based Concentrations									USEPA Region III BTAG Screening Levels		
		Soil		Water			Tap Water			Soil Industrial			Soil Residential					
	CAS Number	MDL	Reporting Limit	MDL	Reporting Limit	MCL	C/N	RBC	Adjusted RBC	C/N	RBC	Adjusted RBC	C/N	RBC	Adjusted RBC	Aqueous Fresh Water	Soil	Sediment
Compounds by Method 8081A		mg/kg	mg/kg	µg/L	µg/L	µg/L		µg/L	µg/L		mg/kg	mg/kg		mg/kg	mg/kg	µg/L	mg/kg	mg/kg
4,4'-DDD	72-54-8	0.00110	0.0033	0.0036	0.10	--	C	2.8E-01	2.8E-01	C	1.2E+01	1.2E+01	C	2.7E+00	2.7E+00	1.1E-02	1.0E-01	4.9E-03
4,4'-DDE	72-55-9	0.00090	0.0033	0.0036	0.10	--	C	2.0E-01	2.0E-01	C	8.4E+00	8.4E+00	C	1.9E+00	1.9E+00	--	1.0E-01	3.2E-03
4,4'-DDT	50-29-3	0.00100	0.0033	0.0036	0.10	--	C	2.0E-01	2.0E-01	C	8.4E+00	8.4E+00	C	1.9E+00	1.9E+00	1.0E-03	1.0E-01	--
Aldrin	309-00-2	0.00054	0.0017	0.0027	0.05	--	C	3.9E-03	3.9E-03	C	1.7E-01	1.7E-01	C	3.8E-02	3.8E-02	3.0E+00	1.0E-01	2.0E-03
alpha-BHC	319-84-6	0.00035	0.0017	0.0034	0.05	--	C	1.1E-02	1.1E-02	C	4.5E-01	4.5E-01	C	1.0E-01	1.0E-01	--	1.0E+02	6.0E-03
alpha-Chlordane[1]	5103-71-9	0.00068	0.0033	0.0033	0.05	--	C	1.9E-01	1.9E-01	C	8.2E+00	8.2E+00	C	1.8E+00	1.8E+00	--	1.0E-01	--
gamma-Chlordane[1]	5103-74-2	0.00067	0.0033	0.0030	0.05	--	C	1.9E-01	1.9E-01	C	8.2E+00	8.2E+00	C	1.8E+00	1.8E+00	--	1.0E-01	--
beta-BHC	319-85-7	0.00094	0.0033	0.0031	0.05	--	C	3.7E-02	3.7E-02	C	1.6E+00	1.6E+00	C	3.5E-01	3.5E-01	--	1.0E+02	5.0E-03
delta-BHC[2]	319-86-8	0.00046	0.0033	0.0032	0.10	--	C	1.1E-02	1.1E-02	C	4.5E-01	4.5E-01	C	1.0E-01	1.0E-01	1.4E+02	1.0E+02	6.4E+00
Dieldrin	60-57-1	0.00090	0.0033	0.0028	0.05	--	C	4.2E-03	4.2E-03	C	1.8E-01	1.8E-01	C	4.0E-02	4.0E-02	5.6E-02	1.0E-01	1.9E-03
Endosulfan I[3]	959-98-8	0.00085	0.0033	0.0031	0.10	--	N	2.2E+02	2.2E+01	N	6.1E+03	6.1E+02	N	4.7E+02	4.7E+01	5.1E-02	--	2.9E-03
Endosulfan II[3]	33213-65-9	0.00100	0.0033	0.0041	0.10	--	N	2.2E+02	2.2E+01	N	6.1E+03	6.1E+02	N	4.7E+02	4.7E+01	5.1E-02	--	1.4E-02
Endosulfan sulfate	1031-07-8	0.00054	0.0033	0.0029	0.10	--	N	2.2E+02	2.2E+01	N	6.1E+03	6.1E+02	N	4.7E+02	4.7E+01	--	--	5.4E-03
Endrin	72-20-8	0.00100	0.0033	0.0037	0.10	2.0E+00	N	1.1E+01	1.1E+00	N	3.1E+02	3.1E+01	N	2.3E+01	2.3E+00	3.6E-02	1.0E-01	2.2E-03
Endrin aldehyde[4]	7421-93-4	0.00100	0.0033	0.0045	0.10	--	N	1.1E+01	1.1E+00	N	3.1E+02	3.1E+01	N	2.3E+01	2.3E+00	--	1.0E-01	--
Endrin ketone[4]	53494-70-5	0.00064	0.0033	0.0026	0.05	--	N	1.1E+01	1.1E+00	N	3.1E+02	3.1E+01	N	2.3E+01	2.3E+00	--	1.0E-01	--
gamma-BHC (Lindane)	58-89-9	0.00047	0.0017	0.0034	0.05	2.0E-01	C	5.2E-02	5.2E-02	C	2.2E+00	2.2E+00	C	4.9E-01	4.9E-01	--	1.0E-01	--
Heptachlor	76-44-8	0.00120	0.0067	0.0030	0.05	4.0E-01	C	1.5E-02	1.5E-02	C	6.4E-01	6.4E-01	C	1.4E-01	1.4E-01	3.8E-03	1.0E-01	6.8E-02
Heptachlor epoxide	1024-57-3	0.00041	0.0017	0.0031	0.05	2.0E-01	C	7.4E-03	7.4E-03	C	3.1E-01	3.1E-01	C	7.0E-02	7.0E-02	3.8E-03	1.0E-01	2.5E-03
Methoxychlor	72-43-5	0.00130	0.0170	0.0036	0.50	4.0E+01	N	1.8E+02	1.8E+01	N	5.1E+03	5.1E+02	N	3.9E+02	3.9E+01	1.9E-02	1.0E-01	1.9E-02
Toxaphene	8001-35-2	0.02200	0.1700	0.1000	5.0	3.0E+00	C	6.1E-02	6.1E-02	C	2.6E+00	2.6E+00	C	5.8E-01	5.8E-01	2.0E-04	--	1.0E-03
Compounds by Method 8151A																		
2,4,5,-T	93-76-5	0.0018	0.050	0.052	5.0	--	N	3.7E+02	3.7E+01	N	1.0E+04	1.0E+03	N	7.8E+02	7.8E+01	6.9E+02	--	1.2E+01
2,4,5-TP (Silvex)	93-72-1	0.0015	0.050	0.040	5.0	5.0E+01	N	2.9E+02	2.9E+01	N	8.2E+03	8.2E+02	N	6.3E+02	6.3E+01	3.0E+01	--	6.8E-01
2,4-D	94-75-7	0.0079	0.200	0.340	5.0	7.0E+01	N	3.7E+02	3.7E+01	N	1.0E+04	1.0E+03	N	7.8E+02	7.8E+01		--	--
2,4-DB	94-82-6	0.0200	0.200	0.340	2.0	--	N	2.9E+02	2.9E+01	N	8.2E+03	8.2E+02	N	6.3E+02	6.3E+01	--	--	--
Dalapon	75-99-0	0.0190	0.200	0.660	2.0	2.0E+02	N	1.1E+03	1.1E+02	N	3.1E+04	3.1E+03	N	2.3E+03	2.3E+02	--	--	--
Dicamba	1918-00-9	0.0015	0.200	0.049	0.50	--	N	1.1E+03	1.1E+02	N	3.1E+04	3.1E+03	N	2.3E+03	2.3E+02	--	--	--
Dichlorprop	120-36-5	0.0064	0.200	0.420	2.0	--	--	--	--	--	--	--	--	--	--	--	--	--
Dinoseb	88-85-7	0.0021	0.200	0.290	1.0	7.0E+00	N	3.7E+01	3.7E+00	N	1.0E+03	1.0E+02	N	7.8E+01	7.8E+00	5.0E-02	--	6.1E-04
MCPA	94-74-6	0.4700	8.300	61.00	200	--	N	1.8E+01	1.8E+00	N	5.1E+02	5.1E+01	N	3.9E+01	3.9E+00	--	--	--
MCPP	93-65-2	0.9400	8.300	61.00	200	--	N	3.7E+01	3.7E+00	N	1.0E+03	1.0E+02	N	7.8E+01	7.8E+00	--	--	--

Notes:

CAS = Chemical Abstract Service
mg/kg = Milligram Per kilogram
µg/L = Microgram Per liter
TCL = Target Compound List
MDL = Method Detection Limit
RL = Reporting Limit
Method Detection and Reporting Limits Provided by TriMatrix
-- = No Risk Criteria Available
MCL = Maximum Contaminant Level
BTAG = Biological Technical Assistance Group
Soil - BTAG Screening Draft Values, 1995
Water - BTAG Freshwater Screening Values, 2004
Sediment - BTAG Sediment Screening Values, 2004

RBC = USEPA Region III Risk-Based Concentration
(RBC) values from the April 6, 2007,
RBC Table and April 10, 20076, Alternate RBC Table
Adjusted RBCs = a Hazard Quotient (HQ) of 0.1 applied to non-carcinogens
C/N = Carcinogenic/Noncarcinogenic status per EPA RBC Table (April 2007)
C = Carcinogenic
C!/N= Carcinogenic RBC/Non-carcinogenic Adjusted RBC taken from Alternate RBC table; see USEPA Region III guidance
N = Non-Carcinogenic
[1] = Chlordane RBC value was used
[2] = alpha-BHC RBC value was used
[3] = Endosulfan RBC value was used
[4] = Endrin RBC value was used

▨ = Reporting limit was not low enough to meet screening criteria - but MDL does

Table 2-9

Summary of Analyte Detection Limits and Reporting Limits

TCL PCBs (EPA Method 8082)

and Perchlorate (EPA Method 6850)

Soil and Water Samples

MWP Addendum 022 - SSP at SWMU 45

Radford Army Ammunition Plant, Radford, Virginia

		Laboratory-Specific Method Detection and Reporting Limits				USEPA MCLs	USEPA Region III Risk-Based Concentrations									USEPA Region III BTAG Screening Levels		
		Soil		Water			Tap Water			Soil Industrial			Soil Residential					
	CAS	MDL	Reporting Limit	MDL	Reporting Limit	MCL		RBC	Adjusted RBC		RBC	Adjusted RBC		RBC	Adjusted RBC	Aqueous Fresh Water	Soil	Sediment
Compound	Number	mg/kg	mg/kg	µg/L	µg/L	µg/L	C/N	µg/L	µg/L	C/N	mg/kg	mg/kg	C/N	mg/kg	mg/kg	µg/L	mg/kg	mg/kg
Aroclor 1016	12674-11-2	0.0043	0.033	0.046	0.2	0.5	C!/N	9.6E-01	2.6E-01	C!/N	4.1E+01	7.2E+00	N	5.5E+00	5.5E-01	7.4E-05	1.0E-01	--
Aroclor 1221	11104-28-2	0.0120	0.067	0.0530	0.2	0.5	C	3.3E-02	3.3E-02	C	1.4E+00	1.4E+00	C	3.2E-01	3.2E-01	7.4E-05	1.0E-01	--
Aroclor 1232	11141-16-5	0.0045	0.033	0.05	0.2	0.5	C	3.3E-02	3.3E-02	C	1.4E+00	1.4E+00	C	3.2E-01	3.2E-01	7.4E-05	1.0E-01	--
Aroclor 1242	53469-21-9	0.0062	0.033	0.053	0.2	0.5	C	3.3E-02	3.3E-02	C	1.4E+00	1.4E+00	C	3.2E-01	3.2E-01	7.4E-05	1.0E-01	--
Aroclor 1248	12672-29-6	0.0037	0.033	0.024	0.2	0.5	C	3.3E-02	3.3E-02	C	1.4E+00	1.4E+00	C	3.2E-01	3.2E-01	7.4E-05	1.0E-01	--
Aroclor 1254	11097-69-1	0.0060	0.033	0.038	0.2	0.5	C	3.3E-02	3.3E-02	C	1.4E+00	1.4E+00	C!/N	3.2E-01	1.6E-01	7.4E-05	1.0E-01	--
Aroclor 1260	11096-82-5	0.0044	0.033	0.045	0.2	0.5	C	3.3E-02	3.3E-02	C	1.4E+00	1.4E+00	C	3.2E-01	3.2E-01	7.4E-05	1.0E-01	--
Aroclor 1262	37324-23-5	0.0100	0.066	0.055	0.2	0.5	--	--	--	--	--	--	--	--	--	--	--	--
Aroclor 1268	11100-14-4	0.0060	0.066	0.0368	0.2	0.5	--	--	--	--	--	--	--	--	--	--	--	--
Perchlorate																		
Perchlorate[1]	14797-73-0	n/a	n/a	0.051	0.2	2.5E+01	N	2.6E+01	2.6E+00	--	--	--	--	--	--	--	--	--

Notes:

CAS = Chemical Abstract Service

mg/kg = Milligram Per kilogram

µg/L = Microgram Per liter

MDL = Method Detection Limit

RL = Reporting Limit

Method Detection and Reporting Limits for PCBs Provided by TriMatrix

Method Detection and Reporting Limits for Perchlorate Provided by CAS Labs

-- = No Risk Criteria Available

MCL = Maximum Contaminant Level

BTAG = Biological Technical Assistance Group

Soil - BTAG Screening Draft Values, 1995

Water - BTAG Freshwater Screening Values, 2004

Sediment - BTAG Sediment Screening Values, 2004

RBC = USEPA Region III Risk-Based Concentration
(RBC) values from the April 6, 2007,
RBC Table and April 10, 2007, Alternate RBC Table

Adjusted RBCs = a Hazard Quotient (HQ) of 0.1 applied to non-carcinogens

C/N = Carcinogenic/Noncarcinogenic status per EPA RBC Table (April 2007)

C = Carcinogenic

C!/N= Carcinogenic RBC/Non-carcinogenic Adjusted RBC taken from Alternate RBC table; see USEPA Region III guidance

N = Non-Carcinogenic

[1] = EPA Drinking Water Equivalent Level (DWEL) value used for perchlorate

▨ = Reporting limit was not low enough to meet screening criteria - but MDL does

Table 2-10
Summary of Analyte Detection Limits and Reporting Limits
Explosives (EPA Methods 8330, 8330M, 8332)
Soil and Water Samples
MWP Addendum 022 - SSP at SWMU 45
Radford Army Ammunition Plant, Radford, Virginia

		Laboratory-Specific Method Detection and Reporting Limits				USEPA MCLs	USEPA Region III Risk-Based Concentrations									USEPA Region III BTAG Screening Levels		
		Soil		Water		MCL	Tap Water			Soil Industrial			Soil Residential			Aqueous Fresh Water	Soil	Sediment
Compound by Method 8330	CAS Number	MDL mg/kg	Reporting Limit mg/kg	MDL µg/L	Reporting Limit µg/L	µg/L	C/N	RBC µg/L	Adjusted RBC µg/L	C/N	RBC mg/kg	Adjusted RBC mg/kg	C/N	RBC mg/kg	Adjusted RBC mg/kg	µg/L	mg/kg	mg/kg
1,3,5-Trinitrobenzene	99-35-4	0.200	2.5	0.16	5.0	--	N	1.1E+03	1.1E+02	N	3.1E+04	3.1E+03	N	2.3E+03	2.3E+02	--	--	--
1,3-Dinitrobenzene	99-65-0	0.052	2.5	0.23	5.0	--	N	3.7E+00	3.7E-01	N	1.0E+02	1.0E+01	N	7.8E+00	7.8E-01	--	--	--
2,4,6-Trinitrotoluene	118-96-7	0.051	2.5	0.08	5.0	--	C!/N	2.2E+00	1.8E+00	C!/N	9.5E+01	5.1E+01	C!/N	2.1E+01	3.9E+00	1.0E+02	--	9.2E-02
2,4-Dinitrotoluene	121-14-2	0.073	2.5	0.12	5.0	--	N	7.3E+01	7.3E+00	N	2.0E+03	2.0E+02	N	1.6E+02	1.6E+01	4.4E+01	--	4.2E-02
2,6-Dinitrotoluene	606-20-2	0.099	2.5	0.27	5.0	--	N	3.7E+01	3.7E+00	N	1.0E+03	1.0E+02	N	7.8E+01	7.8E+00	8.1E+01	--	--
2-Amino-4,6-dinitrotoluene[1]	35572-78-2	0.088	2.5	0.20	5.0	--	N	7.3E+01	7.3E+00	N	2.0E+03	2.0E+02	N	1.6E+02	1.6E+01	1.5E+03	--	--
2-Nitrotoluene	88-72-2	0.071	2.5	0.26	5.0	--	N	6.1E+01	6.1E+00	N	1.0E+04	1.0E+03	N	7.8E+02	7.8E+01	--	--	--
3-Nitrotoluene	99-08-1	0.120	2.5	0.22	5.0	--	--	--	--	--	--	--	--	--	--	7.5E+02	--	--
4-Amino-2,6-dinitrotoluene[1]	1946-51-0	0.053	2.5	0.31	5.0	--	N	7.3E+01	7.3E+00	N	2.0E+03	2.0E+02	N	1.6E+02	1.6E+01	--	--	--
4-Nitrotoluene	99-99-0	0.120	2.5	0.15	5.0	--	--	--	--	--	--	--	--	--	--	1.9E+03	--	4.1E+00
HMX (Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine)	2691-41-0	0.089	2.5	0.16	5.0	--	N	1.8E+03	1.8E+02	N	5.1E+04	5.1E+03	N	3.9E+03	3.9E+02	1.5E+02	--	--
Nitrobenzene	98-95-3	0.059	2.5	0.18	5.0	--	N	3.5E+00	3.5E-01	N	5.1E+02	5.1E+01	N	3.9E+01	3.9E+00	--	--	--
RDX (Hexahydro-1,3,5-trinitro-1,3,5-triazine)	121-82-4	0.089	2.5	0.06	5.0	--	C	6.1E-01	6.1E-01	C	2.6E+01	2.6E+01	C	5.8E+00	5.8E+00	3.6E+02	--	1.3E-02
Tetryl (Methyl-2,4,6-trinitrophenylnitramine)	479-45-8	0.170	2.5	0.25	5.0	--	N	1.5E+02	1.5E+01	N	4.1E+03	4.1E+02	N	3.1E+02	3.1E+01	--	--	--
Compound by Method 8330M																		
PETN	78-11-5	0.228	5.0	0.61	10.0	--	--	--	--	--	--	--	--	--	--	8.5E+04	--	--
Compound by Method 8332																		
Nitroglycerin	55-63-0	0.387	5.0	0.58	5.0	--	N	3.7E+00	3.7E-01	N	1.0E+02	1.0E+01	N	7.8E+00	7.8E-01	1.4E+02	--	--

Notes:

CAS = Chemical Abstract Service
mg/kg = Milligram Per kilogram
µg/L = Microgram Per liter
TCL = Target Compound List
MDL = Method Detection Limit
RL = Reporting Limit
Method Detection and Reporting Limits Provided by TriMatrix
-- = No Risk Criteria Available
MCL = Maximum Contaminant Level
BTAG = Biological Technical Assistance Group
  Soil - BTAG Screening Draft Values, 1995
  Water - BTAG Freshwater Screening Values, 2004
  Sediment - BTAG Sediment Screening Values, 2004

RBC = USEPA Region III Risk-Based Concentration
  (RBC) values from the April 6, 2007,
  RBC Table and April 10, 2007, Alternate RBC Table
Adjusted RBCs = a Hazard Quotient (HQ) of 0.1 applied to non-carcinogens
C/N = Carcinogenic/Noncarcinogenic status per EPA RBC Table (April 2007)
C = Carcinogenic
C!/N= Carcinogenic RBC/Non-carcinogenic Adjusted RBC taken from Alternate RBC table; see USEPA Region III guidance
N = Non-Carcinogenic
[1] = RBC value is for the sum of the isomers called aminodinitrotoluenes

▒ = Reporting limit was not low enough to meet screening criteria - but MDL does

Table 2-11
Summary of Analyte Detection Limits and Reporting Limits
TAL Metals (EPA Methods 6010, 6020, 7470A, 7471A, 9012B)
Soil and Water Samples
MWP Addendum 022 - SSP at SWMU 45
Radford Army Ammunition Plant, Radford, Virginia

		Laboratory-Specific Method Detection and Reporting Limits				USEPA MCLs	USEPA Region III Risk-Based Concentrations									USEPA Region III BTAG Screening Levels		
		Soil		Water			Tap Water			Soil Industrial			Soil Residential					
Compound	CAS Number	MDL mg/kg	Reporting Limit mg/kg	MDL µg/L	Reporting Limit µg/L	MCL µg/L	C/N	RBC µg/L	Adjusted RBC µg/L	C/N	RBC mg/kg	Adjusted RBC mg/kg	C/N	RBC mg/kg	Adjusted RBC mg/kg	Aqueous Fresh Water µg/L	Soil mg/kg	Sediment mg/kg
Aluminum	7429-90-5	1.6	10	16	50	--	N	3.7E+04	3.7E+03	N	1.0E+06	1.0E+05	N	7.8E+04	7.8E+03	8.7E+01	1.0E+00	--
Antimony	7440-36-0	0.036	0.2	0.73	3	6.0E+00	N	1.5E+01	1.5E+00	N	4.1E+02	4.1E+01	N	3.1E+01	3.1E+00	3.0E+01	4.8E-01	2.0E+00
Arsenic	7440-38-2	0.023	0.1	0.47	2	1.0E+01	C	4.5E-02	4.5E-02	C	1.9E+00	1.9E+00	C	4.3E-01	4.3E-01	5.0E+00	3.3E+02	9.8E+00
Barium	7440-39-3	0.10	1	0.34	2	2.0E+03	N	7.3E+03	7.3E+02	N	2.0E+05	2.0E+04	N	1.6E+04	1.6E+03	4.0E+00	4.4E+02	--
Beryllium	7440-41-7	0.016	1	0.50	2	4.0E+00	N	7.3E+01	7.3E+00	N	2.0E+03	2.0E+02	N	1.6E+02	1.6E+01	6.6E-01	2.0E-02	--
Cadmium	7440-43-9	0.50	2	0.062	0.2	5.0E+00	N	1.8E+01	1.8E+00	N	5.1E+02	5.1E+01	N	3.9E+01	3.9E+00	2.5E-01	2.5E+00	9.9E-01
Calcium	7440-70-2	10	50	52	500	--	--	--	--	--	--	--	--	--	--	1.2E+05	--	--
Chromium (VI)[1]	7440-47-3	0.57	5	0.66	2	1.0E+02	N	1.1E+02	1.1E+01	N	3.1E+03	3.1E+02	N	2.3E+02	2.3E+01	8.5E+01	7.5E-03	4.3E+01
Cobalt	7440-48-4	0.35	2	0.22	1	--	--	--	--	--	--	--	--	--	--	2.3E+01	1.0E+02	5.0E+01
Copper	7440-50-8	0.022	0.1	0.32	1	1.3E+03	N	1.5E+03	1.5E+02	N	4.1E+04	4.1E+03	N	3.1E+03	3.1E+02	9.0E+00	1.5E+01	3.2E+01
Cyanide	57-12-5	0.0356	0.21	0.0022	0.01	2.0E+02	N	7.3E+02	7.3E+01	N	2.0E+04	2.0E+03	N	1.6E+03	1.6E+02	5.0E+00	5.0E-03	1.0E-01
Iron	7439-89-6	0.46	10	3.2	10	--	N	2.6E+04	2.6E+03	N	7.2E+05	7.2E+04	N	5.5E+04	5.5E+03	3.0E+02	1.2E+01	2.0E+04
Lead[2]	7439-92-1	0.041	0.2	0.24	1	1.5E+01	--	--	--	--	7.5E+02	7.5E+02	--	4.0E+02	4.0E+02	2.5E+00	1.0E-02	3.6E+01
Magnesium	7439-95-4	3.4	50	32	100	--	--	--	--	--	--	--	--	--	--	8.2E+04	4.4E+03	--
Manganese (non-food)	7439-96-5	0.14	1	0.74	3	--	N	7.3E+02	7.3E+01	N	2.0E+04	2.0E+03	N	1.6E+03	1.6E+02	1.2E+02	3.3E+02	4.6E+02
Mercury[3]	7439-97-6	0.0077	0.05	0.0367	0.2	2.0E+00	--	--	--	N	3.1E+02	3.1E+01	N	2.3E+01	2.3E+00	1.0E-01	5.8E-02	1.8E-01
Nickel	7440-02-0	0.027	0.1	0.45	2	--	N	7.3E+02	7.3E+01	N	2.0E+04	2.0E+03	N	1.6E+03	1.6E+02	5.2E+01	2.0E+00	2.3E+01
Potassium	7440-09-7	7.5	50	36	200	--	--	--	--	--	--	--	--	--	--	--	--	--
Selenium	7782-49-2	0.063	0.2	0.73	3	5.0E+01	N	1.8E+02	1.8E+01	N	5.1E+03	5.1E+02	N	3.9E+02	3.9E+01	1.0E+00	1.8E+00	2.0E+00
Silver	7440-22-4	0.017	0.1	0.073	0.3	--	N	1.8E+02	1.8E+01	N	5.1E+03	5.1E+02	N	3.9E+02	3.9E+01	3.2E+00	9.8E-06	1.0E+00
Sodium	7440-23-5	19	100	59	500	--	--	--	--	--	--	--	--	--	--	6.8E+05	--	--
Thallium	7440-28-0	0.0085	0.1	0.14	1	2.0E+00	N	2.6E+00	2.6E-01	N	7.2E+01	7.2E+00	N	5.5E+00	5.5E-01	8.0E-01	1.0E-03	--
Vanadium	7440-62-2	0.024	0.1	0.26	1	--	N	3.7E+01	3.7E+00	N	1.0E+03	1.0E+02	N	7.8E+01	7.8E+00	2.0E+01	5.0E-01	--
Zinc	7440-66-6	0.85	5	0.82	3	--	N	1.1E+04	1.1E+03	N	3.1E+05	3.1E+04	N	2.3E+04	2.3E+03	1.2E+02	1.0E+01	1.2E+02

Notes:

CAS = Chemical Abstract Service
mg/kg = Milligram Per kilogram
µg/L = Microgram Per liter
TAL = Target Analyte List
MDL = Method Detection Limit
RL = Reporting Limit
Method Detection and Reporting Limits Provided by TriMatrix
-- = No Risk Criteria Available
MCL = Maximum Contaminant Level
BTAG = Biological Technical Assistance Group
Soil - BTAG Screening Draft Values, 1995
Water - BTAG Freshwater Screening Values, 2004
Sediment - BTAG Sediment Screening Values, 2004

RBC = USEPA Region III Risk-Based Concentration
(RBC) values from the April 6, 2007,
RBC Table and April 10, 2007, Alternate RBC Table
Adjusted RBCs = a Hazard Quotient (HQ) of 0.1 applied to non-carcinogens
C/N = Carcinogenic/Noncarcinogenic status per EPA RBC Table (April 2007)
C = Carcinogenic
C!/N= Carcinogenic RBC/Non-carcinogenic Adjusted RBC taken from Alternate RBC table; see USEPA Region III guidance
N = Non-Carcinogenic
[1] = Chromium MCL is for total
[2] = Lead criteria are Action Levels; see USEPA Region III guidance
[3] = Mercuric chloride soil RBC value used

▨ = Reporting limit was not low enough to meet screening criteria - but MDL does

Table 2-12

Summary of Analyte Detection Limits, Reporting Limits, and Risk Screening Criteria

for TCL Dioxin/Furans (EPA Method 8290)

MWP Addendum 022 - SSP at SWMU 45

Radford Army Ammunition Plant, Radford, Virginia

Compound	CAS Number	Laboratory-Specific Method Detection and Reporting Limits				USEPA MCLs	USEPA Region III Risk-Based Concentrations							USEPA Region III Draft BTAG Screening Levels		
		Soil		Water												
		MDL pg/g	Reporting Limit pg/g	MDL ng/L	Reporting Limit ng/L	ng/L	C/N	Tap Water RBC ng/L	Adjusted Tap Water RBC ng/L	Soil RBC (Industrial) pg/g	Adjusted Soil RBC (Industrial) pg/g	Soil RBC (Residential) pg/g	Adjusted Soil RBC (Residential) pg/g	Aquatic Fresh Water ng/L	Soil mg/kg	Sediment mg/kg
2,3,7,8-TCDD	1746-01-6	0.088	1	0.00082	0.01	3.00E+01	C	4.5E-04	4.5E-04	1.9E+01	1.9E+01	4.3E+00	4.3E+00	3.1E-06	1.0E-02	--
1,2,3,7,8-PeCDD	40321-76-4	0.452	5	0.00192	0.05	--	--	--	--	--	--		--	--	--	--
1,2,3,4,7,8-HxCDD	39227-28-6	0.398	5	0.00201	0.05	--	--	--	--	--	--	--	--	--	--	--
1,2,3,6,7,8-HxCDD	57653-85-7	0.426	5	0.0014	0.05	--	--	--	--	--	--	--	--	--	--	--
1,2,3,7,8,9-HxCDD	19408-74-3	0.478	5	0.0016	0.05	--	C	1.1E-02	1.1E-02	4.6E+02	4.6E+02	1.0E+02	1.0E+02	--	--	--
1,2,3,4,6,7,8-HpCDD	35822-39-4	1.015	5	0.0028	0.05	--	--	--	--	--	--	--	--	--	--	--
OCDD	3268-87-9	1.33	10	0.01595	0.1	--	--	--	--	--	--	--	--	--	--	--
2,3,7,8-TCDF	51207-31-9	0.136	1	0.00089	0.01	--	--	--	--	--	--	--	--	--	--	--
1,2,3,7,8-PeCDF	57117-41-6	0.373	5	0.00229	0.05	--	--	--	--	--	--	--	--	--	--	--
2,3,4,7,8-PeCDF	57117-31-4	0.502	5	0.00371	0.05	--	--	--	--	--	--	--	--	--	--	--
1,2,3,4,7,8-HxCDF	70648-26-9	0.459	5	0.00185	0.05	--	--	--	--	--	--	--	--	--	--	--
1,2,3,6,7,8-HxCDF	57117-44-9	0.363	5	0.00126	0.05	--	--	--	--	--	--	--	--	--	--	--
2,3,4,6,7,8-HxCDF	60851-34-5	0.621	5	0.00323	0.05	--	--	--	--	--	--	--	--	--	--	--
1,2,3,7,8,9-HxCDF	72918-21-9	0.422	5	0.00484	0.05	--	--	--	--	--	--	--	--	--	--	--
1,2,3,4,6,7,8-HpCDF	67562-39-4	0.698	5	0.00263	0.05	--	--	--	--	--	--	--	--	--	--	--
1,2,3,4,7,8,9-HpCDF	55673-89-7	0.517	5	0.00284	0.05	--	--	--	--	--	--	--	--	--	--	--
OCDF	39001-02-0	1.896	10	0.00195	0.1	--	--	--	--	--	--	--	--	--	--	--

Notes:

CAS = Chemical Abstract Service

MCL = Maximum Contaminant Level

MDL = Method Detection Limit

Method Detection and Reporting Limits Provided by SGS

pg/g = Picogram Per Gram

ng/L = Nanogram Per Liter

USEPA = U.S. Environmental Protection Agency

RBC = USEPA Region III Risk-Based Concentration
(RBC) values from the April 6, 2007,
RBC Table and April 10, 2007, Alternate RBC Table

Adjusted RBCs = a Hazard Quotient (HQ) of 0.1 applied to non-carcinogens

BTAG = Biological Technical Assistance Group Screening Level
Soil - BTAG Screening Draft Values, 1995
Water - BTAG Freshwater Screening Values, 2004
Sediment - BTAG Sediment Screening Values, 2004

-- = No Risk Criteria Available

C/N = Carcinogenic/Noncarcinogenic status per EPA RBC Table (April 2007)

C = Carcinogenic

C!/N= Carcinogenic RBC/Non-carcinogenic Adjusted RBC taken from Alternate RBC table; see USEPA Region III guidance

N = Non-Carcinogenic

Adjusted RBCs = a Hazard Quotient (HQ) of 0.1 applied to non-carcinogens

▨ = Reporting limit was not low enough to meet screening criteria - but MDL does

2.5.1 Organics

The following techniques will be used for analysis of organic constituents.

2.5.1.1 VOCs by SW-846 Test Method 8260B

The aqueous samples are prepared for analysis by purge-and-trap Method 5030 and the solid samples are prepared by purge-and-trap Method 5035. The volatile compounds are introduced into the gas chromatograph by the purge-and-trap method or by other methods (Section 1.2 of Method SW8260B). The analytes are introduced directly to a wide-bore capillary column or cryofocused on a capillary pre-column before being flash evaporated to a narrow-bore capillary for analysis. The column is temperature-programmed to separate the analytes, which are then detected with a mass spectrometer (MS) interfaced to the gas chromatograph (GC). Analytes eluted from the capillary column are introduced into the mass spectrometer via a jet separator or a direct connection. (Wide-bore capillary columns normally require a jet separator, whereas narrow-bore capillary columns may be directly interfaced to the ion source.) Identification of target analytes is accomplished by comparing their mass spectra with the electron impact (or electron impact-like) spectra of authentic standards. Quantitation is accomplished by comparing the response of a major (quantitation) ion relative to an internal standard using a five-point calibration curve.

2.5.1.2 SVOCs by SW-846 Test Method 8270C

The samples are prepared for analysis by GC/MS using Method 3510C for aqueous media and Method 3540C for solid media, or other appropriate methods. The semi-volatile compounds are introduced into the GC/MS by injecting the sample extract into a GC with a narrow-bore fused-silica capillary column. The GC column is temperature-programmed to separate the analytes, which are then detected with a MS, connected to the gas chromatograph. Analytes eluted from the capillary column are introduced into the mass spectrometer via a direct connection. Identification of target analytes is accomplished by comparing their mass spectra with the electron impact (or electron impact-like) spectra of authentic standards. Quantitation is accomplished by comparing the response of a major (quantitation) ion relative to an internal standard using a five-point calibration curve.

2.5.1.3 Pesticides by SW-846 Test Method 8081A

A measured volume or weight of sample (approximately one liter for liquids, and two to 30 grams (g) for solids) is extracted using the appropriate matrix-specific sample extraction technique. Liquid samples are extracted at neutral pH with methylene chloride using Method 3520C (continuous liquid-liquid extractor), or other appropriate technique. Solid samples are extracted using Method 3540C (Soxhlet) or other appropriate technique. A variety of cleanup steps may be applied to the extract, depending on the nature of the matrix interferences and the target analytes. Suggested cleanups include alumina (Method 3610), Florisil (Method 3620), silica gel (Method 3630), gel permeation chromatography (Method 3640), and sulfur (Method 3660). After cleanup, the extract is analyzed by injecting a one-microliter (µL) sample into a gas chromatograph with a narrow- or wide-bore fused silica capillary column. The GC column is temperature-programmed to separate the analytes. An electron capture detector (ECD) or an electrolytic conductivity detector (ELCD) detects analytes eluted from the capillary column. Quantitation is accomplished by comparing the response of a peak within a retention time window to a five-point calibration curve.

2.5.1.4 Herbicides by SW-846 Test Method 8151A

Method 8151 provides extraction, derivatization, and gas chromatographic conditions for the analysis of chlorinated acid herbicides in water, soil, and waste samples. Samples are extracted with diethyl ether and then esterified with either diazomethane or pentafluorobenzyl bromide. Organic acids, especially chlorinated acids, cause the most direct interference with the determination by methylation. Phenols, including chlorophenols, may also interfere with this procedure. The determination using pentafluorobenzylation is more sensitive, and more prone to interferences from the presence of organic acids or phenols than by methylation. The derivatives are assessed by gas chromatography with an electron capture detector (GC/ECD). The results are reported as acid equivalents. Quantitation is accomplished by comparing the response of a peak within a retention time window to a five-point calibration curve.

2.5.1.5 PCBs by SW-846 Test Method 8082

A measured volume or weight of sample (approximately one liter for liquids, and two to 30 g for solids) is extracted using the appropriate matrix-specific sample extraction technique. Aqueous samples are extracted at neutral pH using Method 3510C, or other appropriate technique. Solid samples are extracted using Method 3540C (Soxhlet) or other appropriate technique. Extracts for PCB analysis may be subjected to a sulfuric acid/potassium permanganate cleanup (Method 3665) or sulfuric acid cleanup (Method 3660B) designed specifically for these analytes. This cleanup technique will remove (destroy) many single component organochlorine or organophosphate pesticides. Therefore, Method 8082 is not applicable to the analysis of those compounds. Instead, use Method 8081. After cleanup, the extract is analyzed by injecting a 2 µL aliquot into a gas chromatograph with a narrow- or wide-bore fused silica capillary column. An ECD detects analytes eluted from the capillary column. Comparing and summing the response of at least three peaks within specified retention time windows to a five-point calibration curve accomplishes quantitation. The chromatographic data may be used to identify the seven Aroclors found in Section 1.1 of Method SW8082, individual PCB congeners, or total PCBs.

2.5.1.6 Explosives by SW-846 Test Methods 8330 and 8332

Test Methods 8330 and 8332 provide for the analysis of ppb levels of certain explosives residues in water, soil, and sediment matrices using HPLC using a UV detector. Before use of these methods, sample preparation techniques must be used. Two sample preparation techniques are available:

1) Low-Level Salting-out Method without Evaporation: Aqueous samples of low concentration are extracted by a salting-out extraction procedure with acetonitrile and sodium chloride. The small volume of acetonitrile that remains un-dissolved above the salt water is drawn off and transferred to a smaller volumetric flask. It is back-extracted by vigorous stirring with a specific volume of salt water. After equilibration, the phases are allowed to separate and the small volume of acetonitrile residing in the narrow neck of the volumetric flask is removed using a Pasteur pipette. The concentrated extract is diluted 1:1 with reagent grade water. An aliquot is separated on a C-18 reverse phase column, analyzed at 254 nanometers (nm), and confirmed on a cyanide (CN) reverse phase column. Quantitation is accomplished by comparing the response of a peak within a retention time window to a five-point calibration curve.

2) Soil and sediment samples are air dried at room temperature to a constant weight. Approximately 2g are extracted using acetonitrile in an ultrasonic bath for 18 hours. Five mL of supernatant is combined with five mL of calcium chloride solution and is shaken and left to stand for 15 minutes. The supernatant is prepared for analysis by filtering through a 0.45 micrometer (µm) Teflon filter. This extract is then separated on a C-18 reverse phase column, determined at 254 nm, and confirmed on a CN reverse phase column. Quantitation is accomplished by comparing the response of a peak within a retention time window to a five-point calibration curve.

2.5.1.7 Dioxins and Furans by SW-846 Test Method 8290

Method 8290 provides procedures for the identification and quantitative measurement of polychlorinated dibenzo-p-dioxins (tetra- though octa-chlorinated homologues; PCDDs) and polychlorinated dibenzofurans (tetra- though octa-chlorinated homologues; PCDFs) in a variety of environmental matrices and at part-per-trillion (ppt) to part-per-quadrillion (ppq) concentrations. A specified amount of sample is spiked with a solution containing specified amounts of each of the nine isotopically ($^{13}C_{12}$) labeled PCDDs/PCDFs. The sample is then extracted according to a matrix-specific extraction procedure.

The samples are prepared for analysis by high-resolution gas chromatography/high-resolution mass spectrometry (HRGC/HRMS) using the matrix specific extraction (refer to Method 8290) and analyte specific cleanup procedures (refer to Method 8290). A high-resolution capillary column (60 m DB-5, J&W Scientific, or equivalent) is used in this method. However, no single column is known to resolve isomers. In order to establish the concentration of the 2,3,7,8-TCDF (if detected on the DB-5 column), the sample extract must be reanalyzed on a column capable of 2,3,7,8-TCDF isomer specificity (e.g., DB-225, SP-2330, SP-2331, or equivalent). Quantitation of the individual congeners, total PCDDs and total PCDFs is achieved in conjunction with the establishment of a multipoint (five points) calibration curve for each homologue, during which each calibration solution is analyzed once. The identification of OCDD and nine of the fifteen 2,3,7,8- substituted congeners, for which a 13C-labeled standard is available in the sample fortification and recovery standard solutions, is based on their elution at their exact retention time (within 0.005 retention time units measured in the routine calibration) and simultaneous detection of the two most abundant ions in the molecular ion region. The remaining six 2,3,7,8-substituted congeners (i.e., 2,3,4,7,8-PeCDF; 1,2,3,4,7,8-HxCDD; 1,2,3,6,7,8-HxCDF; 1,2,3,7,8,9-HxCDF; 2,3,4,6,7,8-HxCDF, and 1,2,3,4,7,8,9-HpCDF), for which no carbon-labeled internal standards are available in the sample fortification solution, and other identified PCDD/PCDF congeners are identified by their relative retention times from the routine calibration data, and the simultaneous detection of the two most abundant ions in the molecular ion region. The identification of OCDF is based on its retention time relative to $^{13}C_{12}$-OCDD and the simultaneous detection of the two most abundant ions in the molecular ion region. Confirmation is based on a comparison of the ratios of the integrated ion abundance of the molecular ion species to their theoretical abundance ratios. A calculation of the toxicity equivalent concentration (TEQ) of each sample is made using international consensus toxicity equivalence factors (TEFs), and the TEQ is used to establish if the concentrations of target compounds in the sample are high enough to warrant confirmation of the results on a second GC column.

2.5.2 Metals

The following techniques will be used for analysis of inorganics.

2.5.2.1 Target Analyte List Metals by ICP SW-846 Test Method 6010B Series

Prior to analysis, samples are prepared by Method 3010A for aqueous media and Method 3050B for solid media, or other appropriate methods. When analyzing groundwater samples for dissolved constituents, acid digestion is not necessary if the samples are filtered and acid preserved before analysis. This method describes multi-elemental determinations by Inductively Coupled Plasma (ICP) - Atomic Emission Spectroscopy (AES) using sequential or simultaneous optical systems and axial or radial viewing of the plasma. The instrument measures characteristic emission spectra by optical spectrometry. Samples are nebulized and the resulting aerosol is transported to the plasma torch. Element-specific emission spectra are produced by radio frequency inductively coupled plasma. The spectra are dispersed by a grating spectrometer, and photosensitive devices monitor the emission line intensities.

Background correction is required for trace element determination. Background must be measured adjacent to analyte lines on samples during analysis. The position selected for the background-intensity measurement, on either or both sides of the analytical line, will be defined by the complexity of the spectrum adjacent to the analyte line. In one mode of analysis, the position used should be as free as possible from spectral interference and should reflect the same change in background intensity as occurs at the analyte wavelength measured. Background correction is not required in cases of line broadening where a background correction measurement would actually degrade the analytical result. The possibility of additional interferences named in Section 3.0 of Method 3050B should also be recognized and appropriate corrections made; tests for their presence are described in Section 8.5 of Method 3035B. Alternatively, users may choose multivariate calibration methods. In this case, point selections for background correction are superfluous since entire spectral regions are processed.

2.5.2.2 Mercury by SW-846 Test Methods 7470A (aqueous) and 7471A (solid)

Prior to analysis, the liquid, solid, or semi-solid samples must be prepared according to the procedure discussed in the method. Methods 7470A and 7471A, cold-vapor atomic absorption techniques are based on the absorption of radiation at 253.7 nm by mercury vapor. The mercury is reduced to the elemental state and aerated from solution in a closed system. The mercury vapor passes through a cell positioned in the light path of an atomic absorption spectrophotometer. Absorbance (peak height or area) is measured as a function of mercury concentration. Quantitation is accomplished by comparing the response of the peak to a five-point calibration curve.

2.5.2.3 Target Analyte List Metals by ICP SW-846 Test Method 6020 Series

Inductively coupled plasma-mass spectrometry (ICP-MS) is applicable to the determination of sub-ppb concentrations of a large number of elements in water samples and in waste extracts or digests. Prior to analysis, samples that require total ("acid-leachable") values must be digested using appropriate sample preparation methods (such as Methods 3005-3051). Acid digestion prior to filtration and analysis is required for groundwater, aqueous samples, industrial waste, soil, sludge, sediment, and other solid waste for which total (acid-leachable) elements are required. When dissolved constituents are required, samples must be filtered and acid-preserved prior to analysis. No digestion is required prior to analysis for dissolved elements in water samples.

Method 6020 describes the multi-elemental determination of analytes by ICP-MS. The method measures ions produced by a radio frequency inductively coupled plasma. Analyte species originating in a liquid are nebulized and the resulting aerosol transported by argon gas into the plasma torch. The ions produced are entrained in the plasma gas and introduced, by means of an interface, into a mass spectrometer. The ions produced in the plasma are sorted according to their mass-to-charge ratios and quantified with a channel electron multiplier. Interferences must be assessed and valid corrections applied or the data flagged to indicate problems. Interference correction must include compensation for background ions contributed by the plasma gas, reagents, and constituents of the sample matrix.

2.5.2.4 Cyanide by SW-846 Test Methods 9010C and 9012B

Samples will be analyzed for total cyanide by SW-846 Test Methods 9010C and 9012B, distillation followed by colorimetric analysis. Hydrocyanic acid (HCN) is released through reflux-distillation and absorbed in a scrubber containing sodium hydroxide solution. The cyanide ion is assessed colorimetrically by converting it to cyanogen chloride (CNCl).

2.5.2.5 Perchlorate by SW-846 Test Method 6850

Groundwater samples will be analyzed for perchlorate by SW-846 Test Method 6850. This method uses HPLC coupled with electrospray ionization (ESI) MS or tandem mass spectrometry (MS/MS) for the determination of perchlorate in surface water, groundwater, wastewater, salt water, and soil. Extracts are filtered. An appropriate volume of the sample or sample extract is introduced into a HPLC/MS instrument. Perchlorate is separated by HPLC from the sample matrix, partially fragmented via negative electrospray ionization and detected by MS using mass-to-charge (m/z) ratios 83, 85, and 89. Quantitation is performed using m/z 83 and internal standard calibration. Isotopically-labeled perchlorate ($Cl^{18}O_4^-$), m/z 89, serves as the internal standard. The 83/85 isotopic ratio reflects the isotopic ratio of naturally occurring $^{35}Cl/^{37}Cl$ and is used for additional confirmation of perchlorate identification.

2.5.2.6 TOC by Walkley-Black Method

Soil samples will be analyzed for TOC by this method. This is a preferred method for TOC analyses of soil samples since the EPA 9060 or 415.1 techniques designed for aqueous samples may leave unextracted organic carbon in the soil. Organic carbon is determined by an oxidation-reduction reaction in which potassium dichromate is added to a sample, followed by addition of concentrated sulfuric acid. Dichromate (Cr2O7 2-) oxidizes organic carbon to CO2 in an acidic medium. The reduced dichromate is quantitatively related to oxidized organic carbon. Any remaining Cr2O7 2- is reduced by Fe2+ from the ferrous sulfate titrant. The endpoint at which all Cr2O7 2- has been reduced is indicated by the maroon color of an o-phenanthroline indicator.

2.5.3 Waste Samples

Samples of IDM will be characterized for disposal purposes by analyzing for the following parameters as discussed in the following sections:

- TCLP – Complete List (solid);
- TCLP metals (aqueous);
- Corrosivity (solid and aqueous);
- COD (aqueous);
- Explosives (solid);
- Reactivity (ATK internal visual method and percent explosive content); and
- Paint Filter Test (solid).

2.5.3.1 TCLP Extraction

For liquid wastes (i.e., those containing less than 0.5% dry solid material), the waste, after filtration through a 0.6 to 0.8-µm glass fiber filter, is defined as the TCLP extract. For wastes containing greater than or equal to 0.5% solids, the liquid, if present, is separated from the solid phase and stored for later analysis; the particle size of the solid phase is reduced, if necessary. The solid phase is extracted with an amount of extraction fluid equal to 20 times the weight of the solid phase. The extraction fluid employed is a function of the alkalinity of the solid phase of the waste. A special extractor vessel is used when testing for volatile analytes. Following extraction, the liquid extract is separated from the solid phase by filtration through a 0.6 to 0.8-µm glass fiber filter. If compatible (i.e., multiple phases will not form on combination), the initial liquid phase of the waste is added to the liquid extract, and these are analyzed together. If incompatible, the liquids are analyzed separately and the results are mathematically combined to yield a volume-weighted average concentration. Extracts are analyzed using the analytical methods described above.

2.5.3.2 Corrosivity by SW-846 Test Methods 9040B (aqueous) and 9045C (solid)

The corrosivity of a sample will be based on its pH. The pH of a liquid sample is either analyzed electrometrically using a glass electrode in combination with a reference potential or a combination electrode. The measuring device is calibrated using a series of standard solutions of known pH. For soil/solid waste samples, the sample is mixed with reagent water, and the pH of the resulting aqueous solution is measured.

2.5.3.3 Chemical Oxygen Demand by EPA Test Method 410.4

Sample, blanks, and standards in sealed tubes are heated in an oven or block digestor in the presence of dichromate at 150 degrees Celsius (^{o}C). After two hours, the tubes are removed from the oven or digestor, cooled, and measured spectrophotometrically at 600 nm.

2.5.3.4 Reactivity

Reactivity of waste samples is assessed by analysis of the sample for explosives by SW-846 Methods 8330 and 8332. Waste material is considered potentially reactive when 10 percent or more explosives by weight are present. A qualitative assessment of samples may also be performed by visual and microscopic methods to identify typical crystalline structures characteristic of the propellants and explosives manufactured at the facility.

2.5.3.5 Paint Filter Test by SW-846 Test Method 9095B

This method is used to determine the presence of liquid in representative samples of waste and to determine compliance with 40 CFR 264.314 and 265.314. A predetermined amount of material is placed in a paint filter. If any portion of the material passes through and drops from the filter within the 5 minute test period, the material is considered to contain free liquid.

2.5.4 Physical/Geotechnical Analysis

Soil samples for physical/geotechnical analysis will be submitted to URS' laboratory in Totawa, New Jersey for the analysis of the following parameters:

- Grain-size analysis (ASTM D 422);
- Atterberg limits (ASTM D 4318);
- Soil moisture content (ASTM D 2216);

- Total Organic Carbon (Walkley-Black Method) and
- pH (ASTM D 4972).

2.6 INTERNAL QUALITY CONTROL CHECK

Internal QC components that will be used by URS during operations at RFAAP are presented below and in Section 8.0 of the MQAP. The internal quality components include the field QC samples and the laboratory QC elements to be followed. Rinse blanks, trip blanks, and field duplicates will be collected during the acquisition of environmental samples at RFAAP. Table 2-13 presents guidelines for the collection of QC samples that will be taken in conjunction with environmental sampling. Field QC acceptance criteria are summarized in Table 2-14.

Table 2-13

Field Quality Control Samples

Control	Purpose of Sample	Collection Frequency
Field Duplicate	Ensure precision in sample homogeneity during collection and analysis	10% of field samples per matrix
Rinse Blank	Ensure the decontamination of sampling equipment has been adequately performed; to assess cross contamination and/or incidental contamination to the sample container	1 per 20 samples per matrix per sample technique
Temperature Blank	Verify sample cooler temperature during transport	1 temperature blank per cooler
Trip Blank	Assess if cross contamination occurs during shipment or storage with aqueous VOC samples	1 trip blank per cooler containing aqueous VOC samples

Table 2-14

Field Quality Control Elements Acceptance Criteria

Item	DQO	Parameter	Frequency of Association	Criteria Goal
Field Duplicate	P	Metals	1 per 10 samples	RPD ≤ 20% Aqueous; difference ± RL* RPD ≤ 35% Solid; difference ± 2xRL*
		Organics	1 per 10 samples	RPD ≤ 40% Aqueous; difference ± RL* RPD ≤ 60% Solid; difference ± 2xRL*
Trip Blank	A,R	VOCs in water	1 per cooler with aqueous VOCs	No target analytes detected greater than the RL
Rinse Blank	A,R	Entire	1 per 20 samples per matrix per equipment type	No target analytes detected greater than the RL
Chain of Custody Forms	R	Entire	Every sample	Filled out correctly to include signatures; no missing or incorrect information.
Representative Sampling Forms	R	Entire	Every sample	Filled out correctly to include signatures; no missing or incorrect information.
Field Logbook	R	Entire	Every sample	Filled out correctly to include analytical parameters; map file data; and applicable coding information.
Field Instrument Calibration Logs	A	Entire	Every measurement	Measurements must have associated calibration reference

Legend: A = Accuracy C = Comparability R = Representativeness P = Precision

*The difference will be evaluated when either of the field duplicate results is less than the reporting limit.

2.6.1 Laboratory Quality Control Elements

The laboratory QC elements are summarized in Table 2-15. Specific laboratory analytical QC criteria and corrective actions are summarized in Tables 2-16 through 2-24 for the parameters specified in Section 2.5.

Table 2-15
Analytical Quality Control Elements of a Quality Assurance Program

Item	DQO	Parameter	Frequency of Association	Criteria Requirement
Analytical Method	C	Entire	Each analysis	Method analyses based on USEPA methods as defined in Section 2.5
Chemical Data Packages	C	Entire	Each lot/batch	Pass peer review and formal QA/QC check.
Laboratory Chain of Custody	R	Entire	Each lot/batch	Custody of sample within laboratory fully accounted for and documented
Laboratory System Controls	A,C,P, R	Entire	During laboratory operations	No deficiencies
Holding Time	A,C,P, R	Entire	Each analysis	No deficiencies (USEPA Region III Modifications)
Method Blanks	A,R	Entire	Each lot/batch	No target analyte detected in the method blanks greater than RL
Laboratory Control Spike	A	Entire	Each lot/batch	Must meet criteria as defined in Tables 2-16 through 2-24
Matrix Spikes and Duplicates	A,P	Entire	Each lot/batch	Must meet criteria as defined in Tables 2-16 through 2-24
Surrogates	A	Entire	Organic fractions, including QC samples	Must meet criteria as defined in Tables 2-16 through 2-20
Serial dilution	A	Metals	Inorganic Fractions, Each lot/batch	Must meet criteria as defined in Table 2-19

Legend: A = Accuracy C = Comparability R = Representativeness P = Precision

Table 2-16

Quality Control Method Criteria for Volatile Organic Compounds by USEPA SW-846 Method 8260B

Procedure	Frequency	Acceptance Criteria		Corrective Action
Initial Calibration 5-pt curve (linear) 6-pt curve (2^{o} order)	Set-up, major maintenance, or for drift correction	RRF > 0.10/0.30 for SPCCs RSD $\leq$ 30% for CCCs response factors RSD for analytes $\leq$ 15% or $r>0.995$ (linear) or $r^2>0.99$ (2^{o} order)		Sample analysis cannot begin until this criterion is met. Data reviewer should review and judge each target compound against the acceptance criteria.
Initial Calibration Verification	Immediately following initial calibration	A second source full compliment target list with a percent recovery = 75-125%		Sample analysis cannot begin until this criterion is met.
Continuing Calibration Check	Every 12 hours	RRF > 0.10/0.30 for SPCCs %Difference for RF of CCCs ±30% from initial calibration. Mean for analytes $\leq$ 20% as no individual target exceeds 40%D		Sample analysis cannot begin until this criterion is met. Data reviewer should review and judge each target compound against the acceptance criteria.
Method Blank	Every day/batch.	No target analytes greater than one half of the RL		Document source of contamination. Re-analysis is required for positive results associated with blank contamination.
Tuning BFB	Prior to calibration and every 12 hours	Must meet tuning criteria		Re-tune, re-calibrate, and re-analyze affected sample analyses.
Laboratory Control Spike	Every batch	<u>Standards</u> Full compliment target list	Laboratory generated control limits not to exceed recovery limits listed in the current version of the DOD QSM	Recoveries indicating a low bias require a re-extraction/reanalysis. Recoveries indicating a high bias require a re-extraction/re-analysis for associated positive field samples. Qualify associated data biased high or biased low as appropriate.
Internal Standards	Every sample	<u>Recommended Standards</u> fluorobenzene chlorobenzene-d_5 1,4-dichlorobenzene-d_4	Retention time ±30 seconds of mid point of initial calibration Area changes within a factor of two (-50% to +100%)	Inspect for malfunction. Demonstrate that system is functioning properly. Reanalyze samples associated with standards outside criteria. A third analytical run may be required at a dilution.
Surrogate	Every sample	<u>Recommended Standards</u> Toluene-d_8 4-Bromofluorobenzene 1,2-Dichloroethane-d_4 Dibromofluoromethane	Laboratory generated control limits not to exceed those listed in the current version of the DOD QSM	If surrogate compounds do not meet criteria, there should be a re-analysis to confirm that the non-compliance is due to the sample matrix effects rather than laboratory deficiencies.
Matrix Spike and Duplicate	1 per 20 per matrix	<u>Standards</u> Full compliment target list	Laboratory generated control limits not to exceed recovery limits listed in the current version of the DOD QSM	If MS/MSD results do not meet criteria, the reviewer should review the data in conjunction with other QC results to identify whether the problem is specific to the QC samples or systematic.

Table 2-17
Quality Control Method Criteria for Semi-volatile Organic Compounds by USEPA SW-846 Method 8270C

Procedure	Frequency	Acceptance Criteria		Corrective Action
Initial calibration 5-pt curve (linear) 6-pt curve (2^o order)	Set-up, major maintenance, or for drift correction	RRF > 0.05 for SPCCs RSD ≤30% for CCC compounds RSD for target analytes ≤ 15% or r>0.995 (linear) or r^2>0.99 (2^o order)		Sample analysis cannot begin until this criterion is met. Data reviewer should review and judge each target compound against the acceptance criteria.
Initial Calibration Verification	Immediately following every initial calibration	A second source full compliment target list with a percent recovery = 80-120%		Sample analysis cannot begin until this criterion is met.
Continuing Calibration Check	12 hours	RRF > 0.05 for SPCCs %Difference for RF of CCCs ±30% from initial calibration Mean for analytes ≤ 20% as no individual target exceeds 40%D		Sample analysis cannot begin until this criterion is met. Data reviewer should review and judge each target compound against the acceptance criteria.
Tuning DFTPP	12 hours	Must meet tuning criteria.		Re-tune, re-calibrate, and re-analyze affected sample analyses.
Method Blank	Per extraction batch	No target analytes greater than one half of the RL		Document source of contamination. Re-extraction/re-analysis is required for positive results associated with blank contamination.
Laboratory Control Spike	Every batch	<u>Standards</u> Full compliment target list	Laboratory generated control limits not to exceed recovery limits listed in the current version of the DoD QSM	Recoveries indicating a low bias require a re-extraction/reanalysis. Recoveries indicating a high bias require a re-extraction/re-analysis for associated positive field samples. Qualify associated data biased high or biased low as appropriate.
Internal Standards	Every sample	<u>Recommended Standards</u> phenanthrene-d10 chrysene-d12 perylene-d12 1,4-dichlorobenzene-d4 naphthalene-d8 acenaphthalene-d10	Retention time ±30 seconds of mid point of initial calibration Area changes within a factor of two (-50% to +100%)	Inspect for malfunction. Demonstrate that system is functioning properly. Reanalyze samples associated with standards outside criteria. A third analytical run may be required at a dilution.
Surrogate Spikes	Every sample	<u>Recommended Standards</u> nitrobenzene-d_5 2-fluorobiphenyl p-terphenyl-d14 phenol-d5 2,4,6-tribromophenol 2-fluorophenol	Laboratory generated control limits not to exceed limits listed in the current version of the DoD QSM	If two base/neutral or acid surrogates are out of specification, or if one base/neutral or acid extractable surrogate has a recovery of less than 10%, then there should be a re-extraction and re-analysis to confirm that the non-compliance is due to sample matrix effects rather than laboratory deficiencies.
Matrix Spike and Duplicate	1 per 20 samples per matrix	<u>Standards</u> Full compliment target list	Laboratory generated control limits not to exceed recovery limits listed in the current version of the DoD QSM	If MS/MSD results do not meet criteria, the reviewer should review the data in conjunction with other QC results to identify whether the problem is specific to the QC samples or systematic.

Table 2-18
Quality Control Method Criteria for Explosives by USEPA SW-846 Methods 8330 and 8332

Procedure	Frequency of QC Procedure	Acceptance Criteria		Corrective Action
Initial Calibration Curve 5-pt curve (linear) 6-pt curve (2o order)	Set-up, major maintenance, or for drift correction for each column used for analysis	%RSD <20% or r>0.995 (linear) or r2>0.99 (2o order)		Sample analysis cannot begin until this criterion is met.
Initial Calibration Verification	Immediately following every initial calibration	A second source full compliment of target list with a percent recovery = 80-120%		Sample analysis cannot begin until this criterion is met.
Continuing Calibration Check	Every ten samples or twelve hours	%D ± 15% of the response factor from the initial curve. The mean may be used as long as no individual target exceeds 30%D		Sample analysis cannot begin until this criterion is met. If criteria are not met, reanalyze the daily standard. If the daily standard fails a second time, initial calibration must be repeated. Data reviewer should review and judge each target compound against the acceptance criteria.
Method Blank	1 per batch	No target analytes detected greater than one half of the RL		Document source of contamination. Re-extraction/re-analysis is required for positive results associated with blank contamination.
Laboratory Control Spike	1 per batch	Standards Full compliment target list	Laboratory generated control limits not to exceed recovery limits listed in the current version of the DOD QSM	Recoveries indicating a low bias require a re-extraction/reanalysis. Recoveries indicating a high bias require a re-extraction/re-analysis for associated positive field samples. Qualify associated data biased high or biased low as appropriate.
Surrogate Spikes	Every sample	Standards A similar compound that is not expected to be found at the site	Laboratory generated control limits not to exceed limits listed in the current version of the DOD QSM	If surrogate compounds do not meet criteria, there should be a re-extraction and re-analysis to confirm that the non-compliance is due to the sample matrix effects rather than laboratory deficiencies.
Matrix Spike and Duplicate	1 per 20 samples per matrix	Standards Full compliment target list	Laboratory generated control limits not to exceed recovery limits listed in the current version of the DOD QSM	If MS/MSD results do not meet criteria, the reviewer should review the data in conjunction with other QC results to identify whether the problem is specific to the QC samples or systematic.
Target Analyte Confirmation	Every positive detection	RPD ≤ 40%		Report the higher of the two concentrations unless a positive bias is apparent and qualify.

