# 6. ENVIRONMENTAL MEASUREMENTS AND MONITORING

Consistent with requirements from U.S. Nuclear Regulatory Commission Regulation (NUREG) 1748 (NRC 2003), this section describes all environmental measurement and monitoring programs as they apply to baseline, operating, and decommissioning conditions for the Proposed Action and each alternative. Although the environmental monitoring program at the Jefferson Proving Ground (JPG) has addressed baseline and operating conditions, license termination is being addressed pursuant to restricted release with institutional controls in accordance with Title 10 Code of Federal Regulations (CFR) Part 20, Section 1403 (10 CFR 20.1403). Given that the Proposed Action under decommissioning does not include remediation, the only alternative addressed herein with respect to environmental monitoring is the No Action alternative under which the existing program would continue to be applied in accordance with current requirements.

This section also summarizes environmental monitoring performed to date and associated results to support the conclusion that depleted uranium (DU) contamination has not migrated offsite in quantities and/or concentrations exceeding any action levels (U.S. Army 2000b). The monitoring program will continue in its present form barring U.S. Nuclear Regulatory Commission (NRC) approval of licensing amendment(s), which authorize modification of the program until license termination.

For JPG, the selected alternative for license termination under restricted conditions involves comparatively very low radiation doses to the average member of the critical group over the required 1,000-year period of evaluation, even in the event of loss of institutional controls. As such, concurrent with license termination, the Army proposes to discontinue implementation of the semi-annual environmental monitoring program and the associated publication of the report entitled "Radiation Monitoring Report for License SUB-1435, Jefferson Proving Ground."

This section includes a summary of protocols that have been employed in the implementation of the site characterization and environmental monitoring programs at JPG. Included in the report is information relative to:

- Locations of monitoring and effluent release points
- Identification of principal radiological exposure pathways (as noted in Section 4.12, principal radiological exposure pathways for uranium penetrators at JPG consist of external exposure and intake of vegetation, which has taken up uranium from contaminated soil)
- Location and characteristics of radiation sources and radioactive effluent (Section 6.1 specifies locations and characteristics of radiation sources, but liquid effluent is not discussed because there is no liquid effluent [i.e., discharge of liquid waste such as from a factory or nuclear plant into the environment from licensed operations] associated with the DU Impact Area)
- Detailed description of the measurement and monitoring program; discussion of sample locations, analyses, frequencies, durations, sizes, and lower limits of detection; and quality assurance (QA) procedures (Section 6.1 summarizes radiological monitoring, Section 6.2 summarizes physicochemical monitoring, and Section 6.3 summarizes ecological monitoring).

## 6.1 RADIOLOGICAL MONITORING

Multiple studies evaluated potential environmental impacts associated with the DU testing program since DU was first used at JPG in 1984 with the primary focus being on potential radiological hazards. For ease of discussion, these studies are described in three distinct parts. Section 6.1.1 discusses site characterization that occurred prior to 2005. This includes studies conducted prior to the commencement of the Environmental Radiation Monitoring (ERM) program as well as several studies conducted after the completion of DU testing related to initial efforts to terminate the Army's Materials License SUB-1435.

Section 6.1.2 discusses results from the ERM program from its inception through sampling conducted in the fall of 2012. This section also discusses the trend analysis that has been conducted for every monitoring point since 2004. Lastly, Section 6.1.3 discusses the radiological monitoring for the 5-year site characterization program. Additional aspects of the 5-year site characterization program, such as well drilling, nonradiological testing, and deer sampling, are discussed in Sections 6.2 and 6.3.

### 6.1.1 Pre-2005 Site Characterization

This section summarizes conclusions and data from studies conducted since DU was first used at JPG in 1984 through 2004 (DU was test fired at JPG from 18 March 1984 to 2 May 1994). These studies generally evaluated potential environmental impacts associated with the DU testing program at JPG. The following bullets summarize several key documents that include additional existing site data, which are followed in Sections 6.1.1.1 and 6.1.1.2 with total uranium data from some of the following studies:

- ***Review of the Environmental Quality Aspects of the U.S. Army Test and Evaluation Command (TECOM) DU Program at JPG, Indiana (Monsanto 1984)***—This document introduced the concept of the DU testing program before it began at JPG in terms of the anticipated environmental consequences of accuracy testing. This document included a description of the planned DU range safety systems and pollution controls. It also included an overview of the physical and environmental characteristics of JPG before DU was used and summarized the results of environmental monitoring data collected at JPG to establish the environmental baseline. Finally, it established an environmental monitoring program related to the use of DU at JPG that continues in a similar form today.
- ***A Review of the Radiological Environmental Monitoring Data at the U.S. Army JPG, Madison, Indiana (EG&G 1988)***—This document describes sampling of various environmental media and biological tissues conducted by EG&G Mound Applied Technologies Corporation (EG&G) after the DU testing program had been initiated. This report examined potential correlations of field investigation data with the use of DU and, in all cases except surface water, the concentration trends appeared to be steady or decreasing. However, the concentrations of DU in surface water appeared to increase steadily. The authors postulated that the increasing concentration trend was potentially due to the lower volume of water available during the summer sampling event and that the overall quantity of DU was probably the same. This trend is notable because the same trend also is apparent in more recent ERM sampling data, which is discussed further in Section 6.1.2.
- ***Environmental Assessment (EA) for Renewal of NRC License for Testing DU at JPG (U.S. Army 1988)***—This document proposed the renewal of the NRC license under the auspices of the National Environmental Policy Act (NEPA) and discussed the effects that testing DU munitions has had at JPG. This EA did not include new DU data collection from the DU Impact Area, but it included a description of the environmental setting, summary of radiological characteristics of DU, and an evaluation of the environmental impacts from the following four alternatives: No Action, build and fire into a sand/earthen backstop, conduct 100 percent recovery, and continue testing DU.
- ***JPG DU Impact Area, Scoping Survey, Report, Volumes 1-3 (SEG 1995)***—The scoping survey was conducted by Scientific Ecology Group (SEG) in 1995 to determine the boundaries of the DU Impact Area. This survey evaluated areas to the north and east of the DU Impact Area as well as radiation surveys along the three affected trajectories from the firing line. The survey included gamma radiation measurements with hand-held instruments in the field and environmental sampling (i.e., soil, groundwater, surface water, sediment, vegetation samples). The sampling results are summarized in Section 6.1.1.1.

- ***JPG DU Impact Area Characterization Survey Report, Volume 1 (SEG 1996)***—A characterization survey of the DU Impact Area was conducted to confirm the amount and extent of uranium activity in the area as determined by the scoping survey. The impacted area was defined as that area that contained radioactivity in excess of 35 picocuries per gram (pCi/g) of DU in soil. In addition, the characterization survey provided estimates of remedial costs, waste volumes, and techniques for DU decontamination. The sampling results are summarized in Section 6.1.1.2.

- ***JPG Data Summary and Risk Assessment (Ebinger and Hansen 1996a)***—This report summarizes the environmental monitoring data collected from 1983 through 1994 and assesses the risk of adverse health effects to humans and the environment due to exposure to DU fragments. This report did not include new DU data collection from the DU Impact Area, but it concluded that recreational use of the DU Impact Area presents immeasurable increases in risk of cancer incidence or death due to cancer and that intensive farming on the impact area could result in significant doses to humans consuming drinking water from the site.

- ***DU Risk Assessment for JPG using Data from Environmental Monitoring and Site Characterization (Ebinger and Hansen 1996b)***—This report documents the third risk assessment completed for the DU munitions testing range at JPG. This report did not include new DU data collection from the DU Impact Area, but it integrates information obtained from site characterization surveys at JPG with environmental monitoring data collected from 1983 through 1994 during DU testing. Three exposure scenarios were evaluated for potential adverse effects to human health: an occasional use scenario and two farming scenarios. Human exposure was minimal from occasional use, but significant risks were predicted from the farming scenarios when contaminated groundwater was used by site occupants. Exposures of white-tailed deer to DU also were estimated in this study, and exposure rates resulted in no significant increase in either toxicological or radiological risks. The results of this study indicated that remediation of the DU Impact Area would not substantially reduce already low risks to humans and the ecosystem, and that managed access to JPG is a reasonable model for future land use options.

- ***Decommissioning Plan and Environmental Report for DU Impact Area, JPG, Indiana (U.S. Army 1999)***—This plan provided TECOM, which was the immediate senior reporting command when JPG was an active military facility, with the information necessary to develop a Decommissioning Plan to be submitted to NRC. This plan did not include new DU data collection from the DU Impact Area, but it included a description of planned decommissioning activities, evaluation of unrestricted and restricted use scenarios, analysis of the site survey and characterization results, and examination of unexploded ordnance (UXO) remediation.

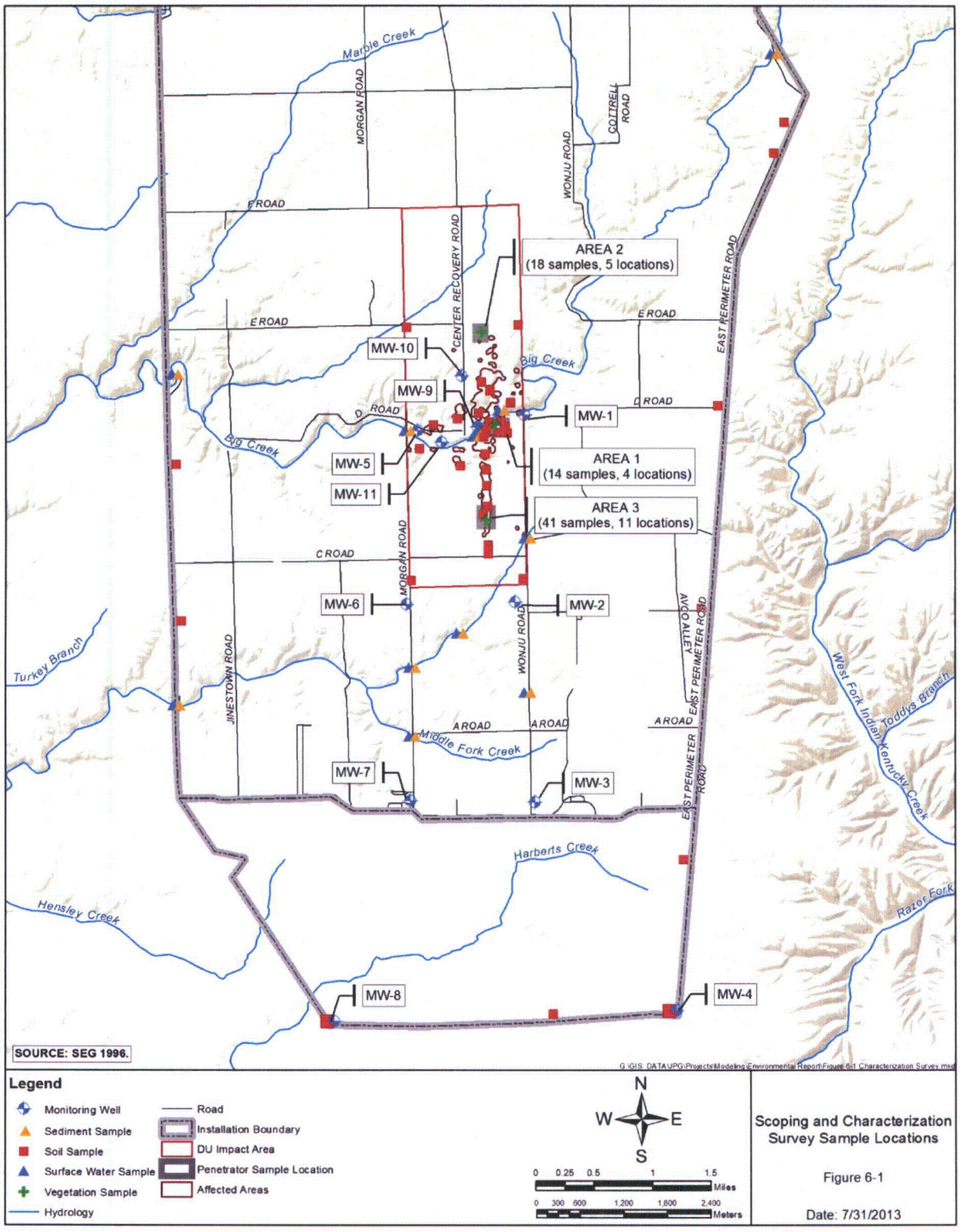
- ***License SUB-1435 Termination Standard Review Plan No. 26-MA-5970-01, JPG, Madison, Indiana (U.S. Army 2001)***—This License Termination Standard Review Plan (SRP) was developed to support NRC Materials License SUB-1435 termination under restricted release conditions for JPG and to describe institutional controls to support the License Termination Plan (LTP). This plan did not include new DU data collection from the DU Impact Area.

- ***Evaluation of JPG for Restricted Release: Risk Assessment Supporting NRC License Termination (Ebinger 2001)***—This document included a risk assessment conducted to support the termination of the Army's radioactive materials license under a restricted release scenario. This plan did not include new DU data collection from the DU Impact Area, but it analyzed risk using existing data to represent the range of potential exposures of humans to DU at JPG under NRC industrial occupant and resident farmer scenarios.

- ***Decommissioning Plan for License SUB-1435, JPG, Madison, Indiana (U.S. Army 2002b)***—The Decommissioning Plan presented the Army's request to terminate Materials License SUB-1435 for possession of DU at JPG under restricted conditions. This plan did not include new DU data collection from the DU Impact Area, but it included additional data analyses and evaluations (e.g., dose modeling, as low as reasonably achievable [ALARA] analysis) to support the license termination request.
- ***Environmental Report, JPG, Madison, Indiana (U.S. Army 2002c)***—The Environmental Report summarized information derived from numerous source documents related to the Army's Proposed Action to terminate its NRC license at JPG. It summarized DU monitoring data that existed at the time the report was prepared and introduced the Proposed Action (i.e., license termination under restricted conditions) and two alternative actions (i.e., No Action and license termination for unrestricted use).
- ***Regional Range Study (U.S. Army 2003a)***—This study was a limited focus investigation of the potential chemical and heavy metal impacts of munitions constituents from former live-fire training operations at JPG. Sampling of soils, surface water, sediment, groundwater, vegetation, and the sperm of a limited number of small mammals was conducted to support screening-level human and ecological risk assessments. Sampling locations for groundwater and soil included several from and near the DU Impact Area. Surface water and sediment sampling was conducted at the entrance and exits points of the installation. Among the munitions constituents assessed in the study was uranium in groundwater, soil, surface water, and sediment. Uranium was one of several metals detected in samples collected from one or more wells at concentrations below the primary maximum contaminant level (MCL). There was an increase in surface water total and dissolved uranium concentrations at midstream and downstream sampling locations in Big Creek, but all concentrations returned to background values by the time Big Creek exited the installation. Sampling during the site characterization from groundwater monitoring wells that were installed during the Range Study is discussed in Section 6.1.3.
- ***ERM Program Plan For License SUB-1435 JPG (U.S. Army 2003b) and ERM Program Plan for License SUB-1435 JPG Addendum (U.S. Army 2004b)***—An environmental monitoring plan was developed for the DU Impact Area before the initial DU munitions were fired in 1984 (Monsanto 1984), and this plan guided sample collection and analysis through 1995. The sampling plan and protocol were updated in 1996 (U.S. Army 1996b) and again in 2000 (U.S. Army 2000b). The ERM Program Plan and Addendum defined the strategy and associated procedures for biannual sampling of environmental media within and surrounding the DU Impact Area at JPG and provided the basis for determining if onsite and offsite receptors are or will be at risk from exposure to DU. The scopes of these plans were limited to the DU Impact Area and its immediate environs to sampling media to determine the presence or absence of DU.
- ***ERM Reports for License SUB-1435 JPG***—These reports summarize the methodology, results, and conclusions of the biannual sampling events based on the procedures established in the ERM Program Plan (U.S. Army 2000b).

#### 6.1.1.1 Summary of Scoping Survey Results

To characterize the nature and extent of DU contamination, scoping and characterization surveys were conducted within the DU Impact Area. The scoping survey consisted of a radiation survey of the DU Impact Area, a radiation survey of the trajectories from the firing line into the DU Impact Area, and environmental sampling and analysis (Figure 6-1). Samples of all media were obtained both within and exterior to the 2,080-acre (ac) (8.4-square kilometer [$km^2$]) DU Impact Area.




Source: SEG 1996

The radiation survey of the DU Impact Area was based on an unbiased, gridded survey with grid lines established at intervals of 164 feet (ft) (50 meters [m]) from north to south on the eastern and western boundaries (SEG 1995). Soil, groundwater, surface water, sediment, and vegetation samples were collected prior to the radiation survey. Table 6-1 summarizes the sampling results from the scoping survey. Detailed results are provided in the scoping survey report (SEG 1995).

**Table 6-1. Scoping Survey Sample Results**
**Jefferson Proving Ground, Madison, Indiana**

| Sample Location | Number of Samples | Total Uranium Range in Concentration |
|---|---|---|
| **DU Impact Area and Environs** | | |
| Soil | 50 | 1.35-201 pCi/g |
| Sediment | 11 | 0.42-1.9 pCi/g |
| Surface Water | 12 | 0.21-3.6 pCi/L |
| Vegetation | 14 | 0.01-0.50 pCi/g |
| **Trajectory Locations*** | | |
| Soil | 12 | 1.42-1.87 pCi/g |
| Sediment | 2 | 2.03-3.08 pCi/g |
| Surface Water | 2 | 0.35-0.88 pCi/L |
| Groundwater | 11 | 0.43-3.6 pCi/L |
| Vegetation | 6 | 0.06-0.65 pCi/g |

Source: Compiled from SEG 1995
* Samples were collected at different points in alignment with the lines of fire.
DU = depleted uranium
pCi/L = picocuries per liter
pCi/g = picocuries per gram

### 6.1.1.2 Summary of Characterization Survey Results

The characterization survey was completed after the scoping survey and it included the collection of exposure rate and gamma spectrometry measurements and soil, groundwater, surface water, sediment, vegetation, and biological samples. Background sampling was completed for surface and subsurface soil (10 locations), groundwater (6 locations), surface water (3 locations), and sediment (3 locations). All samples were analyzed by alpha spectrometry for uranium-234 (U-234), uranium-235 (U-235), and uranium-238 (U-238). Table 6-2 summarizes the sampling results from the characterization survey. Detailed results are provided in the characterization survey report (SEG 1996). Figure 6-1 shows the sampling locations for environmental media collected in support of the characterization survey.

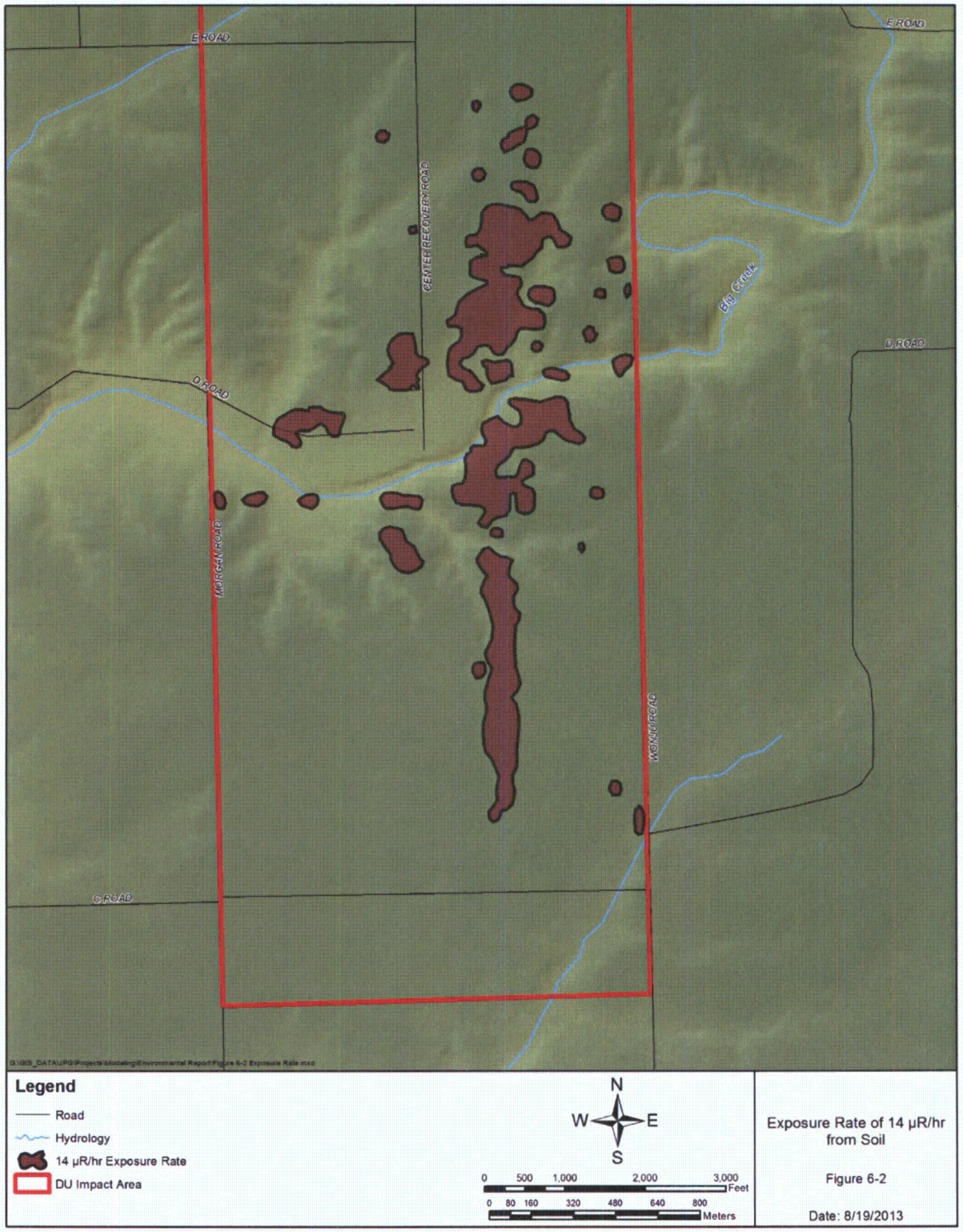
To further define the affected area, the relationship between the average concentration of DU in the ground and exposure rate was analyzed to determine isotopic concentrations from the gamma spectrometry data collected with field instruments. These measurements were obtained with the same instrument used in the scoping survey (SEG 1995).

At each location, a single gamma spectrometry measurement yielded the total inventory of activity for each nuclide presented as an area of activity-concentration at the surface. Using these results, the concentrations of thorium-234 (Th-234) and polonium-234m (Po-234m) were calculated for depth ranges of 0 to 5.9 inches (in) (0 to 15 centimeter [cm]), 5.9 to 11.8 in (15 to 30 cm), and 11.8 to 17.7 in (30 to 45 cm) below ground surface (BGS). The specific assumptions used to determine this relationship are presented in SEG (1996). The exposure rate corresponding to a DU concentration of 35 pCi/g is 14.4 microRoentgens per hour (μR/hr). The contour map showing areas with an exposure rate greater than 14.4 μR/hr is shown in Figure 6-2.

## Table 6-2. Summary of Characterization Survey Results Jefferson Proving Ground, Madison, Indiana

| Environmental Medium | Number of Samples | Total Uranium Range in Concentration (pCi/g) | Average Concentration (pCi/g) |
|---|---|---|---|
| **Background:** | | | |
| 0-15 | 10 | 1.52-2.53 | 1.97 |
| 15-30 | 10 | 1.33-2.59 | 1.84 |
| 30-45 | 10 | 1.33-2.76 | 1.95 |
| **Penetrator Soil Samples:** | | | |
| 0-15 | 20 | 2.9-12,318 | 2,881 |
| 15-30 | 20 | 1.5-547 | 79.5 |
| 30-45 | 20 | 1.8-63 | 12.7 |
| 45-60 | 13 | 1.4-11.5 | 4.50 |
| **Random Soil Samples:** | | | |
| 0-15 | 20 | 1.46-4.73 | 2.60 |
| 15-30 | 20 | 1.51-6.91 | 2.40 |
| 30-45 | 20 | 1.34-4.21 | 2.00 |
| **Other Media:** | | | |
| Surface Water | 10 | 0.62-25.02 | 3.55 |
| Sediment | 10 | 0.75-6.20 | 2.5 |

Source: Compiled from SEG 1996
BGS = below ground surface
pCi/g = picocuries per gram




Source: SEG 1996

### 6.1.2 ERM Results

As mentioned above, a comprehensive environmental monitoring program has been employed at JPG from initiation of DU testing to the present day. Sampling locations for soils, surface water, and groundwater are shown in Figure 6-3 from the environmental monitoring plan (U.S. Army 2000b). Samples have been collected and analyzed semiannually for total uranium and, often, the isotopic composition of uranium in samples. The environmental sampling data are summarized for the 1984 to 1994 period (Ebinger and Hansen 1996a) (Table 6-3). Sampling conducted since 2000 yielded similar results; no increasing or decreasing trends were identified and all results are below action levels (CHPPM 2001; 2002a,b; U.S. Army 2003b, 2013).

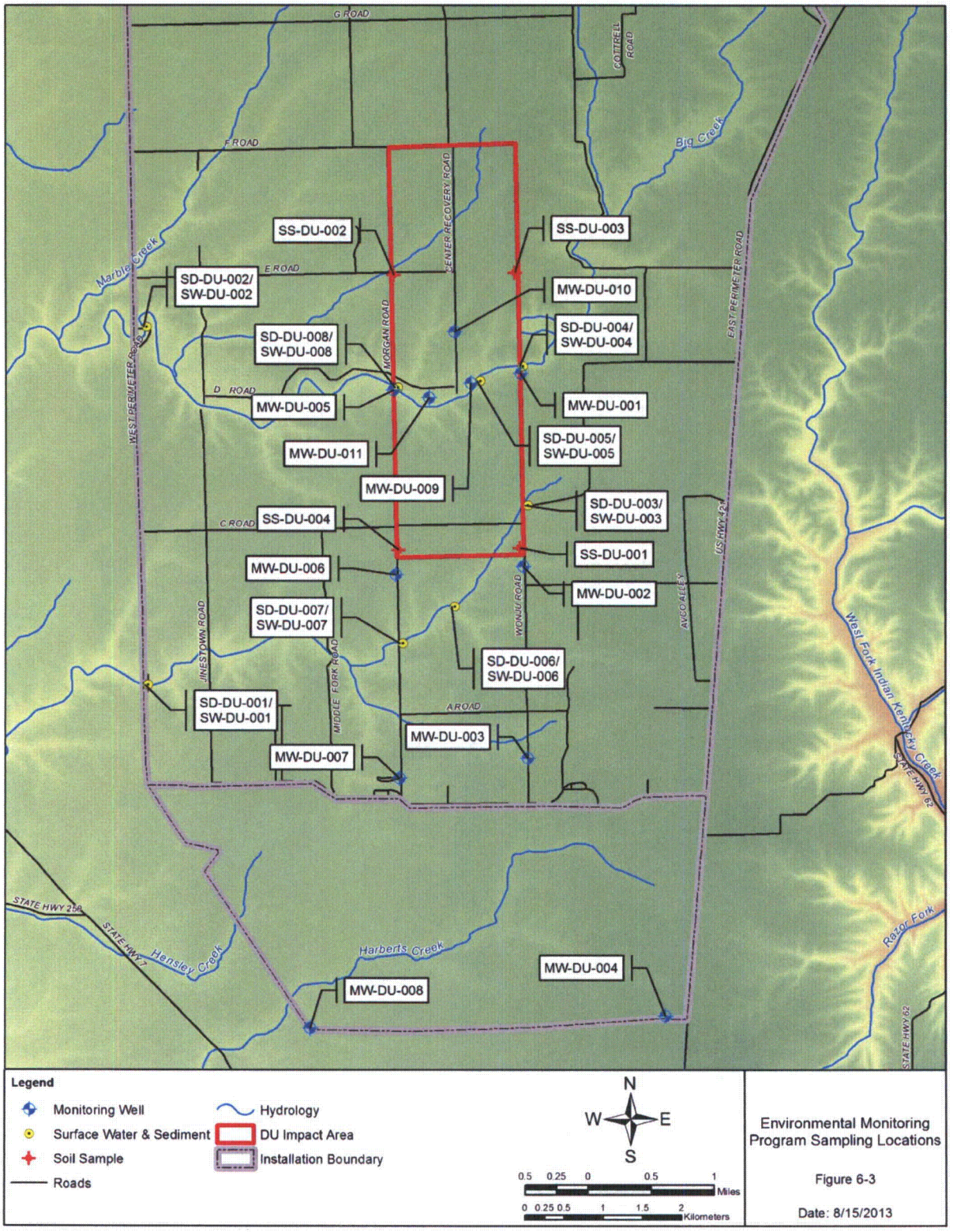
The environmental data indicate that the expected concentrations of uranium or DU are significantly less than the derived concentration guideline (DCGL) of 35 pCi/g for soil and 150 picocuries per liter (pCi/L) for surface water and groundwater (U.S. Army 2000b). Soil concentration data for the DU Impact Area from 1984 to 1994 are skewed left with a mean value of 19 pCi/g and a median value of 1.5 pCi/g; the standard deviation of these samples is almost 200 pCi/g. Of nearly 400 soil samples analyzed since 1984, most are less than 2 pCi/g, which is consistent with the average background soil concentration of uranium at JPG. Additional results from surface soil sampling are discussed in Section 6.1.2.4.

Similar distributions for DU concentrations in groundwater and surface water were obtained for the same period (Table 6-3). In addition, uranium activity contained in surface water and groundwater samples are present at concentrations that are a small percentage of the applicable 150 pCi/L action level (i.e., 50 percent of the water effluent standards specified in 10 CFR 20, Appendix B [U.S. Army 1996b]).

Several monitoring wells were completed around the DU firing range between 1984 and 1994. These wells were drilled to various depths that ranged to more than 40 ft from the surface (SEC Donohue 1992). The groundwater data from these wells showed some variation in the concentrations of uranium in wells between 1984 and 1994, with the largest variation being attributed to issues involving analytical laboratories (Ebinger and Hansen 1996a,b). Overall, the data indicated that there was not significant movement of DU to the groundwater from the DU Impact Area between 1984 and 1994. This conclusion was further supported by the isotopic composition of uranium in the groundwater samples (Ebinger and Hansen 1996a,b). Additional results from surface water sampling are discussed in Section 6.1.2.1.

Surface water samples from monitoring locations on Big Creek upstream and downstream from the DU Impact Area varied in uranium and DU concentration during the 1984 to 1994 period, but there was neither a long-term elevation of the concentration, nor sustained, elevated concentrations at any sampling site. The observed variation in surface water samples could be attributable in part to uranium present in geologic deposits or as a trace constituent of phosphate fertilizer (Ebinger and Hansen 1996a,b). Isotopic ratios of these samples indicate that most of the observed variation was due to natural uranium in surface water and not DU, but some surface water samples appear to show the presence of DU. Irrespective of the source of the uranium, it is notable that the concentrations encountered were well below water effluent limits specified in 10 CFR 20, Appendix B, and the Army DCGLs (U.S. Army 1996b), as applicable, and are low enough to be of little concern. Additional results from surface water sampling are discussed in Section 6.1.2.2.

In March 2000, the U.S. Army Center for Health Promotion and Preventive Medicine (CHPPM) (subsequently reorganized as the U.S. Army Public Health Command's Army Institute of Public Health) published the standard operating procedure (SOP) entitled "Depleted Uranium Sampling Program, Environmental Radiation Monitoring Program SOP Number OHP 40-2" (U.S. Army 2000b). This SOP specifies the protocol for the collection and analysis of 11 groundwater, 8 surface water, 8 sediment, and 4 surface soil samples (with appropriate duplicates) in and around the DU Impact Area (Figure 6-3). This


G ROAD
F ROAD
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D ROAD
C ROAD
A ROAD
GOTTREL ROAD
Big Creek
CENTER RECOVERY ROAD
MORGAN ROAD
WONJU ROAD
EAST PERIMETER ROAD
WEST PERIMETER ROAD
JINESTOWN ROAD
MIDDLE FORK ROAD
AVCO ALLEY
US HWY 421
Marble Creek
West Fork Indian Kentucky Creek
STATE HWY 62
STATE HWY 52
STATE HWY 7
Hensley Creek
Harberts Creek
Razor Fork
SS-DU-002
SS-DU-003
SD-DU-002/ SW-DU-002
MW-DU-010
SD-DU-008/ SW-DU-008
SD-DU-004/ SW-DU-004
MW-DU-005
MW-DU-001
MW-DU-011
SD-DU-005/ SW-DU-005
MW-DU-009
SD-DU-003/ SW-DU-003
SS-DU-004
SS-DU-001
MW-DU-006
MW-DU-002
SD-DU-007/ SW-DU-007
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SD-DU-001/ SW-DU-001
MW-DU-003
MW-DU-007
MW-DU-004
MW-DU-008
Legend
Monitoring Well
Surface Water & Sediment
Soil Sample
Roads
Hydrology
DU Impact Area
Installation Boundary
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0.5 0.25 0 0.5 1
Miles
0 0.25 0.5 1 1.5 2
Kilometers
Environmental Monitoring Program Sampling Locations
Figure 6-3
Date: 8/15/2013

**Table 6-3. Descriptive Statistics of Total Uranium in ERM Samples (1984-1994) Jefferson Proving Ground, Madison, Indiana**

| Statistic | Soil (pCi/g) | Groundwater (pCi/L) | Surface Water (pCi/L) |
|---|---|---|---|
| Mean | 19 | 2.7 | 1.6 |
| Median | 1.5 | 1.3 | 0.26 |
| Standard Deviation | 200 | 5.6 | 5.6 |
| Minimum | -0.8 | -0.1 | -1.2 |
| Maximum | 3,900 | 81 | 49 |
| Number of Samples | 388 | 365 | 312 |

Measurement data is rounded to two significant digits.
Source: Ebinger and Hansen 1996
pCi/g = picocuries per gram
pCi/L = picocuries per liter

semi-annual plan, which was approved by NRC, continues to fulfill the Army's responsibilities for monitoring under NRC Radioactive Materials License SUB-1435 (U.S. Army 2000b).

An assessment of historical trends for ERM program data was first provided in the April 2006 Radiation Monitoring Report (U.S. Army 2006). That assessment focused on available sampling data for groundwater, surface water, sediment, and soil since 1998. QA/quality control (QC) records for data collected prior to 1998 were not available to support the trend analyses. In addition, there were changes to analytical methods that were implemented beginning in December 2004. Therefore, although historical data are reported beginning in 1998, trend analyses included in the ERM reports addresses the time period from December 2004 to the present. In addition, surface water and groundwater results for the April 2004 sampling event were not trended as the results were provided in mass units rather than radiological units and information was not available with respect to accurate unit conversions (U.S. Army 2006). Sections 6.1.2.1 through 6.1.2.5 summarize the ERM data to include groundwater, surface water, sediment, and surface soil sampling results from December 2004, when laboratory analytical methods were revised and standardized, through October 2012 (i.e., the most recently available report).

### 6.1.2.1 Groundwater

For 202 discrete samples (inclusive of duplicates) available from 11 monitoring wells (MW-DU-001 to MW-DU-011) during the period from December 2004 through October 2012, the average total uranium activity-concentration is 1.4 pCi/L, the standard deviation is 1.2 pCi/L, and the maximum detected activity-concentration is 5.7 ± 0.6 pCi/L. The activity-concentrations for each well are clearly significantly less than both the U.S. Environmental Protection Agency (USEPA) drinking water standard for uranium of 30 micrograms per liter (μg/L) and the 150 pCi/L action level for groundwater (i.e., 50 percent of the water effluent concentration limit for uranium prescribed in 10 CFR 20, Appendix B). Table 6-4 summarizes groundwater sampling results by groundwater monitoring well.

U-238/U-234 ratios were reviewed for the period June 2004 to the present, excluding the spring of 2005 for which information has not currently been located. In addition, the June 2004 report included results only for soil and sediment. The only groundwater sample that appears to have exhibited a U-238/U-234 ratio exceeding 3.0 was the sample collected from MW-DU-001 in October 2008. The ratio was 5.99 ± 0.75. This ratio was not seen in subsequent sampling and, as shown in Table 6-4, the total uranium concentrations from this well have been comparatively low with mean total uranium concentrations ranging from 0.3 to 1.3 pCi/L. Additional information about potential trends observed in samples collected from this and other groundwater wells may be found in the most recent ERM report (U.S. Army 2013d).

**Table 6-4. Summary of JPG Groundwater Data (December 2004-October 2012) Jefferson Proving Ground, Madison, Indiana**

| Monitoring Well Location | Range of Total Uranium (pCi/L)* | Mean and Standard Deviation of Total Uranium (pCi/L)* |
|---|---|---|
| MW-DU-001 | 0.3-1.3 | 0.54 ± 0.28 |
| MW-DU-002 | 0.59-4.5 | 1.8 ± 1.0 |
| MW-DU-003 | 0.52-1.7 | 1.0 ± 0.3 |
| MW-DU-004 | 0.19-3.1 | 1.3 ± 0.9 |
| MW-DU-005 | 0.11-0.81 | 0.43 ± 0.19 |
| MW-DU-006 | 1.6-5.7 | 3.8 ± 1.1 |
| MW-DU-007 | 0.81-2.7 | 2.0 ± 0.4 |
| MW-DU-008 | 0.23-0.92 | 0.54 ± 0.17 |
| MW-DU-009 | 0.9-1.9 | 1.3 ± 0.3 |
| MW-DU-010 | 2.0-3.2 | 2.7 ± 0.3 |
| MW-DU-011 | 0.0-0.62 | 0.26 ± 0.17 |
| Overall (202 data points) | 0.115.7 | 1.4 ± 1.2 |

*Data rounded to two significant digits.

### 6.1.2.2 Surface Water

For 145 discrete samples (inclusive of duplicates) available from 8 surface water sampling locations (SW-DU-001 to SW-DU-008) collected during the period from December 2004 through October 2012, the average total uranium activity-concentration is 0.88 pCi/L, the standard deviation is 2.4 pCi/L, and the maximum detected activity-concentration is 19 ± 2 pCi/L. The activity-concentrations for each surface water sampling location exhibit average concentrations, which are significantly less than both the USEPA uranium drinking water standard of 30 μg/L and the 150 pCi/L action level for groundwater (i.e., 50 percent of the water effluent concentration limit for uranium prescribed in 10 CFR 20, Appendix B) with the highest individual result (i.e., 19 pCi/L) being about 6 percent of the water effluent concentration limit. Table 6-5 summarizes surface water sampling results.

**Table 6-5. Summary of JPG Surface Water Data (December 2004-October 2012) Jefferson Proving Ground, Madison, Indiana**

| Surface Water Location | Range of Total Uranium (pCi/L)* | Mean and Standard Deviation of Total Uranium (pCi/L)* |
|---|---|---|
| SW-DU-001 | 0.2-1.5 | 0.42 ± 0.32 |
| SW-DU-002 | 0.21-0.90 | 0.48 ± 0.28 |
| SW-DU-003 | 0.036-3.5 | 0.53 ± 0.88 |
| SW-DU-004 | 0.10-16 | 1.9 ± 4.5 |
| SW-DU-005 | 0.13-19 | 2.4 ± 4.7 |
| SW-DU-006 | 0.04-1.1 | 0.30 ± 0.03 |
| SW-DU-007 | 0.09-0.21 | 0.29 ± 0.21 |
| SW-DU-008 | 0.12-1.3 | 0.59 ± 0.36 |
| Overall (145 data points) | 0.04-19 | 0.88 ± 2.4 |

*Data rounded to two significant digits.

U-238/U-234 ratios were reviewed for the period June 2004 to the present, excluding the spring of 2005 for which information has not currently been located. In addition, the June 2004 report included results only for soil and sediment. Table 6-6 lists the 15 surface water samples that appear to have exhibited U-238/U-234 ratios exceeding 3.0.

Surface water samples SW-DU-006, SW-DU-007, and SW-DU-008 are of particular importance given their locations and their potential for offsite releases via the surface water pathway:

- SW-DU-006 is located a short distance south of the DU Impact Area adjacent to Middle Fork Creek

**Table 6-6. U-238/U-234 Ratios in Surface Water Data Exceeding 3.0**
**Jefferson Proving Ground, Madison, Indiana**

| Sample Collection Date | Surface Water Location | U-238/U/234 Ratio |
|---|---|---|
| April 2006 | SW-DU-002 | 3.75 |
| April 2006 | SW-DU-008 | 3.08 |
| October 2006 | SW-DU-006 | 2.65 ± 2.02 |
| October 2007 | SW-DU-005 | 6.3 |
| October 2007 | SW-DU-008 | 2.16 ± 1.0 |
| October 2008 | SW-DU-005 | 7.02 ± 1.38 |
| October 2008 | SW-DU-008 | 3.58 ± 0.18 |
| April 2009 | SW-DU-003 | 2.15 ± 2.71 |
| October 2010 | SW-DU-005 | 7.79 ± 0.08 |
| October 2010 | SW-DU-004/SW-DU-004D | 6.36/6.63 |
| October 2011 | SW-DU-002 | 3.8 ± 1.8 |
| October 2011 | SW-DU-008 | 3.5 ± 1.7 |
| April 2012 | SW-DU-003 | 3.1 ± 5.3 |
| April 2012 | SW-DU-004 | 2.8 ± 3.9 |
| April 2012 | SW-DU-006 | 1.7 ± 2.0 |

- SW-DU-007 is located south of the DU Impact Area where Middle Fork Creek crosses Morgan Road (i.e., south of but parallel to the western boundary of the DU Impact Area)
- SW-DU-008 is located adjacent to Big Creek where it exits the DU Impact Area.

The maximum surface water concentrations at these locations are 1.1, 0.21, and 1.3 pCi/L for SW-DU-006, SW-DU-007, and SW-DU-008, respectively. Each of these maximum results equates to less than 1 percent of the uranium in water effluent concentration limit prescribed by 10 CFR 20, Appendix B. In addition, it is notable that the 95 percent upper confidence limit on the arithmetic mean (UCL-95) (i.e., 0.88 ± 2.4 pCi/L) equates to about one-third of the USEPA uranium drinking water standard of 30 µg/L. Additional information about potential trends observed in samples collected from these same locations may be found in the most recent ERM report (U.S. Army 2013b).