Table 2-19

Quality Control Method Criteria for Target Analyte List Metals by USEPA SW-846 Methods 6020/ 6010B/7471A/ 7470A/ 9010C/ 9012B

Procedure	Frequency of QC Procedure	Acceptance Criteria		Corrective Action
Tune (MS)	Daily	Analyzed a minimum of four times with RSD < 5% for analytes in the solution.		Sample analysis cannot begin until this criterion is met.
Mass Calibration (MS)	Daily	Difference < 0.1 amu from true value.		Adjust to the correct value.
Resolution Check (MS)	Daily	Peak width <0.9 amu at 10% peak height		Sample analysis cannot begin until this criterion is met.
Initial Calibration Curve (MS, ICP, Hg, & CN)	Daily, major maintenance, or to correct drift.	MS & ICP Option 1: 1-standard and a blank with a low level standard at RL.	Low level check standard ± 20%.	The standards for that element must be re-prepared and re-analyzed again.
		MS & ICP Option 2: 3-standards and a blank	r > 0.995 for each element	
		Hg – 5-standards and a blank	r > 0.995	
		CN – 6 standards and a blank	r > 0.995	
Distilled Standards (CN)	Once per calibration	One high and one low distilled standard within ± 10% of the true value		Sample analysis cannot begin until this criterion is met.
Initial Calibration Verification (MS, ICP, Hg, & CN)	Immediately following initial calibration.	MS & ICP - A second source full compliment of target list with a percent recovery = 90-110%		Sample analysis cannot begin until this criterion is met.
		Hg – A second source full compliment of target list with a percent recovery = 80-120%		
		CN - A second source full compliment of target list with a percent recovery = 85-115%		
Initial Calibration Blank (MS, ICP, Hg, & CN)	Immediately following initial calibration verification.	No target analytes detected at concentration above 2 X MDL.		Sample analysis cannot proceed until this criterion is met.
Interference Check (MS & ICP)	Beginning of each sample analytical run.	Recovery ±20% of true value.		Terminate the analysis, correct the problem, re-calibrate, re-verify the calibration, and reanalyze associated samples.
Continuing Calibration Check (MS, ICP, Hg, & CN)	Every 10 samples and end of analytical run.	MS & ICP - Recovery ±10%.		Reanalyze; if the CCV fails again, stop analysis, the problem corrected, the instrument recalibrated, and the calibration re-verified prior to continuing sample analyses.
		Hg - Recovery ±20%.		
		CN - Recovery ±15%.		
Continuing Calibration Blank (MS, ICP, Hg, & CN)	Every 10 samples and end of analytical run.	No target analytes detected at concentration above 2 X MDL.		Sample sequence should not continue until this criterion is met. Demonstrate "clean". Affected samples will be reanalyzed.
Preparation Blank (MS, ICP, Hg, & CN)	1 per batch per matrix	No target analytes detected at concentration above one half of the RL.		Document source of contamination. Re-digestion/re-analysis is required for positive results associated with blank contamination, unless DQOs are still met.

Table 2-19 (Continued)

Quality Control Method Criteria for Target Analyte List Metals by USEPA SW-846 Methods 6020/ 6010B/7471A/ 7470A/ 9010C/ 9012B

Procedure	Frequency of QC Procedure	Acceptance Criteria		Corrective Action
Laboratory Control Sample (MS, ICP, Hg, & CN)	1 per batch per matrix	Standards Full compliment target list.	80-120% recovery Soil use generated limits	Recoveries indicating a low bias require a redigestion/ reanalysis. Recoveries indicating a high bias require a redigestion/ reanalysis for associated positive field samples. Qualify data biased high or biased low as appropriate.
Matrix Spike and Duplicate or Sample Duplicate (MS, ICP, Hg, & CN)	1 per 20 samples per matrix	Standards Full compliment target list.	75-125% recovery; ICP & Hg: RPD≤25%; CN: RPD≤20%; MS: [analyte]>100xIDL -RPD≤20%; Soil use generated limits	Qualify associated data biased high or biased low as appropriate.
Post Digestion Spike (PDS) (MS & ICP)	1 per 20 samples per matrix	Standards Full compliment target list.	75-125% recovery	
Serial Dilution (MS & ICP)	1 per 20 samples per matrix	Used to assess new matrices	For sample results > 5x RL for ICP or > 20x RL for MS, %D between diluted and undiluted sample result ≤10%.	Chemical or physical interference indicated. Investigate to identify cause.
Internal Standards (MS)	Every Analytical Sequence	Standards & Blanks	80-120% of initial calibration intensity	Terminate the analysis, correct the problem, re-calibrate, re-verify the calibration, and reanalyze associated samples.
		Samples	30-120% of initial calibration intensity	Reanalyze at consecutive five fold dilutions until criteria is met.

Table 2-20
Quality Control Method Criteria for Pesticides, Herbicides, and PCBs by USEPA SW-846 Methods 8081A, 8082, and 8151A

Procedure	Frequency of QC Procedure	Acceptance Criteria		Corrective Action
Initial calibration curve 5-pt curve (linear) 6-pt curve (2o order)	Set-up, major maintenance	%RSD<20% or r>0.995 (linear) or r2>0.99 (2o order)		Sample analysis cannot begin until this criterion is met.
Initial Calibration Verification	Immediately following every initial calibration	A second source full compliment of target list with a percent recovery = 85-115%		Sample analysis cannot begin until this criterion is met.
Continuing Calibration Check	Bracketing samples	%D recovery ± 15% of the response factor from the initial curve or mean with no individual peak >30%		Sample analysis cannot begin until this criterion is met. If criteria are not met, reanalyze the daily standard. If the daily standard fails a second time, initial calibration must be repeated. Data reviewer should review and judge each target compound against the acceptance criteria.
Endrin/4,4-DDT Breakdown	Bracketing samples	endrin degradation ≤15%. 4,4-DDT degradation ≤15%.		If criterion is not met, system must be deactivated and the affected samples reanalyzed.
Instrument Blank	After continuing calibration and highly contaminated samples.	No target analytes detected greater than one half the RL.		Demonstrate "clean". Affected samples will be reanalyzed.
Method Blank	Per extraction batch	No target analytes detected greater than one half the RL.		Document source of contamination. Re-extraction/re-analysis is required for positive results associated with blank contamination.
Laboratory Control Spike	Per extraction batch	<u>Standards</u> Full target list for 8081A and a mix of 1016 & 1260 for 8082	Laboratory generated control limits not to exceed limits listed in the current version of DOD QSM	Recoveries indicating a low bias require a re-extraction/reanalysis. Recoveries indicating a high bias require a re-extraction/re-analysis for associated positive field samples. Qualify associated data biased high or biased low as appropriate.
Surrogate Spikes	Every sample	<u>Standards</u> TCMX and DCB	Laboratory generated control limits not to exceed limits listed in the current version of DOD QSM	Investigate to assess cause, correct the problem, and document actions taken; re-extract and re-analyze sample. Specific method cleanups may be used to eliminate or minimize sample matrix effects. If still out, qualify.

Table 2-20 (Continued)
Quality Control Method Criteria for Pesticides, Herbicides, and PCBs by USEPA SW-846 Methods 8081A, 8082, and 8151A

Procedure	Frequency of QC Procedure	Acceptance Criteria		Corrective Action
Matrix Spike and Duplicate	1 per 20 samples per matrix	Standards Full target list for 8081A and a mix of 1016 & 1260 for 8082	Laboratory generated control limits not to exceed limits listed in the current version of DOD QSM	If MS/MSD results do not meet criteria, the reviewer should review the data in conjunction with other QC results to identify whether the problem is specific to the QC samples or systematic. Specific method cleanups may be used to eliminate or minimize sample matrix effects.
Target Analyte Confirmation	Every positive detection	RPD ≤ 40%		Report the higher of the two concentrations unless a positive bias is apparent and qualify.

Table 2-21
Quality Control Method Criteria for Perchlorate by USEPA SW-846 Method 6850

Procedure	**Frequency of QC Procedure**	**Acceptance Criteria**	**Corrective Action**
Initial calibration curve 5-pt curve	Major maintenance, instrument modification, per manufacturer's specifications	r > 0.995	If outside criteria, the standards must be reanalyzed until correlation passes. Must meet criteria prior to sample analysis.
Independent Calibration Verification (ICV))	1 per batch	Recover = 90-110%	Sample must be pretreated.
Method Blank	1 per 20 samples or Batch	Not detected greater than ½ RL.	Re-prep and analyze whole batch after source of contamination is found and eliminated.
Continuing calibration verification (CCV)	All samples must be bracketed by an acceptable CCV.	Recovery = 50%-150% (low range) Recovery = 85% -115% (mid range)	If outside criteria, the standard must be reanalyzed. Must meet criteria prior to sample analysis.
Matrix spike and Duplicate	One per Batch or every 20 samples	Recovery = 75-125% (water and soil)	If MS/MSD results do not meet criteria, the reviewer should review the data in conjunction with other QC results to identify whether the problem is specific to the QC samples or systematic.
Laboratory Control Sample	1 per 20 samples or batch	Recovery = 85-115% (water and soil)	Recoveries indicating a low bias require a re-extraction/reanalysis. Qualify associated data biased high or biased low as appropriate.
Precision (RPD)	1 per 20 samples	20%.	If the RPD between MS/MSD exceed 15%, the reviewer should only flag positive results as necessary.
Internal Standard Response Verification	One for each samples and QC standard	Area count = +/- 30% of that of ICV or CCV	If the area count exceeds criterion, a second sample aliquot should be analyzed. If the second run still exceeds the limit, the data should be flagged and noted in the case narrative.

Table 2-22
Quality Control Method Criteria for Total Organic Carbon by Walkley-Black Method (Argonomy, Methods of Soil Analysis 29-3.5.2)

Procedure	Frequency of QC Procedure	Acceptance Criteria	Corrective Action
Calibration (Titration Method)	Before Processing Samples a titration blank must be analyzed	0.5+/- 0.05N	If the titrant normality is not within the QC limit, clean the burette and remake the titrant solution and/or the 1N K2Cr2O7.
Laboratory Duplicate	1 per 20 samples or batch per matrix	RPD = 20%	If the RPD is out side the QC limit, it should be noted in the lab narrative.
Method Blank	1 per 20 samples or batch per matrix	No target analytes detected greater than the RL.	Document source of contamination. Re-extraction/re-analysis is required for positive results associated with blank contamination.
Laboratory Control Sample	1 per 20 samples per matrix	Laboratory generated control limits not to exceed recovery limits of 64-128%	Recoveries indicating a low bias require a re-extraction/reanalysis. Recoveries indicating a high bias require a re-extraction/re-analysis for associated positive field samples. Qualify associated data biased high or biased low as appropriate.
Matrix Spike and Duplicate	1 per 20 samples per batch, per matrix	Laboratory generated control limits not to exceed recovery limits of 68-142%	If MS/MSD results do not meet criteria, the reviewer should review the data in conjunction with other QC results to identify whether the problem is specific to the QC samples or systematic.

Table 2-23
Quality Control Method Criteria for Chemical Oxygen Demand by USEPA Method of Chemical Analysis for Water and Wastes Method 410.4

Procedure	Frequency of QC Procedure	Acceptance Criteria	Corrective Action
Initial calibration curve 5-pt curve	Major maintenance, instrument modification, per manufacturer's specifications	r>0.995 (linear) or r>0.99 (2^o order)	Sample analysis cannot begin until this criterion is met.
Initial Calibration Verification	Immediately following every initial calibration	Recovery ±10% of true value	Sample analysis cannot begin until this criterion is met. If criteria are not met, reanalyze the daily standards. If the ICV fails a second time, initial calibration must be repeated.
Continuing Calibration Check	Every 10 samples, end of analytical run	Recovery ±10% of true value	Sample analysis cannot proceed until this criterion is met. Reanalyze CCC. If the CCC fails second time, the analysis must be terminated, the problem corrected, the instrument re-calibrated, and the calibration re-verified prior to continuing sample analyses.
Continuing Calibration Blank	Every 10 samples, end of analytical run	No target analytes detected greater than the RL.	If not within criteria, terminate the analysis, correct the problem, re-calibrate, and reanalyze each sample analyzed since the last acceptable CCB.
Method Blank	1 per 20 samples or batch per matrix	No target analytes detected greater than the RL.	Document source of contamination. Re-extraction/re-analysis is required for positive results associated with blank contamination.
Laboratory Control Sample	1 per 20 samples per matrix	Laboratory generated control limits not to exceed recovery limits of 60-140% or RPD of 30%	Recoveries indicating a low bias require a re-extraction/reanalysis. Recoveries indicating a high bias require a re-extraction/re-analysis for associated positive field samples. Qualify associated data biased high or biased low as appropriate.
Matrix Spike and Duplicate	1 per 20 samples per batch, per matrix	Laboratory generated control limits not to exceed recovery limits of 60-140% or RPD of 30%	If MS/MSD results do not meet criteria, the reviewer should review the data in conjunction with other QC results to identify whether the problem is specific to the QC samples or systematic.

Table 2-24
Quality Control Method Criteria for Dioxin/Furans by USEPA SW-846 Method 8290

Procedure	Frequency	Acceptance Criteria		Corrective Action
Initial calibration 5-pt	Set-up, major maintenance, or for drift correction	RSD ≤20% for standard compounds RSD ≤30% for reference compounds		Sample analysis cannot begin until this criterion is met. Data reviewer should review and judge each target compound against the acceptance criteria.
Continuing Calibration Check	12 hours	%Difference within s ±30% for reference compounds And ≤ 20% for standard compounds		Sample analysis cannot begin until this criterion is met. Data reviewer should review and judge each target compound against the acceptance criteria.
Internal standards	Every sample	Are all percent recoveries within 40-135%		Inspect for malfunction. Demonstrate that system is functioning properly. Reanalyze samples with internal standards outside criteria.
Tuning	12 hours	Must meet tuning criteria.		Re-tune, re-calibrate, and re-analyze affected sample analyses.
Method Blank	Per extraction batch	No target analytes greater than one half of the RL		Document source of contamination. Re-extraction/re-analysis is required for positive results associated with blank contamination.
Laboratory Control Spike	Every batch	<u>Standards</u> Full compliment target list	Laboratory generated control limits not to exceed recovery limits listed in the current version of the DoD QSM	Recoveries indicating a low bias require a re-extraction/reanalysis. Recoveries indicating a high bias require a re-extraction/re-analysis for associated positive field samples. Qualify associated data biased high or biased low as appropriate.
Matrix Spike and Duplicate	1 per 20 samples per matrix	<u>Standards</u> Full compliment target list	Laboratory generated control limits not to exceed recovery limits listed in the current version of the DoD QSM	If MS/MSD results do not meet criteria, the reviewer should review the data in conjunction with other QC results to identify whether the problem is specific to the QC samples or systematic.

2.7 DATA COLLECTION AND VALIDATION

Non-CLP SW-846 Test Methods are proposed for analytical work for this WPA and analyses will be conducted by a National Environmental Laboratory Accreditation Program (NELAP) accredited analytical laboratory. Level IV CLP-like raw data will be provided along with the Form 1. Additional discussion as to the laboratory deliverables may be found in Section 9.8.3 of the MQAP. Data will be made available to the USEPA upon request and presented in the SSP Report.

Data validation will be conducted on 100% of the data and documented based on the MQAP Section 9.5, USEPA SW-846 Test Method criteria, DOD QSM, and USEPA Region III guidance. Data qualifiers will follow the USEPA Region III Modifications to the USEPA National Functional Guidelines for Evaluating Inorganic Analysis and USEPA Region III Modifications to the USEPA National Functional Guidelines for Organic Data Review Multi-media, Multi-concentration (OLM01.0-OLM01.9). Verification for organic data will be performed at level M3 and the verification for inorganic data will be performed at level IM2.

Manual data validation will be conducted by an independent, third party data validator not directly associated with the field-sampling program. Ms. Roshanak Aryan, Quality Assurance Manager, will oversee the performance of data validation functions. Data validation will be performed by knowledgeable and experienced individuals who can best perform evaluations within the necessary validation components. The data validator’s qualifications will include experience with each of the elements required for the data verification and validation including ensuring that the measuring system meets the user’s needs, assigning qualifiers to individual data values, assessing the relevancy of performance criteria, and concluding that data can proceed to quality assessment and reporting.

URS will direct the overall data management. Data management activities for the sampling program will be divided between URS, TriMatrix Laboratories, Columbia Analytical Services for perchlorate analyses, and Paradigm Analytical Laboratories for Dioxin/Furan analyses. Each firm has the equipment needed to perform the required data management functions. The laboratory will perform data entry and manipulation operations associated with the analysis of raw analytical data and provisions of chemical analysis results by sampling location. These data will be transmitted to URS for evaluation and interpretation. In addition, URS will review boring logs and sample location maps.

3.0 HEALTH AND SAFETY PLAN ADDENDUM

3.1 INTRODUCTION

This site-specific HSPA was developed to provide the requirements for protection of site personnel, including government employees, URS personnel, regulators, subcontractors, and visitors, which are expected to be involved with soil boring advancement/sampling at SWMU 45.

This HSPA addresses project-specific hazards, which include physical hazards, biological hazards, and chemical hazards, as identified in Section 3.2.2, below.

This addendum addresses site-specific training, personal protective equipment (PPE), and air monitoring requirements. General health and safety issues that are also applicable to this scope of work are addressed in Master Health and Safety Plan, as shown in Table 3-1.

Table 3-1

Health and Safety Issues Discussed in the MHSP

Health and Safety Issue	Section in MHSP
Site Safety and Health Documentation	1.4
Safety Statement	1.5
Health and Safety Personnel and Responsibilities	2.1
Hazard Assessment and Hazard Control	3.0
Training Plan	4.0
Medical Surveillance Plan	5.0
Site Safety and Control	6.0
PPE	7.0
Personnel and Equipment Decontamination	8.0
Monitoring Plan	9.0
Emergency Response and Contingency Plan	10.0

URS, subcontractor personnel, and site visitors will read this HSPA and will be required to follow its protocols as minimum standards. This HSPA is written for the site-specific conditions at SWMU 45 and must be amended if conditions change. A copy of this HSPA will be available at each work site.

The contractor will provide a safe work environment for personnel involved in RFAAP investigative activities. The contractor will emphasize the importance of personnel injury and illness prevention at the work site.

3.2 TRAINING PLAN

Training will be used to review important topics outlined in this addendum and to inform URS personnel and subcontractor personnel of the hazards and control techniques associated with facility-wide conditions.

Site personnel will be informed of the specific PPE that will be worn during field activities. This includes, at a minimum, steel-toed boots, safety glasses (with side shields), gloves, and hardhat. Each field person will also have a respirator on the site, in the event that an emergency occurs and a respirator is necessary for site evacuation, or if the use of a respirator is necessary based on air monitoring results. Prior to initiation of fieldwork, the staff will be required to review the manual *Safety, Security and Environmental Rules for Contractors and Subcontractors* (ATK 2000). Additional training, which will be conducted during daily safety “tailgate” meetings, will include emergency and evacuation procedures, general safety rules, and use of automobiles. Written documentation of safety briefings will be kept on the site.

3.2.1 Hazard Information Training

Hazard information training will be presented to URS and subcontractor personnel to provide a description of the Hazardous, Toxic, and Radioactive Waste (HTRW) with the potential to be found at SWMU 45. Training will also be provided on the potential biological, chemical, and physical hazards to be found at the Installation. The URS SHSO will conduct this training based on information provided by the operating contractor.

3.2.2 Project-Specific Hazard Analysis

The following hazards must be recognized and controlled during applicable investigative activities:

(1) Physical Hazards

- Cold stress – refer to Section 3.2.2 of the MHSP;
- Falls, open excavation, confined-space entry;
- Noise from heavy equipment;
- Cuts, abrasions, and lacerations;
- Manual lifting – refer to Section 3.2.4 of the MHSP;
- Slips, trips, and falls associated with walking through heavily vegetated areas – refer to Section 6.1.1 of the MHSP;
- Heavy equipment – refer to Section 6.1.2.1 of the MHSP; and
- MMA – overhead power lines.

(2) Biological Hazards (refer to Section 3.3 of the MHSP)

- Insect bites and stings;
- Tick bites;
- Snake, rodent, or other animal bites; and
- Dangerous plants.

(3) Chemical Hazards

- Potential exposure to toxic chemicals; and
- Potential exposure to dangerous fumes in case of a nearby release or spill of acids, resulting in the creation of a fume cloud.

3.2.3 Hearing Conservation Training

Site personnel involved in heavy equipment operation in addition to other operations involving exposure to noise levels exceeding 85 decibels on the A-weighted scale Decibels on the A-Weighted Scale (dBA) eight-hour time-weighted average (TWA) shall be trained according to 29 CFR 1910.95. This training shall address the effects of noise on hearing, the purpose, advantages, disadvantages, and selection of hearing protection devices, and the purpose and explanation of Audiometric test procedures.

3.2.4 Hazard Communication Training

In order to comply with the requirements of the OSHA Hazard Communication (HAZCOM) Standard, 29 CFR 1910.1200, URS will have a written HAZCOM Program in place. The written hazard communication program addresses training (including potential safety and health effects from exposure), labeling, current inventory of hazardous chemicals on the site, and the location and use of Material Safety Data Sheets (MSDSs). The SHSO will arrange HAZCOM training for site personnel at the time of initial site assignment. Whenever a new hazardous substance is introduced into the work area or an employee changes job locations where new chemicals are encountered, supplemental HAZCOM training shall be scheduled and presented. HAZCOM training shall be documented by the SHSO using a HAZCOM Employee Training Record. This documentation and the URS HAZCOM Program will be maintained on the site for the duration of the project, and later incorporated in the employees' personal training file.

3.2.5 Confined Space Entry Training

Confined space entry training will not be required for fieldwork, as there will be no confined spaces entered during this investigation.

3.3 PERSONAL PROTECTIVE EQUIPMENT AND CLOTHING

The minimum and initial level of PPE for these activities will be Level D. The initial selection of PPE is based on a hazard assessment, including the review of existing analytical data and related toxicological information with respect to the proposed field activities. PPE assignments are subject to change based upon site conditions and task variation. The SHSO will review the required level of protection and safety equipment for each task with the sampling crew. The decisions on which protective level is most appropriate will be made by the SHSO.

In accordance with 29 CFR 1910.134, URS personnel working on the site will be required to participate in the written URS respiratory protection program. Personnel slated for fieldwork will have a qualitative fit test performed at least once per year or more frequently as required by law. Site personnel will be trained on the use, limitations, maintenance, inspection, and cleaning of respirators.

3.4 MONITORING PLAN

During sampling activities, the SHSO will monitor the site initially and periodically for potentially hazardous airborne constituents or physical hazards. The SHSO will use a photoionization detector (PID) to detect volatile organic vapors. SOP 90.1 describes the calibration of the PID that the SHSO will conduct daily. The action levels for volatile organic compounds at sustained concentrations in the breathing zone are as follows:

PID Readings	**Action**
Background plus 5 ppm	Investigate
Five ppm to 25 ppm	Upgrade to Level C (full face air-purifying respirator with organic vapor/acid gas cartridges), and investigate
Greater than 25 ppm	Suspend work, depart area, and investigate
ppm = Parts Per Million	

3.5 EMERGENCY RESPONSE PLAN

Emergency response will follow the protocols set fort in MHSP, Section 10.0. Table 3-2 presents the current emergency telephone numbers applicable to activities performed at RFAAP.

Table 3-2
Emergency Telephone Numbers

Contact	Telephone Number
Emergency Response Services	
Installation Fire Department**	16 (on post)
Installation Security Police**	7325 (on post) (540) 639-7325 (off post)
Installation Safety Department**	7294 (on post) (540) 639-7294 (off post)
Installation Spill Response**	7323, 7324 or 7325 (on post) (540) 639-7323, 7324, or 7325 (off post)
Installation Medical Facility** (RFAAP Hospital)	7323 or 7325 (on post) (540) 639-7323 or 7325 (off post)
Local Police Department	911
New River Valley Medical Center	(540) 731-2000 - General Telephone Number
National Poison Control Center	(800) 222-1222
National Response Center	(800) 424-8802
Regional USEPA Emergency Response	(215) 814-9016
Chemical Manufacturers Association Chemical Referral Center	(800) 262-8200

Directions from the Main Gate:

New River Valley Medical Center
2900 Lamb Circle
Christiansburg, VA 24073

Take Route 114 toward Radford to first traffic light. Take U.S. Route 11 South and go across the bridge over the New River. Turn left after crossing the bridge, continue to Virginia Route 177 South, and turn right. Proceed on VA 177 South and cross over Interstate 81. New River Valley Medical Center is on the left.

** These telephone numbers are referenced from *Safety, Security and Environmental Rules for Contractors and Subcontractors* (ATK 2000).

4.0 REFERENCES

Alliant TechSystems (ATK). 1998. Closure *Documentation for Solid Waste Management Unit 10, Biological Treatment Plant Equalization Basin*.

Alliant TechSystems (ATK). 2000. *Safety, Security and Environmental Rules for Contractors and Subcontractors*.

ASTM International (ASTM). 2002. ASTM Standard D 422-63 (2002)e1. *Test Method for Particle-Size Analysis of Soils*.

ASTM International (ASTM). 2005a. ASTM Standard D 2216-05. *Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass*.

ASTM International (ASTM). 2005b. ASTM Standard D 4318-05. *Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils*.

ASTM International (ASTM). 2007a. ASTM Standard D 4972-01 (2007). *Standard Test Method for pH of Soils*.

Dames & Moore. 1991. *Bio-Plant Environmental Site Investigation*. Radford Army Ammunition Plant, Virginia. Prepared for Wiley & Wilson, Lynchburg, Virginia.

Dames & Moore. 1992a. *Draft VI Report for the Radford Army Ammunition Plant, Virginia*. Prepared for the U.S. Army Toxic and Hazardous Materials Agency.

Dames & Moore. 1994a. *Verification Investigation Revised Section 7.0, SWMU 10, Biological Treatment Equalization Basin and SWMU 35, Calcium Sulfate Drying Bed (Draft).* Radford Army Ammunition Plant, Virginia. Prepared for the U.S. Army Environmental Center.

IT Corporation (IT). 2001. *Facility-Wide Background Study Report*. Radford Army Ammunition Plant, Virginia. Final. Delivery Order No. 0013, Contract No. DACA31-94-D-0064. December 2001.

URS Corporation (URS). 2003. *Final Master Work Plan, Quality Assurance Plan, Health and Safety Plan*. Radford Army Ammunition Plant, Radford, Virginia. Prepared for U.S. Army Corps of Engineers, Baltimore District. August 2003.

URS Corporation (URS). 2004. *Soil Screening Report for Solid Waste Management Units 8 and 36.* Radford Army Ammunition Plant, Virginia. Prepared for U.S. Army Corps of Engineers, Baltimore District. January 2004.

URS Corporation (URS). 2005a. *Decision Document for Solid Waste Management Unit 8.* Radford Army Ammunition Plant, Virginia. Prepared for U.S. Army Corps of Engineers, Baltimore District. July 2005.

URS Corporation (URS). 2005b. *Decision Document for Solid Waste Management Unit 36.* Radford Army Ammunition Plant, Virginia. Prepared for U.S. Army Corps of Engineers, Baltimore District. July 2005.

URS Corporation (URS). 2007. *Site Screening Process Report for Solid Waste Management Units 13, 37, 38, 46, 57, 68, 69, 75, 76, and Areas Of Concern A, F, and Q.* Radford Army Ammunition Plant, Virginia. Prepared for U.S. Army Corps of Engineers, Baltimore District. January 2007.

U.S. Army Corps of Engineers (USACE). 2001. *Requirements for the Preparation of Sampling and Analysis Plans*. Engineer Manual, No. 200-1-3. February 1, 2001.

U.S. Environmental Protection Agency (USEPA). 1987. *RCRA Facility Assessment for Radford Army Ammunition Plant, Radford, Virginia, VAD-21-002-0730*.

U. S. Environmental Protection Agency (USEPA). 1992. *Installation Assessment, Radford Army Ammunition Plant, Radford, Virginia*. Environmental Photographic Interpretation Center (EPIC).

U.S. Environmental Protection Agency (USEPA). 2000a. *Permit for Corrective Action and Waste Minimization; Pursuant to the Resource Conservation and Recovery Act as Amended by the Hazardous and Solid Waste Amendments of 1984.* Radford Army Ammunition Plant, Radford, Virginia, VA1210020730.

U.S. Environmental Protection Agency (USEPA). 2000b. *Guidance for the Data Quality Objectives Process, EPA QA/G-4.* EPA/600/R-96/055. August 2000.

U.S. Environmental Protection Agency (USEPA). 2000c. *Guidance for Data Quality Objectives for Hazardous Waste Sites*. EPA/300/R-00/007. Office of Solid Waste and Emergency Response.

U.S. Environmental Protection Agency (USEPA). 2001. *Site Screening Process Guidance-Final*. Radford Army Ammunition Plant. October 26, 2001.

U.S. Environmental Protection Agency (USEPA). 2007. *USEPA Region III Risk-Based Concentration Table.* April 2007.

WORK PLAN
ADDENDUM
022

SITE SCREENING
PROCESS AT
SOLID WASTE
MANAGEMENT
UNIT 45

RADFORD ARMY
AMMUNITION PLANT
RADFORD, VIRGINIA

FINAL
DECEMBER 2007

URS

CONTRACT NO.
W9128F-04D-000
DELIVERY ORDER NO.
DO-DA01

WORK PLAN
ADDENDUM
022

SITE SCREENING
PROCESS AT
SOLID WASTE
MANAGEMENT
UNIT 45

RADFORD ARMY
AMMUNITION PLANT
RADFORD, VIRGINIA

FINAL
DECEMBER 2007

URS

CONTRACT NO.
W9128F-04D-000
DELIVERY ORDER NO.
DO-DA01

WORK PLAN
ADDENDUM
022

SITE SCREENING
PROCESS AT
SOLID WASTE
MANAGEMENT
UNIT 45

RADFORD ARMY
AMMUNITION PLANT
RADFORD, VIRGINIA

FINAL
DECEMBER 2007

URS

CONTRACT NO.
W9128F-04D-000
DELIVERY ORDER NO.
DO-DA01

WORK PLAN
ADDENDUM
022

SITE SCREENING
PROCESS AT
SOLID WASTE
MANAGEMENT
UNIT 45

RADFORD ARMY
AMMUNITION PLANT
RADFORD, VIRGINIA

FINAL
DECEMBER 2007

URS

CONTRACT NO.
W9128F-04D-000
DELIVERY ORDER NO.
DO-DA01

APPENDIX A

STANDARD OPERATING PROCEDURES

THIS PAGE LEFT INTENTIONALLY BLANK

Standard Operating Procedures

SOP SERIES	TITLE
10.0	**DOCUMENTATION**
10.1	Field Logbook
10.2	Surface Water, Groundwater, and Soil/Sediment Field Logbooks
10.3	Boring Logs
10.4	Chain-of-Custody Forms
20.0	**SUBSURFACE INVESTIGATION**
20.1	Monitoring Well Installation
20.2	Monitoring Well Development
20.3	Well and Boring Abandonment
20.4	Test Pits
20.7	Resistivity and Electromagnetic Surveys
20.8	Magnetic and Metal Detection Surveys
20.11	Drilling Methods and Procedures
30.0	**SAMPLING**
30.1	Soil Sampling
30.2	Groundwater Sampling
30.6	Containerized Material
30.7	Sampling Strategies
30.9	Collection of Soil Samples By USEPA SW-846 Method 5035 Using Disposable Samplers
40.0	**FIELD EVALUATION**
40.1	Multiparameter Water Quality Monitoring Instrument
40.2	Water Level and Well-Depth Measurements
40.3	Slug Tests
50.0	**SAMPLE MANAGEMENT**
50.1	Sample Labels
50.2	Sample Packaging
70.0	**INVESTIGATION-DERIVED MATERIAL**
70.1	Investigation-Derived Material
80.0	**DECONTAMINATION**
80.1	Decontamination
90.0	**AIR MONITORING EQUIPMENT**
90.1	Photoionization Detector (HNu Model PI-101 and HW-101)

THIS PAGE LEFT INTENTIONALLY BLANK

STANDARD OPERATING PROCEDURE 10.1
FIELD LOGBOOK

1.0 SCOPE AND APPLICATION

The purpose of this standard operating procedure (SOP) is to delineate protocols for recording daily site investigation activities.

Records should contain sufficient information so that anyone can reconstruct the sampling activity without relying on the collector's memory.

2.0 MATERIALS

- Field Logbook;
- Indelible ink pen; and
- Clear tape.

3.0 PROCEDURE

Information pertinent to site investigations will be recorded in a bound logbook. Each page/form will be consecutively numbered, dated, and signed. All entries will be made in indelible ink, and all corrections will consist of line out deletions that are initialed and dated. If only part of a page is used, the remainder of the page should have an "X" drawn across it. At a minimum, entries in the logbook will include but not be limited to the following:

- Project name (cover);
- Name and affiliation of personnel on site;
- Weather conditions;
- General description of the field activity;
- Sample location;
- Sample identification number;
- Time and date of sample collection;
- Specific sample attributes (e.g., sample collection depth flow conditions or matrix);
- Sampling methodology (grab or composite sample);
- Sample preservation, as applicable;
- Analytical request/methods;
- Associated quality assurance/quality control (QA/QC) samples;
- Field measurements/observations, as applicable; and
- Signature and date of personnel responsible for documentation.

4.0 MAINTENANCE

Not applicable.

5.0 PRECAUTIONS

None.

6.0 REFERENCES

USEPA. 1990. *Sampler's Guide to the Contract Laboratory Program*. EPA/540/P-90/006, Directive 9240.0-06, Office of Emergency and Remedial Response, Washington, DC.

USEPA. 1991. *User's Guide to the Contract Laboratory Program*. EPA/540/O-91/002, Directive 9240.0-01D, Office of Emergency and Remedial Response, January.

USEPA. 1998. *EPA Requirements for Quality Assurance Project Plans.* EPA/600/R-98/018, QA/R5, Final, Office of Research and Development, Washington, D.C.

STANDARD OPERATING PROCEDURE 10.2
SURFACE WATER, GROUNDWATER, AND SOIL/SEDIMENT FIELD LOGBOOKS

1.0 SCOPE AND APPLICATION

The purpose of this standard operating procedure (SOP) is to delineate protocols for recording surface water, groundwater, and soil/sediment sampling information, as well as instrument calibration data in field logbooks.

2.0 MATERIAL

- Applicable field logbook (see attached forms); and
- Indelible ink pen.

3.0 PROCEDURE

All information pertinent to surface water, groundwater, or soil/sediment sampling will be recorded in the appropriate logbook. Each page/form of the logbook will be consecutively numbered. All entries will be made with an indelible ink pen. All corrections will consist of line out deletions that are initialed and dated.

3.1 SOIL/SEDIMENT

3.1.1 Field Parameters/Logbook (Form 10.2-a)

1. HIGH CONCENTRATION EXPECTED?: Answer “Yes” or “No.”;
2. HIGH HAZARD?: Answer “Yes” or “No.”;
3. INSTALLATION/SITE: Record the complete name of the installation or site;
4. AREA: Record the area designation of the sample site;
5. INST. NAME: Record the two-letter installation name for Radford Army Ammunition Plant – “RD”;
6. SAMPLE MATRIX CODE: Record the appropriate sample matrix code. Common codes are “SD” for solid - sediment, “SI” for soil - gas, “SL for solid sludge, “SO” for surface other, “SS” for solid – soil, “SW” for surface wipe, “WD” for water – potable, “WG” for water – ground, “WS” water – surface, “WT” – water treated and “WW” water -waste;
7. SITE ID: Record a code up to 20 characters or numbers that is unique to the site;
8. ENV. FIELD SAMPLE IDENTIFIER: Record a code up to 20 characters specific for the sample;
9. DATE: Enter the date the sample was taken;
10. TIME: Enter the time (12-hour or 24-hour clock acceptable as long as internally consistent) the sample was taken;
11. AM PM: Circle “AM” or “PM” to designate morning or afternoon (12-hour clock);
12. SAMPLE PROG: Record “RFI” (RCRA Facility Investigation) or other appropriate sample program;
13. DEPTH (TOP): Record the total depth sampled;
14. DEPTH INTERVAL: Record the intervals at which the plug will be sampled;

15. UNITS: Record the units of depth (feet, meters);
16. SAMPLE MEASUREMENTS: Check the appropriate sampling method;
17. CHK: Check off each container released to a laboratory;
18. ANALYSIS: Record the type of analysis to be performed on each sample container;
19. SAMPLE CONTAINER: Record the sample container type and size;
20. NO.: Record the number of containers;
21. REMARKS: Record any remarks about the sample;
22. TOTAL NUMBER OF CONTAINERS FOR SAMPLE: Record the total number of containers;
23. SITE DESCRIPTION: Describe the location where the sample was collected;
24. SAMPLE FORM: Record the form of the sample (i.e., clay, loam, etc.) using The Unified Soil Classification System (USCS);
25. COLOR: Record the color of the sample as determined from standard Munsell Color Charts;
26. ODOR: Record the odor of the sample or "none";
27. PID: Record the measured PID values or other similar measurement instrument value;
28. UNUSUAL FEATURES: Record anything unusual about the site or sample;
29. WEATHER/TEMPERATURE: Record the weather and temperature; and
30. SAMPLER: Record your name.

3.1.2 Map File Form (refer to form 10.2-c)

1. SITE ID: Record the Site ID from the field parameter form;
2. POINTER: Record the field sample number for the sample being pointed to;
3. DESCRIPTION/MEASUREMENTS: Describe the location where the sample was taken, along with distances to landmarks;
4. SKETCH/DIMENSIONS: Diagram the surroundings and record the distances to landmarks;
5. MAP REFERENCE: Record which U.S.G.S. Quad Map references the site;
6. COORDINATE DEFINITION: Write the compass directions and the X- and Y-coordinates of the map run;
7. COORDINATE SYSTEM: Write "UTM" (Universal Transverse Mercator);
8. SOURCE: Record the 1-digit code representing the Map Reference;
9. ACCURACY: Give units (e.g., write "1-M" for 1 meter);
10. X-COORDINATE: Record the X-coordinate of the sample site location;
11. Y-COORDINATE: Record the Y-coordinate of the sample site location;
12. UNITS: Record the units used to measure the map sections;
13. ELEVATION REFERENCE: Record whether topography was determined from a map or a topographical survey;
14. ELEVATION SOURCE: Record the 1-digit code representing the elevation reference;

15. ACCURACY: Record the accuracy of the map or survey providing the topographical information;
16. ELEVATION: Record the elevation of the sampling site;
17. UNITS: Write the units in which the elevation is recorded; and
18. SAMPLER: Write your name.

3.2 SURFACE WATER

3.2.1 Field Parameter Logbook (Forms 10.2-b and 10.2-c)

1. CAL REF: Record the calibration reference for the pH meter;
2. pH: Record the pH of the sample;
3. TEMP: Record the temperature of the sample in degrees Celsius;
4. COND: Record the conductivity of the water;
5. Description of site and sample conditions (refer to 10.2-b);
6. Map File Form (refer to Section 3.1.2).

3.3 GROUNDWATER (FORMS 10.2- D)

3.3.1 Field Parameter Logbook (Form 10.2.b)

Refer to Section 3.2.1.

3.3.2 Map File and Purging Forms

1. WELL NO. OR ID: Record the abbreviation appropriate for where the sample was taken. Correct abbreviations can be found on pages 18-21 of the IRDMIS User's Guide for chemical data entry;
2. SAMPLE NO.: Record the reference number of the sample;
3. WELL/SITE DESCRIPTION: Describe the location where the sample was taken, along with distances to landmarks;
4. X-COORD AND Y-COORD: Record the survey coordinates for the sampling site;
5. ELEV: Record the elevation where the sample was taken;
6. UNITS: Record the units the elevation was recorded in;
7. DATE: Record the date in the form MM/DD/YY;
8. TIME: Record the time, including a designation of AM or PM;
9. AIR TEMP.: Record the air temperature, including a designation of C or F (Celsius or Fahrenheit);
10. WELL DEPTH: Record the depth of the well in feet and inches;
11. CASING HEIGHT: Record the height of the casing in feet and inches;
12. WATER DEPTH: Record the depth (underground) of the water in feet and inches;
13. WELL DIAMETER: Record the diameter of the well in inches;
14. WATER COLUMN HEIGHT: Record the height of the water column in feet and inches;
15. SANDPACK DIAM.: Record the diameter of the sandpack. Generally, this will be the same as the bore diameter;

16. EQUIVALENT VOLUME OF STANDING WATER: Use one of the following equations to determine one equivalent volume (EV);

    1 EV = volume in casing + volume in saturated sandpack. Or:

    1 EV = $[\pi R_w^2 h_w + 0.30p(R_s^2 - R_w^2)h_s] * (0.0043)$

Where:

R_s = radius of sandpack in inches
R_w = radius of well casing in inches
h_s = height of sandpack in inches
h_w = water depth in inches

0.0043 = gal/in^3
and filter pack porosity is assumed as 30%, or

Volume in casing =
(0.0043 gal/in^3)(p)(12 in/ft)(R_c^2)(W_h)

Where:

R_c = radius of casing in inches, and
W_h = water column height in feet

Vol. in sandpack =
(0.0043 gal/in3)(p)(12 in/ft)(Rb2 - Rc2)(Wh)(0.30)

(if Wh is less than the length of the sandpack), or

Vol. in sandpack =
(0.0043 gal/in3)(p)(12 in/ft)(Rb2 - Rc2)(Sh)(0.30)

(if Wh is greater than the length of the sandpack).

where:

Rb = radius of the borehole, and
Sh = length of the sandpack.

Show this calculation in the comments section.

1. PUMP RATE: Record pump rate;
2. TOTAL PUMP TIME: Record total purge time and volume;
3. WELL WENT DRY? Write “YES” or “NO”;
4. PUMP TIME: Record pump time that made the well go dry;
5. VOLUME REMOVED: Record the volume of water (gal) removed before the well went dry;
6. RECOVERY TIME: Record the time required for the well to refill;

7. PURGE AGAIN?: Answer “YES” or “NO”;
8. TOTAL VOL. REMOVED: Record the total volume of water (in gallons) removed from the well;
9. CAL REF.: Record the calibration reference for the pH meter;
10. TIME: Record time started (INITIAL T(0)), 2 times DURING the sampling and the time sampling ended (FINAL);
11. pH: Record the pH at start of sampling (INITIAL), twice DURING the sampling, and at the end of sampling (FINAL);
12. TEMP: Record the water temperature (Celsius) at the start of sampling, twice DURING the sampling, and at the end of sampling (FINAL);
13. COND: Record the conductivity of the water at the start of sampling, twice DURING the sampling, and at the end of sampling (FINAL);
14. D.O.: Record the dissolved oxygen level in the water at the start of sampling, twice DURING the sampling, and at the end of sampling (FINAL);
15. TURBIDITY: Record the readings from the turbidity meter (nephelometer) and units at the start of sampling, twice DURING the sampling, and at the end of sampling (FINAL);
16. ORD: Record the oxidation/reduction (RedOx) potential of the water sample at the start of sampling, twice DURING the sampling, and at the end of sampling (FINAL);
17. HEAD SPACE: Record any positive readings from organic vapor meter reading taken in well headspace before sampling;
18. NAPL: Record the presence and thickness of any non-aqueous phase liquids (LNAPL and DNAPL)
19. COMMENTS: Record any pertinent information not already covered in the form; and
20. SIGNATURE: Sign the form.

3.4 FIELD CALIBRATION FORMS (REFER TO FORM 10.2-E)

1. Record time and date of calibration;
2. Record calibration standard reference number;
3. Record meter ID number;
4. Record initial instrument reading, recalibration reading (if necessary), and final calibration reading on appropriate line;
5. Record value of reference standard (as required);
6. COMMENTS: Record any pertinent information not already covered on form; and
7. SIGNATURE: Sign form.

4.0 MAINTENANCE

Not applicable.

5.0 PRECAUTIONS

None.

6.0 REFERENCE

USEPA. 1991. *User's Guide to the Contract Laboratory Program*. EPA/540/O-91/002, Directive 9240.0-01D, Office of Emergency and Remedial Response, January.

FIELD PARAMETER/LOGBOOK FORM 10.2-a
SOIL AND SEDIMENT SAMPLES

HIGH CONCENTRATION EXPECTED? ___________________ HIGH HAZARD?

INSTALLATION/SITE ____ AREA ___________________

INST NAME ___________ FILE NAME ____

SAMPLE MATRIX CODE _____________ SITE ID _____________________
ENV. FIELD SAMPLE IDENTIFIER ___________________

DATE (MM/DD/YY) __/__/__ TIME ___________ AM PM SAMPLE PROGRAM

DEPTH (TOP) _______ DEPTH INTERVAL ______________ UNIT _____________

SAMPLING METHOD:

SPLIT SPOON ___ AUGER ___ SHELBY TUBE ___ SCOOP ___ OTHER

CHK	ANALYSIS	SAMPLE CONTAINER	NO.	REMARKS

TOTAL NUMBER OF CONTAINERS FOR SAMPLE______

DESCRIPTION OF SITE AND SAMPLE CONDITIONS

SITE DESCRIPTION:____

____

____

SAMPLE FORM ______________________ COLOR _______________ ODOR _____________
PID (HNu)_____________________ UNUSUAL FEATURES_______________________

____

WEATHER/TEMPERATURE

SAMPLER ___________________

FIELD PARAMETER/LOGBOOK FORM 10.2-b
GROUNDWATER AND SURFACE WATER SAMPLES

HIGH CONCENTRATION EXPECTED? _________________ HIGH HAZARD?

INSTALLATION/SITE _______________________ AREA
INST CODE ___________ FILE NAME _____________________ SITE TYPE
SITE ID ____________________ FIELD SAMPLE NUMBER
DATE (MM/DD/YY) __/__/__ TIME ___________ AM PM SAMPLE PROG.
DEPTH (TOP) __________ DEPTH INTERVAL ____________ UNITS

SAMPLING MEASUREMENTS

CAL REF. _____ pH _____ TEMPERATURE °C _____ CONDUCTIVITY _____ REDOX _____
DISSOLVED OXYGEN ____ TURBIDITY _____ OTHER

CHK	ANALYSIS	SAMPLE CONTAINER	NO.	REMARKS

TOTAL NUMBER OF CONTAINERS FOR SAMPLE______

DESCRIPTION OF SITE AND SAMPLE CONDITIONS

SITE DESCRIPTION____
SAMPLING METHOD______________________________________
SAMPLE FORM __________________ COLOR ________ ODOR ________
PID (HNu)____
UNUSUAL FEATURES______________________________
WEATHER/TEMPERATURE____ SAMPLER ________________

EXAMPLE MAP FILE LOGBOOK FORM 10.2-c
SURFACE WATER, SOIL, AND SEDIMENT SAMPLES

SITE ID__________________________ POINTER____________________

DESCRIPTION/MEASUREMENTS____

SKETCH/DIMENSIONS :

MAP REFERENCE____

COORDINATE DEFINITION (X is ________________ Y is ____________)

COORDINATE SYSTEM ________________ SOURCE ________________ ACCURACY___________________

X-COORDINATE ____________ Y-COORDINATE ____________ UNITS_________

ELEVATION REFERENCE__________________________________

ELEVATION SOURCE _________________ ACCURACY _______________ELEVATION__________________

UNITS________________

SAMPLER__________

EXAMPLE MAP FILE AND PURGING LOGBOOK FORM 10.2-d
GROUNDWATER SAMPLES

WELL COORD. OR ID _______________________ SAMPLE NO.______________

WELL/SITE DESCRIPTION____

____

X-COORD. _______ Y-COORD. _______________ ELEV. _________ UNITS

DATE ____/____/____ TIME _________________ AIR TEMP.

WELL DEPTH _____________ FT. ______ IN. CASING HT. _____ FT. ____ IN.

WATER DEPTH ______ FT. ______ IN. WELL DIAMETER _________ IN.

WATER COLUMN HEIGHT ________ FT. ______ IN. SANDPACK DIAM. _____ IN.

EQUIVALENT VOLUME OF STANDING WATER ________________ (GAL) (L)

VOLUME OF BAILER _______ (GAL) (L) or PUMP RATE _________ (GPM) (LPM)

TOTAL NO. OF BAILERS (5 EV) _________ or PUMP TIME ________ MIN.

WELL WENT DRY? [Yes] [No] NUM. OF BAILERS ________ or PUMP TIME

VOL. REMOVED ______________ (GAL) (L) RECOVERY TIME

PURGE AGAIN? [Yes] [No] TOTAL VOL. REMOVED ___________ (GAL) (L)

DATE & TIME	QUANTITY REMOVED	TIME REQ'D	pH	Cond	Temp	ORD	Turb	DO	Character of water (color / clarity / odor / partic.)
(before)									
(during)									
(during)									
(during									
(after)									

COMMENTS____

SIGNATURE____

EXAMPLE FIELD CALIBRATION FORM 10.2-e
FOR pH, CONDUCTIVITY, TEMPERATURE, TURBIDITY, ORD, AND DISSOLVED OXYGEN METERS

INITIAL CALIBRATION	FINAL CALIBRATION
DATE:	DATE:
TIME:	TIME:

pH METER CALIBRATION

CALIBRATION STANDARD REFERENCE NO:_________________

METER ID____________________

pH STANDARD	INITIAL READING	RECALIB. READING	FINAL READING
7.0			
10.0			
4.0			

CONDUCTIVITY METER CALIBRATION

CALIBRATION STANDARD REFERENCE NO:_________________

METER ID____________________

COND. STANDARD	INITIAL READING	RECALIB. READING	FINAL READING

TEMPERATURE METER CALIBRATION

METER ID____________________

TEMP. STANDARD	INITIAL READING	RECALIB. READING	FINAL READING
ICE WATER			
BOILING WATER			
OTHER _________			

EXAMPLE FIELD CALIBRATION FORM 10.2-e
FOR pH, CONDUCTIVITY, TEMPERATURE, TURBIDITY, ORD, AND DISSOLVED OXYGEN METERS

TURBIDITY METER CALIBRATION

CALIBRATION STANDARD REFERENCE NO:_________________

METER ID____________________

STANDARD	INITIAL READING	RECALIB. READING	FINAL READING

ORD METER CALIBRATION

CALIBRATION STANDARD REFERENCE NO:_________________

METER ID____________________

STANDARD	INITIAL READING	RECALIB. READING	FINAL READING

DISSOLVED OXYGEN METER CALIBRATION

CALIBRATION STANDARD REFERENCE NO:_________________

METER ID____________________

STANDARD	INITIAL READING	RECALIB. READING	FINAL READING

COMMENTS____

SIGNATURE______________________________________

STANDARD OPERATING PROCEDURE 10.3
BORING LOGS

1.0 INTRODUCTION

The purpose of this standard operating procedure (SOP) is to describe the methods to be followed for classifying soil and rock, as well as preparing borehole logs and other types of soil reports.

2.0 MATERIALS

The following equipment is required for borehole logging:

- HTRW ENG Form 5056-R and 5056A-R boring log forms;
- Daily inspection report forms;
- Chain-of-custody forms;
- Request for analysis forms;
- ASTM D 2488 classification flow chart;
- Soil and/or Rock color chart (i.e., Munsell®);
- Grain size and roundness chart;
- Graph paper;
- Engineer's scale;
- Previous reports and boring logs;
- Pocketknife or putty knife;
- Hand lens;
- Dilute hydrochloric acid (10% volume);
- Gloves;
- Personal protective clothing and equipment, as described in work plan addenda health and safety plan;
- Photoionization detector or other appropriate monitoring equipment per site-specific health and safety plan; and
- Decontamination supplies (SOP 80.1).

3.0 PROCEDURE

Each boring log should fully describe the subsurface environment and the procedures used to obtain this description.

Boring logs should be prepared in the field on USACE Engineer Form 5056-R and 5056-R. Logs should be recorded in the field directly on the boring log form and not transcribed from a field book.

A “site geologist” should conduct borehole logging and soil/rock identification and description or other professional trained in the identification and description of soil/rock.

3.1 BORING LOG INFORMATION

As appropriate, the following information should be recorded on the boring log during the course of drilling and sampling activities:

- Project information including name, location, and project number;
- Each boring and well should be uniquely numbered and located on a sketch map as part of the log;
- Type of exploration;
- Weather conditions including events that could affect subsurface conditions;
- Dates and times for the start and completion of borings, with notations by depth for crew shifts and individual days;
- Depths/heights in feet and in decimal fractions of feet;
- Descriptions of the drilling equipment including rod size, bit type, pump type, rig manufacturer and model, and drilling personnel;
- Drilling sequence and descriptions of casing and method of installation;
- Description and identification of soils in accordance with ASTM Standard D 2488;
- Descriptions of each intact soil sample for the parameters identified in Section 3.2;
- Descriptions and classification of each non-intact sample (e.g., wash samples, cuttings, auger flight samples) to the extent practicable;
- Description and identification of rock;
- Description of rock (core(s)) for the parameters identified in Section 3.7;
- Scaled graphic sketch of the rock core (included or attached to log) according to the requirements identified in Section 3.7;
- Lithologic boundaries, with notations for estimated boundaries;
- Depth of water first encountered in drilling, with the method of first determination (any distinct water level(s) below the first zone will also be noted);
- Interval by depth for each sample taken, classified, and/or retained, with length of sample recovery and sample type and size (diameter and length);
- Blow counts, hammer weight, and length of fall for driven samplers;
- Rate of rock coring and associated rock quality designation (RQD) for intervals cored;
- Drilling fluid pressures, with driller’s comments;
- Total depth of drilling and sampling;
- Drilling fluid losses and gains should be recorded;
- Significant color changes in the drilling fluid returned;
- Soil gas or vapor readings with the interval sampled, with information on instrument used and calibration;

- Depth and description of any in-situ test performed; and
- Description of other field tests conducted on soil and rock samples.

3.2 SOIL PARAMETERS FOR LOGGING

In general, the following soil parameters should be included on the boring log when appropriate:

- Identification per ASTM D 2488 with group symbol;
- Secondary components with estimated percentages per ASTM D 2488;
- Color;
- Plasticity per ASTM D 2488;
- Density of non-cohesive soil or consistency of cohesive soil;
- Moisture condition per ASTM D 2488 (dry, moist, or wet);
- Presence of organic material;
- Cementation and HCL reaction testing per ASTM D 2488;
- Coarse-grained particle description per ASTM D 2488 including angularity, shapes, and color;
- Structure per ASTM D 2488 and orientation;
- Odor; and
- Depositional environment and formation, if known.

ASTM D 2488 categorizes soils into 13 basic groups with distinct geologic and engineering properties based on visual-manual identification procedures. The following steps are required to classify a soil sample:

1. Observe basic properties and characteristics of the soil. These include grain size grading and distribution, and influence of moisture on fine-grained soil.
2. Assign the soil an ASTM D 2488 classification and denote it by the standard group name and symbol.
3. Provide a written description to differentiate between soils in the same group if necessary.

Many soils have characteristics that are not clearly associated with a specific soil group. These soils might be near the borderline between groups, based on particle distribution or plasticity characteristics. In such a case, assigning dual group names and symbols (e.g., GW/GC or ML/CL) might be an appropriate method of describing the soil. The two general types of soils, for which classification is performed, coarse- and fine-grained soils, are discussed in the following sections.

3.3 COURSE-GRAINED SOIL IDENTIFICATION

For soils in the coarse-grained soils group, more than half of the material in the soil matrix will be retained by a No. 200 sieve (75-µm).

1. Coarse-grained soils are identified on the basis of the following:
   a) Grain size and distribution;
   b) Quantity of fine-grained material (i.e., silt and clay as a percentage); and

c) Character of fine-grained material.

2. The following symbols are used for classification:

Basic Symbols	Modifying Symbols
G = gravel	W = well graded
S = sand	P = poorly graded
	M = with silty fines
	C = with clayey fines

3. The following basic facts apply to coarse-grained soil classification.

- The basic symbol G is used if the estimated percentage of gravel is greater than that for sand. In contrast, the symbol S is used when the estimated percentage of sand is greater than the percentage of gravel.
- Gravel ranges in size from 3-inch to 1/4-inch (No. 4 sieve) diameter. Sand ranges in size from the No. 4 sieve to No. 200 sieve. The Grain Size Scale used by Engineers (ASTM Standard D 422-63) is the appropriate method to further classify grain size as specified by ASTM D 2488.
- Modifying symbol W indicates good representation of all particle sizes.
- Modifying symbol P indicates that there is an excess or absence of particular sizes.
- The symbol W or P is used only when there are less than 15% fines in a sample.
- Modifying symbol M is used if fines have little or no plasticity (silty).
- Modifying symbol C is used if fines have low to high plasticity (clayey).

Figure 10.03a is a flowchart for identifying coarse-grained soils by ASTM D 2488.

3.4 FINED-GRAINED SOIL IDENTIFICATON

If one-half or more of the material will pass a No. 200 sieve (75 μm), the soil is identified as fine-grained.

1. Fine-grained soils are classified based on dry strength, dilatancy, toughness, and plasticity.
2. Classification of fine-grained soils uses the following symbols:

Basic Symbols	Modifying Symbols
M = silt (non plastic)	L = low liquid limit (lean)
C = clay (plastic)	H = high liquid limit (fat)
O = organic	
Pt = peat	

3. The following basic facts apply to fine-grained soil classification:
    - The basic symbol M is used if the soil is mostly silt, while the symbol C applies if it consists mostly of clay.
4. Use of symbol O (group name OL/OH) indicates that organic matter is present in an amount sufficient to influence soil properties. The symbol Pt indicates soil that consists mostly of organic material.

- Modifying symbols (L and H) are based on the following hand tests conducted on a soil sample:

  - Dry strength (crushing resistance).
  - Dilatancy (reaction to shaking).
  - Toughness (consistency near plastic limit).

- Soil designated ML has little or no plasticity and can be recognized by slight dry strength, quick dilatency, and slight toughness.
- CL indicates soil with slight to medium plasticity, which can be recognized by medium to high dry strength, very slow dilatancy, and medium toughness.

Criteria for describing dry strength per ASTM D 2488 are as follows:

Description	Criteria
None	Dry sample crumbles into powder with pressure of handling
Low	Dry specimen crumbles into powder with some finger pressure
Medium	Dry specimen breaks into pieces or crumbles with considerable finger pressure
High	Dry specimen cannot be broken with finger pressure but will break into pieces between thumb and a hard surface
Very high	Dry specimen cannot be broken between the thumb and a hard surface stiffness

Criteria for describing dilatancy per ASTM D 2488 are as follows:

None	No visible change in the sample
Slow	Water appears slow on the surface of the sample during shaking and does not disappear or disappears slowly upon squeezing
Rapid	Water appears quickly on the surface of the sample during shaking and disappears quickly upon squeezing

Criteria for describing toughness per ASTM D 2488 are as follows:

Description	Criteria
Low	Only slight pressure is required to roll the thread near the plastic limit and the thread and lump are weak and soft
Medium	Medium pressure is required to roll the thread to near the plastic limit and the thread and lump have medium stiffness
High	Considerable pressure is required to roll the thread to near the plastic limit and the thread and lump have very high stiffness

Figure 10.03b is a flowchart for identifying fine-grained soils by ASTM D 2488.

3.5 DENSITY AND CONSISTENCY

Relative density for coarse-grained soils and consistency for fine-grained soils can be estimated using standard penetration test blow count data (ASTM D 1586). The number of blows required for each 6 inches of penetration or fraction thereof is recorded. If the sampler is driven less than 18 inches, the number of blows per each complete 6-inch interval and per partial interval is recorded.

For partial increments, the depth of penetration should be recorded to the nearest 1 inch. If the sampler advances below the bottom of the boring under the weight of rods (static) and/or hammer, then this information should be recorded on the log.

The following are some “rule-of-thumb” guidelines for describing the relative density of coarse-grained soils:

Blow Count	Relative Density for Sand
0–4	Very loose
4–10	Loose
10–30	Medium dense
30–50	Dense
>50	Very Dense

The following are some “rule-of-thumb” guidelines for describing the consistency of fine-grained soils:

Blow Count	Consistency for Clays	Description
0–2	Very Soft	Sample sags or slumps under its own weight
2–4	Soft	Sample can be pinched in two between the thumb and forefinger
4–8	Medium Stiff	Sample can be easily imprinted with fingers
8–16	Stiff	Sample can be imprinted only with considerable pressure of fingers
16–32	Very Stiff	Sample can be imprinted very slightly with fingers
>32	Hard	Sample cannot be imprinted with fingers; can be pierced with pencil

3.6 OTHER DESCRIPTIVE INFORMATION

The approximate percentage of gravel, sand, and fines (use a percentage estimation chart) should be recorded per ASTM D 2488 as follows:

Modifiers	Descriptions
Trace	Less than 5%
Few	5%–10%
Little	15%–25%
Some	30%–45%
Mostly	50%–100%

Color/discoloration should be recorded and described using a soil color chart, such as the Munsell® Soil Color Charts. A narrative and numerical description should be given from the color chart, such as Brown 10 YR, 5/3 (Munsell®). Odor should be described if organic or unusual.

Plasticity should be described as follows:

Description	Criteria
Non-plastic	A 1/8-inch thread cannot be rolled at any water content
Low	Thread can barely be rolled and lump cannot be formed when drier than plastic limit.

Medium	Thread is easy to roll; plastic limit can be reached with little effort and lump crumbles when drier than plastic limit.
High	Considerable time is required to reach the plastic limit and lump can be formed without crumbling when drier than plastic limit

Moisture condition should be recorded as dry (absence of moisture), moist (damp but no visible water) or wet (visible free water).

Cementation should be recorded (carbonates or silicates) along with the results of HCL reaction testing. The reaction with HCL should be described as none (no visible reaction), weak (some reaction with slowly forming bubbles) or strong (violent reaction with bubbles forming immediately).

Particle description information for coarse-grained soil should be recorded where appropriate per ASTM D 2488 including maximum particle size, angularity (angular, subangular, subrounded, or rounded), shape (flat, elongated or flat and elongated), and color.

Structure (along with orientation) should be reported using the following ASTM D 2488 descriptions:

Description	Criteria
Stratified	Alternating layers of varying material or color with layers greater than 6 millimeters thick
Laminated	Alternating layers of varying material or color with layers less than 6 millimeters thick
Fissured	Breaks along definite planes of fracture with little resistance
Slickensided	Fracture planes that appear polished or glossy, can be striated
Blocky	Inclusion of small pockets of different soils
Homogeneous	Same color and appearance throughout

3.7 ROCK CORE PARAMETERS FOR LOGGING

In general, the following parameters should be included on the boring log when rock coring is conducted:

- Rock type;
- Formation;
- Modifier denoting variety;
- Bedding/banding characteristics;
- Color;
- Hardness;
- Degree of cementation;
- Texture;
- Structure and orientation;
- Degree of weathering;
- Solution or void conditions;
- Primary and secondary permeability including estimates and rationale; and
- Lost core interval and reason for loss.

A scaled graphic sketch of the core should provided on or attached to the log, denoting by depth, location, orientation, and nature (natural, coring-induced, or for fitting into core box) of all core breaks. Where fractures are too numerous to be shown individually, their location may be drawn as a zone.

The RQD values for each core interval (run) should be calculated and included on the boring log. The method of calculating the RQD is as follows per ASTM D 6032:

RQD = [Σ length of intact core pieces > 100 mm (4-inches)] x 100%/total core length.

3.8 PROCEDURES FOR ROCK CLASSIFICATION

For rock classification record mineralogy, texture, and structural features (e.g., biotite and quartz fine grains, foliated parallel to relict bedding oriented 15 to 20 degrees to core axis, joints coated with iron oxide). Describe the physical characteristics of the rock that are important for engineering considerations such as fracturing (including minimum, maximum, and most common and degree of spacing), hardness, and weathering.

1. The following is to be used as a guide for assessing fracturing:

AEG Fracturing	Spacing
Crushed	up to 0.1 foot
Intense	0.1–0.5 foot
Moderate	0.5 foot–10 feet
Slight	1.0 foot–3.0 feet
Massive	>3.0 feet

2. Record hardness using the following guidelines:

Hardness	Criteria
Soft	Reserved for plastic material
Friable	Easily crumbled by finger pressure
Low	Deeply gouged or carved with pocketknife
Moderate	Readily scratched with knife; scratch leaves heavy trace of dust
Hard	Difficult to scratch with knife; scratch produces little powder and is often faintly visible
Very Hard	Cannot be scratched with knife

3. Describe weathering using the following guidelines:

Weathering	**Decomposition**	**Discoloration**	**Fracture Condition**
Deep	Moderate to complete alteration of minerals feldspars altered to clay, etc.	Deep and thorough	All fractures extensively coated with oxides, carbonates, or clay

Weathering	Decomposition	Discoloration	Fracture Condition
Moderate	Slight alteration of minerals, cleavage surface lusterless and stained	Moderate or localized and intense	Thin coatings or stains
Weak	No megascopic alteration of minerals	Slight and intermittent and localized	Few strains on fracture surfaces
Fresh	Unaltered, cleavage, surface glistening		

3.9 PROCEDURE FOR LOGGING REFUSE

The following procedure applies to the logging of subsurface samples composed of various materials in addition to soil as may be collected from a landfill or other waste disposal site.

1. Observe refuse as it is brought up by the hollow stem auger, bucket auger, or backhoe.

2. If necessary, place the refuse in a plastic bag to examine the sample.

3. Record observations according to the following criteria:

   - Composition (by relative volume), e.g., paper, wood, plastic, cloth, cement, or construction debris. Use such terms as "mostly" or "at least half." Do not use percentages;
   - Moisture condition: dry, moist, or wet;
   - State of decomposition: highly decomposed, moderately decomposed, slightly decomposed, etc.;
   - Color: obvious mottling and/or degree of mottling;
   - Texture: spongy, plastic (cohesive), friable;
   - Odor;
   - Combustible gas readings (measure down hole and at surface); and
   - Miscellaneous: dates of periodicals and newspapers, ability to read printed materials, degree of drilling effort (easy, difficult, and very difficult).

3.10 SUBMITTAL REQUIREMENTS

Each original boring log should be submitted to the Contracting Officer Representative (CRO) after completion of the boring. When a monitoring well will be installed in a boring, the boring log and well installation diagram should be submitted together.

4.0 MAINTENANCE

Not applicable.

5.0 PRECAUTIONS

Not applicable.

6.0 REFERENCES

ASTM Standard D 422-63 (2002)e1. 2002. *Standard Test Method for Particle-Size Analysis of Soils.*

ASTM Standard D 1586–99 (1999). 1999. *Standard Test Method for Penetration Test and Split-Barrel Sampling of Soils.*

ASTM Standard D 2488-06. 2006. *Standard Practice for Description and Identification of Soils Visual-Manual Procedure).*

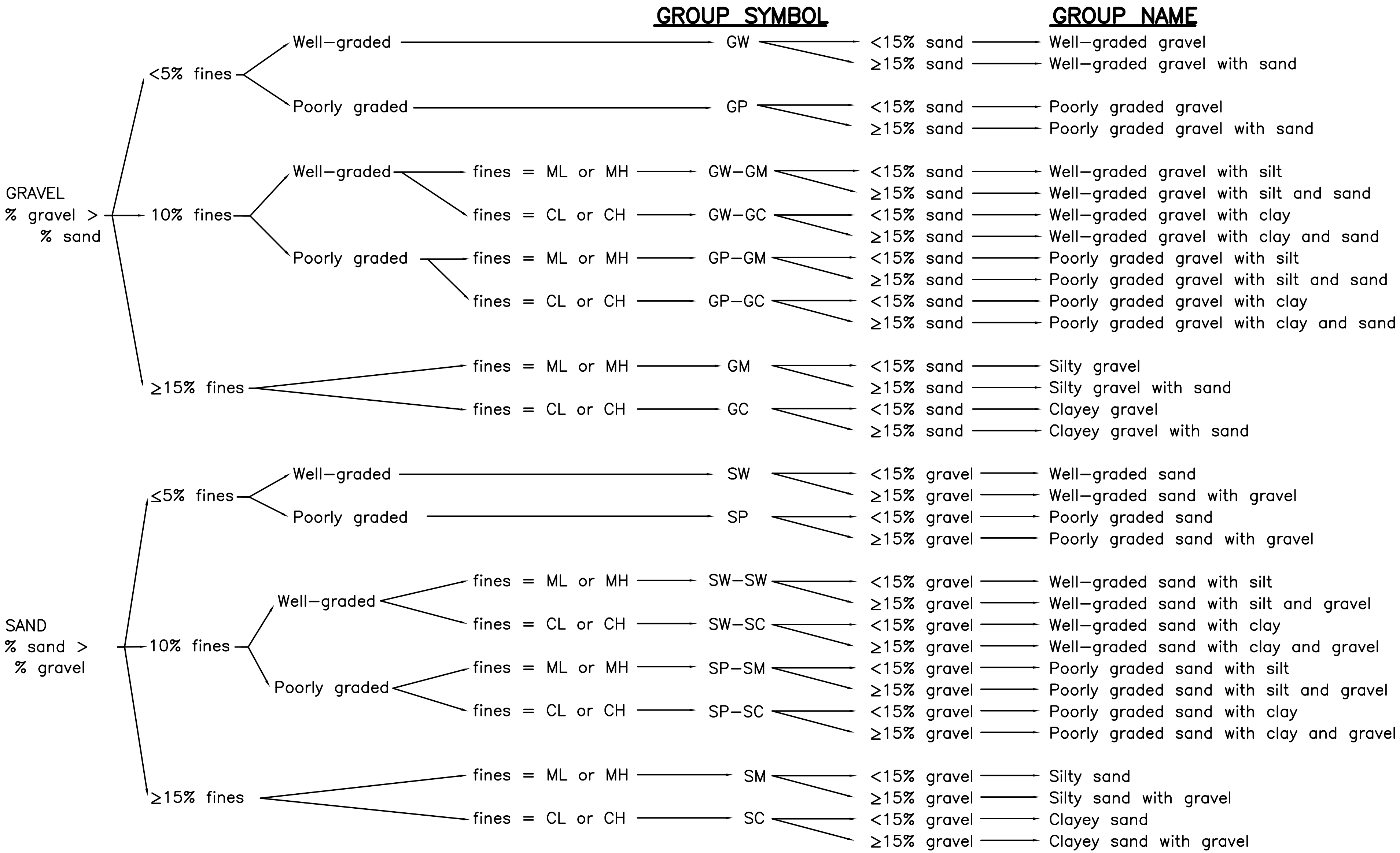
ASTM Standard D 5434-03. 2003. *Guide for Field Logging of Subsurface Explorations of Soil and Rock.*

ASTM Standard D 6032-02 (2006). 2006. *Standard Test Method for Determining Rock Quality Designation (RQD) of Rock Core.*

Compton, R. R. 1962. *Manual of Field Geology.* John Wiley & Sons, Inc., New York.

USACE. 1998. *Monitoring Well Design, Installation, and Documentation at Hazardous, Toxic, and Radioactive Waste Sites.* EM 1110-1-4000, 1, November.

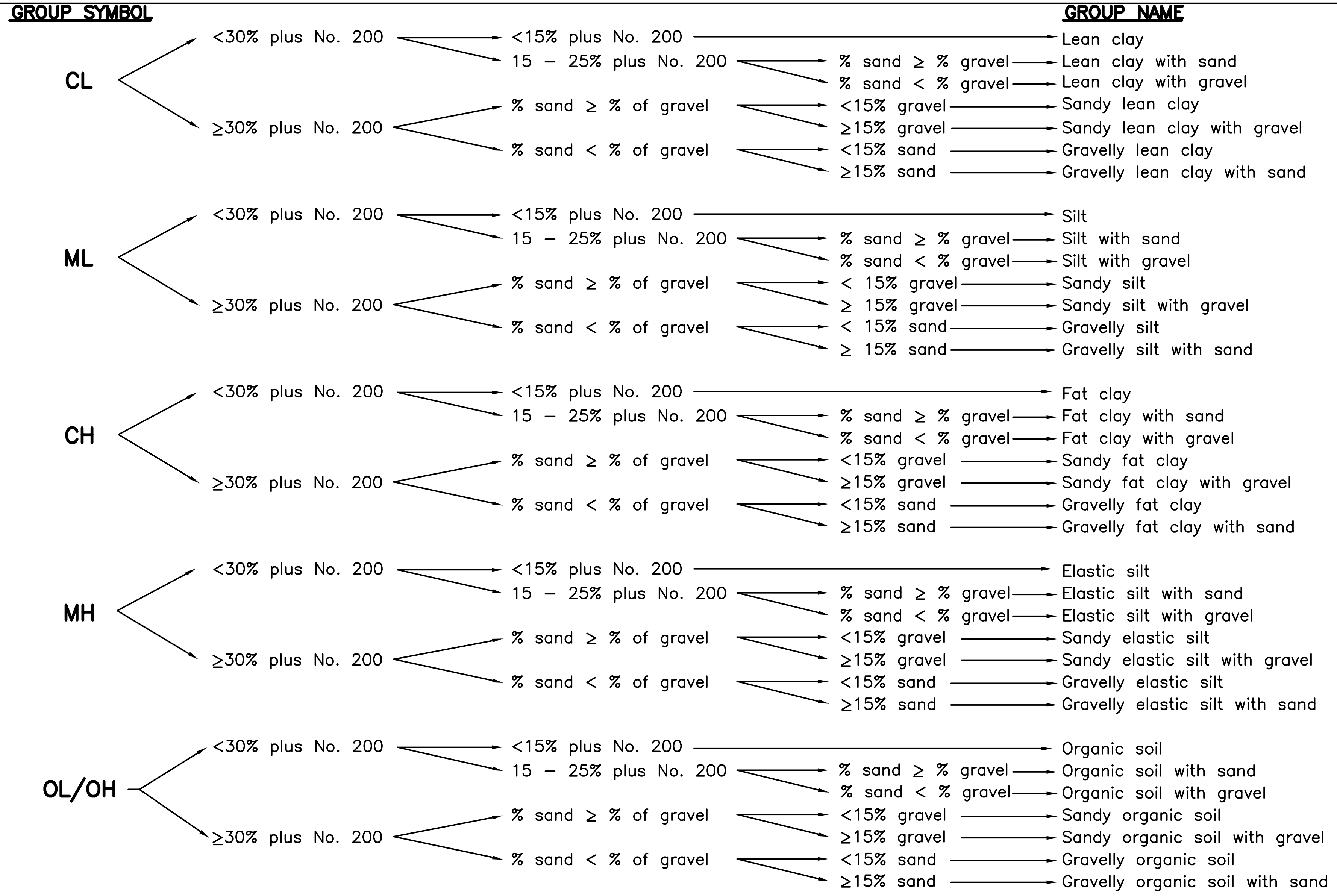
U.S. Department of the Interior. 1989. *Earth Manual.* Water and Power Resources Service, Washington, DC.



NOTE: PERCENTAGES ARE BASED ON ESTIMATING AMOUNTS OF FINES, SAND, AND GRAVEL TO THE NEAREST 5%.

SOURCE: ASTM D 2488

Radford Army Ammuntion Plant		**FIGURE 10.03a**
Date: October 2007	**Prepared By:** DBC/TLD	**FLOW CHART FOR IDENTIFYING COARSE-GRAINED SOILS**
Scale: N.T.S.	**File Name:** SOP Figure 10.03a_Coarse	



NOTE: PERCENTAGES ARE BASED ON ESTIMATING AMOUNTS OF FINES, SAND, AND GRAVEL TO THE NEAREST 5%.

SOURCE: ASTM D 2488

Radford Army Ammuntion Plant

Date: *October 2007*	**Prepared By:** *DBC/TLD*
Scale: *N.T.S.*	**File Name:** *SOP Figure 10.03b_Fine*

FIGURE 10.03b

FLOW CHART FOR IDENTIFYING FINE-GRAINED SOILS

STANDARD OPERATING PROCEDURE 10.4
CHAIN-OF-CUSTODY FORM

1.0 SCOPE AND APPLICATION

The purpose of this standard operating procedure (SOP) is to delineate protocols for use of the chain-of-custody form. An example is provided as part of this SOP. Other formats with similar levels of detail are acceptable.

2.0 MATERIALS

- Chain-of-custody form; and
- Indelible ink pen.

3.0 PROCEDURE

1. Record the project name and number.
2. Record the project contact's name and phone number.
3. Print sampler's names in "Samplers" block.
4. Enter the Field Sample No.
5. Record the sampling dates for all samples.
6. List the sampling times (military format) for all samples.
7. Indicate, "grab" or "composite" sample with an "X."
8. Record matrix (e.g., aqueous, soil).
9. List the analyses/container volume across top.
10. Enter the total number of containers per Field Sample No. in the "Subtotal" column.
11. Enter total number of containers submitted per analysis requested.
12. State the carrier service and airbill number, analytical laboratory, and custody seal numbers.
13. List any comments or special requests in the "Remarks" section.
14. Sign, date, and time the "Relinquished By" section when the cooler is relinquished to the next party.
15. Upon completion of the form, retain the shipper copy and place the forms and the other copies in a zip seal bag to protect from moisture. Affix the zip seal bag to the inside lid of the sample cooler to be sent to the designated laboratory.

4.0 MAINTENANCE

Not applicable.

5.0 PRECAUTIONS

None.

6.0 REFERENCES

USEPA. 1990. *Sampler's Guide to the Contract Laboratory Program.* EPA/540/P-90/006, Directive 9240.0-06, Office of Emergency and Remedial Response, Washington, DC, December 1990.

USEPA. 1991. *User's Guide to the Contract Laboratory Program..* EPA/540/O-91/002, Directive 9240.0-01D, Office of Emergency and Remedial Response, January 1991.

USEPA. 1998. *EPA Requirements for Quality Assurance Project Plans.* EPA/600/R-98/018, QA/R5, Final, Office of Research and Development, Washington, D.C.

FIGURE 10.4-a
EXAMPLE CHAIN-OF-CUSTODY FORM

Project Number	Project Name				Matrix	A	N	A	L	Y	S	E	S		LAB :
Project Contact (Name and Phone Number)															AIRBILL No:
Samplers:															Courier:
Field Sample No.	Date (MM-DD-YY)	Time	Comp	Grab										Subtotal	REMARKS
TOTAL															

Relinquished by:	Date/time	Received by:	Relinquished by:	Date/Time	Received by:
Relinquished by:	Date/time	Received by: (for lab)	Date/Time	Remarks	

STANDARD OPERATING PROCEDURE 20.1
MONITORING WELL INSTALLATION

1.0 SCOPE AND APPLICATION

The installation of monitoring wells is contingent upon the existing conditions at the project site. The purpose of this standard operating procedure (SOP) is to delineate the quality control measures required to ensure the accurate installation of monitoring wells. For a particular site investigation, the associated work plan addenda should be consulted for specific installation instructions. The term "monitoring wells", as used herein is defined to denote any environmental sampling well.

2.0 MATERIALS

2.1 DRILLING EQUIPMENT

- Appropriately sized drill rig adequately equipped with augers, bits, drill stem, etc;
- Steam cleaner and approved source water for decontamination of drilling equipment, etc.;
- Source of approved water;
- Photoionization detector or other appropriate monitoring instrument per the site-specific Health and Safety plan;
- Water level indicator (electrical);
- Weighted steel tape measure;
- Steel drums and other appropriate containers for investigation-derived materials (drill cuttings, contaminated PPE, decontamination solutions, etc.);
- Absorbent pads and/or logs;
- Personal protective equipment and clothing (PPE) per site-specific health and safety plan; and
- Decontamination supplies, pad with heavy plastic sheeting (SOP 80.1).

2.2 WELL INSTALLATION MATERIALS

Technical information on all installed materials (screens, riser pipe, filter pack, bentonite, cement, etc.) and representative samples of the proposed filter pack will be supplied to the Contracting Officer's Representative (COR) before initiating well installation.

Well screen slot size and filter pack gradation will be determined based on existing site geology before initiating site-specific investigations.

- Well screen:

  Polyvinyl Chloride (PVC): JOHNSON (or equivalent); PVC commercially slotted continuous slot, wire wrapped screen; 4-in. diameter.; SCH 40; SCH 80; flush-threaded (leak-proof) joints; PVC should conform to National Sanitation Foundation (NSF) Standard 14 for potable water usage or ASTM Standard Specification F 480 and bear the appropriate rating logo. PVC should be free of ink markings, cleaned, and prepackaged by manufacturer;

Stainless Steel: JOHNSON (or equivalent); stainless steel Vee-Wire continuous slot, wire wrapped screen; 304 stainless steel (unless the sum concentration of Cl^-, F^-, and Br^- is <1000 ppm, case type 316 should be used); ASTM F 480 flush threads; cleaned, wrapped, and heat-sealed by manufacturer;

- Riser pipe:
    - PVC: JOHNSON (or equivalent); STD. PVC; 4-in. diameter.; SCH 40; SCH 80; flush-threaded (leak-proof) joints; PVC should conform to NSF Standard 14 or F 480; free of ink markings; cleaned and prepackaged by manufacturer;
    - Stainless Steel: JOHNSON (or equivalent); SCH 5; 304 stainless steel; ASTM type A312 material; 4-in. diameter.; cleaned, wrapped and heat-sealed by manufacturer;
- Plugs/Caps: JOHNSON (or equivalent); standard PVC or stainless steel;
- Filter pack: MORIE, clean sorted gravel (or equivalent);
- Bentonite seal: BAROID, bentonite pellets (3/8-in. diameter.);
- Cement: Type II Portland Cement; if sulfate concentrations are higher than 1500 ppm, Type IV Portland Cement will be used;
- Bentonite powder: BAROID, Aquagel Gold Seal;
- Steel Protective Casing: BRAINARD-KILMAN (or equivalent) zinc-plated steel, lockable, painted;
- Containers for purged water, as required;
- Submersible pump or bailer of appropriate capacity, and surge block sized to fit well;
- Hach DREL 2000 portable laboratory (or equivalent);
- Multiprobe Electronic Water Quality Recorder (Hydrolab);
- Electric well sounder and measuring tape;
- Portland Type II cement (see footnote); and
- Steel Posts (pickets), painted (see footnote).

2.3 DOCUMENTATION

- Copy of work plans and health and safety plan;
- Copy of USACE EM 110-1-4000 Monitoring Well Requirements;
- Copies of permits (area entry, hot work, well, and utility clearance);
- Boring log forms;
- Well completion diagram form; and
- Field logbook.

2.4 GEOLOGIST'S PERSONAL EQUIPMENT

- Boring log materials per SOP 10.3; and
- Personal protective equipment and clothing (PPE) as required by the site-specific health and safety plan.

3.0 PROCEDURE

3.1 MATERIALS APPROVAL

3.1.1 Source Water

Water sources for drilling, grouting, sealing, filter pack placement, well installation, and equipment decontamination must be approved by the COR before arrival of the drilling equipment. Information required for the water source includes:

- Water source;
- Manufacturer/owner and their address and telephone number;
- Type of treatment and filtration prior to tap;
- Time of access;
- Cost per gallon (if applicable); and
- Dates and results associated with all available chemical analyses over the past 2 years, and the name and address of the analytical laboratory (if applicable).

3.1.2 Bentonite

Pure sodium bentonite with no additives (bentonite) will be the only drilling fluid additive allowed, and its use must be approved by the COR before the arrival of the drilling equipment. The information required for evaluation includes brand name, manufacturer, manufacturer's address and telephone number, product description, and intended use for the product, and potential effects on chemical analysis of water samples.

3.1.3 Granular Filter Pack

Granular filter pack material must be approved by the COR before drilling. A one-pint representative sample must be supplied to the COR. Information required includes lithology, grain size distribution, brand name, source, processing method, and size of intended screen.

3.1.4 Cement

Portland Type II cement will be used for grout (or Type IV, as noted in Section 2.2).

3.2 DRILLING

The objective of the selected drilling technique used at given site is to ensure that the drilling method provides representative data while minimizing subsurface contamination, cross contamination, and drilling costs.

Drilling methods that are appropriate for boring or monitoring well installation will depend on the subsurface geology most likely to be encountered in the boring. The geology for each site should be determined by reviewing previous investigation data (boring data, geophysics, etc.) from the site or nearby areas. Specific drilling methods that will be used to support site activities will be incorporated into work plan addenda.

Section 5.2.2 of the Master Work Plan discusses the different drilling methods that may be appropriate for installation of monitoring wells at the Radford Army Ammunition Plant (RFAAP) based on the different types of conditions encountered. The different drilling methods discussed in this section of the Master Work Plan including:

- Hollow Stem Auger (for soil);

- Air Rotary (soil and rock);
- Water Rotary and wire-line casing advancement (soil and rock);
- Drill-Through-Casing Driver (soil and rock); and
- Sonic (soil and rock).

3.2.1 Responsibilities of the Site Geologist

A Site Geologist will be present during all well drilling and installation activities and will fully characterize all tasks performed in support of these activities in the monitoring well logbook. The Site Geologist will be responsible for the logging samples, monitoring drilling operations, recording water losses/gains and groundwater data, preparing the boring logs and well diagrams, and recording the well installation procedures for one operating rig. The Site Geologist will have sufficient equipment in operable condition on-site to perform efficiently his/her duties.

3.2.2 Additives

No lubricants will be used on down hole drilling equipment. Additives containing either lead or copper will not be allowed. In addition, polychlorinated biphenyls will not be permitted in hydraulic fluids or other fluids used in the drilling rig, pumps, or other field equipment and vehicles.

Surface runoff or other fluids will not be allowed to enter any boring or well during or after drilling/construction.

Antifreeze used to keep equipment from freezing will not contain rust inhibitors and sealants. Antifreeze is prohibited in any areas in contact with drilling fluid. Absorbent pillows will be placed to catch any obvious leaks from the drill rig.

3.2.3 Boring Logs and Field Notes

Borings for monitoring wells will be logged by a geologist as described in SOP 10.3. Logs will be recorded on USACE HTRW ENG Form 5056-R and 5056A-R boring log forms.

Daily investigation activities at the site related to drilling should be recorded in field logbooks as described in SOPs 10.1 and 10.2.

3.3 WELL CONSTRUCTION AND INSTALLATION

Specifications for monitoring well construction and installation for a given site being investigated are to be included in work plan addenda. In case the previously defined criteria have not been met before the depth range for a given hole is reached, the geologist will stop the drilling and confer with the supervisor. The current boring conditions (depth, nature of the stratigraphic unit, and water-table depth) will be compared to those of other wells nearby to decide whether to continue drilling or to terminate and complete the well.

3.3.1 Overburden Wells

Overburden wells at the RFAAP are typically designed as a 4-inch diameter, single cased well (see Figure 20-1a) installed into a surficial aquifer, which is present above bedrock. For this type of well, the well boring would be terminated before penetrating any underlying confining unit and/or bedrock.

Section 5.2.2 of the Master Work Plan discusses the different drilling methods that may be appropriate for installation of overburden wells.

If dense, non-aqueous liquid (DNAPL) is encountered during drilling, the well boring will be terminated and completed at the base of the overburden aquifer being monitored.

3.3.2 Bedrock Wells

Multi-cased wells or wells with an outer casing installed into competent bedrock should be specified for wells that are designed to monitor groundwater within bedrock (see Figure 20-1c). The installation of a multi-cased well or outer casing will isolate the zone(s) monitored from overburden and will minimize the potential for cross-contamination during and after drilling.

The general procedure to be followed for installation of a multi-cased well is as follows. This procedure assumes the installation of a 4-inch diameter monitoring well. Specific procedures, drilling techniques and design of monitoring wells will be presented in work plan addenda for site-specific investigations.

1. If soil sampling is required within overburden, use appropriate drilling techniques to advance the boring and collect the soil samples.

2. A minimum 10-inch drill bit should be advanced from the surface into competent bedrock a distance not less than 2 feet. A drilling technique appropriate for penetrating overburden and bedrock should be used such as air rotary.

3. After the borehole has been advanced to the target depth within competent bedrock, a 6-inch diameter steel or Schedule 80 PVC outer casing should be lowered to the bottom of the boring.

4. Once the outer casing has been lowered to the bottom of the boring, the casing should be grouted in-place using a decontaminated tremie pipe equipped with a side discharge. The annulus between the outer casing and borehole wall will be injected with grout until undiluted grout reaches the surface.

5. The grouting mixture, specification, and placement should be consistent with the requirements identified in Section 3.3.8.

6. The grout should be allowed to cure a minimum of 24 hours before further drilling.

7. After adequate curing time for outer casing, drilling with a 5-5/8-inch bit until the desired total depth is reached should complete the well boring.

8. Once the well boring is completed, an appropriate bedrock well will be constructed based on site-specific conditions. The types of wells that may be installed may include a constructed well with screen, casing, filter pack, seal, and grout; an open-bedrock well; or a lined open bedrock well (see Section 3.3.3).

3.3.3 Well Screen Usage

Well screen usage for a given site should be specified in work plan addenda based on expected site conditions.

In general, wells installed within overburden will be installed with a screen as per Figure 20.01-a or 20.01-b. Bedrock wells may be installed with or without a screen depending on site specific conditions such as the depth of water bearing zones, stability of bedrock, occurrence of karst zones, and construction of existing wells at the site being investigated.

In general, bedrock wells installed within karst zones will be completed as open-hole construction (see Figure 20.01c). If evidence of potential or severe borehole collapse (unstable bedrock) is indicated during drilling, casing and screen will be installed in the borehole as a removable lining. If desired, multiple flow zones may be monitored in an open bedrock well by installing a multiport well, which has monitoring/sampling intervals sealed off from the rest of the boring and from each other by packers.

3.3.4 Beginning Well Installation

Schedule

Monitoring well installation should begin within 12 hours of boring completion for holes that are uncased or partially cased with temporary drill casing. In the case where a partially cased hole into bedrock is to be partially developed prior to well insertion, the well installation should begin within 12 hours of this initial development. For holes that are fully cased, installation should begin within 48 hours. Once begun, well installation should not be interrupted.

Placement of Materials

Temporary casing and hollow stem augers may be removed from the boring prior to well installation if the potential for cross contamination is low and if the borehole will remain stable during the time required for installation.

Where borehole conditions are unstable, some or all of the well materials may need to be installed prior to removal of the temporary casing or hollow stem augers. The casing or hollow stem augers should have an inside diameter sufficient to allow the installation of the screen and casing plus annular space for a pipe through which to place filter pack and grout.

Any materials blocking the bottom of the drill casing or hollow stem auger should be dislodged and removed from the casing prior to well insertion.

3.3.5 Screens, Casing, and Fittings

Borehole Specifications

The borehole for each well should be of sufficient diameter to provide for at least 2 inches of annular space between the borehole wall and all sides of the casing.

Well Screens

Material specifications for well screens, casings, and fittings are discussed in Section 2.2.
Screen bottoms should be securely fitted with a threaded cap or plug of the same composition as the screen. The cap/plug should be within 0.5 feet of the open portion of the screen. A sediment trap/sump will not be used.

Screen slot size will be appropriately sized to retain 90%–100% of the filter pack material, the size of which will be determined by sieve analysis of formation material.

Well screen lengths should be specified in work plan addenda and will be based on various site-specific factors such as environmental setting, subsurface conditions, analytes of concern, regulatory considerations, etc.

Assembly and Placement of Well Screen and Casing

Personnel should take precautions to assure that grease, oil, or other contaminants do not contact any portion of the well screen and casing assembly. Clean latex or nitrile gloves should be worn when handling the screen and casing assembly. Flush, threaded joints usually can be tightened by hand. If necessary, steam cleaned wrenches may be used to tighten joints.

In general, each section of the well assembly is lowered into the borehole, one section at a time, screwing each section securely into the section below it. No grease, lubricant, polytetrafluoroethylene (PTFE) tape, or glue may be used in joining the sections of screen and casing.

The assembly should be lowered to its predetermined level and held in position for placement of the filter pack. It is essential that the assembly be installed straight (with centralizers as appropriate) to allow for appropriate sampling. Buoyant forces associated with fluids in the borehole may require that the assembly be installed with the aid of hydraulic rams of the drill rig. When the well assembly is placed to predetermined level, a temporary cap should be place on the well to prevent foreign material from entering the well.

The bottoms of well screens should be placed no more than 3 feet above the bottom of the drilled borehole. If significant overdrilling is required, a pilot boring should be used. Sufficient filter pack should be placed at the bottom of the borehole

The well casing should be pre-cut (square) to extend 2 to 2.5 feet above the ground surface. Before placement of the last piece of well casing, a notch or other permanent reference point will be cut, filed, or scribed into the top edge of the casing.

The tops of all well casing will be capped with covers composed of materials compatible with the products used in the well installation. Caps will be loose fitting, constructed to preclude binding to the well casing caused by tightness of fit, unclean surfaces, or weather conditions. In either case, it should be secure enough to preclude the introduction of foreign material into the well, yet allow pressure equalization between the well and the atmosphere.

The top of each well casing should be level so that the maximum difference in elevation between the highest and lowest points of the casing is less than or equal to 0.02 ft.

3.3.6 Filter Pack

The volume of filter pack that is required to fill the annular between the well screen/casing and borehole should be computed, measured, and recorded.
Granular filter packs will be chemically and texturally clean, inert, and siliceous. The gradation of filter packs will be selected based on the screen size used and will be specified in the work plan addenda for the site being investigated.

<u>Primary Filter Pack</u>

Filter pack material should be placed in the borehole using a decontaminated tremie pipe. An appropriate amount of primary filter pack should be placed in the borehole prior to final positioning of the well screen to provide an appropriate barrier between the bottom of the borehole and the bottom of the screen. Once the initial filter pack has been placed and the well assembly is appropriately positioned and centered in the borehole, the remaining primary filter pack should be placed in increments (and tamped) as the tremie pipe is gradually raised.

As the primary filter pack is placed, approved source water may need to be added to help move the filter pack. A weighted tape should be used to measure the top of the filter pack as it is being placed. If bridging of the filter pack occurs, then this bridging should be broken mechanically prior to adding additional filter pack.

When temporary casing or hollow stem augers are used, the casing or augers should be removed in increments such that lifting of the well assembly is minimal. After removal of each increment, it should be confirmed by direct measurement that the primary filter pack has not been displaced during the removal.
The primary filter pack should extend from the bottom of the borehole to 3 to 5 ft above the top of the screen.

Secondary Filter Pack

The primary filter pack may be capped with 1 to 2 feet of feet of secondary filter pack to prevent the intrusion of the bentonite seal into the primary filter pack. The need for this filter pack (and specifications) should be addressed in work plan addenda for the site being investigated. Such factors as the gradation of the primary filter pack, the potential for grout extrusion, and site hydrogeology should be considered when evaluating the need for this filter pack.

3.3.7 Bentonite Seal

A bentonite seal, consisting of hydrated 3/8-inch diameter. bentonite pellets, will be installed immediately above the filter pack. The seal may be installed with a tremie pipe, which is lowered to the top of the filter pack and slowly raised as the pellets fill the annular space. In deep wells, the pellets may bridge and block the tremie pipe; in this case, pellets may be placed by free fall into the borehole. A weighted tape should be used to measure the top of seal as it is installed.

When cement grout is to be used above the bentonite seal, a minimum of 3 to 4 hours should be allowed for hydration of the pellets.

When installing a seal above the water table, water should be added to the bentonite for proper hydration. In this case, the seal should be placed in lifts of 0.5 to 1 foot with each lift hydrated for a period of 30 minutes.
If the bentonite seal is to be installed far below the water table, a bentonite slurry seal will be installed. Cement-bentonite grout will not be used below the water table. The slurry will be mechanically blended aboveground to ensure a lump-free mixture. The slurry will consist of bentonite powder and approved water mixed to a minimum of 20 percent solids by weight of pumpable slurry with a density of 9.4 pounds per gallon or greater. The slurry will be pumped into place through a tremie pipe and measured as installed.
Bentonite seals should be 3 to 5 ft thick as measured immediately after placement. The final depth to the top of the bentonite seal will be measured and recorded before grouting.

3.3.8 Grout

Cement grout used in construction will be composed of the following:

- Type II Portland Cement (or Type IV as noted in Section 2.2);
- Bentonite (2 to 5% dry bentonite per 94-lb sack of dry cement); and
- A maximum of 6 to 7-gallons of approved water per 94-lb sack of cement

Neither additives nor borehole cuttings will be mixed with the grout. Bentonite will be added after the required amount of cement is mixed with the water.

All grout material will be combined in an aboveground container and mechanically blended to produce a thick, lump-free mixture. The mixed grout will be recirculated through the grout pump before placement.
Grout placement should be performed as follows:

1. Grout should be placed from a rigid tremie pipe located just over the top of the bentonite seal. The tremie pipe should be decontaminated prior to use.
2. The tremie pipe should be kept full of grout from start to finish with the discharge end of the pipe completely submerged as it is slowly and continuously lifted.
3. The annulus between the drill casing and well casing should be filled with sufficient grout to allow for the planned drill casing removal. Grout should not penetrate the well screen or filter pack.

- For incremental removal of drill casing, grout should be pumped to maintain at least 10 ft of grout in the drill casing remaining in the borehole after removing the selected length of casing. After each section of casing is removed, the tremie pipe may be reinserted to the base of the casing not yet removed.
- In the case where drill casing will be removed all at once, grout should be pumped from the tremie pipe until undiluted grout flows from the annulus at the ground surface.

4. If the un-grouted portion of a borehole is less than 15 feet and without fluids after drill casing removal, then the un-grouted portion may be filled by pouring grout from the surface.
5. If drill casing was not used for well installation, grouting should proceed to the surface in one continuous operation.
6. For grout placement in a dry and open hole less than 15 ft deep, grout may be manually mixed and poured in from the surface providing that integrity of the bentonite seal is maintained.
7. Protective casing should be installed immediately after completion of grouting.
8. Grout settlement should be checked within 24 hours of the initial grout placement. Additional grout should be added grout should be added to fill any observed depressions.

The following will be noted in the boring logs: (1) exact amounts of cement, bentonite, and water used in mixing grout and (2) actual volume of grout placed in the hole.

3.3.9 Well Protection

The major elements of well protection will include:

- A protective casing;
- Protective concrete pad around the well; and
- Protective steel posts set around the well outside of the concrete pad.

Well Protective Casing

Well protective casings will be installed around all monitoring wells immediately after grouting. The protective casing should consist of a minimum 5-ft long, steel pipe (protective casing) installed over the well casing and into the grout. The protective casing should be installed to a depth of approximately 2.5-feet below ground surface (extending approximately 2.5 feet above ground surface). The internal well casing (riser) and protective casing will not be separated by more than 0.2 feet of height.

An internal mortar collar will be placed within the protective steel casing and outside the well casing to a height of 0.5 above ground surface.

After placement and curing of the mortar collar, an internal drainage hole will be drilled through the protective casing, which is centered no more than 1/8 inch above the grout filled annulus between the well riser and the protective casing.

Any annulus formed between the outside of the protective casing and the borehole will be filled to ground surface with cement.

Concrete Pad

After the grout has thoroughly set and the well protective casing has been installed, a protective concrete pad will be installed around the well. This pad will be at least 4 inches thick and 4 feet square and sloped away from the well to provide for adequate drainage.

Protective Posts

Additional protection will be provided at each well location by the installation of four steel posts outside of each corner of the concrete pad. The installation of protective posts should occur before the well is sampled. The posts should have a minimum diameter of 3 inches, be placed 2 to 3 feet below ground surface, and extend at least 3 feet above ground surface. Posts should be painted orange using a brush.

Posts should be set in post holes, which are backfilled with concrete. For additional protection, the posts can be filled with concrete.

3.3.10 Well Construction Diagram and Field Notes

The construction of each well will be depicted as built in a well construction diagram (see Figure 20.1a). The diagram will be attached to the boring log and the following will be graphically denoted:

- Bottom of boring;
- Screen location, length, and size;
- Coupling locations;
- Granular filter pack;
- Seal;
- Grout;
- Cave-in;
- Centralizers;
- Height of riser;
- Protective casing detail;
- Water level 24 hours after completion with date and time of measurement;
- Quantity and composition of materials used; and
- Material between bottom of boring and bottom of screen.

Daily activities at the site related to monitoring well installation should be recorded in the field logbooks as described in SOPs 10.1 and 10.2.

3.4 GENERAL SEQUENCE OF MONITORING WELL COMPLETION

The following is a general sequence of monitoring well completion with reference to the specific details included in Section 3.3.

1. Completion of borehole;
2. Assembly and placement of well assembly as described in Section 3.3.5;
3. Placement of the appropriate filter pack(s) as discussed in Section 3.3.6;
4. Installation of an appropriate bentonite seal as discussed in Section 3.3.7;
5. Grouting the remaining annular space of the borehole as discussed in Section 3.3.8;
6. Set the protective casing for the well as discussed in Section 3.3.9;

7. Complete the protective concrete pad as discussed in Section 3.3.9; and
8. Install the protective posts as discussed in Section 3.3.9.

3.5 INVESTIGATION-DERIVED MATERIAL

Investigation-derived material will be managed in accordance with procedures defined in the work plan addenda for the site being investigated and SOP 70.1.

4.0 MAINTENANCE

Not applicable.

5.0 PRECAUTIONS

Refer to the site-specific health and safety plan.

6.0 REFERENCES

ASTM Standard D 5092-04e1. 2004. *Standard Practice for Design and Installation of Ground Water Monitoring Wells in Aquifers.*

ASTM Standard F 480-06b. 2006. *Standard Specification for Thermoplastic Well Casing Pipe and Couplings Made in Standard Dimension Ratios (SDR), SCH 40 and SCH 80.*

USACE. 1998. *Monitoring Well Design, Installation, and Documentation at Hazardous, Toxic, and Radioactive Waste Sites.* EM 1110-1-4000, 1, November.

EXAMPLE WELL DEVELOPMENT FORM

WELL DESIGNATION:___________________ DATE(S) OF INSTALLATION:_____/_____/_____

SITE GEOLOGIST:_______________________ DEVELOPMENT DATE(S):_____/_____/_____

STATIC WATER LEVELS BEFORE AND AFTER DEVELOPMENT * :

BEFORE ______________ DATE ____________ 24 HR. AFTER ____________ DATE____________

DEPTH TO SEDIMENT BEFORE AND AFTER DEVELOPMENT * :

BEFORE ______________ DATE ____________ 24 HR. AFTER ____________ DATE____________

DEPTH TO WELL BOTTOM *: __________________ SCREEN LENGTH _______________

HEIGHT OF WELL CASING ABOVE GROUND SURFACE: ____________________

QUANTITY OF MUD/WATER:

LOST DURING DRILLING	(+)______________________gallons
REMOVED PRIOR TO WELL INSERTION	(-)______________________gallons
LOST DURING THICK FLUID DISPLACEMENT	(+)______________________gallons
ADDED DURING FILTER PACK PLACEMENT	(+)______________________gallons
TOTAL LOSSES	______________________gallons

(a) Water column ht. (ft.) ______________ (b) Well radius (in.)_____________

(c) Screen length (ft.) ______________ (d) Borehole radius (in.)_____________

(e) QUANTITY OF FLUID STANDING IN WELL

Install Equation Editor and double-click here to view equation. 1 __________ gallons

(Show Calculation)

(f) QUANTITY OF FLUID IN ANNULUS Install Equation Editor and double-click here to view equation. 1__________gallons

(Show Calculation)

DEVELOPMENT VOLUME = (5 * TOTAL LOSSES) + [5 * (e + f)] = ______________ gallons

(Show Calculation)

*** ALL DEPTHS MEASURED FROM TOP OF WELL CASING**

EXAMPLE WELL DEVELOPMENT RECORD

WELL DESIGNATION _______________ DATE(S) OF DEVELOPMENT: _____/_____/_____

TYPE AND SIZE OF PUMP:____

TYPE AND SIZE OF BAILER:____

DESCRIPTION OF SURGE TECHNIQUE:____

____

____

RECORD OF DEVELOPMENT

DATE & TIME	QUANTITY REMOVED	TIME REQ'D	pH	Cond	Temp	ORD	Turb	DO	Character of water (color/clarity/ odor/partic.)
(before)									
(during)									
(during)									
(during									
(after)									

TYPICAL PUMPING RATE________ GAL./HR. EST. RECHARGE RATE___________________________

TOTAL QUANTITY OF WATER REMOVED_________ TIME REQUIRED________________

REMARKS____

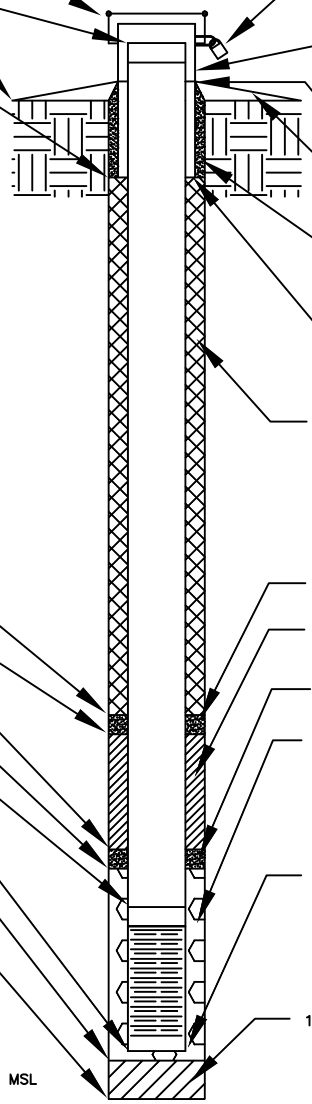
____

____

SIGNATURE OF SITE GEOLOGIST______________________________________

Facility/Project Name	Local Grid Location of Well ________m. ☐N. ☐S. ________m. ☐E. ☐W.	Well Number
Facility License, Permit or Monitoring Number	Grid Origin Location Lat.____ ____ ____ Long ____ ____ ____ or	Date Well Installed (Start)
Type of Protective Cover: Above–Ground ☐ Flush–To–Ground ☐	St. Plane ________m. N. ________m. E. Section Location of Waste/Source	Date Well Installed (Completed)
Well Distance From Waste/Source Boundary	____1/4 of____1/4 of Sec.____T.____N.R.____ ☐E. ☐W.	Well Installed By: (Person's Name & Firm) ________________
Maximum Depth of Frost Penetration (estimated)	Location of Well Relative to Waste/Source u ☐ Upgradient s ☐ Sidegradient d ☐ Downgradient n ☐ Not Known	________________

Note: Use top of casing (TOC) for all depth measurments.



A. Protective casing, top elevation ________m. MSL

B. Well casing, Top elevation ________m. MSL

C. Land surface elevation ________m. MSL

D. Surface seal, bottom ______m. TOC or ______m. MSL

16. USCS classification of sell near screen:
GP ☐ GM☐ GC ☐ GW☐ SW☐ SP☐
SM ☐ SC☐ ML ☐ MH☐ CL ☐ CH☐
Bedrock ☐

17. Sieve analysis attached? ☐ Yes ☐ No

18. Drilling method used: Rotary ☐
Hollow Stem Auger ☐
________________ Other ☐

19. Drilling fluid used Water ☐ Air ☐
Drilling mud ☐ None ☐

20. Drilling additives used? ☐ Yes ☐ No
Describe ________________

21. Source of water (attach analysis):
____

E. Secondary filter, top______m. TOC or______m. MSL

F. Bentonite seal, top ______m. TOC or______m. MSL

G. Secondary filter, top______m. TOC or______m. MSL

H. Primary filter, top ______m. TOC or______m. MSL

I. Screen joint ______m. TOC or______m. MSL

J. Well bottom ______m. TOC or______m. MSL

K. Filter pack, bottom______m. TOC____m. MSL

L. Borehole, bottom_____m. TOC or_____m. MSL

M. Borehole, diameter________mm.

N. O.D. well casing ________mm.

O. I.D. well casing ________mm.

P. 24–hr water level after completion ______m. TOC or________m. MSL

1. Cap and Lock? ☐ Yes ☐ No

2. Protective posts? ☐ Yes ☐ No

3. Protective casing:
a. Inside diameter: ________mm.
b. Length: ________m.

4. Drainage port(s) ☐ Yes ☐ No

5. Surface seal: Gravel blanket ☐
a. Cap Bentonite ☐
Concrete ☐
________________Other ☐

b. Annular space seal: Bentonite ☐
Cement ☐
________________Other ☐

6. Material between well casing and protective casing: Bentonite ☐
Cement ☐
________________Other ☐

7. Annular space seal: A. Granular Bentonite ☐
b. ______Lbs/gal mud weight........Bentonite–sand slurry ☐
c. ______Lbs/gal mud weight..................Bentonite slurry ☐
d. ______x Bentonite..................Bentonite–cement grout ☐
e. __________m^3 volume added for any of the above
f. How installed: Tremie ☐
Tremie pumped ☐
Gravity ☐

8. Centralizers ☐ Yes ☐ No

9. Secondary Filter ☐ Yes ☐ No
a. Volume added ________m^3________Bags/Size

10. Bentonite seal: a. Bontonite granules ☐
b. 1/4in. 3/6in. 1/2in. Bentonite pellets ☐
c. ________________Other ☐

11 Secondary Filter ☐ Yes ☐ No
a. Volume added________ m^3________ Bags/Size

12. Filter pack material: Manufacturer, product name & mesh size
a.
b. Volume added________m^3________Bags/Size

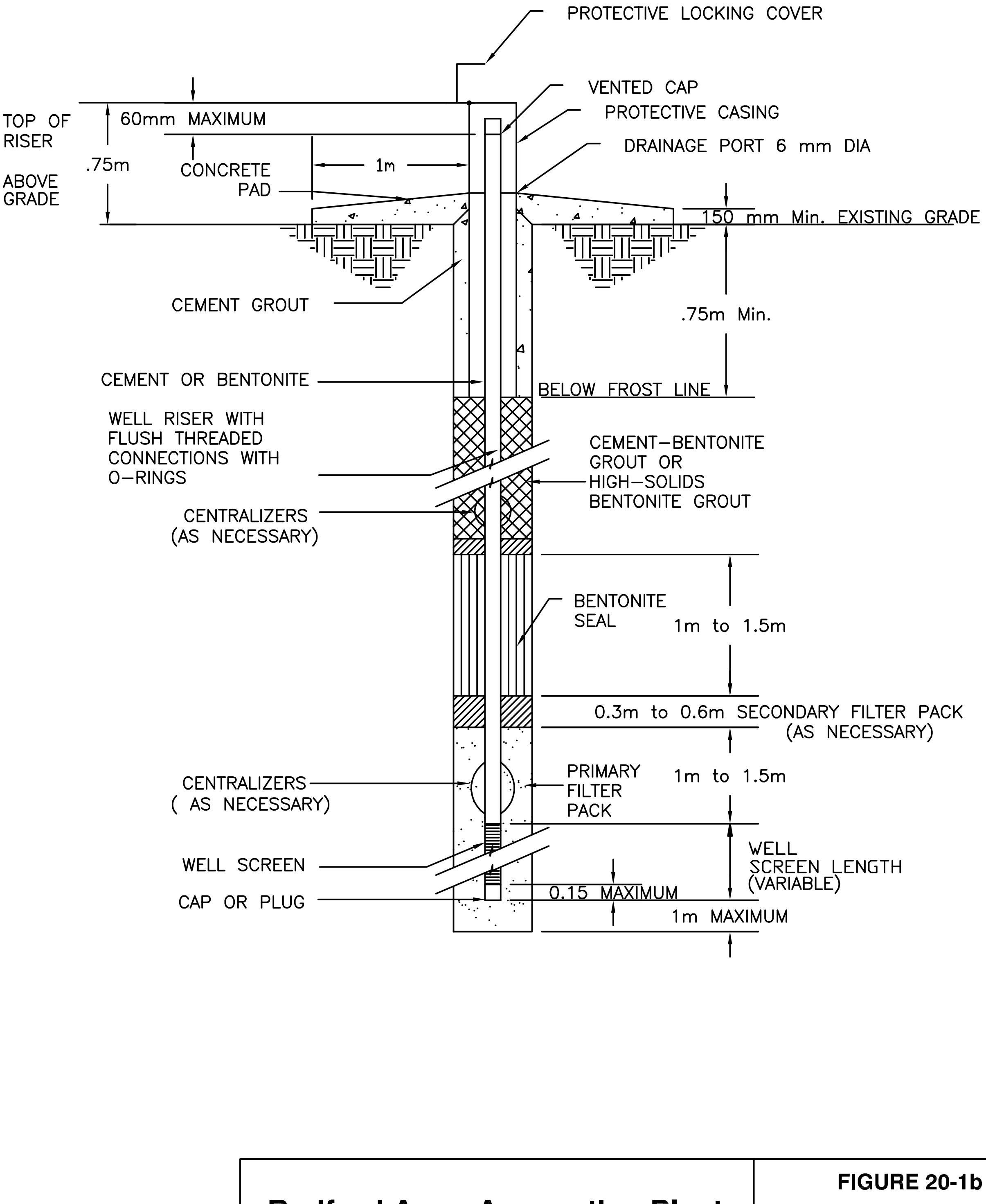
13. Well casing: Flush threated PVC schedule 40 ☐
Flush threated PVC schedule 80 ☐
________________ Other ☐

14. Screen material:
a. Screen type: Factory cut ☐
Continous slot ☐
________________ Other ☐
b. Manufacturer
c. Slot size: 0.________In.
d. Slotted length: ________In.

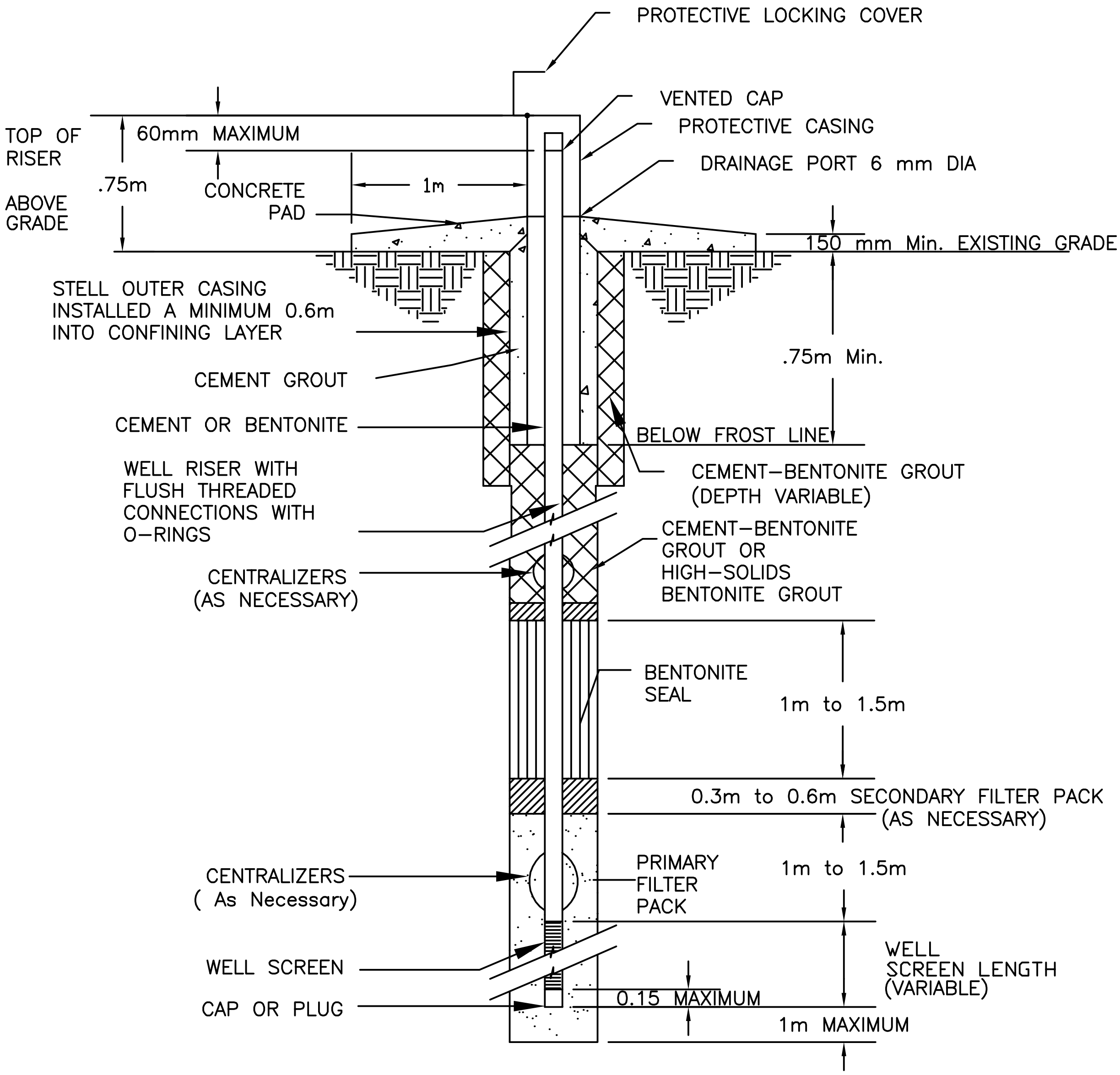
15. Backfill material (below filter pack): None ☐
________________ Other ☐

Radford Army Ammuntion Plant	**FIGURE 20-1a**
Date: *October 2007*	**Prepared By:** *URS Corp./DBC*
Scale: *NO SCALE*	**File Name:** *SOP Figure 20-1a*

SCHEMATIC CONSTRUCTION DIAGRAM OF MONITORING WELL



Radford Army Ammuntion Plant		**FIGURE 20-1b**
Date: *October 2007*	**Prepared By:** *URS Corp./DBC*	**SCHEMATIC CONSTRUCTION OF SINGLE-CASED WELL WITH STICKUP COMPLETION**
Scale: *NO SCALE*	**File Name:** *SOP Figure 20-1b*	



Radford Army Ammuntion Plant

Date: *October 2007*

Prepared By: *URS Corp./DBC*

Scale: *NO SCALE*

File Name: *SOP Figure 20-1c*

FIGURE 20-1c

SCHEMATIC CONSTRUCTION OF MULTI-CASED WELL WITH CONCRETE PAD

STANDARD OPERATING PROCEDURE 20.2
MONITORING WELL DEVELOPMENT

1.0 SCOPE AND APPLICATION

Well development is the process by which drilling fluids, solids, and other mobile particulates within the vicinity of the newly installed monitoring well are removed, while ensuring proper hydraulic connection to the aquifer. Development stabilizes the formation and filter pack sands around the well screen to ensure aquifer water moves freely to the well.

Well development will be initiated not less than 48 consecutive hours but no longer than 7 calendar days following grouting and/or placement of surface protection.

2.0 MATERIALS

- Work Plans;
- Well Development Form;
- Field Logbook;
- Boring Log and Well Completion Diagram for the well;
- Submersible pump, control box, associated equipment, etc;
- Photoionization detector or other appropriate monitoring instrument as specified in site-specific health and safety plan;
- Personal protective equipment and clothing (PPE) as specified in site-specific health and safety plan;
- Flow-through-cell and probes measuring specific conductance, pH, temperature, oxidation/reduction potential, dissolved oxygen, and turbidity;
- Decontamination supplies (SOP 80.1);
- Electric well level indicator and measuring tape;
- Appropriate containers for purged water and other investigation-derived material, as required; and
- Drilling tools for reverse-air circulation development, as appropriate.

3.0 PROCEDURE

3.1 SELECTING METHOD OF DEVELOPMENT

The type of subsurface conditions encountered should determine the method of well development used at a particular site at the Radford Army Ammunition Plant (RFAAP).

When monitoring wells are installed within overburden material, fractured bedrock or karst aquifers producing little sediment, a combination of mechanical surging and pumping (over pumping) or bailing is generally appropriate for well development. In general, over-pumping is the method of pumping the well at a rate higher than recharge occurs. Moving a tight-fitting surge block along the inside of the well screen to create a vacuum completes surging.

When monitoring wells are installed with solution features containing excessive amounts of sediment, reverse-circulation airlifting should be used as the initial step of development. Because reverse-circulation tools airlift methods avoid forcibly exposing the annular space to air, reverse-circulation tools can be run throughout the entire water column in the wells being developed.

After the excessive sediment has been removed by reverse-circulation airlifting, conventional pumping techniques may be used as appropriate to complete the well development.

3.2 DEVELOPMENT AND SAMPLING TIMING

Final development of monitoring wells should not be initiated any sooner than 48 hours after or more than 7 days beyond the final grouting of the well. Pre-development or preliminary development may be initiated before this 48-hour minimum period. Preliminary development may be conducted for open wells or for screened wells after installation of the well screen, casing, and filter pack but before installation of the annular seal. Pre-development is recommended when the natural formation will be used as a filter pack.
Well development should be completed at least 14 days prior to sampling.

3.3 SUMMARY OF PROCEDURES

In general, the following procedure should be followed when developing a well using the pump and surge technique:

1. Prepare the work area outside the well by placing plastic sheeting on the ground to avoid cross-contamination.
2. Calibrate water quality meters (refer to SOP 40.1).
3. Determine the depth to water and total depth of well (refer to SOP 40.2).
4. Calculate the equivalent volume (EV) of water in well to be developed (refer to SOP 30.2).
5. Pump or bail the well to ensure that water flows into it and to remove some of the fine materials from the well. Removal of a minimum of one EV is recommended at this point. The rate of removal should be high enough to stress the well by lowering the water level to approximately one-half its original level.
6. Remove pump or bailer, slowly lower a close-fitting surge block into the well until it rests below the static water level but above the screened interval. (NOTE: The latter is not required in the case of an LNAPL well.)
7. Begin a gentle surging motion along top on-third length of the screen, which will allow any material blocking the screen to break up, go into suspension, and move into the well. Note that development should always begin above or at the top of the screen and move progressively downward to prevent the surge block from becoming sand locked in the well casing. Continue surging for 5-10 minutes, remove surge block, and pump or bail the well, rapidly removing at least one EV.
8. Repeat previous step at successively lower levels within the well screen, until the bottom of the well is reached. As development progresses, successive surging can be more vigorous and of longer duration as long as the amount of sediment in the screen is kept to a minimum.
9. Development should continue until the well development criteria listed in Section 3.1.3 have been achieved.
10. All water removed must be managed as directed by the site investigation plan.

3.3.1 Well Development Criteria

In general, well development should proceed until the following criteria are met:

1. At a minimum, removal of three EV of water from the well.
2. Removal of three times of the amount of fluid (mud and/or water) lost during drilling.
3. Removal of three times the fluid used for well installation.
4. The following indicator parameters should be stabilized as indicated by three successive readings within:
   - ± 0.2 for pH;
   - ±3% for specific conductance;
   - ±10 mV for oxidation/reduction potential;
   - ± 1 degree Celsius for temperature; and
   - ±10% for turbidity and dissolved oxygen (except for wells installed in karst aquifers).
5. Well water is clear to the unaided eye (except for wells installed in karst aquifers).
6. The sediment thickness remaining within the well is less than one percent of the screen length or less than 0.1 ft for screens equal to or less than 10 feet.
7. Site specific factors should be evaluated to determine appropriate well development criteria have been if:
   - Well recharge is so slow that the required volume of water cannot be removed during 48 consecutive hours of development;
   - Water discoloration persists after the required volumetric development; and
   - Excessive sediment remains after the required volumetric development.

3.4 WELL DEVELOPMENT RECORD

Record all data as required on a Well Development Record Form (see example), which becomes a part of the complete Well Record. These data include the following:

- Project name, location;
- Well designation, location;
- Date(s) and time(s) of well installation;
- Static water level from top of well casing before and 24 hours after development;
- Depths and dimensions of the well, the casing, and the screen, obtained from the Well Diagram;
- Water losses and uses during drilling, obtained from the boring log for the well;
- Water contained in the well, obtained from calculations using the depth of the water column and the well radius, plus the radius and height of the filter pack and an assumed 30% porosity;
- Measurements of the following indicator parameters: pH, conductivity, oxidation/reduction potential, temperature, and turbidity before and after development and once during each EV;
- Notes on characteristics of the development water;
- Data on the equipment and technique used for development; and
- Estimated recharge rate and rate/quantity of water removal during development.