### 6.1.2.3 Sediment

For 151 discrete samples (inclusive of duplicates) available from 8 sediment sampling locations (SD-DU-001 to SD-DU-008) during the period from December 2004 through October 2012, the average total uranium activity-concentration is 0.97 pCi/g, the standard deviation is 0.49 pCi/g, and the maximum detected activity-concentration is 2.4 ± 0.4 pCi/g. The activity-concentrations at each location are well below the 35 pCi/g action level, which has historically served as a common DCGL for uranium in surface soils, although DCGLs for sediments are typically much higher than the value used for surface soils. Table 6-7 summarizes sediment sampling results.

**Table 6-7. Summary of JPG Sediment Data (December 2004-October 2012)**
**Jefferson Proving Ground, Madison, Indiana**

| Sediment Location | Range of Total Uranium (pCi/g)* | Mean and Standard Deviation of Total Uranium (pCi/g)* |
|---|---|---|
| SD-DU-001 | 0.36-1.9 | 1.2 ± 0.48 |
| SD-DU-002 | 0.35-1.6 | 0.91 ± 0.36 |
| SD-DU-003 | 0.75-2.2 | 1.5 ± 0.4 |
| SD-DU-004 | 0.21-2.4 | 0.57 ± 0.51 |
| SD-DU-005 | 0.28-0.94 | 0.59 ± 0.19 |
| SD-DU-006 | 0.43-1.6 | 1.0 ± 0.36 |
| SD-DU-007 | 0.41-1.9 | 1.2 ± 0.19 |
| SD-DU-008 | 0.19-1.9 | 0.87 ± 0.50 |
| Overall (151 data points) | 0.19-2.4 | 0.97 ± 0.49 |

*Data rounded to two significant digits.

### 6.1.2.4 Surface Soils

For 91 discrete samples (inclusive of duplicates) available from 4 surface soil sampling locations (SS-DU-001 to SS-DU-004) during the period from 2004 through October 2012, the average total uranium activity-concentration is 1.5 pCi/g, the standard deviation is 0.3 pCi/g, and the maximum detected activity-concentration is 2.2 ± 0.5 pCi/g. The activity-concentration at each location is well below the action level of 35 pCi/g. Surface soil data are summarized in Table 6-8.

**Table 6-8. Summary of JPG Surface Soil Data (December 2004-October 2012) Jefferson Proving Ground, Madison, Indiana**

| Surface Soil Location | Range of Total Uranium (pCi/g)* | Mean and Standard Deviation of Total Uranium (pCi/g)* |
|---|---|---|
| SS-DU-001 | 1.2-2.2 | 1.7 ± 0.28 |
| SS-DU-002 | 0.36-2.1 | 1.6 ± 0.33 |
| SS-DU-003 | 1.0-1.7 | 1.4 ± 0.2 |
| SS-DU-004 | 0.80-2.1 | 1.4 ± 0.33 |
| Overall (91 data points) | 0.36-2.2 | 1.5 ± 0.31 |

*Data rounded to two significant digits.

### 6.1.2.5 Comparison of Sediment and Surface Soil Concentrations to Site Surface Soil Background

A comprehensive background study performed in the fall of 2008 and spring of 2012 assessed the presence of uranium in a variety of soil types (i.e., Avonburg/Cobbsfork, Cincinnati/Rossmoyne, and Grayford/Ryker) for surface soils (i.e., uppermost 0.5 ft BGS) and for subsurface soils at depths below ground surface of 0.5 to 1, 1 to 2, and 2 to 4 ft BGS. Nine background surface soil samples were collected for each of the cited soil type groupings. Results reflected means of 1.5 ± 0.1 pCi/g for Avonburg/Cobbsfork, 1.6 ± 0.2 pCi/g for Cincinnati/Rossmoyne, and 1.5 ± 0.2 pCi/g for Grayford/Ryker with an overall mean of 1.5 ± 0.2 pCi/g for all 127 samples. This background data reflects two significant digits and two standard deviation errors.

Comparison of sediment and surface soil results listed in Tables 6-7 and 6-8, respectively, with site background surface soil data supports the conclusion that the uranium present at each of the four surface soil locations and at each of the nine sediment sampling locations is within the range of surface soil background. In addition, with respect to sediment, it is notable that the mean and associated standard deviation for each sediment sampling location are within the range of surface soil background and do not reflect a buildup of DU.

### 6.1.2.6 Future Implementation of Environmental Monitoring

A comprehensive environmental monitoring program has been employed at JPG from initiation of DU testing to the present. This program supports the conclusion that DU has not migrated offsite in quantities exceeding any action levels. The current ERM program will continue to be implemented using existing protocols and procedures until the results of the site characterization in Section 6.1.3 can be used to modify the existing ERM program SOP (U.S. Army 2000b), which will be implemented until NRC terminates the Army's Materials License SUB-1435.

### *6.1.3 Site Characterization*

Although none of the existing reports provides conclusive evidence of elevated levels of DU migrating outside the DU Impact Area, the Army's responses (U.S. Army 2004a) to the NRC-issued Requests for Additional Information (RAIs) (NRC 2004a,b) pointed to an incomplete understanding of the conceptual site model (CSM) and gaps in the current set of site characterization data. Therefore, these RAIs formed the basis of the approach for site characterization that was completed between 2005 and

2013. This site characterization started with the development of a Field Sampling Plan (FSP) (SAIC 2005) and supporting addenda to the FSP (SAIC 2006b,c; 2007a,b; 2008a,b,c,d; 2009).

The FSP included details only for the earlier years of the overall project schedule. Details for the latter years were provided in addenda to the FSP following an iterative and adaptive approach for site characterization. This approach served as a foundational element of the FSP and necessitated frequent meetings, teleconferences, and written transmittals between the Army, NRC, and contractor personnel. The letter dated 26 April 2006 from the NRC to the Army stated that "...NRC anticipates having annual (or more frequent) meetings at NRC headquarters, open to the public, to discuss the Army's progress in completing the site characterization and new decommissioning plan. These meetings should occur prior to the initiation of significant planned field activities, such as determining the number and location of new monitoring wells" (NRC 2006a). Eight meetings and 11 teleconferences involving Army, NRC, and contractor personnel were held to discuss results and conclusions of completed studies, status of ongoing work, and plans for upcoming work. In addition, 17 letters and other correspondence were exchanged to ensure Army/NRC coordination of site characterization activities for the JPG DU Impact Area for Materials License SUB-1435. These meetings, teleconferences, and correspondence are enumerated in Section 1 of the Decommissioning Plan (U.S. Army 2013a).

The Army submitted the FSP (SAIC 2005) to NRC to augment the Army's strategy for site characterization, including plans to collect data to support offsite transport modeling, which were included in a January 2005 letter to the NRC (U.S. Army 2005). The FSP identified the key problems:

- Limited understanding of the nature and extent of contamination in the DU Impact Area
- Limited understanding of the potential fate and transport of DU outside the DU Impact Area.

The enhanced understanding gained by completing tasks specified in the FSP (SAIC 2005) will serve as the basis for modifying the current ERM program and serving as the foundation to initiate decommissioning. NRC issued the following RAIs and the comment on groundwater action level (NRC 2004a). This information details the data needs addressed in the FSP (SAIC 2005):

- ***Question 1, CSM***—The Army should provide additional information on the CSM that was used originally to locate the sampling points for groundwater, surface water, and stream sediments. The CSM of the hydrologic system for the DU Impact Area should include all potential water-bearing units, surface water systems, caves, springs, and the unsaturated zone that may be impacted by the degradation and movement of the DU penetrators. The Army should provide information on the interrelationship between DU concentrations in the groundwater, surface water, caves, springs, and stream sediments.
- ***Question 2, Groundwater Flow and Well Placement***—There appears to be conflicting information on the direction of groundwater flow. The Army should provide additional information on the adequacy of the placement (and screened interval), number, and spacing of the current 11 monitoring wells to detect DU in groundwater.
- ***Question 3, Well Construction Details***—The Army should provide additional information on the construction, development, and maintenance of the current 11 monitoring wells.
- ***Question 4, Groundwater and Surface Water Relationships***—The Army should provide additional information on the relationship between stream flow in Big Creek and Middle Fork Creek, and DU concentrations in surface water and stream sediments. The Army should describe how DU concentration in the surface water and stream sediments vary during high, average, and low stream flow conditions. The Army also should state if its corrective measures first proposed in 1984, to be taken if the surface water action level is exceeded, are still current.
- ***Question 5, Penetrator Dissolution Rate and DU Solubility***—The Army should provide additional information on the rate of dissolution of the penetrators. The Army also should provide data on the solubility of DU.

- ***Question 6, Groundwater Corrective Measures***—The Army should state if its corrective measures first proposed in 1984, to be taken if the groundwater action level is exceeded, are still current.
- ***Question 7, Uranium Concentrations in Deer***—The Army should provide additional information on the apparent trend of increasing uranium concentration in deer kidneys and bone, and how this relates to the potential for DU in deer meat that is consumed by humans.
- ***Cover Letter Comment on Groundwater Action Level***—The staff has discussed the groundwater action level proposed in the ERM with the Army and the Army has indicated that the action level for DU in groundwater in the impact area should be changed. Please include this modification to the action level with your response to the requests for additional information.

The Army submitted responses to the RAIs in November 2004 (U.S. Army 2004a) and addressed the Army's revised position on the subject action level.

A central concept to understand for the site-specific problem was articulated in the dose assessment in support of the Decommissioning Plan for Materials License SUB-1435 (U.S. Army 2013a) that indicated, "Doses to humans and ecosystem receptors can come from any number of exposure pathways beginning when the munitions are tested and lasting until the DU is removed from the system. Thus, the dose to humans from DU must be assessed for a variety of pathways, and for a relatively long time due to slow transport through the soils." Appendix C includes the CSM, including a graphical representation and written description of the DU sources, transport mechanisms, potential exposure pathways, and potential receptors. This CSM has been revised with respect to information obtained during the tiered, time-phased site characterization activities that allowed for decisions at intermediate milestones regarding the need for collecting additional site data. Subsequent tasks and associated activities were planned and detailed as addenda to the FSP (SAIC 2006b,c; 2007a,b; 2008a,b,c,d; 2009). The FSP (SAIC 2005) and related addenda described numerous activities including four consecutive quarters of groundwater, surface water, and sediment sampling in April 2008, July 2008, October 2008, and February 2009. Extensive soil sampling was completed in October 2008, December 2009, and March 2012. The following sections summarize results from the sampling of groundwater (Section 6.1.3.1), surface water (Section 6.1.3.2), sediment (Section 6.1.3.3), and soil (Section 6.1.3.4).

### 6.1.3.1 Groundwater Sampling

Groundwater sampling was conducted during four consecutive quarters (i.e., April 2008, June 2008, October 2008, and January 2009) with one event (October 2008) occurring during the expected low point in the hydrologic year and another event (April 2008) occurring near the expected high point in the hydrologic year. Samples were collected from the 19 existing groundwater monitoring wells in addition to the 23 newly installed wells listed in Table 6-9 and shown in Figure 6-4. Eight of the existing wells were installed in August 2002 during the Army's Range Study (U.S. Army 2003a). Eleven of the existing wells were installed in December 1983 and September 1988 and have been sampled as part of the semi-annual ERM program since being installed. All of the existing wells listed in Table 6-9 were re-developed and locations were re-surveyed in accordance with the procedures for developing and surveying new wells, as described in FSP Addendum 4 (SAIC 2007b).

Samples were collected from 42 groundwater monitoring wells, including 11 ERM wells, 5 wells installed in the soil overburden, 9 wells installed in shallow/weathered bedrock, 9 wells installed in deep bedrock, and 8 Range Study wells. Sections 6.2.3 through 6.2.5 describe the phased and progressive approach for identifying groundwater flow pathways and installing wells to intercept those flow pathways for use in characterizing groundwater. Section 6.2.5 describes the installation of the wells, conditions encountered and observations made during drilling, and conclusions derived from the subsequent evaluation of drilling logs after the completion of the drilling and well development activities. It also

## Table 6-9. Summary of Site and Background Wells by Hydrostratigraphic Unit Jefferson Proving Ground, Madison, Indiana

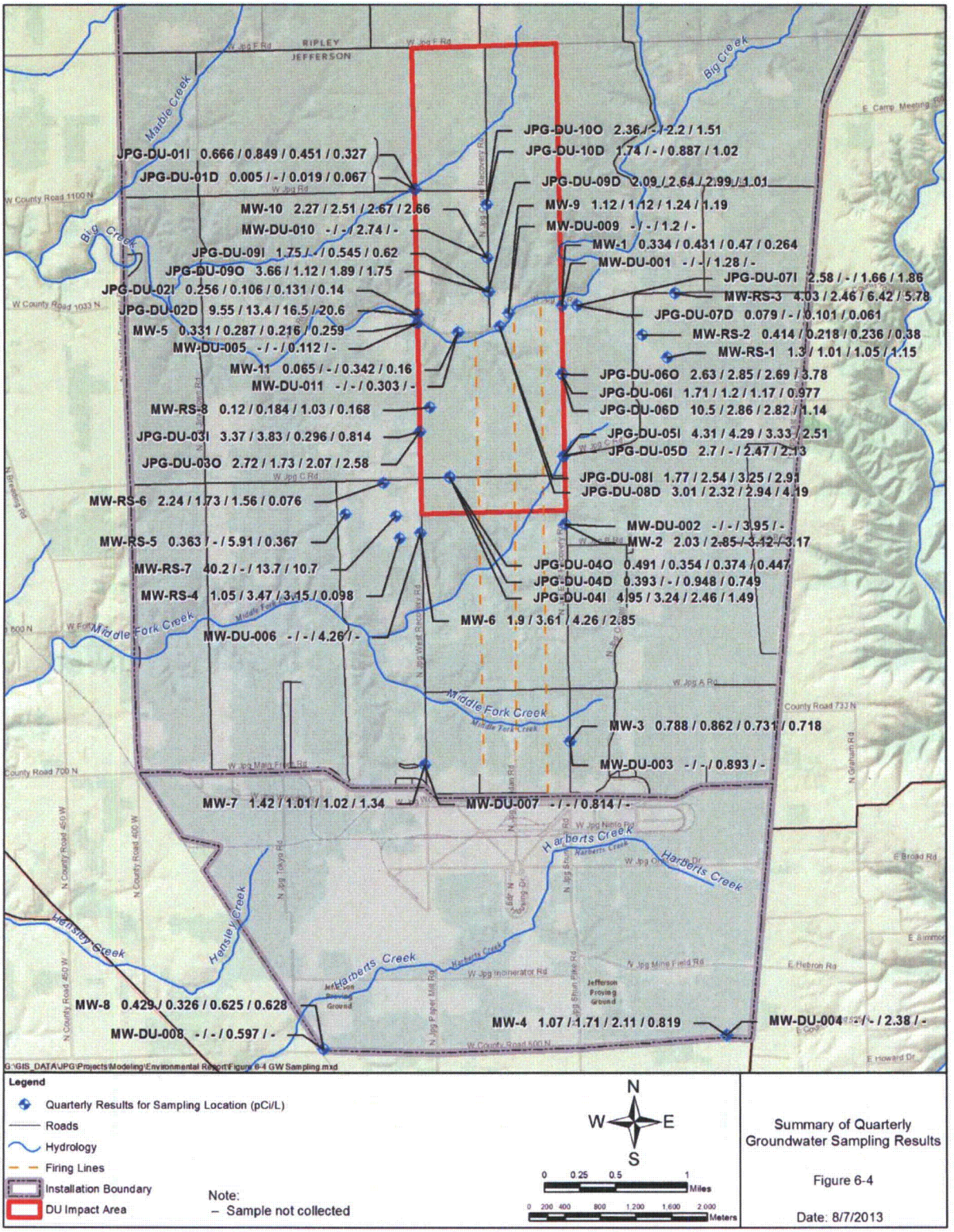
| Overburden | | Shallow Bedrock | | Deep Bedrock |
|---|---|---|---|---|
| ***Background Wells*** | | | | |
| MW-RS1 | | JPG-DU-07I | MW-7 | JPG-DU-07D |
| MW-RS3 | | MW-3 | MW-8 | |
| | | MW-4 | MW-RS2 | |
| ***Site Wells*** | | | | |
| JPG-DU-03O | MW-RS4 | JPG-DU-01I | JPG-DU-09I | JPG-DU-01D |
| JPG-DU-04O | MW-RS5 | JPG-DU-02I | JPG-DU-10I | JPG-DU-02D |
| JPG-DU-06O | MW-RS6 | JPG-DU-03I | MW-1 | JPG-DU-04D |
| JPG-DU-09O | MW-RS7 | JPG-DU-04I | MW-2 | JPG-DU-05D |
| JPG-DU-10O | MW-RS8 | JPG-DU-05I | MW-5 | JPG-DU-06D |
| MW-6 | | JPG-DU-06I | MW-9 | JPG-DU-08D |
| MW-10 | | JPG-DU-08I | MW-11 | JPG-DU-09D |

Nomenclature for 42 groundwater monitoring wells:

- 11 ERM wells = MW-x or MW-DU-xxx
- 5 site characterization wells installed in overburden: JPG-DU-xxO
- 9 site characterization wells installed in shallow bedrock (intermediate wells): JPG-DU-xxI
- 9 site characterization wells installed in deep bedrock: JPG-DU-xxD
- 8 Range Study wells: MW-RS-x

3 Hydrostratigraphic Units:

- 14 overburden wells include 2 background and 12 site wells
- 20 shallow bedrock wells include 6 background and 14 site wells
- 8 deep bedrock wells include 1 background and 7 site wells


RIPLEY
JEFFERSON
Marble Creek
Big Creek
Middle Fork Creek
Harberts Creek
Hemsley Creek
JPG-DU-01I 0.666 / 0.849 / 0.451 / 0.327
JPG-DU-01D 0.005 / - / 0.019 / 0.067
MW-10 2.27 / 2.51 / 2.67 / 2.66
MW-DU-010 - / - / 2.74 / -
JPG-DU-09I 1.75 / - / 0.545 / 0.62
JPG-DU-09O 3.66 / 1.12 / 1.89 / 1.75
JPG-DU-02I 0.256 / 0.106 / 0.131 / 0.14
JPG-DU-02D 9.55 / 13.4 / 16.5 / 20.6
MW-5 0.331 / 0.287 / 0.216 / 0.259
MW-DU-005 - / - / 0.112 / -
MW-11 0.065 / - / 0.342 / 0.16
MW-DU-011 - / - / 0.303 / -
MW-RS-8 0.12 / 0.184 / 1.03 / 0.168
JPG-DU-03I 3.37 / 3.83 / 0.296 / 0.814
JPG-DU-03O 2.72 / 1.73 / 2.07 / 2.58
MW-RS-6 2.24 / 1.73 / 1.56 / 0.076
MW-RS-5 0.363 / - / 5.91 / 0.367
MW-RS-7 40.2 / - / 13.7 / 10.7
MW-RS-4 1.05 / 3.47 / 3.15 / 0.098
MW-DU-006 - / - / 4.26 / -
MW-7 1.42 / 1.01 / 1.02 / 1.34
MW-8 0.429 / 0.326 / 0.625 / 0.628
MW-DU-008 - / - / 0.597 / -
JPG-DU-10O 2.36 / - / 2.2 / 1.51
JPG-DU-10D 1.74 / - / 0.887 / 1.02
JPG-DU-09D 2.09 / 2.64 / 2.99 / 1.01
MW-9 1.12 / 1.12 / 1.24 / 1.19
MW-DU-009 - / - / 1.2 / -
MW-1 0.334 / 0.431 / 0.47 / 0.264
MW-DU-001 - / - / 1.28 / -
JPG-DU-07I 2.58 / - / 1.66 / 1.86
MW-RS-3 4.03 / 2.46 / 6.42 / 5.78
JPG-DU-07D 0.079 / - / 0.101 / 0.061
MW-RS-2 0.414 / 0.218 / 0.236 / 0.38
MW-RS-1 1.3 / 1.01 / 1.05 / 1.15
JPG-DU-06O 2.63 / 2.85 / 2.69 / 3.78
JPG-DU-06I 1.71 / 1.2 / 1.17 / 0.977
JPG-DU-06D 10.5 / 2.86 / 2.82 / 1.14
JPG-DU-05I 4.31 / 4.29 / 3.33 / 2.51
JPG-DU-05D 2.7 / - / 2.47 / 2.13
JPG-DU-08I 1.77 / 2.54 / 3.25 / 2.91
JPG-DU-08D 3.01 / 2.32 / 2.94 / 4.19
MW-DU-002 - / - / 3.95 / -
MW-2 2.03 / 2.85 / 3.42 / 3.17
JPG-DU-04O 0.491 / 0.354 / 0.374 / 0.447
JPG-DU-04D 0.393 / - / 0.948 / 0.749
JPG-DU-04I 4.95 / 3.24 / 2.46 / 1.49
MW-6 1.9 / 3.61 / 4.26 / 2.85
MW-3 0.788 / 0.862 / 0.731 / 0.718
MW-DU-003 - / - / 0.893 / -
MW-DU-007 - / - / 0.814 / -
MW-4 1.07 / 1.71 / 2.11 / 0.819
MW-DU-004 - / - / 2.38 / -
G:\GIS_DATA\JPG\Projects\Modeling\Environmental Report\Figure 6-4 GW Sampling.mxd
Legend
Quarterly Results for Sampling Location (pCi/L)
Roads
Hydrology
Firing Lines
Installation Boundary
DU Impact Area
Note:
– Sample not collected
N
W
E
S
0 0.25 0.5 1 Miles
0 200 400 800 1,200 1,600 2,000 Meters
Summary of Quarterly Groundwater Sampling Results
Figure 6-4
Date: 8/7/2013

summarizes information about each well (e.g., total depth) and shows the locations. Table 6-9 lists the wells according to their respective hydrostratigraphic unit (overburden, shallow bedrock, or deep bedrock) and purpose (ERM, site characterization, or Range Study).

In addition to analyzing samples for total and isotopic uranium (U-234, U-235, and U-238), samples also were analyzed for alkalinity, anions (nitrate, chloride, sulfate), cations (calcium, potassium, magnesium, sodium), and dissolved concentrations of aluminum, iron, manganese, silicon, and total organic carbon (TOC). The analytical methods and detection limits are listed in Table 6-10. Additional procedures related to sample collection, handling, and analysis are discussed in FSP Addendum 5 (SAIC 2008b).

**Table 6-10. Summary of Sampling and Analysis Requirements for Groundwater and Surface Water Jefferson Proving Ground, Madison, Indiana**

| Parameter | Analytical Method | Detection Limit |
|---|---|---|
| Total and isotopic uranium: U-234, U-235, and U-238 | ASTM D3972-90M | 0.1 pCi/L |
| Nitrate | E300 | 600 µg/L |
| Chloride | E300 | 3,000 µg/L |
| Sulfate | E300 | 1,000 µg/L |
| Calcium | SW 6020 | 5,000 µg/L |
| Potassium | SW 6020 | 5,000 µg/L |
| Sodium | SW 6020 | 5,000 µg/L |
| Magnesium | SW 6020 | 5,000 µg/L |
| Alkalinity | E310.1 | 1 mg/L |

Water level measurements were taken manually at all 42 wells prior to initiating each quarterly groundwater sampling event. Attempts were made to collect water level measurements from all of the required wells within 24 hours prior to any groundwater purging and sampling activities. Manual water level measurements were taken in accordance with the requirements in Field Technical Procedure (FTP) 370 and FSP Addendum 4 (SAIC 2007b). Continuous, automatic groundwater stage monitoring was completed in selected monitoring wells with automatic electronic data recorders and pressure transducers. All water level measurements, along with the reference location, were recorded in a designated project field logbook and reported on an appropriate water level form (Appendix F).

A well yield matched purge sampling technique was applied to sample groundwater monitoring wells where possible and low-yield techniques were applied to the remaining wells where necessary. The well yield matched purge sampling technique incorporated some of the aspects of low-flow or micro purge sampling techniques in an attempt to acquire samples that were representative of the actual conditions within the aquifer and to ensure reproducible sampling results. If a well was determined to have difficulty recharging groundwater in sufficient time, a hydrasleeve was used to capture groundwater instead of a pump or bailer. The hydrasleeve was installed in a well and sufficient time was allowed for it to capture groundwater (typically, in 3 months time). The collection of groundwater samples from monitoring wells using the well yield matched purge sampling technique was accomplished in the following four general steps:

1. Set the purge flow rate
2. Control drawdown in the well by adjusting flow to match or be less than well yield
3. Obtain stabilized water quality indicator parameters
4. Collect groundwater samples.

Once the pump was set in the well, the purge rate was adjusted, as necessary, until a stabilized flow rate was achieved that resulted in a stabilized water level. Field water quality parameters (i.e., pH, oxidation-reduction (redox) potential [ORP], conductivity, temperature, dissolved oxygen [DO], and turbidity) were measured and recorded a minimum of every 5 minutes immediately after the start of purging. Well purging was considered complete when the field parameters stabilized after a minimum of three readings at 5-minute intervals according to the following criteria:

- DO: ± 0.2 milligrams per liter (mg/L)
- Conductivity: ± 25 micromhos per centimeter (µmhos/cm)
- Temperature: ± 0.5 °
- pH: ± 0.1 standard units (S.U.)
- Turbidity: < 50 nephelometric turbidity units (NTUs).

The collection of groundwater samples from a monitoring well started immediately after stabilization of field parameters. If one or more key indicator parameters failed to stabilize after 4 hours, additional pumping was completed and wells were eventually sampled. The lack of stability was documented in the sampling forms.

Low-yield wells with respect to sampling are defined as wells that do not have a sufficient yield that enabled purging with stabilization of the water level. The low-yielding wells were purged at the lowest rate available with the submersible positive-displacement pump. Water quality field parameters were collected every 5 minutes during the purge. If the well cavitated before the desired purge volume was removed, the well was left to recharge and the sample was collected as soon as sufficient volume was present.

If, through calculation, a well was nonetheless going to be cavitated after 4 hours at the lowest possible purge rate, the purge rate was increased to dry the well. Then, the well was allowed to naturally recharge and subsequently a sample would be collected as sufficient volume was present.

If a low-yield well did not recharge a sufficient volume, a hydrasleeve was installed in the well to capture groundwater. Typically, it required an entire sampling period (2 to 4 weeks) for a hydrasleeve to capture sufficient groundwater volume for sampling purposes.

Decontamination was conducted in accordance with requirements in FTP-405. The pump was decontaminated by immersion in deionized water and Alconox® solution and cleaning any excess materials on the pump exterior off with a brush. The pump then received a final deionized water rinse. Other nondisposable sampling equipment that came in contact with contaminated media (i.e., the water level indicator, field multi-meter flow cell) was decontaminated with deionized water. For example, the water level indicator was properly decontaminated before introducing into any new well and in between well locations to minimize the potential for cross-contamination.

Sampling results from all groundwater wells were statistically analyzed via ProUCL computer software (USEPA 2007) to evaluate data by the hydrostratigraphic units listed in Tables 6-11 and 6-12. Total uranium concentrations for groundwater samples varied depending on the hydrostratigraphic unit (i.e., overburden, shallow bedrock, deep bedrock) and whether the samples were filtered or not and whether samples were collected from site or background wells. The following bullets summarize the results presented in Tables 6-11 and 6-12:

- Ten samples collected from overburden wells in background/upgradient locations were analyzed for total and isotopic uranium and 10 additional samples were collected, filtered in the

## Table 6-11. Summary Statistics for Groundwater Sampling
## Jefferson Proving Ground, Madison, Indiana

| Sample Group | Number of Samples | Minimum | Maximum | Mean | Median | Variance | SD | MAD/ 0.675 | Skewness | Kurtosis | CV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Background Groundwater*** | | | | | | | | | | | |
| Overburden Wells (filtered) | 10 | 0.98 | 4.8 | 2.2 | 1.2 | 2.1 | 1.5 | 0.29 | 0.90 | -0.82 | 0.67 |
| Overburden Wells (unfiltered) | 10 | 0.81 | 6.4 | 2.5 | 1.2 | 4.6 | 2.1 | 0.56 | 1.1 | -0.34 | 0.86 |
| Shallow Bedrock Wells (filtered) | 35 | 0.18 | 2.2 | 0.79 | 0.69 | 0.31 | 0.55 | 0.56 | 1.0 | 0.20 | 0.70 |
| Shallow Bedrock Wells (unfiltered) | 188 | 0 | 4.0 | 1.0 | 0.86 | 0.79 | 0.89 | 0.86 | 0.97 | 0.62 | 0.87 |
| Deep Bedrock Wells (filtered) | 1 | 0.11 | 0.11 | 0.11 | 0.11 | N/A | N/A | 0 | N/A | N/A | N/A |
| Deep Bedrock Wells (unfiltered) | 3 | 0.060 | 0.10 | 0.080 | 0.078 | 0.00044 | 0.021 | 0.027 | 0.42 | N/A | 0.26 |
| ***Site Groundwater*** | | | | | | | | | | | |
| Overburden Wells (filtered) | 59 | 0.027 | 47 | 2.9 | 1.6 | 43 | 6.6 | 1.5 | 5.7 | 36 | 2.3 |
| Overburden Wells (unfiltered) | 120 | 0 | 40 | 2.6 | 2.2 | 16 | 4.0 | 1.8 | 7.3 | 66 | 1.5 |
| Shallow Bedrock Wells (filtered) | 54 | 0.085 | 4.7 | 1.4 | 1.2 | 1.5 | 1.2 | 1.4 | 0.99 | 0.33 | 0.88 |
| Shallow Bedrock Wells (unfiltered) | 208 | 0 | 5.0 | 0.77 | 0.41 | 0.93 | 0.97 | 0.61 | 1.9 | 3.8 | 1.3 |
| Deep Bedrock Wells (filtered) | 27 | 0.042 | 17 | 3.0 | 2.0 | 15 | 3.9 | 1.4 | 2.6 | 6.5 | 1.3 |
| Deep Bedrock Wells (unfiltered) | 31 | 0.066 | 21 | 3.9 | 2.3 | 24 | 4.9 | 1.5 | 2.3 | 4.6 | 1.3 |

SD = standard deviation
MAD/0.675 = median absolute deviation (MAD)/0.675 is robust estimate of variability
CV = coefficient of variation

## Table 6-12. Percentiles From Frequency Distributions of Groundwater Sampling Data
## Jefferson Proving Ground, Madison, Indiana

| Sample Group | Number of Samples | Percentile | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 5th | 10th | 20th | 25th | 50th | 75th | 80th | 90th | 95th | 99th |
| ***Background Groundwater*** | | | | | | | | | | | |
| Overburden Wells (filtered) | 10 | 1.0 | 1.1 | 1.1 | 1.1 | 1.2 | 3.1 | 3.4 | 4.2 | 4.5 | 4.8 |
| Overburden Wells (unfiltered) | 10 | 0.85 | 0.89 | 0.99 | 1.0 | 1.2 | 3.6 | 4.4 | 5.8 | 6.1 | 6.4 |
| Shallow Bedrock Wells (filtered) | 35 | 0.21 | 0.23 | 0.26 | 0.31 | 0.69 | 1.00 | 1.2 | 1.6 | 1.8 | 2.1 |
| Shallow Bedrock Wells (unfiltered) | 188 | 0 | 0 | 0.22 | 0.37 | 0.86 | 1.6 | 1.9 | 2.3 | 2.6 | 3.9 |
| Deep Bedrock Wells (filtered) | 1 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 |
| Deep Bedrock Wells (unfiltered) | 3 | 0.062 | 0.064 | 0.067 | 0.069 | 0.078 | 0.090 | 0.092 | 0.097 | 0.100 | 0.10 |
| ***Site Groundwater*** | | | | | | | | | | | |
| Overburden Wells (filtered) | 59 | 59 | 0.060 | 0.085 | 0.17 | 0.25 | 1.6 | 2.4 | 2.5 | 3.8 | 12 |
| Overburden Wells (unfiltered) | 120 | 120 | 0.097 | 0.20 | 0.44 | 0.70 | 2.2 | 3.2 | 3.5 | 4.3 | 5.3 |
| Shallow Bedrock Wells (filtered) | 54 | 54 | 0.14 | 0.18 | 0.25 | 0.28 | 1.2 | 2.1 | 2.4 | 2.9 | 3.8 |
| Shallow Bedrock Wells (unfiltered) | 208 | 208 | 0 | 0 | 0 | 0.098 | 0.41 | 1.1 | 1.3 | 1.9 | 3.2 |
| Deep Bedrock Wells (filtered) | 27 | 27 | 0.24 | 0.42 | 0.83 | 0.98 | 2.0 | 2.4 | 3.0 | 6.9 | 11 |
| Deep Bedrock Wells (unfiltered) | 31 | 31 | 0.57 | 0.89 | 1.0 | 1.1 | 2.3 | 3.0 | 3.0 | 10 | 15 |

field, and analyzed for total and isotopic uranium. Total uranium concentrations in unfiltered samples ranged from 0.81 ± 0.21 to 6.4 ± 1.1 pCi/L (2.2 to 18 µg/L) and from 0.98 ± 0.25 to 4.8 ± 0.88 pCi/L (2.7 to 13 µg/L) in filtered samples with mean concentrations of 2.5 (unfiltered) and 2.2 (filtered) pCi/L (6.9 and 6.1 µg/L, respectively).

- Sixty samples collected from overburden wells within and downgradient from the site were analyzed for total and isotopic uranium and 59 additional samples were collected, filtered in the field, and analyzed for total and isotopic uranium. Total uranium concentrations in unfiltered samples ranged from 0.076 ± 0.15 to 40 ± 6.6 pCi/L (0.21 to 112 µg/L) and from 0.027 ± 0.14 to 47 ± 7.7 pCi/L (0.075 to 131 µg/L) in filtered samples with mean concentrations of 2.6 (unfiltered) and 2.9 (filtered) pCi/L (7.2 and 8.1 µg/L, respectively).
- Thirty-six samples collected from shallow bedrock wells in background/upgradient locations were analyzed for total and isotopic uranium and 35 additional samples were collected, filtered in the field, and analyzed for total and isotopic uranium. Total uranium concentrations in unfiltered samples ranged from 0.14 ± 0.16 to 2.6 ± 0.58 pCi/L (0.39 to 7.2 µg/L) and from 0.18 ± 0.13 to 2.2 ± 0.49 pCi/L (0.5 to 6.0 µg/L) in filtered samples with mean concentrations of 0.88 (unfiltered) and 0.79 (filtered) pCi/L (2.4 and 2.2 µg/L, respectively).
- Fifty-six samples collected from shallow bedrock wells within and downgradient from the site were analyzed for total and isotopic uranium and 54 additional samples were collected, filtered in the field, and analyzed for total and isotopic uranium. Total uranium concentrations in unfiltered samples ranged from 0.065 ± 0.065 to 5.0 ± 0.98 pCi/L (0.18 to 14 µg/L) and from 0.085 ± 0.071 to 4.7 ± 0.92 pCi/L (0.24 to 13 µg/L) in filtered samples with mean concentrations of 1.4 (unfiltered and filtered) pCi/L (3.9 µg/L).
- Three samples collected from deep bedrock wells in background/upgradient locations were analyzed for total and isotopic uranium and one additional sample was collected, filtered in the field, and analyzed for total and isotopic uranium. Total uranium concentrations in unfiltered samples ranged from 0.060 ± 0.058 to 0.10 ± 0.065 pCi/L (0.17 to 0.28 µg/L) with a mean concentration of 0.080 pCi/L (0.22 µg/L). Total uranium was detected in the single filtered sample at 0.11 pCi/L (0.31 µg/L).
- Thirty-one samples collected from deep bedrock wells within and downgradient from the site were analyzed for total and isotopic uranium and 27 additional samples were collected, filtered in the field, and analyzed for total and isotopic uranium. Total uranium concentrations in unfiltered samples ranged from 0.066 ± 0.059 to 21 ± 3.5 pCi/L (0.18 to 57 µg/L) and from 0.042 ± 0.17 to 17 ± 2.8 pCi/L (0.12 to 47 µg/L) in filtered samples with mean concentrations of 3.9 (unfiltered) and 3.0 (filtered) pCi/L (10.8 and 8.3 µg/L, respectively).

Only one U-238/U-234 ratio in groundwater, MW-DU-001 for the October 2008 sampling event with a ratio of 6.0 ± 3.5, exhibited a U-238/U-234 ratio exceeding 3.0; thus, groundwater results did not generally reflect the presence of DU. Results for total uranium are summarized for samples collected during all four quarters of sampling in Figure 6-4 and Tables 6-11 and 6-12. Detailed sampling results, including results for individual uranium isotopes and results for individual samples on data presentation tables, frequency distributions, sampling forms, logbooks, and water quality criteria during sampling (e.g., pH, turbidity), are included in Appendix F.

### 6.1.3.2 Surface Water Sampling

Filtered and unfiltered surface water samples (plus duplicates) were collected from 20 locations, which were selected based on a stream survey (Section 6.2.6) conducted from February to April 2008 when a hydrologist walked along the streams looking for mixing zones, caves, and seeps along Big Creek, Middle Fork Creek, and the northern tributary of Big Creek. Samples were collected upgradient of the

DU Impact Area, within the DU Impact Area near and downgradient from areas with the highest suspected sources of DU, and downgradient from the DU Impact Area. Samples from seven locations were relocated since they were dry when sampling occurred and some samples were not collected because water was not available even at backup sampling locations. In total, 59 filtered and 59 unfiltered samples were collected from Big Creek, 19 unfiltered and 16 filtered samples were collected from Middle Fork Creek, and 11 unfiltered and 10 filtered samples were collected from the Northern Tributary of Big Creek (North Tributary).

Surface water samples were collected quarterly between April 2008 and February 2009 from 20 primary and/or pre-determined alternative locations chosen from data collected during the February to April 2008 stream survey (Section 6.2.6). When surface water and sediments were collected from the same location, the surface water samples were collected first and sediments second to minimize collection of sediment with the water samples. When possible, surface water samples that were collected from groundwater influx points (springs, seeps) or from intermittent tributaries were collected prior to convergence with the main surface water body.

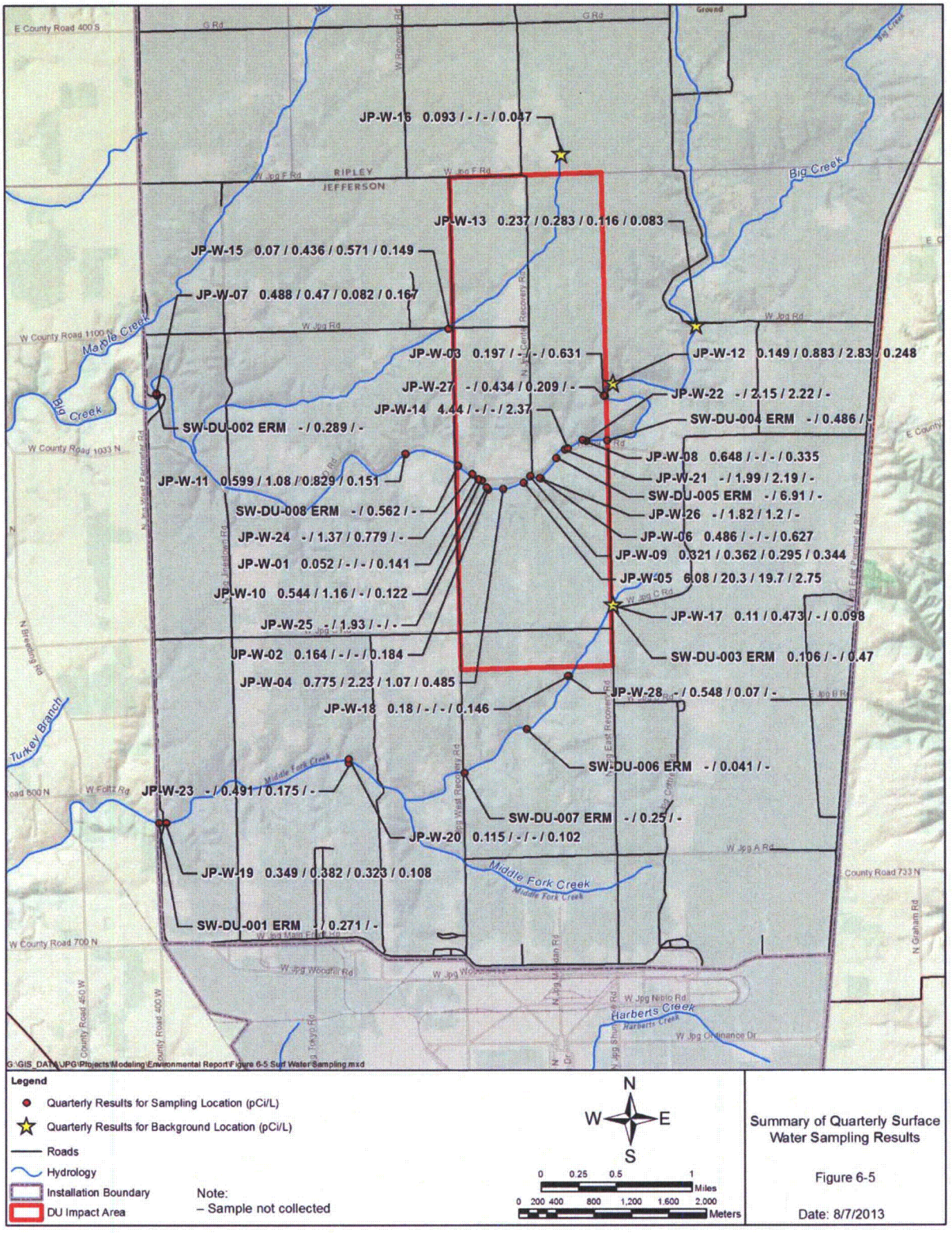
In the event that a primary surface water sample location was dry, the field crew utilized a matrix to determine the appropriate alternative sample location. If a primary surface water sample location was dry and an alternative location was sampled, a sediment sample was still collected at the primary location because even if a primary sample location was dry, representative sediment would still have been deposited during intermittent flows associated with storm events. If a surface water sample was collected at an alternative location, a new unique identification (ID) was assigned to the location in sequential order from the 20 sample IDs already assigned. The new location was documented with photographs and if field conditions permitted, accurately located with a global positioning system (GPS) unit. Section 6.2.6 discusses the stream survey and features identified. Figure 6-5 shows the locations for all surface water sampling locations. The following summarizes alternative surface water sampling locations by sampling quarter:

***April 2008***

- Surface water samples were collected at the 20 primary locations. No alternate locations were sampled.