Well development records shall be submitted to the COR after the development has been completed.

3.5 INVESTIGATION-DERIVED MATERIAL

Investigation-derived material will be managed in accordance with procedures defined in the work plan addendum for the site being investigated and SOP 70.1.

4.0 MAINTENANCE

Not applicable.

5.0 PRECAUTIONS

Refer to the site-specific health and safety plan.

6.0 REFERENCES

Aller, Linda, et al. 1989. *Handbook of Suggested Practices for the Design and Installation of Ground-Water Monitoring Wells.* National Water Well Association.

ASTM Standard D 5092-04e1. 2004. *Standard Practice for Design and Installation of Ground Water Monitoring Wells in Aquifers.*

EPA Groundwater Handbook. 1989.

Nielsen, David M. 1993. *Correct Well Design Improves Monitoring,* in “Environmental Protection,” Vol. 4, No.7, July, 1993.

USACE. 1998. *Monitoring Well Design, Installation, and Documentation at Hazardous, Toxic, and Radioactive Waste Sites.* EM 1110-1-4000, 1 November.

EXAMPLE WELL DEVELOPMENT FORM

WELL DESIGNATION:____________________ DATE(S) OF INSTALLATION:_____/_____/_____

SITE GEOLOGIST:________________________ DEVELOPMENT DATE(S):_____/_____/_____

STATIC WATER LEVELS BEFORE AND AFTER DEVELOPMENT :

BEFORE ______________ DATE ____________ 24 HR. AFTER ____________ DATE____________

DEPTH TO SEDIMENT BEFORE AND AFTER DEVELOPMENT * :

BEFORE ______________ DATE ____________ 24 HR. AFTER ____________ DATE____________

DEPTH TO WELL BOTTOM *: __________________ SCREEN LENGTH _______________

HEIGHT OF WELL CASING ABOVE GROUND SURFACE: ____________________

QUANTITY OF MUD/WATER:

LOST DURING DRILLING	(+)______________________gallons
REMOVED PRIOR TO WELL INSERTION	(-)______________________gallons
LOST DURING THICK FLUID DISPLACEMENT	(+)______________________gallons
ADDED DURING FILTER PACK PLACEMENT	(+)______________________gallons
TOTAL LOSSES	______________________gallons

(a) Water column ht. (ft.) ______________	(b) Well radius (in.)_____________
(c) Screen length (ft.) ______________	(d) Borehole radius (in.)_____________

(e) QUANTITY OF FLUID STANDING IN WELL

Install Equation Editor and double-click here to view equation. 1 __________ gallons
(Show Calculation)

(f) QUANTITY OF FLUID IN ANNULUS Install Equation Editor and double-click here to view equation. 1__________gallons
(Show Calculation)

DEVELOPMENT VOLUME = (3 * TOTAL LOSSES) + [5 * (e + f)] = ______________ gallons
(Show Calculation)

*** ALL DEPTHS MEASURED FROM TOP OF WELL CASING**

EXAMPLE WELL DEVELOPMENT RECORD

WELL DESIGNATION _______________ DATE(S) OF DEVELOPMENT: _____/_____/_____

TYPE AND SIZE OF PUMP:____

TYPE AND SIZE OF BAILER:____

DESCRIPTION OF SURGE TECHNIQUE:____
____
____

RECORD OF DEVELOPMENT

DATE & TIME	QUANTITY REMOVED	TIME REQ'D	pH	Cond	Temp	ORD	Turb	DO	Character of water (color/clarity/ odor/partic.)
(before)									
(during)									
(during)									
(during									
(after)									

TYPICAL PUMPING RATE________ GAL./HR. EST. RECHARGE RATE___________________________

TOTAL QUANTITY OF WATER REMOVED__________ TIME REQUIRED________________

REMARKS____
____
____

SIGNATURE OF SITE GEOLOGIST____

STANDARD OPERATING PROCEDURE 20.3
WELL AND BORING ABANDONMENT

1.0 SCOPE AND APPLICATION

The purpose of this standard operating procedure (SOP) is to establish the protocols by which all borings and wells will be abandoned. The primary objective of boring or well abandonment activities is to permanently abandon the boring or well so that the natural migration of groundwater or soil vapor is not significantly influenced.

2.0 MATERIALS

- Well abandonment equipment including appropriate grout mixing/placement equipment, and heavy equipment as appropriate (drill rig, crane, backhoe, etc.);
- Pure sodium bentonite powder with no additives (bentonite);
- Bentonite pellets (seal);
- Cement (Portland Type II); and
- Approved source water.

3.0 PROCEDURE

The volume of grout required for borehole or well abandonment should be calculated prior to proceeding with abandonment. These calculations should consider loss of material to the formation, changes in borehole diameter, potential zones of washout, and shrinkage of material. Calculations should be recorded on an abandonment record (see Section 3.1.4).

In general, cement grout should be used for boring and well abandonment per the specifications in Section 3.1 and procedures identified in the following sections. Specialized narrow diameter soil borings (3-inches or less) associated with direct push methods or hand augers may be abandoned using bentonite pellets or chips (see Section 3.5).

Any replacement borings or wells associated with the abandonment should be offset at least 20 feet from any abandoned site in a presumed up- or cross-gradient direction.

3.1 GROUT

Grout used in construction will be composed by weight of the following:

- Type II Portland cement (Type IV Portland Cement if sulfate concentrations are greater than 1,500 ppm);
- Bentonite (2 to 5% dry bentonite per 94-lb sack of dry cement); and
- A maximum of 6 to 7 gallons of approved water per 94-lb sack of cement.

Neither additives nor borehole cuttings will be mixed with the grout. Bentonite will be added after the required amount of cement is mixed with the water.

All grout material will be combined in an aboveground container and mechanically blended to produce a thick, lump-free mixture. The mixed grout will be recirculated through the grout pump before placement.

Grout placement will be performed using a commercially available grout pump and a rigid tremie pipe. Removal and grouting will be accomplished in stages, aquifer by aquifer, sealing the boring from the bottom to ground surface. This will be accomplished by placing a grout pipe to the bottom and pumping grout through the pipe until undiluted grout reaches the bottom of the next higher section of casing or, for the top-most section, until grout flows from the boring at ground surface.

After 24 hours, the abandoned drilling site will be checked for grout settlement. Any settlement will be filled with grout and rechecked 24 hours later. This process will be repeated until firm grout remains at the ground surface.

3.2 BORINGS

The term "borings" as used in this SOP applies to any drilled hole made that is not completed as a well. This includes soil test borings, soil sampling borings, and deep stratigraphic borings. Whether completed to the planned depth or aborted for any reason before reaching that depth, borings will be grouted and will be normally closed within 12 hours.

To achieve an effective seal, the borehole to be abandoned should be free of debris and foreign matter that may restrict the adhesion of the grout to the borehole wall. Borehole flushing with a tremie pipe may be required to remove such materials prior to grouting.

Each boring to be abandoned should be sealed by grouting from the bottom of the boring to the ground surface. This will be accomplished by placing a tremie pipe to the bottom of the borehole and pumping grout through the pipe at a steady rate. The grouting should be completed slowly and continuously to prevent channeling of material. The tremie pipe should be raised when pumping pressure increases significantly or when undiluted grout reaches the surface.

After 24 hours of completing the abandonment, the abandoned boring or well should be checked for any grout settlement. The settlement depression should be filled with grout and rechecked 24 hours later. Grout should be placed with a tremie pipe if the open hole is 15 feet or deeper or if the hole is not dry. Otherwise, the grout may be poured from the surface.

3.3 NARROW BORINGS

Narrow borings, those with diameter less than 3 inches, advanced by hand auger or direct push methods, may be sealed using bentonite pellets or chips rather than a grout mixture. Often times a grout pump is not available to mix the grout when these methods have been used. Bentonite pellets or chips will be poured into the boring from the ground surface. Then bentonite will hydrate by absorbing moisture from the ground; unapproved water should not be added to the boring. After 24 hours, the abandoned boring will be checked, and any grout settlement will be topped off with more bentonite. The process will be repeated until bentonite remains at ground surface unless site condition indicates otherwise.

3.4 WELLS

The following procedure applies to wells aborted before completion and existing wells determined to be ineffective or otherwise in need of closure.

<u>General Considerations</u>

A number of techniques are available for abandoning monitoring wells and other monitoring devices including:

- Abandonment in place by grouting the well screen and casing in place;
- Removal of the well by pulling; and
- Overdrilling.

The particular method used for abandonment should be specified in the work plan addenda developed for a site-specific investigation. Several factors must be considered when selecting the appropriate abandonment technique including well construction, well condition, and subsurface conditions.

In general the preferred method for abandonment of wells is to remove all existing well materials to:

- Reduce the potential for the formation of a vertical conduit to occur at the contact between the casing and annular seal;
- Reduce the potential for well materials interfering with the abandonment procedures; and
- Decrease the potential for reaction between the well materials and grout used for abandonment.

In general, all well materials will be removed during abandonment (including screen and casing) by either pulling out the casing, screen, and associated materials or by overdrilling using a rotary or hollow stem auger drilling procedure.

Abandonment with Well Materials In Place

In the event that it is not possible to remove the casing and screen, the casing and screen will be perforated using a suitable tool. A minimum of four rows of perforations several inches long and a minimum of five perforations per linear foot of casing or screen is recommended.

After the screen and casing have been appropriately perforated, the well should be abandoned by grouting from the bottom of the well to the ground surface using a tremie pipe as described in Section 3.2. The tremie pipe should be raised when pumping pressure increases significantly or when undiluted grout reaches the surface.

After 24 hours of completing the abandonment, the abandoned well should be checked for any grout settlement. The settlement depression should be filled with grout and rechecked 24 hours later. Grout should be placed with a tremie pipe if the open hole is 15 feet or deeper or if the hole is not dry. Otherwise, the grout may be poured from the surface.

Abandonment by Removal

Site conditions permitting, relatively shallow monitoring wells may be successfully abandoned by removal providing that the well is generally good condition and sections of casing (including screen) can be successfully removed with materials intact.

This method of abandonment is generally accomplished by removing (pulling) sections of casing and screen out of the subsurface using a drill rig, backhoe, crane, etc. of sufficient capacity. Materials with lower tensile strength such as polyvinyl chloride (PVC) generally cannot be removed by pulling if they have been appropriately cemented in place.

Once the well materials have been removed from the borehole, the borehole should be abandoned by grouting in the same manner discussed for borings in Section 3.2. If the borehole collapses after removal of well materials, then the borehole should be over drilled to remove all material and then grouted to the surface.

Overdrilling

With this method of abandonment, the well materials are removed by overdrilling (overreaming) the well location. Overdrilling using rotary techniques may be accomplished using an overreaming tool. This tool consists of a pilot bit that is approximately the same size as the inner diameter of well casing and a reaming bit that is slightly larger than the diameter of the borehole. As drilling proceeds, all well materials are destroyed and returned to the surface. After completion of the overdrilling, the borehole should be immediately grouted with a tremie pipe as described in Section 3.2.

In the case of overburden wells, a hollow stem auger may be used for overdrilling providing that this method of drilling appropriate for the subsurface conditions. The hollow stem auger should be equipped with outward facing carbide-cutting teeth with a diameter 2 to 4 inches larger than the well casing. With this method, the casing guides the cutting head and remains inside the auger. When the auger reaches the bottom of the well boring and the well materials have been removed, the borehole may be grouted with a tremie pipe (Section 3.2) through the augers as the augers are gradually withdrawn.

Considerations for Fractured Bedrock and Karst Wells

Multi-cased wells completed into bedrock as screened wells, open wells, or open-lined wells may be abandoned with the outer casing left in place providing that the integrity of this casing and associated annular seal is good. A cement bond log (acoustic amplitude boring geophysical log) may be used to evaluate the integrity of the casing and annular seal, if the outer casing is to be left in place.

Borings or wells completed in karst zones may be difficult to abandon because of the potential presence of large conduits, which may make it difficult to grout. Where large conduits exist or difficulties are encountered when abandoning a boring or well, fill the portion of the borehole penetrating the solution cavity with inert gravel (quartz, claystone, etc.). Packers can be used to isolate critical intervals for filling with grout above and below these zones.

3.5 RESTORATION

All work areas around the borings or wells abandoned should be restored to a condition essentially equivalent to that before the borings and wells were installed.

3.6 INVESTIGATION-DERIVED MATERIAL

Investigation-derived material should be managed in accordance with the requirements of SOP 70.1 and the work plan addenda associated with the site investigation

3.7 DOCUMENTATION

For each abandoned boring or well, a record should be prepared to include the following as appropriate:

- Project and boring/well designation;
- Location with respect to replacement boring well (if any);
- Open depth of well/annulus/boring prior to grouting;
- Casing or items left in hole by depth, description, composition, and size;
- Copy of the boring log;
- Copy of construction diagram for abandoned well;
- Reason for abandonment;
- Description and total quantity of grout used initially;

- Description and daily quantities of grout used to compensate for settlement;
- Disposition of investigation-derived material;
- Water or mud level prior to grouting and date measured; and
- Remaining casing above ground surface, height above ground surface, size, and disposition of each.

Daily investigation activities at the site related to boring and well abandonment should be recorded in field logbooks as described in SOPs 10.1 and 10.2.

4.0 PRECAUTIONS

Refer to the health and safety plan associated with the Work Plan Addenda and the Master Health and Safety Plan.

5.0 REFERENCES

ASTM Standard D 5299-99 (2005). 2005. *Standard Guide for Decommissioning of Ground Water Wells, Vadose Zone Monitoring Devices, Boreholes, and Other Devices for Environmental Activities.*

USACE. 1998. *Monitoring Well Design, Installation, and Documentation at Hazardous, Toxic, and Radioactive Waste Sites.* EM 1110-1-4000, 1 November.

STANDARD OPERATING PROCEDURE 20.4
TEST PITS

1.0 SCOPE AND APPLICATION

The purpose of this standard operating procedure (SOP) is to delineate protocols for the excavation of test pits and provide general guidelines for sample collection from the test pits.

Test pit excavations are conducted to investigate and identify possible areas of contamination. Thus, samples taken from the excavation will be positively biased according to visual inspection (i.e., soil discoloration, soil staining) and field screening. Areas showing evidence of possible contamination will be sampled directly. If no evidence of contamination is present during excavation, then samples will be collected in two equally spaced intervals or at intervals specified in work plan addenda for site-specific investigations. In either case, no less than two representative samples per excavation site should be collected. Excavation (and sampling) shall terminate if the water table is encountered before terminal depth.

2.0 MATERIALS

- Master Work Plan;
- Work Plan Addenda;
- Field log books;
- Appropriate health and safety equipment for monitoring conditions in the work zone and excavation area including a photoionization detector (PID) or other types of monitoring equipment;
- Personal protective equipment and clothing (PPE) per the site-specific health and safety plan;
- Backhoe and associated equipment;
- Appropriate soil sampling equipment such as stainless steel scoops, trowels, spoons, and bowls/trays SOP 30.1);
- Appropriate sample bottles, labels, chain-of-custody forms, and sample shipping supplies etc;
- Tarps or plastic sheeting;
- Measuring tape;
- Camera and film; and
- Decontamination equipment and supplies.

3.0 PROCEDURE

3.1 DOCUMENTATION

Field activities and sampling information should be recorded in the field logbooks as outlined in SOPs 10.1 and 10.2.

Cross-sections and sketches of the layout will be prepared upon completion of the excavation. The sketches will indicate soil horizons and geologic observations. Soil horizons will be differentiated based upon variations in soil color (i.e., Munsell Chart), texture, coarse fragment content, structure, and consistence.

Refer to SOP 10.3 for boring log completion procedures. In addition, depth and thickness of horizontal depth to bedrock (if encountered) and indicators of seasonal high water table (presence of redoximorphic features) will be recorded. Sketches will also indicate the location of any samples collected. Photographs of the excavation will be taken and locations noted on the field map.

3.2 DECONTAMINATION

Decontamination of the backhoe, trowels or spoons, bowls, field tape measure, and other associated equipment will be carried out before use and between each test pit as outlined in work plan addenda and SOP 80.1.

3.3 SITE PREPARATION

Mark out dimensions of excavation and possible hazards (e.g., utilities, former structures). The backhoe must be equipped with a protective shield and the operator properly trained in the use of level B respiratory and dermal protection. The backhoe bucket and arm must be thoroughly decontaminated by steam cleaning before use and between each test pit location as described in work plan addenda and SOP 80.1. Discuss all hazards with equipment operator before any intrusive activities.

Set up exclusion zone with caution tape and position backhoe upwind of excavation site. All activities must be conducted in accordance with the health and safety plan developed for work plan addenda.

3.4 EXCAVATION AND SAMPLING

The backhoe operator shall be directed to excavate until the sampler indicates the desired depth has been reached. If the pit is less than 3 ft deep, the sampler can enter the pit and collect the samples using a decontaminated stainless steel trowel or spoon as described in SOP 30.1. As the pit becomes deeper, the sampler will collect the soil samples directly from the center of the bucket of the backhoe in an area not in contact with the sides of the bucket. The samples will then be transferred from the bucket into the appropriate sample container following sampling techniques outlined in SOP 30.1. Screening processes and analytical parameters for field screening soil samples will vary from site to site as specified per scope of work.

Begin excavating in increments of 6 to12 inches per pass. Deeper passes may be necessary if the soil is rocky. Total excavation width will be of adequate dimensions to visually characterize the soil profile as observed on the excavation walls, typically not exceeding the width of the backhoe bucket. However, total width of the excavation will be dependent on the depth of the excavation, thus wider dimensions may be necessary for characterization of deeper pits. Excavation will be continuously monitored with health and safety monitoring equipment. Safety measures must be exercised when working near and around the backhoe arm and excavation pit. Health and safety procedures and any installation safety procedures must be strictly followed.

All soil removed during excavation shall be placed on a tarp or plastic sheeting. Soil exhibiting signs of contamination based on visual or olfactory observations, as well as monitoring results, will be separated from uncontaminated soil and containerized for site removal.

Samples will be collected at desired intervals as specified in work plan addenda. Sampling procedures will follow the requirement of work plan addenda and SOP 30.1.

3.5 BACK FILL

Once the terminal depth of the excavation is reached or the water table is encountered and all samples are collected, the trench will be backfilled with certified clean fill. Soils removed during excavation shall be containerized and disposed of at an approved landfill or moved to an approved storage area for subsequent disposal. All backfilled material will be tamped to a proper compacted level to ensure no major settling will occur. After all backfilling and compacting procedures are complete, the area will be raked and seeded or resurfaced with asphalt, as appropriate. When the area is properly secured, decontamination procedures shall begin.

4.0 PRECAUTIONS

- Appoint an excavation competent person;
- Conduct daily inspections of excavation and surrounding area;
- Excavation entry is prohibited without approval of the excavation competent person;
- Protect employees in excavations deeper than four feet by means of properly designed protective systems;
- Protective systems must comply with 29 CFR 1926 Subpart P Appendices B, D, and E;
- Excavations will be clearly identified and barricaded to keep unauthorized individuals out.

5.0 REFERENCE

USEPA. 1987. *A Compendium of Superfund Field Operations Methods.* December.

STANDARD OPERATING PROCEDURE 20.7
RESISTIVITY AND ELECTROMAGNETIC INDUCTION SURVEYS

1.0 PURPOSE

The purpose of this standard operating procedure (SOP) is to provide a general description and technical management guidance on the use of Resistivity and Electromagnetic Induction (Terrain Conductivity) Surveys.

2.0 MATERIALS

- Work Plans;
- Field Logbook;
- Site maps;
- Electromagnetic induction unit; and
- Personal protective equipment and clothing (PPE) per the site-specific health and safety plan.

3.0 PROCEDURE

3.1 DESCRIPTION OF METHODS

3.1.1 Theory and Principles of Operations

Resistivity. A resistivity survey measures the electrical resistivity of a geohydrologic section indirectly. A DC or low-frequency AC electrical current is injected into the ground through electrodes embedded in the ground surface. The flow of current within the subsurface produces an electric field with lines of equal potential perpendicular to the current flow. This potential field (voltage) is measured between a second pair of electrodes also embedded in the ground surface.

The actual resistivity is a complex function of the applied current, observed voltage, and the characteristics of the subsurface section that provide multiple current flow paths. The apparent subsurface resistivity can be calculated as a function of the applied current, the measured voltage, the separation of the electrodes, and the geometry of the current and potential electrode pairs. For the simplest electrode configuration in which all four electrodes are equally spaced in the order current-potential-current (i.e., the Wenner array) the apparent resistivity is given by the following equation:

$$a = \frac{2\pi AV}{I}$$

Where:
a = apparent resistivity in ohm-meters or ohm-feet,
V = the measured potential difference in volts, and
I = the applied current in amperes.

The calculations are similar for other electrode configurations except geometric factors other than 2 are used. Equipment operating manuals provide nomographs for determination of apparent resistivity from field measurements for all standard electrode configurations. These calculations are simple and can be performed on a hand-held calculator.

Of the many possible geometric configurations of current and potential electrodes, some of the most commonly used arrays are as follows:

- Linear array with electrodes in the order current-potential-potential-current. A Wenner array results if the spacing between each successive pair of electrodes is equal. For a Schlumberger array, the distance between the two potential electrodes is a small fraction of the distance between the two current electrodes.
- Linear array with electrodes in the order current-current-potential-potential. In this dipole-dipole configuration, the separation of the two current and the two potential electrodes is equal, with an equal or greater separation of the two dipole pairs.

Resistivity surveys may be conducted to determine either vertical or horizontal electrical anomalies. *Vertical electrical soundings* (VES) are made by symmetrically expanding a Wenner or Schlumberger array in line about a point, i.e., the electrode spacing is increased for successive readings. Measurements of potential and input current are made for each set of electrode spacings, and the apparent resistivity is calculated as described below. The resultant plot of spacing versus apparent resistivity is interpreted to yield the resistivity distribution with depth beneath the midpoint between the potential electrodes. However, the resistivity being measured is that of the materials beneath the entire array.

For *horizontal profiling,* apparent resistivity from a series of measurements is plotted as a function of the X+Y coordinates of the site. One or more of the following procedures accomplishes horizontal profiling:

- A series of VES profiles at several locations are compared;
- Measurements are made with fixed-electrode spacing along a line or over an area; and/or
- Dipole-dipole measurements are made with the current or potential dipole at a fixed location and the other dipole located at increasing distances along a line. This process provides a resistivity “cross-section” beneath the line.

The Wenner and Schlumberger configurations are most often used for vertical investigation, whereas the dipole-dipole configuration is most often used for lateral surveys.

Electromagnetic Induction (EM). In the Electromagnetic Induction (EM) method, the electrical conductivity of a geohydrologic section is measured by transmitting a high-frequency electromagnetic field into the earth, producing eddy currents that generate secondary electromagnetic fields that can be detected by a receiver. The eddy currents are induced in the earth by an aboveground transmitter coil, and the resulting secondary electromagnetic fields are coupled to an aboveground receiver coil. Thus, EM measurements do not require direct ground contact, as is the case for resistivity measurements, and surveys across a line or area may be performed quite rapidly.

EM instruments are calibrated to read subsurface conductivity directly in units of millimhos per meter, Where:

$$1{,}000 \text{ milliohm per meter} = \frac{1}{\text{ohm-meter}}$$

This relation indicates that the conductivity obtained from EM measurements varies inversely with the resistivity measured using a resistivity survey. However, because the subsurface sections associated with the two methods are generally of different depth or cross-sectional area, there is not an exactly inverse relationship between conductivity and resistivity surveys.

The conductivity value obtained by an EM instrument depends on the combined effects of the number of soil and rock layers, their thicknesses and depths, and the inherent conductivities of the materials. The quantity actually measured is an apparent conductivity of the earth volume between the ground surface and an effective penetration depth, which is defined as the depth at which variations in conductivity no longer have a significant effect on the measurement. The sampling depth is related to the spacing between the transmitter and receiver coils of the instrument, approximately as follows:

Sampling depth = 1.5 (coil spacing) (Vertical Dipole)
= 0.75 (coil spacing) (Horizontal Dipole)

Vertical profiling can be accomplished by multiple measurements about a point, with varying coil spacings. Horizontal profiling is performed by making measurements along traverses with a fixed coil spacing.

3.1.2 Application

The measurement of a subsurface resistivity or conductivity at a hazardous waste site provides a valuable contribution to site characterization for the following reasons:

1. Conductivity (resistivity) is a function of the geohydrologic section and is overwhelmingly influenced by the presence of water. Therefore, conductivity (resistivity) can provide indirect evidence on the porosity and permeability of subsurface materials and the degree of saturation. These parameters, in turn, are directly related to subsurface lithology, and to the potential for infiltration/migration of contaminants from a source area.
2. Conductivity (resistivity) is influenced by the presence of dissolved electrolytes in soil or rock pore fluids. Contaminant plumes in the vadose (unsaturated) and saturated zones can be mapped if there is sufficient change in conductivity to be detected by EM or resistivity measurements.

   In general, contaminant plumes of inorganic wastes are most easily detected because conductivity may be increased by 1 to 3 orders of magnitude above background values. The limit of detection is a change from a background of 10%–20%. Plumes of non-polar organic constituents from spills or leaking containers may be detected if sufficient soil moisture has been displaced to affect the ground conductivity to a measurable degree.
3. Conductivity (resistivity) can be used to detect the presence of buried wastes if the degree of saturation, containerization, or inherent electrical properties of the wastes produce sufficient variation from the soil matrix. The degree of detail provided by typical surveys cannot distinguish the size, shape, or mass of sources except in a qualitative manner.

For these reasons, resistivity and conductivity surveys should be investigated as potentially appropriate site characterization tools when any of the following information is desirable:

- Detection and mapping of contaminant plumes; the rate of plume movement may also be deduced from measurements made over time;
- Estimates of depth, thickness, and resistivity of subsurface layers, depth to the water table, or probable geologic composition of a layer;
- Detection, mapping, and depths of burial pits, landfills, clay caps or lenses, or deposits of buried waste;
- Determination of locations for drilling to intercept contamination or to investigate aquifer properties; and
- Corroboration of limited chemical and geohydrologic data at a site.

In general, surface geophysical measurements alone cannot provide a complete assessment of subsurface conditions, When appropriately integrated with other investigative information from subsurface borings, borehole geophysics, etc., surface geophysical surveys can be an effective, accurate, and cost effective method of obtaining subsurface information. Geophysics at Radford Army Ammunition Plant will, where coverage permits, integrate surface and down hole methods to develop more accurate and refined interpretations of subsurface conditions that possible with either type of method alone.

3.1.3 Instrumentation

Resistivity. The basic components of a field resistivity system are two current and two potential electrodes, electrical cables, centralized power unit (current source), and resistivity meter. Automated instrumentation is commonly used to conduct two or three-dimensional surveys. One such system is the Advanced Geosciences, Inc. (AGI) Sting/Swift system, which includes a central power unit, resistivity meter (Sting), control unit (Swift), and switched electrode cables for use with up to 254 electrodes. This AGI allows for automated measurements, complete control of the measurement array, programmable measurement cycles, large capacity storage of data with linkup to a personal computer. The Sting/Swift system allows for rapid collection of resistivity data and testing of arrays. Measurement ranges for the Sting/Swift system are 0.1 milliohm to 400kohms (resistance) and 0 to 500 volts full-scale auto ranging (volts).

Electromagnetic Induction (EM). Generally EM instruments are available in two forms:

1. Single-piece models operable by one person, with a fixed coil spacing 12 feet; these provide sampling depths on the order of 10 and 20 feet. The Geonics EM31DL is one example of this type of instrument.
2. Dual-coil models, operable by two persons, with variable coil spacing up to about 40 feet (sampling depth up to about 60 feet). The Geonics EM 34-3XL is an example of this type of instrument.

The 12-foot fixed coil and the dual coil apparatus are most commonly used in hazardous waste site investigations. In either case, an additional person to record data and identify measurement locations is highly desirable and more time efficient. The instruments are calibrated to read directly in conductivity units, and values are typically read and recorded on a data sheet. Some units have been modified to provide direct digital recording on magnetic tape.

3.2 DATA ACQUISITION

3.2.1 Field Procedures

Initial Operations. As with most geophysical surveys, conductivity or resistivity surveys involve the following initial steps:

- **Planning.** Known or assumed geohydrologic features of the site, potential source locations and migration characteristics of hazardous constituents, are used to select specific techniques and equipment to establish appropriate locations and depths for geophysical measurements (see Section 5.1.2). The level of detail necessary (data quality objectives) determines the amount of effort and, in simple terms, the required number and density of data points. As a minimum, the data quality will depend on the method and specific equipment selected and the supporting hardware and software capabilities.

An "expert" system known as the Geophysics Advisor Expert System, developed by the Environmental Monitoring Systems Laboratory (EMSL) in Las Vegas, may be used as a planning tool to assist in selecting an appropriate geophysical method. This system prompts the user through a series of site-specific questions that will eventually rank various geophysical methods as to their feasibility at a specific site.

Most of the details can be planned before site activities; however, some leeway must be accorded to the field procedures to account for variable site conditions and weather.

- **Site Layout.** One of the most labor-intensive and time-consuming aspects of the fieldwork involves layout of grids and surveying or careful measurement of locations to allow geophysical surveys to be accomplished in a systematic, documentable manner. Location coordinates of sufficient resolution to accomplish the objectives of the survey must uniquely identify every data point.
- **Array and Spacing Tests.** Select one area or line that typifies the site. Test different array types and spacing. Analyze the data to see if the results match induction or normal resistivity and drilling logs from nearby wells. Select the optimal array type and spacing configuration, and proceed with the survey. If induction or normal resistivity logs are not available for wells at or near the site, log these wells before executing the surface surveys.

Resistivity Measurements. Resistivity electrodes must be installed in the proper array and spacing at a particular site grid location (according to specific manufacturers directions). The cables connecting the electrodes to the current source and potentiometer are then attached, and the current flow is initiated. Voltage is measured directly on the potentiometer. The process is repeated at the next site grid location (for horizontal profiling) or with the next electrode spacing (for vertical electric soundings) as necessary for QC purposes.

General rules for electrode spacings are difficult to specify because of site-specific variation; depending on the site geohydrology and source characteristics. As a general rule of thumb, the maximum electrode spacing should be at least three to five times that of the maximum target depth.

Electromagnetic Induction Measurements. At a given site grid location, the specified orientation of the apparatus is established, i.e., with the axis of the coils either parallel or perpendicular to the direction of the survey line. The meter reading is recorded and the apparatus is moved to the next site grid location.

For the dual-coil method, both the intercoil spacing and coplanarity of the coils must be established before recording the data. Surveys are normally conducted with the coil axes horizontal and at right angles to the survey direction.

EM profiles can be accomplished in a continuous manner using vehicle-mounted equipment in conjunction with strip charts, magnetic tape recorders, or digital recorders. Location information must be appended by tic marks or voice-over and some means provided to reference written field logs in a consistent manner.

3.2.2 Data Format

General. Information obtained during a resistivity or EM survey should be presented according to a standard data format, using standardized data sheets with original field entries. As a minimum, the heading for each data sheet should contain the following information:

- Project, task, site, and location identification;
- Company or organization;
- Date (and time, if applicable);
- Operator's name and signature;
- Method/technique identification;
- Instrument make, model, serial number, and calibration date/frequency (if applicable);
- Test location (according to the survey plan);
- Electrode or coil type and configuration;

- Line or site grid location(s);
- Weather and site conditions and temperatures;
- Identity of relevant calibration and QC data; and
- Records of data for each sounding or profile on a single sheet, if possible;

Resistivity. Survey data should include, in a tabular format, the following information:

- Electrode location, per the survey plan;
- Electrode spacing, in feet or meters;
- Input current applied, in amperes; and
- Measured potential, in volts.

Electromagnetic Induction. Survey data should include, in a tabular format, the following information:

- Coil location, per the survey plan;
- Coil spacing;
- Coil configuration (unless specified in the heading); and
- Meter reading, in millimhos per meter.

Special precautions to systematize and preserve data will be required for data that are recorded continuously on strip charts, magnetic tape recorders, or digital recorders. Strip charts should be permanently affixed to the field logbook. The first original hard copy of output from magnetic tape should be treated similarly. Identifying header information must be recorded directly on the tape.

3.3 DATA INTERPRETATION

3.3.1 Resistivity Data

For each data point, the apparent resistivity is calculated according to the formula appropriate for the type of electrode array employed. For horizontal profiling, curves of apparent resistivity versus distance along a line defined by the site grid locations are plotted. These curves of lateral changes in resistivity at a given electrode spacing (therefore, at a given survey depth) provide a cross-section for interpretation of the anomalous subsurface features. Multiple parallel profile lines can be combined to produce an area map of apparent resistivity at a particular depth.

For vertical electrical soundings, the series of apparent resistivities are plotted versus corresponding electrode spacings on log-log graph paper. The curves can be compared qualitatively with known or suspected subsurface conditions or with idealized layer-models to determine layer thicknesses and depths. Computer processing is typically applied for analysis of complex data sets and inverse layer modeling.

3.3.2 Electromagnetic Induction Data

Corrections may be applied to EM data for accuracy and drift, variation in location from pre-established coordinates, topography, changes in scale, and non-linearities associated with high conductivity values. In all cases, such corrections must be fully supported by data originally recorded or annotated in the field. Profile data along traverses are obtained as plots of conductivity versus distance. As with resistivity profiling, parallel traverse data may be combined to provide conductivity contour maps of a site. Two or more profiles at different sampling depths, as well as sounding data at a given location, provide information on the relative conductivities of shallow and deeper layers. Contour plots may provide valuable information on the extent and direction of groundwater flow and contaminant transport.

Detailed comparison of EM sounding measurements with layer models of the site can be made. This type of interpretation has been used at sites with relatively simple, uniform geohydrology to determine overburden and bedrock spatial and depth relationships. In some cases, very detailed interpretations, including aquifer flow properties, location of permeable zones, and interaquifer transfer, are possible.

3.4 POTENTIAL PROBLEMS

Resistivity and EM surveys are geophysical methods that, although standardized and frequently applied, are subject to a wide variety of problems. Problems can be expected to arise in the following areas:

- **Planning and Execution.** Rarely is a survey accomplished exactly according to the original plan. Site features not previously specified and myriad other variations can occur that force changes in the details of the approach. However, the data quality objectives of the survey, the general methodology, the amount of data required, and the degree of data interpretation requested should remain unchanged. Project work scopes should be written with some degree of latitude to allow a change in plans whenever justified.
- **Noise and Interferences.** Measurements can be affected severely both by natural and man-made sources of electrical and electromagnetic noise. Nearby power lines, stray ground currents, and atmospheric discharges adversely affect both types of surveys. Large masses of buried metal, fences, railroad tracks and underground pipes or cables can strongly distort measurements and reduce instrument sensitivity to features of interest. These problems generally can be accounted for or overcome but must be recognized early in the survey so that appropriate avoidance measures can be implemented. Known or suspected sources of interference should be included in the initial planning for a project.
- **Weather Conditions**. It is possible to conduct the surveys under almost any conditions that permit traverse of the site. However, snow cover, standing water, heavy rainfall, or thoroughly saturated surface soils may severely restrict the ability to meet project objectives and schedules. Scheduling contingencies should be included whenever possible, especially during periods when inclement weather is expected.
- **Technical Difficulties.** Preventable difficulties include equipment malfunction or misapplication, poor operator training, and lack of applications experience. Other difficulties may arise because the geophysical response of the site is not as initially conceptualized. Early recognition and response by technical management can minimize the effect and severity of any problems. Interim, real-time scrutiny of the data by the site geophysicist is essential. The geophysicist must be responsive regarding equipment replacement, repair, or changes in personnel. The site manager and the site geologist should be cognizant of technical difficulties beyond the control of the field personnel and should recognize the need to change plans, field personnel, or cancel a survey, as appropriate.
- **Topographic Changes.** Significant changes in topography should be addressed when planning and making measurements.

3.5 QUALITY CONTROL

3.5.1 General

Geophysical surveys, including resistivity and conductivity surveys, are subject to misapplication, erroneous interpretations, and use of incomplete or inadequate data. All of these avoidable errors can severely affect both the cost of subsequent site investigations and the validity of the site characterization. This susceptibility to misuse and potential for negative effect demands an assurance that appropriate quality control measures have been implemented. Quality control aspects common to most types of geophysical field programs are as follows:

- Integrating surface-based results (indirect measurements) with well sampling results, drilling logs, and down hole (direct measurement) geophysical logs.
- Program management personnel with technical expertise in preparing statements of work; reviewing proposals, work plans, and reports; and supervising technical subcontracts and field-related programs.
- Insistence on a defined scope of work, clear specifications, and data validation procedures.
- Appropriate justification before rejection of data points from a data set. Field data sheets should contain all observed data and the conditions that could affect data validity.
- Field data should be recorded in permanent ink in a bound logbook with each page signed and dated by the operator. Original unaltered logbooks should be retained in the site file.
- Complete and clear understanding of manufacturer's operation manual for the particular apparatus being used.
- Properly calibrated instrument provides an added measure of data validity and permits correlation and comparison of the associated data with site features and geohydrologic characteristics not evident at the time of the field effort. Some geophysical survey objectives can be met by relative measurements across an area or with depth.
- An evaluation should be made of noise, interferences, and obstructions at a site. Such measurements, inferences, and explanations should be recorded in the field. These real-time quality control procedures aid field personnel in correction of noise sources over which they have control, in validating suspected external sources, and in early detection of problems that may jeopardize the survey objectives.

3.5.2 Resistivity Surveys

The resistivity apparatus consists of a current source and potentiometer, both of which must be calibrated at least twice a day, e.g., once at the beginning of the day and once at the end of the day.

The current source (source of the energy driving the system) is calibrated by placing an ammeter in series with the electrode cables. The reading obtained on the reference ammeter is then compared with the value read from the ammeter on the current source. The current source ammeter is then adjusted to the reading on the reference ammeter.

The potentiometer is the other apparatus that must be calibrated. This is normally accomplished by placing a precision resistor in series with the current load. A precision resistor is an electronic device that has a predetermined (as specified by the manufacturer) resistance to the electric current passing through the device, i.e., reduction in amperage. The potentiometer is then placed across the resistor. The potential measured should be equal to the product of the known resistance and the indicated current. Precision resistors can be purchased at most electronics supply stores.

All data sets should be accompanied by quality control data that indicate the level of quality of each individual data point. Periodically taking replicate measurements or re-running with the spacing and array configuration accomplishes this. These measurements should be averaged or statistically compared so that measurement precision can be estimated. Each data set should also be referenced to the most recent calibration. Data obtained before a calibration requiring significant changes in instrument controls is suspect. (NOTE: A significant change in instrument readings as a result of recalibration is interpreted as successive calibration values that vary by more than 10%).

Resistivities should be calculated and plotted during data acquisition to determine the overall quality of the data and whether the survey results are consistent with the site conceptualization. Data points representing discontinuities in the curves should be validated by repetition and, if necessary, a fine grid of measurements made to determine whether the anomaly represents a site feature of interest, a spurious reading, or an obstructive interference.

3.5.3 Electromagnetic Induction Surveys

Calibration. The manufacturer calibrates EM instruments over massive rock outcrops of known characteristic that are used as a geologic standard to measure the absolute conductivity over a uniform section of earth. The user should maintain the EM apparatus in calibration by noting drift in the readings at a stable “secondary standard” site. A secondary standard site is a location established in the field that is used to check the accuracy (calibration of the instrument and the drift precision of the instrument). A secondary standard site is a location used daily on large projects to check instrument accuracy, much the same way the manufacturer uses massive rock outcrops for precision and accuracy determination.

Unacceptable drift or erratic operation shall be corrected by replacement with an instrument in proper working order. Values that are obtained from measurements over the stable secondary standard site that vary by more than 10%–15% are considered to be unacceptable drift, if environmental conditions remain somewhat constant (i.e., heavy precipitation can make measurements radically different).

All aspects of the daily quality control measures discussed for resistivity measurements apply also to EM measurements. Repeated periodic measurements (at least twice a day) should be made at one or more locations and orientations at the site to determine the precision of measurements and to detect instrument drift.

4.0 HEALTH AND SAFETY CONSIDERATIONS

All procedures for hazardous waste site entrance, traverse, and egress that apply to general field operations also apply to conduct of geophysical surveys. Resistivity and conductivity surveys depend on traverse of the site on foot or in vehicles, and there are extended periods during which personnel are subject to adverse environments at the site. In addition, resistivity measurements require implanting electrodes beneath the surface, which increases the risk of contact with toxic or hazardous agents. An appropriate level of protection against these risks must be provided during the surveys.

The geophysical methods discussed herein do not require extremely strenuous activity, and exposure to heat or cold is similar to that during other field activities. Extreme weather conditions will have adverse effects on the time required to obtain validated data, thereby increasing the duration of personal exposure to the elements and to hazardous site influences.

In resistivity surveys, substantial levels of electrical charges and voltage may be present across the current electrodes, and field procedures must be designed to ensure that no personnel are in contact with the electrodes when the current source is energized. The site-specific Health and Safety Plan must address emergency procedures in the event of electrical shock and possible loss of consciousness.

5.0 REFERENCES

Discussion of various survey techniques and applications can be found in the following references:

ASTM Standard D 6429-99 (2006). 2006. *Standard Guide for Selecting Surface Geophysical Methods.*

ASTM Standard D 6431-99 (2005). 2005. *Standard Guide for Using the Direct Current Resistivity Method for Subsurface Investigation.*

Benson, Richard C., Robert A. Glaccum and Michael R. Noel. 1982. *Geophysical Techniques for Sensing Buried Wastes and Waste Migration.* Technos, Inc., Miami, FL., Contract No. 68-03-3050, USEPA Environmental Monitoring Systems Laboratory, Las Vegas, NV.

Costello, Robert L. 1980. *Identification and Description of Geophysical Techniques.* Report No. DRXTH-TE-CR-80084, US Army Toxic and Hazardous Materials Agency, Aberdeen Proving Ground, MD; Defense Technical Information System No. ADA 123939.

Keiswetter, D., Won, I. J., Bell, T., Barrow, B., and Khadr, N. 1998. Electromagnetic Induction Spectroscopy. Geophex, Ltd., Raleigh, N.C. and AETC Inc., Arlington, VA.

Loke, M.H. 2000. *Electrical Imaging Surveys for Environmental and Engineering Studies.*

McKown, G.L., G.A. Sandness and G.W. Dawson, 1980. *Detection and Identification of Buried Waste and Munitions.* Proceedings of the 11th American Defense Preparedness Association Environmental Systems Symposium, Arlington, VA.

Olhoeft, Gary R. 1989. *Geophysics Advisor Expert System: Version 1.0.* Interagency Agreement DW 14932497, USEPA EMSL, Las Vegas, NV.

USACE. 1995. *Geophysical Exploration for Environmental and Engineering Investigations.* EM 1100-1-19802. 31 August.

STANDARD OPERATING PROCEDURE 20.8
MAGNETIC AND METAL DETECTION SURVEYS

1.0 PURPOSE

The purpose of this standard operating procedure (SOP) is to provide a general description of and technical management guidance on the use of Magnetic and Metal Detection Surveys.

2.0 MATERIALS

- Work Plans;
- Site maps;
- Field logbook;
- Metal detectors;
- Magnetometers;
- Pin flags;
- Surveys tape; and
- Personal protective equipment and clothing (PPE) per the site-specific health and safety plan.

3.0 PROCEDURE

3.1 DESCRIPTION OF METHODS

3.1.1 Theory and Principles of Operation

Magnetometry: All materials subjected to a magnetic field (including the magnetic field of the earth) will develop an induced magnetization, the intensity of which is proportional to the applied magnetic field and the magnetic susceptibility of the material. Ferromagnetic materials, such as iron or steel, have very high magnetic susceptibilities.

Induced magnetization in an object produces a local magnetic field that either reinforces (positive magnetic susceptibility) or reduces (negative susceptibility) the external applied field. The variations in an otherwise homogenous field caused by the presence of the object are called a magnetic anomaly, and observations of such anomalies can be used to infer the presence of nearby objects.

Magnetometry consists of measuring local variations in the earth's magnetic field along a traverse or across an area on the surface. Because the intensity of the earth's magnetic field depends in part on the magnetic susceptibility of subsurface material, a knowledge of variations in field intensity provides an indication of variations in the distribution of materials with different magnetic susceptibilities. In particular, the anomalies produced by buried ferromagnetic objects can be detected by magnetometers, which are instruments designed to measure the earth's magnetic field at a given location. In addition, many natural subsurface features, some of which are of interest in geohydrologic site investigations, may produce magnetic anomalies.

The intensity and inclination, or dip, of the earth's magnetic field varies smoothly (except for anomalies) with latitude. From the south to north across the United States, the intensity and inclination vary from about 49,000 to 60,000 gammas and from about 580 to 760, respectively. Nominal values for the Middle Atlantic Region (Washington, DC) are about 56,500 gammas and 690 for intensity and inclination, respectively. The intensity can vary (“drift”) daily due to changes in the ionosphere, sunspots, and other phenomena. Therefore, the latitude, time, and regional magnetic trends are important considerations during the magnetic surveys.

The myriad features of both natural and artificial origin that influence magnetic field measurements means that there is no unique interpretation of a set of magnetometry data. Conversely, there is no unique magnetic anomaly produced by a particular kind of buried object. Factors that influence the response of a magnetometer include the size, shape, depth, orientation, magnetic susceptibility, and permanent magnetism of a buried object. The sensitivity of magnetometers is such that many objects of interest at hazardous waste sites (particularly buried ferromagnetic materials such as drums, tanks, pipes, and iron scrap) are detectable. However, it is often difficult to interpret and identify the source of magnetic anomalies.

Metal Detection: When a radio frequency electromagnetic field generated by a transmitter coil encounters a highly conductive object such as a metal (not necessarily ferromagnetic), alternating currents are induced in the object that, in turn, generate alternating secondary magnetic fields which can be detected as alternating voltages by a receiver coil. The presence of the metal object effectively “couples” the transmitter and receiver coils, which otherwise are oriented so that little or no coupling exists. The principles of metal detector operation are very similar to those associated with electromagnetic induction instruments.

A number of factors influence the response of a metal detector. The receiver response increases with the size and surface area and decreases with the depth of a buried object. Factors such as soil properties and shape complicate detectability and interpretation of responses. Certain shapes, such as elongated metal rods, are difficult to detect. Iron minerals and conductive fluids will affect the detector response in much the same manner as a target of interest. Generally, metal detectors show greater response to smaller nearby targets than to larger targets at greater depth, and the presence of widespread metallic debris at a site can interfere with attempts to detect buried drums and other objects.

3.2 GENERAL APPLICABILITY

Magnetic Surveys (Magnetometry): Applications of magnetic surveys at hazardous waste sites center on confirming the presence (or absence) and location of buried ferromagnetic objects. Location of buried waste containers such as drums or tanks and surveying of proposed drill sites to detect interfering pipes, cables, or tanks are two important applications. Typically, a single 55-gallon drum can be detected at depths of up to 6 meters and large drum deposits or large tanks can be detected at depths of 20 meters or more.

Magnetic surveys can more readily detect metallic masses than identify or characterize targets. Calculations of the mass or size of detected objects generally yields only approximate results.

Magnetic surveys may be impractical in areas where metal pipes, fences, railroad tracks, buildings, and other ferrous metal artifacts are abundant. However, proper selection of equipment and survey techniques can often alleviate some of these problems.

Metal Detection: Metal detectors (MDs) can be used for locating buried metallic containers of various sizes; defining the boundaries of trenches containing metallic containers; locating buried metallic storage tanks; locating buried metallic pipes; avoiding buried utilities when drilling or trenching; or locating utility trenches that may provide a permeable pathway for contaminants.

The detection range of a MD is relatively short. Its sensitive areas are focused directly above and below the coil, providing good definition of object location. Quart-sized metal objects can be detected at a distance of about 1 meter; objects the size of a 55-gallon drum can be detected at depth up to 3 meters; and massive piles of metals can be detected at depths of 3 to 6 meters. Deeper objects are difficult to detect with a MD. Although most MDs are operated on foot, some can be vehicle-mounted if desired.

3.2.1 Instrumentation

Magnetometers: Two types of magnetometers, the fluxgate and proton procession magnetometers, are commonly used at hazardous waste sites. The fluxgate magnetometer uses an iron core sensor of high magnetic susceptibility. The amount of coiled electrical current necessary to induce magnetic saturation of the rod is directly dependent upon, and thus measures, the strength of the ambient magnetic field. In a proton magnetometer, a strong magnetic field is applied to a bottle of proton-rich fluid (e.g., kerosene), which realigns the protons. The field is then turned off and the frequency of the signal generated by the protons as they realign themselves ("process") to the earth's magnetic field is dependent upon, and thus measures, the strength of the field at that point. Some magnetometers, such as the fluxgate, are extremely sensitive to orientation during measurement. To alleviate this problem, two sensors are connected by a rigid pole to form a "gradiometer" that measures only a certain directional component of the earth's magnetic field. These gradiometers are commonly used at hazardous waste sites.

The type of magnetometer best suited for a particular site investigation depends upon characteristics of that site and should be chosen by a person familiar with the different instruments available. Proton magnetometers, for example, while very useful in some situations, will cease to function in an area with high magnetic gradients such as a junkyard or near a steel bridge.

Different instruments have different levels of sensitivity. In some cases, high sensitivity may be desired to detect deeply buried objects; in other instances, a low sensitivity instrument may be desired to reduce the effects of "noise" from nearby fences or cars. Furthermore, the size of the survey area and the resolution required will determine whether the magnetometer used is hand-held for stationary measurements or a vehicle-mounted continuous sensor model.

Metal Detectors (MDs): Three general classes of metal detectors are commonly used in hazardous waste site studies: pipeline/cable locators, conventional "treasure hunter" detectors, and specialized detectors. EPA field investigation teams commonly use the pipeline/cable detectors; they do not respond to small objects like soda cans. Although most of the "treasure hunter" type detectors are used for locating coin-sized objects, some can be fitted with larger sensor coils suitable for detection of larger objects at greater depths. Some of these models also can operate with adverse soil conditions such as high iron content. Specialized detectors are also available to operate to greater depths, operate over a wide sweep area, operate continuously, cope with special field problems, or operate while vehicle-mounted. These special MDs require an experienced operator and are not commonly available.

3.3 DATA ACQUISITION

3.3.1 Field Procedures

Magnetics: Magnetic measurements are generally made in a cross-grid pattern or if a continuous sensor is used, in a series of parallel lines across the survey area. The desired resolution (reconnaissance or high density) and the size and depth of the objects sought determine the spacing of measurement stations or surveys lines. Because of the phenomenon of temporal magnetic drift, a magnetic survey must include a base station at which magnetic measurements are made at regular intervals. These base stations are later used to correct all survey data for temporal differences due to drift. If the survey area permits, surveys are often conducted in a loop, the base station forming the end and starting points.

Magnetometers require special care during use. An experienced technician is recommended. The operator must not take measurements with the sensor near ferromagnetic objects such as belt buckles or steel-toed boots. The orientation of the magnetometer and its height from the ground must also be carefully controlled during operation. Recorded data must be annotated with station locations to allow construction of a site magnetic map.

Metal Detector: Planning surveys with metal detectors are similar to surveys with magnetometers. A grid pattern of evenly spaced parallel lines is used. Desired resolution and the size of objects determine the grid spacing. In some cases, elevating the MD a few feet off the ground may help to eliminate noise from small surface objects. An experienced operator is recommended. Recorded data must be annotated with station locations to allow construction of a site metal detection map.

3.3.2 Data Format

Magnetics: The output of a magnetometer is a numerical value (in gausses) of the intensity of the earth's magnetic field at a location. It may be displayed electronically or printed on tape depending on the instrument used. Because the object of a magnetic survey is often to complete a map of the survey area, each magnetic reading must be coupled with a record of its precise location.

The time of each reading must also be recorded to allow temporal drift connection. Some recent proton magnetometers include microprocessors for recording information on readings, locations, and times in one memory for playback at the survey's completion.

Metal Detection: The data provided by a metal detector is less quantitative than that of a magnetometer. The MD signal strength may vary (depending on the instrument) with object depth, size and shape, but this signal does not translate into a quantity such as field strength. It merely indicates the presence of a metal object. This on/off type of signal is useful because it can indicate the boundaries of a metal-bearing zone more clearly than some quantitative data such as magnetometer recordings.

3.4 DATA INTERPRETATION

3.4.1 Magnetics

Before interpreting magnetic data, it must first be corrected for regional trends and temporal drift. Regional trends, as determined from magnetic maps, are subtracted from the observed values to resolve magnetic anomalies due to objects at the site. Temporal drift is corrected by calculating the base station field strength changes over time and subtracting the appropriate time-dependent value from each observation. Other corrections for terrain or for compliance with other magnetic data are also sometimes employed.

The calculations can be done by hand or via computer processing. Once these mathematical corrections have been performed, the result is a set of profiles on a magnetic contour map. Interpretation then involves matching the observed anomalies with inferred underground shapes of given magnetic properties. This "modeling" of the subsurface (or data conversion) can involve mathematical techniques such as upward and downward continuations that reduce topographic and other interfering effects. The interpretation of magnetic anomalies must be based upon auxiliary evidence of what is at the site because there is no unique geometric solution for any magnetic anomaly. Furthermore, because of magnetic inclination, magnetic anomalies do not appear directly above their source. An experienced geophysicist must perform interpretation of magnetic maps.

3.4.2 Metal Detection

Very little interpretation is necessary for metal detection surveys performed to provide qualitative data on the presence of metallic objects in the survey area as a precursor to more detailed subsequent geophysical surveys. For these cases, the positive audible response or meter deflections are recorded on site grid maps, and no further processing or interpretation is made. More detailed metal detection surveys using strip chart or magnetic tape recording are possible. Typically, data is plotted on site grid maps following computer processing. Corrections are made for nonlinearities and to eliminate small-target responses.

3.5 POTENTIAL PROBLEMS

Magnetic and metal detection surveys are geophysical methods that, although frequently applied, are subject to a wide variety of problems. Problems can be expected to arise in the following areas:

Planning and Execution: Rarely is a survey accomplished exactly according to the original plan. Site features not previously specified and other variations can occur that force changes in the details of the approach. However, the objectives of the survey, the general methodology, the amount of data required, and the degree of data interpretation requested should remain unchanged. Project work scopes should be written with some degree of latitude to allow a change in plans whenever justified.

Noise and Interferences: Measurements can be affected severely by both natural and man-made sources of metal and electrical currents. Iron-bearing minerals, metallic structures, and the presence of metal on the operator can adversely affect both types of surveys. Large masses of buried metal, fences, railroad tracks, and underground pipes or cables can strongly distort measurements and reduce instrument sensitivity to features of interest. These problems generally can be overcome but must be recognized early in the survey so that appropriate avoidance measures can be implemented. Known or suspected sources of interference should be included in the initial planning for a project.

Weather Conditions: It is possible to conduct the surveys under almost any conditions that permit traverse of the site. However, snow covers, standing water, heavy rainfall, or thoroughly saturated surface soils adversely affect metal detection surveys.

Technical Difficulties: Preventable difficulties include equipment malfunction or misapplication, poor operator training, and lack of applications experience. Other difficulties may arise because the magnetic character of the site is not as initially conceptualized. Early recognition and response by trained geophysicists can minimize the effect of any problems. Interim, real-time scrutiny of the data by the site geophysicists is essential. The geophysicist must be responsive regarding equipment replacement and/or repair or changes in personnel.

3.6 QUALITY CONTROL

Geophysical surveys, including magnetic and metal detection surveys, are subject to misapplication, erroneous interpretations, and use of incomplete or inadequate data, all of which can severely affect both the cost of subsequent site investigations and the validity of the survey. This susceptibility to misuse and the potential for negative effects demands that appropriate quality control measures have been implemented. Quality control aspects common to most types of geophysical field programs include the following:

- Program management personnel (i.e., the field operations leaders, RI leader and site manager) with adequate technical expertise in the subject for preparing statements of work; reviewing proposals, work plans, and reports; and supervising technical subcontracts.
- Insistence on a defined scope of work, specifications, and data validation procedures.
- Requirement of a field quality control program.
- No data point should be rejected from a data set without appropriate justification; field data sheets should contain all observed data and the conditions that could affect data validation.

- All field data should be recorded in permanent ink in a bound logbook with each page signed and dated by the operator. Original unaltered logbooks should remain in the project files of the RI/FS contractor.
- In general, the objectives of geophysical surveys can be met by relative measurements across an area or with depth. Absolute calibration is therefore of lesser importance than precision of measurements. However, a properly calibrated instrument provides an added measure of data validity and permits correlation and comparison of the associated data with site features and geohydrologic characteristics not evident at the time of the field effort.
- An evaluation should be made of noise, interferences, and obstructions at a site and such measurements, inferences, and explanations should be recorded in the field. These real-time quality control procedures aid field personnel in correcting noise sources over which they have control and validating suspected external sources and in early detection of problems that might jeopardize the survey objectives.

3.6.1 Magnetic Surveys

Calibration: Magnetometer readings should regularly be compared with readings of a reference base station magnetometer; this procedure is necessary if corrections are to be made for changes in the earth's magnetic field over time. Absolute calibration should be performed periodically by use of a reference magnet or a standard laboratory electromagnet. Calibration should be recorded on an instrument calibration sheet, a copy of which accompanies the instrument to the field. Fluxgate magnetometers are inherently calibrated except for the crystal-controlled frequency counter, which requires periodic laboratory calibration.

Daily Quality Control: All data sets should be accompanied by quality control data that indicate the level of quality of each individual data point. Periodically, replicate measurements should be made so that measurement precision can be established. This procedure also requires corrections for variations in the earth's magnetic field with time. Each data set should be referenced to the most recent calibrations. All data obtained before a calibration requiring significant changes in instrument controls is suspect and the measurements should be repeated or otherwise validated. Data should be preliminarily reduced and plotted during the field program to determine the overall quality of the data and whether the survey results are consistent with the site conceptualization. Data points representing discontinuities in the curves should be validated by repetition and, if necessary, a fine grid of measurements made to determine whether the anomaly represents a site feature of interest, a spurious reading, or an obstructive interference.

3.6.2 Metal Detection

Calibration: Metal detectors normally are not calibrated, and only relative response is of interest. Periodically, nulling the instrument at a fixed location known to be free of metal and adjusting the gain to provide a proper response over a known target should check the sensitivity.

Daily Quality Control: Metal detector data should be accompanied by sufficient quality control data to verify that the instrument was operating properly. Occasional repetitive measurements and a log of the sensitivity adjustments usually suffice for this purpose.

4.0 HEALTH AND SAFETY CONSIDERATIONS

All procedures for hazardous waste site entrance, traverse, and egress that apply to general field operations also apply to the conduct of geophysical surveys. Magnetic and metal detection surveys depend on traverse of the site on foot or in vehicles, and there are extended periods during which personnel are subject to adverse environments at the site. A site health and safety survey must be performed before the geophysical survey, and an appropriate level of protection must be provided during the geophysical surveys.

The geophysical methods discussed here do not require sub-surface penetration and do not require extremely strenuous activity. Exposure to heat or cold is similar to that experienced during other field activities. Extreme weather conditions will have adverse effects on the time required to obtain validated data, thereby increasing the duration of personnel exposure to the elements and to hazardous site influences.

Although the instruments themselves are held above the ground (unless sled mounted) the probes should be covered with non-metallic (i.e., plastic) covers to avoid the possibility of accidental contamination.

5.0 REFERENCES

Discussion of various geophysical survey techniques and applications can be found in the following references:

ASTM Standard D 6429-99 (2006). 2006. *Standard Guide for Selecting Surface Geophysical Methods.*

Benson, R.C., R.A. Glaccum and M.R. Noel. 1982. *Geophysical Techniques for Sensing Buried Wastes and Waste Migration.* Technos, Inc., Miami, FL, Contract No. 68-03-3050, US EPA Environmental Monitoring Systems Laboratory, Las Vegas, NV.

Costello, R.L. 1980. *Identification and Description of Geophysical Techniques*. Report No. DRXTH-TE-CR-80084, US Army Toxic and Hazardous Materials Agency, Aberdeen Proving Ground, MD; Defense Technical Information System Number ADA 123939.

McKown, G.L., G. A. Sandness and G.W. Dawson. 1980. *Detection and Identification of Buried Waste and Munitions.* Proceedings of the 11th American Defense Preparedness Association Environmental Systems Symposium, Arlington, VA, 1980.

Olhoeft, Gary R. 1989. *Geophysics Advisor Expert System: Version 1.0.* Interagency Agreement DW 14932497, USEPA EMSL, Las Vegas, NV.

USACE. 1995. *Geophysical Exploration for Environmental and Engineering Investigations.* EM 1100-1-19802. 31 August.

STANDARD OPERATING PROCEDURE 20.11
DRILLING METHODS AND PROCEDURES

1.0 SCOPE AND APPLICATION

The use of an appropriate drilling procedure is contingent upon the existing conditions at the project site. The purpose of this standard operating procedure (SOP) is to outline procedures for the various methods of soil and rock drilling identified in the Master Work Plan. In addition it provides procedures for using sampling devices commonly used during soil and rock drilling such as split-barrel sampling, thin walled tube sampling, direct push samplers, and rock coring. For a particular site investigation, the associated work plan addendum will identify the appropriate drilling method and method of sampling, along with proposed sampling depths and intervals and any special procedures or methods.

2.0 MATERIALS

The following types of materials are generally appropriate for drilling:

2.1 SPLIT-BARREL SAMPLING

- Split barrel sampler;
- Borehole logging materials per SOP 10.3 and sampling equipment and materials, as appropriate per SOP 30.1;
- Containers to manage investigation-derived material per SOP 70.1; and
- Decontamination supplies and equipment per SOP 80.1.

2.2 THIN WALLED TUBE SAMPLING

- Thin walled tubes;
- Sealing materials for sample such as sealing wax, metal disks, wood disks, tape, cheesecloth, caps, etc;
- Borehole logging materials per SOP 10.3 and sampling equipment and materials, as appropriate per SOP 30.1;
- Containers to manage investigation-derived material per SOP 70.1; and
- Decontamination supplies and equipment per SOP 80.1.

2.3 DIRECT PUSH SAMPLING

- Direct push unit with hydraulic ram, hammer, etc;
- Sample collection devices, associated equipment and expendable supplies such as sample liners, sample retainers, appropriate lubricants, etc;
- Hollow extension rods;
- Auxiliary tools for handling, assembling, and disassembling tools and samplers;
- Borehole logging materials per SOP 10.3 and sampling equipment and materials, as appropriate per SOP 30.1;

- Containers to manage investigation-derived material per SOP 70.1; and
- Decontamination supplies and equipment per SOP 80.1.

2.4 HOLLOW-STEM AUGER DRILLING

- Drill rig and associated equipment;
- Hollow stem auger assemblies for drilling to appropriate depth including auger heads, drive assembly, pilot assembly, and hollow-stem auger sections;
- Auxiliary devices such as wrenches, auger forks, hoisting hooks, swivels, and adaptors;
- Borehole logging materials per SOP 10.3 and sampling equipment and materials, as appropriate per SOP 30.1;
- Containers to manage investigation-derived material per SOP 70.1; and
- Decontamination supplies and equipment per SOP 80.1.

2.5 DIRECT AIR ROTARY DRILLING

- Drill rig with rotary table and Kelly or top-head drive unit;
- Drill rods, bits, and core barrels (as appropriate);
- Casing;
- Sampling devices and equipment, as appropriate;
- Air compressor and filters, pressure lines, discharge hose, swivel, dust collector, and air-cleaning device (cyclone separator);
- Auxiliary tools for handling, assembling, and disassembling tools and samplers;
- Borehole logging materials per SOP 10.3 and sampling equipment and materials, as appropriate per SOP 30.1;
- Containers to manage investigation-derived material per SOP 70.1; and
- Decontamination supplies and equipment per SOP 80.1.

2.6 DRILL-THROUGH CASING DRIVER

- Drill rig equipped with a mast-mounted, percussion driver;
- Casing, drill rods, and drill bits or hammers;
- Air compressor and filters, pressure lines, discharge hose, swivel, dust collector, and air-cleaning device (cyclone separator);
- Sampling devices and equipment, as appropriate;
- Auxiliary tools for handling, assembling, and disassembling tools and samplers;
- Welding equipment and materials for installation of casing;
- Borehole logging materials per SOP 10.3 and sampling equipment and materials, as appropriate per SOP 30.1;
- Containers to manage investigation-derived material per SOP 70.1; and

- Decontamination supplies and equipment per SOP 80.1.

2.7 DIRECT WATER-BASED ROTARY DRILLING

- Drill rig with derrick, rotary table and Kelly or top-head drive unit;
- Drill rods, bits, and core barrels (as appropriate);
- Casing;
- Water based drilling fluid, with approved additives as appropriate;
- Mud tub, suction hose, cyclone de-sander(s), drilling fluid circulation pump, pressure hose, and swivel;
- Auxiliary tools for handling, assembling, and disassembling tools and samplers;
- Borehole logging materials per SOP 10.3 and sampling equipment and materials, as appropriate per SOP 30.1;
- Containers to manage investigation-derived material per SOP 70.1.
- Decontamination supplies and equipment per SOP 80.1.

2.8 DIRECT ROTARY WIRELINE-CASING ADVANCEMENT DRILLING

- Drill rig with either hollow spindle or top-head drive;
- Drill rods, coring or casing bits, overshot assembly, pilot bit, and core barrel;
- Water based drilling fluid, with approved additives as appropriate;
- Mud tub, suction hose, drilling fluid circulation pump, pressure hose, and swivel;
- Auxiliary tools for handling, assembling, and disassembling tools and samplers;
- Borehole logging materials per SOP 10.3 and sampling equipment and materials, as appropriate per SOP 30.1;
- Containers to manage investigation-derived material per SOP 70.1; and
- Decontamination supplies and equipment per SOP 80.1.

2.9 DIAMOND CORE DRILLING

- Direct rotary drill rig and associated equipment (see Sections 2.4, 2.5 or 2.6);
- Core barrels and core bits;
- Core lifters;
- Core boxes, engineers scale, permanent marking pen, and camera for photographing cores;
- Auxiliary tools for handling, assembling, and disassembling tools and samplers;
- Borehole logging materials per SOP 10.3 and sampling equipment and materials, as appropriate per SOP 30.1;
- Containers to manage investigation-derived material per SOP 70.1; and
- Decontamination supplies and equipment per SOP 80.1.

3.0 PROCEDURES

3.1 PENETRATION TEST AND SPLIT-BARREL SAMPLING OF SOILS

The following general procedure may be followed as outlined in ASTM Standard Test Method D 1586.

1. Advance the boring to the desired sampling depth using an appropriate drilling method (see sections below) and remove excessive cuttings from the borehole.
2. Attach the split-barrel sampler to the sampling rods and lower into the borehole. Do not allow the sampler to drop onto the soil to be sampled.
3. Position the hammer above and attach the anvil to the top of the drilling rods.
4. Rest the dead weight of the sampler, rods, anvil, and drive weight on the bottom of the boring and apply a seating blow. If excessive cuttings are encountered at the bottom of the borehole, remove the sampler and rods from borehole and remove the cuttings.
5. Mark the drill rods in three successive 6-inch increments so that the advance of the sampler can be observed.
6. Drive the sampler with blow from the 140 pound hammer and count the number of blows applied in each 6-inch increment until:
   a. Fifty (50) blows have been applied during one of the three 6-inch increments.
   b. A total of 100 blows have been applied.
   c. There is no observed advance of the sampler during the application of 10 successive blows of the hammer.
7. The sampler is advanced the complete 18-inches without the limiting blow counts occurring as described above.
8. Record the number of blows that is required to achieve each 6-inch increment of penetration or fraction of this increment on the boring.
   a. The first 6 inches is considered the seating driver.
   b. The sum of the second and third 6-inch penetration intervals is termed the “standard penetration resistance” or “N-value.”
   c. If the sampler is driven less than 18 inches as discussed in No. 6, then the number of blow for each partial increment will be recorded.
   d. For partial increments, the depth of penetration should be recorded to the nearest 1-inch on the boring log.
   e. If the sampler advances below the bottom of the boring under the weight of rods (static) and/or hammer, then this information will be recorded on the boring log.
9. The raising and dropping of the 140 pound hammer may be accomplished by:
   a. Using a trip, automatic, or semi-automatic hammer drop system that lifts the hammer and allows it to drop 30± 1 inches.
   b. Using a cathead shall be essentially free of rust, oil, or grease and have a diameter in the range of 6 to 10 inches. The cathead should be operated at a minimum speed of rotation of 100

revolutions per minute. No more than 2-1/4 rope turns on the cathead may be used when conducting the penetration test.

10. For each hammer blow, a 30-inch lift and drop shall be used.
11. After completing the penetration test, retrieve the sampler and open. Record the percent recovery or the length of sample recovered. Following the procedures outlined in SOP 30.1 when collecting environmental soil samples.
12. Borehole logging should be completed per SOP 10.3.
13. Split-barrel samples must be decontaminated before and after each use per the requirements of SOP 80.1.

3.2 THIN WALLED TUBE SAMPLING

The following general procedure may be followed for collection of relatively undisturbed, thin walled tube samples (e.g., Shelby tube) as outlined in ASTM Standard Practice D 1587.

1. Clean out the borehole to targeted sampling depth using most appropriate method, which avoids disturbing the material to be sampled. If groundwater is encountered, maintain the liquid level in the borehole at or above the groundwater level during sampling.
2. Place the sample tub so that its bottom rests on the bottom of the borehole.
3. Advance the sampler without rotation by a continuous relatively rapid motion.
4. Determine the length of the advance by the resistance and condition of the formation, the length of the advance should never exceed 5 to 10 diameters of the tube in sands and 10 to 15 diameters of the tube in clay.
5. When the formation is too hard for push type of sampling, the tube may be driven or the practice used for ring-lined barrel sampling may be used per ASTM Standard D 3550. When a sample is driven, the weight and fall of the hammer must be recorded along with the penetration achieved.
6. The maximum length of sample advance will be no longer than the sample-tube length minus an allowance for the sample head and a minimum of 3-inches for sludge-end cuttings.
7. Upon removal of the tube, measure the length of the sample in the tube. Remove the disturbed material in the upper end of the tube and re-measure the sample length.
8. Remove at least one-inch of material from the lower end of the tube for soil description and identification per SOP 10.3. Measure the overall sample length. Seal the lower end of the tube. If directed, the material from the end of the tube will not be removed for soil identification and description; in this case the tube will be sealed promptly.
9. Prepare sample labels and affix (or markings) on the tube.

3.3 DIRECT PUSH SOIL BORING

The following general procedures outlined in this section may be followed as described in ASTM Standard Test Method D 6282.

General considerations for this method include the following:

- A variety of direct push drive systems may be used to advance soil borings based on the intended sampling depths and subsurface conditions and include the following:

Shallower Depths and Less Difficult Conditions

- Percussive driving systems – use hydraulically operated hammers and mechanically operated hammers.
- Static push drive systems – use hydraulic rams to apply pressure and exert static pull (e.g., cone penetrometer systems).
- Vibratory/sonic systems – use a vibratory device, which is attached to the top of the sampler extension rods.

Greater Depths and More Difficult Conditions

- Sonic or resonance drilling systems – use a high power vibratory system to advance larger diameter single or dual tube systems.
- Rotary drilling equipment – use hydraulic system of drill rig for direct push.

- The equipment used for direct push must be capable of apply sufficient static force, or dynamic force, or both, to advance the sampler to the required depth of collection. Additionally, this equipment must have adequate retraction force to remove the sampler and extension/drive rods once the sample has been collected.
- Avoid using excessive down pressure when advancing the drilling tools/sampler. Excessive pressure may cause the direct push unit to offset from the boring location and may damage drilling tools and samplers.
- Sample liners should be compatible with the material being sampled and the type of analysis to be conducted on the sample. Sealing of liners for submittal to the laboratory for physical testing should be accomplished according to ASTM Standard D 4220 (Standard Practice for Preserving and Transporting Soil Samples).
- The general procedure for completing direct push soil borings is the following:

1. Stabilize direct push unit and raise mast at desired location.
2. Attach the hammer assembly to the drill head if not permanently attached. Attach the anvil assembly in the prescribed manner, slide the direct push unit the position over the borehole, and ready the tools for insertion.
3. Inspect the direct push tools before and after use. Decontaminate all down hole tools before and after use per SOP 80.1.
4. Inspect drive shoes for damaged cutting edges, dents or thread failures and these conditions could cause loss of sample recovery and slow the rate of advancement.
5. Assemble samplers and install where required, install sample retainers where needed, and install and secure sampler pistons to ensure proper operation where needed (see Steps 14 through 20 for the various sampler assembly procedures, etc.).
6. After sampler has been appropriately installed (see Steps 14 through 20 for installation procedures, etc.) advance the boring to the target sampling depth using an appropriate direct push technique, as identified above under general considerations.
7. Collect the soil sample from the target sampling depth using one of the methods identified in Steps 14 through 20.
8. Retrieve the sampler and appropriately process the soil sample as identified in Steps 14 through 20 below and in SOP 30.1.
9. Log the borehole per the requirements of SOP 10.3.
10. If collecting another soil sample, decontaminate the sampler for reuse per the requirements of SOP 80.1 or use another decontaminated sampler.

11. Appropriately manage investigation-derived material (discarded samples, decontamination fluids, etc.) per SOP 70.1.
12. Upon completion of the boring and collection of the desired soil samples, abandon the boring per the requirements of SOP 20.2.
13. The following single tube sampling systems (generally piston rod) may be used to collect soil samples (see Steps 14 through 16 below):
    a. Open Solid Barrel Sampler;
    b. Closed Solid Barrel Sampler (e.g. Geoprobe Macro-Core® Piston Rod Sampler); and
    c. Standard Split Barrel Sampler (see Section 3.1).
14. The following two tube sampling systems may be used to collect soil samples (see Steps 17 through 20 below):
    a. Split Barrel Sampler;
    b. Thin Wall Tubes;
    c. Thin Wall Tube Piston Sampler; and
    d. Open Solid Barrel Samplers.
15. Sampling with the single tube, open solid barrel sampler:
    a. Attach the required liner to the cutting shoe by insertion into the machined receptacle are or by sliding over the machined tube.
    b. Insert the liner and shoe into the solid barrel and attach the shoe.
    c. Attach the sampler head to the sampler barrel.
    d. Attach the sampler assembly to the drive rod and the drive head to the drive rod.
    e. Position the sampler assembly under the hammer anvil and advance the sampler assembly into the soil at a steady rate slow enough to allow the soil to be cut by the shoe and move up into the sample barrel.
    f. At the completion of the sampling interval, removal the sampler from the borehole. Remove the filled sampler liner from the barrel by unscrewing the shoe. Cap the liner for laboratory testing or split open for field processing (see SOP 30.1).
    g. Log the borehole per the requirements of SOP 10.3.
16. Sampling with the closed, solid barrel sampler (e.g., Macro-Core® sampler).
    a. Insert or attach the sample liner to the shoe and insert the assembly into the solid barrel sampler. Install the sample, retaining basket, if desired.
    b. Attach the latch coupling or sampler head to the sampler barrel, and attach the piston assembly with point and "O" rings if free water is present, to the latching mechanism.
    c. Insert the piston or packer into the liner to its proper position so that the point leads the sampler shoe. Set latch, charge packer, or install locking pin, and attach assembled sampler to drive rod.
    d. Add drive head and position under the hammer anvil. Apply down pressure, and hammer if needed, to penetrate the soil strata above the targeted sampling interval.
    e. When the sampling interval is reached, insert the piston latch release and recovery tool, removing the piston, or insert the locking pin removal/extension rods through the drive rods, turn counter clockwise, and remove the piston locking pin so the piston can float on top of the sample, or release any other piston holding device.
    f. Direct push or activate the hammer to advance the sampler the desired interval.

   g. Retrieve the sampler from the borehole by removing the extension/drive rods. Remove the shoe, and withdraw the sample line with sample for processing (see SOP 30.1).

   h. Clean and decontaminate the sampler, reload as described above and repeat the same procedure for collection of addition samples.

   i. Log the borehole per the requirements of SOP 10.3.

17. Sampling with standard split barrel (split spoon) sampler generally consists of the following:

   a. Attach the split barrel sampler to an extension rod or drill rod.

   b. Using a mechanical or hydraulic hammer drive the ampler into the soil the desired interval. The maximum interval that should be driven is equal to the sample chamber length of the split barrel sampler, which is either 18-inches or 24-inches.

   c. Retrieve the sampler from the borehole by removing the extension/drive rods.

   d. Split the sampler open for field processing (see SOP 30.1).

   e. Clean and decontaminate the sampler (SOP 80.1), re-attach and repeat the same procedure for collection of additional samples.

   f. Log the borehole per the requirements of SOP 10.3.

18. Sampling with a two tube, split barrel sampler generally consists of the following:

   a. Assemble the outer casing with the drive shoe on the bottom, attach the drive head to the top of the outer casing, and attach the sampler to the extension rods.

   b. Connect the drive head to the top of the sampler extension rods, and insert the sampler assembly into the outer casing.

   c. The cutting shoe of the sampler should contact the soil ahead of the outer casing to minimize sample disturbance.

   d. The sample barrel should extend a minimum of 0.25 inches ahead of the outer casing.

   e. Mark the outer casing to identify the required drive length, position the outer casing and sampler assembly under the drill head.

   f. Move the drill head downward to apply pressure on the tool string. Advance the casing assembly into the soil at a steady rate, which is slow enough to allow the soil to be cut by the shoe and move up inside the sample barrel.

   g. Occasional hammer action during the push may assist recovery.

   h. If smooth push advancement is not possible because of subsurface conditions, use the hammer to advance the sampler.

   i. Stop the application of pressure or hammering when target interval has been sampled. Move the drill head off the drive head. Attach a pulling device to the extension rods or position the hammer bail and retrieve the sampler from the borehole.

   j. At the surface, remove the sampler from the extension rods and process the sample per Section 3.01 and SOP 30.1.

   k. Log the borehole per the requirements of SOP 10.3.

19. Sampling with a two tube, thin wall tube sampler generally consists of the following:

   a. Attach the tube to the tube head using removable screws.

   b. Attach the tube assembly to the extension rods and position at the base of the outer casing shoe protruding a minimum of 0.25 inches to contact the soil ahead of the outer casing.

   c. Advance the tube with or without the outer casing at a steady rate.

   d. After completing the sampling interval, let the tube remain stationary for one minute. Rotate the tube slowly two revolutions to shear off the sample.
   e. Remove the tube from the borehole and measure the recovery, and log the borehole per the requirements of SOP 10.3.
   f. For field processing, extrude the sample from the tube sampler and process per SOP 30.1. Alternatively, the tube may be sealed and shipped to the laboratory.

20. Sampling with two tube, thin wall tube, piston sampler generally consists of the following:
    a. Check the fixed piston sampling equipment for proper operation of the cone clamping assembly and the condition of the "O" rings.
    b. Slide the thin wall tube over the piston, and attach it to the tube head. Position the piston at the sharpened end of the thin wall tube just above the sample relief bend.
    c. Attach the tube assembly to the extension rods and lower the sampler into position through the outer casing. Install the actuator rods through the extension rod, and attach to the actuator rod in the sampler assembly.
    d. Attach a holding ring to the to top of the actuator rod string and hook the winch cable or other hook to the holding ring to hold the actuator rods in a fixed position.
    e. Attach the pushing fork to the drill head/probe hammer and slowly apply downward pressure to the extension rods advancing the thin wall tube over the fixed piston into the soil for the length of the sampling interval.
    f. After completing the sampling interval, let the tube remain stationary for one minute. Rotate the tube slowly one revolution to shear off the sample.
    g. Remove the tube sampler from the borehole and measure the recovery, and log the borehole per the requirements of SOP 10.3.
    h. For field processing, extrude the sample from the tube sampler and process per SOP 30.1.
21. Sampling with an two tube, open solid barrel sampler generally consists of the following:
    a. This sampling technique may be used when soil conditions prevent advancement of a split barrel sampler or advancement of an outer casing.
    b. The solid, single, or segmented barrel sampler requires the use of a liner.
    c. Use sampler in advance of outer casing when this casing cannot be advanced.
    d. Follow the procedures outlined for two tube, split barrel sampling.

3.4 HOLLOW-STEM AUGER DRILLING

The following general procedure may be followed as outlined in ASTM Standard Guide D 5784.

1. Stabilize drill rig and raise mast at desired location.
2. Attach an initial assembly of hollow-stem auger components (hollow stem auger, hollow auger head, center rod and pilot assembly, as appropriate) to the rotary drive of the drill rig.
3. Push the auger assembly below the ground surface and initiate rotation at a low velocity.
4. Decontamination of auger head may be necessary after this initial penetration if this surface soil is contaminated.
5. Continue drilling from the surface, usually at a rotary velocity of 50 to 100 rotations per minute to the depth where sampling or in-situ testing is required or until the drive assembly is within approximately 6- to 18 inches of the ground surface.
6. As appropriate, collect a soil sample from the required depth interval. The sample may be conducted by

    a. Removing the pilot assembly, if used, and inserting and driving a sampler through the hollow stem auger of the auger column; or
    b. Using a continuous sampling device within the lead auger section, where the sampler barrel fills with material as the auger is advanced.

7. Additional sections of hollow stems augers may be added to drill to a greater depth. After these auger sections are added, rotation of the hollow-stem auger assembly may be resumed.
8. When drilling through material suspected of being contaminated, the installation of single or multiple (nested) outer casings may be required to isolate zones suspected contamination (see SOP 20.1). Outer casings may be installed in a pre-drilled borehole or using a method in which casing is advanced at the same of drilling.

   Monitoring wells or piezometers may be installed using hollow-stem augers by:

    a. Drilling with or without sampling to the target depth.
    b. Removal of the pilot assembly, if used, and insertion of the monitoring well (or piezometer) assembly.
    c. The hollow stem auger column should be removed incrementally as the monitoring well (or piezometer) completion materials are placed (see SOP 20.1 for grouting).

9. If materials enter the bottom of the auger hollow stem during the removal of the pilot assembly, it should be removed with a drive sampler or other appropriate device.
10. If sampling or *in-situ* testing is not required during completion of the boring, the boring may be advanced with an expendable knock out plate or plug of an appropriate material instead of a pilot assembly.
11. Drill cuttings should be appropriately controlled and contained as IDM per SOP 70.1. It may be necessary to drill through a hole of sheet of plywood or similar material to prevent cuttings from contacting the ground surface.
12. The hollow-auger assembly and sampling devices must be decontaminated before and after each use per the methods specified in SOP 80.1.
13. Borehole logging should be completed per SOP 10.3.
14. Borehole abandonment, when required, should be conducted according to SOP 20.3.

3.5 DIRECT AIR ROTARY DRILLING

The following general procedure may be followed as outlined in ASTM Standard Guide D 5784.

1. Stabilize drill rig and raise mast at desired location. Appropriately position the cyclone separator and seal it to the ground surface considering the prevailing wind direction (exhaust).
2. Establish point for borehole measurements.
3. Attach an initial assembly of a bit, down hole hammer, or core barrel with a single section of drill rod, below the rotary table or top-head drive unit, with the bit placed below the top of the dust collector.
4. Activate the air compressor to circulate air through system.
5. Initiate rotation of bit.
6. Continue with air circulation and rotation of the drill-rod column to the depth where sampling or in-situ testing is required or until the length of the drill rod section limits further penetration.
7. Monitor air pressure during drilling operations. Maintain low air pressure at bit to prevent fracturing of surrounding material.
8. Stop rotation and lift the bit slightly off the bottom of the hole to facilitate removal of drill cuttings and continue air circulation until the drill cuttings are removed from the borehole annulus.

9. Open reaching a desired depth of sampling, stop the air circulation and rest bit on bottom of hole to determine the depth. Record the borehole depth and any resultant caving in. If borehole caving is apparent set a decontaminated casing to protect the boring.
10. When sampling, remove the drill rod column from the borehole or leave the drill rod assembly in place if the sampling can be performed through the hollow axis of the drill rods and bit.
11. Compare the sampling depth to clean-out depth by first resting the sampler on the bottom of the hole and compare that measurement with the clean-out depth measurement.
12. If bottom-hole contamination is apparent (indicated by comparison of sample depth to clean-out depth), it is recommended that the minimum depth below the sampler/bit be 18 inches for testing. Record the depth of sampling or in-situ testing and the depth below the sampler/bit.
13. The procedure described in Steps 8 through 12 should be conducted for each sampling or testing interval.
14. Drilling to a greater depth may be accomplished by attaching an additional drill rod section to the top of the previously advanced drill-rod column and resuming drilling operations as described above.
15. When drilling through material suspected of being contaminated, the installation of single or multiple (nested) outer casings may be required to isolate zones suspected contamination (see SOP 20.1 for grouting requirements). Outer casings may be installed in a pre-drilled borehole or using a method in which casing is advanced at the same of drilling.
16. Monitoring wells or piezometers may be installed by:
    a. Drilling with or without sampling to the target depth.
    b. Removal of the drill rod assembly and insertion of the monitoring well (or piezometer) assembly.
    c. Addition of monitoring well (or piezometer) completion materials (see SOP 20.1).
17. Drill cuttings should be appropriately controlled and contained as IDM per SOP 70.1.
18. The drill rod assembly, sampling devices, and other drilling equipment contacting potentially contaminated material must be decontaminated before and after each use per the methods specified in SOP 80.1.
19. Borehole logging should be completed per SOP 10.3.
20. Borehole abandonment, when required, should be conducted according to SOP 20.3

3.6 DRILL-THROUGH CASING DRILLING

The following general procedure may be followed as outlined in ASTM Standard Guide D 5872.

1. Stabilize drill rig and raise mast at desired location. Appropriately position the cyclone separator and seal it to the ground surface considering the prevailing wind direction (exhaust).
2. Establish point for borehole measurements.
3. Attach an initial assembly of a bit or down hole hammer with a single section of drill rod and casing to the top-head drive unit.
4. Activate the air compressor to circulate air through system.
5. Drilling may be accomplished by
    a. Method 1- the casing will fall, or can be pushed downward behind the bit.
    b. To drill using Drive the casing first followed by drilling out the plug inside the casing.
    c. Method 2 - Advancing the casing and bit as a unit, with the drill bit or hammer, extending up to 12-inches below the casing.
6. Method 3 - Under reaming method where bit or hammer pens a hole slightly larger than the casing so that Method 1, drive the casing first and drill out the plug in the casing by moving the bit or hammer beyond

the casing and then withdrawing it into the casing. Air exiting the bit will remove the cuttings up the hole. Separate cuttings from the return air with a cyclone separator or similar device.

7. To drill using Method 2, advance casing and bit as unit with the bit or hammer extending up to 12-inches beyond the casing depending on the conditions. While drilling, occasionally stop the casing advancement, retract the bit or hammer inside the casing to clear and maintain air circulation to clear cuttings.
8. To drill using Method 3, use a special down hole bit or hammer to open a hole slightly larger than the outside diameter of the casing so that the casing will fall or can be pushed downward immediately behind the bit. After advancing the casing, retract the radial dimension of the drill bit to facilitate removal of the down hole bit or hammer and drill tools inside the casing. Cuttings are removed from the borehole with the air that operates the bit or hammer and can be separated from the air with a cyclone separator or similar device.
9. Monitor air pressure during drilling operations. Maintain low air pressure at bit or hammer to prevent fracturing of surrounding material.
10. Continue air circulation and rotation of the drill rod column until drilling is completed to the target depth (for sampling, in-situ sampling, etc.) or until the length of the drill-rod section limits further penetration.
11. Stop rotation and lift bit or hammer slightly off the bottom of the hole to facilitate removal of drill cuttings and continue air circulation until the drill cuttings are removed from the borehole annulus.
12. After reaching a desired depth of sampling, stop the air circulation and rest the bit on bottom of hole to determine the depth. Record the borehole depth and any resultant caving in. If borehole caving is apparent set a decontaminated casing to protect the boring.
13. When sampling, remove the drill rod column from the borehole. Compare the sampling depth to clean-out depth by first resting the sampler on the bottom of the hole and compare that measurement with the clean-out depth measurement.
14. If bottom-hole contamination is apparent (indicated by comparison of sample depth to clean-out depth), it is recommended that the minimum depth below the sampler/bit be 18 inches for testing. Record the depth of sampling or in-situ testing and the depth below the sampler/bit.
15. The procedure described in Steps 11 through 14 should be conducted for each sampling or testing interval.
16. Drilling to a greater depth may be accomplished by attaching an additional drill rod section and casing section to the top of the previously advanced drill-rod column/casing and resuming drilling operations as described above.
17. Monitoring wells or piezometers may be installed by:
    a. Casing advancement in increments, with or without sampling to the target depth.
    b. Removal of the drill rods and the attached drill bit while the casing is temporarily left in place to support the borehole wall.
    c. Insertion of the monitoring well (or piezometer) assembly.
    d. Addition of monitoring well (or piezometer) completion materials (see SOP 20.1).
18. Drill cuttings should be appropriately controlled and contained as IDM per SOP 70.1.
19. The drill rod assembly, casing, sampling devices, and other drilling equipment contacting potentially contaminated material must be decontaminated before and after each use per the methods specified in SOP 80.1.
20. Borehole logging should be completed per SOP 10.3.
21. Borehole abandonment, when required, should be conducted according to SOP 20.3.

3.7 DIRECT WATER-BASED ROTARY DRILLING

The following general procedure may be followed as outlined in ASTM Standard Guide D 5783.

1. Stabilize drill rig and raise mast at desired location. Appropriately position the mud tub and install surface casing and seal at the ground surface.
2. Establish point for borehole measurements.
3. Attach an initial assembly of a bit or core barrel with a single section of drill rod, below the rotary table or top-head drive unit, with the bit placed with the top of the surface casing.
4. Activate the drilling-fluid circulation pump to circulate drill fluid through the system.
5. Initiate rotation of bit and apply axial force to bit.
6. Document drilling conditions and sequence (fluid loss, circulation pressures, depths of lost circulation, etc.) as described in SOP 10.3.
7. Continue with drill fluid circulation as rotation and axial force are applied to the bit until drilling to the depth
    - a) Where sampling or in-situ testing is required;
    - b) Until the length of the drill rod section limits further penetration; or
    - c) Until core specimen has completely entered the core barrel (when coring) or blockage has occurred.
8. Stop rotation and the lift bit slightly off the bottom of the hole to facilitate removal of drill cuttings and continue fluid circulation until the drill cuttings are removed from the borehole annulus.
9. After reaching a desired depth of sampling, stop the fluid circulation and rest the bit on bottom of hole to determine the depth. Record the borehole depth and any resultant caving in. If borehole caving is apparent set a decontaminated casing to protect the boring.
10. When sampling, drill rod removal is not necessary if the sampling can be performed through the hollow axis of the drill rods and bit.
11. Compare the sampling depth to clean-out depth by first resting the sampler on the bottom of the hole and compare that measurement with the clean-out depth measurement.
12. If bottom-hole contamination is apparent (indicated by comparison of sample depth to clean-out depth), it is recommended that the minimum depth below the sampler/bit be 18 inches for testing. Record the depth of sampling or in-situ testing and the depth below the sampler/bit.
13. The procedure described in Steps 8 through 11 should be conducted for each sampling or testing interval.
14. Drilling to a greater depth may be accomplished by attaching an additional drill rod section to the top of the previously advanced drill-rod column and resuming drilling operations as described above.
15. When drilling through material suspected of being contaminated, the installation of single or multiple (nested) outer casings may be required to isolate zones suspected contamination (see SOP 20.1 for grouting requirements). Outer casings may be installed in a pre-drilled borehole or using a method in which casing is advanced at the same of drilling.
16. Monitoring wells or piezometers may be installed using hollow-stem augers by:
    - a. Drilling with or without sampling to the target depth.
    - b. Removal of the drill rod assembly and insertion of the monitoring well (or piezometer) assembly.
    - c. Addition of monitoring well (or piezometer) completion materials (see SOP 20.1).
17. Drill cuttings and fluids should be appropriately controlled and contained as IDM per SOP 70.1.

18. The drill rod assembly, sampling devices, and other drilling equipment contacting potentially contaminated material must be decontaminated before and after each use per the methods specified in SOP 80.1.
19. Borehole logging should be completed per SOP 10.3.
20. Borehole abandonment, when required, should be conducted according to SOP 20.3.

3.8 DIRECT ROTARY WIRELINE CASING ADVANCEMENT DRILLING

The following general procedure may be followed as outlined in ASTM Standard Guide D 5876.

1. Stabilize drill rig and raise mast at desired location. Appropriately position the mud tub (for water based rotary) and install surface casing and seal at the ground surface.
2. Record the hole depth by knowing the length of the rod-bit assemblies and comparing its position relative to the established surface datum.
3. Attach an initial assembly of a lead drill rod and a bit or core barrel below the top-head drive unit, with the bit placed with the top of the surface casing.
4. Activate the drilling-fluid circulation pump to circulate drill fluid through the system.
5. Initiate rotation of bit and apply axial force to bit.
6. Document drilling conditions and sequence (fluid loss, circulation pressures, depths of lost circulation, down feed pressures etc.) as described in SOP 10.3.
7. In general, the pilot bit or core barrel can be inserted or removed at any time during the drilling process and the large inside diameter rods can act as a temporary casing for testing or installation of monitoring devices.
8. Continue with drill fluid circulation as rotation and axial force are applied to the bit until drilling to the depth
    a) Where sampling or in-situ testing is required;
    b) Until the length of the drill rod section limits further penetration; or
    c) Until core specimen has completely entered the core barrel (when coring) or blockage has occurred.
9. Stop rotation and lift the bit slightly off the bottom of the hole to facilitate removal of drill cuttings and continue fluid circulation until the drill cuttings are removed from the borehole annulus.
10. After reaching a desired depth of sampling, stop the fluid circulation and rest the bit on bottom of hole to determine the depth. Record the borehole depth and any resultant caving in. If borehole caving is apparent set a decontaminated casing to protect the boring.
11. When sampling, drill rod removal is not necessary if the sampling can be performed through the hollow axis of the drill rods and bit.
12. Compare the sampling depth to clean-out depth by first resting the sampler on the bottom of the hole and compare that measurement with the clean-out depth measurement.
13. If bottom-hole contamination is apparent (indicated by comparison of sample depth to clean-out depth), it may be necessary to further clean the hole by rotary recirculation.
14. Continuous sampling may be conducted with a soil core barrel or rock core barrel (see Section 1.7).
15. The pilot bit or core barrel may need to be removed during drilling such as when core barrels are full or there is evidence of core blocking. Before the drill string is reinserted, the depth of the boring should be rechecked to evaluate hole quality and determine whether casing may be required.

16. Water testing may be performed in consolidated deposits by pulling back on the drill rods and passing inflatable packer(s) with pressure fitting to test the open borehole wall (see ASTM Standards D 4630 and D 4631).
17. Drilling to a greater depth may be accomplished by attaching an additional drill rod section to the top of the previously advanced drill-rod column and resuming drilling operations as described above.
18. When drilling through material suspected of being contaminated, the installation of single or multiple (nested) outer casings might be required to isolate zones suspected contamination (see SOP 20.1 for grouting requirements). Outer casings may be installed in a pre-drilled borehole or using a method in which casing is advanced at the same of drilling.
19. Monitoring wells or piezometers may be installed by:
    a. Drilling with or without sampling to the target depth.
    b. Removal of the pilot bit or core barrel and insertion of the monitoring well (or piezometer) assembly.
    c. Addition of monitoring well (or piezometer) completion materials (see SOP 20.1).
20. Drill cuttings and fluids should be appropriately controlled and contained as IDM per SOP 70.1.
21. The drill rod assembly, sampling devices, and other drilling equipment contacting potentially contaminated material must be decontaminated before and after each use per the methods specified in SOP 80.1.
22. Borehole logging should be completed per SOP 10.3.
23. Borehole abandonment, when required, should be conducted according to SOP 20.3.

3.9 DIAMOND CORE DRILLING

The following general procedure may be followed as outlined in ASTM Standard Practice D 2113.

1. Use core-drilling procedures, such as the water-rotary drilling method outlined in Section 3.6.
2. Seat the casing on bedrock or firm formation to prevent raveling of the borehole and to prevent loss of drilling fluid. Level the formation that the casing will be seated on as needed.
3. Begin core drilling using an N-size double-tube, swivel-type core barrel or other approved size or type. Continue core drilling until core blockage occurs or until the net length of the core has been drilled.
4. Remove the core barrel from the borehole, and dis-assemble the core barrel as necessary to remove the core.
5. Reassemble the core barrel and return it to hole.
6. Continue core drilling.
7. Place the recovered core in the core box with the upper (surface) end of the core at the upper-left corner of the core box. Wrap soft or friable cores, etc. as needed or required. Use spacer blocks or slugs properly marked to indicate any noticeable gap in recovered core that might indicate a change or void in the formation. Fit fracture, bedded, or jointed pieces of core together as they naturally occurred.
8. The core within each completed box should be photographed after core surface has been cleaned or peeled, as appropriate, and wetted. Each photo should be in sharp focus and contain a legible scale in feet and tenths of feet (or metric if appropriate). The core should be oriented so that the top of the core is at the top of the photograph. A color chart should be included in the photograph frame as a check on photographic accuracy. The inside lid of the box should also be shown.
9. The inside of the box lid should be labeled at a minimum with the facility name, project name, boring number, box number, and core interval.

10. A preliminary field log of the core must be completed before the core box has been packed for transport (see SOP 10.3). Detailed logging may be conducted at a later time providing the core is appropriately handled and transported.
11. Four levels of sample protection may be used depending on character of the rock and the intended use of the rock core including:
    a. *Routine care* – for rock cored in 5 to 10 foot runs. Consists of placing in structurally sound boxes. Lay flat tubing may be used prior to placing the core.
    b. *Special care* – for rock samples to be tested that are potentially moisture sensitive, such as shale. This care consists of sealing with a tight fitting wrapping of plastic film and application of wax at the ends of the sample.
    c. *Critical care* – for rock samples that may be sensitive to shock and vibration and/or temperature. Protect by encasing each sample in cushioning material, such as sawdust, rubber, polystyrene, foam, etc. A minimum one-inch thick layer of cushioning material should be used. Thermally insulate samples that are potentially sensitive to changes in temperature.
    d. *Soil-Like care* – handle per ASTM Standard D 4220.
12. Drilling conditions and sequence (fluid loss, circulation pressures, depths of lost circulation, down feed pressures, core blockage etc.) should be documented on the boring log as described in SOP 10.3.
13. Drill cuttings and fluids should be appropriately controlled and contained as investigation-derived material per SOP 70.1.
14. The drill rod assembly, sampling devices, and other drilling equipment contacting potentially contaminated material must be decontaminated before and after each use per the methods specified in SOP 80.1.
15. Borehole logging should be completed per SOP 10.3.
16. Borehole abandonment, when required, should be conducted according to SOP 20.3.

4.0 MAINTENANCE

Not applicable.

5.0 PRECAUTIONS

Refer to site-specific health and safety plan included in work plan addenda.

6.0 REFERENCES

ASTM Standard D 2113-06 (2006). 1993. *Standard Practice for Rock Core Drilling and Sampling of Rock for Site Investigation.*

ASTM Standard D 1586-99. 1999. *Standard Test Method for Penetration Test and Split-Barrel Sampling of Soils.*

ASTM Standard D 1587-00 (2007) e1. 2007. *Standard Practice for Thin-Walled Tube Sampling of Soils for Geotechnical Purposes.*

ASTM Standard D 3550-01 (2007). 2007. *Standard Practice for Think Wall, Ring-Lined, Split Barrel, Drive Sampling of Soils.*

ASTM Standard D 4220-95 (2007). 2007. *Standard Practices for Preserving and Transporting Soil Samples.*

ASTM Standard D 4630-96 (2002). 2002. *Standard Test Method for Determining Transmissivity and Storage Coefficient of Low-Permeability Rocks by In Situ Measurements Using the Constant Head Injection Test.*

ASTM Standard D 4631-95 (2000). 2000. *Standard Test Method for Determining Transmissivity and Storativity of Low-Permeability Rocks by In Situ Measurements Using Pressure Pulse Technique.*

ASTM Standard D 5079-02 (2006). 2006. *Standard Practices for Preserving and Transporting Rock Core Samples.*

ASTM Standard D 5782-95 (2006). 2006. *Standard Guide for Use of Direct Air-Rotary Drilling for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices.*

ASTM Standard D 5783-95 (2006). 2006. *Standard Guide for Use of Direct Rotary Drilling with Water-Based Drilling Fluid for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices.*

ASTM Standard D 5784-95 (2006). 2006. *Standard Guide for Use of Hollow-Stem Augers for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices.*

ASTM Standard D 5872-95 (2006). 2006. *Standard Guide for Use of Casing Advancement Drilling Methods for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices.*

ASTM Standard D 5876-95 (2005). 2005. *Standard Guide for Use of Direct Rotary Wireline Casing Advancement Drilling Methods for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices.*

ASTM Standard D 6282-98 (2005). 2005. *Standard Guide for Direct Push Soil Sampling for Environmental Site Characterizations.*

USACE. 1998. *Monitoring Well Design, Installation, and Documentation at Hazardous, Toxic, and Radioactive Waste Sites.* EM 1110-1-4000. 1, November.

STANDARD OPERATING PROCEDURE 30.1
SOIL SAMPLING

1.0 SCOPE AND APPLICATION

The purpose of this standard operating procedure (SOP) is to delineate protocols for sampling surface and subsurface soils.

2.0 MATERIALS

- Stainless steel scoop, spoon, trowel, knife, spatula, (as needed);
- Split-spoon, Shelby tube, or core barrel sampler;
- Hand auger or push tube sampler;
- Drill rig and associated equipment (subsurface soil);
- Stainless steel bowls;
- Photoionization detector or other appropriate instrument as specified in site-specific health and safety plan;
- Sampling equipment for collection of volatile organic samples;
- Appropriate sample containers;
- Appropriate sample labels and packaging material.;
- Personal protective equipment and clothing (PPE) per site-specific health and safety plan; and
- Decontamination equipment and supplies (SOP 80.1).

3.0 PROCEDURE

3.1 DOCUMENTATION

Soil sampling information should be recorded in the field logbooks as described in SOPs 10.1 and 10.2.

3.2 SURFICIAL SOIL SAMPLES

The targeted depths for surficial soil samples (surface and near surface) will be specified in the work plan addenda developed for site-specific investigations.

1. All monitoring equipment should be appropriately calibrated before beginning sampling according to the requirements of the work plan addenda and SOP 90.1 or 90.2.
2. All sampling equipment should be appropriately decontaminated before and after use according to the requirements of the work plan addendum and SOP 80.1.
3. Use a spade, shovel, or trowel or other equipment (manufactured from material, which is compatible with the soil to be sampled) to remove any overburden material present (including vegetative mat) to the level specified for sampling.
4. Measure and record the depth at which the sample will be collected with an engineers scale or tape.

5. Remove the thin layer that was in contact with the overburden removal equipment using a clean stainless steel scoop or equivalent and discard it.
6. Begin sampling with the acquisition of any discrete sample(s) for analysis of volatile organic compounds (VOCs), with as little disturbance as possible. VOC samples will not be composited or homogenized.
7. When a sample will not be collected with a core type of sampler (push tube, split spoon, etc.), the sample for VOC analysis will be collected from freshly exposed soil. The method of collection will follow the procedures specified in SOP 30.8 (Methanol Preservation Method) or 30.9 (En Core® Method) based on the requirements of the work plan addenda.
8. Field screen the sample with properly calibrated photoionization detector (PID) or other appropriate instrument. Cut a cross-sectional slice from the core or center of the sample and insert the monitoring instrument(s). Based on the screening results, collect the VOC fraction, as applicable.
9. Collect a suitable volume of sample from the targeted depth with a clean stainless steel scoop (or similar equipment), push tube sampler, or bucket auger
10. For core type of samplers, rough trimming of the sampling location surface should be considered if the sampling surface is not fresh or other waste, different soil strata, or vegetation may contaminate it. Surface layers can be removed using a clean stainless steel, spatula, scoop, or knife. Samples collected with a bucket auger or core type of sampler should be logged per the requirements of SOP 10.3.
11. If homogenization or compositing of the sampling location is not appropriate for the remaining parameters, the sample should be directly placed into appropriate sample containers with a stainless steel spoon or equivalent.
12. If homogenization of the sample location is appropriate or compositing of different locations is desired, transfer the sample to a stainless steel bowl for mixing. The sample should be thoroughly mixed with a clean stainless steel spoon, scoop, trowel, or spatula and then placed in appropriate sample containers per the requirements for containers and preservation specified in work plan addenda. Secure the cap of each container tightly.
13. Appropriately, label the samples (SOP 50.1), complete the chain-of-custody (SOP 10.4), and package the samples for shipping (SOP 50.2).
14. Return any remaining unused soil to the original sample location. If necessary, add clean sand to bring the subsampling areas back to original grade. Replace the vegetative mat over the disturbed areas.

3.3 SUBSURFACE SAMPLES

All sampling equipment should be appropriately decontaminated before and after use according to the requirements of the work plan addendum and SOP 80.1.

1. All monitoring equipment should be appropriately calibrated before sampling according to the requirement of the work plan addendum and SOP 90.1 or SOP 90.2.
2. All sampling equipment should be appropriately decontaminated before and after use according to the requirements of the work plan addendum and SOP 80.1.
3. Collect split-spoon; core barrel, Shelby tube, sonic core or other similar samples during drilling.
4. Upon opening sampler or extruding sample, immediately screen soil for VOCs using a PID or appropriate instrument. If sampling for VOCs, determine the area of highest concentration; use a

stainless steel knife, trowel, or lab spatula to cut the sample; and screen for VOCs with monitoring instrument(s).

5. Log the sample on the boring log before extracting from the sampler per the requirements of SOP 10.3.
6. Any required VOC samples will be collected first followed by the other parameters. VOC samples will not be composited or homogenized and will be collected from the area exhibiting the highest screening level. The method of VOC sample collection will follow the procedures specified in SOP 30.8 (Methanol Preservation Method) or 30.9 (En Core® Method) based on the requirements of the work plan addenda.
7. Field screen the sample with properly calibrated photoionization detector (PID) or other appropriate instrument. Cut a cross-sectional slice from the core or center of the sample and insert the monitoring instrument(s). Based on the screening results, collect the VOC fraction, as applicable.
8. Rough trimming of the sampling location surface should be considered if the sampling surface is not fresh or other waste, different soil strata, or vegetation may contaminate it. Surface layers can be removed using a clean stainless steel, spatula, scoop, or knife.
9. If homogenization or compositing of the sampling location is not appropriate for other parameters, the sample should be directly placed into appropriate sample containers with a stainless steel spoon or equivalent.
10. If homogenization of the sample location is appropriate or compositing of different locations is desired, transfer the sample to a stainless steel bowl for mixing. The sample should be thoroughly mixed with a clean stainless steel spoon, scoop, trowel, or spatula and placed in appropriate sample containers per the requirements for containers and preservation specified in work plan addenda. Secure the cap of each container tightly.
15. Appropriately, label the samples (SOP 50.1), complete the chain-of-custody (SOP 10.4), and package the samples for shipping (SOP 50.2).
16. Discard any remaining sample into the drums used for collection of cuttings.
17. Abandon borings according to procedures outlined in SOP 20.3.

3.4 INVESTIGATION-DERIVED MATERIAL

Investigation-derived material will be managed in accordance with procedures defined in the work plan addenda for the site being investigated and SOP 70.1.

NOTES: If sample recoveries are poor, it may be necessary to composite samples before placing them in jars. In this case, the procedure will be the same except that two split-spoon samples (or other types of samples) will be mixed together. The boring log should clearly state that the samples have been composited, which samples were composited, and why the compositing was done. In addition, VOC fraction should be collected from the first sampling device.

When specified, samples taken for geotechnical analysis (e.g., percent moisture, density, porosity, and grain size) will be undisturbed samples, such as those collected using a thin-walled (Shelby tube) sampler, sonic core sampler, etc.

4.0 MAINTENANCE

Not applicable.

5.0 PRECAUTIONS

Refer to the site-specific health and safety plan.

Soil samples will not include vegetative matter, rocks, or pebbles unless the latter are part of the overall soil matrix.

6.0 REFERENCES

ASTM Standard D 1586-99. 1999. *Standard Test Method for Penetration Test and Split-Barrel Sampling of Soils.*

ASTM Standard D 1587-00 (2007) e1. 2007. *Standard Practice for Thin-Walled Tube Sampling of Soils for Geotechnical Purposes.*

ASTM Standard D 5633-04. 2004. *Standard Practice for Sampling with a Scoop.*

USACE. 2001. *Requirements for the Preparation of Sampling and Analysis Plans.* EM 200-1-3. 1 February.

STANDARD OPERATING PROCEDURE 30.2
GROUNDWATER SAMPLING

1.0 SCOPE AND APPLICATION

The purpose of this standard operating procedure (SOP) is to delineate protocols for the collection of groundwater samples from monitoring wells.

2.0 MATERIALS

- Work Plans;
- Field logbooks and field parameter forms;
- Plastic sheeting;
- Decontamination equipment and supplies (SOP 80.1);
- Variable-speed, low-flow submersible pump with safety drop cable;
- Nylon stay-ties;
- Generator;
- Dedicated Teflon tubing or Teflon lined polyethylene tubing;
- Flow-through-cell and probes for measuring pH, temperature, specific conductance, oxidation/reduction potential, dissolved oxygen, and turbidity (SOP 40.1);
- Electronic water-level indicator;
- Appropriate sample bottles, labels, chain-of-custody forms, and sample shipping supplies etc;
- Cooler with ice;
- Silicone tubing;
- 0.45-micron disposable filters (as appropriate).
- Personal protective equipment and clothing (PPE) per site-specific health and safety plan;
- Photoionization detector (PID) or other appropriate monitoring instrument per the site-specific health and safety plan; and
- Appropriate containers for investigation-derived material.

3.0 PROCEDURE

3.1 DOCUMENTATION

Groundwater sampling information should be recorded in the field logbooks as described in SOPs 10.1 and 10.2.

The following are general rules for the field parameter logbook for groundwater, as described in SOP 10.2:

- Only information for one site or installation per logbook. The same book maybe used for more than one sampling event.

- The first five pages will be reserved for index, general notes, etc. Sign and date each entry.
- Fill in the forms.
- Duplicate copies, index pages, and calibration sheets remain intact.

3.2 OVERVIEW OF SAMPLING TECHNIQUES

In general, two different techniques may be used to sample groundwater from monitoring wells at Radford Army Ammunition Plant (RFAAP):

- Low flow purging and sampling (Type I); and
- Conventional purging and low-flow sampling (Type II).

These two sampling techniques are intended to address the different groundwater conditions that may be encountered at RFAAP.

The Type I sampling technique will be used in the following situations:

- In wells where only one discrete water-producing zone is encountered;
- In wells with no discrete water bearing zone and a low yield (generally < 0.5 liters per minute); and
- In wells sampled during seasonal low groundwater conditions with greatly reduced yield.

The Type II sampling technique will be used in the following situations:

- In a well with potential or documented multiple flow zones and where individual flow zones will not be evaluated;
- In moderately producing wells (> 0.5 liters per minute) where no discrete flow zones were documented during drilling; and
- In wells sampled during seasonal high groundwater conditions with enhanced yield (and potentially additional flow zones).

Groundwater samples should be collected no sooner than 14 days after well development. Information from the boring logs, well completion records, and well development records should be reviewed before sampling a well to determine the most appropriate sampling technique. Pertinent information for each well to be sampled includes:

- Well construction;
- Depth and nature of water producing zones;
- Sustainable pumping rate of the well to be sampled;
- Well recharge characteristics; and
- Baseline turbidity.

Because of the heterogeneous nature of the fracture and solution-enhanced fractured bedrock at RFAAP, monitoring well purging and sampling techniques will need to be flexible. This flexibility is necessary to obtain representative samples that meet the data quality objectives (DQOs) specified in site-specific work plan addenda.

In general, when using the pumps specified in the following sections, situate any gasoline-powered generator on level ground approximately 15 ft downwind from the well. All generator maintenance (oil and fueling) is to be performed off site. If the hose(s) and/or power cord of the pump is not on a reel, place the pump with its hose and power cord on the plastic sheeting downhill from the well.

3.3 TYPE I SAMPLING PROCEDURES

Type I low flow purging and sampling procedures include the following:

- The work area outside the well will be prepared by placing plastic sheeting on the ground around the well casing to avoid cross-contamination.
- All equipment used to purge and sample the wells will be thoroughly decontaminated before and after use according to the requirements of the work plan addenda and SOP 80.1.
- All equipment to be used for monitoring water quality parameters will be calibrated before beginning purging according to the requirements of the work plan addenda and SOP 40.1.
- Note the condition of the well and well head.
- Monitor the headspace of the well with a photoionization detector as the well cap is removed.
- Measure and record the depth to water with an electronic water level indicator. The measurement of well depth will not be taken until after sampling is completed so that potential re-suspension of any settled solids at the bottom of the well is avoided.
- Well depth at the time of purging will be obtained from well construction and existing data.
- Slowly lower a clean, stainless steel, adjustable flow rate, submersible pump and dedicated Teflon or Teflon-lined polyethylene tubing to the desired depth. As the pump is slowly lowered into the well, secure the safety drop cable, tubing, and electrical lines to each other using nylon stay-ties.
- For wells with very low sustainable pumping rates (≤ 0.5 liters per minute), the pump should be set in the middle of the saturated screen section of the well or middle of the water column for open wells. The pump should be set 12 hours prior to purging so that the depth to water equilibrates and sediments disturbed during pump placement have time to settle.
- For wells with sustainable pumping rates (> 0.5 liters per minute), the pumps will be set at a desired depth prior to purging, allowing for the depth to water to equilibrate before sampling. The desired depth will be specified in work plan addenda based on site-specific conditions and DQOs.
- Connect the pump tubing to an in-line flow-through cell(s) and connect the multi-parameter probe to the cell(s). The end of the tubing exiting the in-line flow-through cell should be placed to discharge into a appropriate container(s) to collect purge water.
- Immediately prior to purging, the depth to water will be measured and record. Start pumping the water at a rate of 100 to 400 milliliters per minute. Avoid surging. The pumping rate should cause minimal drawdown (less than 0.2 ft). Water level measurements should be collected continuously to document stabilization of the water level. Pumping rates should, if needed, be reduced to the minimal capabilities of the pump to avoid dewatering the screen interval and ensure stabilization of indicator parameters.
- During purging, water quality indicator parameters will be monitored at the in-line flow-through cell(s) every 3 to 5 minutes. The parameters to be monitored include pH, specific conductance, oxidation/reduction potential (Eh), dissolved oxygen, and turbidity.

- Continue purging until stabilization of indicator parameters is achieved. Stabilization is defined as three consecutive readings that are within the following criteria:
  - ± 0.1 for pH;
  - ±3% for specific conductance;
  - ±10 mV for oxidation/reduction potential (Eh); and
  - ±10% for turbidity and dissolved oxygen.
- If the parameters have stabilized, but the turbidity is not in the range of 5 to 10 NTU, then both filtered and unfiltered samples should be collected for any metals analysis. Filter metal samples should be collected with an in-line filter using a high capacity 0.45-micron particulate filter. This filter should be pre-rinsed according to the manufacturer's instructions.
- Once purging is completed, reduce the pumping rate to its lowest steady rate and disconnect the tubing from the in-line flow-though cell(s).
- Collect groundwater samples directly from the end of the tubing into clean containers provided by the laboratory. The container requirements and preservatives for groundwater samples are specified in work plan addenda. Allowing the pump discharge to flow gently down the inside of the container with minimal turbulence should fill all sample containers. Volatile organic compound (VOC) and gas sensitive parameter samples should be collected first followed by other parameters.
- In general, samples should be collected and containerized in the order of the volatilization sensitivity of the parameters. A preferred collection order for some common parameters is VOCs, extractable organics, metals, cyanide, sulfate and chloride, turbidity, and nitrate and ammonia. The parameters to be collected at any well location are site-specific and are specified in work plan addenda.
- Appropriately, label the samples (SOP 50.1), complete the chain-of-custody (SOP 10.4), and package the samples for shipping (SOP 50.2).
- After the sample collection is complete, remove the pump, tubing, and associated lines. Note: sample tubing will be dedicated to each well.
- Measure and record the total depth of the well.
- Secure the well be replacing and locking the lid.

3.4 TYPE II SAMPLING PROCEDURES

- The work area outside the well will be prepared by placing plastic sheeting on the ground around the well casing to avoid cross-contamination.
- All equipment used to purge and sample the wells will be thoroughly decontaminated before and after use according to the requirements of the work plan addenda and SOP 80.1.
- All equipment to be used for monitoring water quality parameters will be calibrated before beginning purging according to the requirements of the work plan addenda and SOP 40.1.
- Note the condition of the well and well head.
- Monitor the headspace of the well with a photoionization detector as the well cap is removed.
- Measure and record the depth to water with an electronic water level indicator. The measurement of well depth will not be taken until after sampling is completed so that potential re-suspension of any settled solids at the bottom of the well is avoided.

- Well depth at the time of purging will be obtained from well construction and existing data.
- Calculate the standing water column in the well by subtracting the depth to water from the total depth of the well as recorded during completion of the well.
- From the water depth, well diameter, sand pack length, etc., calculate the equivalent volume (1 EV) of water in the well.

  1 EV = volume in casing + volume in saturated sand pack. Therefore; if the water table lies below the top of the sand pack, use the following equation:

  $1\ EV = (pR_w^2h_w) + (0.30p(R_s^2\text{-}R_w^2)h_w) * (0.0043)$

  If the water table lies above the top of the sand pack use this equation:

  $1\ EV = [(pR_w^2h_w) + (0.30p(R_s^2\text{-}R_w^2)h_s)] * (0.0043)$

  Where: R_s = radius of sand pack in inches
  R_w = radius of well casing in inches
  h_s = height of sand pack in inches
  h_w = water depth in inches

  0.0043 gal/in^3
  Assumed filter pack porosity = 30%

Tables and graphs showing equivalent volumes for typical well constructions are available.

- Slowly lower a clean, stainless steel, adjustable flow rate, submersible pump and dedicated Teflon or Teflon-lined polyethylene tubing to the middle of the saturated screen interval or water column in an open borehole. As the pump is slowly lowered into the well, secure the safety drop cable, tubing, and electrical lines to each other using nylon stay-ties.
- Connect the pump tubing to an in-line flow-through cell(s) and connect the multi-parameter probe to the cell(s). The end of the tubing exiting the in-line flow-through cell should be placed to discharge into an appropriate container to collect purge water.
- Start purging the well at the minimally achievable pumping rate. Gradually increase the pumping rate to achieve the maximum flow rate of the pump or the maximum sustainable flow rate that does not draw down the static water level to a point below the top of the first water bearing zone, whichever is achieved first.
- During purging, water level measurements should be collected periodically to verify water levels in the well.
- During purging, water quality indicator parameters will be monitored at the in-line flow-through cell(s) every 3 to 5 minutes. The parameters to be monitored include pH, specific conductance, oxidation/reduction potential (Eh), dissolved oxygen, and turbidity.
- Note when each indicator parameter stabilizes. Stabilization is defined as three consecutive readings that are within the following criteria:
  - ± 0.1 for pH;
  - ±3% for specific conductance;
  - ±10 mV for oxidation/reduction potential (Eh); and
  - ±10% for turbidity and dissolved oxygen.

- Three calculated eVs of water in the will be purged prior to sampling. It will be documented if stabilization of the indicator parameters has not occurred after three calculated well volumes have been removed and sampling procedures begin.
- If the turbidity is not in the range of 5 to 10 NTU when purging has been completed, then both filtered and unfiltered samples should be collected for any metals analysis. Filter metal samples should be collected with an in-line filter using a high capacity 0.45-micron particulate filter. This filter should be pre-rinsed according to the manufacturer's instructions.
- Once purging is completed, reduce the pumping rate to its lowest steady rate and disconnect the tubing from the in-line flow-though cell(s).
- Collect groundwater samples directly from the end of the tubing into clean containers provided by the laboratory. The container requirements and preservatives for groundwater samples are specified in work plan addenda. Allowing the pump discharge to flow gently down the inside of the container with minimal turbulence should fill all sample containers. Volatile organic compound (VOC) and gas sensitive parameter samples should be collected first followed by other parameters.
- Appropriately, label the samples (SOP 50.1), complete the chain-of-custody (SOP 10.4), and package the samples for shipping (SOP 50.2).
- After the sample collection is complete, remove the pump, tubing, and associated lines. Note: sample tubing will be dedicated to each well.
- Measure and record the total depth of the well.
- Secure the well be replacing and locking the lid.

3.5 INVESTIGATION-DERIVED MATERIAL

Investigation-derived material will be managed in accordance with procedures defined in the work plan addendum for the site being investigated and SOP 70.1.

4.0 MAINTENANCE

Refer to manufacturer's requirements for maintenance of pumps and generators.

5.0 PRECAUTIONS

Refer to the site-specific health and safety plan.

6.0 REFERENCES

ASTM Standard D 5903-96 (2006). 2006. *Planning and Preparing for a Groundwater Sampling Events.*

USACE. 2001. R*equirements for the Preparation of Sampling and Analysis Plans.* EM 200-1-3, 1 February.

USEPA. 1995. *Low-Flow (Minimal Drawdown) Ground-Water Sampling Procedures United States Environmental Protection Agency*, Office of Solid Waste and Emergency Response, EPA/540/S-95/504, December 1995.

USEPA. 1997. *Recommended Procedure for Low-flow Purging and Sampling of Groundwater Monitoring Wells.* Bulletin No. QAD023, October.

STANDARD OPERATING PROCEDURE 30.6
CONTAINERIZED MATERIAL

1.0 SCOPE AND APPLICATION

The purpose of this standard operating procedure (SOP) is to delineate protocols for the opening and sampling of containerized liquids of potentially unknown substances.

2.0 MATERIALS

- Work Plans;
- Field logbooks;
- Personal protective equipment and clothing per the site-specific health and safety plan;
- Monitoring instruments per the site-specific health and safety plan;
- Decontamination equipment and supplies (SOP 80.1);
- Tools;
- Historical data, if available;
- Sampling tube; and
- Remote samplers, as required.

3.0 PROCEDURE

Sealed containers with unknown contents represent potential severely hazardous situations for sampling teams. Even when the original identity of the contents is reasonably certain, contents may be under pressure or in a decomposed state and may readily react (sometimes violently) with air or water vapor in the atmosphere.

Only hazardous material specialists that have appropriate training and experience will inspect and sample unidentifiable drums or containers. Specialist team members will use extreme caution and care when opening sealed drums or cans of unknown content for purposes of inspection and sampling.

Efforts will be made to determine the identity of the contents, through markings, history of activities at the site, and similarity and proximity to containers of known contents. The range of possible hazards will dictate which specific procedure will be followed, and specific procedures will be identified in work plan addenda. All predetermined procedures will be strictly followed as designated by the site-specific conditions.

Using this SOP and appropriate health and safety protocols, field personnel will use extreme caution and care in opening sealed drums or cans of unknown contents for purposes of inspection and sampling. Specific activities include the following:

- Determine the identity of the contents through markings, history of activities at the site, and similarity and proximity to containers of known contents. The range of possible hazards will dictate which specific procedure should be followed.