***July 2008***

- JP-W-24 was sampled as an alternate to the JP-W-01 location. The water sample was collected from a pool where cave flow would enter Big Creek.
- JP-W-25 was sampled as an alternate to the JP-W-02 location. The water sample was collected from a pool where cave flow would enter Big Creek.
- JP-W-27 was sampled as an alternate to the JP-W-03 location. The water sample was collected from a pool where cave flow would enter Big Creek. This cave passageway was mistaken for the passageway assigned as the primary sample location from the stream survey. There are several passageways in this area of "horseshoe bend," all of which drain from the eastern side of the DU Impact Area. For consistency, the mistaken passageway was sampled from July forward as the primary location.
- JP-W-26 was sampled as an alternate to the JP-W-06 location. The water sample was collected from a pool where cave flow would enter Big Creek.
- JP-W-22 was sampled as an alternate to the JP-W-08 location. The water sample was collected approximately 10 feet south of the primary location from a pool at Big Creek.


JP-W-16 0.093 / - / - / 0.047
JP-W-13 0.237 / 0.283 / 0.116 / 0.083
JP-W-15 0.07 / 0.436 / 0.571 / 0.149
JP-W-07 0.488 / 0.47 / 0.082 / 0.167
JP-W-03 0.197 / - / - / 0.631
JP-W-12 0.149 / 0.883 / 2.83 / 0.248
JP-W-27 - / 0.434 / 0.209 / -
JP-W-22 - / 2.15 / 2.22 / -
JP-W-14 4.44 / - / - / 2.37
SW-DU-002 ERM - / 0.289 / -
SW-DU-004 ERM - / 0.486 /
JP-W-08 0.648 / - / - / 0.335
JP-W-11 0.599 / 1.08 / 0.829 / 0.151
JP-W-21 - / 1.99 / 2.19 / -
SW-DU-005 ERM - / 6.91 / -
SW-DU-008 ERM - / 0.562 / -
JP-W-26 - / 1.82 / 1.2 / -
JP-W-24 - / 1.37 / 0.779 / -
JP-W-06 0.486 / - / - / 0.627
JP-W-01 0.052 / - / - / 0.141
JP-W-09 0.321 / 0.362 / 0.295 / 0.344
JP-W-10 0.544 / 1.16 / - / 0.122
JP-W-05 6.08 / 20.3 / 19.7 / 2.75
JP-W-25 - / 1.93 / - / -
JP-W-17 0.11 / 0.473 / - / 0.098
JP-W-02 0.164 / - / - / 0.184
SW-DU-003 ERM 0.106 / - / 0.47
JP-W-04 0.775 / 2.23 / 1.07 / 0.485
JP-W-28 - / 0.548 / 0.07 / -
JP-W-18 0.18 / - / - / 0.146
SW-DU-006 ERM - / 0.041 / -
JP-W-23 - / 0.491 / 0.175 / -
SW-DU-007 ERM - / 0.25 / -
JP-W-20 0.115 / - / - / 0.102
JP-W-19 0.349 / 0.382 / 0.323 / 0.108
SW-DU-001 ERM - / 0.271 / -
E County Road 400 S
G Rd
RIPLEY
JEFFERSON
W Jpg F Rd
Big Creek
W County Road 1100 N
Maple Creek
W Jpg Rd
W County Road 1033 N
W Jpg C Rd
W Jpg A Rd
W Jpg Woodfill Rd
W Jpg Niblo Rd
W Jpg Ordinance Dr
Harberts Creek
Middle Fork Creek
Turkey Branch
W County Road 700 N
County Road 733 N
G:\GIS_DATA\JPG\Projects\Modeling\Environmental Report\Figure 6-5 Surf Water Sampling.mxd
Legend
Quarterly Results for Sampling Location (pCi/L)
Quarterly Results for Background Location (pCi/L)
Roads
Hydrology
Installation Boundary
DU Impact Area
Note:
– Sample not collected
N
W
E
S
0 0.25 0.5 1 Miles
0 200 400 800 1,200 1,600 2,000 Meters
Summary of Quarterly Surface Water Sampling Results
Figure 6-5
Date: 8/7/2013

- JP-W-21 was sampled as an alternate to the JP-W-14 location. The water sample was collected from pooled water at the mouth of the tributary.
- No water sample was collected at the primary JP-W-16 location. This location is near the headwaters of the northern tributary to Big Creek and a representative alternate could not be located.
- JP-W-28 was sampled as an alternate to the JP-W-18 location. The water sample was collected from a pool approximately 30 feet downstream from the primary location.
- JP-W-23 was sampled as an alternate to the JP-W-20 location. The water sampled was collected from a pool where cave flow would enter Middle Fork Creek.

***October 2008***

- JP-W-24 was sampled as an alternate to the JP-W-01 location. The water sample was collected from a pool where cave flow would enter Big Creek.
- No water sample was collected from the primary JP-W-02 location. The nearest pooled water was approximately 100 feet downstream, but it was not representative of cave flows.
- JP-W-27 was sampled as an alternate to the JP-W-03 location. The water sample was collected from a pool where cave flow would enter Big Creek.
- JP-W-26 was sampled as an alternate to the JP-W-06 location. The water sample was collected from a pool where cave flow would enter Big Creek.
- JP-W-22 was sampled as an alternate to the JP-W-08 location. The water sample was collected approximately 10 feet south of the primary location from a pool at Big Creek.
- No water sample was collected from the primary JP-W-10 location. The cave had no flow and the weir pool was dry. A representative alternative was not located.
- JP-W-21 was sampled as an alternate to the JP-W-14 location. The water sample was collected from pooled water approximately 30 feet downstream from the tributary mouth on Big Creek.
- No water sample was collected at the primary JP-W-16 location. This location is near the headwaters of the northern tributary to Big Creek and a representative alternate could not be located.
- No water sample was collected at the primary JP-W-17 location. The section of creek was completely dry.
- JP-W-28 was sampled as an alternate to the JP-W-18 location. The water sample was collected from a pool approximately 40 feet downstream from the primary location.
- JP-W-23 was sampled as an alternate to the JP-W-20 location. The water sampled was collected from a pool where cave flow would enter Middle Fork Creek.

***February 2009***

- Surface water samples were collected at the 20 primary locations. No alternate locations were sampled.

Surface water sample containers were filled by one of several methods based on the feature being sampled. If sufficient depth permitted, sample containers were filled by immersing them immediately below the surface of the water avoiding floating debris. If sufficient depth was not available or when the feature to be sampled could not be reached by hand, a decontaminated Teflon® dipper/ladle was used to fill the sample containers. At some DU Impact Area cave locations, flow was very low and dispersed

over the entire mouth of the cave or at the bedrock ledge prior to the cave flow entering the creek. If this situation was encountered, plastic sheeting was stretched across the cave mouth or ledge to direct the flow to the sample containers.

At each surface water sample location, water flow rate, temperature, pH, specific conductance, DO, ORP, and turbidity were measured and recorded in the field logbook and on a Surface Water Sample Collection Worksheet (Appendix F). If possible, flow rates were measured following the manual flow measurement procedures detailed in FSP Addendum 3 (SAIC 2006c). Additional information (i.e., presence of penetrators, relation of sample location to prominent land features, cave entrances, and seeps; changes in stream configuration between sampling events; and composition of stream bottom) was documented at the time of sampling in the field logbook and Surface Water Sample Collection Worksheet. A background radiation reading also was collected at the sample location and recorded on the Surface Water Sample Collection Worksheet. The following summarizes the procedures followed during surface water sampling:

1. The sampler donned clean nitrile gloves.
2. Samples were collected in new sample containers using one of several grab methods. Containers were filled in a manner to minimize floating debris.
3. A sample quantity of water designated in FSP Addendum 5 (SAIC 2008b) was collected and analyzed for parameters in Addendum 5.
4. Radiation dose rate measurements were collected above the sample location and recorded on Surface Water Sample Collection Worksheets (Appendix F).
5. Two sample aliquots were collected for uranium analysis. One aliquot was field filtered through a 0.45 micrometer (μm) filter.
6. The sample containers were wiped clean, labeled, security sealed, placed into sealed Ziploc® bags, and placed in a cooler with ice.

Samples were analyzed for total and isotopic uranium, alkalinity, anions, cations, aluminum, iron, manganese, silicon, and TOC (Table 6-10). Samples filtered in the field and unfiltered samples were collected and analyzed.

Sampling results from all surface water sampling locations (including site characterization and ERM locations) were statistically analyzed via ProUCL computer software (USEPA 2007) to evaluate data for Big Creek, Middle Fork Creek, and the North Tributary and are listed in Tables 6-13 and 6-14. Total uranium concentrations in 59 unfiltered samples collected from Big Creek ranged from 0.082 ± 0.14 to 20 ± 4.1 pCi/L (0.23 to 56 μg/L) and from 0.059 ± 0.14 to 22 ± 4.4 pCi/L (0.16 to 61 μg/L) in 59 filtered samples with average concentrations of 1.6 pCi/L (4.4 μg/L) for both filtered and unfiltered samples. Total uranium concentrations in 19 unfiltered samples collected from Middle Fork Creek ranged from 0.070 ± 0.15 to 0.55 ± 0.21 pCi/L (0.19 to 1.5 μg/L) and from 0.32 ± 0.14 to 0.65 ± 0.23 pCi/L (0.089 to 1.8 μg/L) in 16 filtered samples with average concentrations of 0.24 and 0.30 pCi/L (0.67 and 0.83 μg/L) for filtered and unfiltered samples, respectively. Total uranium concentrations in 11 unfiltered samples collected from North Tributary ranged from 0.047 ± 0.14 to 0.64 ± 0.24 pCi/L (0.13 to 1.8 μg/L) and from 0.057 ± 0.068 to 0.56 ± 0.17 pCi/L (0.16 to 1.6 μg/L) in 10 filtered samples with average concentrations of 0.26 and 0.23 pCi/L (0.72 and 0.64 μg/L) for filtered and unfiltered samples, respectively.

Most concentrations were low with respect to potential radiological doses when surface water is used as a drinking water source. Results from four samples exceeded USEPA's 30 μg/L (9 pCi/L) Safe Drinking Water Act (SDWA) maximum contaminant level (MCL). Results for the following four

## Table 6-13. Summary Statistics for Surface Water Sampling
## Jefferson Proving Ground, Madison, Indiana

| Sample Group | Number of Samples | Minimum | Maximum | Mean | Median | Variance | SD | MAD/ 0.675 | Skewness | Kurtosis | CV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Big Creek Locations (filtered) | 59 | 0.059 | 22 | 1.6 | 0.56 | 14 | 3.7 | 0.57 | 4.6 | 22 | 2.3 |
| Big Creek (filtered) | 59 | 0.059 | 22 | 1.6 | 0.56 | 14 | 3.7 | 0.57 | 4.6 | 22 | 2.3 |
| Big Creek (unfiltered) | 59 | 0.082 | 20 | 1.6 | 0.54 | 13 | 3.6 | 0.56 | 4.6 | 22 | 2.3 |
| Middle Fork Creek (filtered) | 16 | 0.032 | 0.65 | 0.30 | 0.27 | 0.044 | 0.21 | 0.27 | 0.19 | -1.5 | 0.70 |
| Middle Fork Creek (unfiltered) | 19 | 0.070 | 0.55 | 0.24 | 0.18 | 0.026 | 0.16 | 0.15 | 0.57 | -1.2 | 0.67 |
| North Tributary (filtered) | 10 | 0.057 | 0.56 | 0.23 | 0.10 | 0.039 | 0.20 | 0.068 | 0.79 | -1.2 | 0.87 |
| North Tributary (unfiltered) | 11 | 0.047 | 0.64 | 0.26 | 0.11 | 0.056 | 0.24 | 0.061 | 0.75 | -1.5 | 0.92 |

SD = standard deviation
MAD/0.675 = median absolute deviation (MAD)/0.675 is robust estimate of variability
CV = coefficient of variation

## Table 6-14. Percentiles From Frequency Distributions of Surface Water Sampling Data
## Jefferson Proving Ground, Madison, Indiana

| Sample Group | Number of Samples | Percentile | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 5th | 10th | 20th | 25th | 50th | 75th | 80th | 90th | 95th | 99th |
| Big Creek (filtered) | 59 | 0.100 | 0.14 | 0.20 | 0.20 | 0.56 | 1.3 | 1.9 | 2.8 | 5.0 | 20 |
| Big Creek (unfiltered) | 59 | 0.12 | 0.15 | 0.19 | 0.22 | 0.54 | 1.3 | 2.0 | 2.4 | 4.6 | 20 |
| Middle Fork Creek (filtered) | 16 | 0.037 | 0.046 | 0.091 | 0.12 | 0.27 | 0.46 | 0.46 | 0.56 | 0.61 | 0.64 |
| Middle Fork Creek (unfiltered) | 19 | 0.073 | 0.085 | 0.10 | 0.11 | 0.18 | 0.38 | 0.38 | 0.48 | 0.50 | 0.54 |
| North Tributary (filtered) | 10 | 0.057 | 0.057 | 0.078 | 0.085 | 0.10 | 0.37 | 0.40 | 0.51 | 0.53 | 0.55 |
| North Tributary (unfiltered) | 11 | 0.059 | 0.070 | 0.070 | 0.080 | 0.11 | 0.49 | 0.53 | 0.57 | 0.61 | 0.63 |

samples collected from JP-W-05 exceeded the MCL: July 2008 at 22 ± 4.4 (filtered) and 20 ± 4.1 (unfiltered) pCi/L and October 2008 at 18 ± 3.5 (filtered) and 20 ± 3.8 (unfiltered) pCi/L. Samples collected from location JP-W-05 were collected from a point in the vicinity where overland flow from 500 Center trench intersects with Big Creek. These samples were collected from standing pools of water (i.e., limited or no water flow).Results are summarized for all four quarters of sampling in Figure 6-5 and Tables 6-13 and 6-14.

Table 6-15 shows evidence of DU in surface water samples based on elevated U-238/U-234 ratios (i.e., exceeding 3.0) during one or more of the quarterly site characterization sampling events. The table also lists results for all four quarters of sampling to show potential seasonal trends and/or locational trends. Generally, the number of samples with isotopic ratios exceeding 3.0 was highest for the July 2008 sampling event and lowest for the April 2008 sampling event. The majority of the samples with elevated isotopic ratios were collected from Big Creek, particularly in close proximity to the trench associated with the 500 Center line of fire, and fewer elevated ratios were associated with samples collected from Middle Fork Creek and North Tributary.

Statistical testing was conducted on the surface water data using the standard general linear model (SAS® v 9.2 PROC GLM procedure) to test whether uranium concentrations at the site differed significantly from background levels and whether concentrations differed by season. Lower p-values indicate that differences (averages are not equal) are unlikely to be due to chance. A 5 percent significance level was used to reject null hypothesis (i.e., tests with p-values <= 0.05 are "significant" and tests with p-values between 0.05 and 0.10 are "marginally significant"). In general, surface water results were about twice as high onsite as compared to background (log mean [arithmetic mean of data transformed to values corresponding with their respective natural logarithms] = 0.46 versus 0.23 pCi/L, p=0.05) and concentrations were significantly higher in summer than at other times. The concentrations in July and August 2008 (log mean=0.75 pCi/L) were much greater than the results for April/May 2008 (log mean=0.20 pCi/L, p<0.001) and February 2009 (log mean=0.19 pCi/L, p<0.001). Results for July and August 2008 were marginally higher than October 2008 (log mean=0.40 pCi/L, p=0.08). October 2008 results were significantly higher than April/May 2008 (p=0.04) and February 2009 (p=0.05).

The point where overland flow from the 500 Center trench intersects with Big Creek was the location with the highest total uranium concentrations and isotopic ratios. Results were generally higher when water flowing through the streams was lowest (e.g., sampling from standing pools of water). Under these low flow conditions, regional agricultural impacts on surface water quality renders surface water even less desirable as a drinking water source (e.g., buildup of bacteria and fertilizer chemicals from farm runoff). Most concentration trends in ERM events over time are not discernible (poor linear correlation – coefficient of determination [$R^2$] <0.5) because results fluctuate just above detection limits, with the possible exception of a nonstatistical observation that elevated U-238/U-234 ratios generally occurred when water was not flowing in Big Creek and/or Middle Fork Creek.

### 6.1.3.3 Gamma Walkover Surveys

#### 6.1.3.3.1 Stream Surveys

A sodium iodide (NaI) gamma scintillation detector coupled with a data logger and GPS was used to conduct gamma walkover surveys. These surveys identified areas with elevated count rates to include those resulting from the presence of DU penetrators or portions thereof. Upon confirmation of anomalies, the locations of the maximum count rates were physically identified with location (pin) flags and the GPS coordinates were recorded.

Gamma walkover surveys were performed in the three creeks (Big Creek, Middle Fork Creek, North Tributary) prior to the first planned quarterly sampling event. The survey covered a total of approximately 3 miles (mi) and was conducted in March/April 2008 while plants were dormant and

## Table 6-15. Summary of Total Uranium Concentrations and Elevated U-238/U-234 Isotopic Ratios for Surface Water Jefferson Proving Ground, Madison, Indiana

| Sample ID | Filtered | April 2008 | | July 2008 | | October 2008 | | February 2009 | |
|---|---|---|---|---|---|---|---|---|---|
| | | Total Uranium (pCi/L) | U-238/U-234 Ratio | Total Uranium (pCi/L) | U-238/U-234 Ratio | Total Uranium (pCi/L) | U-238/U-234 Ratio | Total Uranium (pCi/L) | U-238/U-234 Ratio |
| ***Big Creek Samples*** | | | | | | | | | |
| JP-W-01 / JP-W-24[a] | Unfiltered | ND | ND | 1.4 ± 0.4 | 2.7 ± 1.6 | 0.78 ± 0.26 | 4.1 ± 2.6 | 0.14 ± 0.08 | 2.0 ± 2.5 |
| | Filtered | ND | ND | 1.2 ± 0.4 | 7.1 ± 5.3 | 1.2 ± 0.3 | 4.0 ± 2.2 | 0.20 ± 0.10 | 1.8 ± 1.9 |
| JP-W-02 / JP-W-25[b] | Unfiltered | ND | ND | 1.9 ± 0.5 | 4.9 ± 2.7 | - -[h] | - -[h] | 0.18 ± 0.096 | 1.0 ± 1.1 |
| | Filtered | ND | ND | 1.6 ± 0.4 | 3.7 ± 2.2 | - -[h] | - -[h] | 0.20 ± 0.099 | 1.4 ± 1.5 |
| JP-W-03 / JP-W-27[c] | Unfiltered | 0.20 ± 0.11 | 1.8 ± 2.1 | 0.43 ± 0.18 | 2.4 ± 2.1 | 0.21 ± 0.17 | 1.8 ± 1.6 | 0.63 ± 0.21 | 9.3 ± 9.1 |
| | Filtered | 0.19 ± 0.11 | 1.6 ± 1.9 | 0.37 ± 0.17 | ND | 0.20 ± 0.16 | 1.1 ± 1.0 | 0.74 ± 0.24 | 5.3 ± 4.4 |
| JP-W-04 | Unfiltered | 0.78 ± 0.25 | 1.6 ± 1.1 | 2.2 ± 0.57 | 4.2 ± 2.2 | 1.1 ± 0.28 | 4.3 ± 2.4 | 0.49 ± 0.16 | 3.2 ± 2.5 |
| | Filtered | 0.75 ± 0.27 | 8.0 ± 8.1 | 1.9 ± 0.49 | 5.5 ± 3.2 | 0.97 ± 0.26 | 5.2 ± 3.2 | 0.48 ± 0.16 | 2.4 ± 1.8 |
| JP-W-05 | Unfiltered | 6.1 ± 1.3 | 6.5 ± 2.8 | 20 ± 4.1 | 7.3 ± 2.6 | 20 ± 3.8 | 6.5 ± 2.2 | 2.8 ± 0.60 | 5.5 ± 2.4 |
| | Filtered | 6.5 ± 1.4 | 6.3 ± 2.7 | 22 ± 4.4 | 6.8 ± 2.4 | 18 ± 3.5 | 6.7 ± 2.2 | 2.9 ± 0.63 | 5.4 ± 2.5 |
| JP-W-06 / JP-W-26[d] | Unfiltered | 0.49 ± 0.20 | 2.3 ± 1.8 | 1.8 ± 0.49 | 3.8 ± 2.1 | 1.2 ± 0.30 | 4.5 ± 2.5 | 0.63 ± 0.18 | 1.9 ± 1.2 |
| | Filtered | 0.32 ± 0.15 | 1.4 ± 1.3 | 2.0 ± 0.49 | 2.9 ± 1.5 | 1.3 ± 0.33 | 8.3 ± 5.4 | 0.58 ± 0.18 | 1.6 ± 1.1 |
| JP-W-07 | Unfiltered | 0.49 ± 0.20 | 4.2 ± 4.0 | 0.47 ± 0.23 | 1.4 ± 1.2 | 0.082 ± 0.14 | 2.6 ± 2.4 | 0.17 ± 0.16 | 0.55 ± 0.58 |
| | Filtered | 0.59 ± 0.20 | 3.5 ± 3.0 | 0.61 ± 0.22 | 3.0 ± 2.4 | 0.090 ± 0.038 | 4.4 ± 4.6 | 0.12 ± 0.097 | 3.0 ± 4.9 |
| JP-W-08 / JP-W-22[e] | Unfiltered | 0.65 ± 0.20 | 1.4 ± 0.93 | 2.2 ± 0.54 | 5.4 ± 3.0 | 2.2 ± 0.51 | 6.9 ± 3.4 | 0.33 ± 0.18 | 2.2 ± 2.5 |
| | Filtered | 0.47 ± 0.18 | 1.4 ± 1.1 | 1.9 ± 0.49 | 7.0 ± 4.5 | 1.9 ± 0.44 | 5.9 ± 3.0 | 0.42 ± 0.17 | 1.6 ± 1.3 |
| JP-W-09 | Unfiltered | 0.32 ± 0.15 | 2.6 ± 2.7 | 0.36 ± 0.21 | 1.3 ± 1.1 | 0.30 ± 0.12 | 1.2 ± 0.99 | 0.34 ± 0.15 | 1.7 ± 1.4 |
| | Filtered | ND | ND | ND | ND | 0.30 ± 0.12 | 2.1 ± 1.8 | 0.41 ± 0.17 | 2.5 ± 2.3 |
| JP-W-10 | Unfiltered | ND | ND | 1.2 ± 0.34 | 2.7 ± 1.6 | - -[h] | - -[h] | 0.12 ± 0.15 | 0.79 ± 0.95 |
| | Filtered | 0.56 ± 0.22 | 9.9 ± 12 | 1.1 ± 0.32 | 3.1 ± 2.0 | - -[h] | - -[h] | 0.059 ± 0.14 | 4.9 ± 11 |
| JP-W-11 | Unfiltered | 0.60 ± 0.20 | 2.4 ± 1.9 | 1.1 ± 0.32 | 4.7 ± 3.2 | 0.83 ± 0.28 | 7.3 ± 5.4 | 0.15 ± 0.17 | 3.3 ± 5.5 |
| | Filtered | 0.71 ± 0.24 | 2.5 ± 1.8 | 1.1 ± 0.32 | 3.3 ± 2.1 | 1.3 ± 0.32 | 5.6 ± 3.2 | 0.33 ± 0.21 | 0.54 ± 0.53 |
| JP-W-12 | Unfiltered | 0.15 ± 0.09 | 0.83 ± 1.0 | 0.88 ± 0.29 | 3.2 ± 2.3 | 2.8 ± 0.62 | 6.1 ± 2.7 | 0.25 ± 0.19 | 0.54 ± 0.58 |
| | Filtered | 0.21 ± 0.12 | 1.0 ± 1.2 | 0.82 ± 0.30 | 6.0 ± 5.0 | 2.9 ± 0.62 | 5.0 ± 2.2 | 0.14 ± 0.16 | 0.71 ± 0.85 |
| JP-W-14 / JP-W-21[f] | Unfiltered | 4.4 ± 1.0 | 7.2 ± 3.6 | 2.0 ± 0.54 | 7.1 ± 4.6 | 2.2 ± 0.50 | 5.0 ± 2.4 | 2.4 ± 0.55 | 5.4 ± 2.7 |
| | Filtered | 4.8 ± 1.1 | 8.4 ± 4.0 | 2.2 ± 0.58 | 5.0 ± 2.8 | 2.7 ± 0.60 | 4.6 ± 2.1 | 2.4 ± 0.55 | 7.2 ± 3.8 |
| SW-DU-002 | Unfiltered | ND | ND | 0.29 ± 0.12 | 1.2 ± 0.99 | 0.17 ± 0.14 J | 0.38 ± 0.38 | 0.68 ± 0.33 J | 2.4 ± 2.1 |
| SW-DU-004 | Unfiltered | 0.15 ± 0.10 | 2.5 ± 1.8 | 0.49 ± 0.17 | 2.1 ± 1.5 | 0.28 ± 0.19 J | 0.43 ± 0.35 | ND | ND |
| SW-DU-005 | Unfiltered | ND | ND | 6.9 ± 1.4 | 7.0 ± 2.6 | 0.51 ± 0.29 J | 0.93 ± 0.71 | 0.55 ± 0.32 J | 1.3 ± 1.2 |
| SW-DU-008 | Unfiltered | ND | ND | 0.56 ± 0.18 | 3.6 ± 2.6 | 0.29 ± 0.19 J | 1.0 ± 0.96 | 0.76 ± 0.32 J | 2.5 ± 2.0 |
| ***Middle Fork Samples*** | | | | | | | | | |
| JP-W-17 | Unfiltered | ND | ND | 0.047 ± 0.19 | 0.86 ± 0.71 | - -[i] | - -[i] | 0.098 ± 0.17 | 6.5 ± 54 |
| | Filtered | ND | ND | 0.046 ± 0.23 | 1.3 ± 1.1 | - -[i] | - -[i] | 0.053 ± 0.14 | 0.29 ± 0.81 |
| JP-W-20 / JP-W-23[g] | Unfiltered | 0.12 ± 0.083 | 0.53 ± 0.79 | 0.49 ± 0.19 | 0.48 ± 0.39 | 0.18 ± 0.16 | 1.1 ± 1.1 | 0.10 ± 0.17 | 1.8 ± 4.0 |
| | Filtered | ND | ND | 0.60 ± 0.25 | 1.2 ± 0.86 | 0.19 ± 0.094 | 1.0 ± 1.0 | 0.18 ± 0.15 | 4.0 ± 9.2 |

## Table 6-15. Summary of Total Uranium Concentrations and Elevated U-238/U-234 Isotopic Ratios for Surface Water Jefferson Proving Ground, Madison, Indiana (Continued)

| Sample ID | Filtered | April 2008 | | July 2008 | | October 2008 | | February 2009 | |
|---|---|---|---|---|---|---|---|---|---|
| | | Total Uranium (pCi/L) | U-238/U-234 Ratio | Total Uranium (pCi/L) | U-238/U-234 Ratio | Total Uranium (pCi/L) | U-238/U-234 Ratio | Total Uranium (pCi/L) | U-238/U-234 Ratio |
| ***Northern Tributary Samples*** | | | | | | | | | |
| JP-W-15 | Unfiltered | ND | ND | 0.44 ± 0.23 | 0.93 ± 0.77 | 0.57 ± 0.18 | 1.3 ± 0.81 | 0.15 ± 0.089 | 0.83 ± 1.0 |
| | Filtered | ND | ND | 0.50 ± 0.24 | 0.61 ± 0.51 | 0.56 ± 0.17 | 0.89 ± 0.56 | 0.11 ± 0.086 | 0.83 ± 1.4 |

[a] Due to lack of water available for sampling at location JP-W-01 during July and October 2008 sampling events, the actual sampling location was relocated and the site ID was changed to JP-W-24.
[b] Due to lack of water available for sampling at location JP-W-02 during July and October 2008 sampling events, the actual sampling location was relocated and the site ID was changed to JP-W-25.
[c] Due to lack of water available for sampling at location JP-W-03 during July and October 2008 sampling events, the actual sampling location was relocated and the site ID was changed to JP-W-27.
[d] Due to lack of water available for sampling at location JP-W-06 during July and October 2008 sampling events, the actual sampling location was relocated and the site ID was changed to JP-W-26.
[e] Due to lack of water available for sampling at location JP-W-08 during July and October 2008 sampling events, the actual sampling location was relocated and the site ID was changed to JP-W-23.
[f] Due to lack of water available for sampling at location JP-W-14 during July and October 2008 sampling events, the actual sampling location was relocated and the site ID was changed to JP-W-21.
[g] Due to lack of water available for sampling at location JP-W-20 during July and October 2008 sampling events, the actual sampling location was relocated and the site ID was changed to JP-W-23.
[h] Sample not collected from mouth of cave because no water was available. Water was not available as a representative backup location.
[i] Sample not collected from Middle Fork Creek because no water was available within 100 yards of planned location and area was covered with waist-height vegetation.

before leaf-growth began. Gamma scan data were recorded in real time, using position and data recording methods.

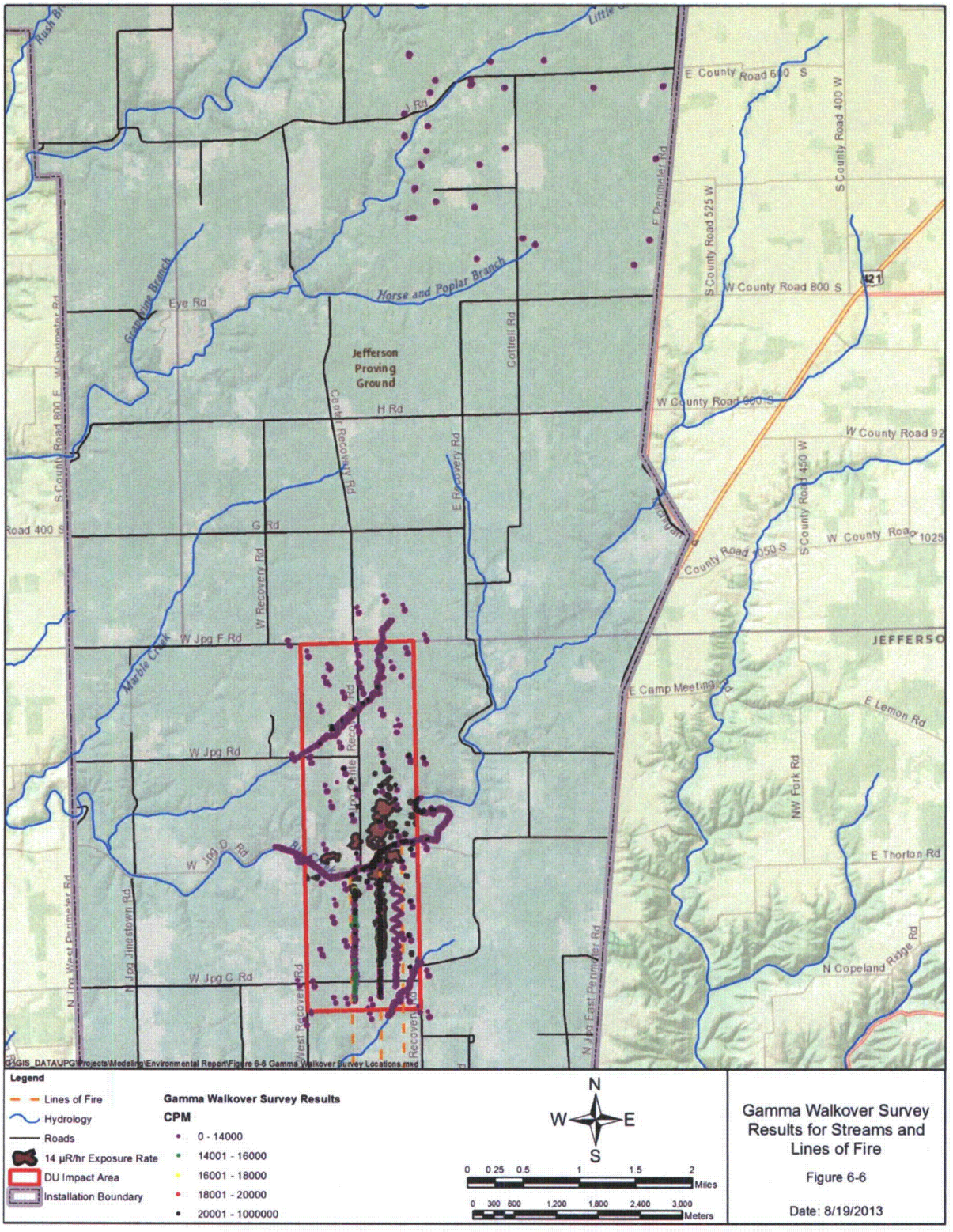
Surface scans for gross gamma radiation were performed in sediment above the surface of the water to identify locations of elevated external radiation that may represent residual radiological contamination. Gamma walkover surveys of sediment below the surface of the water were not performed due to lower detection sensitivity, since water provides shielding of the expected low levels of gamma radiation. To account for this, depositional areas were identified through visual observation because they were the mostly likely location for transported DU radioactivity.

Accessible portions of both banks of the creeks were scanned. The surveyor advanced at a speed of approximately 2 feet per second (ft/s) while passing the detector over the surface in a serpentine pattern. Audible responses from the instrument were monitored and locations of elevated audible response were investigated to identify locations of DU penetrators, penetrator fragments, and other areas with elevated radioactivity.

The ambient background for an area was determined at the start of the survey and a scanning response that was detectable above the background level (e.g., 1,500 to 2,000 counts per minute [cpm] above background) was set as the investigation level. Sediment gamma scan background values in cpm were determined by collecting 10 scan background samples from sediment found on the banks of both creeks upstream of the entrance point to the DU Impact Area. An appropriate background value was determined for application to gamma scans conducted on the banks of the creeks within the DU Impact Area. The gamma scan investigation threshold of 2,000 cpm or greater above background was the detection threshold. The correlation between count rates and sample results above this threshold was developed.

NUREG-1507, Minimum Detectable Concentrations with Typical Radiation Survey Instruments for Various Contaminants and Field Conditions, provides a minimum detectable count (MDC) for scanning equal to 56 pCi/g for DU containing 0.34 percent U-235 in surface soil when using a 2- × 2-inch NaI detector. Further evaluation indicates that a DU penetrator fragment as small as 0.37 cubic inches ($in^3$) (6 cubic centimeters, $cm^3$) can be located easily on the soil surface during a typical scan (assuming an investigation threshold of 2,000 cpm above background). A similar evaluation indicates that a DU penetrator fragment as small as 0.61 $in^3$ (10 $cm^3$) can be located easily below 2 in (5 cm) of soil during a typical scan (assuming an investigation threshold of 2,000 cpm above background). This evaluation is provided in Appendix C of the original FSP (SAIC 2005).

In July 2008, an investigation was performed such that a penetrator was placed under a measured amount of soil and the count rates at the surface of the ground (i.e., at a consistent distance not more than 6 in above the ground) were measured. This effort was performed to estimate the relationship between count rates and the associated penetrator depth. This effort documented that the count rate inclusive of background was approximately 14,000 cpm for a penetrator with 6 in (15 cm) of soil cover. Walkover survey data were subsequently reviewed to estimate the relative number of penetrators (or large fragments of DU) encountered in the top 6 in (15 cm) of soil within the survey area with count rates exceeding 14,000 being indicative of the presence of a penetrator. Using this approach, it was estimated that 137 penetrators were encountered during walkover surveys of banks of Big Creek (130 penetrators), Middle Fork Creek (no penetrators), and North Tributary (7 penetrators). The information obtained together with other relevant data is presented in Appendix C. Results from the gamma walkover surveys conducted for the streams are shown in Figure 6-6. Figure 6-6 also shows results from the in situ gamma spectrometry measurements from the Characterization Survey (SEG 1996) with areas exceeding 14 µR/hr/35 pCi/g shown in brown.


Jefferson Proving Ground
Horse and Poplar Branch
Eye Rd
H Rd
G Rd
W Jpg F Rd
W Jpg Rd
W Jpg D Rd
W Jpg C Rd
E County Road 600 S
W County Road 800 S
W County Road 600 S
W County Road 925
W County Road 1025
S County Road 400 W
S County Road 525 W
S County Road 450 W
E Camp Meeting Rd
E Lemon Rd
E Thorton Rd
N Copeland Ridge Rd
NW Fork Rd
Cottrell Rd
E Recovery Rd
W Recovery Rd
Marble Creek
Legend
Lines of Fire
Hydrology
Roads
14 µR/hr Exposure Rate
DU Impact Area
Installation Boundary
Gamma Walkover Survey Results
CPM
0 - 14000
14001 - 16000
16001 - 18000
18001 - 20000
20001 - 1000000
N
W
E
S
0 0.25 0.5 1 1.5 2 Miles
0 300 600 1,200 1,800 2,400 3,000 Meters
Gamma Walkover Survey Results for Streams and Lines of Fire
Figure 6-6
Date: 8/19/2013

#### 6.1.3.3.2 Lines of Fire Surveys

As shown in Figure 6-6, the presumed location for each of the three lines of fire (J, 500 Center, and K5) also was subjected to gamma walkover surveys. Using the same approach as defined above for stream walkovers, 6 mi of walkover data were collected in October 2008 and evaluated to determine the relative number of penetrators (or large fragments of DU) that were encountered along each of the lines of fire. This information together with the relative quantity of DU fired from each firing point provides additional insight to quantify the spatial distribution of residual penetrators and estimate the DU source term.

The survey over the westernmost line of fire, which is associated with the J firing point, identified a previously unknown dense area of penetrators and fragments that is approximately 550 ft in length and 150 ft in width (168 by 46 m). It is located approximately 700 ft (198 m) south of Big Creek.

The walkover survey readily identified the line of fire associated with the 500 Center firing point. The region of elevated activity (i.e. above background) extends from approximately 750 ft (229 m) south of C Road to the downsloping area 1,200 ft south of Big Creek and appears to be approximately 164 ft (50 m) wide in the widest area.

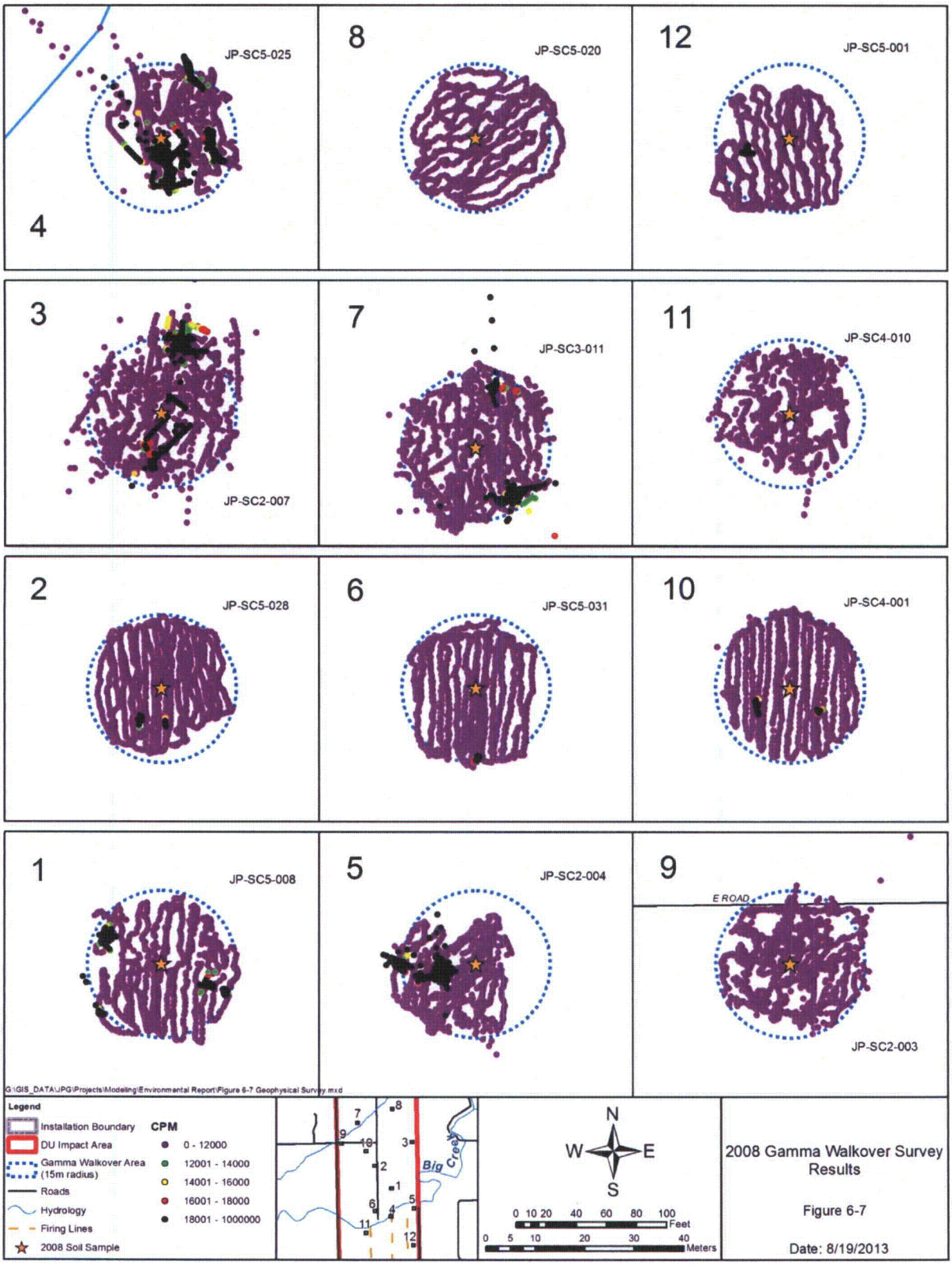
A survey was conducted between the lines of fire associated with the 500 Center firing point and the easternmost line of fire (i.e., from the K5 firing point). Originally, the survey was intended to cover the K5 line of fire, but features on the ground led to an incorrect starting point for the survey of the K5 line of fire. As surveyors progressed from south to north, the serpentine survey pattern progressively widened to maximize the likelihood of intersecting the K5 line of fire. As shown in Figure 6-6, the walkover survey did not cross the easternmost line of fire. However, no penetrators or areas of elevated radioactivity were identified between the lines of fire. This finding suggests that dense areas of penetrators, fragments, and DU corrosion products are mainly limited to north and south oriented lines of fire associated with the three DU firing points. However, DU penetrators were identified in Big Creek between lines of fire. In addition, penetrators were located east of the eastern boundary of the DU Impact Area (i.e., upstream), but the penetrators could not have been transported by surface water flow.

#### 6.1.3.3.3 Background Soil Sampling Surveys

An area was identified approximately 3 mi north of the DU Impact Area along the eastern boundary of the JPG property for defining background concentrations of uranium. This area was selected because it included the three soil type groups of interest (Avonburg/Cobbsfork, Cincinnati/Rossmoyne, and Grayford/Ryker) in a relatively small area. To ensure that these areas were not impacted by potential onsite or offsite radiological sources, a gamma walkover survey covering a 15-m radius from the center of each proposed background sampling location was surveyed with 2- × 2-in NaI detectors to identify any elevated areas that may be present. Locations selected during planning based on reviewing the soil maps for this area were confirmed in the field by an experienced geologist. No elevated readings were identified within the surveyed areas, so alternate locations were not selected based on the gamma walkover survey results for those areas.

#### 6.1.3.3.4 Soil Sampling Surveys

Surveys were performed within a radius of approximately 15 m of each location where soil was sampled for the purpose of extent and depth determination. These surveys facilitated the collection of soil samples in a manner that ensured results were appropriately representative of site concentrations and that sampling was not excessively biased high or low (i.e., soil samples obtained no closer than 3.3 ft [1 m]) from the nearest penetrator as indicated by gamma walkover surveys of sampling areas). Figure 6-7 shows gamma walkover surveys from 12 representative locations with respective soil sampling ID provided.


4
JP-SC5-025
8
JP-SC5-020
12
JP-SC5-001
3
JP-SC2-007
7
JP-SC3-011
11
JP-SC4-010
2
JP-SC5-028
6
JP-SC5-031
10
JP-SC4-001
1
JP-SC5-008
5
JP-SC2-004
9
E ROAD
JP-SC2-003
G:\GIS_DATA\JPG\Projects\Modeling\Environmental Report\Figure 6-7 Geophysical Survey.mxd
Legend
Installation Boundary
DU Impact Area
Gamma Walkover Area (15m radius)
Roads
Hydrology
Firing Lines
2008 Soil Sample
CPM
0 - 12000
12001 - 14000
14001 - 16000
16001 - 18000
18001 - 1000000
Big Creek
N
W
E
S
0 10 20 40 60 80 100 Feet
0 5 10 20 30 40 Meters
2008 Gamma Walkover Survey Results
Figure 6-7
Date: 8/19/2013

### 6.1.3.4 Sediment Sampling

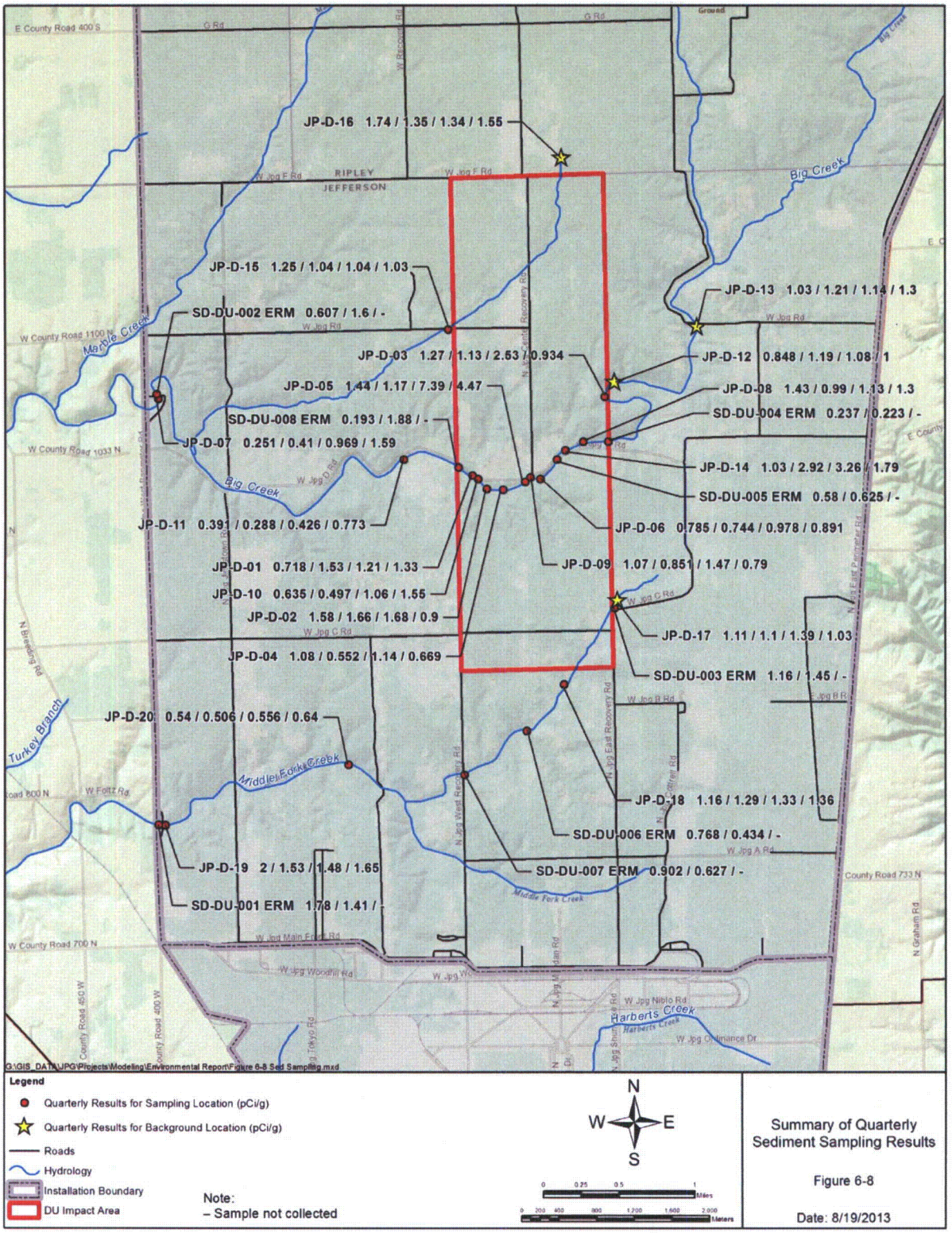
Sediment samples (plus 10 duplicates) were collected from 20 locations, which were selected based on a February 2008 stream survey when a hydrologist scouted for areas with deposition of finer-grain sediments based on channel widths; water depths/directions; changes in slope; and flow velocities along Big Creek, Middle Fork Creek, and the North Tributary. Samples were collected from the same locations regardless of whether or not they were dry when sampling occurred.

Sediment samples were collected quarterly between April 2008 and February 2009 from 20 primary locations chosen from data collected during the February to April 2008 stream survey. Samples were analyzed for total and isotopic uranium. When surface water and sediments were collected from the same location, the surface water samples were collected first and sediments second to minimize collection of sediment with the water samples. Sediment samples were collected within the top 6 in of the sediment surface with new, disposable plastics scoops. When possible, the sediments samples were biased toward the fine-grained material present at the sample locations. Samples were collected into Ziploc® bags at the sample location to allow for compositing before transferring to glass sample containers. No effort was made to separate the sample into liquid and solid components. A background radiation reading was collected at the sample location and a radiological measurement of the composited sample was measured and recorded on the Surface Water Sample Collection Worksheet. The following summarizes the procedures followed during sediment sampling:

1. The sampler donned clean nitrile gloves.
2. Prior to sampling of sediment, the sampling device was rinsed in surface water at a point downstream from the sampling location.
3. Sediment samples were collected after water samples.
4. A photograph of the sediment sample location was collected.
5. Samples were collected using new, disposable plastic scoops.
6. The quantity of sediment designated in FSP Addendum 5 (SAIC 2008b) was collected and analyzed for the parameters also listed in FSP Addendum 5.
7. The sediment samples were composited in Ziploc® bags, photographed, and transferred to glass sample jars. Foreign components (e.g., twigs, leaves, pebbles, debris) of the sediment matrix were removed.
8. Radiation dose rate measurements were collected above the sample location and recorded on Surface Water Sample Collection Worksheets.
9. The sample containers were wiped clean, labeled, security sealed, placed into sealed Ziploc® bags, and put in a cooler with ice.

Some evidence of DU was suspected in two samples (based on U-238/U-234 ratios exceeding 3.0). All concentrations were detected well below the 35 pCi/g action level for ERM sampling, which has historically served as a common DCGL for uranium in surface soils. The highest concentrations were observed where runoff enters Big Creek from the DU trench. Results are summarized for all four quarters of sampling in Figure 6-8 and Tables 6-16 and 6-17.

Sediment sampling results from all locations were statistically analyzed via ProUCL computer software (USEPA 2007). As shown in Figures 6-8 and 6-9, most samples indicate total uranium concentrations were detected at less than 2 pCi/g. Tables 6-16 and 6-17 show that total uranium concentrations ranged from 0.25 ± 0.13 to 7.4 ± 1.6 pCi/g (0.70 to 21 milligrams per kilogram [mg/kg])


JP-D-16 1.74 / 1.35 / 1.34 / 1.55
JP-D-15 1.25 / 1.04 / 1.04 / 1.03
SD-DU-002 ERM 0.607 / 1.6 / -
JP-D-03 1.27 / 1.13 / 2.53 / 0.934
JP-D-05 1.44 / 1.17 / 7.39 / 4.47
SD-DU-008 ERM 0.193 / 1.88 / -
JP-D-07 0.251 / 0.41 / 0.969 / 1.59
JP-D-11 0.391 / 0.288 / 0.426 / 0.773
JP-D-01 0.718 / 1.53 / 1.21 / 1.33
JP-D-10 0.635 / 0.497 / 1.06 / 1.55
JP-D-02 1.58 / 1.66 / 1.68 / 0.9
JP-D-04 1.08 / 0.552 / 1.14 / 0.669
JP-D-20 0.54 / 0.506 / 0.556 / 0.64
JP-D-19 2 / 1.53 / 1.48 / 1.65
SD-DU-001 ERM 1.78 / 1.41 / -
JP-D-13 1.03 / 1.21 / 1.14 / 1.3
JP-D-12 0.848 / 1.19 / 1.08 / 1
JP-D-08 1.43 / 0.99 / 1.13 / 1.3
SD-DU-004 ERM 0.237 / 0.223 / -
JP-D-14 1.03 / 2.92 / 3.26 / 1.79
SD-DU-005 ERM 0.58 / 0.625 / -
JP-D-06 0.785 / 0.744 / 0.978 / 0.891
JP-D-09 1.07 / 0.851 / 1.47 / 0.79
JP-D-17 1.11 / 1.1 / 1.39 / 1.03
SD-DU-003 ERM 1.16 / 1.45 / -
JP-D-18 1.16 / 1.29 / 1.33 / 1.36
SD-DU-006 ERM 0.768 / 0.434 / -
SD-DU-007 ERM 0.902 / 0.627 / -
RIPLEY
JEFFERSON
Big Creek
Marble Creek
Turkey Branch
Middle Fork Creek
Harberts Creek
E County Road 400 S
W County Road 1100 N
W County Road 1033 N
W County Road 700 N
County Road 733 N
G:\GIS_DATA\JPG\Projects\Modeling\Environmental Report\Figure 6-8 Sed Sampling.mxd
Legend
Quarterly Results for Sampling Location (pCi/g)
Quarterly Results for Background Location (pCi/g)
Roads
Hydrology
Installation Boundary
DU Impact Area
Note:
– Sample not collected
N
W
E
S
Miles
Meters
Summary of Quarterly Sediment Sampling Results
Figure 6-8
Date: 8/19/2013

## Table 6-16. Summary Statistics for Sediment Sampling
## Jefferson Proving Ground, Madison, Indiana

| Sample Group | Number of Samples | Minimum | Maximum | Mean | Median | Variance | SD | MAD/ 0.675 | Skewness | Kurtosis | CV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Sediment Groupings by Water Body*** | | | | | | | | | | | |
| Big Creek Sediment[a] | 56 | 0.25 | 7.4 | 1.3 | 1.1 | 1.2 | 1.1 | 0.40 | 3.8 | 18 | 0.84 |
| Middle Fork Creek Sediment[a] | 16 | 0.51 | 2.0 | 1.2 | 1.2 | 0.18 | 0.42 | 0.29 | -0.028 | -0.31 | 0.37 |
| North Tributary Sediment[a] | 8 | 0.96 | 1.7 | 1.3 | 1.3 | 0.074 | 0.27 | 0.38 | 0.49 | -0.63 | 0.21 |
| ***Sediment Groupings for Upgradient and Site/Downgradient Sampling Locations*** | | | | | | | | | | | |
| Site/Downgradient Sediment[b] | 64 | 0.25 | 7.4 | 1.3 | 1.1 | 1.1 | 1.0 | 0.48 | 3.8 | 19 | 0.81 |
| Upgradient Sediment[b] | 16 | 0.85 | 1.7 | 1.2 | 1.2 | 0.052 | 0.23 | 0.22 | 0.75 | 0.55 | 0.19 |

SD = standard deviation
MAD/0.675 = median absolute deviation (MAD)/0.675 is robust estimate of variability
CV = coefficient of variation
[a] Big Creek sediment samples include JP-D-1 through JP-D-14, North Tributary samples include JP-D-15 and JP-D-16, and JP-D-17 through JP-D-20. Statistics represent results for samples collected in April 2008, July 2008, October 2008, and February 2009.
[b] Upgradient sediment samples include JP-D-12 and JP-D-13 (Big Creek), JP-D-16 (North Tributary), and JP-D-17 (Middle Fork Creek).

## Table 6-17. Percentiles From Frequency Distributions of Sediment Sampling Data
## Jefferson Proving Ground, Madison, Indiana

| Sample Group | Number of Samples | Percentile | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 5th | 10th | 20th | 25th | 50th | 75th | 80th | 90th | 95th | 99th |
| ***Sediment Groupings by Water Body*** | | | | | | | | | | | |
| Big Creek Sediment[a] | 56 | 0.41 | 0.53 | 0.77 | 0.83 | 1.1 | 1.4 | 1.5 | 1.7 | 3.0 | 5.8 |
| Middle Fork Creek Sediment[a] | 16 | 0.53 | 0.55 | 0.64 | 0.93 | 1.2 | 1.4 | 1.4 | 1.6 | 1.7 | 1.9 |
| North Tributary Sediment[a] | 8 | 0.99 | 1.0 | 1.0 | 1.0 | 1.3 | 1.4 | 1.5 | 1.6 | 1.7 | 1.7 |
| ***Sediment Groupings for Upgradient and Site/Downgradient Sampling Locations*** | | | | | | | | | | | |
| Site/Downgradient Sediment[b] | 64 | 0.41 | 0.52 | 0.70 | 0.78 | 1.1 | 1.4 | 1.5 | 1.8 | 2.9 | 5.6 |
| Upgradient Sediment[b] | 16 | 0.96 | 1.0 | 1.0 | 1.0 | 1.2 | 1.3 | 1.4 | 1.5 | 1.6 | 1.7 |

[a] Big Creek sediment samples include JP-D-1 through JP-D-14, North Tributary samples include JP-D-15 and JP-D-16, and JP-D-17 through JP-D-20. Statistics represent results for samples collected in April 2008, July 2008, October 2008, and February 2009.
[b] Upgradient sediment samples include JP-D-12 and JP-D-13 (Big Creek), JP-D-16 (North Tributary), and JP-D-17 (Middle Fork Creek).

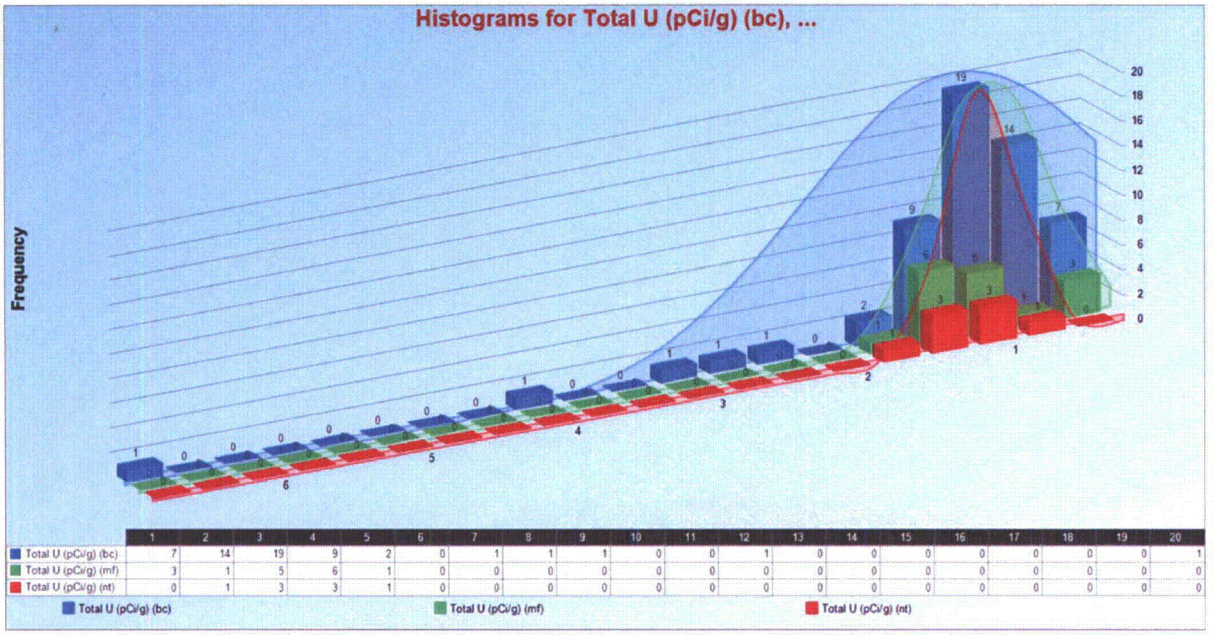



**Figure 6-9. Histogram of Sediment Sampling Results**

for Big Creek sediment samples, 0.51 ± 0.20 to 2.0 ± 0.55 pCi/g (1.4 to 5.6 mg/kg) for Middle Fork Creek sediment samples, and 0.96 ± 0.16 to 1.7 ± 0.38 pCi/g (0.97 to 4.7 mg/kg) for North Tributary sediment samples, with overall mean concentrations of 1.3, 1.2, and 1.3 pCi/g (3.6, 3.4, and 3.6 mg/kg) for Big Creek, Middle Fork Creek, and North Tributary, respectively. All concentrations are low with respect to potential radiological dose (35 pCi/g). The highest concentrations were observed where runoff is expected to enter Big Creek from the 500 Center trench.

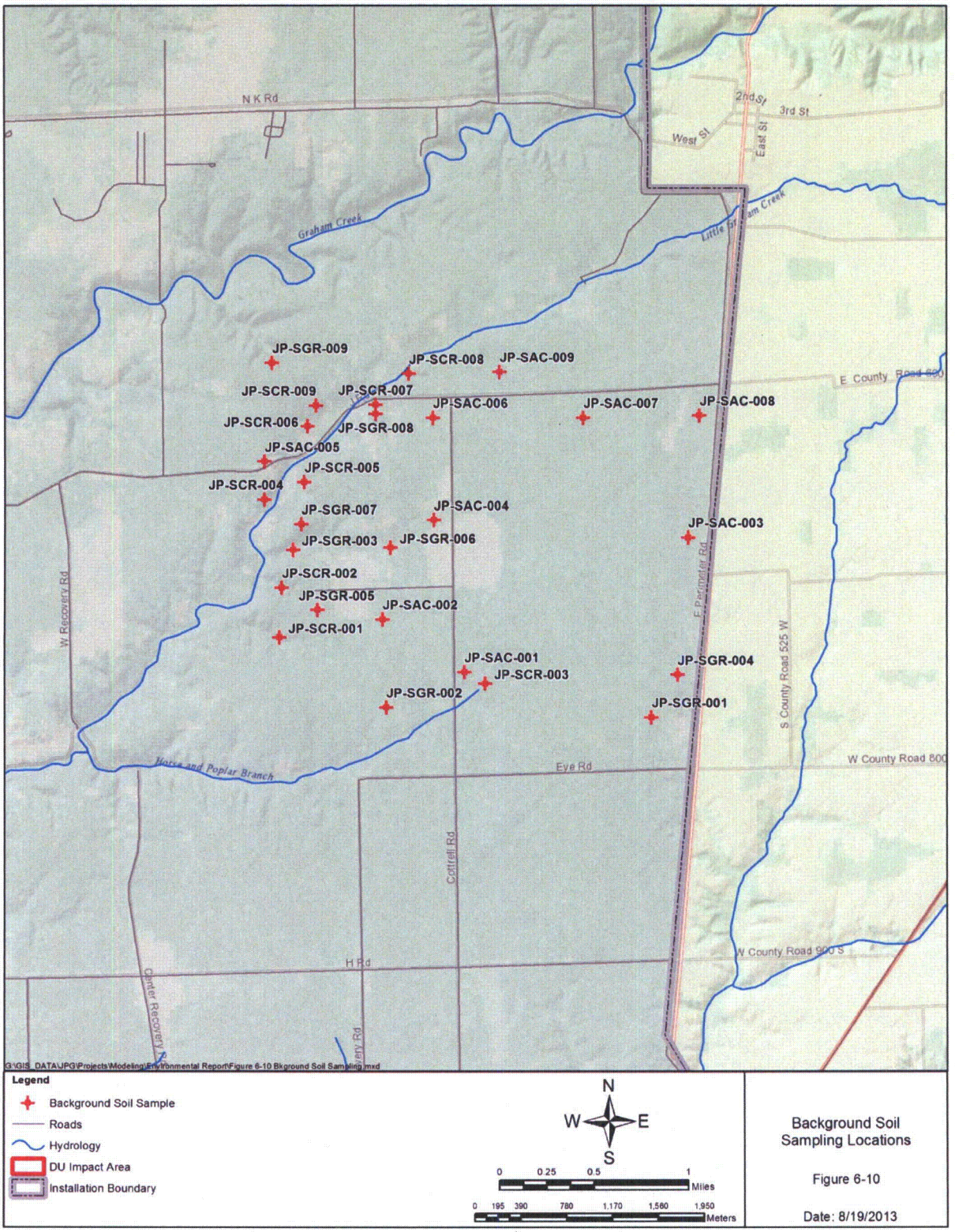
Evidence of DU was observed in eight sediment samples collected from five locations based on elevated U-238/U-234 ratios (i.e., exceeding 3.0) during one or more of the quarterly site characterization sampling events. Locations with isotopic ratios (U-238/U-234) exceeded 3.0 include the following: JP-D-05 (4.7 ± 2.9 in April 2008, 4.4 ± 2.9 in July 2008, 5.1 ± 1.7 in October 2008, and 4.5 ± 1.5 in February 2009) and JP-D-14 (4.2 ± 2.7 in April 2008, 5.2 ± 2.5 in July 2008, 5.2 ± 1.8 in October 2008, and 1.7 ± 0.6 in February 2009). All sediment samples with elevated isotopic ratios were collected from Big Creek in close proximity to the trench associated with the 500 Center line of fire.

No concentration trends are discernible from ERM data collected over time as evidenced by poor linear correlation ($R^2$ <0.5) in run charts plotting concentrations over time. Most results show total uranium concentrations having fluctuated slightly above detection limits over time.

Statistical testing was conducted on the sediment data using the standard general linear model (SAS® v 9.2 PROC GLM procedure) to test whether uranium concentrations at the DU Impact Area differed significantly from background levels and whether concentrations differed by season. DU Impact Area concentrations were lower than background at a statistically significant level ($p < 0.05$) and no concentration trends were observed between quarterly sampling events.

### 6.1.3.5 Soil Sampling

Soil sampling in October 2008, December 2009, and March 2012 included the collection of 767 soil samples from 152 locations in accordance with requirements in FSP Addenda 7 (SAIC 2008d) and 8 (SAIC 2009). Background samples (127 samples, Figure 6-10) and samples under penetrators


N K Rd
2nd St
3rd St
West St
East St
Graham Creek
Little Graham Creek
JP-SGR-009
JP-SCR-008
JP-SAC-009
JP-SCR-009
JP-SCR-007
JP-SAC-006
JP-SAC-007
JP-SAC-008
JP-SCR-006
JP-SGR-008
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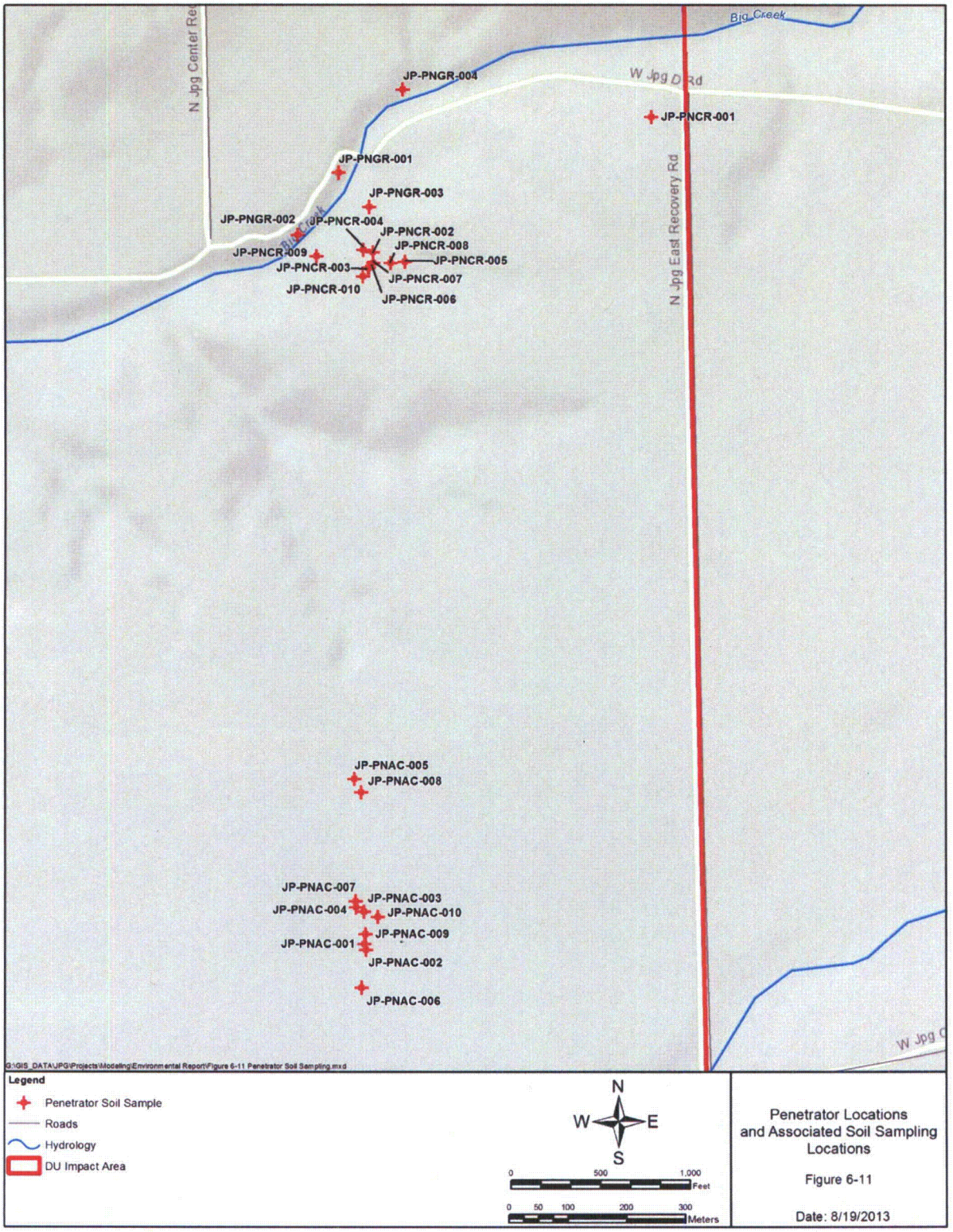
JP-SGR-007
JP-SAC-004
JP-SAC-003
JP-SGR-003
JP-SGR-006
JP-SCR-002
JP-SGR-005
JP-SAC-002
JP-SCR-001
JP-SAC-001
JP-SCR-003
JP-SGR-004
JP-SGR-002
JP-SGR-001
E County Road 800
W Recovery Rd
E Perimeter Rd
S County Road 525 W
W County Road 800
Eye Rd
Horse and Poplar Branch
Cottrell Rd
H Rd
W County Road 900 S
Center Recovery Rd
G:\GIS_DATA\JPG\Projects\Modeling\Environmental Report\Figure 6-10 Bkground Soil Sampling.mxd
Legend
Background Soil Sample
Roads
Hydrology
DU Impact Area
Installation Boundary
N
W
E
S
0 0.25 0.5 1 Miles
0 195 390 780 1,170 1,560 1,950 Meters
Background Soil Sampling Locations
Figure 6-10
Date: 8/19/2013

(107 samples, Figure 6-11) were collected and identified based on their respective soil type groupings: Avonburg/Cobbsfork, Cincinnati/Rossmoyne, and Grayford/Ryker. The remaining 400 samples (Figure 6-12) were collected from various locations in and around the DU Impact Area: Category 1 – outside DU Impact Area perimeter, Category 2 – immediately inside DU Impact Area, Category 3 – midway to DU Impact Area trenches, Category 4 – immediately outside DU Impact Area trenches, Category 5 – other nature and extent samples, and Category 6 – trench locations.

In October 2008, surface and near surface soil samples were collected using hand augers in and near the JPG DU Impact Area to characterize the extent and depth of DU contamination and from background areas to determine levels of natural uranium for each soil type grouping. In late March and early April 2012, soil samples were recollected from the same (or as close as possible) location as the October 2008 sampling. The resampling was necessary because all of NRC's issues related to the $K_d$ study were not resolved until November 2011 when the samples were more than 3 years old. Results shown below reflect both sets of data, but the $K_d$ study was conducted using only the March/April 2012 samples. Background soil samples were recollected using hand augers from locations where they were previously collected in October 2008. Samples from under penetrators were collected as close as possible to previous sampling locations (i.e., within approximately 1 m given the accuracy of typical GPS units and NaI gamma scintillation radiation detectors), since penetrators were removed after previous sampling in October 2008. The soil sampling hand auger instructions were as follows:

1. The sampling team and a health physics technician arrived at soil sample locations using a GPS and NaI detector. A UXO technician conducted anomaly avoidance for the sample location using a Schonstedt® magnetometer prior to any hand augering activities.
2. The sampling team donned clean nitrile gloves at each soil sampling location.
3. Soil samples were recollected using a properly decontaminated hand auger, which included auger bucket/basket and auger rods. The hand auger decontamination procedure is listed in FSP Addendum 7 (SAIC 2008b).
4. Soil was hand augered and placed on a new sheet of plastic sheeting at each location. Refusal information was recorded in the logbook when the soil sampling team was unable to hand auger to 4 ft BGS. Except where sampling with hand augers was limited due to auger refusal (e.g., roots, stones), samples were collected from the following depth intervals:
    a. For October 2008 sampling, the following sample groups were collected from depths of 0 to 0.5, 0.5 to 1, 1 to 2, and 2 to 4 ft BGS: background samples; samples collected in Categories 1, 2, and 5; and samples collected from under penetrators .
    b. For October 2008 sampling, samples were collected in Categories 3, 4, and 6 from depths of 0 to 0.5, 0.5 to 1, 1 to 2, 2 to 4, and 4 to 6 ft BGS.
    c. For March/April 2012, samples were collected from 0 to 4 ft BGS to address concerns raised by NRC (2011).
5. Soil was composited on the new sheet of plastic sheeting via several minutes of mixing.
6. Soil samples were photographed.
7. Soil samples were transferred from the plastic sheeting into laboratory provided sample containers.
8. The exterior sample container sides were wiped clean so that a sample label and container custody seal were placed on them.
9. Soil sample containers were bubble-wrapped for protection and placed in sealed Ziploc® bags before placing them in a cooler with ice.


Big Creek
N Jpg Center Rd
W Jpg D Rd
N Jpg East Recovery Rd
JP-PNGR-004
JP-PNCR-001
JP-PNGR-001
JP-PNGR-003
JP-PNGR-002
JP-PNCR-004
JP-PNCR-002
JP-PNCR-008
JP-PNCR-009
JP-PNCR-005
JP-PNCR-003
JP-PNCR-007
JP-PNCR-010
JP-PNCR-006
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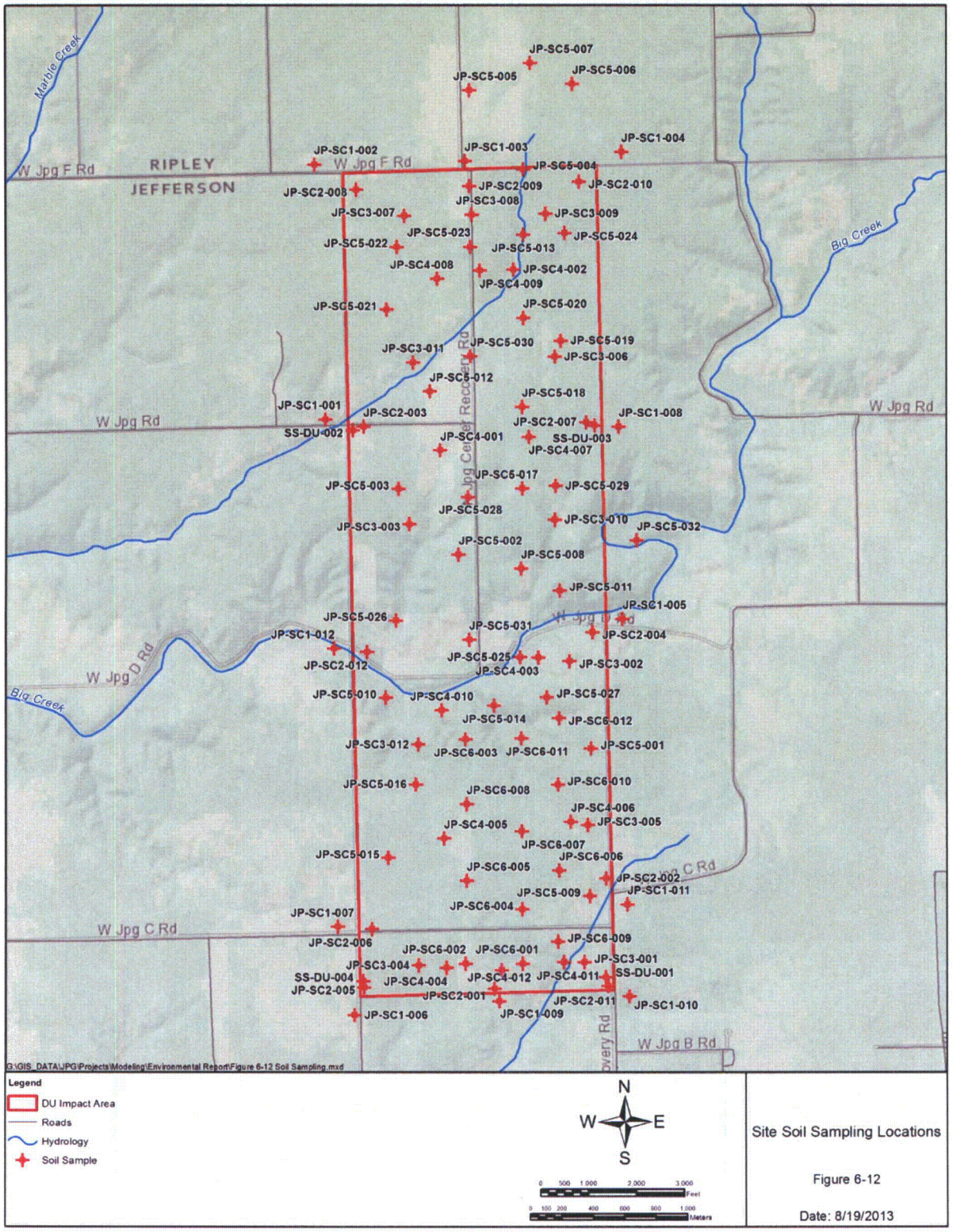
JP-PNAC-003
JP-PNAC-004
JP-PNAC-010
JP-PNAC-009
JP-PNAC-001
JP-PNAC-002
JP-PNAC-006
W Jpg C
G:\GIS_DATA\JPG\Projects\Modeling\Environmental Report\Figure 6-11 Penetrator Soil Sampling.mxd
Legend
Penetrator Soil Sample
Roads
Hydrology
DU Impact Area
N
W
E
S
0
500
1,000
Feet
0
50
100
200
300
Meters
Penetrator Locations and Associated Soil Sampling Locations
Figure 6-11
Date: 8/19/2013


Marble Creek
RIPLEY
JEFFERSON
W Jpg F Rd
W Jpg Rd
W Jpg D Rd
W Jpg C Rd
W Jpg B Rd
Big Creek
Jpg Cemetery Rd
Jpg C Rd
JP-SC5-007
JP-SC5-006
JP-SC5-005
JP-SC1-004
JP-SC1-002
JP-SC1-003
JP-SC5-004
JP-SC2-008
JP-SC2-009
JP-SC2-010
JP-SC3-008
JP-SC3-007
JP-SC3-009
JP-SC5-023
JP-SC5-024
JP-SC5-022
JP-SC5-013
JP-SC4-008
JP-SC4-002
JP-SC4-009
JP-SC5-021
JP-SC5-020
JP-SC3-011
JP-SC5-030
JP-SC5-019
JP-SC3-006
JP-SC5-012
JP-SC5-018
JP-SC1-001
JP-SC2-003
JP-SC1-008
JP-SC2-007
SS-DU-002
JP-SC4-001
SS-DU-003
JP-SC4-007
JP-SC5-017
JP-SC5-003
JP-SC5-029
JP-SC5-028
JP-SC3-003
JP-SC3-010
JP-SC5-032
JP-SC5-002
JP-SC5-008
JP-SC5-011
JP-SC1-005
JP-SC5-026
JP-SC5-031
JP-SC2-004
JP-SC1-012
JP-SC5-025
JP-SC3-002
JP-SC2-012
JP-SC4-003
JP-SC5-010
JP-SC4-010
JP-SC5-027
JP-SC5-014
JP-SC6-012
JP-SC3-012
JP-SC6-003
JP-SC6-011
JP-SC5-001
JP-SC5-016
JP-SC6-008
JP-SC6-010
JP-SC4-006
JP-SC4-005
JP-SC3-005
JP-SC6-007
JP-SC5-015
JP-SC6-006
JP-SC6-005
JP-SC2-002
JP-SC5-009
JP-SC1-011
JP-SC6-004
JP-SC1-007
JP-SC2-006
JP-SC6-009
JP-SC6-002
JP-SC6-001
JP-SC3-001
JP-SC3-004
SS-DU-001
SS-DU-004
JP-SC4-004
JP-SC4-012
JP-SC4-011
JP-SC2-005
JP-SC2-001
JP-SC2-011
JP-SC1-010
JP-SC1-006
JP-SC1-009
G:\GIS_DATA\JPG\Projects\Modeling\Environmental Report\Figure 6-12 Soil Sampling.mxd
Legend
DU Impact Area
Roads
Hydrology
Soil Sample
N
W
E
S
0 500 1,000 2,000 3,000 Feet
0 100 200 400 600 800 1,000 Meters
Site Soil Sampling Locations
Figure 6-12
Date: 8/19/2013

10. Remaining nonsampled soils were returned to the hand augered hole.

11. Plastic sheeting was lightly decontaminated and scanned prior to disposal.

Twelve samples from the deeper glacial till hydrostratigraphic unit were collected with a hydraulic direct-push technology (DPT) Geoprobe® 6620DT 2 Track with 4.25-in hollow stem auger and sampler, as shown in Figure 6-13. In December 2009, soil samples were collected using the DPT (i.e., Geoprobe®) within areas cleared for previous drilling inside the DU Impact Area. The soil samples covered the range of conditions affecting partitioning present in the till stratigraphic layer. Samples were located adjacent to monitoring wells that were observed during drilling to have overburden with characteristics of glacial till above bedrock, and with sufficient thickness to produce the necessary sample volume. The sample locations had minimal impacts from site-related DU due to their depth BGS (6 to 18 feet BGS) and the relatively impermeable nature of the till. In addition, the sample locations covered the predominant soil type groupings present within the DU Impact Area (i.e., Avonburg/Cobbsfork, Cincinnati/Rossmoyne, and Grayford/Ryker) and provided a relatively widespread geographic distribution.

**Figure 6-13. Geoprobe® 6620DT 2 Track with 4.25-in Hollow Stem Auger Kit and Sampler**

In late March 2012, the Army used a DPT Geoprobe® to recollect the glacial till soil samples from the same locations and depth intervals where they had previously been collected in December 2009. The DPT Geoprobe® soil sampling instructions were as follows:

1. The sampling team and a health physics technician arrived at soil sample locations using a GPS and NaI detector. A UXO technician conducted anomaly avoidance using a Schonstedt®

flux-gate magnetometer prior to any drilling activities and during drilling until 20 ft BGS (Step 5).