- Handle containers as little as possible; however, if it is necessary to reorient a drum to allow access to a bung or cap, perform this activity using remote-handling forklift equipment with special drum-holding attachments.
- If contents are deemed to be under pressure, highly reactive, or highly toxic (or if these possibilities cannot be disproven), perform initial opening of the container remotely.
- Air monitoring stations will be established as necessary, using the following procedures:
    1. Affix a remote bung opener to the drum.
    2. Evacuate personnel to a safe distance or station them behind a barricade.
    3. Activate the non-sparking motor of the opener.
    4. After the bung is removed, monitor the drum for potential activity of the contents, such as vapor emission, smoking, or audible reaction.
    5. Approach cautiously while monitoring for toxic levels of airborne contaminants.
- If the contents of the drum pose acceptable hazards, accomplish opening (or inspection if previously opened remotely) and sampling with one of three approved devices. The preferred method is to use a clean glass tube, with or without bottom stopper, which can be placed in the drum (breaking it if necessary) after sampling is complete. Alternately (if a bung has been removed), a well sampler such as a Kemmererbailer can be used (but would require removal and cleaning or disposal according to the nature of the waste). By opening either of these devices at a desirable depth, stratified sampling can be performed. Also, the sampling tubes can be made with a plunger rod and O-ring seals at selected intervals, allowing simultaneous collection of multiple samples in a stratified medium.
- Following sampling, the drum will be resealed and/or overpacked to prevent any possibility of leakage while analysis determines the identity of the contents.
- Drums that do not have removable bungs may be opened remotely with a solenoid-activated punch (this requires that the drum be recontainerized or overpacked after sampling is complete).

4.0 MAINTENANCE

Not applicable.

5.0 PRECAUTIONS

Not applicable.

6.0 REFERENCE

USEPA, 1989. A Compendium of Superfund Field Operation Methods. EPA/540/P-87/001. December.

STANDARD OPERATING PROCEDURE 30.7
SAMPLING STRATEGIES

1.0 SCOPE AND APPLICATION

The purpose of this standard operating procedure (SOP) is to delineate sampling strategies for sampling various media.

2.0 MATERIALS

- Historical site data;
- Site topography;
- Soil types; and
- Sampled media.

3.0 PROCEDURE

The primary goal of any investigation is to collect samples representative of existing site conditions. Statistics are generally used to ensure samples are as representative as possible. Sampling plans may employ more than one approach to ensure project data quality objectives are adequately addressed. A comparison of sampling strategies is presented in Table 1.

3.1 CLASSICAL STATISTICAL SAMPLING

Classical statistical sampling strategies are appropriately applied to either sites where the source of contamination is known or small sites where the entire area is remediated as one unit. Primary limitations of this sampling approach include (1) inability to address media variability; (2) inadequate characterization of heterogenous sites; and (3) inadequate characterization of sites with unknown contamination characteristics.

3.1.1 Simple Random Sampling

Simple random sampling is generally more costly than other approaches because of the number of samples required for site characterization. This approach is generally used when minimal site information is available and visible signs of contamination are not evident and includes the following features:

- Sampling locations are chosen using random chance probabilities.
- This strategy is most effective when the number of sampling points is large.

3.1.2 Stratified Random Sampling

This sampling approach is a modification to simple random sampling. This approach is suited for large site investigations that encompass a variety of soil types, topographic features, and/or land uses. By dividing the site into homogenous sampling strata based on background and historical data, individual random sampling techniques are applied across the site. Data acquired from each stratum can be used to determine the mean or total contaminant levels and provide these advantages:

- Increased sampling precision results due to sample point grouping and application of random sampling approach.
- Control of variances associated with contamination, location, and topography.

3.1.3 Systematic Grid

The most common statistical sampling strategy is termed either systematic grid or systematic random sampling. This approach is used when a large site must be sampled to characterize the nature and extent of contamination.

Samples are collected at predetermined intervals within a grid pattern according to the following approach:

- Select the first sampling point randomly; remaining sampling points are positioned systematically from the first point.
- Determine the grid design: one or two-dimensional. One-dimensional sample grids may be used for sampling along simple man-made features. Two-dimensional grid systems are ideal for most soil applications.
- Determine the grid type: square or triangular. Sampling is usually performed at each grid-line intersection. Other strategies include sampling within a grid center or obtaining composite samples within a grid.
- Each stratum is sampled based on using the simple random sampling approach but determined using a systematic approach.

3.1.4 Hot-Spot Sampling

Hot spots are small, localized areas of media characterized by high contaminant concentrations. Hot-spot detection is generally performed using a statistical sampling grid. The following factors should be addressed:

- Grid spacing and geometry. The efficiency of hot-spot searches is improved by using a triangular grid. An inverse relationship exists between detection and grid point spacing, e.g., the probability of hot-spot detection is increased as the spacing between grid points is decreased.
- Hot-spot shape/size. The larger the hot spot, the higher the probability of detection. Narrow or semicircular patterns located between grid sampling locations may not be detected.
- False-negative probability. Estimate the false negative (β-error) associated with hot-spot analysis.

3.1.5 Geostatistical Approach

Geostatistics describe regional variability in sampling and analysis by identifying ranges of correlation or zones of influence. The general two-stage approach includes the following:

- Conducting a sampling survey to collect data defining representative sampling areas.
- Defining the shape, size, and orientation of the systematic grid used in the final sampling event.

3.2 NON-STATISTICAL SAMPLING

3.2.1 Biased Sampling

Specific, known sources of site contamination may be evaluated using biased sampling. Locations are chosen based on existing information.

3.2.2 Judgmental Sampling

This sampling approach entails the subjective selection of sampling locations that appear to be representative of average conditions. Because this method is highly biased, it is suggested that a measure of precision be included through the collection of multiple samples.

4.0 MAINTENANCE

Not applicable.

5.0 REFERENCES

Gilbert, R.O. 1987. *Statistical Methods for Environmental Pollution Monitoring.* John Wiley & Sons, Inc. 320 p.

USACE. 2001. *Requirements for the Preparation of Sampling and Analysis Plans.* EM200-1-3. 1 February.

TABLE 1
SAMPLING STRATEGIES

SAMPLING STRATEGY	DESCRIPTION	APPLICATION	LIMITATIONS
Classical Statistical Sampling Strategies			
Simple Random Sampling	Representative sampling locations are chosen using the theory of random chance probabilities.	Sites where background information is not available and no visible signs of contamination are present.	May not be cost-effective because samples may be located too close together. Does not take into account spatial variability of media.
Stratified Random Sampling	Site is divided into several sampling areas (strata) based on background or site survey information.	Large sites characterized by a number of soil types, topographic features, past/present uses, or manufacturing storage areas.	Often more cost-effective than random sampling. More difficult to implement in the field and analyze results. Does not take into account spatial variability of media.
Systematic Grid Sampling	Most common statistical strategy; involves collecting samples at predetermined, regular intervals within a grid pattern.	Best strategy for minimizing bias and providing complete site coverage. Can be used effectively at sites where no background information exists. Ensures that samples will not be taken too close together.	Does not take into account spatial variability of media.
Hot-Spot Sampling	Systematic grid sampling strategy tailored to search for hot spots.	Sites where background information or site survey data indicate that hot spots may exist.	Does not take into account spatial variability of media. Tradeoffs between number of samples, chance of missing a hot spot, and hot spot size/shape must be weighed carefully.
Geostatistical Approach	Representative sampling locations are chosen based on spatial variability of media. Resulting data are analyzed using kriging, which creates contour maps of the contaminant concentrations and the precision of concentration estimates.	More appropriate than other statistical sampling strategies because it takes into account spatial variability of media. Especially applicable to sites where presence of contamination is unknown.	Previous investigation data must be available and such data must be shown to have a spatial relationship.
Non-Statistical Sampling Strategies			
Biased Sampling	Sampling locations are chosen based on available information.	Sites with known contamination sources.	Contaminated areas can be overlooked if background information or visual signs of contamination do not indicate them. Best used if combined with a statistical approach, depending on the project objectives.
Judgmental Sampling	An individual subjectively selects sampling locations that appear to be representative of average conditions.	Homogenous, well-defined sites.	Not usually recommended due to bias imposed by individual, especially for final investigations.

STANDARD OPERATING PROCEDURE 30.9
COLLECTION OF SOIL SAMPLES BY USEPA SW 846 METHOD 5035 USING DISPOSABLE SAMPLERS

1.0 SCOPE AND APPLICATION

This standard operating procedure (SOP) outlines the recommended protocol and equipment for collection of representative soil samples to monitor potential volatile organic contamination in soil samples.

This method of sampling is appropriate for surface or subsurface soils contaminated with low to high levels of volatile organic compounds (VOCs). This sampling procedure may be used in conjunction with any appropriate determinative gas chromatographic procedure, including, but not necessarily limited to, SW-846 Method 8015, 8021, and 8260.

2.0 MATERIALS

- Work Plans;
- Field Logbook;
- Photoionization Detector (PID) or other monitoring instrument(s) per site-specific health and safety plan;
- Personal protective equipment and clothing per site-specific health and safety plan;
- Soil sampling equipment, as applicable (SOP 30.1);
- Disposable sampler;
- T-handle and/or Extrusion Tool; and
- Decontamination equipment and supplies (SOP 80.1).

3.0 PROCEDURE

3.1 METHOD SUMMARY

Disposable samplers are sent to the field to be used to collect soil samples. Three samplers must be filled for each soil sampling location, two for the low-level method (sodium bisulfate preservation) and one for the high level method (methanol preservation). After sample collection, disposable samplers are immediately shipped back to the laboratory for preservation (adding soil sample into methanol and sodium bisulfate solution). The ratio of volume of methanol to weight of soil is 1:1 as specified in SW-846 Method 5035 (Section 2.2.2). The amount of preservative in the solution corresponds to approximately 0.2 g of preservative for each 1 g of sample. Enough sodium bisulfate should be present to ensure a sample pH of ≤ 2.

If quality assurance/quality control (QA/QC) samples are needed, seven samplers will be needed for the original, matrix spike, and matrix spike duplicate analysis. Soil samples are collected in the field using the disposable samplers, sealed and returned to the laboratory. A separate aliquot of soil is collected in a 125-mL container for dry weight determination.

3.2 SAMPLE CONTAINERS, PRESERVATION, HANDLING AND STORAGE

After sample collection, the disposable samplers must be cooled to and maintained at 4°C. The contents of the samplers will be analyzed using EPA methods 8015, 8021, and/or 8260. The **disposable** sampler is a single use device. It cannot be cleaned and/or reused.

Disposable samplers have a 48 hour holding time from sample collection to sample preparation in the laboratory. Return the samplers to the laboratory immediately after sampling.

3.3 SAMPLE PROCEDURES

Before sampling, the disposable sampler should be prepared as follows:

1. Unpack the cooler/sampling kit received from the laboratory. Disposable samplers are packed in sealed aluminized bags. These should be over packed in plastic zip lock bags. A T-Handle will also be needed to collect samples with the disposable sampler.
2. Hold coring body and push plunger rod down until small 0-ring rests against tabs. This will assure that plunger moves freely.
3. Depress locking lever on the sampler T-Handle (or other extraction device). Place coring body, plungers end first, into the open end of the T-Handle, aligning the two slots on the coring body with the two locking pins in the T-Handle. Twist the coring body clockwise to lock the pins in the slots. Check to ensure the sampler is locked in place. Sampler is ready for use.

The following procedure should be followed when using a disposable sampler to sample for VOCs in soil:

1. After the soil-sampling device (split spoon, corer, etc.) is opened, the sampling process should be completed in a minimum amount of time with the least amount of disruption.
2. Visual inspection and soil screening should be conducted after the sampler is opened and a fresh surface is exposed to the atmosphere. Soil screening should be conducted with an appropriate instrument (PID or FID).
3. Rough trimming of the sampling location surface should be considered if the sampling surface is not fresh or other waste, different soil strata, or vegetation may contaminate it. Surface layers can be removed using a clean stainless steel, spatula, scoop, or knife.
4. Orient the T-Handle with the T-up and the coring body down. This positions the plunger bottom flush with bottom of coring body (ensure that plunger bottom is in position). Using T-Handle, push sampler into soil until the coring body is completely full taking care not to trap air behind the sampler. When full, the small o-ring will be centered in the T-Handle viewing hole. Remove sampler from soil. Wipe excess soil from coring body exterior with a clean disposable paper towel.
5. Cap coring body while it is still on the T-Handle. ***Push*** cap over flat area of ridge ***and twist*** to lock cap in place. ***Cap must be seated to seal sampler.***
6. Remove the capped sampler by depressing locking lever on T-Handle while twisting and pulling sampler from T-Handle.
7. Lock plunger by rotating extended plunger rod fully counterclockwise until wings rest firmly against tabs.
8. Fill the 125-mL wide mouth jar for the non-preserved portion of the sample to be used for a moisture determination. These may be in a cardboard box. Retain all packaging to return the samples.
9. The disposable sampler should collect approximately 5 grams of soil (not necessary to weigh in the field). After a sample has been collected and capped, tear off the identification tag found at the bottom of the label on the aluminized bag. This tag is added to the sampler on the cap used to seal the sampler.

10. Place the sampler back in the aluminized bag and seal the top (a zip-lock seal). Make sure all the appropriate information is on the label. Record the sampler ID number on the chain-of-custody. Make sure each sampler and 125-mL container is labeled with the same location identification. The sampler should be placed inside the plastic zip-lock bags.
11. Place the 125-mL wide mouth jars in the cooler with the sampler on top. These should be sandwiched between bags of ice to maintain the correct temperature. If sent with the jars and samplers, a temperature bottle (used to evaluate the temperature on receipt) should be placed in the middle of the jars. The sample temperature should be 4ºC during shipment.
12. Ship the samples so that they will be received within 24 hours of sampling. The laboratory must receive the sampler within 40 hours of the collection so that they can be correctly preserved.

3.4 QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)

1. All data must be documented on chain-of-custody forms, field data sheets and in the field logbook.
2. An equipment blank is a QA/QC sample that will determine potential contamination from sampling equipment used to collect and transfer samples from the point of collection to the sample container. An equipment blank is performed by pouring demonstrated analyte free water from one sample container, over a sampler, and into a separate set of identical sample containers. The equipment blank is optional when sampling with the methanol preservation technique. It may be required on a site-specific basis if elevated analytical results are suspected to be due to cross contamination from sampling equipment.
3. A trip blank is a QA/QC sample, which will determine additional sources of contamination that may potentially influence the samples. The sources of the contamination may be from the laboratory, sample containers, or during shipment. The laboratory prepares a trip blank at the same time and in the same manner as the sample containers. The trip blank must accompany the sample containers to the field and back to the laboratory along with the collected samples for analysis. It must remain sealed at all times until it is analyzed at the laboratory. The frequency of collection for the trip blank must be at a rate of one per sample shipment.

3.5 LIMITATIONS IN SAMPLING

This sampling protocol will not be applicable to all solid environmental matrices, such as those that cannot be cored including non-cohesive granular material, gravel, or hard dry clay. In this case, the procedure for collecting VOC samples using Methanol Preservation should be used (see SOP 30.8).

4.0 MAINTENANCE

Not applicable.

5.0 PRECAUTIONS

None.

6.0 REFERENCES

En Novative Technologies, Inc. 2000. Users Manual for En Core® Sampler. February 2001.

USACE. 2001. *Requirements for the Preparation of Sampling and Analysis Plans.* EM 200-1-3, 1 February.

USEPA. 1997. *Test Methods for Evaluating Solid Waste, Volume IB: Laboratory Manual Physical/Chemical Methods*, Third Edition, (as updated through update IIIA). Office of Solid Waste and Emergency Response, Washington, DC.

STANDARD OPERATING PROCEDURE 40.1
MULTIPARAMETER WATER QUALITY MONITORING INSTRUMENT

1.0 SCOPE AND APPLICATION

The purpose of this standard operating procedure (SOP) is to delineate protocols for field operation with the multiparameter water quality logging system (data transmitter and visual display). This system can monitor up to eleven basic parameters, including dissolved oxygen, percent saturation, temperature, pH, specific conductance, resistivity, salinity, total dissolved solids, redox, level, and depth.

2.0 MATERIALS

- Visual display;
- Data transmitter;
- Underwater cables; and
- Field logbooks.

3.0 PROCEDURE

3.1 CALIBRATION

Calibration will be performed in the field daily before use according to manufacturer's specifications. The following parameters are calibrated to the following standards:

- Temperature—none required;
- Specific conductance—KCl or seawater standards;
- pH—pH 7 buffer plus a slope buffer;
- Dissolved oxygen—saturated air or saturated water;
- Redox—quinhydrone or transfer;
- Depth—set zero in air;
- Level—set zero in air; and
- Salinity—uses calibration for specific conductance.

3.2 OPERATION

1. Attach the cable to the transmitter.
2. Connect the other end of the cable to the display.
3. Press the On/Off key on the display panel. Allow a few seconds for the transmitter to start sending data to the display screen.
4. Calibrate the transmitter.
5. Deploy the sensor into a minimum of 4 in. of water.
6. Write data values from the display screen in the appropriate field logbook.

7. Retrieve sensor and clean the transmitter to prevent cross-contamination.
8. Move to the next sampling location. If travel time is great, turn off display by pressing On/Off key. Check condition of probes after each deployment.
9. Disconnect the transmitter when finished sampling for the day.

4.0 MAINTENANCE

Maintain according to specific manufacturer's specifications.

5.0 PRECAUTIONS

- Check condition of probes frequently between sampling; and
- Do not force pins into the connectors; note the keying sequence.

6.0 REFERENCES

Manufacturer's Handbook.

STANDARD OPERATING PROCEDURE 40.2
WATER LEVEL AND WELL-DEPTH MEASUREMENTS

1.0 SCOPE AND APPLICATION

The purpose of this standard operating procedure (SOP) is to delineate protocols for measuring water level and well depth. This procedure is applicable to the sampling of monitoring wells and must be performed before any activities that may disturb the water level, such as purging or aquifer testing.

2.0 MATERIALS

- Work Plans;
- Well construction diagrams;
- Field logbook;
- Photoionization detector (PID) or other monitoring instruments per site-specific health and safety plan;
- Decontamination equipment and supplies (SOP 80.1);
- Electric water level indicator (dipmeter) with cable measured at 0.01 ft increments;
- Oil-water interface probe (if non-aqueous phase liquid (NAPLs) are suspected to be present); and
- Plastic sheeting.

3.0 PROCEDURE

3.1 PRELIMINARY STEPS

1. Locate the well and verify its position on the site map. Record whether positive identification was obtained, including the well number and any identifying marks or codes contained on the well casing or protective casing. Gain access to the top of the well casing.
2. Locate the permanent reference mark at the top of the casing. This reference point will be scribed, notched, or otherwise noted on the top of the casing. If no such marks are present, measure to the top of the highest point of the well casing and so note this fact in field logbook. Determine from the records and record in the notebook the elevation of this point.
3. Record any observations and remarks regarding the completion characteristics and well condition, such as evidence of cracked casing or surface seals, security of the well (locked cap), and evidence of tampering.
4. Keep all equipment and supplies protected from gross contamination; use clean plastic sheeting. Keep the water level indicator probe in its protective case when not in use.

3.2 OPERATION

1. Sample the air in the well head for gross organic vapors by lifting the well cap only high enough for an organic vapor meter (PID or FID) probe to be entered into the well casing. This will indicate the presence of gross volatile contaminants as well as indicating potential sampler exposure.

2. Remove cap. Allow well to vent for 60–90 seconds. Resample headspace. Record both readings. If the second reading is lower than the first, use the second reading to determining whether respiratory protection will be required during subsequent water level and well depth determinations and sampling.
3. Note that all headspace sampling must be performed at arm's length and from the upwind side of the well if possible.
4. If NAPL contamination is suspected, use an interface probe to determine the existence and thickness of NAPLs.
   - Open the probe housing, turn the probe on, and test the alarm. Slowly lower the probe into the well until the alarm sounds. A continuous alarm indicates a NAPL, while an intermittent alarm indicates water. If a NAPL is detected, record the initial level (first alarm). Mark the spot by grasping the cable with the thumb and forefingers at the top of the casing. If a mark is present on the casing, use the mark as the reference point. If no mark is present, use the highest point on the casing as the reference point. Withdraw the cable sufficiently to record the depth.
   - Continue to slowly lower the probe until it passes into the water phase. Slowly retract the probe until the NAPL alarm sounds and record that level in the manner as described above.
   - Record the thickness of the LNAPL (see Section 3.3.1).
   - Continue to slowly lower the interface probe through the water column to check for the presence of DNAPL.
   - Measure and record the thickness of the DNAPL layer (if any) as described above.
   - Slowly raise the interface probe, recording the depth to each interface as the probe is withdrawn. If there is a discrepancy in depths, clean the probe sensors and re-check the depths.
   - NOTE: Air-liquid interface depth is more reliable if probe is lowered into liquid. NAPL-water depths are more accurate if probe is moved from water into NAPL.
   - Always lower and raise interface probe slowly to prevent undue mixing of media.
   - Always perform NAPL check in wells installed in areas with suspected NAPL contamination. Always perform NAPL check if headspace test reveals presence of volatiles. Always perform NAPL check the first time a well is sampled. If a well has been sampled previously and no NAPLs were present and none of the proceeding conditions are met, the NAPL check may be omitted.
5. If no NAPL is present, use an electronic water level detector as follows.
   - Remove the water level indicator probe from the case, turn on the sounder, and test check the battery and sensitivity scale by pushing the red button. Adjust the sensitivity scale until you can hear the buzzer.
   - Slowly lower the probe and cable into the well, allowing the cable reel to unwind. Continue lowering until the meter buzzes. Very slowly, raise and lower the probe until the point is reached where the meter just buzzes. Marking the spot by grasping the cable with the thumb and forefingers at the top of the casing. If a mark is present on the casing, use the mark as the reference point. If no mark is present, use the highest point on the casing as the reference point. Withdraw the cable and record the depth.

6. To measure the well depth, lower electric water level indicator probe or tape until slack is noted. Very slowly raise and lower the cable until the exact bottom of the well is “felt.” Measure (cable) or read the length (tape) and record the depth.
7. Note that if the electric water level indicator is used to determine depth of well, the offset distance between the tip of the probe and the electrode must be added to the reading to determine actual depth.
8. Withdraw the probe or tape.
9. Decontaminate the probe(s) and cable(s), in accordance with SOP 80.1.

3.3 DATA RECORDING AND MANIPULATION

Record the following information in the field logbook and appropriate sampling forms:

- Date and time;
- Weather;
- Method of measurement;
- Casing elevation;
- NAPL surface elevation = casing elevation - depth to NAPL;
- Apparent measured LNAPL thickness = depth to bottom of NAPL - depth to top of NAPL;
- Water level elevation = casing elevation - depth to water; and
- Well bottom elevation = casing elevation - depth to bottom (or read directly from tape).

4.0 CALIBRATION

No calibration is required. Ensure operability of electric water level indicator by testing sounder before use.

5.0 PRECAUTIONS

- Depending upon the device used, correction factors may be required for some measurements;
- Check instrument batteries before each use; and
- Exercise care not to break the seals at the top of the electric water level indicator probe.

6.0 REFERENCES

ASTM Standard D 4750-87 (2001). 2001. *Standard Test Method for Determining Subsurface Liquid Levels in a Borehole or Monitoring Well (Observation Well).*

M^{c}Alary, T. A., and Barker, J.F. 1987. “Volatilization Losses of Organics During Ground Water Sampling from Low Permeability Materials” in *Ground Water Monitoring Review.* Fall 1987.

Thornhill, Jerry T. 1989. Accuracy of Depth to Groundwater Measurements; in “EPA Superfund Ground Water Issue” EPA/540/4-89/002.

STANDARD OPERATING PROCEDURE 40.3
SLUG TESTS

1.0 PURPOSE

The purpose of this standard operating procedure (SOP) is to provide information and technical guidance for performing falling- and rising-head *in situ* hydraulic conductivity tests and data analyses. The slug test method involves causing a sudden change in head in a control well and measuring the water level response within that control well. Head change may be induced by suddenly injecting into the well or removing from the well a known quantity of water, rapid removal of a mechanical "slug" from below the water level, increasing or decreasing the air pressure in the well casing, or emplacement of a mechanical slug into the water column.

The water level response in the well is a function of the mass of water in the well and the transmissivity and coefficient of storage of the aquifer. The results of the slug test may be used to determine an estimate of the hydraulic conductivity of the aquifer material near the well.

2.0 MATERIALS

- Work Plans;
- Field logbook;
- Well construction information and boring log;
- Photoionization detector (PID) or other monitoring instruments per site-specific health and safety plan;
- Decontamination equipment and supplies (SOP 80.1);
- Aquifer test data sheets;
- Personal protective equipment and clothing (PPE) per site-specific health and safety plan; and
- Slug-inducing equipment (solid slug, line, etc.) large enough to displace groundwater beyond the well filter pack.

3.0 PROCEDURE

Initially, an appropriate test methodology should be chosen. The selection of the appropriate test method (rising or falling head) is dependent primarily on saturated screen length, the well diameter, and the estimated hydraulic conductivity. If the screen extends above the water table, a rising-head test (water removal) should be used. The performance of a falling-head test (water added) in this circumstance would overstate the hydraulic conductivity value, as the measured response would reflect the equilibration rate of previously unsaturated material; unsaturated materials would equilibrate faster than saturated materials. When the measured water level in a monitoring well is above the screened portion of the well, a falling-head test methodology should be employed. A rising-head test may also be performed, but only if the initial water level reading (after the slug is removed) is above the screened interval.

For larger diameter and deeper wells, as a general rule and particularly for high conductivity materials, it is not feasible to remove a large enough slug or water volume to cause a sufficient change in head. In these cases the falling-head test method should be used.

It is recommended that a pressure transducer be used whenever possible to record water levels and time. A pressure transducer is required to record useful data when the hydraulic conductivity is high (greater than 10^{-3} cm/sec). The standard stopwatch and water-level indicator method is adequate for lower conductivity units.

The procedures outlined below assume use of a pressure transducer. Readings should be collected at intervals set on the data logger if used. If manual readings are collected, the following intervals should be applied:

- 0 to 5 minutes, every 10 seconds;
- 5 to 10 minutes, every 30 seconds;
- 10 to 30 minutes, every 1 minute; and
- 30 to 60 minutes, every 2 minutes.

3.1 Falling-Head Tests

1. Install pressure transducer near the total well depth and permit transducer and water levels to equilibrate to ambient conditions. Secure transducer cable to prevent movement during the test. Begin transducer readings.
2. Manually measure the static water level.
3. Insert slug completely below static water level or add a water "slug."
4. Intermittently measure water level and note the time of measurement with reference to the data logger.
5. Continue monitoring until water level is within 90% of the static level.

If a solid slug was used, stop the falling-head test recording at this point and begin a rising-head test by removing the solid slug from the well. If a solid slug was not used, simply end recording by the data logger at the completion of the falling-head test.

3.2 Rising-Head Tests

1. Install pressure transducer near the total well depth and permit transducer and water levels to equilibrate to ambient conditions. Secure transducer cable to prevent movement during testing.
2. Manually measure the static water level.
3. Remove sufficient volume of water to lower the water level a minimum of 1 ft below static water level, or
4. Install the solid slug fully below water level; permit static conditions to return and then remove the solid slug.
5. Begin readings with data logger.
6. Intermittently measure water level and note time of measurement with reference to data logger.
7. Continue monitoring until the water level is within 90% of the static level.

As a check on equipment operation and in the event that test data for a particular well are not usable, the data should be printed out in the field. If there is equipment failure (e.g., a non-attainment of a 1-foot minimum head change, unexplained fluctuations in water levels, etc.), the test can be rerun with minimum time lost.

The well numbers, static and subsequent water levels, programmed test numbers, and general comments should be recorded in the field notebook.

4.0 PRECAUTIONS

Not applicable.

5.0 REFERENCES

ASTM Standard D 4043-96 (2004). *Standard Guide for Selection of Aquifer-Test Method in Determining of Hydraulic Properties of Well Techniques.*

Hvorslev, M.J. 1951. *Time-Lag and Soil Permeability in Ground Water Observations.* U.S. Army Engineers, Bulletin 36 - This method can be applied to both unconfined and confined aquifers but provides only approximate conductivity values (Freezer R.A. and J.A. Cherry, 1979, Groundwater, Prentice-Hall, Inc.).

Cooper, H.H., J.D. Bredehoeft, I.S. Papadopulos. 1967. *Response of a Finite-Diameter Well to an Instantaneous Charge of Water.* Water Resources Division, U.S. Department of the Interior Geological Survey, Vol. 3, No. 1 - This method can be applied to aquifers under confined conditions and requires that the well completely penetrate the aquifer. This method is believed to produce most reliable data when applied to low-permeability materials.

Bouwer, H. 1989. *The Bouwer and Rice Slug Test -- An Update.* Ground Water, Vol. 27, No. 3; and Bouwer, H. and R.C. Rice. 1976. *A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers with Completely or Partially Penetrating Wells.* Water Resources Research, Vol. 12, No. 3 - This method takes into account additional well and aquifer configuration data points not considered by Hvorslev's more simplistic method. Computer analyses are available.

Nguyen, V., G.F. Pinder. 1984. *Direct Calculation of Aquifer Parameters in Slug Test Analyses, Groundwater Hydraulics.* American Geophysical Union Water Resources Monograph 9 - This method can be applied to partially penetrating wells in both confined and unconfined aquifers it produces better values for low- to moderate-permeability materials.

STANDARD OPERATING PROCEDURE 50.1
SAMPLE LABELS

1.0 SCOPE AND APPLICATION

Every sample will have a sample label uniquely identifying the sampling point and analysis parameters. The purpose of this standard operating procedure (SOP) is to delineate protocols for the use of sample labels. An example label is included as Figure 50.1-A. Other formats with similar levels of detail are acceptable.

2.0 MATERIALS

- Sample label; and
- Indelible marker.

3.0 PROCEDURE

The use of preprinted sample labels is encouraged and should be requested from the analytical support laboratory during planning activities.
As each sample is collected, fill out a sample label ensuring the following information has been collected:

- Project name;
- Sample ID: enter the SWMU number and other pertinent information concerning where the sample was taken. This information should be included in site-specific work plan addenda;
- Date of sample collection;
- Time of sample collection;
- Initials of sampler(s);
- Analyses to be performed (NOTE: Due to number of analytes, details of analysis should be arranged with lab *a priori*); and
- Preservatives (water samples only).

Double-check the label information to make sure it is correct. Detach the label, remove the backing and apply the label to the sample container. Cover the label with clear tape, ensuring that the tape completely encircles the container.

4.0 MAINTENANCE

Not applicable.

5.0 PRECAUTIONS

None.

6.0 REFERENCES

USEPA. 2001 (Reissued May 2006). *EPA Requirements for Quality Assurance Project Plans.* EPA/240/B-01/003, QA/R5, Final, Office of Research and Development, Washington, D.C. March 2001

FIGURE 50.1-A
SAMPLE LABEL

PROJECT NAME ___________________________
SAMPLE ID ____________________________
DATE: ____/____/____ TIME: _____:_____
ANALYTES: VOC SVOC P/P METALS CN
PAH D/F HERBs ANIONS TPH
ALK TSS
PRESERVATIVE: [HCl] [HNO_3] [NaOH] [H_2SO_4]
SAMPLER: ____________________

STANDARD OPERATING PROCEDURE 50.2
SAMPLE PACKAGING

1.0 SCOPE AND APPLICATION

The purpose of this standard operating procedure (SOP) is to delineate protocols for the packing and shipping of samples to the laboratory for analysis.

2.0 MATERIALS

- Waterproof coolers (hard plastic or metal);
- Metal cans with friction-seal lids (e.g., paint cans);
- Chain-of-custody forms;
- Chain-of-custody seals (optional);
- Packing material;
- Sample documentation;
- Ice;
- Plastic garbage bags;
- Clear Tape;
- Zip-top plastic bags; and
- Temperature blanks provided by laboratory for each shipment.

3.0 PROCEDURE

1. Check cap tightness and verify that clear tape covers label and encircles container.
2. Wrap sample container in bubble wrap or closed cell foam sheets. Samples may be enclosed in a secondary container consisting of a clear zip-top plastic bag. Sample containers must be positioned upright and in such a manner that they will not touch during shipment.
3. Place several layers of bubble wrap, or at least 1 in. of vermiculite on the bottom of the cooler. Line cooler with open garbage bag, place all the samples upright inside the garbage bag and tie.
4. Double bag and seal loose ice to prevent melting ice from soaking the packing material. Place the ice outside the garbage bags containing the samples.
5. Pack shipping containers with packing material (closed-cell foam, vermiculite, or bubble wrap). Place this packing material around the sample bottles or metal cans to avoid breakage during shipment.
6. A temperature blank (provided by laboratory) will be included in each shipping container to monitor the internal temperature. Samples should be cooled to 4 degrees C on ice immediately after sampling.
7. Enclose all sample documentation (i.e., Field Parameter Forms, Chain-of-Custody forms) in a waterproof plastic bag and tape the bag to the underside of the cooler lid. If more than one cooler is being used, each cooler will have its own documentation. Add the total number of shipping containers included in each shipment on the chain-of-custody form.

8. Seal the coolers with signed and dated custody seals so that if the cooler were opened, the custody seal would be broken. Place clear tape over the custody seal to prevent damage to the seal.
9. Tape the cooler shut with packing tape over the hinges and place tape over the cooler drain.
10. Ship all samples via overnight delivery on the same day they are collected if possible.

4.0 MAINTENANCE

Not applicable.

5.0 PRECAUTIONS

5.1 PERMISSIBLE PACKAGING MATERIALS

- Non-absorbent
    - Bubble wrap; and
    - Closed cell foam packing sheets.
- Absorbent
    - Vermiculite.

5.2 NON-PERMISSIBLE PACKAGING MATERIALS

- Paper;
- Wood shavings (excelsior); and
- Cornstarch “peanuts”.

6.0 REFERENCES

USEPA. 1990. *Sampler's Guide to the Contract Laboratory Program.* EPA/540/P-90/006, Directive 9240.0-06, Office of Emergency and Remedial Response, Washington, D.C., December 1990.

USEPA. 1991. *User's Guide to the Contract Laboratory Program.* EPA/540/O-91/002, Directive 9240.0-01D, Office of Emergency and Remedial Response. January 1991.

USEPA. 2001 (Reissued May 2006). *EPA Requirements for Quality Assurance Project Plans.* EPA/240/B-01/003, QA/R5, Final, Office of Research and Development, Washington, D.C. March 2001

STANDARD OPERATING PROCEDURE 70.1
INVESTIGATION-DERIVED MATERIAL

1.0 SCOPE AND APPLICATION

Management of investigation-derived material (IDM) minimizes the potential for the spread of waste material onsite or offsite through investigation activities. The purpose of this standard operating procedure (SOP) is to provide general guidelines for appropriate management of potentially contaminated materials derived from the field investigations. Specific procedures related to the transportation and disposal of hazardous waste are beyond the scope of this SOP.

2.0 INTRODUCTION

Investigation derived material (IDM) consists of waste materials that are known or suspected to be contaminated with waste substances through the actions of sample collection or personnel and equipment decontamination. These materials include decontamination solutions, disposable equipment, drill cuttings and fluids, and water from groundwater monitoring well development and purging. To the extent possible, the site manager will attempt to minimize the generation of these materials through careful design of decontamination schemes and groundwater sampling programs. Testing conducted on soil and water investigation-derived material will show if they are also hazardous wastes as defined by RCRA. This will determine the proper handling and ultimate disposal requirements.

The criteria for designating a substance as hazardous waste according to RCRA is provided in 40 CFR 261.3. If IDM meet these criteria, RCRA requirements will be followed for packaging, labeling, transporting, storing, and record keeping as described in 40 CFR 262.34. Those materials that are judged potentially to meet the criteria for a regulated solid or hazardous waste will be placed in DOT-approved 55-gallon steel drums or another type of DOT approved container; based on waste characteristics and volume.
Investigation-derived material will be appropriately placed in containers, labeled, and tested to determine disposal options in accordance with RCRA regulations and Virginia Hazardous Waste Management Regulations.

3.0 INVESTIGATION-DERIVED MATERIAL MANAGEMENT

Procedures that minimize potential for the spread of waste material include minimizing the volume of material generated, material segregation, appropriate storage, and disposal according to RCRA requirements.

3.1 WASTE MINIMIZATION

In the development of work plan addenda, each aspect of the investigation will be reviewed to identify areas where excess waste generation can be eliminated. General procedures that will eliminate waste include avoidance of unnecessary exposure of materials to hazardous material and coordination of sampling schedules to avoid repetitious purging of wells and use of sampling equipment.

3.2 WASTE SEGREGATION

Waste accumulation and management procedures to be used depend upon the type of material generated. For this reason, IDM described below are segregated into separate 55-gallon storage drums or other appropriate DOT containers. Waste materials that are known to be free of potential hazardous waste contamination (such as broken sample bottles or equipment containers and wrappings) must be collected separately for disposal to municipal systems. Large plastic garbage or “lawn and leaf” bags are useful for collecting this trash. Even "clean" sample bottles or Tyvek should be disposed of with care. Although they are not legally a problem, if they are discovered by the public they may cause concern. Therefore, items that are known to be free from contamination but are also known to represent "hazardous or toxic waste" to the public must not be disposed of in any public trash receptacle, such as found at your hotel or park.

3.2.1 Decontamination Solutions

Solutions considered investigation-derived materials range from detergents, organic solvents, and acids used to decontaminate small hand samplers to steam-cleaning rinsate used to wash drill rigs and other large equipment. These solutions are to be placed in 55-gallon drums with bolt-sealed lids or other appropriate DOT approved containers. Residual liquid IDM from decontamination pads will be removed and appropriately placed in container(s) at the end of each field day.

3.2.2 Soil Cuttings and Drilling Muds

Soil cuttings are solid to semi-solid soils generated during trenching activities or drilling for the collection of subsurface soil samples or the installation of monitoring wells. Depending on the type of drilling, drilling fluids known as "muds" may be used to remove soil cuttings. Drilling fluids flushed from the borehole must be directed into a settling section of a mud pit. This allows reuse of the decanted fluids after removal of the settled sediments. Drill cuttings, whether generated with or without drilling fluids, are to be removed with a flat-bottomed shovel and placed in 55-gallon drums with bolt-sealed lids or other appropriate DOT containers, as conditions or volume of IDM dictate.

3.2.3 Well Development and Purge Water

Well development and purge water is removed from monitoring wells to repair damage to the aquifer following well installation, obtain characteristic aquifer groundwater samples, or measure aquifer hydraulic properties. The volume of groundwater to be generated will determine the appropriate container to be used for accumulation of IDM.

For well development and purging, 55-gallon drums are typically an efficient container for accumulation. When larger volumes of water are removed from wells, such as when pumping tests are conducted, the use of large-volume portable tanks such as "Baker Tanks" should be considered for IDM accumulation.

Analytical data for groundwater samples associated with the well development and purge water will be used to assist in characterizing IDM and evaluating disposal options.

3.2.4 Personal Protective Equipment and Disposable Sampling Equipment

Personal protective equipment and clothing (PPE) may include such items as Tyvek coveralls, gloves, booties, and APR cartridges. Disposable sampling equipment may include such items as plastic sheeting, bailers, disposable filters, disposable tubing and paper towels. PPE and disposable sampling equipment that have or may have contacted contaminated media (soil, water, etc.) will be segregated and placed in 55-gallon drums separate from soil and water IDM. Disposition of this type of IDM will be determined by the results of IDM testing of the media in which the PPE and sampling equipment contacted.

3.3 MATERIAL ACCUMULATION

The IDM in containers must be placed in an appropriate designated RCRA container accumulation area at RFAAP, where it is permissible to accumulate such waste. IDM placed into a designated 90-day accumulation area will be properly sealed, labeled and covered. All drums will be placed on pallets.

A secure and controlled waste staging area will be designated by the installation prior the commencement of field sampling activities. Per the facility's requirements as a RCRA large quantity generator, waste accumulation cannot exceed 90 days for materials presumed or shown to be RCRA-designated hazardous wastes; waste which is known not to be RCRA-designated waste should be promptly disposed to municipal waste systems or appropriate facility.

3.3.1 IDM Accumulation Containers

Containers will be DOT-approved (DOT 17H 18/16GA OH unlined) open-head steel drums or other DOT approved container, as appropriate.

Container lids should lift completely off be secured by a bolt ring (for drum). Order enough containers to accumulate all streams of expected IDM including soil, PPE and disposable sampling equipment, decontamination water, purge water, etc.

Solid and liquid waste streams will not be mixed in a container. PPE and expendable sampling equipment will be segregated from other IDM and placed in different containers than soil. Containers inside containers are not permitted. PPE must be placed directly in a drum not in a plastic bag.

Pallets are often required to allow transport of filled drums to the staging area with a forklift. Normal pallets are 3×4 ft and will hold two to three 55-gallon drums depending on the filled weight. If pallets are required for drum transport or storage, field personnel are responsible for ensuring that the empty drums are placed on pallets before they are filled and that the lids are sealed on with the bolt-tighten ring after the drums are filled. Because the weight of one drum can exceed 500 lbs, under no circumstances should personnel attempt to move the drums by hand.

3.3.2 Container Labeling

Each container that is used to accumulate IDM will be appropriately labeled at the time of accumulation and assigned a unique identification number for tracking purposes. The following information will be written in permanent marker on a drum label affixed on the exterior side at a location at least two-thirds of the way up from the bottom of the drum.

- Facility name.
- Accumulation start date and completion date.
- Site identifier information (SWMU, boring, well, etc.).
- Description of IDM.
- Drum ID No.

4.0 MATERIAL CHARACTERIZATION AND DISPOSAL

IDM will be characterized and tested to determine whether it is a hazardous waste as defined by 40 CFR Part 261 and to determine what disposal options exist in accordance with RCRA regulations and the Virginia Hazardous Waste Management Regulations (VHWMR).

In general, IDM will be considered a hazardous waste if it contains a listed hazardous waste or if the IDM exhibits a characteristic of hazardous waste.

Work plan addenda will identify the appropriate characterization and testing program for IDM based on the following:

- Site-specific conditions related to chemicals of concern, etc.
- The nature and quantity of expected IDM to be generated during site-specific investigations.

- Applicable Federal, State, and local regulations, such as RCRA, VHWMR regulations and policies and procedures, and Army Regulation 200-1.
- RFAAP specific requirements and policies for IDM characterization and disposal at the time of the investigation.

In general, appropriate USEPA SW 846 Test Methods for Evaluating Solid Waste will be used for testing IDM and will be specified in work plan addenda. Other appropriate test methods may be specified by RFAAP in addition to SW 846 Methods that are specific to installation operations, the site of interest (percent explosive content, reactivity, etc.), or requirements for disposal at RFAAP water treatment facilities or publicly owned treatment works.

Responsibility for the final disposal of IDM will be determined before field activities are begun and will be described in work plan addenda. Off-site disposal of IDM will be coordinated with RFAAP (generator) to ensure appropriate disposition. The contractor will coordinate IDM transportation and disposal activities for RFAAP (generator).

At the direction of RFAAP, appropriate waste manifests will be prepared by the USACE contractor or Alliant Techsystems subcontractor for transportation and disposal. Alliant Techsystems or other appropriate RFAAP entity will be listed as the generator and an appointed representative from RFAAP will review and sign the manifest for offsite disposal.

RFAAP will make the final decision on the selection of the transporter, storage, and disposal facility (TSDFs) or recycling facility. RFAAP will provide the contractor a listing of previously used TSDFs for priority consideration. Proposed facilities that are not included on the listing are required to provide a copy of the TSDFs most recent state or federal inspection to the installation. Waste characterization and testing results will be submitted to RFAAP (generator) for review and approval before final disposition of the material.

Hazardous waste: Prior to final disposition, a hazardous waste manifest will be furnished by the TSDF to accompany transport to the disposal facility. Following final disposition, a certificate of disposal will be furnished by the disposal facility. Copies of the manifests and certificates of disposal are to be provided to RFAAP and retained on file by the contractor or subcontractor.

4.0 PRECAUTIONS

- Because the weight of one drum can exceed 500 lbs, under no circumstances should personnel attempt to move drums by hand.
- Refer to the site-specific health and safety plan when managing IDM.

5.0 REFERENCES

Safety Rules for Contractors and Subcontractors, (As Updated). Alliant Techsystems, Incorporated, Radford Army Ammunition Plant.

STANDARD OPERATING PROCEDURE 80.1
DECONTAMINATION

1.0 SCOPE AND APPLICATION

Before leaving the site, all personnel or equipment involved in intrusive sampling or having entered a hazardous waste site during intrusive sampling must be thoroughly decontaminated to prevent adverse health effects and minimize the spread of contamination. Equipment must be decontaminated between sites to preclude cross-contamination. Decontamination water will be free of contaminants as evidenced through either chemical analyses or certificates of analysis. This standard operating procedure (SOP) describes general decontamination requirements for site personnel and sampling equipment. Decontamination procedures for contaminants requiring a more stringent procedure, e.g., dioxins/furans, will be included in site-specific addenda.

2.0 MATERIALS

- Plastic sheeting, buckets or tubs, pressure sprayer, rinse bottles, and brushes;
- U.S. Army Corps of Engineers or installation approved decontamination water source;
- Deionized ultra-filtered, HPLC-grade organic free water (DIUF);
- Non-phosphate laboratory detergent;
- Nitric Acid, 0.1 Normal (N) solution;
- Pesticide-grade solvent, Methanol;
- Aluminum foil;
- Paper towels;
- Plastic garbage bags; and
- Appropriate containers for management of investigation-derived material (IDM).

3.0 PROCEDURE

3.1 SAMPLE BOTTLES

At the completion of each sampling activity the exterior surfaces of the sample bottles must be decontaminated as follows:

- Be sure that the bottle lids are on tight.
- Wipe the outside of the bottle with a paper towel to remove gross contamination.

3.2 PERSONNEL DECONTAMINATION

Review the site-specific health and safety plan for the appropriate decontamination procedures.

3.3 EQUIPMENT DECONTAMINATION

3.3.1 Drilling Rigs

Drilling rigs and associated equipment, such as augers, drill casing, rods, samplers, tools, recirculation tank, and water tank (inside and out), will be decontaminated before site entry, after over-the-road mobilization and immediately upon departure from a site after drilling a hole. Supplementary cleaning will be performed before site entry. There is a likelihood that contamination has accumulated on tires and as spatter or dust en route from one site to the next.

1. Place contaminated equipment in an enclosure designed to contain all decontamination residues (water, sludge, etc.).
2. Steam-clean equipment until all dirt, mud, grease, asphaltic, bituminous, or other encrusting coating materials (with the exception of manufacturer-applied paint) has been removed.
3. Water used will be taken from an approved source.
4. When cross-contamination from metals is a concern, rinse sampling components such as split spoons, geo-punch stems, and augers with nitric acid, 0.1N.
5. Rinse with DIUF water.
6. When semi-volatile and non-volatile organics may be present, rinse the sampling components with pesticide-grade solvent methanol.
7. Double rinse the sampling components with DIUF water.
8. Decontamination residues and fluids will be appropriately managed as IDM per work plan addenda and SOP 80.1.

3.3.2 Well Casing and Screen

Prior to use, well casing and screen materials will be decontaminated. This activity will be performed in the leak proof, decontamination pad, which will be constructed prior to commencement of the field investigation. The decontamination process will include:

- Steam cleaning with approved source water.
- Rinse with DUIF water.
- Air-dry on plastic sheeting.
- Wrap in plastic sheeting to prevent contamination during storage/transit.

3.3.3 Non Dedicated Submersible Pumps Used for Purging and Sampling

1. Scrub the exterior of the pump to remove gross (visible) contamination using appropriate brushes, approved water, and non-phosphate detergent (steam cleaning may be substituted for detergent scrub).
2. Pump an appropriate amount of laboratory detergent solution (minimum 10 gallons) to purge and clean the interior of the pump.
3. Rinse by pumping no less than 10 gallons of approved water to rinse.
4. Rinse the pump exterior with approved decontamination water.

5. When cross-contamination from metals is a concern, rinse the pump exterior with approved nitric acid 0.1N solution.
6. Rinse the pump exterior with DIUF water.
7. When semi-volatile and non-volatile organics may be present, rinse the pump exterior with pesticide-grade solvent methanol.
8. Double rinse the pump exterior with DIUF water.
9. Air-dry on aluminum foil or clean plastic sheeting.
10. Wrap pump in aluminum foil or clean plastic sheeting, or store in a clean, dedicated PVC or PTFE storage container.
11. Solutions and residuals generated from decontamination activities will be managed appropriately as IDM per work plan addenda and SOP 80.1.

3.3.4 Sample Equipment and Measuring Water Level Devices

1. Scrub the equipment to remove gross (visible) contamination using appropriate brush (es), approved water, and non-phosphate detergent.
2. Rinse with approved source water.
3. When cross-contamination from metals is a concern, rinse the sampling equipment with approved nitric acid 0.1N solution.
4. Rinse equipment with DIUF water.
5. When semi-volatile and non-volatile organics may be present, rinse the sampling equipment with pesticide-grade solvent methanol.
6. Double rinse the sampling equipment with DIUF water.
7. Air-dry on aluminum foil or clean plastic sheeting.
8. Wrap in aluminum foil, clean plastic sheeting, or zip top bag or store in a clean, dedicated PVC or PTFE storage container.
9. Solutions and residuals generated from decontamination activities will be managed appropriately as IDM per work plan addenda and SOP 80.1.

3.3.5 Other Sampling and Measurement Probes

Temperature, pH, conductivity, Redox, and dissolved oxygen probes will be decontaminated according to manufacturer's specifications. If no such specifications exist, remove gross contamination and triple-rinse probe with DIUF water.

4.0 PRECAUTIONS

- Manage IDM appropriately according to the requirements specified in work plan addenda.
- Follow appropriate procedures as specified in the site-specific health and safety plan.

5.0 REFERENCES

USACE. 2001. Requirements for the Preparation of Sampling and Analysis Plans. EM 200-1-3. 1 February.

STANDARD OPERATING PROCEDURE 90.1
PHOTOIONIZATION DETECTOR (HNu Model PI–101 and HW–101)

1.0 SCOPE AND APPLICATION

The purpose of this standard operating procedure (SOP) is to delineate protocols for field operations with a photoionization detector (HNu Systems Model PI–101 or HW–101). The photoionization detector (PID) detects total ionizables; hence it is used to monitor both organic and inorganic vapors and gases to determine relative concentrations of air contaminants. This information is used to establish level of protection and other control measures such as action levels. The PID cannot effectively detect compounds having ionization potentials above the photon energy level of the lamp used; therefore, methane, which has an ionization potential of 12.98 eV, is undetectable by PIDs because the lamps produce 9.5, 10.2, or 11.7 eV.

Use of brand names in this SOP is in not intended as an endorsement or mandate that a given brand be used. Alternate equivalent brands of detectors, sensors, meters, etc., are acceptable. If alternate equipment is to be used, the contractor shall provide applicable and comparable SOPs for its maintenance and calibration.

2.0 MATERIALS

- HNu Systems Model PI–101 or HW–101 survey probe with 9.5, 10.2, or 11.7 eV lamp;
- Lead-acid gel-cell battery;
- Calibration gas (e.g., isobutylene, 101 ppm) with regulator;
- Tygon tubing;
- Tedlar bag (optional);
- Instrument logbook; and
- Field logbook.

3.0 PROCEDURE

These procedures are to be followed when using the HNu in the field.

3.1 STARTUP

1. Before attaching the probe, check the function switch on the control panel to ensure that it is in the off position. Attach the probe by plugging it into the interface on the top of the readout module.
2. Turn the function switch to the battery check position. The needle on the meter should read within or above the green battery arc on the scale; if not, recharge the battery. If the red indicator light comes on, the battery needs recharging or service may be indicated.
3. Turn the function switch to any range setting. Listen for the hum of the fan motor. Check meter function by holding a solvent-based marker pen near the sample intake. If there is no needle deflection, look briefly into the end of the probe (no more than 1 or 2 sec) to see if the lamp is on; if it is on, it will give a purple glow. Do not stare into the probe any longer than 2 sec. Long-term exposure to UV light can damage the eyes. (See further information in Section 5.)
4. To zero the instrument, turn the function switch to the standby position and rotate the zero adjustment until the meter reads zero. A calibration gas is not needed since this is an electronic zero adjustment. If

the span adjustment setting is changed after the zero is set, the zero should be rechecked and adjusted if necessary. Allow the instrument to warm up for 3–5 min to ensure that the zero reading is stable. If necessary, readjust the zero.

3.2 OPERATIONAL CHECK

Follow the startup procedure in Section 3.1.
With the instrument set on the 0–20 range, hold a solvent-based marker near the probe tip. If the meter deflects upscale, the instrument is working.

3.3 FIELD CALIBRATION PROCEDURE

1. Follow the startup procedures in Section 3.1 and the operational check in Section 3.2.
2. Set the function switch to the range setting for the concentration of the calibration gas.
3. Attach a regulator HNu P/N 101-351 or equivalent (flow = 200 to 300 ml/min) to a disposable cylinder of isobutylene (HNu 101-351 or equivalent). Connect the regulator to the probe of the HNu with a piece of clean Tygon tubing. Turn on the valve of the regulator.
4. After 5 sec, adjust the span dial until the meter reading equals the benzene concentration of the calibration gas used, corrected to its equivalence, which should be marked on the canister (Isobutylene ~0.7X benzene).
5. Record in the field log the instrument ID No., serial No., initial and final span settings, date, time, location, concentration and type of calibration gas used, and the signature of the person who calibrated the instrument.
6. If the HNu does not function or calibrate properly, the project equipment manager is to be notified as soon as possible. Under no circumstances is work requiring monitoring with a PI–101 or HW–101 to be done with a malfunctioning instrument.

3.4 CALIBRATION TO A GAS OTHER THAN ISOBUTYLENE

The HNu may be calibrated to any certified calibration gas. However, after calibration, all subsequent instrument readings will be relative to the calibration gas used. General procedures include the following:

1. Calibrate according to procedure 3.3.
2. Partially fill and flush one-to-two times a gas bag (Tedlar recommended) with the certified National Institute of Standards and Technology (NIST) (formerly NBS) traceable calibration gas. Then fill the bag with 1–3 L of the calibration gas. If the gas is toxic, this must be done in a fume hood.
3. Feed the calibration gas into the probe with the range set for the value of the gas. After 5 sec, adjust the span control until the meter reads the value of the calibration gas.
4. Record the results of the calibration on the calibration/maintenance log and attach a new calibration sticker (if available) or correct the existing sticker to reflect the new calibration data. All subsequent readings will be relative to the new calibration gas.

3.5 OPERATION

1. Follow the startup procedure, operational check, and calibration check (refer to Section 3.1).
2. Set the function switch to the appropriate range. If the concentration of gas vapors is unknown, set the function switch to 0-20 ppm range. Adjust if necessary.

3. Prevent exposing the HNu to excessive moisture, dirt, or contaminant while monitoring the work activity as specified in the Site Health and Safety Plan.
4. When the activity is completed, or at the end of the day, carefully clean the outside of the HNu with a damp disposable towel to remove all visible dirt. Return the HNu to a secure area and place on charge. Charge after each use; the lead acid batteries cannot be ruined by over charging.
5. With the exception of the probe's inlet and exhaust, the HNu can be wrapped in clear plastic to prevent it from becoming contaminated and to prevent water from getting inside in the event of precipitation. If the instrument becomes contaminated, make sure to take necessary steps to decontaminate it. Call the Equipment Administrator if necessary; under no circumstances should an instrument be returned from the field in a contaminated condition.

4.0 MAINTENANCE

Calibration/maintenance logs are to be filled in completely whenever a PI-101 or HW-101 receives servicing. This is true of both contractor-owned and rental instruments.

The equipment manager should be called to arrange for a fresh instrument when necessary. The contractor's equipment facility is responsible for arranging all repairs that cannot be performed by the project equipment manager.

4.1 ROUTINE SERVICE

The PID's performance is affected by a number of factors. These include but are not limited to the decay of the UV lamp output over time and the accumulation of dust and other particulate material and contaminates on the lamp and in the ion chamber. Because of these factors, the PID should not be left in the field for a period of more than 2 weeks before being replaced with a fresh instrument. If a site is going to be inactive for a period of more than a week, all monitoring instruments are to be returned to the project equipment manager or his trained designee for servicing and/or reassignment. The following procedures are to be performed at the designated intervals for routine service.

Procedure	Frequency
Operational check	Before use and at instrument return
Field calibration	Before use and at instrument return
Full calibration	Bi-weekly (return instrument to equipment manager for replacement with a fresh unit)
Clean UV lamp and	Bi-weekly or as needed ion chamber
Replace UV Lamp	As needed

4.1.1 UV Lamp and Ion Chamber Cleaning

During periods of analyzer operation, dust and other foreign materials are drawn into the probe forming deposits on the surface of the UV lamp and in the ion chamber. This condition is indicated by meter readings that are low, erratic, unstable, non-repeatable, or drifting and show apparent moisture sensitivity. These deposits interfere with the ionization process and cause erroneous readings. Check for this condition regularly to ensure that the HNu is functioning properly. If the instrument is malfunctioning, call your equipment manager to arrange to have a fresh replacement.

4.1.2 Lamp eV Change

If different applications for the analyzer would require different eV lamps, separate probes, each with its own eV lamp, must be used. A single readout assembly will serve for any of the probes (9.5, 10.2, and 11.7 eV). A change in probe will require resetting of the zero control and recalibrating the instrument. The 11.7 eV lamp will detect more compounds than either of the two lower eV lamps. However, the 11.7 eV probe needs more frequent calibration; it burns out much faster than the lower eV lamps.

5.0 PRECAUTIONS

- The HNu PI–101 and HW–101 are designed to sample air or vapors only. *Do not allow any liquids or low boiling vapors to get into the probe or meter assembly.*
- High concentrations of any gas can cause erroneous readings. High humidity can also cause the instrument readings to vary significantly from the actual concentration of gases or vapors present. This is true even through the HNu cannot react to water vapor.
- High humidity, dust, and exposure to concentrations of low boiling vapors will contaminate the ion chamber, causing a steady decrease in sensitivity.
- Continued exposure to ultraviolet light generated by the light source can be harmful to eyesight. If a visual check of the UV lamp is performed *do not look at the light source from a distance closer than 6 inches with unprotected eyes.* Use eye protection (UV-blocking sunglasses or safety glasses). Only look briefly—never more than about 2 sec.
- Place the instrument on charge after each use; the lead batteries cannot be ruined by over charging.
- If at any time the instrument does not check out or calibrate properly in the field, the equipment manager is to be notified immediately and a replacement obtained for the malfunctioning instrument. Under no circumstances should fieldwork requiring continuous air monitoring for organic vapors and/or gases be done with a malfunctioning Hnu or without a HNu or an approved comparable instrument.

6.0 REFERENCES

Manufacturer’s Equipment Manual.

APPENDIX B
SITE PHOTOGRAPHS

THIS PAGE LEFT INTENTIONALLY BLANK

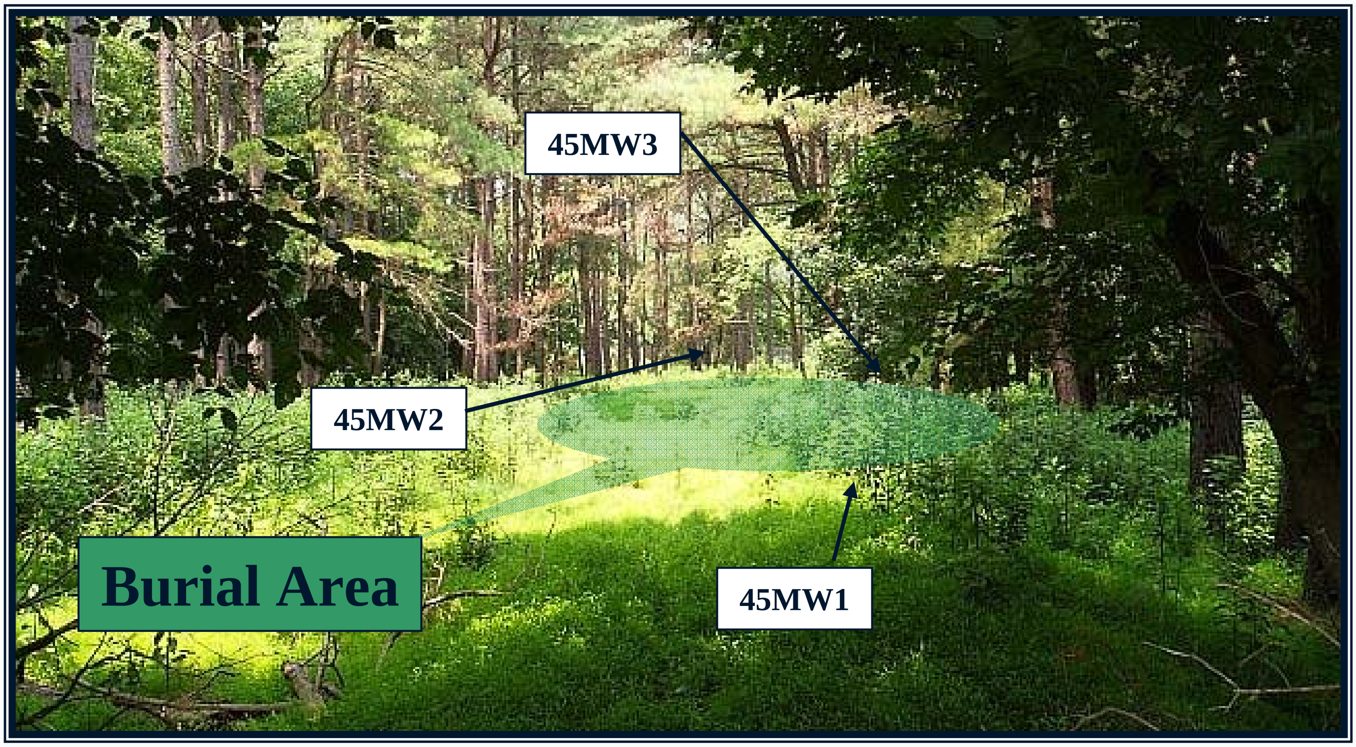


PHOTO 1: Burial area facing north-northwest toward the New River.