2. Radiation exposure rate measurements were taken at approximately 1 m (3.3 ft) above the sample location and recorded in the field logbook prior to any drilling activities.
3. The sampling team donned clean nitrile gloves and/or radiological or equivalent gloves at each soil sampling location.
4. Soil samples were collected and recollected using a Geoprobe® with new macro-core sampler acetate liners and properly decontaminated DPT stainless steel samplers. The DPT sampler decontamination procedure is listed in FSP Addendum 8 (SAIC 2009). A combination of discrete (i.e., targeted a prescribed or distinct depth interval) and nondiscrete (i.e., an open sampling tool for continuous soil collection) soil samplers was used.
5. Soil drilling was completed to a maximum of 20 ft BGS using anomaly avoidance procedures in accordance with FSP Addendum 8 (SAIC 2009). All of the DPT sampling was completed under the supervision of a Certified Professional Soil Scientist (CPSS) from the American Registry of Certified Professionals in Agronomy, Crops and Soils (ARCPACS). The CPSS determined the interval of soil to be sampled as representative of glacial till. Sampled soil intervals ranged from 6 to 16 ft BGS for the collection and recollection of glacial till samples.
6. Prior to the collection of samples from the sampling device, the soil was classified by the CPSS and photographs of the sampled soil interval were taken.
7. Soil samples were transferred from the macro-core sampler acetate liners into laboratory provided sample containers.
8. The soil sample container exteriors were wiped clean so that a sample label and container custody seal could be placed on it.
9. Soil sample containers were bubble-wrapped for protection and placed in sealed Ziploc® bags before placing them in a cooler with ice.
10. Remaining non-sampled soils were returned to the newly drilled borehole. GPS coordinates were collected for the newly drilled borehole.

Samples were analyzed for total and isotopic uranium and other nonradiological constituents listed in Table 6-18. During the analysis of soil samples collected in the fall of 2008, the Army became aware that alpha spectrometry results for a limited portion of the higher activity samples appeared to be biased high. This conclusion was based on reported results for one alpha spectrometry sample, which exceeded the specific activity of DU as stated in Title 10, CFR, Part 20, Appendix B (i.e., $3.6 \times 10^{-7}$ curies per gram [Ci/g]). This conclusion was reinforced by the reanalysis results from six high-activity samples using gamma spectrometry and the associated comparison of radioanalytical results for the two methods. The alpha spectrometry results for the highest activity sample were a factor of 50 times higher than the gamma spectrometry results. In addition, alpha spectrometry results for each of the other five samples were a factor of 3.1 to 7.2 times higher than the gamma spectrometry results for the same samples. Investigations into the cause suggested that the elevated alpha spectrometry results were associated with poor tracer recoveries and sample dilutions required to accommodate the high uranium concentrations. Based on the high bias that had been encountered with alpha spectrometry, the Army discussed the issue with NRC staff and re-analyzed samples by gamma spectrometry as follows:

- All samples with total uranium activities greater than 1,000 pCi/g (39 samples) were re-analyzed. The lowest total uranium activity in this range was from JP-PNAC-009/SAIC01 that was collected from 0.5 to 1 ft BGS. The alpha spectrometry result was 1,200 ± 258 pCi/g and

**Table 6-18. Summary of Sampling and Analysis Requirements for Soil Jefferson Proving Ground, Madison, Indiana**

| Parameter | Analytical Method | Detection Limit |
|---|---|---|
| Total and Isotopic Uranium: U-234, U-235, and U-238 | ASTM D3972-90M | 0.1 pCi/g |
| Moisture Content | ASTM D2216-05 | NA |
| Soil pH | ASTM D4972-01/E9045C | NA |
| Particle Size Distribution | ASTM D422-63 | NA |
| Total Organic Carbon | SW9060/415.2 | 200 mg/kg |
| Total Carbon | SW9060/415.2 | 2,000 mg/kg |
| Total Iron | SW6010 | 20 mg/kg |
| Total Manganese | SW6010 | 1 mg/kg |
| Uranium Corrosion Product Speciation by XRD | ASTM D934-80 | NA |
| Uranium Corrosion products by XPS | NA | NA |
| Uranium Corrosion products by SEM-EDS | NA | NA |
| $K_d$ Testing | ASTM C1733-10 | NA |

ASTM = American Society for Testing and Materials
$K_d$ = Partition Coefficient
SEM-EDS = Scanning Electron Microscopy/Energy Dispersive Spectroscopy
XPS = X-Ray Photoelectron Spectroscopy
XRD = X-Ray Diffraction

the corresponding reanalysis result using gamma spectrometry was 537 ± 48 pCi/g. The highest total uranium activity measured was 720,430 ± 264,000 pCi/g from JP-PNAC-009/ SAIC01 that was collected from 0.5 to 1 ft BGS. The corresponding reanalysis for this sample using gamma spectrometry was 10,149 ± 885 pCi/g.

- Since the issue was related to higher activity samples, results for alpha and gamma spectrometry results were previously expected to converge at 1,000 pCi/g. However, gamma spectrometry re-analysis results remained incongruent around 1,000 pCi/g. For this reason, all samples with total uranium activities greater than 15 pCi/g were re-analyzed, which included 62 samples.
- To ensure parity between the alpha and gamma spectrometry results, five percent of the remaining samples (35 samples) were re-analyzed.

Results from alpha and gamma spectrometry analysis are included in Appendix F. Data from the gamma spectrometry analysis are used for the tables, interpretations, and conclusions presented below.

Sampling results from all soil site characterization sampling were statistically analyzed via ProUCL computer software (USEPA 2007) to evaluate data from background, Categories 1 through 6, glacial till, and soil from under/over penetrators. Results are summarized for sampling in Figure 6-14 and Tables 6-19 through 6-22. Total uranium concentrations ranged from -3.2 ± 2.3 to 40,693 ± 3,580 pCi/g with overall mean concentrations ranging from 0.76 to 6,831 pCi/g.

As shown in Figure 6-14, most soil concentrations (578 results, 76 percent) were low with respect to potential radiological doses (i.e., 35 pCi/g is a common DCGL). Total uranium concentrations in 127 background soil samples ranged from 0.15 (0.43 mg/kg, measured with inductively coupled plasma-mass spectrometry [ICP-MS]) to 3.8 ± 0.81 pCi/g. Total uranium concentrations in 336 soil samples collected away from the trench and penetrators ranged from 0.71 ± 0.18 to 19 ± 5.4 pCi/g. Total uranium concentrations in 12 samples from the glacial till ranged from 0.16 pCi/g (0.45 mg/kg, measured with ICP-MS) to 2.2 ± 0.24 pCi/g. Total uranium concentrations in 63 samples collected from within the trench area (Category 6) ranged from -1.8 ± 2.7 to 142 ± 16 pCi/g. Total uranium concentrations in 107 samples collected from over or under penetrators ranged from 22 ± 4.7 to 40,693 ± 3,580 pCi/g.

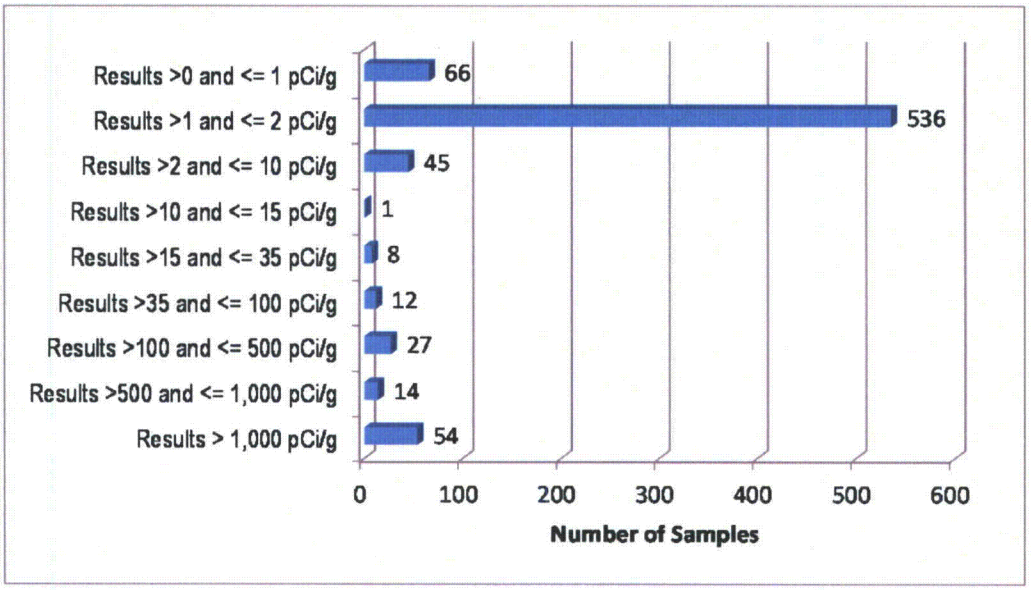



**Figure 6-14. Bar Chart with Total Uranium Concentrations Versus Number of Samples**

## Table 6-19. Summary Statistics for Soil Sampling Across All Depths Jefferson Proving Ground, Madison, Indiana

| Sample Group | Number of Samples | Minimum | Maximum | Mean | Median | Variance | SD | MAD/0.675 | Skewness | Kurtosis | CV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Background Soil*** | | | | | | | | | | | |
| Avonburg and Cobbsfork | 45 | 0.16 | 1.8 | 1.3 | 1.5 | 0.30 | 0.54 | 0.21 | -1.3E+00 | 0.13 | 0.43 |
| Cincinnati and Rossmoyne | 45 | 0.16 | 2.1 | 1.4 | 1.6 | 0.32 | 0.57 | 0.37 | -1.1E+00 | -6.9E-03 | 0.40 |
| Grayford and Ryker | 37 | 0.20 | 3.8 | 1.7 | 1.7 | 0.35 | 0.59 | 0.36 | 0.23 | 5.1 | 0.35 |
| ***Categories 1 through 6*** | | | | | | | | | | | |
| 1 – Outside DU Impact Area Perimeter | 45 | 1.3 | 2.1 | 1.6 | 1.6 | 0.034 | 0.18 | 0.16 | 0.80 | 0.95 | 0.12 |
| 2 – Immediately Inside DU Impact Area | 48 | 1.00 | 2.3 | 1.6 | 1.6 | 0.064 | 0.25 | 0.19 | -0.21 | 0.85 | 0.16 |
| 3 – Midway to DU Impact Area Trenches | 58 | 1.2 | 19 | 1.9 | 1.5 | 5.3 | 2.3 | 0.24 | 7.5 | 57 | 1.2 |
| 4 – Immediately Outside DU Impact Area Trenches | 58 | 1.1 | 2.1 | 1.5 | 1.5 | 0.034 | 0.18 | 0.17 | 0.42 | 0.78 | 0.12 |
| 5 – Other Nature and Extent Samples | 127 | 0.71 | 2.6 | 1.6 | 1.5 | 0.072 | 0.27 | 0.21 | 0.38 | 2.3 | 0.17 |
| 6 – Trench Locations | 64 | -3.2 | 142 | 8.5 | 1.9 | 607 | 25 | 0.58 | 4.5 | 21 | 2.9 |
| ***Glacial Till Soil Samples*** | | | | | | | | | | | |
| Glacial Till Samples | 12 | 0.16 | 2.2 | 0.76 | 0.50 | 0.39 | 0.62 | 0.49 | 1.2 | 1.2 | 0.82 |
| ***Soil Over/Under Penetrators*** | | | | | | | | | | | |
| Avonburg and Cobbsfork | 46 | 23 | 40,693 | 6,831 | 1,547 | 1.1E+08 | 10,355 | 2,192 | 1.7 | 2.1 | 1.5 |
| Cincinnati and Rossmoyne | 42 | 22 | 27,253 | 3,956 | 1,248 | 31,112,638 | 5,578 | 1,723 | 2.3 | 6.6 | 1.4 |
| Grayford and Ryker | 20 | -1.5 | 27,469 | 3,620 | 406 | 51,524,172 | 7,178 | 525 | 2.6 | 6.4 | 2.0 |

SD = standard deviation
MAD/0.675 = median absolute deviation (MAD)/0.675 is robust estimate of variability
CV = coefficient of variation

## Table 6-20. Percentiles From Frequency Distributions of Soil Sampling Data Across All Depths Jefferson Proving Ground, Madison, Indiana

| Sample Group | Number of Samples | Percentile | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 5th | 10th | 20th | 25th | 50th | 75th | 80th | 90th | 95th | 99th |
| ***Background Soil*** | | | | | | | | | | | |
| Avonburg and Cobbsfork | 45 | 0.19 | 0.22 | 1.1 | 1.3 | 1.5 | 1.6 | 1.6 | 1.7 | 1.8 | 1.8 |
| Cincinnati and Rossmoyne | 45 | 0.30 | 0.34 | 1.0 | 1.4 | 1.6 | 1.8 | 1.9 | 1.9 | 2.0 | 2.1 |
| Grayford and Ryker | 37 | 0.40 | 1.2 | 1.4 | 1.5 | 1.7 | 1.9 | 2.0 | 2.1 | 2.2 | 3.2 |
| ***Categories 1 Through 6*** | | | | | | | | | | | |
| 1 – Outside DU Impact Area Perimeter | 45 | 1.3 | 1.4 | 1.4 | 1.5 | 1.6 | 1.7 | 1.7 | 1.8 | 2.0 | 2.1 |
| 2 – Immediately Inside DU Impact Area | 48 | 1.2 | 1.3 | 1.5 | 1.5 | 1.6 | 1.7 | 1.8 | 1.9 | 2.0 | 2.2 |
| 3 – Midway to DU Impact Area Trenches | 58 | 1.3 | 1.3 | 1.4 | 1.4 | 1.5 | 1.7 | 1.8 | 2.0 | 2.0 | 9.4 |
| 4 – Immediately Outside DU Impact Area Trenches | 58 | 1.3 | 1.3 | 1.4 | 1.4 | 1.5 | 1.6 | 1.7 | 1.8 | 1.9 | 2.0 |
| 5 – Other Nature and Extent Samples | 127 | 1.2 | 1.3 | 1.4 | 1.4 | 1.5 | 1.7 | 1.7 | 1.9 | 2.0 | 2.3 |
| 6 – Trench Locations | 64 | 0.31 | 1.4 | 1.6 | 1.6 | 1.9 | 2.8 | 3.3 | 9.5 | 45 | 132 |
| ***Glacial Till Soil Samples*** | | | | | | | | | | | |
| Glacial Till Samples | 12 | 0.16 | 0.18 | 0.27 | 0.27 | 0.50 | 1.2 | 1.2 | 1.2 | 1.7 | 2.1 |
| ***Soil Over/Under Penetrators*** | | | | | | | | | | | |
| Avonburg and Cobbsfork | 46 | 42 | 58 | 125 | 143 | 1,547 | 11,617 | 15,096 | 21,608 | 29,775 | 36,637 |
| Cincinnati and Rossmoyne | 42 | 85 | 129 | 479 | 531 | 1,248 | 5,607 | 7,200 | 11,887 | 13,766 | 22,340 |
| Grayford and Ryker | 20 | 31 | 68 | 137 | 159 | 406 | 2,545 | 3,044 | 12,954 | 17,618 | 25,499 |

# Table 6-21. Summary Statistics for Soil Sampling by Area and Depth
# Jefferson Proving Ground, Madison, Indiana

| Sample Group | Number of Samples | Minimum | Maximum | Mean | Median | Variance | SD | MAD/ 0.675 | Skewness | Kurtosis | CV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Background Samples (0 to 0.5 ft BGS) | 27 | 1.1 | 1.9 | 1.5 | 1.6 | 0.042 | 0.20 | 0.19 | -0.28 | -0.23 | 0.13 |
| Samples Outside of Trench/Away From Penetrators (0 to 0.5 ft BGS) | 80 | 0.71 | 19 | 1.8 | 1.5 | 3.9 | 2.0 | 0.19 | 8.8 | 78 | 1.1 |
| Samples From Trench (0 to 0.5 ft BGS) | 14 | 0.13 | 142 | 26 | 2.9 | 2,160 | 46 | 1.8 | 2.0 | 2.8 | 1.8 |
| Samples From Over/Under Penetrators[a] (0 to 0.75 ft BGS) | 34 | 773 | 40,693 | 13,729 | 12,404 | 97,597,452 | 9,879 | 9,384 | 0.96 | 0.32 | 0.72 |
| Background Samples (0.5 to 1 ft BGS) | 27 | 1.3 | 2.2 | 1.7 | 1.6 | 0.053 | 0.23 | 0.21 | 0.45 | -0.80 | 0.14 |
| Samples Outside of Trench/Away From Penetrators (0.5 to 1 ft BGS) | 80 | 0.92 | 2.6 | 1.6 | 1.6 | 0.071 | 0.27 | 0.19 | 0.95 | 2.6 | 0.17 |
| Samples From Trench (0.5 to 1 ft BGS) | 13 | -1.8 | 48 | 6.2 | 2.5 | 167 | 13 | 0.86 | 3.3 | 11 | 2.1 |
| Samples From Over/Under Penetrators[b] (0.5 to 1.25 ft BGS) | 26 | 86 | 10,149 | 1,926 | 1,709 | 4,237,153 | 2,058 | 1,723 | 2.7 | 9.8 | 1.1 |
| Background Samples (1 to 2 ft BGS) | 27 | 1.3 | 3.8 | 1.8 | 1.7 | 0.21 | 0.46 | 0.31 | 3.2 | 14 | 0.26 |
| Samples Outside of Trench/Away From Penetrators (1 to 2 ft BGS) | 79 | 1.00 | 2.1 | 1.6 | 1.6 | 0.050 | 0.22 | 0.19 | -0.042 | 0.31 | 0.14 |
| Samples From Trench (1 to 2 ft BGS) | 12 | 1.4 | 25 | 3.8 | 1.7 | 47 | 6.8 | 0.28 | 3.5 | 12 | 1.8 |
| Samples from Over/Under Penetrators[c] (1 to 2.5 ft BGS) | 26 | 22 | 3,137 | 547 | 234 | 526,794 | 726 | 224 | 2.3 | 6.0 | 1.3 |
| Background Samples (2 to 4 ft BGS) | 25 | 1.0 | 2.2 | 1.7 | 1.6 | 0.072 | 0.27 | 0.30 | -0.24 | -0.089 | 0.16 |
| Samples Outside of Trench/Away From Penetrators (2 to 4 ft BGS) | 77 | 0.83 | 2.4 | 1.6 | 1.6 | 0.058 | 0.24 | 0.23 | -0.00096 | 1.6 | 0.15 |
| Samples From Trench (2 to 4 ft BGS) | 12 | 1.5 | 5.3 | 2.2 | 1.8 | 1.2 | 1.1 | 0.25 | 2.6 | 6.8 | 0.51 |
| Samples From Over/Under Penetrators[d] (2 to 4.5 ft BGS) | 18 | 24 | 670 | 208 | 126 | 49,970 | 224 | 109 | 1.3 | 0.11 | 1.1 |
| Background Samples (0 to 4 ft BGS) | 21 | 0.16 | 1.0 | 0.31 | 0.28 | 0.032 | 0.18 | 0.12 | 3.2 | 12 | 0.58 |
| Samples Outside of Trench/Away From Penetrators (4 to 6 ft BGS) | 20 | 1.2 | 1.8 | 1.5 | 1.6 | 0.028 | 0.17 | 0.15 | -0.75 | -0.12 | 0.11 |
| Samples From Trench (4 to 6 ft BGS) | 12 | 1.3 | 3.9 | 1.9 | 1.7 | 0.44 | 0.66 | 0.29 | 2.9 | 9.3 | 0.35 |
| Samples From Over/Under Penetrators[e] (0 to 4 ft BGS) | 3 | 23 | 17,100 | 6,063 | 1,066 | 91,633,507 | 9,573 | 1,545 | 1.7 | N/A | 1.6 |
| Glacial Till Samples[f] (6 to 18 ft BGS) | 12 | 0.16 | 2.2 | 0.76 | 0.50 | 0.39 | 0.62 | 0.49 | 1.2 | 1.2 | 0.82 |

BGS = below ground surface
SD = standard deviation
MAD/0.675 = median absolute deviation (MAD)/0.675 is robust estimate of variability
CV = coefficient of variation

[a] Sampling depths for the planned 0- to 0.5-ft BGS interval actually extended from 0 to 0.75 ft BGS for samples collected over/under subsurface penetrators due to the depth to the penetrator. Other depth variations resulted from the presence of subsurface obstructions (e.g., stones, bedrock, roots). Specific sampling intervals included 0 to 0.125, 0 to 0.15, 0 to 0.25, 0 to 0.3, 0 to 0.35, 0 to 0.5, 0.125 to 0.625, 0.15 to 0.5, 0.25 to 0.5, 0.25 to 0.75, and 0.35 to 0.5 ft BGS.

[b] Sampling depths for the planned 0.5- to 1-ft BGS interval actually extended from 0.5 to 1.25 ft BGS for samples collected over/under subsurface penetrators due to the depth to the penetrator. Other depth variations resulted from the presence of subsurface obstructions (e.g., stones, bedrock, roots). Specific sampling intervals included 0.5 to 1, 0.625 to 1.125, 0.75 to 1.0, and 0.75 to 1.25 ft BGS.

[c] Sampling depths for the planned 1- to 2-ft BGS interval actually extended from 1 to 2.5 ft BGS for samples collected over/under subsurface penetrators due to the depth to the penetrator. Other depth variations resulted from the presence of subsurface obstructions (e.g., stones, bedrock, roots). Specific sampling intervals included 1 to 1.25, 1 to 1.5, 1 to 2, 1.125 to 2.125, 1.25 to 2.25, and 1.5 to 2.5 ft BGS.

[d] Sampling depths for the planned 2- to 4-ft BGS interval actually extended from 2 to 4.5 ft BGS for samples collected over/under subsurface penetrators due to the depth to the penetrator. Other depth variations resulted from the presence of subsurface obstructions (e.g., stones, bedrock, roots). Specific sampling intervals included 2 to 2.5, 1.5 to 2.5, 2 to 4, 2.125 to 4.125, and 2.5 to 4.5 ft BGS.

[e] The presence of subsurface obstructions (e.g., stones, bedrock, roots) prevented the collection of the full 4-ft interval (0 to 4 ft BGS) for some samples. Specific sampling intervals included 0 to 2, 0 to 3, 0 to 3.3, and 0 to 4 ft BGS.

[f] Samples were collected from 6- to 18-ft BGS depending on the zone where glacial till was encountered at the specific location. Specific sampling intervals included 6 to 10, 8 to 14, 10 to 16, and 10 to 18 ft BGS.

## Table 6-22. Percentiles From Frequency Distributions of Soil Sampling Data By Area and Depth Jefferson Proving Ground, Madison, Indiana

| Sample Group | Number of Samples | Percentile | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 5th | 10th | 20th | 25th | 50th | 75th | 80th | 90th | 95th | 99th |
| Background Samples (0 to 0.5 ft BGS) | 27 | 1.2 | 1.3 | 1.3 | 1.4 | 1.6 | 1.7 | 1.7 | 1.8 | 1.8 | 1.9 |
| Samples Outside of Trench/Away From Penetrators (0 to 0.5 ft BGS) | 80 | 1.3 | 1.3 | 1.4 | 1.4 | 1.5 | 1.7 | 1.7 | 1.8 | 2.0 | 5.7 |
| Samples From Trench (0 to 0.5 ft BGS) | 14 | 0.98 | 1.6 | 1.9 | 2.0 | 2.9 | 24 | 38 | 98 | 126 | 139 |
| Samples From Over/Under Penetrators[a] (0 to 0.75 ft BGS) | 34 | 2,675 | 3,798 | 5,102 | 5,927 | 12,404 | 17,081 | 21,606 | 28,774 | 30,537 | 37,719 |
| Background Samples (0.5 to 1 ft BGS) | 27 | 1.4 | 1.4 | 1.5 | 1.5 | 1.6 | 1.9 | 1.9 | 2.0 | 2.0 | 2.1 |
| Samples Outside of Trench/Away From Penetrators (0.5 to 1 ft BGS) | 80 | 1.2 | 1.3 | 1.4 | 1.4 | 1.6 | 1.6 | 1.7 | 1.9 | 2.0 | 2.4 |
| Samples From Trench (0.5 to 1 ft BGS) | 13 | -0.83 | 0.20 | 1.9 | 2.0 | 2.5 | 2.8 | 3.5 | 9.8 | 26 | 44 |
| Samples From Over/Under Penetrators[b] (0.5 to 1.25 ft BGS) | 26 | 149 | 313 | 488 | 531 | 1,709 | 2,686 | 2,785 | 3,436 | 3,950 | 8,638 |
| Background Samples (1 to 2 ft BGS) | 27 | 1.4 | 1.4 | 1.5 | 1.5 | 1.7 | 1.9 | 2.0 | 2.1 | 2.1 | 3.3 |
| Samples Outside of Trench/Away From Penetrators (1 to 2 ft BGS) | 79 | 1.2 | 1.3 | 1.4 | 1.4 | 1.6 | 1.7 | 1.8 | 1.8 | 2.0 | 2.0 |
| Samples From Trench (1 to 2 ft BGS) | 12 | 1.5 | 1.5 | 1.6 | 1.6 | 1.7 | 2.0 | 2.1 | 2.3 | 13 | 23 |
| Samples From Over/Under Penetrators[c] (1 to 2.5 ft BGS) | 26 | 74 | 81 | 111 | 130 | 234 | 749 | 767 | 1,383 | 1,878 | 2,860 |
| Background Samples (2 to 4 ft BGS) | 25 | 1.3 | 1.4 | 1.4 | 1.5 | 1.6 | 1.9 | 1.9 | 1.9 | 2.1 | 2.1 |
| Samples Outside of Trench/Away From Penetrators (2 to 4 ft BGS) | 77 | 1.3 | 1.3 | 1.4 | 1.5 | 1.6 | 1.8 | 1.8 | 1.9 | 2.0 | 2.2 |
| Samples From Trench (2 to 4 ft BGS) | 12 | 1.5 | 1.6 | 1.6 | 1.6 | 1.8 | 2.0 | 2.0 | 3.2 | 4.2 | 5.1 |
| Samples From Over/Under Penetrators[d] (2 to 4.5 ft BGS) | 18 | 25 | 31 | 44 | 52 | 126 | 194 | 399 | 570 | 646 | 665 |
| Background Samples (0 to 4 ft BGS) | 21 | 0.16 | 0.18 | 0.19 | 0.20 | 0.28 | 0.32 | 0.36 | 0.40 | 0.43 | 0.89 |
| Samples Outside of Trench/Away From Penetrators (4 to 6 ft BGS) | 20 | 1.2 | 1.3 | 1.4 | 1.5 | 1.6 | 1.6 | 1.7 | 1.7 | 1.8 | 1.8 |
| Samples From Trench (4 to 6 ft BGS) | 12 | 1.4 | 1.4 | 1.5 | 1.6 | 1.7 | 1.9 | 1.9 | 2.0 | 2.8 | 3.7 |
| Samples From Over/Under Penetrators[e] (0 to 4 ft BGS) | 3 | 128 | 232 | 440 | 545 | 1,066 | 9,083 | 10,686 | 13,893 | 15,497 | 16,779 |
| Glacial Till Samples[f] (6 to 18 ft BGS) | 12 | 0.16 | 0.18 | 0.27 | 0.27 | 0.50 | 1.2 | 1.2 | 1.2 | 1.7 | 2.1 |

BGS = below ground surface
SD = standard deviation
MAD/0.675 = median absolute deviation (MAD)/0.675 is robust estimate of variability
CV = coefficient of variation

[a] Sampling depths for the planned 0- to 0.5-ft BGS interval actually extended from 0 to 0.75 ft BGS for samples collected over/under subsurface penetrators due to the depth to the penetrator. Other depth variations resulted from the presence of subsurface obstructions (e.g., stones, bedrock, roots). Specific sampling intervals included 0 to 0.125, 0 to 0.15, 0 to 0.25, 0 to 0.3, 0 to 0.35, 0 to 0.5, 0.125 to 0.625, 0.15 to 0.5, 0.25 to 0.5, 0.25 to 0.75, and 0.35 to 0.5 ft BGS.

[b] Sampling depths for the planned 0.5- to 1-ft BGS interval actually extended from 0.5 to 1.25 ft BGS for samples collected over/under subsurface penetrators due to the depth to the penetrator. Other depth variations resulted from the presence of subsurface obstructions (e.g., stones, bedrock, roots). Specific sampling intervals included 0.5 to 1, 0.625 to 1.125, 0.75 to 1.0, and 0.75 to 1.25 ft BGS.

[c] Sampling depths for the planned 1- to 2-ft BGS interval actually extended from 1 to 2.5 ft BGS for samples collected over/under subsurface penetrators due to the depth to the penetrator. Other depth variations resulted from the presence of subsurface obstructions (e.g., stones, bedrock, roots). Specific sampling intervals included 1 to 1.25, 1 to 1.5, 1 to 2, 1.125 to 2.125, 1.25 to 2.25, and 1.5 to 2.5 ft BGS.

[d] Sampling depths for the planned 2- to 4-ft BGS interval actually extended from 2 to 4.5 ft BGS for samples collected over/under subsurface penetrators due to the depth to the penetrator. Other depth variations resulted from the presence of subsurface obstructions (e.g., stones, bedrock, roots). Specific sampling intervals included 2 to 2.5, 1.5 to 2.5, 2 to 4, 2.125 to 4.125, and 2.5 to 4.5 ft BGS.

[e] The presence of subsurface obstructions (e.g., stones, bedrock, roots) prevented the collection of the full 4-ft interval (0 to 4 ft BGS) for some samples. Specific sampling intervals included 0 to 2, 0 to 3, 0 to 3.3, and 0 to 4 ft BGS.

[f] Samples were collected from 6- to 18-ft BGS depending on the zone where glacial till was encountered at the specific location. Specific sampling intervals included 6 to 10, 8 to 14, 10 to 16, and 10 to 18 ft BGS.

With the exception of the surface (0.0- to 0.50-ft) interval of JP-SC3-005, all U-238/U-234 ratios were less ≤3 for samples from Category 1 through 5 locations. The U-238/U-234 ratio for the surface interval of JP-SC3-005 was 5.9 ± 2.0. Table 6-23 shows evidence of DU (based on U-238/U-234 ratios exceeding 3.0) in all 105 samples collected under/over penetrators to depths of 4.5 ft BGS. Isotopic ratios for samples collected within the 500 Center trench (Category 6) based on U-238/U-234 ratios also exceeded 3.0 in 7 of 52 samples. None of the isotopic ratios for samples collected deeper than 4 ft BGS exceeded 3.0 for samples collected within the 500 Center trench.

**Table 6-23. Summary of Elevated Isotopic Uranium Ratio by Area and Depth Jefferson Proving Ground, Madison, Indiana**

| Sample Group | Number of Samples | Number of Samples with U-238/U-234 Ratios >3.0 | Number of Samples with Weight Percent U-235 <0.7 Percent |
|---|---|---|---|
| Samples Outside of Trench/Away From Penetrators (0 to 0.5 ft BGS) | 164 | 1 | -- |
| Samples From Trench (0 to 0.5 ft BGS) | 7 | 3 | -- |
| Samples From Over/Under Penetrators[a] (0 to 0.75 ft BGS) | 34 | 34 | -- |
| Samples Outside of Trench/Away From Penetrators (0.5 to 1 ft BGS) | 107 | -- | -- |
| Samples From Trench (0.5 to 1 ft BGS) | 10 | 2 | -- |
| Samples From Over/Under Penetrators[b] (0.5 to 1.25 ft BGS) | 26 | 26 | -- |
| Samples Outside of Trench/Away From Penetrators (1 to 2 ft BGS) | 106 | -- | -- |
| Samples From Trench (1 to 2 ft BGS) | 12 | 1 | -- |
| Samples From Over/Under Penetrators[c] (1 to 2.5 ft BGS) | 27 | 27 | -- |
| Samples Outside of Trench/Away From Penetrators (2 to 4 ft BGS) | 102 | -- | -- |
| Samples From Trench (2 to 4 ft BGS) | 12 | 1 | -- |
| Samples From Over/Under Penetrators[d] (2 to 4.5 ft BGS) | 18 | 18 | -- |
| Samples Outside of Trench/Away From Penetrators (4 to 6 ft BGS) | 20 | -- | -- |
| Samples From Trench (4 to 6 ft BGS) | 11 | -- | -- |
| Samples Outside of Trench/Away From Penetrators (0 to 4 ft BGS) | -- | -- | -- |
| Samples From Over/Under Penetrators[e] (0 to 4 ft BGS) | 2 | -- | 2 |
| Samples Outside of Trench/Away From Penetrators[f] (6 to 18 ft BGS) | 6 | -- | -- |
| **Total** | 662 | 122 | 2 |

BGS = below ground surface
SD = standard deviation
MAD/0.675 = median absolute deviation (MAD)/0.675 is robust estimate of variability
CV = coefficient of variation

[a] Sampling depths for the planned 0- to 0.5-ft BGS interval actually extended from 0 to 0.75 ft BGS for samples collected over/under subsurface penetrators due to the depth to the penetrator. Other depth variations resulted from the presence of subsurface obstructions (e.g., stones, bedrock, roots). Specific sampling intervals included 0 to 0.125, 0 to 0.15, 0 to 0.25, 0 to 0.3, 0 to 0.35, 0 to 0.5, 0.125 to 0.625, 0.15 to 0.5, 0.25 to 0.5, 0.25 to 0.75, and 0.35 to 0.5 ft BGS.

[b] Sampling depths for the planned 0.5- to 1-ft BGS interval actually extended from 0.5 to 1.25 ft BGS for samples collected over/under subsurface penetrators due to the depth to the penetrator. Other depth variations resulted from the presence of subsurface obstructions (e.g., stones, bedrock, roots). Specific sampling intervals included 0.5 to 1, 0.625 to 1.125, 0.75 to 1.0, and 0.75 to 1.25 ft BGS.

[c] Sampling depths for the planned 1- to 2-ft BGS interval actually extended from 1 to 2.5 ft BGS for samples collected over/under subsurface penetrators due to the depth to the penetrator. Other depth variations resulted from the presence of subsurface obstructions (e.g., stones, bedrock, roots). Specific sampling intervals included 1 to 1.25, 1 to 1.5, 1 to 2, 1.125 to 2.125, 1.25 to 2.25, and 1.5 to 2.5 ft BGS.

[d] Sampling depths for the planned 2- to 4-ft BGS interval actually extended from 2 to 4.5 ft BGS for samples collected over/under subsurface penetrators due to the depth to the penetrator. Other depth variations resulted from the presence of subsurface obstructions (e.g., stones, bedrock, roots). Specific sampling intervals included 2 to 2.5, 1.5 to 2.5, 2 to 4, 2.125 to 4.125, and 2.5 to 4.5 ft BGS.

[e] The presence of subsurface obstructions (e.g., stones, bedrock, roots) prevented the collection of the full 4-ft interval (0 to 4 ft BGS) for some samples. Specific sampling intervals included 0 to 2, 0 to 3, 0 to 3.3, and 0 to 4 ft BGS.

[f] Samples were collected from 6- to 18-ft BGS depending on the zone where glacial till was encountered at the specific location. Specific sampling intervals included 6 to 10, 8 to 14, 10 to 16, and 10 to 18 ft BGS.

Figures 6-15 through 6-17 show the results for gamma activity scans of soil samples collected under penetrators as a function of depth. The gamma activities measured at ground surface (or immediately underneath subsurface penetrators) ranged from 646 to 88,873 cpm. At 24 in BGS, which is the deepest depth with numerous measurements, the gamma activities ranged from 62 to 607 cpm. Figures 6-15 through 6-17 show 90 to >99 percent reductions to demonstrate a rapid attenuation in gamma activity. A rapid reduction in total uranium activity as a function of depth also is shown in Tables 6-21 and 6-22. For example, from Table 6-21, the mean concentration for samples from over/under penetrators decreases from 13,729 pCi/g (0 to 0.75 ft BGS) to 1,926 pCi/g (0.5 to 1.25 ft BGS) to 547 pCi/g (1 to 2.5 ft BGS) to 208 pCi/g (2 to 4.5 ft BGS). However, the deepest samples, on average, are well above background levels for total uranium with means from 1.3 to 1.7 pCi/g (Table 6-19).

In addition to displaying spatial patterns for elevated U-238/U-234 ratios (i.e., under penetrators and within trench), Table 6-23 also indirectly shows depths of DU migration. Consistent with the attenuation of gamma activity demonstrated in Figures 6-15 through 6-17 and reductions in total uranium activities under penetrators from Table 6-21, the number of samples exceeding U-238/U-234 ratios of 3.0 generally diminish with depth from 34 (0 to 0.75 ft BGS) to 26 (0.5 to 1.25 ft BGS) to 27 (1 to 2.5 ft BGS) to 18 (2 to 4.5 ft BGS). Elevated ratios were observed in 18 samples in the 2- to 4.5-ft BGS interval, and elevated average concentrations at that same depth (208 pCi/g from 2 to 4.5 ft BGS, Table 6-21) suggesting that DU has migrated to 4.5 ft BGS and possibly even deeper. Additional discussion regarding migration of DU with depth over time is presented in the groundwater modeling report (Appendix B) and the $K_d$ study report (Appendix D).

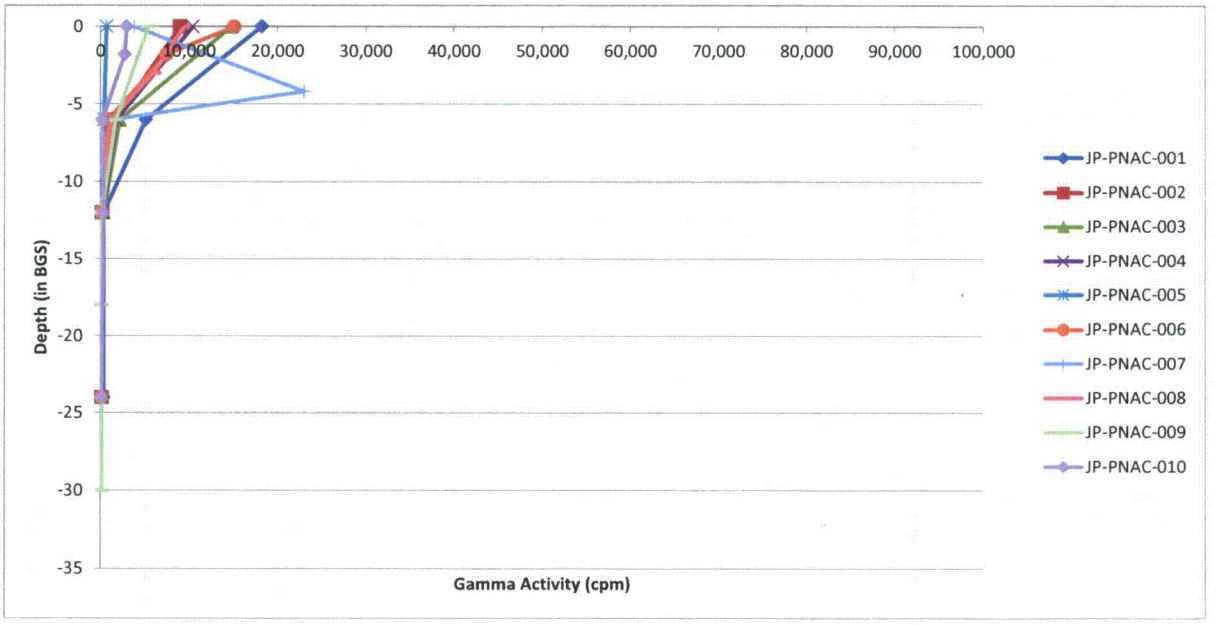



**Figure 6-15. Scatterplot for Gamma Activity Measurements Versus Depth for Soil Under Penetrators Collected From Areas With Avonburg/Cobbsfork Soil Types**

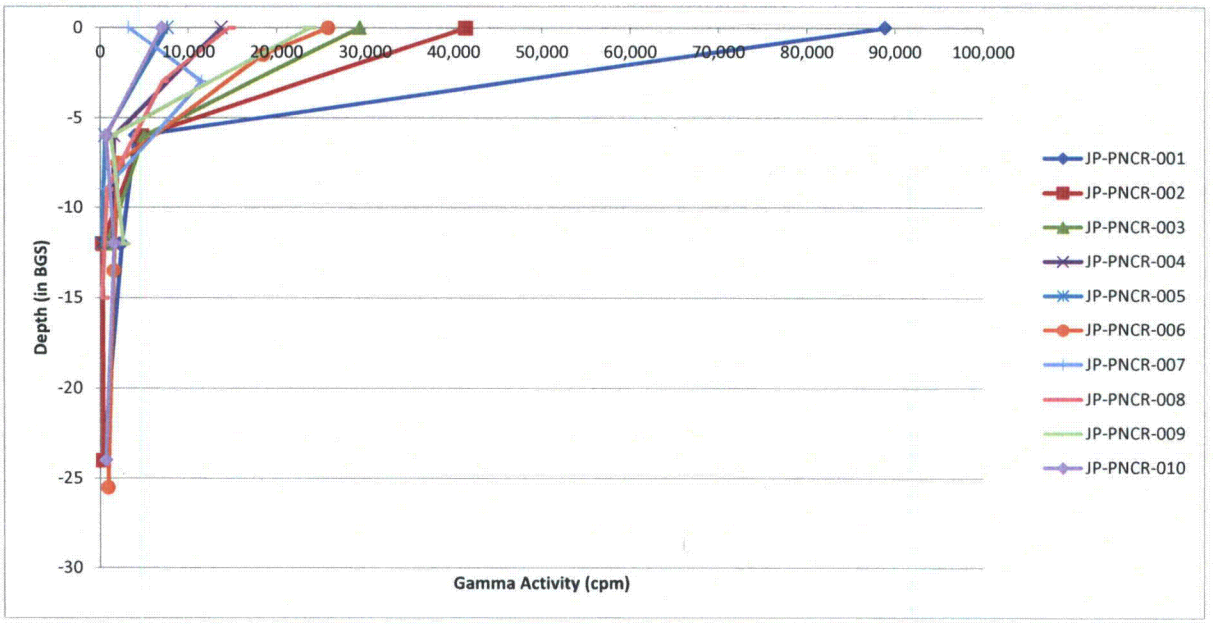



**Figure 6-16. Scatterplot for Gamma Activity Measurements Versus Depth for Soil Under Penetrators Collected From Areas With Cincinnati/Rossmoyne Soil Types**

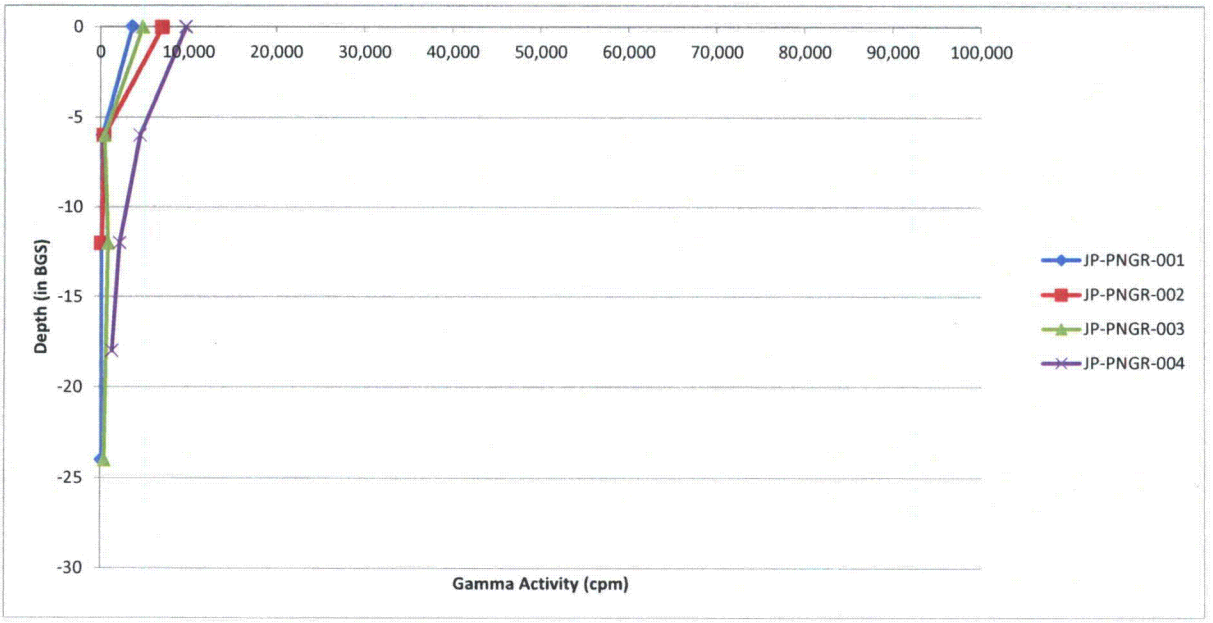



**Figure 6-17. Scatterplot for Gamma Activity Measurements Versus Depth for Soil Under Penetrators Collected From Areas With Grayford/Ryker Soil Types**

Statistical testing was conducted on the soil data using the standard general linear model (SAS® v 9.2 PROC GLM procedure) to test whether uranium concentrations within the DU Impact Area differed significantly from background levels. The F-test was conducted to evaluate the overall significance in difference among categories and pairwise t-tests were used to compare individual categories. Lower p-values indicate that differences (averages are not equal) are unlikely to be due to chance. With a 5 percent significance level used to reject null hypothesis, tests with p-values <= 0.05 are "significant" and tests with p-values between 0.05 and 0.10 are "marginally significant." In general, concentrations differed by soil type and differences among soil types varied by category. Significant differences were determined among soil types at the background categories and between soil types in Categories 1 and 4. Concentrations were significantly higher at background than in Categories 1 through 5 for Cincinnati/Rossmoyne (log mean [arithmetic mean of data transformed to values corresponding with their respective natural logarithms] = 1.70 versus 1.55 pCi/g, p=0.02), and marginally higher for Grayford/Ryker (log mean=1.58 versus 1.45 pCi/g, p=0.08). For Avonburg and Cobbsfork, background mean was lower than onsite but the difference was not significant (log mean=1.54 versus 1.59 pCi/g, p=0.41). The mean concentrations for Category 6 (under trenches) and soil under/over penetrators were much higher than either background or the other categories. Concentrations did not differ significantly by depth at background or in Categories 1 through 5. For soil under/over penetrators, the surface soil mean was much higher than means for lower depths (log mean=9,190 versus 597 versus 137 pCi/g for 0, 1, and 2 ft BGS; p<0.001 for all different from surface soil). For samples under trenches, concentrations decreased by depth although the only significant contrast was for the comparison of 4 ft BGS versus surface soil (log means=5.28, 2.63, 2.03, and 1.81 pCi/g for 0, 1, 2, and 4 ft BGS, p=0.12, 0.07, 0.05, and 0.05, respectively compared to surface soil).

## 6.2 PHYSICOCHEMICAL MONITORING

The CSM for the DU Impact Area is based on the DU penetrators having been deposited on or immediately below the ground surface and/or within the surface water (streams). The CSM in Appendix C defines the source term as the penetrators that were used at JPG and shows the expected spatial distribution of DU penetrators and fragments remaining at JPG. DU corrosion products from the weathering of penetrators over time primarily include uranium (VI) oxide or schoepite ($UO_3 \cdot 2H_2O$), uranium (VI) dioxide ($UO_2$), and hydrated uranium (VI) peroxide ($UO_4 \cdot H_2O$). The transformation of metallic DU to these oxides and other unnamed uranium species likely to be present does not alter the radiological properties described in Section 6.1. Following the corrosion of penetrators, the corrosion products dissolve and transform into secondary byproducts available for transport through the environment. This section includes information related to the environmental fate of DU, particularly with respect to the chemistry.

The corrosion products and secondary byproducts transformed in the soil are subject to lateral transport in surface runoff and to a lesser extent vertical transport through the soil column to groundwater. Some migration can be expected due to the dissolution of soluble DU corrosion products and transport of dissolved species in rainfall and snowmelt, movement of dust-bound DU by wind or fire, and leaching of dissolved species through the soil column and subsequent migration in groundwater. Sections 6.2.1 through 6.2.10 describe the physical parameters that were obtained to understand and quantify the transport of DU through various transport mechanisms for potential uptake by humans through contact (primarily ingestion) with groundwater, surface water, and sediment.

The physical movement of DU penetrators and/or fragments could have occurred through stream channel erosion. Some studies have been conducted to ascertain the distance that naval bottom mines move under tidal conditions (Inman and Douglas 2002) that could be used to deduce physical movement of penetrators in JPG streams. The movement is due to the hydrodynamic and gravitational forces acting on mines (or DU penetrators) based on Newton's second law of motion (i.e., acceleration depends directly upon the net forces acting on the object, and inversely on the mass of the object). In the case of mines

acted upon by tides (or penetrator acted upon by stream current), hydrodynamic forces are caused by water flowing against objects that include positive frontal pressure against the structure, drag along the sides, and negative pressure in the downstream side. When the hydrodynamic forces caused by stream currents in JPG creeks exceed gravitational forces, DU penetrators could move "by scour and roll or scour and slip mechanisms" (Inman and Douglas 2002). The process involves the displacement of streambed sediments such that penetrators rolls or slide along the bottom. However, very limited mechanical movement of DU penetrators or fragments is expected on land or in stream channels. While processes of stream channel erosion could cause limited migration and transport of DU penetrators or fragments (during floods and high runoff events) along streambeds in drainageways, large obstacles present in the channels, such as boulders, bedrock outcrops, the remnants of the former Wilson dam (over 1,600 ft [0.5 kilometer (km)] west of the western perimeter of the DU Impact Area on Big Creek and over 9,800 ft [3.0 km] from the western boundary of JPG along Big Creek), and at-grade river crossings would prevent the migration of penetrators or fragments outside the boundaries of the DU Impact Area. Therefore, this phenomenon is not discussed further.

### 6.2.1 Soil Verification

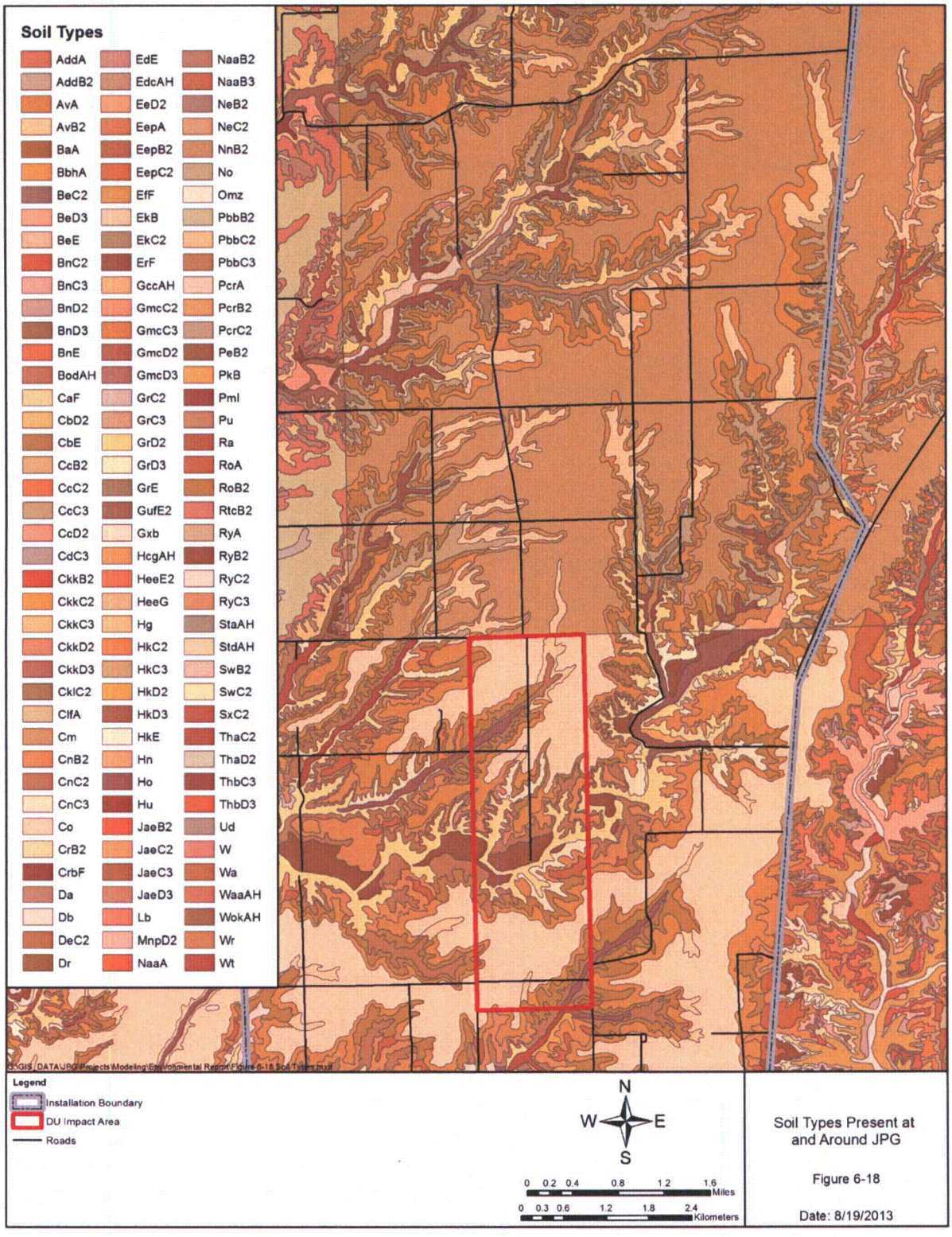
A soil verification study (SVS) was conducted to determine if published soil mapping information could be used in the process of defining and completing future soil sampling and related efforts (SAIC 2006b). In August 2006, a soil scientist collected, observed, and described soil at 22 boring locations along 2 transects. The soil mapping units were generated from the data from the Soil Survey Geographic (SSURGO) data base (USDA NRCS 2005) that was available at the time of developing FSP Addendum 2 (SAIC 2006b). The resulting soil map was used to identify the locations of prospective transects for conducting field soil verification. For each soil series present in the DU Impact Area (Table 6-24), an Official Soil Description (OSD) was printed from the online data base maintained by the Natural Resources Conservation Service (NRCS) (SAIC 2007a). The relevant soil description data from the OSD forms were reviewed along with other information pertaining to Indiana soils in preparation for the field verification study. From the review of available soil data, the following soil series are mapped in the DU Impact Area: Avonburg, Cincinnati, Cobbsfork, Grayford, Holton, Rossmoyne, and Ryker (Figure 6-18 and Table 6-24). A detailed description of the typical soil profile for each series is included in the Well Location Selection Report (SAIC 2007a). The total acreage of each soil series mapped by the NRCS was measured (Table 6-24) using a geographic information system (GIS).

**Table 6-24. DU Impact Area Mapped Soil Series and Total Acreage Jefferson Proving Ground, Madison, Indiana**

| Soil Series | Total Acreage as Mapped* | Percent of Total Acres |
|---|---|---|
| Avonburg | 311.97 | 14.8 |
| Cincinnati | 409.12 | 19.4 |
| Cobbsfork | 861.47 | 40.7 |
| Grayford | 144.81 | 6.8 |
| Holton | 36.22 | 1.7 |
| Rossmoyne | 259.85 | 12.3 |
| Ryker | 90.8 | 4.3 |

* Mapped by NRCS within the DU Impact Area/SSURGO data base (USDA NRCS 2005)

The majority of soil groupings exhibit somewhat poorly drained soil with redoximorphic features that indicate a reducing environment exists in the shallow (<3 ft BGS) subsurface for some period of time during the growing season. Corrosion of metals and, therefore, DU penetrators can be greatly affected by the surrounding environment. Corrosion rates and processes are much different under reducing


Soil Types
AddA
AddB2
AvA
AvB2
BaA
BbhA
BeC2
BeD3
BeE
BnC2
BnC3
BnD2
BnD3
BnE
BodAH
CaF
CbD2
CbE
CcB2
CcC2
CcC3
CcD2
CdC3
CkkB2
CkkC2
CkkC3
CkkD2
CkkD3
CklC2
ClfA
Cm
CnB2
CnC2
CnC3
Co
CrB2
CrbF
Da
Db
DeC2
Dr
EdE
EdcAH
EeD2
EepA
EepB2
EepC2
EfF
EkB
EkC2
ErF
GccAH
GmcC2
GmcC3
GmcD2
GmcD3
GrC2
GrC3
GrD2
GrD3
GrE
GufE2
Gxb
HcgAH
HeeE2
HeeG
Hg
HkC2
HkC3
HkD2
HkD3
HkE
Hn
Ho
Hu
JaeB2
JaeC2
JaeC3
JaeD3
Lb
MnpD2
NaaA
NaaB2
NaaB3
NeB2
NeC2
NnB2
No
Omz
PbbB2
PbbC2
PbbC3
PcrA
PcrB2
PcrC2
PeB2
PkB
Pml
Pu
Ra
RoA
RoB2
RtcB2
RyA
RyB2
RyC2
RyC3
StaAH
StdAH
SwB2
SwC2
SxC2
ThaC2
ThaD2
ThbC3
ThbD3
Ud
W
Wa
WaaAH
WokAH
Wr
Wt
Legend
Installation Boundary
DU Impact Area
Roads
N
W
E
S
0 0.2 0.4 0.8 1.2 1.6 Miles
0 0.3 0.6 1.2 1.8 2.4 Kilometers
Soil Types Present at and Around JPG
Figure 6-18
Date: 8/19/2013

conditions than those present under oxidation. The presence of the reducing environment was considered when defining corrosion rates.

The SVS concluded the following: 1) soil mapping units are reasonably accurate and sufficient for defining sampling efforts/sample locations, 2) mapped soil series can be grouped based on drainage classes/soil conditions, and 3) samples for corrosion and $K_d$ studies should be distributed with respect to the soil types (SAIC 2007a). Additional details are provided in the Well Location Selection Report (SAIC 2007a).

### 6.2.2 Stream and Cave Spring Gauges

Science Applications International Corporation (SAIC) completed the installation of surface water gauging stations in September 2006. These gauges consisted of automatic, continuous, recording stream gauging stations on Big Creek (three locations) and Middle Fork (four locations), selected cave springs along Big Creek (two locations) inside the DU Impact Area, and one visual staff gauge along an unnamed tributary of Big Creek. These locations are shown in Figure 6-19 and listed in Table 6-25. Surface water stage data and manual flow measurements were collected to calculate surface water flows and estimate recharge to the aquifer at the DU Impact Area. The installation and monitoring plan was included in FSP Addendum 3 (SAIC 2006c). Details and pictures of the gauging station installations after installation are provided in the Well Location Selection Report (SAIC 2007a).

The surface water gauging stations collected stream stage data at each location automatically from September 2006 through April 2010. Data were downloaded from the data recorders and manual measurements of stream flow were collected monthly for the first year (September 2006 to August 2007), quarterly during surface water/sediment sampling from April 2008 to February 2009, and semi-annually until April 2010. Stage data then were used to calculate corresponding surface water flows by constructing rating curves using manual flow measurements collected at each location (SAIC 2007a). The rating curves were used to construct hydrographs for each gauge station. These hydrographs were compared to hydrographs from established U.S. Geological Survey (USGS) gauge stations near JPG.

The surface water stage and flow data were used in conjunction with data from the groundwater monitoring wells to develop a water budget for the DU Impact Area and to define the interrelationship between surface water and groundwater. A water budget accounts for the inflow, outflow, and storage changes of water in a hydrologic unit (USGS 2008b). It includes precipitation, irrigation, dew, and capillary rise from groundwater as inputs and evapotranspiration (ET), runoff, and deep percolation as outputs (USGS 2007). Water budgets are tools to quantify the hydrologic cycle (USGS 2007). The water budget for the DU Impact Area is used to describe the hydrologic cycle as it relates to the CSM. The hydrologic cycle includes the potential migration mechanisms and potential rates of DU transport through the environment at the DU Impact Area that could result in potential exposures to onsite and offsite receptors currently and in the future. The total average annual water budget consists of 46.97 in of rain, as recorded by the U.S. Fish and Wildlife Service (FWS) station located approximately 2.8 mi northeast of the DU Impact Area. Rainfall for the period of record (1 October 2006 through 30 September 2007) equaled 45.21 in.

The following conclusions (SAIC 2008a) were developed based on interpretation of data collected from stream gauges and manual flow measurements and the resulting hydrographs: 1) conditions in the creeks in the DU Impact Area are indicative of a hydrologic system with unusually high surface water runoff and unusually low groundwater recharge; 2) the preliminary water budget includes 56 percent of annual onsite precipitation returning to atmosphere via evapotranspiration, 36 percent leaving the site as runoff, and 8 percent infiltrating ground surface to become groundwater; and 3) surface water in Big Creek appears to be the greatest avenue of potential DU migration from the DU Impact Area. Additional details are provided in the Well Construction and Surface Water Data Report (SAIC 2008a).

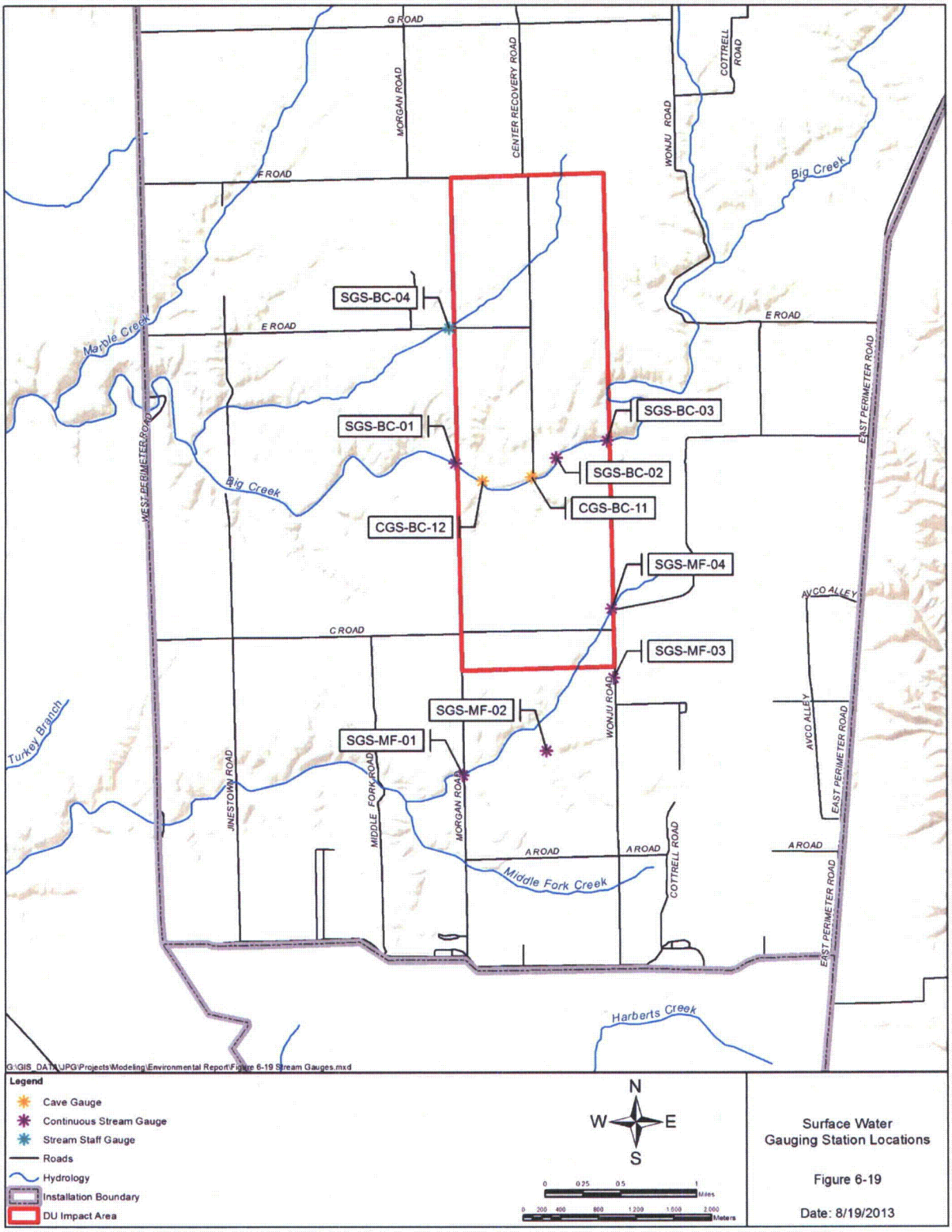

G ROAD
F ROAD
E ROAD
C ROAD
A ROAD
MORGAN ROAD
CENTER RECOVERY ROAD
WONJU ROAD
COTTRELL ROAD
EAST PERIMETER ROAD
WEST PERIMETER ROAD
JINESTOWN ROAD
MIDDLE FORK ROAD
AVCO ALLEY
Big Creek
Maple Creek
Turkey Branch
Middle Fork Creek
Harberts Creek
SGS-BC-04
SGS-BC-01
SGS-BC-03
SGS-BC-02
CGS-BC-11
CGS-BC-12
SGS-MF-04
SGS-MF-03
SGS-MF-02
SGS-MF-01
G:\GIS_DATA\JPG\Projects\Modeling\Environmental Report\Figure 6-19 Stream Gauges.mxd
Legend
Cave Gauge
Continuous Stream Gauge
Stream Staff Gauge
Roads
Hydrology
Installation Boundary
DU Impact Area
N
W
E
S
0 0.25 0.5 1 Miles
0 200 400 800 1,200 1,600 2,000 Meters
Surface Water Gauging Station Locations
Figure 6-19
Date: 8/19/2013

**Table 6-25. Surface Water/Cave Spring Gauge Locations**
**Jefferson Proving Ground, Madison, Indiana**

| Station ID | X | Y | Bottom of Weir Notch | Cave Base | Top of Stilling Well | Top of Visual Staff Gauge |
|---|---|---|---|---|---|---|
| | Meters | Meters | FTAMSL | FTAMSL | FTAMSL | FTAMSL |
| Continuous Stream Gauging Station | | | | | | |
| SGS-BC-01 | 636557.228 | 4305244.037 | NA | NA | 800.53 | NA |
| SGS-BC-02 | 637627.106 | 4305304.529 | NA | NA | 802.09 | NA |
| SGS-BC-03 | 638168.7473 | 4305487.166 | NA | NA | 800.6 | NA |
| SGS-MF-01 | 636628.431 | 4301916.068 | NA | NA | 811.95 | NA |
| SGS-MF-02 | 637519.8045 | 4302177.442 | NA | NA | 814.45 | NA |
| SGS-MF-03 | 638232.977 | 4302952.03 | NA | NA | 846.84 | NA |
| SGS-MF-04 | 638217.459 | 4303695.692 | NA | NA | 849.4 | NA |
| Cave Gauging Sation | | | | | | |
| CGS-BC-11 | 637364.4306 | 4305099.367 | 789.02 | 790.56 | 798.67 | NA |
| CGS-BC-12 | 636847.0895 | 4305058.422 | 791.97 | 791.64 | 797.87 | NA |
| Stream Staff Gauging Station | | | | | | |
| SGS-BC-04 | 636495.181 | 4306681.686 | NA | NA | NA | 837.09 |

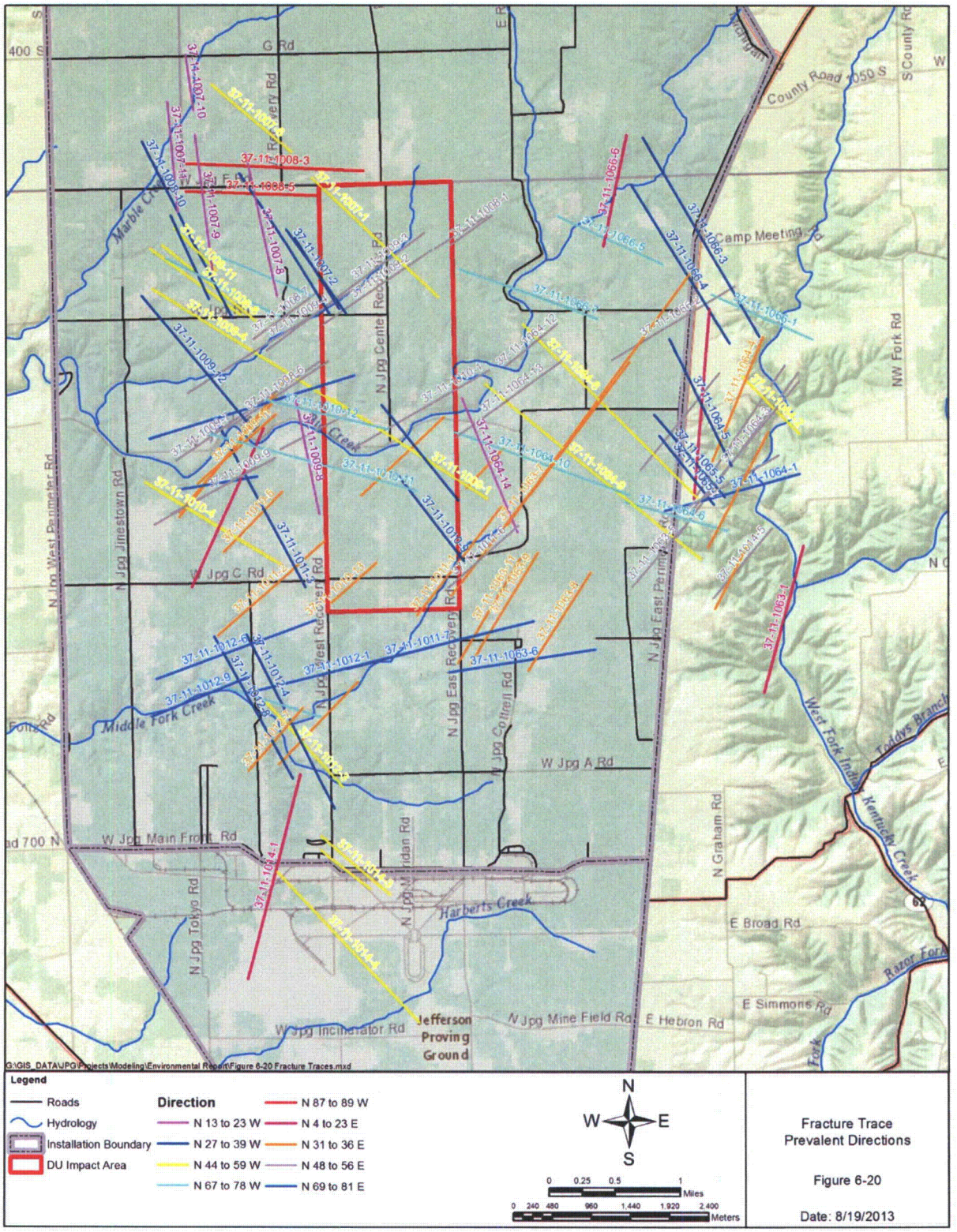
### *6.2.3 Fracture Trace Analysis*

Groundwater characterization was a phased task and followed a progression of identifying flow pathways and installing wells to intercept groundwater to characterize the flow pathways. Each step or task built on the previous and the results of each were used to further evaluate the presence of the flow pathways. The fracture trace analysis was the first step in identifying and locating preferential groundwater flow pathways or conduits at the site and is used to help define the electrical imaging (EI) survey (Section 6.2.4). Following the completion of the EI survey, the results from both the fracture trace analysis and EI survey were evaluated together along with a visual reconnaissance, which is discussed in the next paragraph, to select sites for installing conduit well pairs.

The Army obtained stereo-paired aerial photographs from U.S. National Archives and Records Administration (NARA) taken of the site prior to construction of JPG and DU Impact Area. An area of approximately 22 square miles ($mi^2$), including the DU Impact Area and the immediate surrounding area, was analyzed (SAIC 2006c). These photographs were viewed obliquely and in stereo at various magnifications. Features observed on the photographs were marked, mapped, and digitized into the GIS. Straight line segments were aligned with mapped fractures on photographs. A total number of 110 fracture trace lines (Figure 6-20) were identified from the aerial photographs reviewed during the analysis. Field verification was completed of fracture trace locations in the immediate area within and surrounding the DU Impact Area. Twenty-four fracture traces were field checked with 22 having good (readily apparent/numerous supporting landforms), one having fair (less obvious/scarce supporting landforms), and one having poor (faint or no supporting landforms) correlating field features.

### *6.2.4 EI Survey*

EI is a modern version of the classic electrical resistivity survey that has been used in geophysical investigations for many decades. It was chosen for this investigation because of its proven success in detecting geologic materials or conditions that represent potential pathways for groundwater flow. It is based on inducing an electrical current into the earth at a pair of electrodes and measuring the amount of current that reaches a second pair of electrodes at a certain distance away. The depth of penetration of the induced electrical current can be adjusted by varying the electrode spacing. The amount of current detected at the second set of electrodes depends, in part, on the resistivity of the subsurface material through which it passes. Dry granular material like sand is relatively more resistant to electrical current flow. On the other hand, moist fine-grained soils like clay are relatively more conductive (i.e., less resistive). In addition to detecting differences in unconsolidated materials, the EI method also can be used to detect discontinuities in bedrock. Discontinuities such as fractures may represent preferential


G Rd
400 S
County Road 1050 S
S County Rd
Camp Meeting Rd
NW Fork Rd
N Jpg Center Recovery Rd
N Jpg East Recovery Rd
N Jpg West Recovery Rd
N Jpg East Perimeter Rd
N Jpg Jinestown Rd
N Jpg Cottrell Rd
N Jpg Meridian Rd
N Jpg Tokyo Rd
N Graham Rd
N Jim West Perimeter Rd
W Jpg C Rd
W Jpg A Rd
W Jpg Main Front Rd
W Jpg Incinerator Rd
E Broad Rd
E Simmons Rd
E Hebron Rd
N Jpg Mine Field Rd
Marble Creek
Middle Fork Creek
Harberts Creek
West Fork Indian Kentucky Creek
Razor Fork
Toddys Branch
Jefferson Proving Ground
37-11-1007-10
37-11-1008-3
37-11-1008-5
37-11-1007-1
37-11-1007-9
37-11-1007-8
37-11-1007-2
37-11-1009-10
37-11-1009-11
37-11-1009-4
37-11-1009-12
37-11-1009-6
37-11-1009-8
37-11-1010-2
37-11-1010-1
37-11-1010-4
37-11-1011-3
37-11-1011-2
37-11-1012-6
37-11-1012-1
37-11-1011-7
37-11-1012-9
37-11-1012-4
37-11-1012-8
37-11-1012-3
37-11-1012-2
37-11-1013-2
37-11-1013-1
37-11-1014-1
37-11-1014-4
37-11-1063-6
37-11-1063-1
37-11-1063-2
37-11-1063-5
37-11-1063-4
37-11-1063-3
37-11-1064-12
37-11-1064-13
37-11-1064-14
37-11-1064-10
37-11-1064-9
37-11-1064-6
37-11-1064-5
37-11-1064-1
37-11-1064-4
37-11-1064-3
37-11-1064-2
37-11-1065-5
37-11-1065-1
37-11-1066-6
37-11-1066-5
37-11-1066-3
37-11-1066-4
37-11-1066-2
37-11-1066-1
37-11-1068-1
37-11-1068-2
37-11-1068-3
G:\GIS_DATA\JPG\Projects\Modeling\Environmental Report\Figure 6-20 Fracture Traces.mxd
Legend
Roads
Hydrology
Installation Boundary
DU Impact Area
Direction
N 13 to 23 W
N 27 to 39 W
N 44 to 59 W
N 67 to 78 W
N 87 to 89 W
N 4 to 23 E
N 31 to 36 E
N 48 to 56 E
N 69 to 81 E
N
W
E
S
0 0.25 0.5 1 Miles
0 240 480 960 1,440 1,920 2,400 Meters
Fracture Trace Prevalent Directions
Figure 6-20
Date: 8/19/2013

pathways for groundwater flow. Dense, competent bedrock would be expected to have a relatively high resistivity. Significantly large and/or solution enhanced fractures tend to have lower resistivity, since they are generally filled with water and fine-grained weathered bedrock debris.

EI field activities were conducted at the DU Impact Area between 17 July and 22 August 2006 in accordance with FSP Addendum 3 (SAIC 2006c). All geophysical measurements were conducted along existing roads in the DU Impact Area. A total of 42,277 ft of EI data were collected and analyzed with 78 anomalies identified. These anomalies were evaluated and are indicated as "possible" or "probable" fractures or features of interest (e.g., potential sediment-filled void, caves). An example of the results of the EI survey transects is illustrated in Figure 6-21. The intersections between the fracture traces and the EI transects are indicated for the purpose of correlation.

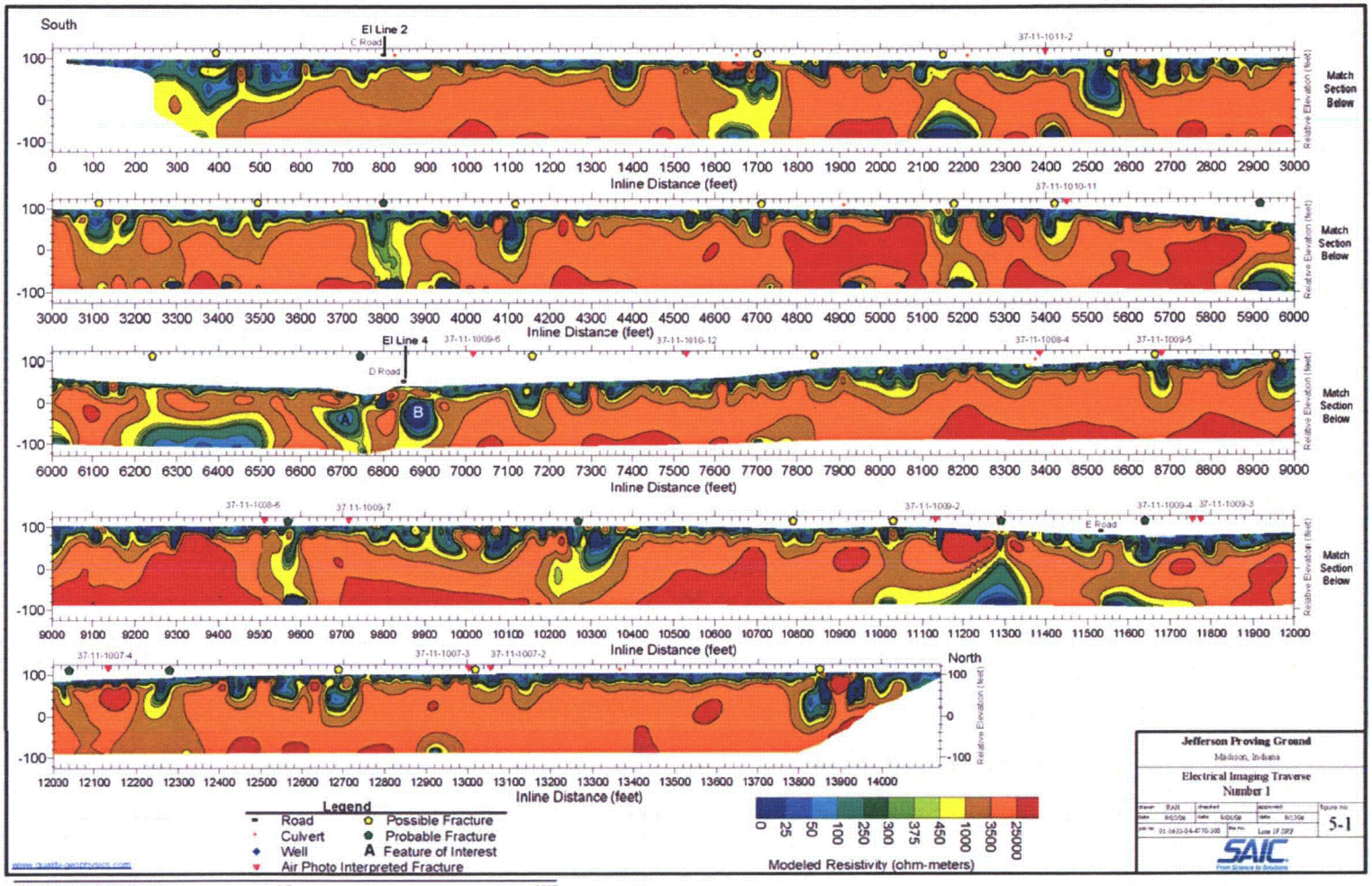
Prior to conducting the EI survey, the area proposed for the data traverse was swept by a UXO technician using a Schonstedt® magnetometer. Identified metallic features that could represent UXO were marked using a pink push flag or spray paint.

Shortly following the installation of the stakes, the soil surface immediately surrounding each stake was soaked with a salt water solution to enhance electrical contact between the stake and soil. The location of every fifth electrode was measured using a real-time differential global positioning system (DGPS) to establish reference coordinates along each traverse and at the locations of key electrodes. DGPS data were recorded on a Trimble Pro-XRS system to establish the location of the geophysical data and not for the purpose of land surveying. Relative elevations of the electrode locations were established using an auto level and stadia rod to gather relative ground surface elevations.

The EI equipment used for this survey was composed of two primary components. The first is the SuperSting® resistivity meter with data storage capability manufactured by Advanced Geosciences, Inc. (AGI) of Austin, Texas. Second, the SuperSting® cables contained fixed cylindrical stainless steel switches that attached to the stainless steel electrode stakes placed into the ground. The SuperSting® system, a multi-electrode switching system, passed an electrical current automatically along multiple paths at various depths and measured the resulting associated voltages. This system utilized two arrays of multicore cables, which extended outward, in opposite directions, from the centrally located SuperSting® main unit. Electrodes were attached to the electrode stakes to complete the electrical circuits between the electrical switching box and the earth.

DGPS data were collected using Universal Transverse Mercator (UTM) northern hemisphere projection system and the 1983 North American Datum (NAD-83), with survey units of meters. Leveling information for each EI traverse was measured relative to the first electrode in the traverse, which was arbitrarily set to 100 ft. Elevations were measured in feet, and converted to meters using a conversion factor of 1 m equals 3.281 ft. Therefore, all site data were collected (or converted) in meters so all resistivity values are presented in ohm-meters.

Due to the potential of detonating fuses in nearby UXO items, the survey was conducted using a remote desktop connection over a wireless network. One personal computer (PC) was directly connected to the SuperSting® to operate the equipment using the AGISSADMIN® software written by AGI, manufacturer of the SuperSting®, which is used to prepare command files, upload command files and firmware upgrades, and download data, as well as to operate the SuperSting® directly from the PC. The PC connected to and operating the SuperSting® also was connected to a Cisco Aironet wireless bridge. The PC operating the SuperSting® was remotely controlled through the wireless bridge by a second PC located at a safe location. Due to the nature of the UXO present, a safe distance established by UXO personnel was 1,000 m (0.6 mi) away. Use of the remote PC operation of the SuperSting® system permitted the operator to initiate the survey while in a safe location, and monitor the data being collected. The operator observed when the ending of the command file was reached, and turned off the SuperSting® prior to re-entering the area.




Well Location Selection Report 5-7 January 2007
JPG Depleted Uranium Impact Area

**Figure 6-21. Example Electrical Imaging Traverse (SAIC 2007a)**

SAIC utilized and modeled the EI data collected to reflect the subsurface conditions at the site. The identified electric boundaries separating layers of different resistivities may or may not coincide with boundaries separating layers of different lithologic composition. This limitation may result in the electrostratigraphy varying from the gross geologic stratigraphy. Given these limitations, the conclusions regarding the results are provided below.