PHOTO 2: Burial area near 45MW2 facing south-southeast.

PHOTO 3: Burial area facing north at 45MW1

PHOTO 4: Near the site center facing north toward 45MW2 and the New River

PHOTO 5: Facing southwest parallel to the Installation perimeter fence along the New River

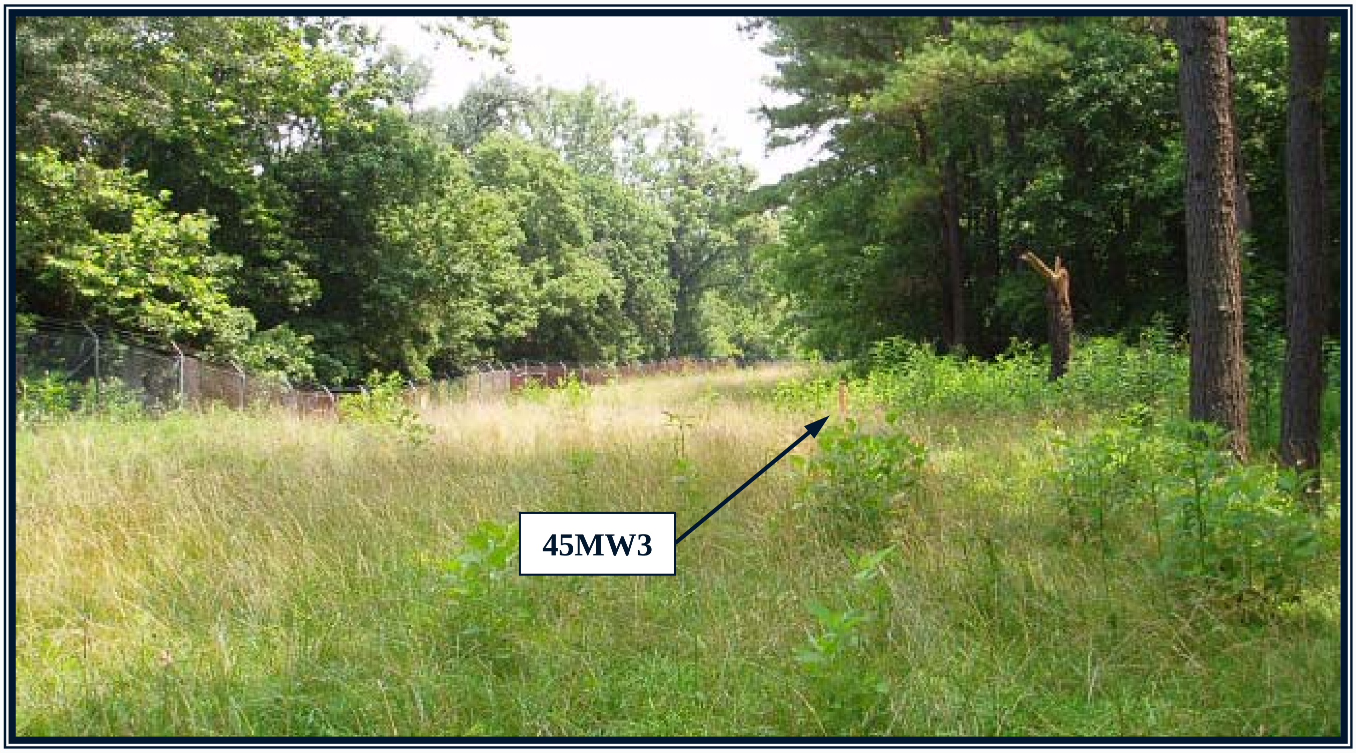


PHOTO 6: Facing northeast parallel to the Installation perimeter fence along the New River

PHOTO 7: At the Installation perimeter fence, facing north-northwest toward the New River

PHOTO 8: SWMU 45: Water-filled depression in center of presumed burial area, approximately six feet wide by 15 feet long and two feet deep

APPENDIX C

VERIFICATION INVESTIGATION BORING LOGS

BORING 45MW1

Surface Elevation: 0
Location: Radford AAP, Virginia
Start: 07:22 on 9-28-91
Finish: 12:20 on 9-28-91

Depth (Feet)	Sampling Method	Sample No.	Blows/Foot	Core Run No.	% Recovery	RQD %	Sample Interval
0	SPT	1	22		80		
5	SPT	2	16		95		
10	SPT	3	16		70		
	SPT	4	100/3		0		
15	SPT	5	103		45		
	SPT	6	21		30		
20							
25	SPT	7	0		5		
	SPT	8	12		50		
30							

Symbols	Description
SM	DARK YELLOWISH BROWN (10YR 4/6) SILTY FINE SAND, WITH CLAY, MICACEOUS, MOIST, MEDIUM DENSE, OVERLAIN BY ONE FOOT OF DARK BROWN (10YR 3/3) FINE SILTY SAND, WITH ROOT MATERIAL CLAY GRADES OUT WITH TRACE PEA GRAVELS SAND GRADES TO MEDIUM GRAVELS INCREASING
GM	DARK YELLOWISH BROWN (10YR 4/6) SILTY SANDY GRAVEL WITH COBBLES, VERY MOIST
ML	DARK YELLOWISH BROWN (10YR 3/6) VERY SOFT SILT, VERY MOIST TO SATURATED ENCOUNTERED WATER AT 22.0 FEET GRADING TO DARK GRAYISH BROWN (10YR 4/2)), WITH SAND BACOMING CLAYEY

BOREHOLE TERMINATED AT A DEPTH OF 29.0 FEET

PLATE
LOG OF BORING

Dames & Moore

FILE

BORING 45MW2

Surface Elevation: 0
Location: Radford AAP, Virginia
Start: 07:22 on 9-29-91
Finish: 08:30 on 9-29-91

Depth (Feet)	Sampling Method	Sample No.	Blows/Foot	Core Run No.	% Recovery	RQD %	Symbols	Description
0	SPT	1	21		91.6		ML	LIGHT BROWN (7.5YR 6/4) SAND WITH SILT, MICACEOUS, SLIGHTLY MOIST, STIFF, ROOTS TO 0.2 FEET
							SM	PALE BROWN (10YR 6/3) SILTY FINE SAND, MEDIUM DENSE, SLIGHTLY MOIST, MICACEOUS
5	SPT	2	14		58.3			
								GRADING BROWN (10YR 5/3) WITH MEDIUM SAND
10	SPT	3	11		91.7			WITH SOME MAGNETITE STAINS
								INCREASING MOISTURE WITH DEPTH
15	SPT	4	15		95.8			
								ENCOUNTERED WATER
								VERY LOOS SILTY SAND 20.0–20.5 FEET
20	SPT	5	0		33		GM	BROWN (10YR 5/3) SILTY GRAVEL, ROUNDED GRAVEL IS WEATHERED DOLOSTONE
25	SPT	6	75/1		25			

BOREHOLE TERMINATED AT A DEPTH OF 26.0 FEET

PLATE
LOG OF BORING

Dames & Moore

FILE

BORING 45MW3

Surface Elevation: 0
Location: Radford AAP, Virginia
Start: 10:41 on 9-29-91
Finish: 11:49 on 9-29-91

Depth (Feet)	Sampling Method	Sample No.	Blows/Foot	Core Run No.	% Recovery	RQD %	Sample Interval
0	SPT	1	18		87.5		
5	SPT	2	11		95.8		
10	SPT	3	13		91.7		
15	SPT	4	15		62.5		
20	SPT	5	31		91.7		
25	SPT	6	9		66.7		
	SPT	7	0		33.3		
30							
35							

Symbols	Description
ML	BROWN (10YR 5/3) FINE SANDY SILT, DRY, VERY STIFF, TRACE ORGANICS, FILL PENETRATED LANDFILL AT 1.0 FEET, OCCASIONAL SMALL BLACK RUBBER AND PAPER GRADING MOIST, NO PAPER BELOW 3.0 FEET
SM	VERY PALE BROWN (10YR 7/4) FINE TO MEDIUM SAND, MOIST, NATURAL UNDISTURBED SOILS, MEDIUM DENSE, MICACEOUS WITH SOME THINLY LAMINATED LENSES OF FINE BROWN SILT INCREASING MOISTURE WITH DAPTH, SOME MAGNETITE STAINS GRADING BROWN (10YR 5/3)
GM	BROWN (10YR 5/3) SILTY GRAVEL, VERY MOIST ENCOUNTERED WATER AT 22.0 FEET
SC	REDDISH BROWN (5YR 4/3) SILTY CLAY, HIGHLY PLASTIC, STICKY, SOME FINE SAND, SOME GRAY MOTTLING GRADING BROWN (10YR 5/3) VERY STIFF

BOREHOLE TERMINATED AT A DEPTH OF 30.5 FEET

PLATE
LOG OF BORING

FILE

Dames & Moore

THIS PAGE LEFT INTENTIONALLY BLANK

APPENDIX D

SWMU 45 GEOPHYSICAL INVESTIGATION

THIS PAGE LEFT INTENTIONALLY BLANK

APPENDIX D.1

GEOPHYSICAL INVESTIGATION PLAN FOR SWMU 45

THIS PAGE LEFT INTENTIONALLY BLANK

RADFORD ARMY AMMUNITION PLANT
SOLID WASTE MANAGEMENT UNIT 45 (LANDFILL #3)
GEOPHYSICAL INVESTIGATION PLAN

1.0 SITE DESCRIPTION

1.1 Site Location and Description

Solid Waste Management Unit (SWMU 45) is an inactive sanitary landfill (Landfill No. 3) located in the north-central section of the Main Manufacturing Area (MMA) at Radford Army Ammunition Plant (RFAAP), Radford, Virginia (Figure 1). The landfill was not permitted and reportedly paper and municipal refuse were only materials disposed of in the landfill. Landfill material consisting of small black rubber and paper was encountered during the installation of site monitoring well 45MW3 at a depth of 1 to 3 feet (ft) below ground surface (bgs). It was also reported that wastes were placed in trenches and burned prior to burial and evidence of burning has been observed in the area (Dames & Moore 1992). Operational plans or drawings are not available and the exact boundaries of the landfill area have not been determined. Figure 2 shows the SWMU 45 area and features including existing monitoring wells 45MW1, 45MW2, and 45MW3.

The site is located on an alluvial terrace approximately 200 ft south of the New River. Topography in the site area slopes gently toward the north and the New River from an elevation of approximately 1,708 ft mean sea level (msl) to 1,702 ft msl. A pine plantation community (loblolly pine) with nearly complete vegetative cover covers most of the site area, except for the approximately 70 ft wide area located between existing monitoring wells 45MW2 and 45MW3 and the RFAAP installation fence to the north.

1.2 Site Background and Previous Investigations

The RCRA Facility Assessment (RFA) conducted by the U.S. Environmental Protection Agency (USEPA) in 1987 identified the site as having the potential to release contaminants into the environment. The site was identified by plant personnel as a landfill but indicated the unit, “was indistinguishable from the surrounding area as a landfill site (USEPA, 1987)”. The RFA described the landfill as having operated during the 1970s but another report (USATHAMA, 1984) describes this landfill as the first known landfill at RFAAP, which purportedly operated between 1957 and 1961.

In 1992, the Environmental Photographic Interpretation Center (EPIC) under the direction of USEPA performed an assessment of multiple SWMUs at RFAAP using selected aerial photographs taken from 1937 to 1986. The study identified features representing a potential groundwater or surface water contamination sources (USEPA 1992). Aerial photography from 1949 shows a cleared area with ground scarring in the area between but just south of wells 45MW2 and 45MW3. An aerial photograph from 1962 does not show the ground scarring but shows a darker-tone and possibly disturbed area south of well 45MW2. An aerial photograph from 1971 did not show the 1949 or 1962 scarring patterns but did show a white-toned scarred area along the former access road approximately 100 ft north of 45MW1.

As part of a Resource Conservation and Recovery Act (RCRA) Verification Investigation, Dames & Moore conducted a reconnaissance-level geophysics survey using the EM-31 in conductivity mode, and a proton magnetometer. For the initial survey, measurements were collected at intervals of 10 ft along seven parallel north-south lines placed 100 ft apart. The survey covered an area of 265 by 600 ft (Figure 15-1). Additional data were collected at intervals of 10 ft from line 2+00 East to 4+00 East and at intervals of five feet from 5+80 East to 6+20 East due to anomalous features detected that warranted further investigation. Figure 15-2 shows the summary interpretation of the geophysical data included in the Dames & Moore VI Report (1992).

Monitoring wells 45MW1, 45MW2, and 45MW3 were installed and sampled as part of the VI. Alluvial deposits were encountered in the well borings to the depths explored (26 to 30.5 ft bgs), with groundwater present at depths ranging from approximately 19 to 22 ft bgs.

2.0 TASK OBJECTIVES

The objectives of the geophysical investigation at SWMU 45 are to:

- Use electromagnetic induction (EM) to delineate the horizontal extent of waste material;
- Use two-dimensional resistivity imaging (2D-ERI) to assess the vertical extent of waste material, assess the potential for leachate migration, and to confirm the horizontal extent of waste delineated by the EM survey.
- Use spectral analysis of surface waves (SASW) to confirm the resistivity interpretation of the vertical extent of waste material;
- Use 2D-ERI to assess the depth to bedrock beneath the site and if possible complete a reconnaissance-level map of the bedrock surface; and
- Use geophysical data to guide follow-up soil investigations at the site and to confirm that existing monitoring wells 45MW1, 45MW2, and 45MW3 are appropriately positioned to detect potential releases to groundwater;

3.0 GEOPHYSICS INVESTIGATION PROGRAM

3.1.1 Site Topographic Survey

A topographic survey will be conducted at the site prior to completion of the geophysical investigation. Existing site features, such as topography (one foot contour), vegetation, utilities, cultural features, monitoring wells, and the proposed geophysical grid area will be surveyed. The survey will be conducted using the North American Datum of 1983 (NAD 1983) and North American Vertical Datum of 1988 (NAVD 1988). As part of the survey, the surveyor will stake a geophysical investigation grid with 100-foot centers large enough to encompass an area beyond the estimated edges of the SWMU 45 landfill. A Commonwealth of Virginia surveyor will complete the topographic survey. A base map will be generated for the geophysical survey and follow-on investigations that is compatible with RFAAP's geographical information system (GIS).

A Trimble global positioning system (GPS) unit will be used to obtain horizontal coordinates (in NAD 1983) of various survey lines, electrode locations, etc. to allow for an overlay of geophysical data on the site topographic map. The GPS unit will have submeter accuracy for horizontal measurements (+1 part per and million) and vertical measurements (+ 2 parts per million for vertical measurements).

3.1.2 EM Survey

An EM survey will be conducted using a Geonics® EM-31 terrain conductivity meter, with the objective of assessing the horizontal extent of waste material at the site and to guide the follow-on 2D-ERI survey. The EM-31 instrument will be programmed to take measurements at one-second intervals. A global positioning unit (GPS) will be time-synchronized with the EM unit and also programmed to collect measurements at intervals of one second. EM data will collected continuously along traverses trending east to west approximately 10 feet apart. The survey data and synchronized GPS and EM data will provide earth conductivity data with spatial coordinates for subsequent contouring on the site base topographic map. Where metallic signatures are found and the terrain is conducive, a Geonics® EM-61 survey will be completed in the target area using both the upper- and lower-coil responses to estimate depth to top of targets. Identified targets will be marked and locations will be obtained with a Trimble GPS unit. Figure 2 shows the planned EM survey area, which covers an approximately 350 by 800 ft area.

EM survey procedures will be consistent with the RFAAP Master Work Plan (MWP) Standard Operating Procedure 20.7 (URS 2003) included in Appendix A of this investigation plan. This SOP also provides information on the principles and theory of EM surveys.

3.1.3 2D-ERI Survey

A 2D-ERI survey will be conducted using a Tigre® 64 resistivity system manufactured by Allied Associates, Ltd in Great Britain with the objective of assessing the vertical extent of waste material at the site, and to confirm the lateral extent of waste material. This system employs up to 64 electrodes with a maximum electrode spacing of 10 meters (33 ft). The exact locations and length of the resistivity lines will be determined from the results of infield processing of the EM survey. It is anticipated that approximately 3,000 to 4,000 linear feet of resistivity will be adequate to characterize the vertical extent of the waste material. The electrodes will be placed at 5-meter (16 ft) intervals and marked with a stake flag with a unique identifier for future reference. The locations of resistivity lines and electrode points will be obtained using a Trimble GPS unit.

2D-ERI survey procedures will be consistent with the RFAAP MWP SOP 20.7 included in Appendix A of this investigation plan. This SOP also provides information on the principles and theory of resistivity.

3.1.4 SASW Profiles

The SASW method uses the propagation of an elastic wave through the ground, usually induced by a blow from a hammer or drop-weight. Two types of waves are generated by such a blow; body waves and surface waves. Approximately two-thirds of the impact energy propagates away from the source in a type of surface wave called the Rayleigh wave. Rayleigh waves travel at speeds governed by the stiffness-depth profile of the earth materials.

In a homogeneous and isotropic material, the speed of a Rayleigh wave will be independent of its wavelength. However, if there is a variation in stiffness or density with depth, then the speed of the Rayleigh wave will be dependent on its wavelength. Low-frequency (long wavelength) Rayleigh waves will extend deeper into the earth materials than high-frequency (short wavelength) waves (Matthews et al., 1996). This behavior is described as “dispersive” in seismological terms, and a curve of velocity versus wavelength (or depth) is called a dispersion curve.

The SASW equipment that will be used for this investigation consists of 2 geophones, a computer control box, and a seismic source. The geophones measure the ground movement associated with the Rayleigh wave as it travels from one geophone to the next. The shallow subsurface is sampled using closely spaced geophones. Increasing the distance between the geophones increases the vertical depth of investigation at the center of the spread, which is ultimately limited by the amount of source energy required to produce a wave in the deeper earth material.

From the raw ground motion data, the dispersion curve of wavelength versus phase velocity is derived. The dispersion curve of the observed shear wave velocity vs. wavelength is used as the input data to the SASW inversion modeling routine. The inversion modeling routine fits the measured data to an earth model that represent the actual shear wave velocities versus depth in the profile. The inversion modeling iteratively calculates a dispersion curve from the earth model for comparison to the observed dispersion curve. If for any iteration the match between the observed and calculated dispersion curves is not satisfactory, another iteration is conducted until a close match is obtained. When a close match is obtained between the observed and calculated dispersion curves, the earth model can be accepted as a reasonable approximation of shear wave velocity versus depth. Details of the inversion modeling can be found in Gucunski and Woods (1991) and Joh (1996).

If landfill leachate is present beneath the landfill materials, the resistivity results may suggest a deeper extent of fill than actually occurs. The SASW will be used to confirm the resistivity interpretation by providing a vertical dispersion curve of the phase velocities of the materials. The natural materials will likely transmit seismic waves at a higher velocity than the landfill materials, and this vertical change in velocity will be used to confirm the resistivity interpretation.

SASW will be used at three to five points within the landfill to confirm the resistivity interpretation of the vertical extent of landfill materials. Each SASW point will be marked with a stake flag with a unique identifier for future reference. The locations of the stakes will be obtained using a Trimble GPS unit.

3.2 Reporting

A geophysical investigation report will be prepared that at minimum includes the following:

- Discussion of the principles of EM;
- Description of the field investigation program, methods and equipment used;
- Location of EM survey lines plotted on the topographic survey plan;
- Results of the EM survey including contours of EM for both the quadrature and in-phase components on the topographic survey plan, and interpreted lateral extent of waste material;
- Discussion of the principles of resistivity;
- Description of the field investigation program, methods, and equipment used;
- Locations of resistivity lines plotted on the topographic survey plan;
- Results of investigation including the presentation of resistivity results as color contoured cross-sections with the interpreted vertical extent of waste material delineated on the cross-sections and contour map of interpreted thickness of waste material; and
- Uncertainties and conclusions.

The geophysical investigation report will be included as an appendix in the Work Plan Addendum (WPA) for the SWMU 45 RFI. The results and interpretations presented will be incorporated into the work plan and used to design the soil investigation program for the RFI and to confirm that the existing three monitoring wells at SWMU 45 are appropriately located to evaluate releases to groundwater from the waste area.

4.0 REFERENCES

Dames and Moore (D&M). 1991. *Draft RCRA Verification Investigation for Radford Army Ammunition Plant.* Prepared for the U.S. Army Toxic and Hazardous Materials Agency.

Gucunski, N. and R. D. Woods. 1991. Inversion of Rayleigh wave dispersion curve for SASW test. *Proceedings of the 5th International Conference on Soil Dynamics and Earthquake Engineering*, 127-138.

Joh, S. J. 1996. Advances in Interpretation and Analysis Techniques for Spectral-Analysis-of-Surface-Waves (SASW) Measurements. Unpublished PhD dissertation, University of Texas at Austin.

Matthews, M. C., Hope, V. S., and R. I. Clayton. 1996. The use of surface waves in the determination of ground stiffness profiles. *Proceedings of the Institution of Civil Engineers in Geotechnical Engineering, Vol. 119, April*, 84-95.

URS Group (URS), 2003. *Radford Army Ammunition Plant, Master Work Plan.*. August.

U.S. Environmental Protection Agency (USEPA). 1987. *RCRA Facility Assessment for Radford Army Ammunition Plant, Radford, Virginia.* VAD-21-002-0730.

U.S. Enviroinmental Protection Agency (USEPA). 1992. *Installation Assessment, Radford Army Ammunition Plant, Radford, Virginia.* Environmental Photographic Interpretation Center.

RADFORD ARMY AMMUNITION PLANT
SOLID WASTE MANAGEMENT UNIT 45 (LANDFILL #3)
GEOPHYSICAL INVESTIGATION PLAN

FIGURES

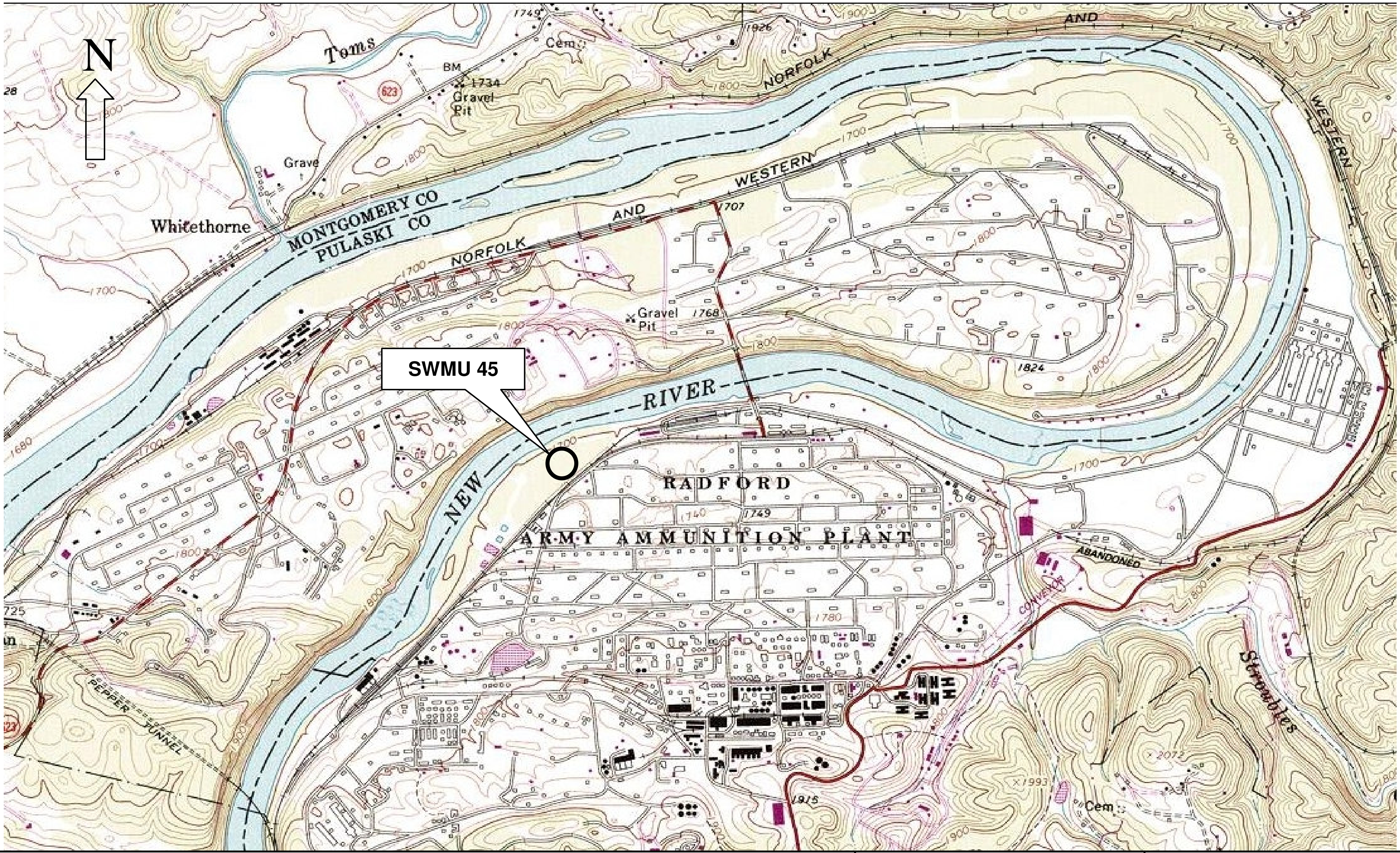


FIGURE 1

Site Location Map

Date:
February 2006

URS Project #:
11656351

Prepared by:
DBC

Approved by:
JOS

Scale:
1" = 2000'

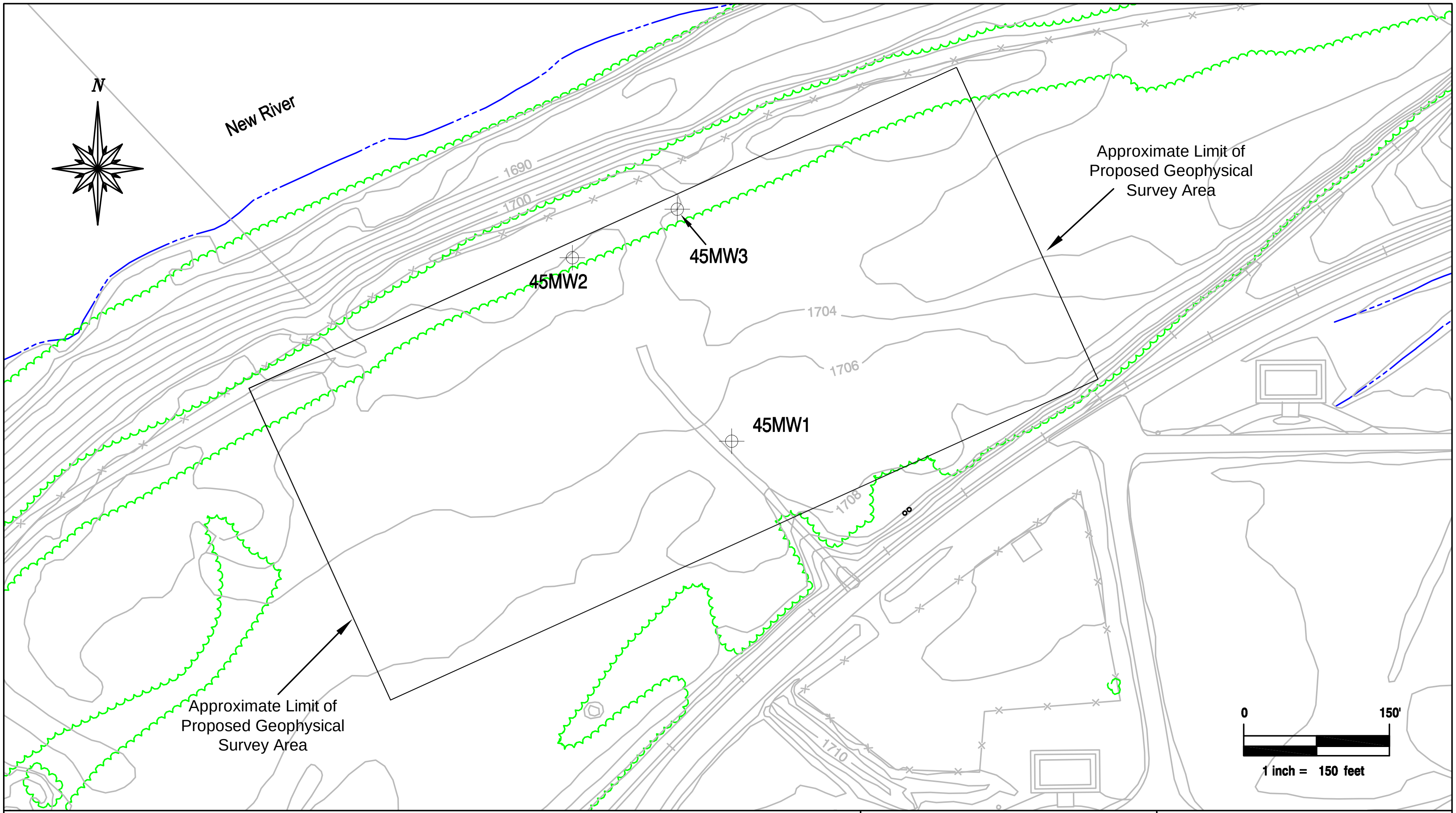
File Name:
Figure 1 Site Loc

SWMU 45

RCRA Facility Investigation
Radford Army Ammunition Plant
Radford, Virginia

URS

URS Group, Inc.
540 Falmouth Street
Suite 201
Richmond, Virginia 23230



Legend

⌖ Monitoring Well Location

— Approximate Limit of Proposed Geophysical Survey Area

— Topographic Contour

FIGURE 2

Site Layout with Monitoring Wells and Proposed Geophysical Survey Area

Date: February 2006	URS Project #: 11656351
Prepared by: DBC	Approved by: JOS
Scale: 1" = 150'	File Name: Fig. 2

SWMU 45

RCRA Facility Investigation
Radford Army Ammunition Plant
Radford, Virginia

URS Group, Inc.
5540 Falmouth Street
Suite 201
Richmond, Virginia 23230

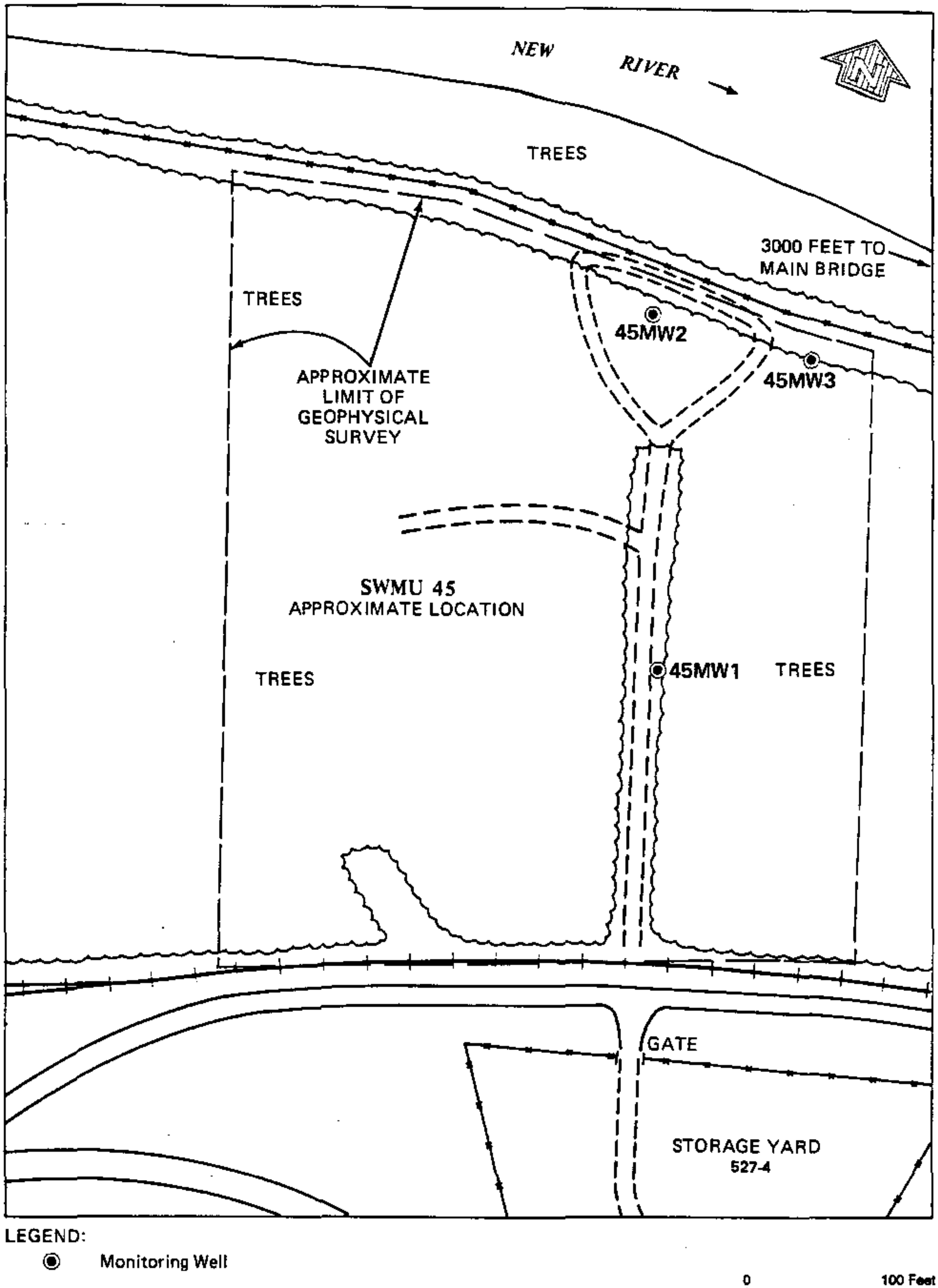
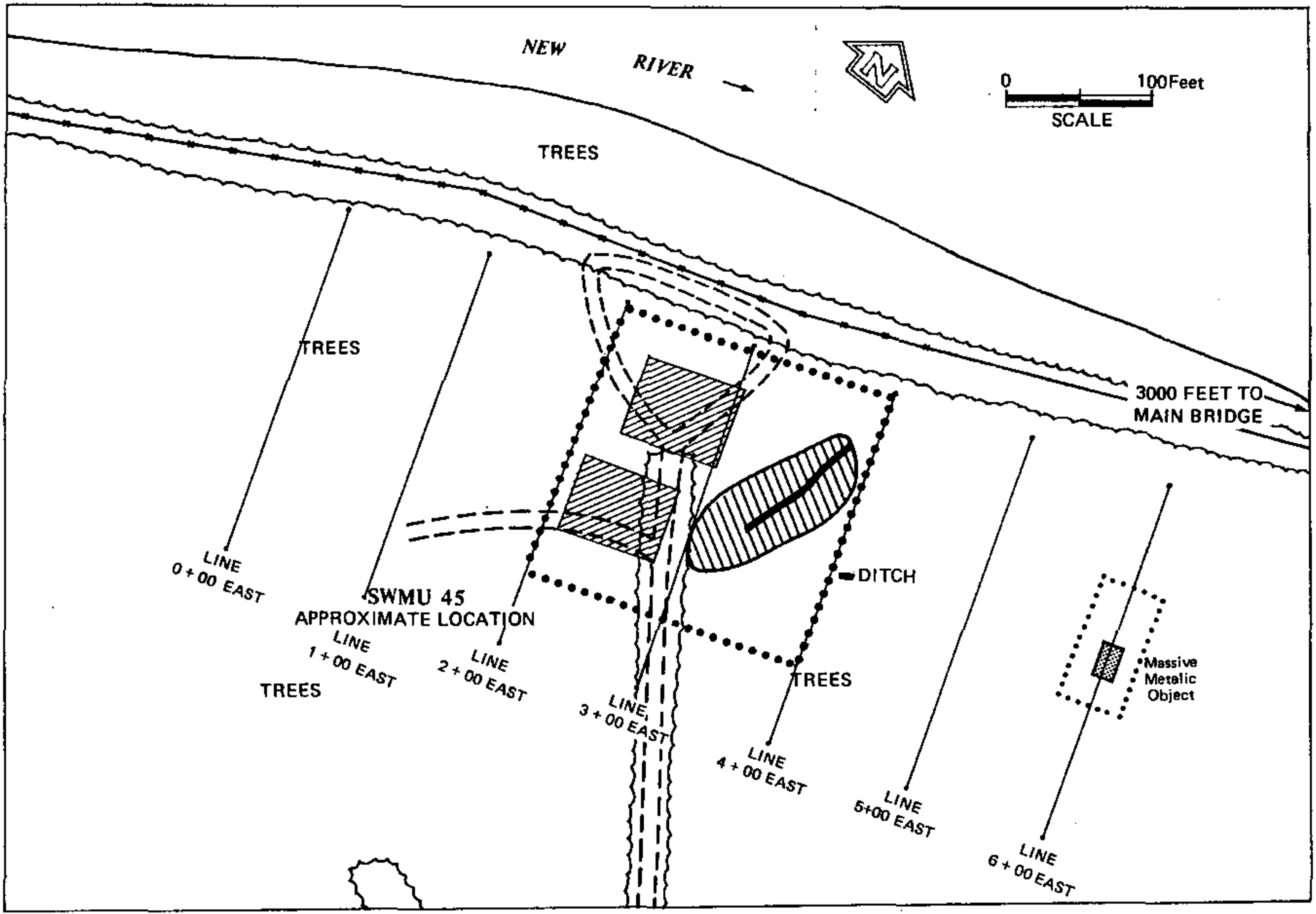


FIGURE 15-1
LOCATION MAP
SWMU 45 – SANITARY LANDFILL
(WEST OF MAIN BRIDGE)
RADFORD ARMY AMMUNITION PLANT, VIRGINIA

Dames & Moore



LEGEND:

▧ NON-METALLIC BURIAL – AREA B

▨ METAL BURIAL – AREA A

━ DITCH

FIGURE 15-2
GEOPHYSICAL SURVEY RESULTS
SWMU 45 – SANITARY LANDFILL
(WEST OF MAIN BRIDGE)
RADFORD ARMY AMMUNITION PLANT, VIRGINIA

Dames & Moore

RADFORD ARMY AMMUNITION PLAN
SOLID WASTE MANAGEMENT UNIT 45 (LANDFILL #3)
GEOPHYSICAL INVESTIGATION PLAN

APPENDIX A

STANDARD OPERATING PROCEDURE 20.7

RESISTIVITY AND ELECTROMAGNETIC INDUCTION SURVEYS

STANDARD OPERATING PROCEDURE 20.7
RESISTIVITY AND ELECTROMAGNETIC INDUCTION SURVEYS

1.0 PURPOSE

The purpose of this standard operating procedure (SOP) is to provide a general description and technical management guidance on the use of Resistivity and Electromagnetic Induction (Terrain Conductivity) Surveys.

2.0 MATERIALS

- Work Plans;
- Field Logbook;
- Site maps;
- Electromagnetic induction unit; and
- Personal protective equipment and clothing (PPE) per the site-specific health and safety plan.

3.0 PROCEDURE

3.1 Description of Methods

3.1.1 Theory and Principles of Operations

Resistivity. A resistivity survey measures the electrical resistivity of a geohydrologic section indirectly. A DC or low-frequency AC electrical current is injected into the ground through electrodes embedded in the ground surface. The flow of current within the subsurface produces an electric field with lines of equal potential perpendicular to the current flow. This potential field (voltage) is measured between a second pair of electrodes also embedded in the ground surface.

The actual resistivity is a complex function of the applied current, observed voltage, and the characteristics of the subsurface section that provide multiple current flow paths. The apparent subsurface resistivity can be calculated as a function of the applied current, the measured voltage, the separation of the electrodes, and the geometry of the current and potential electrode pairs. For the simplest electrode configuration in which all four electrodes are equally spaced in the order current-potential-current (i.e., the Wenner array) the apparent resistivity is given by the following equation:

$$a = \frac{2\pi AV}{I}$$

Where:

a = apparent resistivity in ohm-meters or ohm-feet,

V = the measured potential difference in volts, and

I = the applied current in amperes.

The calculations are similar for other electrode configurations except geometric factors other than 2 are used. Equipment operating manuals provide nomographs for determination of apparent resistivity from field measurements for all standard electrode configurations. These calculations are simple and can be performed on a hand-held calculator.

Of the many possible geometric configurations of current and potential electrodes, some of the most commonly used arrays are as follows:

- Linear array with electrodes in the order current-potential-potential-current. A Wenner array results if the spacing between each successive pair of electrodes is equal. For a Schlumberger array, the distance between the two potential electrodes is a small fraction of the distance between the two current electrodes; and
- Linear array with electrodes in the order current-current-potential-potential. In this dipole-dipole configuration, the separation of the two current and the two potential electrodes is equal, with an equal or greater separation of the two dipole pairs.

Resistivity surveys may be conducted to determine either vertical or horizontal electrical anomalies. Vertical electrical soundings (VES) are made by symmetrically expanding a Wenner or Schlumberger array in line about a point, i.e., the electrode spacing is increased for successive readings. Measurements of potential and input current are made for each set of electrode spacings, and the apparent resistivity is calculated as described below. The resultant plot of spacing versus apparent resistivity is interpreted to yield the resistivity distribution with depth beneath the midpoint between the potential electrodes. However, the resistivity being measured is that of the materials beneath the entire array.

For horizontal profiling, apparent resistivity from a series of measurements is plotted as a function of the X+Y coordinates of the site. One or more of the following procedures accomplishes horizontal profiling:

- A series of VES profiles at several locations are compared;
- Measurements are made with fixed-electrode spacing along a line or over an area; and/or
- Dipole-dipole measurements are made with the current or potential dipole at a fixed location and the other dipole located at increasing distances along a line. This process provides a resistivity "cross-section" beneath the line.

The Wenner and Schlumberger configurations are most often used for vertical investigation, whereas the dipole-dipole configuration is most often used for lateral surveys.

Electromagnetic Induction (EM). In the Electromagnetic Induction (EM) method, the electrical conductivity of a geohydrologic section is measured by transmitting a high-frequency electromagnetic field into the earth, producing eddy currents that generate secondary electromagnetic fields that can be detected by a receiver. The eddy currents are induced in the earth by an aboveground transmitter coil, and the resulting secondary electromagnetic fields are coupled to an aboveground receiver coil. Thus, EM measurements do not require direct ground contact, as is the case for resistivity measurements, and surveys across a line or area may be performed quite rapidly.

EM instruments are calibrated to read subsurface conductivity directly in units of millimhos per meter,

Where:

1,000 milliohm per meter = $\frac{1}{\text{ohm-meter}}$

This relation indicates that the conductivity obtained from EM measurements varies inversely with the resistivity measured using a resistivity survey. However, because the subsurface sections associated with the two methods are generally of different depth or cross-sectional area, there is not an exactly inverse relationship between conductivity and resistivity surveys.

The conductivity value obtained by an EM instrument depends on the combined effects of the number of soil and rock layers, their thicknesses, and depths, and the inherent conductivities of the materials. The quantity actually measured is an apparent conductivity of the earth volume between the ground surface and an effective penetration depth, which is defined as the depth at which variations in conductivity no longer have a significant effect on the measurement. The sampling depth is related to the spacing between the transmitter and receiver coils of the instrument, approximately as follows:

Sampling depth = 1.5 (coil spacing) (Vertical Dipole)
= 0.75 (coil spacing) (Horizontal Dipole)

Vertical profiling can be accomplished by multiple measurements about a point, with varying coil spacings. Horizontal profiling is performed by making measurements along traverses with fixed coil spacing.

3.1.2 Application

The measurement of a subsurface resistivity or conductivity at a hazardous waste site provides a valuable contribution to site characterization for the following reasons:

- Conductivity (resistivity) is a function of the geohydrologic section and is overwhelmingly influenced by the presence of water. Therefore, conductivity (resistivity) can provide indirect evidence on the porosity and permeability of subsurface materials and the degree of saturation. These parameters, in turn, are directly related to subsurface lithology, and to the potential for infiltration/migration of contaminants from a source area.
- Conductivity (resistivity) is influenced by the presence of dissolved electrolytes in soil or rock pore fluids. Contaminant plumes in the vadose (unsaturated) and saturated zones can be mapped if there is sufficient change in conductivity to be detected by EM or resistivity measurements.
- In general, contaminant plumes of inorganic wastes are most easily detected because conductivity may be increased by 1 to 3 orders of magnitude above background values. The limit of detection is a change from a background of 10%–20%. Plumes of non-polar organic constituents from spills or leaking containers may be detected if sufficient soil moisture has been displaced to affect the ground conductivity to a measurable degree.
- Conductivity (resistivity) can be used to detect the presence of buried wastes if the degree of saturation, containerization, or inherent electrical properties of the wastes produces sufficient variation from the soil matrix. The degree of detail provided by typical surveys cannot distinguish the size, shape, or mass of sources except in a qualitative manner.

For these reasons, resistivity and conductivity surveys should be investigated as potentially appropriate site characterization tools when any of the following information is desirable:

- Detection and mapping of contaminant plumes; the rate of plume movement may also be deduced from measurements made over time;
- Estimates of depth, thickness, and resistivity of subsurface layers, depth to the water table, or probable geologic composition of a layer;
- Detection, mapping, and depths of burial pits, landfills, clay caps or lenses, or deposits of buried waste;
- Determination of locations for drilling to intercept contamination or to investigate aquifer properties; and
- Corroboration of limited chemical and geohydrologic data at a site.

In general, surface geophysical measurements alone cannot provide a complete assessment of subsurface conditions, when appropriately integrated with other investigative information from subsurface borings, borehole geophysics, etc., surface geophysical surveys can be an effective, accurate, and cost effective method of obtaining subsurface information. Geophysics at Radford Army Ammunition Plant will, where coverage permits, integrate surface and down hole methods to develop more accurate and refined interpretations of subsurface conditions that possible with either type of method alone.

3.1.3 Instrumentation

Resistivity. The basic components of a field resistivity system are two current and two potential electrodes, electrical cables, centralized power unit (current source), and resistivity meter. Automated instrumentation is commonly used to conduct two or three-dimensional surveys. One such system is the Advanced Geosciences, Inc. (AGI) Sting/Swift system, which includes a central power unit, resistivity meter (Sting), control unit (Swift), and switched electrode cables for use with up to 254 electrodes. This AGI allows for automated measurements, complete control of the measurement array, programmable measurement cycles, large capacity storage of data with linkup to a personal computer. The Sting/Swift system allows for rapid collection of resistivity data and testing of arrays. Measurement ranges for the Sting/Swift system are 0.1 milliohm to 400kohms (resistance) and 0 to 500 volts full-scale auto ranging (volts).

Electromagnetic Induction (EM). Generally EM instruments are available in two forms:

- Single-piece models operable by one person, with a fixed coil spacing 12 feet; these provide sampling depths on the order of 10 and 20 feet. The Geonics EM31DL is one example of this type of instrument.
- Dual-coil models, operable by two persons, with variable coil spacing up to about 40 feet (sampling depth up to about 60 feet). The Geonics EM 34-3XL is an example of this type of instrument.

The 12-foot fixed coil and the dual coil apparatus are most commonly used in hazardous waste site investigations. In either case, an additional person to record data and identify measurement locations is highly desirable and more time efficient. The instruments are calibrated to read directly in conductivity units, and values are typically read and recorded on a data sheet. Some units have been modified to provide direct digital recording on magnetic tape.

3.2 Data Acquisition

3.2.1 Field Procedures

Initial Operations. As with most geophysical surveys, conductivity or resistivity surveys involve the following initial steps:

Planning. Known or assumed geohydrologic features of the site, potential source locations and migration characteristics of hazardous constituents, are used to select specific techniques and equipment to establish appropriate locations and depths for geophysical measurements (see Section 5.1.2). The level of detail necessary (data quality objectives) determines the amount of effort and, in simple terms, the required number, and density of data points. As a minimum, the data quality will depend on the method and specific equipment selected and the supporting hardware and software capabilities.

An “expert” system known as the Geophysics Advisor Expert System, developed by the Environmental Monitoring Systems Laboratory (EMSL) in Las Vegas, may be used as a planning tool to assist in selecting an appropriate geophysical method. This system prompts the user through a series of site-specific questions that will eventually rank various geophysical methods as to their feasibility at a specific site.

Most of the details can be planned before site activities; however, some leeway must be accorded to the field procedures to account for variable site conditions and weather.

Site Layout. One of the most labor-intensive and time-consuming aspects of the fieldwork involves layout of grids and surveying or careful measurement of locations to allow geophysical surveys to be accomplished in a systematic, documentable manner. Location coordinates of sufficient resolution to accomplish the objectives of the survey must uniquely identify every data point.

Array and Spacing Tests. Select one area or line that typifies the site. Test different array types and spacing. Analyze the data to see if the results match induction or normal resistivity and drilling logs from nearby wells. Select the optimal array type and spacing configuration, and proceed with the survey. If induction or normal resistivity logs are not available for wells at or near the site, log these wells before executing the surface surveys.

Resistivity Measurements. Resistivity electrodes must be installed in the proper array and spacing at a particular site grid location (according to specific manufacturers directions). The cables connecting the electrodes to the current source and potentiometer are then attached, and the current flow is initiated. Voltage is measured directly on the potentiometer. The process is repeated at the next site grid location (for horizontal profiling) or with the next electrode spacing (for vertical electric soundings) as necessary for QC purposes.

General rules for electrode spacings are difficult to specify because of site-specific variation; depending on the site geohydrology and source characteristics. As a general rule of thumb, the maximum electrode spacing should be at least three to five times that of the maximum target depth.

Electromagnetic Induction Measurements. At a given site grid location, the specified orientation of the apparatus is established, i.e., with the axis of the coils either parallel or perpendicular to the direction of the survey line. The meter reading is recorded and the apparatus is moved to the next site grid location.

For the dual-coil method, both the intercoil spacing and coplanarity of the coils must be established before recording the data. Surveys are normally conducted with the coil axes horizontal and at right angles to the survey direction.

EM profiles can be accomplished in a continuous manner using vehicle-mounted equipment in conjunction with strip charts, magnetic tape recorders, or digital recorders. Location information must be appended by tic marks or voice-over and some means provided to reference written field logs in a consistent manner.

3.2.2 Data Format

General. Information obtained during a resistivity or EM survey should be presented according to a standard data format, using standardized data sheets with original field entries. As a minimum, the heading for each data sheet should contain the following information:

- Project, task, site, and location identification;
- Company or organization;
- Date (and time, if applicable);
- Operator's name and signature;
- Method/technique identification;
- Instrument make, model, serial number, and calibration date/frequency (if applicable);
- Test location (according to the survey plan);
- Electrode or coil type and configuration;
- Line or site grid location(s);

- Weather and site conditions and temperatures;
- Identity of relevant calibration and QC data; and
- Records of data for each sounding or profile on a single sheet, if possible;

Resistivity. Survey data should include, in a tabular format, the following information:

- Electrode location, per the survey plan;
- Electrode spacing, in feet or meters;
- Input current applied, in amperes; and
- Measured potential, in volts.

Electromagnetic Induction. Survey data should include, in a tabular format, the following information:

- Coil location, per the survey plan;
- Coil spacing;
- Coil configuration (unless specified in the heading); and
- Meter reading, in millimhos per meter.

Special precautions to systematize and preserve data will be required for data that are recorded continuously on strip charts, magnetic tape recorders, or digital recorders. Strip charts should be permanently affixed to the field logbook. The first original hard copy of output from magnetic tape should be treated similarly. Identifying header information must be recorded directly on the tape.

3.3 Data Interpretation

3.3.1 Resistivity Data

For each data point, the apparent resistivity is calculated according to the formula appropriate for the type of electrode array employed. For horizontal profiling, curves of apparent resistivity versus distance along a line defined by the site grid locations are plotted. These curves of lateral changes in resistivity at a given electrode spacing (therefore, at a given survey depth) provide a cross-section for interpretation of the anomalous subsurface features. Multiple parallel profile lines can be combined to produce an area map of apparent resistivity at a particular depth.

For vertical electrical soundings, the series of apparent resistivities are plotted versus corresponding electrode spacing on log-log graph paper. The curves can be compared qualitatively with known or suspected subsurface conditions or with idealized layer-models to determine layer thicknesses and depths. Computer processing is typically applied for analysis of complex data sets and inverse layer modeling.

3.3.2 Electromagnetic Induction Data

Corrections may be applied to EM data for accuracy and drift, variation in location from pre-established coordinates, topography, changes in scale, and non-linearities associated with high conductivity values. In all cases, such corrections must be fully supported by data originally recorded or annotated in the field. Profile data along traverses are obtained as plots of conductivity versus distance. As with resistivity profiling, parallel traverse data may be combined to provide conductivity contour maps of a site. Two or more profiles at different sampling depths, as well as sounding data at a given location, provide information on the relative conductivities of shallow and deeper layers. Contour plots may provide valuable information on the extent and direction of groundwater flow and contaminant transport.

Detailed comparison of EM sounding measurements with layer models of the site can be made. This type of interpretation has been used at sites with relatively simple, uniform geohydrology to determine overburden and bedrock spatial and depth relationships. In some cases, very detailed interpretations, including aquifer flow properties, location of permeable zones, and interaquifer transfer, are possible.

3.4 Potential Problems

Resistivity and EM surveys are geophysical methods that, although standardized and frequently applied, are subject to a wide variety of problems. Problems can be expected to arise in the following areas:

Planning and Execution. Rarely is a survey accomplished exactly according to the original plan. Site features not previously specified and myriad other variations can occur that force changes in the details of the approach. However, the data quality objectives of the survey, the general methodology, the amount of data required, and the degree of data interpretation requested should remain unchanged. Project work scopes should be written with some degree of latitude to allow a change in plans whenever justified.

Noise and Interferences. Measurements can be affected severely both by natural and man-made sources of electrical and electromagnetic noise. Nearby power lines, stray ground currents, and atmospheric discharges adversely affect both types of surveys. Large masses of buried metal, fences, railroad tracks and underground pipes or cables can strongly distort measurements and reduce instrument sensitivity to features of interest. These problems generally can be accounted for or overcome but must be recognized early in the survey so that appropriate avoidance measures can be implemented. Known or suspected sources of interference should be included in the initial planning for a project.

Weather Conditions. It is possible to conduct the surveys under almost any conditions that permit traverse of the site. However, snow cover, standing water, heavy rainfall, or thoroughly saturated surface soils may severely restrict the ability to meet project objectives and schedules. Scheduling contingencies should be included whenever possible, especially during periods when inclement weather is expected.

Technical Difficulties. Preventable difficulties include equipment malfunction or misapplication, poor operator training, and lack of applications experience. Other difficulties may arise because the geophysical response of the site is not as initially conceptualized. Early recognition and response by technical management can minimize the effect and severity of any problems. Interim, real-time scrutiny of the data by the site geophysicist is essential. The geophysicist must be responsive regarding equipment replacement, repair, or changes in personnel. The site manager and the site geologist should be cognizant of technical difficulties beyond the control of the field personnel and should recognize the need to change plans, field personnel, or cancel a survey, as appropriate.

Topographic Changes. Significant changes in topography should be addressed when planning and making measurements.

3.5 Quality Control

3.5.1 General

Geophysical surveys, including resistivity and conductivity surveys, are subject to misapplication, erroneous interpretations, and use of incomplete or inadequate data. All of these avoidable errors can severely affect both the cost of subsequent site investigations and the validity of the site characterization. This susceptibility to misuse and potential for negative effect demands an assurance that appropriate quality control measures have been implemented. Quality control aspects common to most types of geophysical field programs are as follows:

- Integrating surface-based results (indirect measurements) with well sampling results, drilling logs, and down hole (direct measurement) geophysical logs;

- Program management personnel with technical expertise in preparing statements of work; reviewing proposals, work plans, and reports; and supervising technical subcontracts and field-related programs;
- Insistence on a defined scope of work, clear specifications, and data validation procedures;
- Appropriate justification before rejection of data points from a data set. Field data sheets should contain all observed data and the conditions that could affect data validity;
- Field data should be recorded in permanent ink in a bound logbook with each page signed and dated by the operator. Original unaltered logbooks should be retained in the site file;
- Complete and clear understanding of manufacturer's operation manual for the particular apparatus being used;
- Properly calibrated instrument provides an added measure of data validity and permits correlation and comparison of the associated data with site features and geohydrologic characteristics not evident at the time of the field effort. Some geophysical survey objectives can be met by relative measurements across an area or with depth; and
- An evaluation should be made of noise, interferences, and obstructions at a site. Such measurements, inferences, and explanations should be recorded in the field. These real-time quality control procedures aid field personnel in correction of noise sources over which they have control, in validating suspected external sources, and in early detection of problems that may jeopardize the survey objectives.

3.5.2 Resistivity Surveys

The resistivity apparatus consists of a current source and potentiometer, both of which must be calibrated at least twice a day, e.g., once at the beginning of the day and once at the end of the day.

The current source (source of the energy driving the system) is calibrated by placing an ammeter in series with the electrode cables. The reading obtained on the reference ammeter is then compared with the value read from the ammeter on the current source. The current source ammeter is then adjusted to the reading on the reference ammeter.

The potentiometer is the other apparatus that must be calibrated. This is normally accomplished by placing a precision resistor in series with the current load. A precision resistor is an electronic device that has a predetermined (as specified by the manufacturer) resistance to the electric current passing through the device, i.e., reduction in amperage. The potentiometer is then placed across the resistor. The potential measured should be equal to the product of the known resistance and the indicated current. Precision resistors can be purchased at most electronics supply stores.

All data sets should be accompanied by quality control data that indicate the level of quality of each individual data point. Periodically taking replicate measurements or re-running with the spacing and array configuration accomplishes this. These measurements should be averaged or statistically compared so that measurement precision can be estimated. Each data set should also be referenced to the most recent calibration. Data obtained before a calibration requiring significant changes in instrument controls is suspect. (Note: A significant change in instrument readings as a result of recalibration is interpreted as successive calibration values that vary by more than 10%).

Resistivities should be calculated and plotted during data acquisition to determine the overall quality of the data and whether the survey results are consistent with the site conceptualization. Data points representing discontinuities in the curves should be validated by repetition and, if necessary, a fine grid of measurements made to determine whether the anomaly represents a site feature of interest, a spurious reading, or an obstructive interference.

3.5.3 Electromagnetic Induction Surveys

Calibration. The manufacturer calibrates EM instruments over massive rock outcrops of known characteristic that are used as a geologic standard to measure the absolute conductivity over a uniform section of earth. The user should maintain the EM apparatus in calibration by noting drift in the readings at a stable "secondary standard" site. A secondary standard site is a location established in the field that is used to check the accuracy (calibration of the instrument and the drift precision of the instrument). A secondary standard site is a location used daily on large projects to check instrument accuracy, much the same way the manufacturer uses massive rock outcrops for precision and accuracy determination.

Unacceptable drift or erratic operation shall be corrected by replacement with an instrument in proper working order. Values that are obtained from measurements over the stable secondary standard site that vary by more than 10%–15% are considered to be unacceptable drift, if environmental conditions remain somewhat constant (i.e., heavy precipitation can make measurements radically different).

All aspects of the daily quality control measures discussed for resistivity measurements apply also to EM measurements. Repeated periodic measurements (at least twice a day) should be made at one or more locations and orientations at the site to determine the precision of measurements and to detect instrument drift.

4.0 HEALTH AND SAFETY CONSIDERATIONS

All procedures for hazardous waste site entrance, traverse, and egress that apply to general field operations also apply to conduct of geophysical surveys. Resistivity and conductivity surveys depend on traverse of the site on foot or in vehicles, and there are extended periods during which personnel are subject to adverse environments at the site. In addition, resistivity measurements require implanting electrodes beneath the surface, which increases the risk of contact with toxic or hazardous agents. An appropriate level of protection against these risks must be provided during the surveys.

The geophysical methods discussed herein do not require extremely strenuous activity, and exposure to heat or cold is similar to that during other field activities. Extreme weather conditions will have adverse effects on the time required to obtain validated data, thereby increasing the duration of personal exposure to the elements and to hazardous site influences.

In resistivity surveys, substantial levels of electrical charges and voltage may be present across the current electrodes, and field procedures must be designed to ensure that no personnel are in contact with the electrodes when the current source is energized. The site-specific Health and Safety Plan must address emergency procedures in the event of electrical shock and possible loss of consciousness.

5.0 REFERENCES

Good discussions of various survey techniques and applications are found in the following references:

ASTM Standard D 6429-99. 1999. *Standard Guide for Selecting Surface Geophysical Methods.*

ASTM Standard D 6431-99. 1999. *Standard Guide for Using the Direct Current Resistivity Method for Subsurface Investigation.*

Benson, Richard C., Robert A. Glaccum and Michael R. Noel. 1982. *Geophysical Techniques for Sensing Buried Wastes and Waste Migration.* Technos, Inc., Miami, FL., Contract No. 68-03-3050, USEPA Environmental Monitoring Systems Laboratory, Las Vegas, NV.

Costello, Robert L. 1980. *Identification and Description of Geophysical Techniques.* Report No. DRXTH-TE-CR-80084, US Army Toxic and Hazardous Materials Agency, Aberdeen Proving Ground, MD; Defense Technical Information System No. ADA 123939.

Keiswetter, D., Won, I. J., Bell, T., Barrow, B., and Khadr, N. 1998. Electromagnetic Induction Spectroscopy. Geophex, Ltd., Raleigh, N.C. and AETC Inc., Arlington, VA.

Loke, M.H. 2000. *Electrical Imaging Surveys for Environmental and Engineering Studies.*

McKown, G.L., G.A. Sandness and G.W. Dawson, 1980. *Detection and Identification of Buried Waste and Munitions.* Proceedings of the 11th American Defense Preparedness Association Environmental Systems Symposium, Arlington, VA.