- Based on modeled resistivity values and gradient changes, average depth to bedrock is interpreted to be at resistivities greater than approximately 500 ohm-meters. Due to the paucity of wells that contacted bedrock and the potential that depth to bedrock is extremely variable over short distances, no correlation between existing well data and EI data was attempted.
- Top of bedrock is variable and undulating across the site with a variety of high and low areas. Bedrock was observed to be exposed at the ground surface during the survey, to as deep as 40 ft or more, depending on the location being assessed or considered.
- Vertical and near vertical discontinuities in high-resistivity bedrock have been interpreted to represent significant bedrock fractures. These fractures represent the preferential groundwater flow pathways. Bedrock fractures are interpreted as "probable fractures," where a clear decrease is present in the resistivities (i.e., probable fractures), or as "possible fractures," where the resistivity decrease is less pronounced or the amount and quality of data may be less than desired to appropriately model the feature (i.e., possible fractures).
- A number of low-resistivity features within the bedrock are present that can be interpreted to represent water or mud filled karst features in the bedrock. When well-supported by low measurement error data and good model block sensitivity, these features have been identified as features of interest. Similar features are not specifically called out given the limited number of data points that define the feature, or variability and lack of stability of the feature observed during the editing and modeling process. Six supported features of interest were interpreted in the data.
- A number of locations have unusually low or high resistivity features below shallow bedrock. These may represent very shallow mud or water (low resistivity) or air (high resistivity) filled voids. When these features appear to be open to soil, above the bedrock, they have not been specifically identified.

Additional details for the EI survey are included in the Well Location Selection Report (SAIC 2007a).

### 6.2.5 Groundwater Well Installation

SAIC reviewed core logs developed from bedrock cores drilled and recovered at all shallow and deep bedrock well locations to determine vertical limits of karst development, fracturing, and groundwater transmission zones within bedrock. The better than 95 percent carbonate formation with limited shale beds and laminations has good to excellent rock quality, with evidence of an immature to very immature karst horizon, characterized by the presence of voids, increased fracturing, vugs (i.e., cavity in rock lined with mineral crystals), and less than excellent rock quality, to an average depth of 26 ft BGS. Overburden generally thickens away from Big Creek. Where overburden is thicker, karst development appears reduced. The effective depth of fracturing in the bedrock is approximately 60 ft below top of rock. Fractures occur in the form of breaks in less competent portions of the carbonate, less so as bedding planes between carbonate and shale beds/laminations, and occasionally as voids several in to less than 1 ft in height. Fracture density is typically greatest in the upper 20 ft of bedrock, with typically only one or two water-bearing fractures present at 50 to 60 ft below top of rock, with little to no fracturing from 60 ft below top of rock to the effective depth of drilling (i.e., 120 to 130 ft below top of

rock). Groundwater storage and transmission occurs in the shallow bedrock and is nonexistent in deep bedrock.

SAIC evaluated the bedrock quality with depth as a means to evaluate karst development within the former DU Impact Area bedrock. Inspection of core logs indicates predominantly variably fossiliferous, thinly bedded to massive, carbonate strata resides beneath the DU Impact Area. Approximately 2 percent of the formation consists on average of thin shale beds and laminations alternating with larger proportions of carbonate. Most of the carbonate is limestone, reacting vigorously to direct application of hydrochloric acid, while some of the limestone as dolomitized, based on acid reaction to powdered rock only and the occurrence of small vugs. Bedrock quality was quantified through use of the Rock Quality Designation (RQD) and calculated for each rock core collected from the shallow and deep well locations shown in Table 6-26.

**Table 6-26. Wells with RQD Calculations Performed**
**Jefferson Proving Ground, Madison, Indiana**

| Well ID | Well ID | Well ID |
|---|---|---|
| JPG-DU-01I | JPG-DU-01D | JPG-DU-02I |
| JPG-DU-02D | JPG-DU-03I | JPG-DU-04I |
| JPG-DU-04D | JPG-DU-05I | JPG-DU-05D |
| JPG-DU-06I | JPG-DU-06D | JPG-DU-07I |
| JPG-DU-07D | JPG-DU-08I | JPG-DU-08D |
| JPG-DU-09I | JPG-DU-09D | JPG-DU-10D |

The RQD was determined from the total length of all core pieces greater than 10 cm (approximately 4 in) divided by the total length of the core run, commonly 5 ft (Deere et al. 1967, Das 1998). The resultant RQD is a percentage, ranked according to a descriptive index related to the stability of underground openings, as shown in Table 6-27.

**Table 6-27. Descriptive Index for RQD Rankings**
**Jefferson Proving Ground, Madison, Indiana**

| RQD (%) | Rock Mass Quality |
|---|---|
| < 25 % | Very Poor |
| 25-50 % | Poor |
| 50-75 % | Fair |
| 75-90 % | Good |
| 90-100 % | Excellent |

Mature karst terrain characterized by numerous sinks holes, pinnacled bedrock surface, highly fractured rock zones with overlying raveled soils, and solution enhanced fracture conduits with washed in fines will result in reduced rock quality within the karst zone (Fetter 1988, Ralston and Oweis 1999). Although a direct correlation between RQD and karst has not been established, for perspective, a single 6-in void in a 5-ft core run would result in an RQD of 90 percent. A 1-ft void in a similar 5-ft run would produce an RQD of 80 percent. Collapsed bedrock could result in poor to very poor core recovery and RQDs much less than 50 percent. Conversely, it could be expected that immature karst terrain, terrain with limited solution of primary fractures and none of the other above features, might have a corresponding RQD better than 95 percent, or within the range of excellent rock quality, as show in Table 6-27.

Results of the RQD analysis for each well are shown in Appendix F. Figure 6-22 shows an example of an RQD graph as a function of depth for well JPG-DU-02D. The graph illustrates the

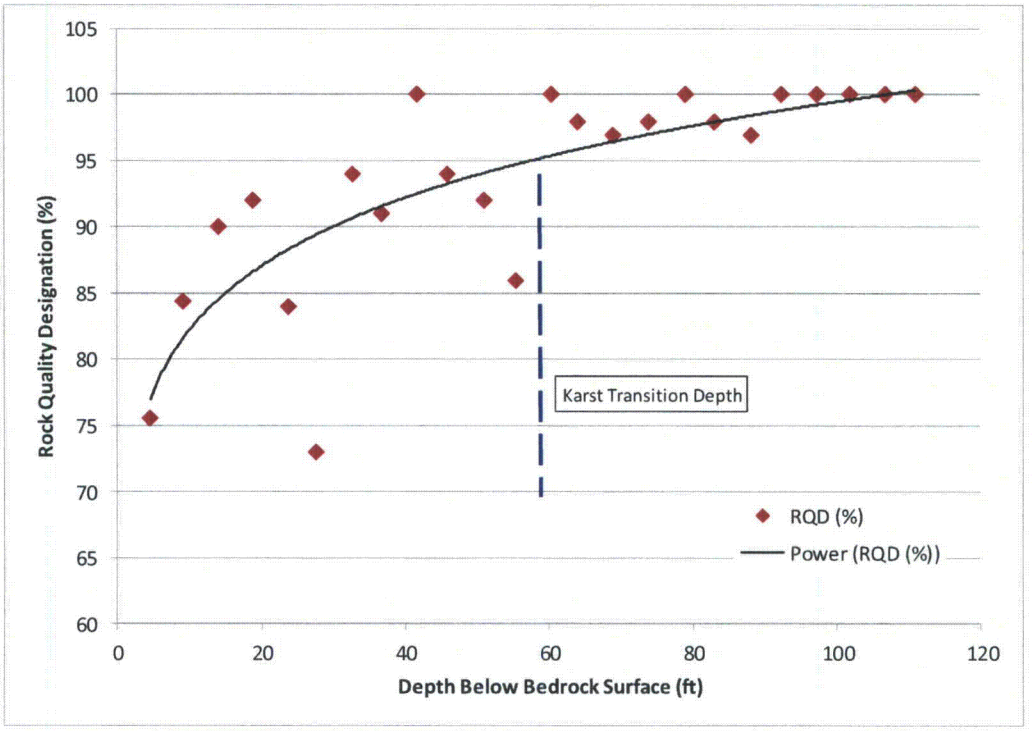



**Figure 6-22. RQD With Depth into Rock for Well JPG-DU-O2D**

variability in rock quality typically seen in the upper 10s of feet of bedrock with progressively more competent and, therefore, higher quality rock at depth.

Figure 6-23 shows a composite or average RQD with depth for 5-ft increments into bedrock for all of the wells listed in Table 6-26. The average inferred depth of the karst zone below top of rock within the DU Impact Area is approximately 26 ft. Overburden ranges in thickness from 1.0 to 72 ft, for an average of 24 ft. The average depth of the karst horizon below ground surface is approximately 50 ft.

There is a direct correlation between overburden thickness and depth of karst zone development. Where overburden thickens, the karst zone tends to thin, or is less developed. Figure 6-24 shows a graph of overburden thickness relative to karst thickness illustrating the relationship.

Spatially, overburden or glacial till tends to thicken away from Big Creek and, as it thickens, karst deformation of the bedrock appears to reduce and penetrate less into rock. The till appears to limit the amount of fresh water that can penetrate the till, recharge the bedrock, and promote solutioning of the rock. This is consistent with the predominantly low permeability of the till as shown from the slug testing program. Closer to Big Creek where the till layer is thin, karst deformation has penetrated deeper into rock, opening solution cavities and in some cases forming caves that regularly drain surface water from hundreds of feet away from the stream, based on the cave study from the mid-1990s. The cave study suggests this cave-conduit system decreases and stops 600 ft or so away from Big Creek, where presumably till has thickened to the point of limiting karst formation and likely provides an abundant source of fine particles to clog any solution zones that may have slowly developed.

SAIC inspected core logs for the incidence of weathered fractures that could be water bearing, for comparison to RQD data and to reach further conclusions on karst zone development and groundwater transmission in general in the DU Impact Area. Figure 6-25 shows the incidence of fractures, bedding

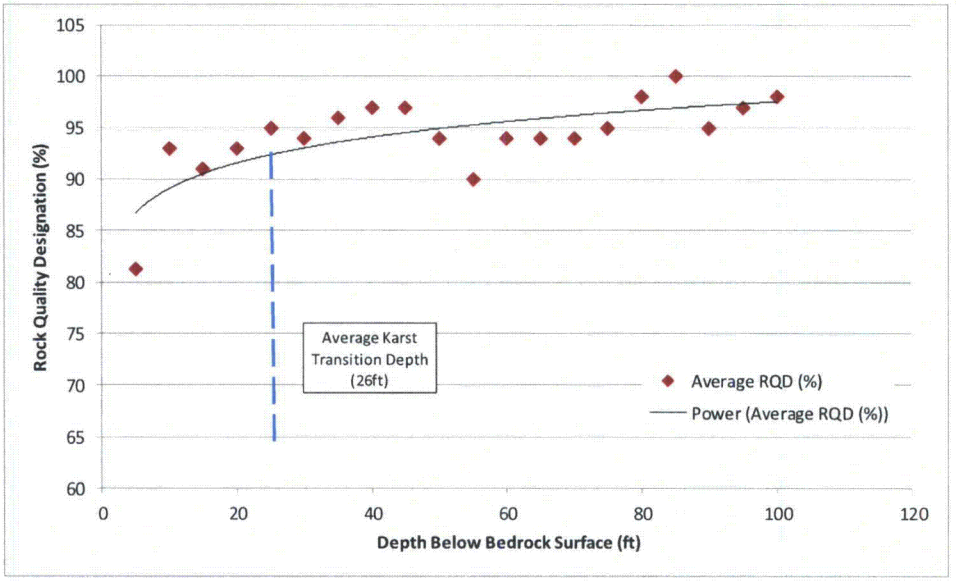



**Figure 6-23. Average Rock Quality With Depth into Bedrock**

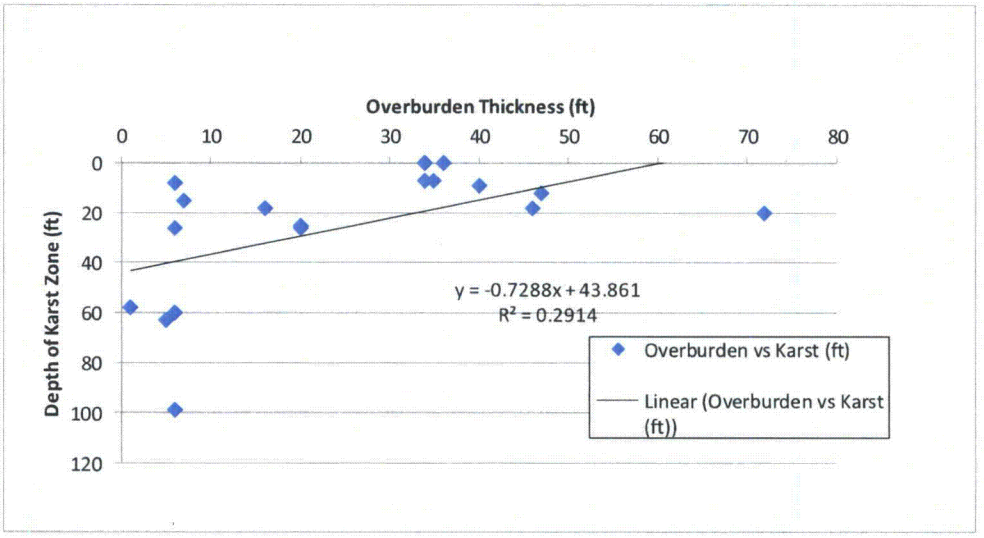



**Figure 6-24. Overburden Thickness Versus Depth of Karst**

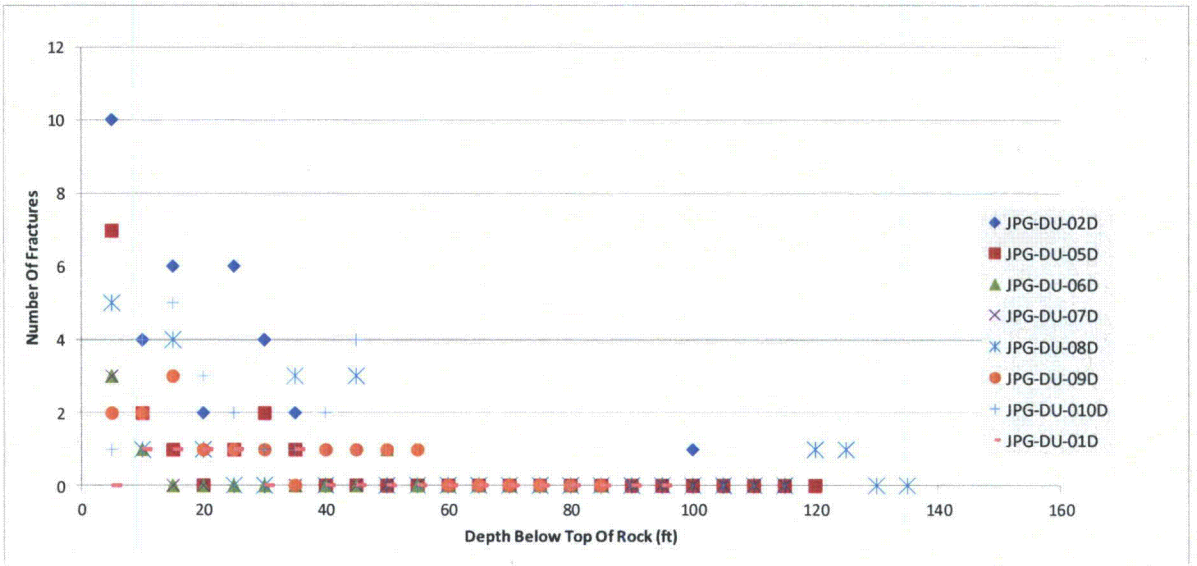



**Figure 6-25. Fracture Occurrence With Depth into Rock**

plane partings, and last of all voids for the eight deep bedrock core holes advanced in the DU Impact Area. Fractures were identified and counted per the 5-ft core runs for consistency. The graph clearly illustrates that fracturing predominates in shallow bedrock. The density and degree of weathering of fractures is most pronounced in the upper 25 ft of rock. At least one to two fractures with evidence of water residence (mineralization) typically could be found down to approximately 60 ft into rock. Below 60 ft, natural fractures typically could not be identified from coring induced breaks, which also diminished with depth as the rock became more competent.

Results of the RQD analysis and fracture interpretation suggest that groundwater transmission in the bedrock occurs in the upper 60 ft, with the upper 25 ft being the most transmissive, especially near Big Creek. The analysis also indicates no structural mechanism for appreciable groundwater storage and virtually no groundwater transmission in the deep bedrock. These findings appear consistent with shallow and deep well hydraulic characteristics. Shallow bedrock wells, completed to depths on the order of 50 to 80 ft BGS, on average about 30 to 60 ft into bedrock, yield water and intercept fractures with measurable hydraulic conductivities. On the other hand, deep wells completed to depths on the order of 120 to 130 ft BGS, or 80 to 120 ft into bedrock, with screens below shallow bedrock wells, almost to the well, do not yield water and do not intercept fractures with measurable hydraulic conductivities.

### *6.2.6 Stream Survey*

An experienced field hydrologist, with the assistance of health physics technicians (HPTs) and a UXO technician, conducted a stream survey of Big Creek, Middle Fork Creek, and North Tributary prior to the first planned quarterly sampling event. The survey was conducted in February/March 2008 when plants were dormant in winter and before leaf-growth began in spring. This enabled the hydrologist to observe seeps and caves such as the cave shown in Figure 6-26 more readily, since areas where groundwater discharges to the surface as springs or seeps were a major focus of the stream surveys. The hydrologist also located mixing zones in Big Creek and Middle Fork Creek where tributaries converge and considered them when selecting surface water sampling locations. To plan for occasions when surface water sample locations were dry or not flowing, the hydrologist designated and prioritized backup locations as replacements. The hydrologist also identified areas of recent sediment deposition suitable

**Figure 6-26. Groundwater Exiting BC-CA-06 During April 2008 Stream Survey**

and applicable for sampling with respect to evaluating potential DU migration along with sediment transport with a preference for fine material sediments.

The locations of these significant features and the actual sampling locations were documented with GPS. The features made from notes during the survey are summarized in Table 6-28 for Big Creek, Middle Fork Creek, and North Tributary. More detailed notes, including field observations (e.g., presence of penetrators, relation to land features, changes in stream configuration, description of stream-bottom, and type/character of sediments), also were recorded during the stream surveys and are provided in Appendix F.

Since samples were to be collected from various locations to measure surface water and sediment quality, surface water sample locations were selected based on observed conditions from general locations upstream of, within, and downstream from the DU Impact Area from each of the following general areas:

- Seven locations on Big Creek (one north of the northern boundary of the DU Impact Area on North Tributary, one at the western boundary of the DU Impact Area on the North Tributary, one upstream of the DU Impact Area in proximity to the location where the North Tributary intersects with E Road, one several hundred feet upstream of the boundary of the DU Impact Area, one within the DU Impact Area, one at the downstream boundary of the DU Impact Area, and one at the downstream boundary of JPG)
- Two possible locations within intermittent tributaries to Big Creek that originate and flow within the DU Impact Area

## Table 6-28. Summary of Stream Survey for Big Creek Jefferson Proving Ground, Madison, Indiana

| Stream Survey Features | Field Description Summary and Sample Location Rationale | Sample IDs |
|---|---|---|
| ***Big Creek Survey*** | | |
| BC-CA-01 to BC-CA-09A | Small cave entrances. Sandy and/or fine-grain material observed at entrances. At time of survey, no flow from three entrances, low flow (up to 5 gpm) at five entrances, and up to 20 gpm at two remaining entrances. Cold air emitting from one cave. | JP-W-01/JP-D-01 to JP-W-03/JP-D-03 and JP-W-06/JP-D-06 |
| BC-CV-01 to BC-CV-02 and 2 unnumbered locations | One location where culverts discharge enters Big Creek and another where culvert discharges from Big Creek. Potential surface drainage from or discharge to DU Impact Area. | JP-W-09/JP-D-09 and JP-W-10/JP-D-10 |
| BC-SD-01 to BC-SD-09 | Stream deposits observed where faster currents enter standing pools of water near bends, rock outcrops, tree stumps, sand bars, and Wilson Dam. Fine-grain to sandy deposits observed on banks, sand bars, or top of exposed bedrock for sampling. | JP-W-04/JP-D-04, JP-W-07/JP-D-07 and JP-W-11/JP-D-11 to JP-W-13/JP-D-13 |
| BC-SE-01 to BC-SE-05 | Possible seep or discharges from creek banks. Flow ranges from "very low" to ~10 gpm. | JP-W-08/JP-D-08 |
| BC-SP-01 to BC-SP-05 | Springs on bank of creek. Flow from ~2 to 10 gpm, but not measurable at one location (originates under flat passage between layers of bedrock). | NA |
| BC-TB-01 to BC-TB-07 | Tributaries entering Big Creek. Fine-grain to coarse sand deposits and bedrock observed. Sample location JP-W-05/JPG-D-05 situated at convergence of tributary draining "trench area" on southern side of Big Creek and JP-W-14/JPG-D-14 from draining of "trench area" on southern side of Big Creek. | JP-W-05/JP-D-05 and JP-W-14/JP-D-14 |
| ***Middle Fork Creek Survey*** | | |
| MF-CA-01 | Cave entrance with sandy material observed at entrances and "good" flow. Located regionally downgradient from the DU Impact Area. | JP-W-20/JP-D-20 |
| MF-CV-01, MF-CV-01L, MF-CV-01U | Culvert crossing under road with surface drainage entering upper limit (MF-CV-01U) of pool on east side of culvert on the northern bank, pool of water bending to the west and water becoming shallower as it exits lower limit (MF-CV-01L) with rock visible on stream bottom. | NA |
| MF-SD-01 to MF-SD-09 | Stream deposits observed near standing pools areas of debris buildup, beaver dams, and gravel/sand bars. Fine-grain to sandy deposits observed on banks, sand bars, or top of exposed bedrock for sampling. Aquatic vegetation and buildup of organic layer observed. | JP-W-17/JP-D-17 to JP-W-19/JP-D-19 |
| MF-SP-01 and 1 unnumbered location | One spring west of western perimeter and other cave spring ~900 ft upstream of Morgan Road. Western perimeter spring from bedrock outcrop that merges nearby stream. | NA |
| ***North Tributary*** | | |
| TBC-BD-01 | Water impounded behind large beaver dam east of road. | NA |
| TBC-SD-01 to TBC-SD-08 | Stream deposits observed where faster currents enter standing pools of water or swampy areas near bends, rock outcrops, sand bars, and beaver dam. Fine-grain to sandy deposits observed on banks, and sand/gravel bars for sampling. | JP-W-15/JP-D-15 and JP-W-16/JP-D-16 |
| TBC-SE-01 and TBC-SE-02 | Groundwater seeps/discharges from creek banks with silty sediment. | NA |
| TBC-TB-01 to TBC-TB-02 | Tributaries entering North Tributary from east. Both characterized with sandy deposits and rock observed. | NA |

- Three locations on Middle Fork Creek (one upstream of the DU Impact Area, one downstream from the DU Impact Area, and one at the downstream boundary of JPG)
- Seven locations at cave spring locations along Big Creek within the DU Impact Area
- One of two locations at cave/springs along Middle Fork Creek (whichever was flowing).

A minimum of four suitable locations for use as upgradient/background surface water and sediment sampling locations were established for comparison to and evaluation of the analytical results obtained from the remainder of the locations: one location north of the northern boundary of the DU Impact Area on the tributary feeding into Big Creek (i.e., North Tributary), two locations on Big Creek east of the boundary of the DU Impact Area, and one location on Middle Fork Creek east of the DU Impact Area.

### 6.2.7 Seepage Run Survey

In May 2008 and again approximately 1 year later in April 2009, SAIC performed seepage run surveys on that portion of Big Creek that crosses the DU Impact Area. The goal of the surveys was to identify the hydraulic relationship between Big Creek stream water and groundwater, whether groundwater discharged into Big Creek (i.e., gaining stream), or whether stream water leaked from Big Creek back into the ground (i.e., losing stream). Groundwater-Big Creek stream hydraulics affects DU transport and the relationship requires understanding for accurate flow modeling and transport predictions.

Most streams in most hydrogeologic settings are gaining streams. They receive contributions from storm runoff and groundwater discharging out of aquifers driven under local to regional gradients from areas of recharge to these points of discharge. Groundwater discharge, or base flow, sustains stream flow between storm events and especially during droughts. Conversely, a losing stream leaks surface water back into groundwater when the stream bed is sufficiently porous and permeable and the water table resides below the base of the stream. This situation creates downward hydraulic gradients capable of driving stream water through the porous bed into the ground. The rate of leakage can vary spatially along a stream course, over time, and with changes in stream stage. Commonly, where a losing stream exists, only a portion of the total stream flow is driven into the ground, but in some cases loss of the entire stream can occur. A losing stream can be a perennial or seasonal situation, or it can be an artificial situation created by high yield pumping of groundwater.

Karst terrain, like the Muscatatuck Plateau where JPG resides, can have losing streams or losing sections or reaches of streams, especially in the low order streams higher up in a watershed. In a karst setting, the point(s) at which a stream starts to lose water is the point at which rock dissolution beneath the stream has created and connected solution channels sufficient enough to hydraulically connect the underlying groundwater system to a surface discharge point lower in elevation than the nearby stream course. As the karst terrain matures, conduits connect more extensively, transmissivity increases, energy/hydraulic gradients decline, the water table flattens, downward vertical gradients between the stream and the water table set up, and a stream begins to leak at rates governed by streambed permeability. The net effect is that groundwater is drained more efficiently to that lower discharge point in the watershed, thereby preventing discharge as base flow to the local stream reach. Where an entire stream goes underground in karst terrain, almost exclusively where sinkholes or coalesced sinkholes have opened up to the surface, the bedrock conduits are so well connected and transmissive that the conduit system provides the flow path(s) of least resistance hydraulically downgradient into the watershed instead of the stream bed (except perhaps during flood events), where both pathways can conjunctively move the water.

Where only a portion of a stream leaks back into the ground, which is a predominantly losing stream situation, available survey methods are only semi-quantitatively capable of detecting these losing situations. Stream morphology (stream width, bed shape), basal bed material, seasonal weather, storm events, contributing springs, and tributaries all contribute to the difficulty in assessing the hydraulic relationship of the stream with the underlying groundwater system. As a consequence, SAIC designed and implemented its best technical program based on conventionally accepted methods to measure flow in Big Creek on two separate dates and flow conditions to achieve the goal of the survey.

Results of that survey suggest that Big Creek is a gaining stream as it flows through the DU Impact Area during the wetter part of the year (i.e., late winter through spring). As stream flow declines, first as rainfall declines and then as stored groundwater is quickly depleted, the stream may transition to a short-lived losing stream until it dries completely. Then, only storm events may create a losing situation for several hours to days.

### 6.2.7.1 Survey Methods

The principal means to establish the discharge relationship of a stream and groundwater system is to measure flow in the stream at multiple locations or stations along the stream for comparative analysis of flow. A two-team approach was utilized during the survey conducted on 7 May 2008 and the second survey conducted on 15 April 2009. Use of two teams allowed for broader coverage of the stream in its length through the DU Impact Area in as short a period of time as was possible. Overlap of a station by both teams allowed for a test on team measurement precision to ensure data integrity between the teams. Stream conditions at the time of the surveys and methods utilized to collect flow measurements are summarized below.

#### 6.2.7.1.1 May 2008 Seepage Run Survey

The first seepage run survey was conducted on the morning of 7 May 2008. The stream was flowing within ambient base flow conditions for the stream, rates on the order of 5.0 cubic feet per second (cfs) or less. The most recent rainfall in the area was approximately 4 days before the survey was conducted based on official gauge data recorded at the Madison, Indiana wastewater treatment plant, which is located approximately 10 mi south of Big Creek. Rainfall reported for 3 May 2008 at this gauge was 0.59 in. Approximately 0.63 in reportedly fell the day before, with no rainfall on 1 May or 30 April. Stream width ranged from 14 to 50 ft in the vicinity of the DU Impact Area, for an average of 26 ft. Stream depth in the main channels varied from as little as several in to at most 1.75 ft.

Two teams were utilized to measure flow in the stream. Each team used a Marsh McBierny model 2000 flow meter with a flow resolution from -0.5 ft/sec to 19.99 ft/sec. Each team consisted of two scientists and a UXO technician. Stream flow was measured at 17 stations or transects along Big Creek (SR-00 to SR-06, SR-91 to SR-99, and BC-01) and at one tributary and one seep observed to be flowing into Big Creek. Figure 6-27 shows the locations of the stream flow stations. Data sheets with flow measurements and stream characteristics are included in Appendix F.

Measurement stations were selected by each team at the time of the survey at locations not impacted by UXO and containing minimal obstructions from debris or bends in the stream that could have led to distortion of flow measurements. The survey began at station SR-00 near existing gauging station CGS-BC-11 (Figure 6-27). Both teams independently measured stream flow at SR-00 before splitting up. One team headed upstream to the east (SR-99 to SR-91) and the other team heeded downstream to the west (SR-01 to SR-06 and BC-01). As the teams walked along Big Creek, tributaries and actively flowing caves were gauged or were attempted to be gauged given the rate of flow encountered and the resolution of the gauging equipment. After the teams finished their respective sections of the stream, they reconvened at SR-00 near CGS-BC-11 to independently measure flow along the same transect as before. Then, teams moved to station SR-06 and both measured the stream as a further check on measurement reproducibility and base flow recession over the course of the survey. The entire event was completed within approximately 4.5 hours.

Stream flow at a given station or transect was determined by multiple velocity measurements at points in the stream along a transect that ran across the flow direction of Big Creek (i.e., north-south direction). A graduated measuring tape was secured on both sides of the stream. At each velocity measurement location, the depth to the base of the stream from water surface was measured along with the distance to the bank so a stream profile could be developed to calculate a volumetric flow rate. Velocity and depth were determined at an average number of 12 transect locations.

In addition to velocity, depth, and length measurements, both teams noted the streambed material in broad categories of sand, gravel, or bedrock (i.e., where no loose material was deposited). Gravel was the dominant substrate at the majority of transects (i.e., 10). A mixture of gravel and sand dominated at four more stations. Lastly, a mixture of gravel sand or bedrock dominated at three transects. Only one

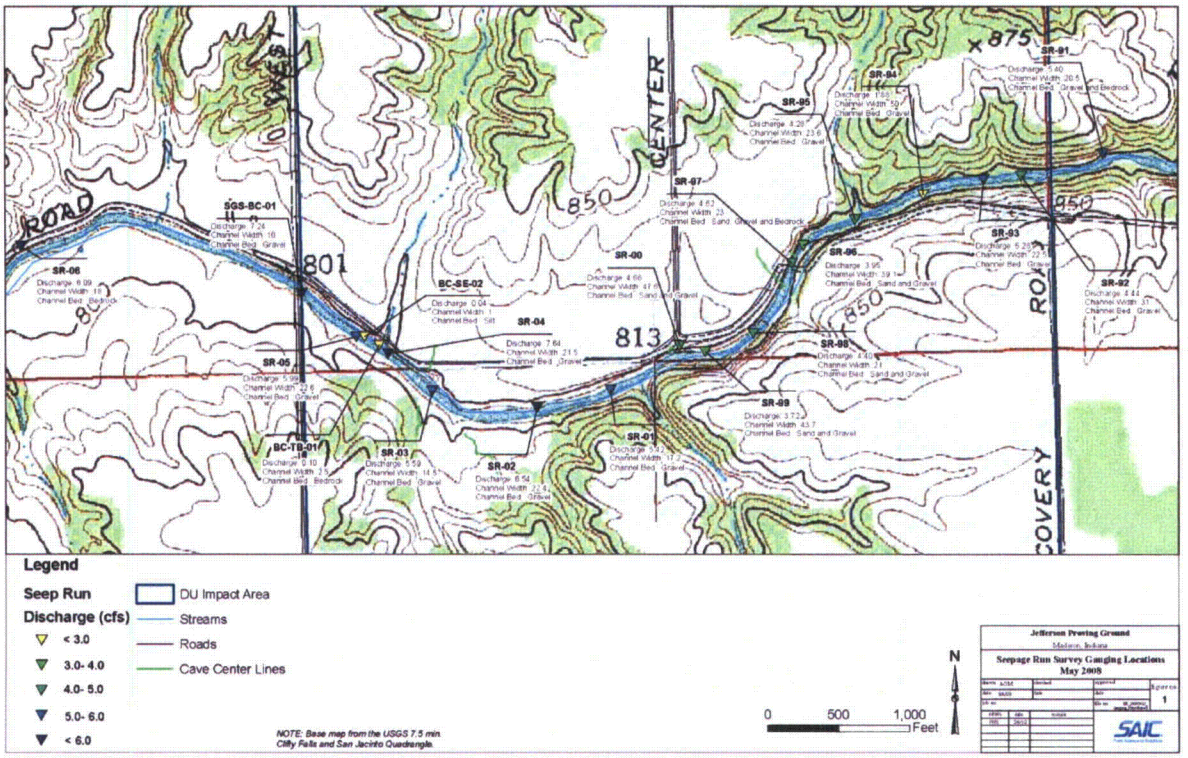



**Figure 6-27. May 2008 Seepage Run Survey Location Map**

transect (SR-91) consisted of more than one channel. As Big Creek flowed into the DU Impact Area, it remained as one channel through the remainder of the DU Impact Area. It is also important to note that given low base flow conditions at the time of the survey, multiple passes were conducted by both teams at SR-00 for QC purposes because water was flowing near the low-end resolution of the flow meters at this transect. At the remainder of the stations, flow meters were accurately scaled to flow conditions, typically at the lower end of resolution. Main channel velocities were typically on the order of several tenths of 1 ft/sec, occasionally around 1.0 ft/sec.

#### 6.2.7.1.2 April 2009 Seepage Run Survey

The second seepage run survey on Big Creek was conducted on 15 April 2009. The same approximate stations were measured for flow as were measured during the first survey in May 2008. The stream was flowing well above ambient base flow conditions for the stream at rates on the order of 50.0 cfs. Approximately 0.08 in of rain fell the day before the survey and 0.79 in reportedly fell on 13 April 2008 according to the Madison gauge. The monthly average of 4.0 in had already fallen in the watershed by the date of the survey. Stream width was on the order of 25 to 57 ft for an average of 40 ft, which is almost twice the average flow width as the May 2008 survey. Stream depth in the main channels was upwards of 3.0 ft. The survey was completed in 8 hours.

Two teams, consisting of scientists and UXO technicians, again completed the survey. Teams used Marsh McBierny model 2000 flow meters with flow resolutions from -0.5 to 19.99 ft/sec. Both teams started at station SR-BC-00 near CGS-BC-11 where an initial transect was measured by both teams for QC purposes. One team then worked upstream (i.e., to the east) from station SR-BC-99 to SR-BC-97, while the other worked downstream (i.e., to the west) from SR-BC-01 to SR-BC-09. At completion of the upstream station SR-BC-97, this team then joined the team working downstream to complete those

stations. Station SR-BC-95 was measured last at the end of the survey. As the teams walked along Big Creek, they attempted to measure flow at tributaries that discharged their water to Big Creek as well as any actively flowing caves that may have impacted flows into the creek. A total of 14 stations were measured on Big Creek along with three tributaries and two seeps flowing into the creek. As a further check on the precision and accuracy of the survey, duplicate measurements were collected at station SR-BC-05. Figure 6-28 shows the locations of the measurement stations. Data sheets with flow measurements and stream characteristics are included in Appendix F.

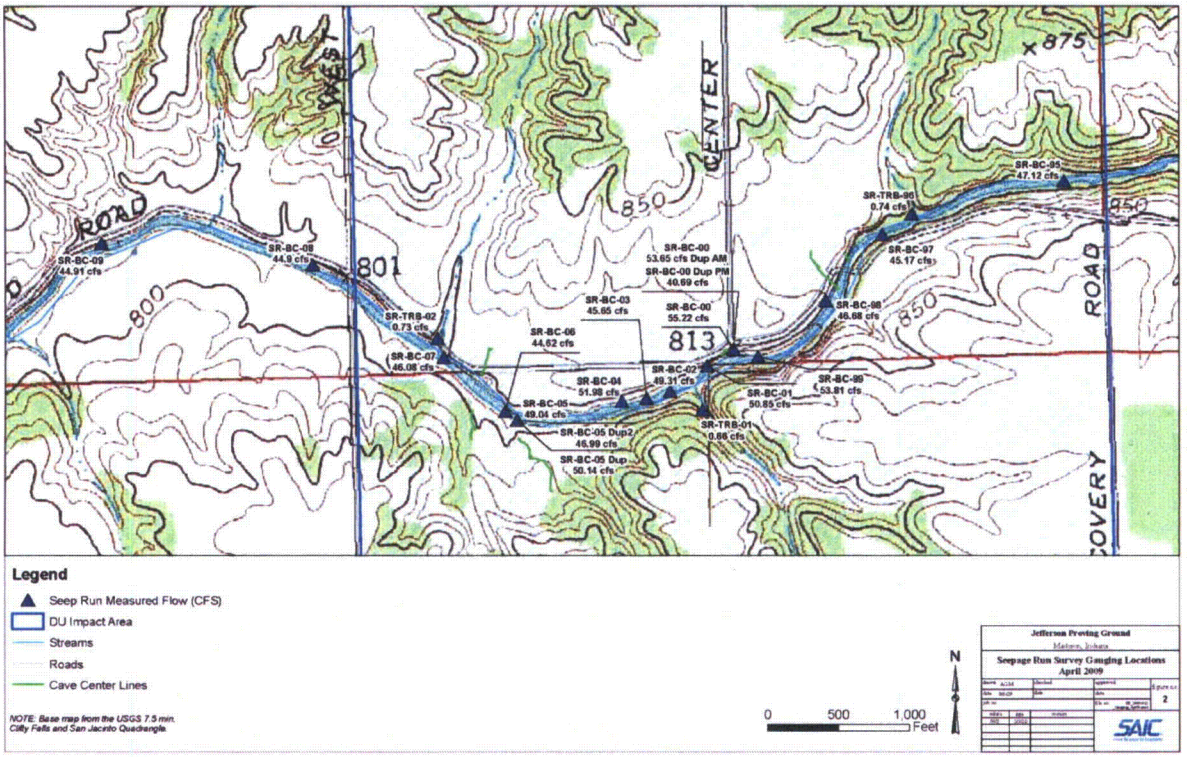



**Figure 6-28. April 2009 Seepage Run Survey Location Map**

Station transects were measured similarly to the May 2008 survey using graduated tape across the stream for horizontal control while measuring depth and flow incrementally across the stream. Station locations were determined with a hand held GPS. The average number of stream flow measurements within 1 transect was approximately 12. Bed morphology was predominantly bedrock, with lesser amounts of sand and gravel as encountered during the May 2008 survey. There were no instances where one transect consisted of more than one channel. Lastly, flow conditions were elevated due to the recent rainfall with the stream flowing under turbulent conditions at 3 of the 14 transects.

### 6.2.7.2 Seepage Run Survey Results

Results of each survey are concisely presented below. The May 2008 survey is presented first and then the April 2009 survey. Results then are discussed relative to the goal of the survey, in the context of the CSM.

#### 6.2.7.2.1 May 2008 Seepage Run Survey Results

Prior to reducing and evaluating flow data relative to the objectives of the survey, duplicate data sets collected by both teams for stations SR-00 and SR-06 were evaluated through correlation to assess and verify that a comparable level of precision was achieved by each team. A consistent bias by one team over another could skew conclusions on stream flow from upstream and downstream reaches. Appendix F contains the results of the correlation. Each team was measuring stream depth and flow velocity on a comparable basis, based on calculated correlation factors of 0.96 and 0.90, respectively. A correlation factor of 1.0 indicates an exact match. Data sets for the entire survey were deemed useful for the goal of the survey and were evaluated further as a result of the strong correlation between team subsets of data.

Table 6-29 lists the respective flow rates measured by each team along Big Creek during the May 2008 survey, including notations on stream details like width and streambed material. Figure 6-29 shows stream discharge over downstream distance from the uppermost station and Figure 6-30 shows accumulated discharge over that same distance. Figure 6-29 shows discharge as it was measured at a given station, as listed in Table 6-29, along with a moving average trend and locations of caves, seeps, and tributaries, and any outflows to Big Creek. Figure 6-30 shows the incremental, additive change in flow and the average trend, whether an increase or decrease, from successive stations.

Figure 6-29 shows an initial flow rate of approximately 4.5 to 5.5 cfs for Big Creek as it entered the DU Impact Area. Flow appears to decline slightly, then decline significantly at station SR-94, then it appears to rise and remain below 5 cfs until station SR-00 is reached. Flow then appears to steadily rise, eventually as high as 7.64 cfs at station SR-04. Average flow from upstream station SR-91 to mid-point station SR-00 was 4.3 cfs. Average flow from station SR-01 to the most distant downstream station (SR-06) was 6.4 cfs. Flow in Big Creek was influenced slightly by a seep and tributary near station SR-03, flowing on the order of 0.04 and 0.1 cfs, respectively. Two caves and a tributary in the upstream reach that flow seasonally were observed to not be flowing the day of the survey.

Figure 6-30 shows a net decrease in flow in the upstream reach followed by a net increase in flow in the downstream reach. An average net increase in flow of 1.5 cfs was experienced by the time Big Creek flowed out of the DU Impact Area.