Olhoeft, Gary R. 1989. *Geophysics Advisor Expert System: Version 1.0.* Interagency Agreement DW 14932497, USEPA EMSL, Las Vegas, NV.

USACE. 1995. *Geophysical Exploration for Environmental and Engineering Investigations.* EM 1100-1-19802. 31 August.

THIS PAGE LEFT INTENTIONALLY BLANK

APPENDIX D.2

ATS GEOPHYSICAL SURVEY REPORT FOR SWMU 45

Geophysical Investigation of SWMU-45 Radford Army Ammunition Plant (RAAP) Radford, Virginia

prepared for

URS Group, Inc.
5540 Falmouth Street, Suite 201
Richmond, VA 23230

by

ATS International, Inc.
107 Lester Street
Christiansburg, Virginia 24073
www.ats-intl.com

ATS International Project No. P06-05

June 12, 2007

Table of Contents

List of Figures

Executive Summary

ATS International, Inc. (ATS) was retained by URS Group, Inc. (URS) to conduct a geophysical investigation at SWMU-45 on the Radford Army Ammunition Plant (RAAP) near Radford, Virginia. The purpose of the study was to use geophysical methods to identify the lateral and vertical extents of potential landfill material. The area of investigation is located at the northern end of the RAAP on a terrace of the New River. The tasks involved in this study included:

(1) Establishment of a survey grid 350 feet wide by 800 long.

(2) Collection, processing, and interpretation of electromagnetic induction (EM) data.

(3) Collection, processing, and interpretation of electrical resistivity data.

(4) Collection, processing, and interpretation of spectral analysis of surface waves (SASW) data.

(5) Preparation of this document detailing our methods and findings.

The purpose of the EM survey was to evaluate lateral changes in EM distribution that may indicate the presence of fill materials. Strong, localized contrasts in conductivity may indicate the presence of buried materials that differ from the natural materials. The resistivity imaging survey was conducted to collect cross-sectional resistivity data over areas of anomalous EM for the purpose of delineating the vertical extents of potential fill materials. The purpose of the SASW survey was to corroborate the vertical extent of potential fill materials in the event that leachate was present beneath the fill that masked the vertical boundary with the natural materials.

The quadrature component of the EM data revealed an area in the north central portion of the study area that is characterized by conductivities that are elevated relative to the majority of the site. While it is normal to see variations in conductivity resulting from natural conditions, the magnitude of the conductivities is unlikely to be the result solely of variations in natural geologic conditions. Though standing water was observed within a ditch in this portion of the site, it is unlikely that the size of the area of elevated conductivities is the result of higher groundwater saturation from the standing water. The distribution of the in-phase component of the EM data is generally consistent with that of the quadrature component. A number of small in-phase anomalies are observed in the north central portion of the site, with additional correlated anomalies in other areas. One of these anomalies, located approximately 75 feet west of 45MW1, is coincident with an observed piece of sheet metal at the ground surface.

The resistivity lines placed through the anomalous EM zones display low-resistivity zones in the shallow subsurface that correlate well with the lateral extents of the elevated EM zones. The low resistivity zones are generally characterized by lower values and greater depth than low resistivity features found elsewhere on the resistivity cross sections. Interpreted together, the EM and resistivity data suggest the presence of fill materials that may be as deep as 20 feet in some places.

It should be noted that there are uncertainties associated with these interpretations. Specifically, the resistivity results from Line 3 are very similar to those of Line 2, but Line 3 is not mapped as passing through the zone of elevated EM. Possible explanations are put forth in Section 4.4.3. However, these results are consistent with other studies conducted by ATS in the past using these methodologies to map the lateral and vertical extent of fill.

The SASW results are not of themselves conclusive, but are supportive of the above interpretations. Specifically, those SASW profiles placed in what is interpreted to be natural materials display a relatively abrupt change from velocities of 500 to 700 ft/s to velocities of approximately 1,700 ft/s at about five to seven feet in depth. Those SASW profiles placed in the shallow low-resistivity zones, interpreted to be potential fill materials, generally display low velocities to depths of 18 to 20 feet below grade where they increase suddenly to greater than 2,000 ft/s.

It is generally not feasible, based on geophysical results, to determine the type of materials comprising the interpreted fill. Fill from displaced natural materials can display similar EM and resistivity signatures to those of municipal waste. It is noteworthy, however, that there is no substantial evidence of leachate present at the site. Leachate or other contaminant plumes would generally be characterized by lobate, low-resistivity features emanating from the low-resistivity fill in the unsaturated zone. In the presence of a leachate plume, the lowest resistivities would tend to be connected to the fill in the unsaturated zone and the plume would be skewed in the down-gradient direction. Neither of those conditions exists in the resistivity data.

1. Introduction

ATS International, Inc. (ATS) was retained by URS Group, Inc. (URS) to conduct a geophysical investigation at SWMU-45 on the Radford Army Ammunition Plant (RAAP) near Radford, Virginia. The purpose of the study was to use geophysical methods to identify the lateral and vertical extents of potential landfill material. The area of investigation is located at the northern end of the RAAP on a terrace of the New River. The tasks involved in this study included:

1. Establishment of a survey grid 350 feet wide by 800 long.
2. Collection, processing, and interpretation of electromagnetic induction (EM) data.
3. Collection, processing, and interpretation of electrical resistivity data.
4. Collection, processing, and interpretation of spectral analysis of surface waves (SASW) data.
5. Preparation of this document detailing our methods and findings.

The purpose of the EM survey was to evaluate lateral changes in EM distribution that may indicate the presence of fill materials. Strong, localized contrasts in conductivity may indicate the presence of buried materials that differ from the natural materials. The resistivity imaging survey was conducted to collect cross-sectional resistivity data over areas of anomalous EM for the purpose of delineating the vertical extents of potential fill materials. The purpose of the SASW survey was to corroborate the vertical extent of potential fill materials in the event that leachate was present beneath the fill that masked the vertical boundary with the natural materials.

The remainder of this document is divided into sections discussing delineation of the study area (Section 2); principles, methods, and results of the EM Survey (Section 3); principles, methods, and results of the resistivity survey (Section 4); and principles, methods, and results of the SASW survey (Section 5). Section 6 provides a summary of results and conclusions drawn from the geophysical investigation. References cited in this report are provided in Section 7. Figure 1 illustrates the locations of the EM survey traverses, the resistivity electrode locations, and the SASW profile locations.

2. Study Area

The study area was defined by using the existing map and global positioning system (GPS) technology to establish a rectangle 350 feet wide by 800 feet long, with the long axis oriented in a northeast-southwest direction. Wooden stakes were used to define the outer boundaries of the rectangle (points GS1 though GS6). Wooden stakes were placed 100 feet apart in the interior of the study area to form a grid. In the interior of the grid, colored fiberglass stake flags were used to delineate a total of 17 rows extending from southwest to northeast. Each row was spaced approximately 20 feet apart in the northwest-southeast direction, with each row being designated with stake flags of a particular color. This alternating color pattern provided a grid for spatial reference and facilitated the subsequent EM data collection.

3. EM Survey

3.1. Principles of EM

EM investigation utilizes a low frequency transmitter to induce electrical current into the subsurface. The induced current creates secondary electromagnetic fields which are measured by the EM device. The amplitude and phase of these secondary fields are related to the electrical properties of the subsurface material, and therefore a measurement of the secondary fields is a measure of how well the subsurface materials conduct electric current.

The EM device measures the quadrature and in-phase components of the electromagnetic fields generated by the instrument’s transmitter. The quadrature component of the EM data reveals apparent terrain conductivity in units of milliSiemens per meter (mS/m), which is a weighted average of the conductivity through the depth of measurement beneath the instrument. High magnitude responses, either positive or negative, indicate high bulk conductivity in the materials under the instrument.

The in-phase component of the EM data is the ratio of the secondary to primary magnetic field, and is presented in parts per thousand (ppt). The in-phase component is sensitive to the presence of highly conductive material, especially shallow metal objects, and is generally considered the metal-detection mode of the EM investigation. It is important to note that the size, depth of burial, and degree of corrosion of a metal object are all factors which affect the in-phase response (Jordan and Constantini, 1995).

The conductivity of subsurface materials is a function of their physical properties, namely porosity, permeability and the nature of the fluid within the pores. Landfill materials tend to have an abundance of pore space that holds moisture, and the materials themselves tend to increase the ionic strength of the pore water. Both of these factors work to increase the electrical conductivity, and thus landfill materials are usually readily distinguished from the surrounding native soils.

3.2. EM Field Methods

The instrument used for this investigation was the Geonics EM-31 terrain conductivity meter. The unit consists of a portable control module attached to a transmitter coil and a receiver coil. The transmitter and receiver coils are spaced are 3.7 meters (12 feet) apart, which allows for an effective depth of exploration of approximately six meters (20 feet) under ideal conditions.

EM surveys are usually conducted along traverses through the area of interest with measurements taken at fixed distances or at a fixed time interval along the traverse. By conducting sub-parallel traverses, substantial lateral coverage can be obtained. The data can then be contoured to evaluate the spatial distribution of the measured conductivity values.

For this study, traverses were conducted in parallel lines spaced approximately 20 feet apart, and oriented in a northeast-southwest direction (Figure 1). The EM data were collected with a continuous time-stamp log, with measurements taken at 1-second intervals, while a concurrent time-stamped global positioning system (GPS) track log was also collected. The EM data were tagged at the locations of each colored stake so that the EM data set would have absolute spatial reference to the survey grid. The time-stamped location data from the GPS track log were integrated with the time-stamped EM data to produce contours of the spatial distribution of the EM measurements across the grid.

3.3. EM Results

3.3.1. Quadrature Component of EM data

The contoured results of the quadrature component of the EM survey reveal background apparent conductivity values between approximately -2 to 3 milliSiemens per meter (mS/m) across much of study area (Figure 2). The zones of higher conductivity are characterized by small or irregularly shaped areas, the largest of which is located in the central portion of the site. This area is characterized by maximum conductivity values of ±16 mS/m.

3.3.2. In-phase Component of EM data

Typically, buried metal objects will exhibit a high-magnitude in-phase response over a short distance. This response can be either positive or negative in value, and will usually take place over a distance represented by one or two measurements. In this study, measurements were collected at 1-second intervals at a slow walking pace resulting in data points approximately 2 to 3 feet apart. Therefore, strong changes in in-phase values over a distance of 2 to 6 feet may be indicative of buried metal. Occasionally, a buried metallic object will exhibit both a large positive and large negative response adjacent to one another in the contoured data, depending on the distance of the EM device to the metallic object at a particular moment. As the ratio of the secondary to primary magnetic fields, changes greater than ±1 ppt can be indicative of the presence of metallic objects.

The contours of the in-phase component of the EM data are characterized by scattered, isolated anomalies (Figure 3). In general, the locations of these anomalies are consistent with the locations of anomalies observed in the quadrature data. An exception occurs in the southwestern corner of the study area where there is a concentration of small in-phase anomalies where the quadrature results display only two or three small areas of high conductivity.

3.3.3. Discussion of Quadrature and In-phase Results

The quadrature component of the EM data reveals background conductivities of -2 to 3 mS/m. These values represent what is likely to be relatively undisturbed sediments of the flood plain. An area in the north-central portion of the study area displays higher conductivity than the observed background values, as high as ±16 mS/m. A ditch was observed in this area approximately six feet wide and 20 feet long containing standing water. The standing water suggests saturated conditions beneath the ditch that would result in higher conductivity in the vicinity. However, the area of higher conductivity is much larger than can be accounted for by the presence of the ditch. Therefore, this area is interpreted to be underlain by potential fill materials.

Contours of the in-phase component of the EM data are characterized by small, isolated anomalies. Many of these in-phase anomalies are consistent with anomalies observed in the quadrature component contours. A few in-phase anomalies, such as those located in the western and southwestern portion of the study area, do not correspond to zones of elevated quadrature values. These in-phase anomalies likely result from small, isolated metallic objects that are not concentrated enough to result in higher bulk conductivity values.

An anomaly is observed in both the quadrature and in-phase data located approximately 75 feet west of 45MW1. It should be noted that a piece of sheet metal approximately 3’ by 5’was observed on the ground surface at this location.

4. Resistivity Imaging

To evaluate the vertical extent of potential fill material at the site, resistivity imaging techniques were employed across areas of anomalous EM data. Resistivity imaging provides cross-sectional images of the resistance to electric current. Electrical resistivity is a fundamental parameter of the material that describes how easily the material can transmit electrical current. High values of resistivity imply that the material is very resistant to the flow of electricity; low values of resistivity imply that the material transmits electrical current very easily.

The primary factors affecting the resistivity of earth materials are porosity, water saturation, clay content, and ionic strength of the pore water. In general, the minerals making up soils and rock do not readily conduct electric current and thus most of the current flow takes place through the material’s pore water. The relatively high levels of pore water in soils and other unconsolidated materials tend to give low resistivity values for the shallow subsurface. Where the levels of pore water in soils and other unconsolidated materials are low, resistivity values tend to be high in the shallow subsurface.

4.1. Principles of Resistivity

Experiments by George Ohm in the early 19th century revealed the empirical relationship between the current flowing through a material and the potential required to drive that current. This relationship is described by:

$$V = IR$$

where V is voltage in volts, I is the current in amperes, and R is the proportionality constant. Rearranging the equation to:

$$\frac{V}{I} = R$$

gives resistance with the units of volts divided by amperes, or ohms.

The resistance of a material is dependent not only on the property of the material but also the geometry of the material. Specifically, a longer travel path for the current or smaller cross-sectional area would cause the resistance to increase. The geometry-independent property used to quantify the flow of electric current through a material is resistivity, given by:

$$\rho = \frac{RA}{L}$$

where ρ is the resistivity, R is the resistance, A is the cross-sectional area through which the current flows, and L is the length of the current flow path. With all length units expressed as meters, the units associated with resistivity are ohm-meters.

Resistivity surveys are conducted by inducing an electric current into the ground between two electrodes, and measuring the potential at other electrodes. Numerous configurations of electrode placement are commonly employed, each with unique data characteristics. The configuration utilized for this study was the dipole-dipole array. For the dipole-dipole array, a current is applied to two adjacent electrodes positioned a predetermined distance apart (distance a). The voltage across two other electrodes is measured simultaneously with the applied current. The two sets of electrodes are always spaced distance a apart and the distance between the current and voltage electrodes is always a multiple of a ($n \bullet a$). To obtain apparent resistivity values, the voltage and current measurements are input into the following formula for dipole-dipole surveys:

$$\rho = 2\pi(n+1)\cdot(n+2)\cdot a\cdot\frac{V}{I}$$

4.2. Field Methods

Five resistivity lines were positioned across the study area on April 24th, 2007 based on the results of the EM survey (Figure 4). Line 1 was oriented to the northeast approximately parallel to the northern edge of the study area through the largest area of anomalous EM data. Lines 2 and 3 were oriented approximately perpendicular to Line 1. Line 4 was oriented sub-parallel to Line 1 in the eastern half of the study area. Line 5 was oriented approximately perpendicular to Lines 1 and 4 in the eastern half of the study area.

Line 1 employed a spacing of 5 meters (16.4 feet) between electrodes. Lines 2 and 3 employed a spacing of 3 meters (10 feet) between electrodes. Line 4 and 5 employed a spacing of 4 meters

(13 feet) between electrodes. The electrodes were assigned a unique identifier consisting of the line number followed by a dash and the electrode number. For example, the first electrode on Line 1 is 1-1, the first electrode on Line 2 is 2-1, etc. Wire stake flags were placed in the ground at the location of each electrode and labeled with the electrode number for future reference. Locations of the resistivity lines were plotted using a combination of GPS and referenced to the colored grid flags and stakes previously laid out.

Field data were collected using a Tigre® multi-electrode resistivity system manufactured by Campus International Products, LTD. Data were collected using the dipole-dipole array with a current of 50 milliamps. For each electrode configuration in the array, measurements were repeated a minimum of two times or until the variance between measurements was less than or equal to five percent.

Measurements were initiated at one end of the resistivity line and incrementally moved through the electrodes until readings had been taken at every position along the line. The value of *n* was then increased to add additional resistivity readings at greater depths in the subsurface.

4.3. Inversion Modeling

The resistivity measurements on a section are called apparent resistivities. They may differ from the true resistivities in the subsurface because the measured data may be affected by passage through non-homogeneous materials and the distance of travel through the media. Apparent resistivity measurements must be processed to model the distribution of resistivities for the site-specific geology. Therefore, linear inversion techniques were applied to the data using RES2DINV inversion modeling software (Geotomo Software, 2006). Linear inversion modeling fits the measured data in the resistivity section to an earth model that may represent the actual resistivities in the section. The inversion modeling is completed by calculating apparent resistivity from the earth model for comparison to the measured data. If the comparison is within reasonable limits, the earth model can be accepted as an approximation of subsurface conditions. Details of the inversion process may be found in Lines and Treitel (1984), Loke and Barker (1995), and Loke and Barker (1996). The inverted resistivity section is the image used for interpretation of geologic conditions.

4.4. Resistivity Results

4.4.1. General Geologic Interpretations

The results of the inversion modeling of the five resistivity lines are illustrated in Figure 5. The contour values selected for these sections range from 0 to 400 ohm meters (ohmm) to best display the variations in the upper 40 feet, but resistivities at depth are in the tens of thousands of ohmm. The approximate depth to the water table (~22 feet) is depicted as a horizontal blue line, based on the approximate vertical distance to the river level and the observed water levels in the three existing monitoring wells.

The shallow subsurface above the water table is generally characterized by relatively high resistivities greater than 350 ohmm, as is characteristic of unsaturated sandy soils. A thin veneer of lower resistivities (~125 to 250 ohmm) are often observed in the upper few feet, probably resulting from soil moisture held by the thick layer of leaf litter at the ground surface. This condition is observed on Line 1 between electrodes 1-37 and 1-58, on Line 2 from 2-22 to 2-30, on Line 3 from 3-23 to 3-30, on Line 4 from 4-2 to 4-15, and on Line 5 from 5-16 to 5-31. This vertical distribution is common in sandy soil environments and is consistent with observations in similar terrain in other studies conducted by ATS.

Beneath the anticipated depth of the water table the resistivities are observed to often be lower than the dry sand above, indicating the transition from unsaturated to saturated soils. This condition is most clearly seen on Line 1 between 1-37 and 1-53, and on Line 4 between 4-6 and 4-13.

At depth, resistivities are observed to increase abruptly to more than 1000 ohmm. This transition from a few hundred ohmm to thousands of ohmm is typical of the transition from soil to bedrock. The interpreted soil-bedrock interface is depicted on Lines 1, 2, 3, and 5 but is not discernible on Line 4. Below the anticipated water table are several bowl-shaped depressions in the interpreted bedrock surface, within which are predominantly low resistivities of 150 ohmm or less. This condition is observed at several locations on Line 1, and beneath the central portions of Lines 2, 3, and 5. As the study area resides within a flood plane of the New River, it is possible that these are former stream channels that have been eroded into the bedrock surface and subsequently filled with terrace deposits.

4.4.2. Possible Fill Materials

Lines 1, 2, 4, and 5 were placed across areas that displayed elevated conductivities in the EM data. Each of these lines displays low resistivity zones in the shallow subsurface that correspond to the lateral extent of the elevated EM contours. In addition, these low resistivity zones are different in extent and in character from the shallow subsurface conditions described in Section 4.4.1, which are interpreted as dry sandy soil overlain by moist humus. Specifically, the low resistivity zones that correlate to the elevated EM data are characterized by values less than 125 ohmm, whereas the low resistivities interpreted to arise from the moist humus are generally between 125 and 250 ohmm. Moreover, the shallow low resistivities interpreted to arise from the moist humus are generally no more than five to seven feet thick, whereas the low resistivity zones correlating to the elevated EM data extend to approximately 20 feet on Lines 1 and 4, and to approximately 15 feet on Lines 2 and 5. These facts suggest that these low-resistivity zones may be fill materials that differ in character from the natural materials surrounding them. This distribution of resistivities in cross-section and the correlation with the lateral distribution of elevated conductivities is characteristic of fill materials and is consistent with other such studies conducted by ATS in the past.

It is noteworthy that if the low-resistivity zones represent fill, there is no evidence of leachate or other contaminant plumes beneath those zones. Leachate or other contaminant plumes would generally be characterized by lobate, low-resistivity features emanating from the low-resistivity fill in the unsaturated zone. In contrast, the low resistivity zones are clearly underlain by higher resistivities on Lines 1, 4, and 5. On lines 2 and 3, the low-resistivity zones are underlain by other low resistivities that are interpreted to be potential channel deposits. If these low-resistivity features in the saturated zone were the result of leachate, the lowest resistivities would tend to be connected to the fill and the plume would be skewed in the down-gradient direction. Neither of those conditions exists beneath Lines 2 and 3.

4.4.3. Uncertainties

Notwithstanding the discussion above, there are two lines of uncertainty in this interpretation. First, Line 3 and Line 2 are approximately parallel and only about 50 to 100 feet apart. The resistivity sections for these two lines are very similar, and both display shallow low-resistivity zones in the central portions of the lines. Line 2, however, was placed through an area of elevated EM conductivity, but that zone of elevated conductivity does not extend beneath Line 3. There are two possible explanations for this apparent discrepancy. First, the low-resistivity zones may be the result of varying natural conditions such as soil moisture and/or clay content that results in both the low resistivity zones and the high conductivity zones. The second possibility is that fill materials exist beneath Line 3 but that they are thin enough and deep enough so as to make less of a contrast to the bulk conductivity, but are resolved in the resistivity section because of its greater vertical depth of investigation.

5. SASW

Spectral analysis of surface waves (SASW) was used to corroborate the resistivity results with respect to vertical changes in materials. Specifically, the SASW was proposed in the event that leachate was present beneath the potential fill materials. Leachate often results in a low-resistivity signature beneath the fill and can make discernment of the boundary between fill and natural materials difficult.

5.1. Principles of SASW

The SASW method measures the shear wave velocity of a material, and provides a profile of velocity versus depth. Vertical changes in shear wave velocity can be used to evaluate the vertical heterogeneity of the materials.

The SASW method uses the propagation of an elastic wave through the ground, usually induced by a blow from a hammer or drop-weight. Two types of waves are generated by such a blow; body waves and surface waves. Approximately two-thirds of the impact energy propagates away from the source in a type of surface wave called the Rayleigh wave. Rayleigh waves travel at speeds governed by the stiffness-depth profile of the earth materials.

In a homogeneous and isotropic material, the speed of a Rayleigh wave will be independent of its wavelength. However, if there is a variation in stiffness or density with depth, then the speed of the Rayleigh wave will be dependent on its wavelength. Low-frequency (long wavelength) Rayleigh waves will extend deeper into the earth materials than high-frequency (short wavelength) waves (Matthews et al., 1996). This behavior is described as "dispersive" in seismological terms, and a curve of velocity versus wavelength (or depth) is called a dispersion curve.

5.2. SASW Field Methods

The SASW equipment consisted of 2 geophones, a computer control box, and a seismic source. The geophones measure the ground movement associated with the Rayleigh wave as it travels away from the source. The shallow subsurface is sampled using closely spaced geophones, with greater depth of investigation achieved by increasing the geophone spacing.

5.3. Rayleigh Wave Data Analysis and Modeling

From the raw ground motion data, the dispersion curve of wavelength versus phase velocity is derived. The dispersion curve of the observed shear wave velocity vs. wavelength is used as the input data to an SASW inversion modeling routine. The inversion modeling routine fits the measured data to an earth model that represent the actual shear wave velocities versus depth in the profile. The inversion modeling iteratively calculates a dispersion curve from the earth model for comparison to the observed dispersion curve. If for any iteration the match between the observed and calculated dispersion curves is not satisfactory, another iteration is conducted until a close match is obtained. When a close match is obtained between the observed and calculated dispersion curves, the earth model can be accepted as a reasonable approximation of shear wave velocity versus depth. Details of the inversion modeling can be found in Gucunski and Woods (1991) and Joh (1996).

5.4. SASW Results

Of the five SASW profiles, SASW-2 and SASW-4 were placed in what is interpreted from the EM and resistivity results to be undisturbed materials. SASW-1, SASW-3, and SASW-5 were placed on what may be interpreted to be potential fill materials.

Naturally deposited materials such as clay, silt, and organic matter tend to display shear wave velocities less than 1000 feet per second (ft/s), sands and gravels between 1,000 and 2,500 ft/s, and cobbles, boulders, and/or bedrock are generally greater than 2,500 ft/s. Fill materials, whether consisting of natural earth materials or man-made materials (with the exception of concrete), generally display shear wave velocities of less than 1,000 ft/s. Natural fill materials can display higher velocities if properly engineered and compacted, but with the exception of concrete most man-made materials will exhibit low velocities.

The SASW results suggest a general correlation among those SASW profiles located on the interpreted fill materials and those located on natural materials. Specifically, SASW-2 and SASW-4 increase relatively suddenly to velocities of 1,500 to 1,700 ft/sec at approximately five to seven feet below the ground surface. SASW-2 contains a thin low-velocity zone between 10 and 12 feet, but otherwise displays higher velocities in the upper 20 feet.

In contrast, SASW-1 and SASW-5 display velocities of approximately 500 to 700 ft/s to a depth of 18 to 20 feet where they increase quickly to velocities of greater than 2,000 ft/s. SASW-1 contains a thin high-velocity zone at approximately five feet, but above and below that zone are low velocities. SASW-3 displays a somewhat more gradual increase with depth than do the other four profiles.

These results alone are not taken to be conclusive evidence for the presence of fill materials. However, they are supportive of the interpretations from the EM and resistivity data.

6. Conclusions

The quadrature component of the EM data revealed an area in the north central portion of the study area that is characterized by conductivities that are elevated relative to the majority of the site. While it is normal to see variations in conductivity resulting from natural conditions, the magnitude of the conductivities is unlikely to be the result solely of variations in natural geologic conditions. Though standing water was observed within a ditch in this portion of the site, it is unlikely that the size of the area of elevated conductivities is the result of higher groundwater saturation from the standing water. The distribution of the in-phase component of the EM data is generally consistent with that of the quadrature component. A number of small in-phase anomalies are observed in the north central portion of the site, with additional correlated anomalies in other areas. One of these anomalies, located approximately 75 feet west of 45MW1, is coincident with an observed piece of sheet metal at the ground surface.

The resistivity lines placed through the anomalous EM zones display low-resistivity zones in the shallow subsurface that correlate well with the lateral extents of the elevated EM zones. The low resistivity zones are generally characterized by lower values and greater depth than low resistivity features found elsewhere on the resistivity cross sections. Interpreted together, the EM and resistivity data suggest the presence of fill materials that may be as deep as 20 feet in some places.

It should be noted that there are uncertainties associated with these interpretations. Specifically, the resistivity results from Line 3 are very similar to those of Line 2, but Line 3 is not mapped as passing through the zone of elevated EM. Possible explanations are put forth in Section 4.4.3. However, these results are consistent with other studies conducted by ATS in the past using these methodologies to map the lateral and vertical extents of fill.

The SASW results are not of themselves conclusive, but are supportive of the above interpretations. Specifically, those SASW profiles place in what is interpreted to be natural materials display a relatively abrupt change from velocities of 500 to 700 ft/s to velocities of approximately 1,700 ft/s at about five to seven feet in depth. Those SASW profiles place in the shallow low-resistivity zones, interpreted to be potential fill materials, generally display low velocities to depths of 18 to 20 feet below grade where they increase suddenly to greater than 2,000 ft/s.

It is impossible to determine the exact materials that compose the interpreted fill. Fill from displaced natural materials can display similar EM and resistivity signatures to those of municipal waste. It is noteworthy, however, that there is no substantial evidence of leachate present at the site. Leachate or other contaminant plumes would generally be characterized by lobate, low-resistivity features emanating from the low-resistivity fill in the unsaturated zone. In the presence of a leachate plume, the lowest resistivities would tend to be connected to the fill in the unsaturated zone and the plume would be skewed in the down-gradient direction. Neither of those conditions exists in the resistivity data.

7. References

Geotomo Software, 2006. RES2DINV version 3.54, Rapid 2-D resistivity and IP inversion using the least squares method, Penang, Malaysia.

Gucunski, N. and R. D. Woods, 1991. *Inversion of Rayleigh wave dispersion curve for SASW test,* Proceedings of the 5th International Conference on Soil Dynamics and Earthquake Engineering, Pages 127-138.

Joh, S. J., 1996. *Advances in Interpretation and Analysis Techniques for Spectral-Analysis-of-Surface-Waves (SASW) Measurements,* Unpublished PhD dissertation, University of Texas at Austin.

Jordan, Thomas E. and Costantini, Darrin, 1995. *The Use of non-Invasive Electromagnetic (EM) Techniques for Focusing Environmental Investigations*, The Professional Geologist, June, Pages 4-9.

Lines, L.R., and S. Treitel, 1984. *A review of least-squares inversion and its application to geophysical problems,* Geophysical Prospecting, Vol. 32, Pages 159-186.

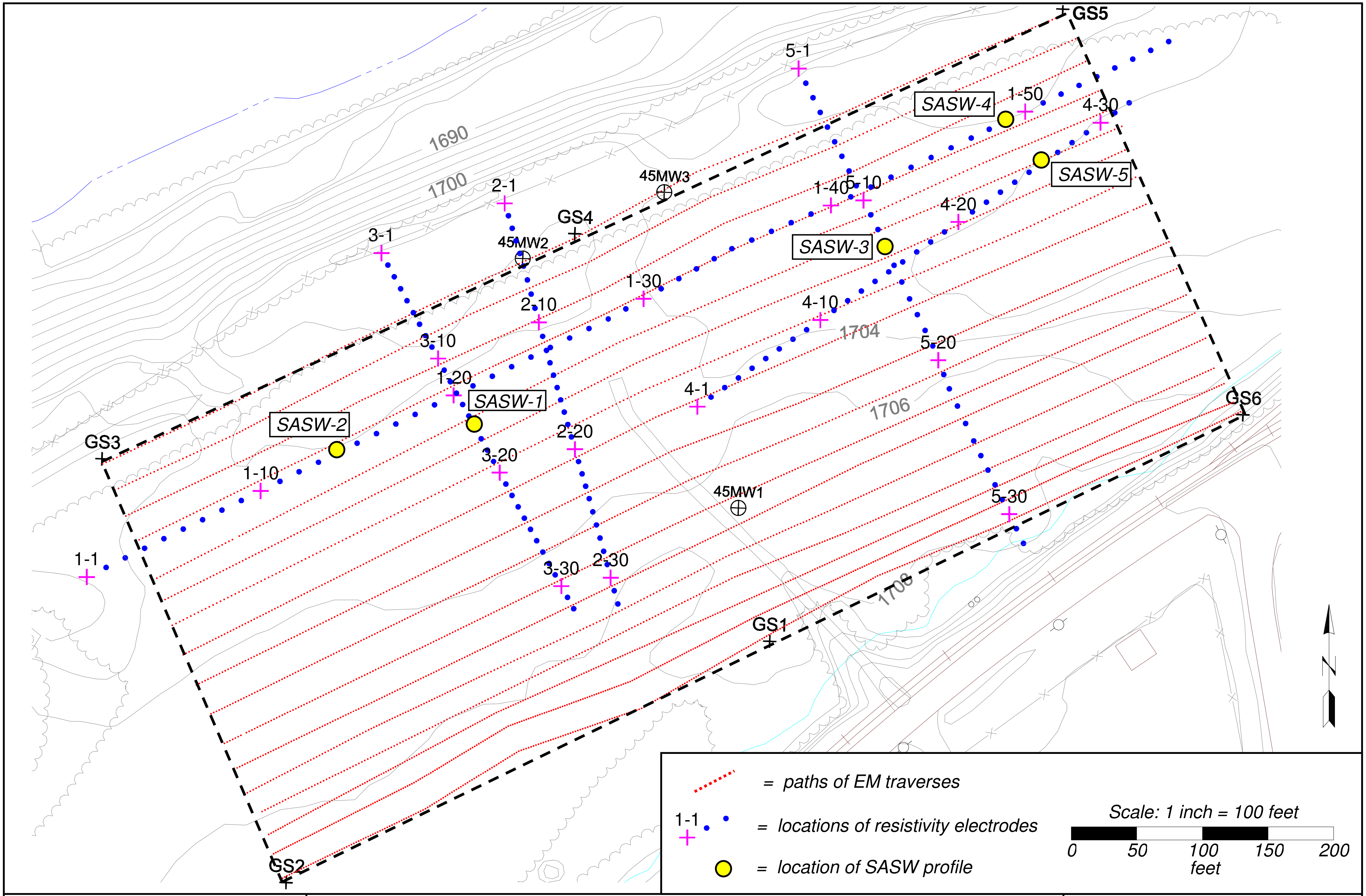
Loke, M.H., and R.D. Barker, 1995. *Least-squares deconvolution of apparent resistivity pseudosections,* Geophysics, Vol. 60, No. 6, Pages 1682-1690.

Loke, M.H., and R.D. Barker, 1996. *Rapid least-squares inversion of apparent resistivity pseudosections by a quasi-Newton method*, Geophysical Prospecting, Vol. 44, No. 1, Pages 131-152.

Matthews, M. C., Hope, V. S., and R. I. Clayton, 1996, *The use of surface waves in the determination of ground stiffness profiles,* Proceedings of the Institution of Civil Engineers in Geotechnical Engineering, Vol. 119, April, Pages 84-95.

McNeill, J. D., 1980. *Electromagnetic terrain conductivity measurement at low induction numbers*, Technical Note TN-6, Geonics, Limited, Mississauga, Ontario, Canada.

Figures



Report Title:
Geophysical Investigation for SWMU-45, RAAP, Radford, Virginia

File Name: *SWMU-45 ls.ppt*

Date: *5-12-07*
Draftsman: *WTD*

ATS Project Number: *P06-05*

Figure 1. Map of the SWMU-45 vicinity illustrating the boundaries of the study area (points GS1 through GS6) and the locations of geophysical surveys.

ATS International
Advanced Technical Services
www.ats-intl.com
Engineering Geology • Hydrogeology • Geophysics
Computer Modeling • Visualization • GIS

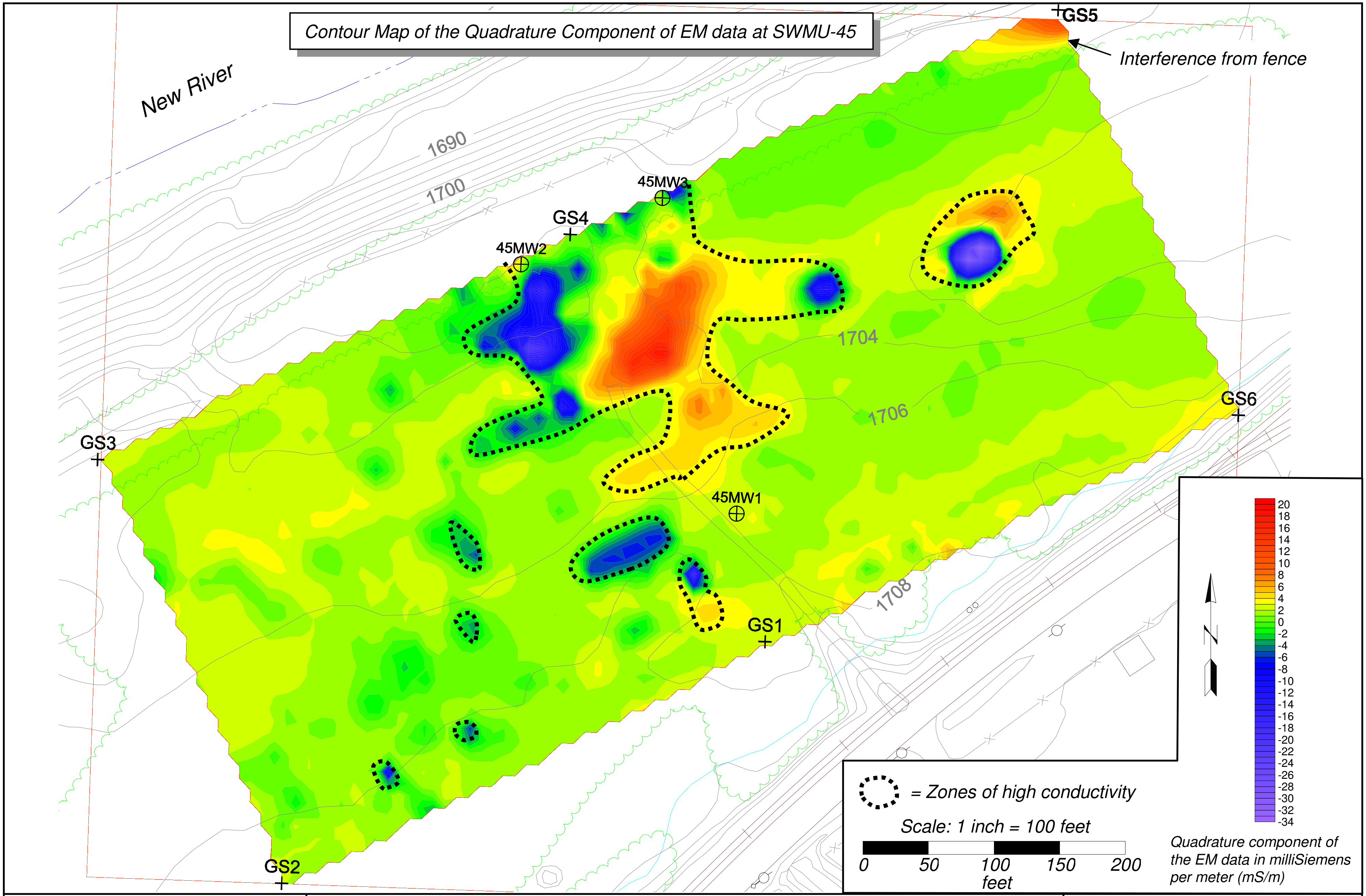
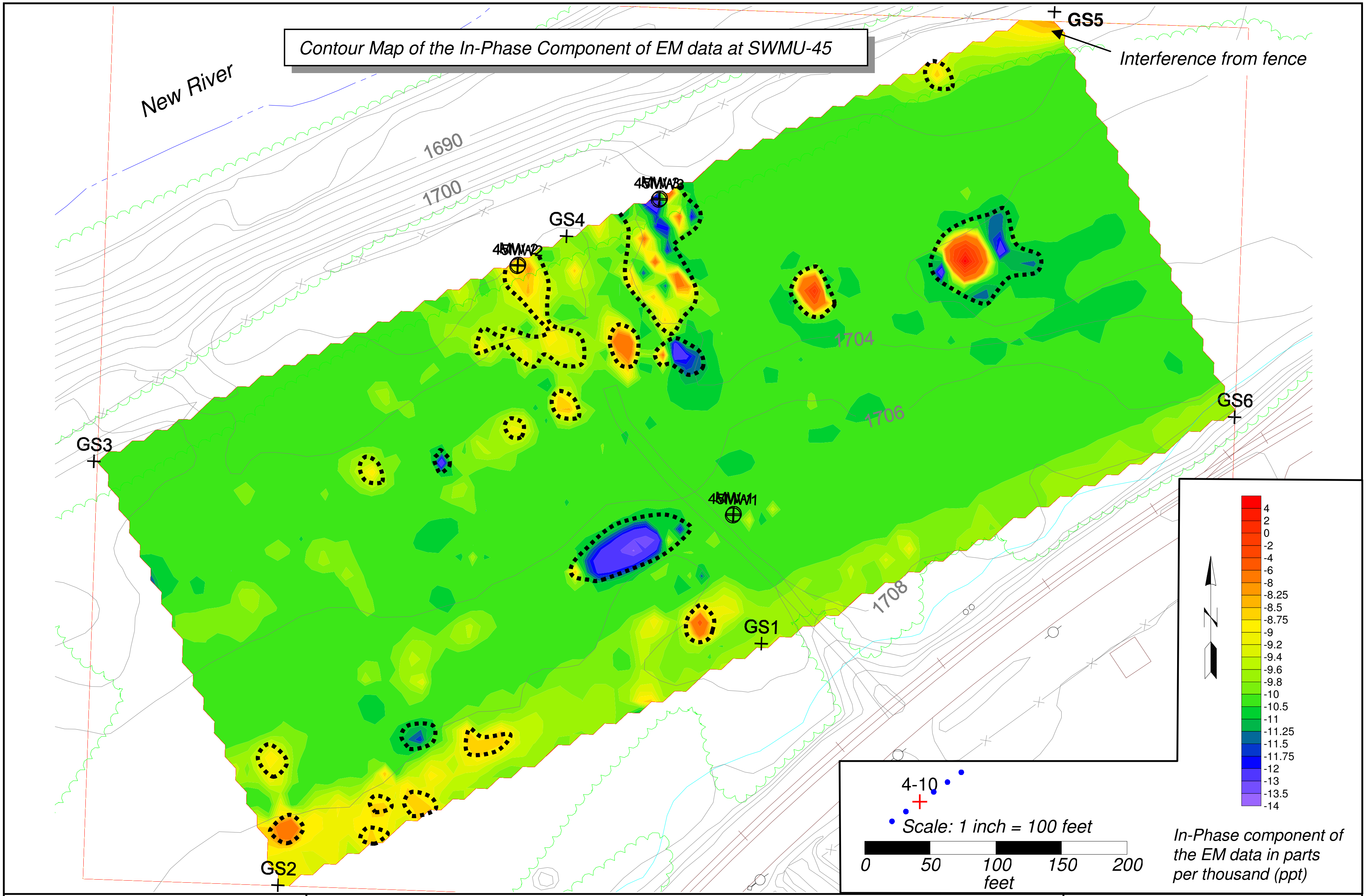


Figure 2. Color contour map of the quadrature component of the EM data.

Report Title:
Geophysical Investigation for SWMU-45, RAAP, Radford, Virginia

File Name: *SWMU-45 ls.ppt*	
Date: *5-12-07*	Draftsman: *WTD*
ATS Project Number: *P06-05*	

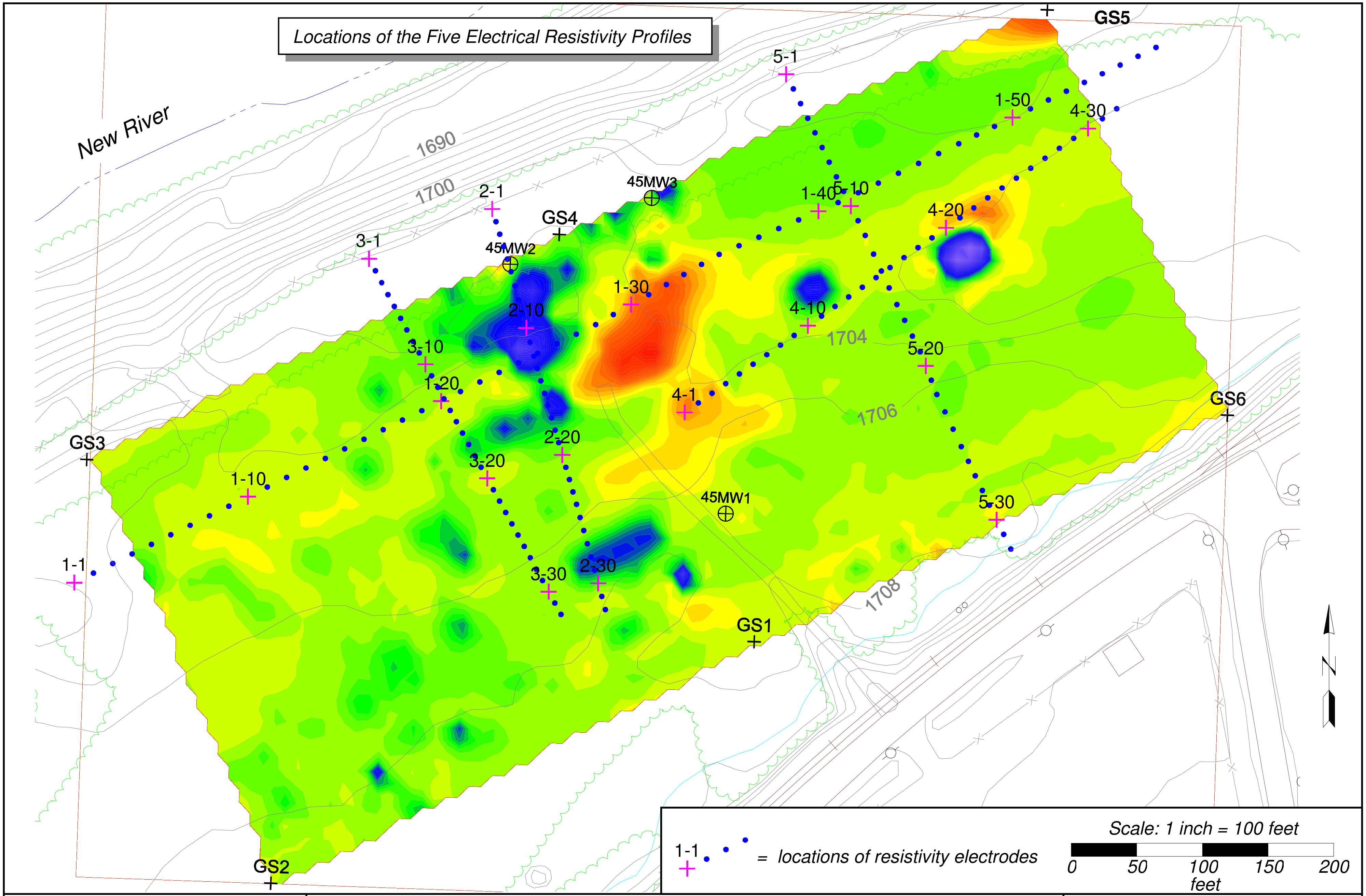
ATS International
Advanced Technical Services
www.ats-intl.com
Engineering Geology • Hydrogeology • Geophysics
Computer Modeling • Visualization • GIS



Report Title:
Geophysical Investigation for SWMU-45,
RAAP, Radford, Virginia
File Name: SWMU-45 ls.ppt
Date: 5-12-07 Draftsman: WTD
ATS Project Number: P06-05

Figure 3. Color contour map of the in-phase component of the EM data.

ATS International
Advanced Technical Services
www.ats-intl.com
Engineering Geology • Hydrogeology • Geophysics
Computer Modeling • Visualization • GIS



Locations of the Five Electrical Resistivity Profiles

Report Title:
Geophysical Investigation for SWMU-45, RAAP, Radford, Virginia

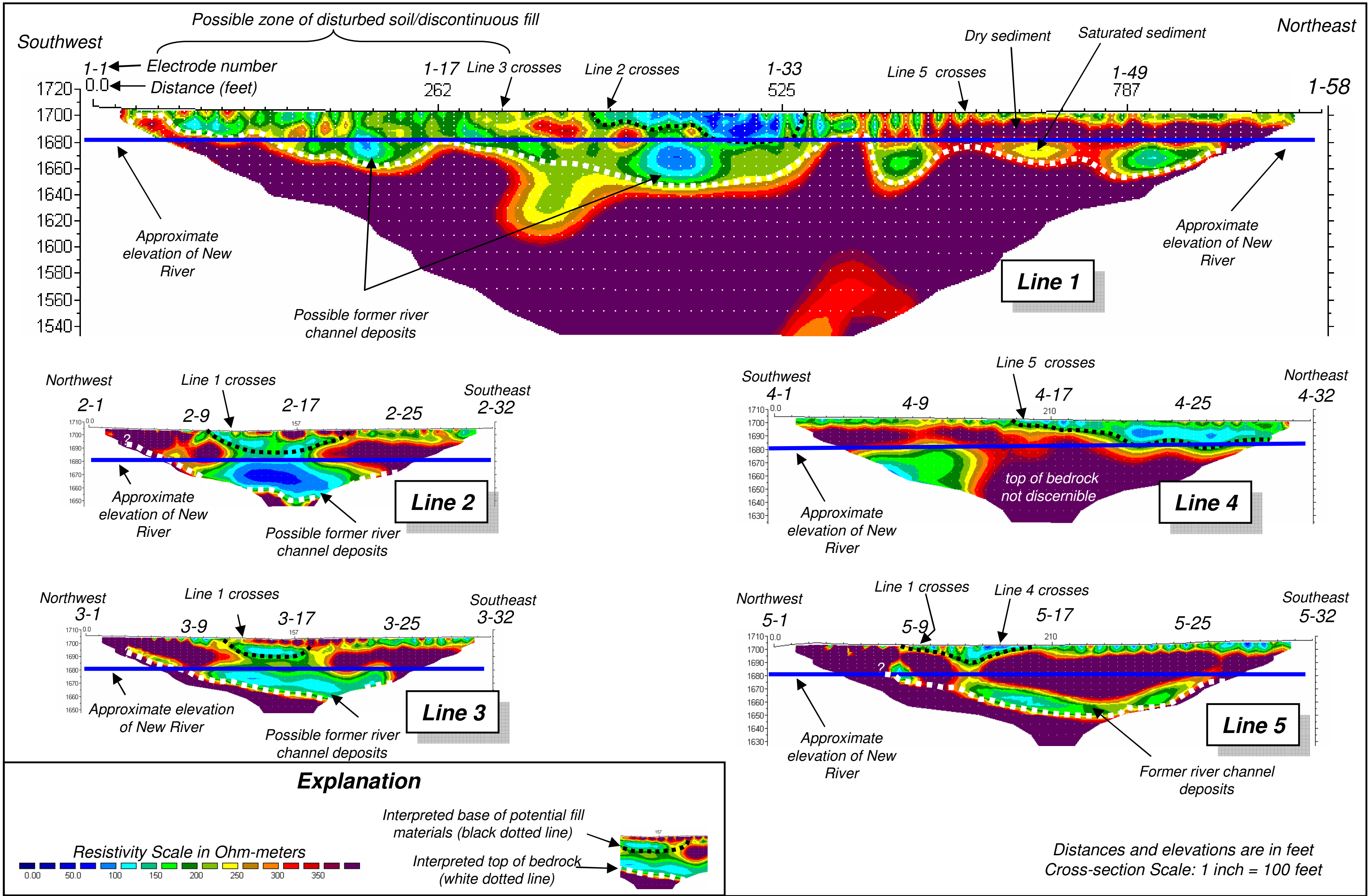
File Name: *SWMU-45 ls.ppt*

Date: *5-12-07* Draftsman: *WTD*

ATS Project Number: *P06-05*

Figure 4. Electrode location map for the five resistivity lines superimposed on the color contour map of the quadrature component of the EM data.

ATS International
Advanced Technical Services
www.ats-intl.com
Engineering Geology • Hydrogeology • Geophysics
Computer Modeling • Visualization • GIS



Report Title:
Geophysical Investigation for SWMU-45, RAAP, Radford, Virginia

File Name: SWMU-45 ls.ppt

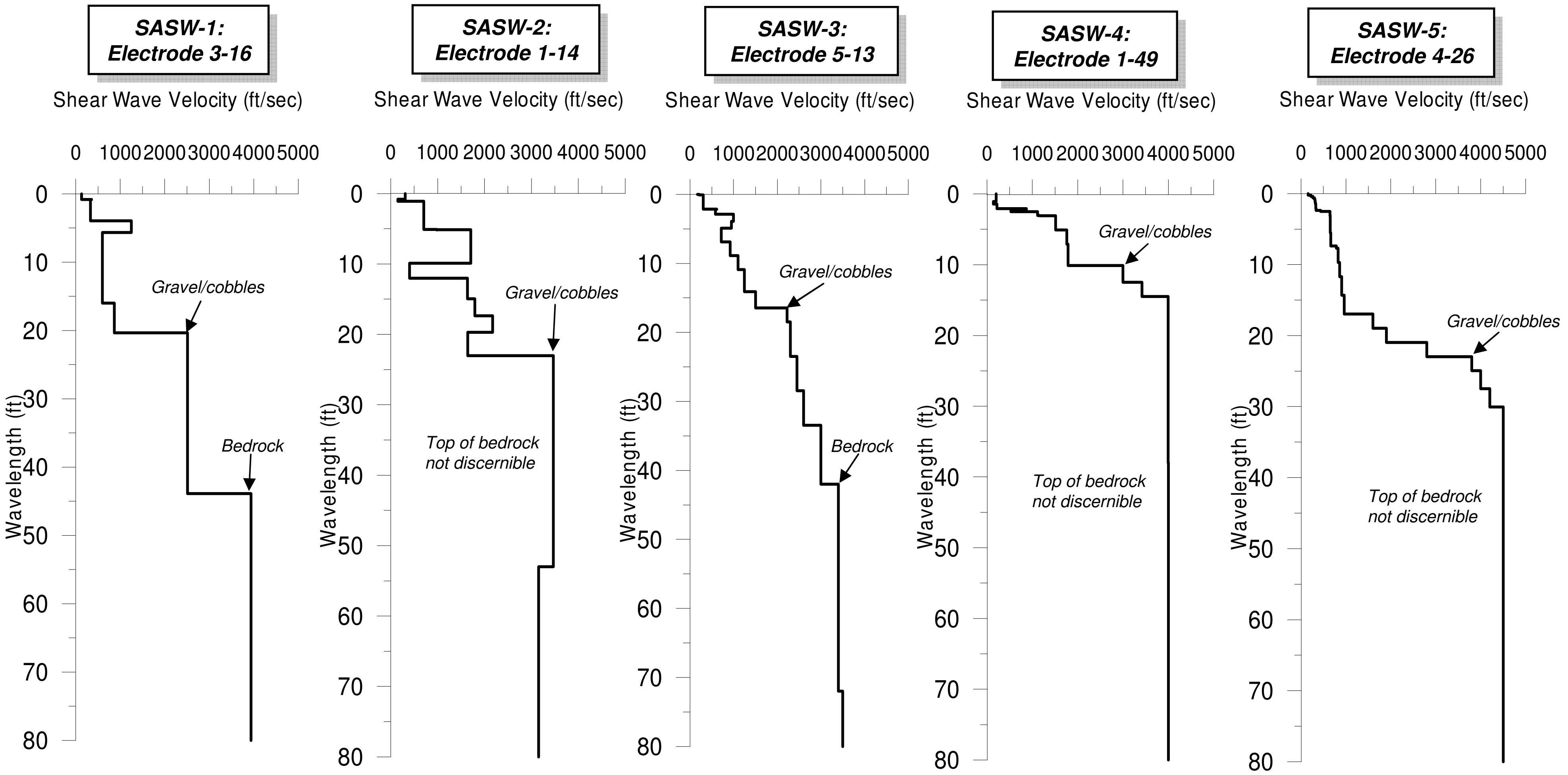
Date: 5-12-07 Draftsman: WTD

ATS Project Number: P06-05

Figure 5. Results of the five resistivity lines.

ATS International
Advanced Technical Services
www.ats-intl.com
Engineering Geology • Hydrogeology • Geophysics
Computer Modeling • Visualization • GIS

Results of the SASW Profiles



Report Title:
Geophysical Investigation for SWMU-45, RAAP, Radford, Virginia
File Name: *SWMU-45 ls.ppt*
Date: *5-12-07* Draftsman: *WTD*
ATS Project Number: *P06-05*

Figure 6. Graphs of modeled shear wave velocities versus depth for SASW locations 1 through 5.

ATS International
Advanced Technical Services
www.ats-intl.com
Engineering Geology • Hydrogeology • Geophysics
Computer Modeling • Visualization • GIS

APPENDIX D.3

PHOTOGRAPHIC LOG FOR ADDITIONAL INVESTIGATION OF ANOMALIES IDENTIFIED DURING GEOPHYSICAL SURVEY

THIS PAGE LEFT INTENTIONALLY BLANK

PHOTO 1: Anomaly 1 – mound approximately 8” high between transects 2-29 and 2-28

PHOTO 2: View facing east towards MW-1, 30’ from transect 2-29 at large fallen tree

PHOTO 3: Facing east standing at transect 2-29 looking towards MW-1, personnel standing at test pit (2’x2’x1’) in Anomaly 1

PHOTO 4: Metal object found in test pit in Anomaly 1; possible 5-gallon bucket lid

PHOTO 5: Opposite side of metal object found in test pit in Anomaly 1

PHOTO 6: Inside view of metal object found in test pit in Anomaly 1; possible handle to bucket lid

PHOTO 7: Metal tags found in test pit in Anomaly 1

PHOTO 8: Metal tags with tape measure for scale

PHOTO 9: Metal blocks found in test pit in Anomaly 1

PHOTO 10: Hard layer reached approximately 8" below surface in test pit in Anomaly 1

PHOTO 11: Close-up view of hard cement-like layer found in test pit in Anomaly 1

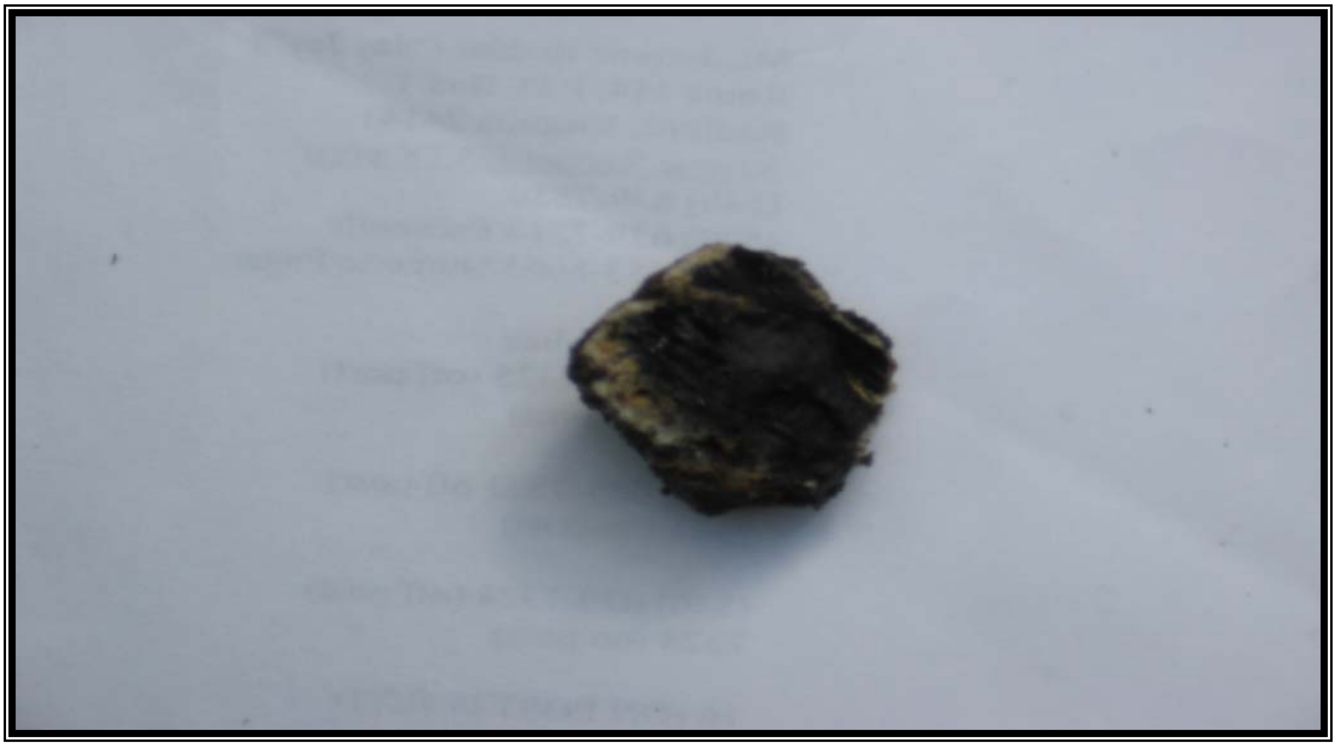


PHOTO 12: Sample broken off from hard layer placed on sheet of white paper

PHOTO 13: Test pit located 10’ north of Anomaly 1 adjacent to fallen tree (no evidence of surficial material present)

PHOTO 14: Location of Anomaly 2 looking towards MW-2, standing at transect 2-11

PHOTO 15: Metal debris found 0-1’ below surface in test pit (2’x2’x1’) in Anomaly 2

PHOTO 16: Large piece of metal debris found in bottom of test pit in Anomaly 2

PHOTO 17: Personnel standing in low point facing mound towards test pit (2’x2’x2) in Anomaly 3

PHOTO 18: Clay soil found at test pit in Anomaly 3

PHOTO 19: Offset hole (2’x2’x1’) to Anomaly 3 located in gulley 6’ from pit in depression

PHOTO 20: Metal debris found in test pit (2’x2’x1’) in Anomaly 4

PHOTO 21: Hole dug at Anomaly 5 approximately 3’x2’x2’ (no evidence of surficial material present)

PHOTO 22: Test holes dug around tree at Anomaly 5 (no evidence of surficial material present)

APPENDIX E

FORMS

Form E-1
Work Plan Revision Form
Work Plan – Quality Assurance Plan – Health and Safety Plan – Addendum 022
SSP at SWMU 45
Radford Army Ammunition Plant, Radford, Virginia

<u>SITE DESIGNATION / LOCATION:</u>	Section: ______________________
Radford Army Ammunition Plant	Addendum: ______________________
Radford, VA	Version: ______________________
	Effective Date: ______________________
<u>SUBJECT:</u>	Approved by:
	Field Operations Leader
	______________________
	Date: ______________________
	Concurrence:
	Project Manager
	______________________
	Date ______________________
	Sheet ______ of ______

Form E-2
Worker Acknowledgement Form
SSP at SWMU 45
Radford Army Ammunition Plant, Radford, Virginia

Document: Master Work Plan/QAP/HSP and Work Plan Addendum 022

Version: Final

Project: Radford Army Ammunition Plant

Location: SWMU 45

Prior to the initiation of field activities, I have been given an opportunity to read and question the contents of this Master Work Plan/QAP/HSP, this Site-Specific Addendum, and approved revisions through the number listed above. With my signature, I certify that I have read, understood, and agree to comply with the information and directions set forth in these plans. I further certify that I am in full compliance with 20 Code of Federal Regulations (CFR) 1910.120 concerning training and medical monitoring requirements.

Site Personnel:

Name (please print)	**Signature**	**Date**