**Table 6-29. May 2008 Seepage Run Survey Data**
**Jefferson Proving Ground, Madison, Indiana**

| Station | Distance Downstream (ft) | Discharge (cfs) | Station Incremental Flow Change (cfs) | Accumulated Discharge (cfs) | Channel Width (ft) | Unit Flow (Q)/ Channel Width (W) | Bed Morphology |
|---|---|---|---|---|---|---|---|
| SR-91 | 0 | 5.40 | | 0.01 | 20.5 | 0.26 | GB |
| SR-92 | 608 | 4.44 | -0.96 | -0.95 | 31 | 0.14 | G |
| SR-93 | 882 | 5.28 | 0.85 | -0.11 | 22.5 | 0.23 | G |
| SR-94 | 1338 | 1.88 | -3.41 | -3.51 | 50 | 0.04 | G |
| SR-95 | 1858 | 4.28 | 2.41 | -1.11 | 23.6 | 0.18 | G |
| SR-96 | 2270 | 3.95 | -0.33 | -1.44 | 39.1 | 0.10 | GS |
| SR-97 | 2423 | 4.62 | 0.67 | -0.76 | 23 | 0.20 | GSB |
| SR-98 | 3017 | 4.40 | -0.22 | -0.99 | 21 | 0.21 | GS |
| SR-99 | 3411 | 3.72 | -0.68 | -1.66 | 43.7 | 0.09 | GS |
| SR-00 | 3592 | 4.66 | 0.93 | -0.73 | 47.6 | 0.10 | GS |
| SR-01 | 4155 | 5.42 | 0.76 | 0.03 | 17.2 | 0.32 | G |
| SR-02 | 4704 | 6.54 | 1.12 | 1.15 | 22.4 | 0.29 | G |
| SR-03 | 5478 | 5.59 | -0.96 | 0.20 | 14.5 | 0.39 | G |
| SR-04 | 5882 | 7.64 | 2.05 | 2.25 | 21.5 | 0.36 | G |
| SR-05 | 6162 | 5.99 | -1.64 | 0.60 | 22.6 | 0.27 | G |
| BC-01 | 6652 | 7.24 | 1.25 | 1.86 | 10 | 0.72 | G |
| SR-06 | 8714 | 6.09 | -1.15 | 0.70 | 18.01 | 0.34 | B |

Bed morphology: B = bedrock, G = gravel, S = sand

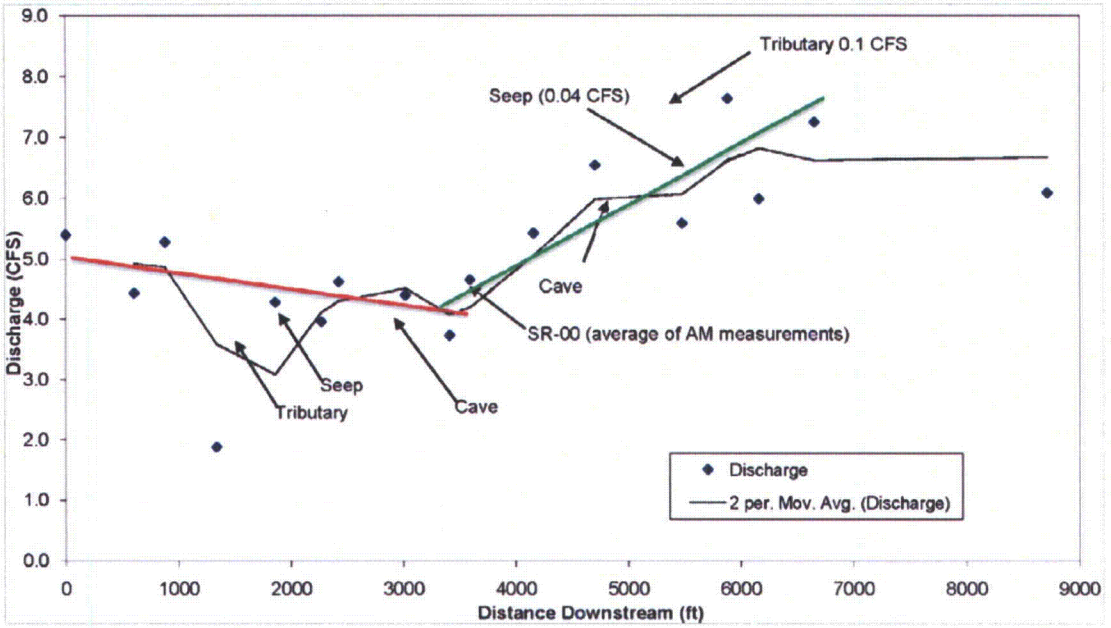



**Figure 6-29. May 2008 Seepage Run Survey Stream (Discharge Over Downstream Distance)**

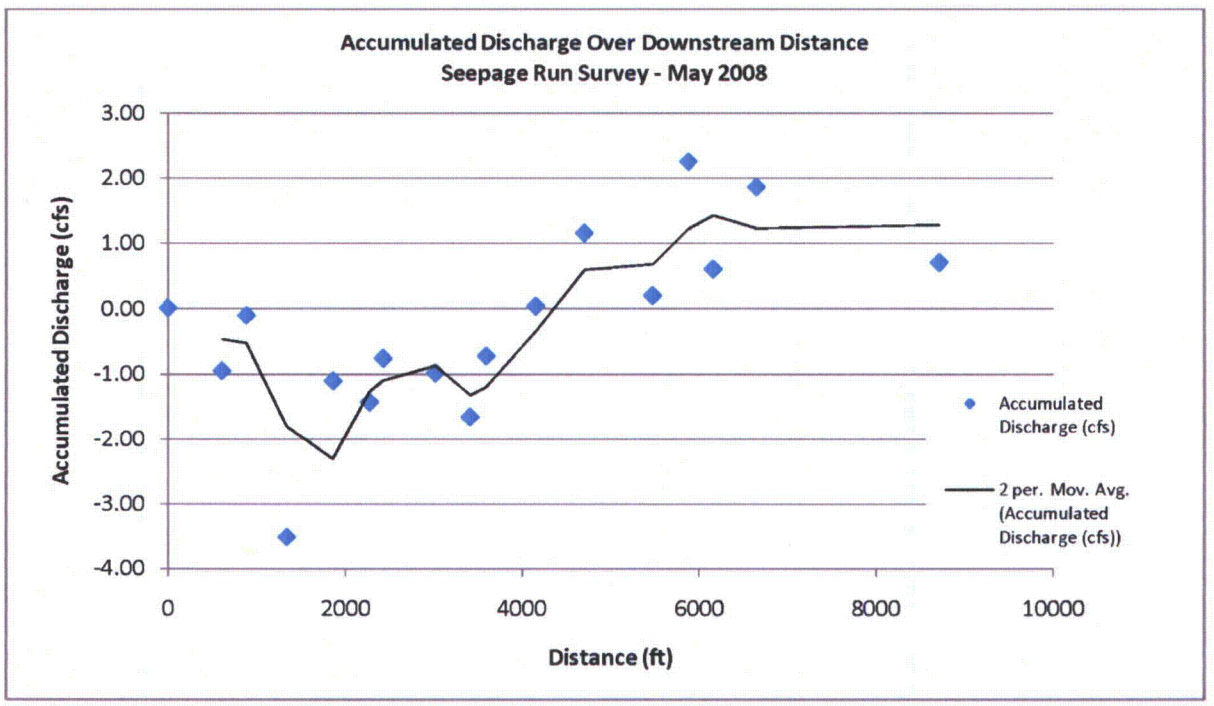



**Figure 6-30. May 2008 Seepage Run Survey Accumulated Discharge Over Downstream Distance**

#### 6.2.7.2.2 April 2009 Seepage Run Survey Results

As with the May 2008 dataset, prior to reducing and evaluating flow data for the April 2009 survey, duplicate data sets collected by both teams for station SR-BC-00 were evaluated through correlation to assess and verify that a comparable level of precision was achieved by each team. Appendix F contains the results of the correlation. Each team was measuring stream depth and flow velocity on a comparable basis, based on calculated correlation factors of 0.99 and 0.94, respectively. Data sets for the entire survey were, therefore, deemed useful for the goal of the survey.

Table 6-30 lists the respective measured and time corrected flow rates for each station along Big Creek, including notations on stream details like width and streambed material. Figure 6-31 shows corrected stream discharges over downstream distance from the uppermost station. Stream flow was receding relatively rapidly during the survey following the prior rain events as evidenced by the respective reduction in runoff, as documented by flow measurements at SR-BC-00 at approximately 9:00 a.m. and again at 7:00 p.m. Measured morning flow was 55.2 cfs and by the evening flow had decreased to 40.7 cfs. Flow rates for successive stations completed after SR-BC-00 were corrected according to the rate of decline in flow established at station SR-BC-00. Correcting the values for flow recession attempted to discount the effect of the declining in-flows to the stream from runoff and bank storage throughout the day. Figure 6-31 also shows the locations of caves, seeps, and tributaries and any inflows to Big Creek.

Figure 6-31 shows an initial flow rate of approximately 57 cfs for Big Creek as it enters the DU Impact Area. Flow declines to 48 cfs, then rises and falls within this range of 48 to 57 cfs downstream, flowing off the DU Impact Area at an average rate of 53.5 cfs, for an apparent net decline of 3.5 cfs. Three tributaries flowing on the order of 0.74, 0.66, and 0.73 cfs contributed to Big Creek flow near stations SR-BC-97, SR-BC-01, and SR-BC-08, respectively. One seep (CGS-BC-11) was flowing at a measured rate of 0.13 cfs.

**Table 6-30. April 2008 Seepage Run Survey Data**
**Jefferson Proving Ground, Madison, Indiana**

| Station | Distance Downstream (ft) | Measured Discharge (cfs) | Baseflow Recession Time Lag* (hrs) | Baseflow Recession Time Lag Correction (%) | Corrected Discharge (cfs) | Station Incremental Flow Change (cfs) | Accumulated Discharge (cfs) | Stream Width (ft). | Unit Flow (Q)/ Channel Width (W) |
|---|---|---|---|---|---|---|---|---|---|
| SGS-BC-03 | 0 | | | | | | | | |
| SR-BC-95 | 225.38 | 47.12 | 8.5 | 21.25% | 57.13 | | 0.01 | 28.4 | 2.01 |
| SR-BC-97 | 1592.43 | 45.17 | 2.5 | 6.25% | 47.99 | -9.14 | -9.13 | 33.7 | 1.42 |
| SR-BC-98 | 2251.52 | 46.68 | 2 | 5.00% | 49.01 | 1.02 | -8.11 | 45.3 | 1.08 |
| SR-BC-99 | 2930.25 | 53.81 | 1 | 2.50% | 55.16 | 6.14 | -1.97 | 45.5 | 1.21 |
| SR-BC-00 | 3102.25 | 55.22 | 0 | 0.00% | 55.22 | 0.06 | -1.90 | 48.6 | 1.14 |
| SR-BC-01 | 3477.98 | 50.85 | 1 | 2.50% | 52.12 | -3.10 | -5.00 | 48.6 | 1.07 |
| SR-BC-02 | 3796.48 | 49.31 | 1.5 | 3.75% | 51.16 | -0.96 | -5.96 | 57 | 0.90 |
| SR-BC-03 | 3981.12 | 45.65 | 2.5 | 6.25% | 48.50 | -2.66 | -8.62 | 45 | 1.08 |
| SR-BC-04 | 4158.54 | 51.98 | 3 | 7.50% | 55.88 | 7.38 | -1.24 | 48 | 1.16 |
| SR-BC-05 | 4919.14 | 49.04 | 3.5 | 8.75% | 53.33 | -2.55 | -3.79 | 30 | 1.78 |
| SR-BC-06 | 5024.18 | 44.62 | 4.5 | 11.25% | 49.64 | -3.69 | -7.48 | 30 | 1.65 |
| SR-BC-07 | 5592.03 | 46.08 | 6.5 | 16.25% | 53.57 | 3.93 | -3.56 | 40 | 1.34 |
| SR-BC-08 | 6723.03 | 44.9 | 7.5 | 18.75% | 53.32 | -0.25 | -3.80 | 41.6 | 1.28 |
| SR-BC-09 | 8324.62 | 44.91 | 8 | 20.00% | 53.89 | 0.57 | -3.23 | 25.5 | 2.11 |

* Time after flow measurement at SR-BC-00
Bed morphology: B = bedrock, G = gravel, S = sand

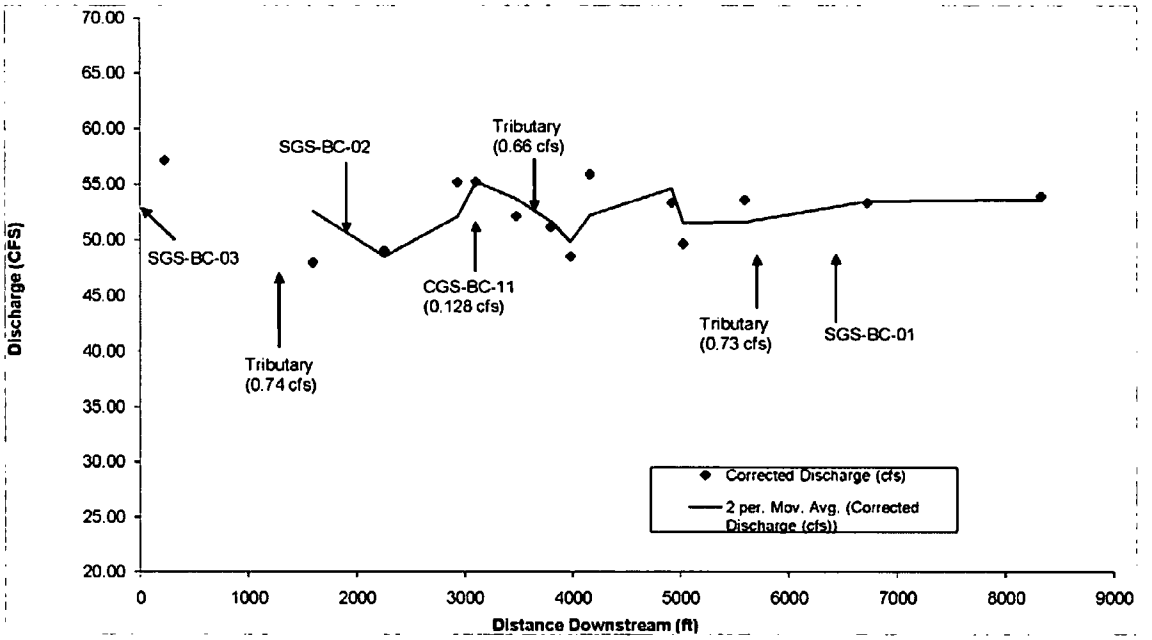



**Figure 6-31. April 2009 Seepage Run Survey Corrected Discharge Over Downstream Distance**

### 6.2.7.3 Seepage Run Survey Results Analysis and Discussion

Seepage run surveys best aid the evaluation of stream-groundwater hydraulics when a stream is flowing within ambient base flow conditions, when the proportion of flow contributed by groundwater is at or near its maximum relative to that proportion contributed by storm runoff (USGS 2008a, 2009). The May 2008 seepage run survey performed within long-term base flow conditions for Big Creek provided more meaningful data to evaluate flow conditions than the April 2009 survey. Analysis of the May 2008 survey results indicates these data, interpreted in the context of the understanding of the hydrogeologic setting, can support meaningful conclusions concerning the relationship between Big Creek stream flow and groundwater.

As storm runoff dominates stream flow, the utility of seepage run surveys in assessing gaining and losing stream reaches declines. Detection of groundwater contributing and especially losing zones becomes more difficult to separate from the larger proportioned surface inflows. This is further complicated by the waning or recession of these inflows and the release of bank storage, or in the case of Big Creek, rapid release of cave and karst conduit storage. Big Creek has been shown to flash in response to rain events, meaning runoff flows in rapidly following the onset of rainfall, raising stream levels rapidly, but then stream flow recedes quickly once rainfall ends. Sinkholes local to Big Creek are connected via karst conduits, many of which are large enough to be termed "caves," with these conduits/caves acting like storm drains during and shortly after rain events. As stream stage rises during runoff, caves and conduits not otherwise directly hydraulically connected to the surface can store water driven in by the flood or near flood stage stream. As runoff declines and stream level declines in response, any conduit/cave stored water quickly flows out, completing the flash response to rainfall. This can be seen in the stream flow hydrographs for Big Creek, and other streams in southern Indiana, where flow suddenly peaks and then wanes within hours to several days. As a consequence, despite its sound implementation on the declining side of a rainfall event, the utility of the April 2009 survey in assessing the long-term hydraulic relationship between Big Creek surface water and groundwater was determined to be of low value and further analysis of these data was not undertaken.

Figures 6-29 and 6-30, which show discharge and accumulated discharge, respectively, for Big Creek during the May 2008 survey, suggest that Big Creek was losing water as it flowed to the mid-point of the DU Impact Area. Stream flow was further evaluated relative to stream width and stream bed material to determine if the decline in stream flow was loss to bedrock or loss to flow through coarse bed load. Appendix F includes this further analysis, expressed in three graphs: stream discharge versus stream width, stream width versus downstream distance, and stream unit discharge per stream width versus downstream distance. The analysis shows a correlation exists, at least for this survey, between measured stream flow and stream width; stream flow decreases as the stream flow path broadens and thins. There is also a spatial correlation between stream width and location in the DU Impact Area, with Big Creek generally wider along the upstream reach relative to the downstream reach. The average width of the stream on 7 May 2008 in the upstream reach (station SR-91 to SR-00) was 32 ft, whereas the width below station SR-00 was 17 ft, almost half the upstream width, on average. During the May survey, the stream base was layered with a gravel base of unknown depth.

The above relationships suggest that the decline in flow in the upstream reach was not water lost to bedrock but lost through the coarser gravel bed load, which cannot be practically measured during a seepage run survey. Loss through bed load would become more of a factor, which is a larger proportional flow component of total stream flow, as a stream broadens and the depth of flow declines. The net effect of bed load loss is an underestimation of the total flow. As the stream flow width shrank and flow depth deepened as Big Creek flowed through the DU Impact Area, that portion of flow lost through bed load declined and stream flow appeared to gain, as the measured total flow rate better approximated actual flow.

As a result of this additional analysis, the reach of Big Creek through the DU Impact Area appears to be a gaining stream when flowing. This implies that groundwater local to the stream reach is driven to the stream for discharge and contribution to the stream during periods of frequent rainfall, usually late winter through spring of an average year.

Well water levels lend further insight into the relationship of groundwater to Big Creek stream flow, suggesting that Big Creek is a gaining stream. On 8 February 2008, water levels were collected from DU Impact Area wells and known gauging stations on Big Creek. Water levels and a well/stream gauge location map are provided in Appendix F. Although water levels in many of the deep bedrock wells were only partially recovered, evaluation of water levels in intermediate bedrock wells compared to measured or estimated Big Creek stream stage indicated upward gradients at three locations along the stream: JPG-DU-02I/SCS-BC-01, MW-9/SCS-BC-02, and JPG-DU-8I. The hydraulic gradient between JPG-DU-02I and stream gauge station SCS-BC-01, located on the most downgradient western edge of the DU Area, was upward at 0.32 feet per foot (ft/ft). The stream stage at SCS-BC-02, as estimated by stream elevations on this date elsewhere along the stream relative to the water level in well MW-9, indicated a likely upward gradient relationship between groundwater and the stream at this location. Likewise, the water level in well JPG-DU-08I appeared to be higher than the estimate of stream stage at this location.

As mentioned previously, in karst terrain, a deep drainage to a lower elevation surface water discharge point through a laterally extensive conduit system is required to: 1) divert groundwater from local stream discharge, and 2) promote stream leakage to bedrock. The relatively thin karst rind characteristic of bedrock in the DU Impact Area appears to be underdeveloped, with insufficient conduits to support deep regional drainage, given the relatively broad flat regional topography.

Nineteen caves are noted along Big Creek and were mapped for dimension and orientation in the early 1990s. Lengths range from 25 to more than 600 ft, for an average of about 160 ft. Some caves flow during the wet season in late winter and spring while some only flow during storm events. Many do not flow at all. These caves appeared to be oriented perpendicular to sub-perpendicular to Big Creek. Caves appeared to be singular occurrences in the rock; as investigation of the caves did not reveal a honeycomb

substructure of caves parallel to Big Creek. Despite evidence of solution zone occurrence at wells (e.g., JPG-DU-02I), the large variation in shallow bedrock permeability determined from the slug testing program further suggests solution enhancement of original fracture pathways has not opened the shallow bedrock groundwater system uniformly nor consistently enough to suggest conduits are interconnected extensively.

Regional topography is relatively flat, with resultant stream gradients being very gentle, on the order of 6 feet per mile (ft/mi), based on the average stream grade of Big Creek through the DU Impact Area. On an average basis, the lower 20 to 40 ft of the karst rind is saturated, indicating that a laterally extensive conduit network could conceivably drain groundwater 3.5 to 6.5 mi hydraulically downgradient. Given evidence regarding rock solution and permeability in the DU Impact Area, subsurface drainage on the above order instead of local stream discharge appears very unlikely.

Lastly, much of the year Big Creek is dry (from June to November), flowing only for several days during and immediately following rain events. There is no groundwater discharge or base flow in Big Creek at this time of the year. This indicates that the groundwater system beneath and along Big Creek is laterally limited, possibly closely approximated by the lateral extent of the cave systems. Once snow melt abates and the frequency of rain events declines, the groundwater system effectively drains quickly, on the order of weeks to only a month and no longer contributes groundwater to Big Creek as base flow. In this instance, groundwater flow moves away from an orientation of more or less perpendicular to the Big Creek stream course, to an orientation aligned in a more regional direction sub-parallel to the Big Creek stream course, controlled by a discharge point at a lower elevation in the watershed. Under these circumstances, Big Creek may transition to a losing stream briefly as rainfall declines and stored groundwater is depleted but likely only locally as a consequence of the above-discussed karst level of maturity and gentle regional gradient. Storm flow during the drier months could and likely does leak to bedrock groundwater, again likely only locally, for only short periods of time on the order of hours to days as the storm event wanes and is absorbed by the local aquifer.

### 6.2.8 DU Penetrator Corrosion Study

The DU penetrator corrosion study was composed of distinct components consisting of speciation (Section 6.2.7.1) and leachability testing (Section 6.2.7.2). Speciation testing determines the nature of corrosion products present as a result of reduction and oxidation. Leachability testing, by comparison, determined the short-term, site-specific leaching rate. Special consideration was given to ensuring that penetrators subjected to speciation included representative samples from each of the three soil type groupings (i.e., Avonburg/Cobbsfork, Cincinnati/Rossmoyne, and Grayford/Ryker) to evaluate any possible soil-specific impacts on the corrosion products formed or leachability rates.

The rate at which the penetrators corrode, the nature of oxidation products formed, and the rate that those products leach into deeper soil affects the rate of movement of DU in the environment. Each of these components provides information that is important to the determination of the dose to the average member of the critical group over the required 1,000-year period of interest. Several DU penetrators were identified historically in the DU Impact Area and inspected visually (SEG 1996). This investigation revealed a variable degree of yellow surface corrosion products. Based upon physical appearance, this corrosion rind may be a relatively soluble (leachable) hexavalent uranium oxide U(VI), such as schoepite (nominally $UO_3 \cdot 2H_2O$), with the increased solubility relative to other forms of DU corrosion products present onsite. Other chemical forms of uranium also may be formed in the vicinity of penetrators, depending upon the site-specific geochemical environment. Thus, uranium speciation, local groundwater and surface water properties (especially solution pH, redox potential, and alkalinity), local soil mineralogy (especially the content of iron-containing minerals), and possibly the presence of indigenous microbes (such as *Thiobacillus ferroxidans*) determines the potential solubility and subsequent potential for migration of DU corrosion products. As such, soil mineralogy, including uranium and iron content,

was determined in the laboratory using representative composites of the soil samples collected from the location of penetrator removal.

Scrape samples were collected from corrosion products present on 24 DU penetrators from JPG to determine the nature of redox products resulting from corrosion. Materials and Chemistry Laboratory, Inc. (MCLinc) analyzed the scrape samples to identify the specific mineral phases and identify uranium valence states that formed under actual field conditions at JPG. MCLinc also analyzed cross-sections of DU penetrators to identify the depths of oxide formation and elemental association within the oxide layer.

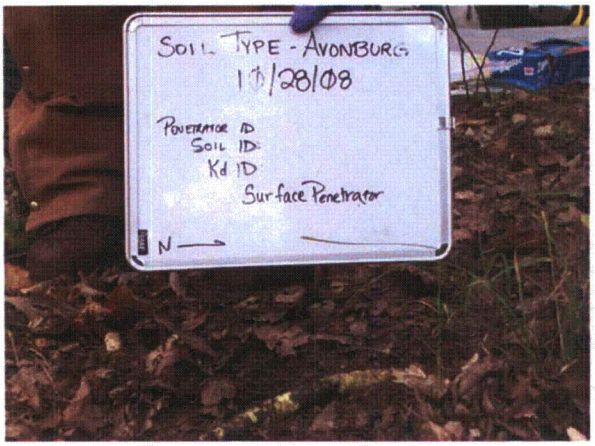
MCLinc also conducted leachability testing in six controlled environmental chambers using three segments of penetrators with site-formed corrosion rinds and three other segments from which MCLinc has mechanically removed the surface rinds. Each environmental chamber included one DU penetrator segment immersed in background soil collected from JPG. Each chamber was subjected to 20 cycles of environmentally simulated meteorological conditions (e.g., flood, drain, wet air, dry air) lasting 3 weeks each. Leachate samples collected and analyzed at the conclusion of each cycle for total and isotopic uranium (U-234, U-235, and U-238) using American Society for Testing and Materials (ASTM) D3972-90M. At the conclusion of the leachability testing, scrape samples of the corrosion products and cross-sections from the six penetrators were re-analyzed.

### 6.2.8.1 Corrosion Study Speciation

To evaluate a range of corrosion conditions, SAIC collect 24 penetrators located at or near the ground surface. Ten penetrators were collected from the Avonburg/Cobbsfork soil type grouping, including five penetrators collected from ground surface (JP-PAC-001, JP-PAC-002, JP-PAC-003, JP-PAC-004, and JP-PAC-005) and five penetrators were collected from various subsurface depths (JP-PAC-006 from 1 to 2 in BGS, JP-PAC-007 from 2 to 4 in BGS, JP-PAC-008 from 2 to 3 in BGS, JP-PAC-009 from 2 to 4 in BGS, and JP-PAC-010 at 2 in BGS). Ten penetrators also were collected from the Cincinnati/Rossmoyne soil type, including seven penetrators collected from ground surface (JP-PCR-001, JP-PCR-002, JP-PCR-003, JP-PCR-004, JP-PCR-005, JP-PCR-009, and JP-PCR-010) and three penetrators were collected from various subsurface depths (JP-PCR-006 from 0 to 2 in BGS, JP-PCR-007 from 0 to 3 in BGS, and JP-PCR-008 from 0 to 3 in BGS). Four penetrators were collected from the Grayford/Ryker soil type grouping, including three penetrators collected from ground surface (JP-PGR-001, JP-PGR-002, and JP-PGR-003) and one penetrator collected from the subsurface (JP-PGR-004 from 4 to 6 in BGS). Figure 6-32 shows one penetrator from the Avonburg/Cobbsfork soil type grouping (JP-PAC-005) as it appeared when discovered, after packaging for shipment, as received by the laboratory (tight- and wide-angle views), and before/after scraping corrosion products for speciation testing.

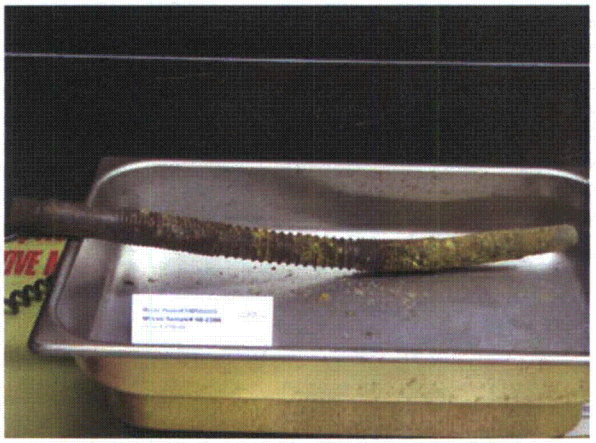
DU penetrators were carefully removed from the ground while attempting to leave corrosion material and/or soil adhering to the penetrator intact. Penetrators were placed into plastic bags for subsequent submission for corrosion speciation analysis. No specific steps were taken to select penetrators based on any criteria other than ensuring the appropriate number of penetrators was collected based on the aforementioned distribution across soil type groupings. The first 24 penetrators encountered according to the soil type grouping were recovered, packaged, and transferred to MCLinc. The outside of each of the bagged DU penetrators was photographed and marked with the date and time of removal, location, depth to the top of the penetrator, and collector's name.

Each penetrator sample was scraped with a plastic polycarbonate ice scrapper to remove corrosion products for analytical characterization. Each sample was then hand ground with a mortar and pestle. A portion of each ground sample was then split and mounted appropriately for each analysis: X-ray diffraction (XRD), scanning electron microscopy with energy dispersive spectrometry (SEM-EDS), and X-ray photoelectron spectrometer (XPS).




Prior to collection


Packaged for shipment



As received (wide-angle)


As received (tight-angle)


Before scraping


After scraping

**Figure 6-32. Avonburg/Cobbsfork Penetrator (JP-PAC-005) From Collection Through Scraping**

XRD was performed using a Philips XRG3100 X-ray diffractometer to determine the crystalline phases present. Diffractogram scans were run from 5 to 85 degrees two theta. The International Centre for Diffraction Data (ICDD) then was used to determine the phases present in the samples. The accuracy of the two theta position and general diffractometer performance were checked using a quartz standard, as described in "MCL-7712: MCL X-Ray Diffraction Operation Guide." All diffractograms are included in Appendix K.

Table 6-31 summarizes the XRD characterization of the penetrators. The major phases were determined by their dominant peaks: trace phases are just recognizable, and minor phases are recognizable but not dominant. The major uranium phase for the samples was $UO_3 \cdot 2H_2O$ (schoepite). The minor phase was $UO_2$. Metallic uranium (U) and $UO_4 \cdot 4H_2O$ also were detected. A number of samples contain several trace-and minor-sized peaks that are unassigned to a phase. These unassigned peaks are not uranium-bearing compounds.

**Table 6-31. XRD Characterization Results Summary for the Penetrator Samples Jefferson Proving Ground, Madison, Indiana**

| Penetrator ID | Major Phases | Minor Phases | Trace Phases |
|---|---|---|---|
| JP-PAC-001 | $UO_3 \cdot 2H_2O$, $SiO_2$ | $UO_2$ | U |
| JP-PAC-002 | $UO_3 \cdot 2H_2O$ | | $UO_2$, $SiO_2$, U |
| JP-PAC-003 | $UO_3 \cdot 2H_2O$ | $UO_2$, $SiO_2$ | $UO_4 \cdot 4H_2O$, U |
| JP-PAC-004 | $UO_3 \cdot 2H_2O$, $UO_2$ | $SiO_2$, U | $UO_4 \cdot 4H_2O$ |
| JP-PAC-005 | $UO_3 \cdot 2H_2O$ | $UO_4 \cdot 4H_2O$ | $UO_2$, $SiO_2$, U |
| JP-PAC-006 | $UO_3 \cdot 2H_2O$ | $UO_2$, $SiO_2$ | $UO_4 \cdot 4H_2O$, U |
| JP-PAC-007 | $UO_3 \cdot 2H_2O$, $UO_2$, $SiO_2$ | U | $UO_4 \cdot 4H_2O$ |
| JP-PAC-008 | $UO_3 \cdot 2H_2O$ | $UO_2$, $UO_4 \cdot 4H_2O$, $SiO_2$ | U |
| JP-PAC-009 | $UO_3 \cdot 2H_2O$, $SiO_2$ | $UO_2$, U | |
| JP-PAC-010 | $UO_3 \cdot 2H_2O$ | $UO_2$ | $UO_4 \cdot 4H_2O$, $SiO_2$, U |
| JP-PCR-001 | $UO_3 \cdot 2H_2O$ | $UO_4 \cdot 4H_2O$, $SiO_2$ | $UO_2$, U |
| JP-PCR-002 | $UO_3 \cdot 2H_2O$ | $UO_4 \cdot 4H_2O$, $SiO_2$ | $UO_2$, U |
| JP-PCR-003 | $UO_3 \cdot 2H_2O$ | $UO_2$, $UO_4 \cdot 4H_2O$, $SiO_2$ | U |
| JP-PCR-004 | $UO_3 \cdot 2H_2O$ | $UO_2$, $SiO_2$, U | $UO_4 \cdot 4H_2O$ |
| JP-PCR-005 | $SiO_2$, $UO_3 \cdot 2H_2O$ | $UO_2$, $UO_4 \cdot 4H_2O$, U | |
| JP-PCR-006 | $SiO_2$, $UO_3 \cdot 2H_2O$ | U | $UO_2$, $UO_4 \cdot 4H_2O$ |
| JP-PCR-007 | $UO_3 \cdot 2H_2O$, $UO_2$, $SiO_2$ | $UO_4 \cdot 4H_2O$, U | |
| JP-PCR-008 | $UO_3 \cdot 2H_2O$, $SiO_2$ | $UO_2$, $UO_4 \cdot 4H_2O$, U | |
| JP-PCR-009 | $UO_3 \cdot 2H_2O$ | $UO_2$, $UO_4 \cdot 4H_2O$ | $SiO_2$, U |
| JP-PCR-010 | $UO_3 \cdot 2H_2O$ | $UO_4 \cdot 4H_2O$, $SiO_2$, U | $UO_2$ |
| JP-PGR-001 | $UO_3 \cdot 2H_2O$ | $UO_2$, $SiO_2$ | $UO_4 \cdot 4H_2O$, U |
| JP-PGR-002 | $UO_3 \cdot 2H_2O$, $SiO_2$ | $UO_2$, $UO_4 \cdot 4H_2O$ | U |
| JP-PGR-003 | $UO_3 \cdot 2H_2O$, $SiO_2$ | $UO_2$, $UO_4 \cdot 4H_2O$ | U |
| JP-PGR-004 | $SiO_2$, $UO_3 \cdot 2H_2O$ | $UO_4 \cdot 4H_2O$, U | $UO_2$ |

The ICDD numbers of the phases are $UO_3 \cdot 2H_2O$ (43-364), $UO_2$ (41-1422), $UO_4 \cdot 4H_2O$ (49-1821), $SiO_2$ (46-1045), and U (11-628).

SEM was used to collect the bulk chemistry to aid in the determination of the phases present using a Hitachi High-Technologies Corporation S-4500 scanning electron microscope (SEM) with associated EDAX Inc. energy dispersive spectrometer (EDS). EDS analysis is based on characteristic X-rays that are produced by the SEM beam/specimen interaction. The elements that can be analyzed using EDS are boron through uranium. The accuracy and resolution of the EDS was checked using standards and procedures outlined in "MCL-7708: MCL Electron Microscopy Operation Guide." All EDS spectra are included in Appendix F.

Table 6-32 summarizes the SEM-EDS characterization of the penetrator corrosion products. The major elements present in each sample are uranium (U) and oxygen (O). Silicon (Si) also was present in

**Table 6-32. EDS Characterization Results Summary for the Penetrator Samples Jefferson Proving Ground, Madison, Indiana**

| Penetrator ID | EDS Results Major Elements | EDS Results Minor Elements | EDS Results Trace Elements |
|---|---|---|---|
| JP-PAC-001 | U, O | Si | Al, Ca, Ti, Fe |
| JP-PAC-002 | U, O | Si | Al, Ti |
| JP-PAC-003 | U, O, Si | | Al, Ti, Fe |
| JP-PAC-004 | U, O | Si | Al, Ti |
| JP-PAC-005 | U | O | Si, Al, Ti |
| JP-PAC-006 | U, O | Si | Al, Ti |
| JP-PAC-007 | U, O | Si | Al, Ti |
| JP-PAC-008 | U, O | Si | Ca, Al, Ti |
| JP-PAC-009 | U, O, Si | Al | Ti, Fe |
| JP-PAC-010 | U | O | Si, Al |
| JP-PCR-001 | U, O | Si | Mg, Al, Ti, Fe |
| JP-PCR-002 | U, O | Si | Mg, Al, Ca, Ti, Fe |
| JP-PCR-003 | U, O | Si | Al, Ti |
| JP-PCR-004 | U, O | Si | Al, Ca, Ti, Fe |
| JP-PCR-005 | U, O, Si | Al | Ca, Ti, Fe |
| JP-PCR-006 | U, O, Si | Al | Mg, Ca, Ti, Fe |
| JP-PCR-007 | U, O | Si | Al, Ti, Fe |
| JP-PCR-008 | U, O, Si | Al | Ca, Ti, Fe |
| JP-PCR-009 | U | O | Si |
| JP-PCR-010 | U, O | Si | Mg, Al, Ca, Ti |
| JP-PGR-001 | U, O | Si | Al, Ti |
| JP-PGR-002 | U, O | Si | Al, Ca |
| JP-PGR-003 | U, O, Si | Al | Fe |
| JP-PGR-004 | U, O, Si | Al | Ca, Ti, Fe |

Note: The carbon peak (C) in the spectra is from the substrate.

the samples as a major or minor component. Minor and trace elements also present were aluminum (Al), magnesium (Mg), calcium (Ca), titanium (Ti), and iron (Fe). EDS spectra from the bulk samples are consistent with the identified XRD patterns.

XPS was used to examine the uranium speciation/phase with a Physical Electronics, Inc. photoelectron spectrometer for this investigation. This was accomplished by performing a detailed multiplex run in the binding energy region where electrons are released from the uranium 4f7 orbitals. This was conducted after a 20-second argon ion sputter to remove the oxidized surface and expose the bulk material for analysis. Each sample was mounted on a gold-coated sample mount. The gold signal then was used as an internal standard to correct the binding energy values for charging. The National Institute of Standards and Technology (NIST) standard XPS database then was used to determine the phases present in the samples. The XPS spectra are included in Appendix F.

Table 6-33 summarizes the XPS characterization of the penetrators. The major phases were determined by the binding energy and standard values from the NIST database. For each sample, the peak width of the 4f7/2 signal was 2 electron volts (eV) or greater, demonstrating that the uranium was composed of two or more phases. After curve fitting with two components, it was determined that each sample contained a mixture of uranium in the +6 and +4 oxidation states with good matches to a mixture of uranium trioxide ($UO_3$) and $UO_2$. No uranium metal was detected, which would produce a signal in the vicinity of 377 eV. There was a small shoulder on some samples at binding energies greater than 382 eV, which could be assignable to uranium peroxide ($UO_4$). Note that the large peak at 388 eV is a signal associated with the 4f5/2 orbital.

**Table 6-33. XPS Characterization Results Summary for the Penetrator Samples Jefferson Proving Ground, Madison, Indiana**

| Penetrator ID | Uranium Compounds Detected | Compound Match NIST Database |
|---|---|---|
| JP-PAC-001 | ≥2 | $UO_3$,$UO_2$ |
| JP-PAC-002 | ≥2 | $UO_3$,$UO_2$ |
| JP-PAC-003 | ≥2 | $UO_3$,$UO_2$ |
| JP-PAC-004 | ≥2 | $UO_3$,$UO_2$ |
| JP-PAC-005 | ≥2 | $UO_3$,$UO_2$ |
| JP-PAC-006 | ≥2 | $UO_3$,$UO_2$ |
| JP-PAC-007 | ≥2 | $UO_3$,$UO_2$ |
| JP-PAC-008 | ≥2 | $UO_3$,$UO_2$ |
| JP-PAC-009 | ≥2 | $UO_3$,$UO_2$ |
| JP-PAC-010 | ≥2 | $UO_3$,$UO_2$ |
| JP-PCR-001 | ≥2 | $UO_3$,$UO_2$ |
| JP-PCR-002 | ≥2 | $UO_3$,$UO_2$ |
| JP-PCR-003 | ≥2 | $UO_3$,$UO_2$ |
| JP-PCR-004 | ≥2 | $UO_3$,$UO_2$ |
| JP-PCR-005 | ≥2 | $UO_3$,$UO_2$ |
| JP-PCR-006 | ≥2 | $UO_3$,$UO_2$ |
| JP-PCR-007 | ≥2 | $UO_3$,$UO_2$ |
| JP-PCR-008 | ≥2 | $UO_3$,$UO_2$ |
| JP-PCR-009 | ≥2 | $UO_3$,$UO_2$ |
| JP-PCR-010 | ≥2 | $UO_3$,$UO_2$ |
| JP-PGR-001 | ≥2 | $UO_3$,$UO_2$ |
| JP-PGR-002 | ≥2 | $UO_3$,$UO_2$ |
| JP-PGR-003 | ≥2 | $UO_3$,$UO_2$ |
| JP-PGR-004 | ≥2 | $UO_3$,$UO_2$ |

The XRD, SEM-EDS, and XPS characterization results showed that the corrosion products consisted of primarily hydrated $UO_3$ and $UO_2$. Uranium metal and a third phase, hydrated $UO_4$, also were present at minor or trace quantities. Other materials present could be assigned to materials from the soil such as $SiO_2$, Al, Mg, Ca, Ti, and Fe.

The three penetrators selected for the leachability/corrosion testing were JP-PAC-005, JP-PCR-008, and JP-PGR-001. Based on this characterization study, these penetrators are acceptable because they are representative of the 24 samples with each having the hydrated $UO_3$ and $UO_2$ phases and the uranium metal plus hydrated $UO_4$ phase.

### 6.2.8.2 DU Penetrator Leachability Testing

Initially, six penetrator segments were prepared, two each cut from three penetrators (JP-PAC-005, JP-PCR-008, and JP-PGR-001). Three segments were used "as-is," without scraping the exterior surface, and three segments were scraped to remove bulk corrosion product from the exterior surface. Soils from three background locations (designed AC, CR, GR, for Avonburg/Cobbsfork, Cincinnati/Rossmoyne, and Grayford/Ryker) also were received by MCLinc. The background soils were collected at least 3 mi from the DU Impact Area. Each soil was mixed separately to provide three homogeneous samples from each location. A scraped penetrator segment was placed in 1 kilogram (kg) of soil from each location in a humidity cell and an "unscraped" (as-received) segment was likewise placed in 1 kg of soil from each location, resulting in six humidity cells that contained a penetrator segment and 1 kg of soil. A seventh humidity cell contained only 1 kg of Avonburg/Cobbsfork soil without a penetrator segment. The recorded initial mass of penetrator includes a relatively small contribution of adherent corrosion product, considered inconsequential for mass balance purposes. The initial masses of soils and penetrators are listed in Table 6-34.

**Table 6-34. Test Cell Preparation for Leachability Test**
**Jefferson Proving Ground, Madison, Indiana**

| Cell Number | Soil Type | Penetrator Segment ID No. (location/condition) | Initial Mass of Soil (g) | Initial Mass of Penetrator (g) |
|---|---|---|---|---|
| 1 | Avonburg/Cobbsfork | JP-PAC-005 (AC/Scraped) | 1,000.1 | 701.8 |
| 2 | Avonburg/Cobbsfork | JP-PAC-005 (AC/Unscraped) | 1,001.4 | 623.5 |
| 3 | Cincinnati/Rossmoyne | JP-PCR-008 (CR/Scraped) | 1,000.2 | 577.1 |
| 4 | Cincinnati/Rossmoyne | JP-PCR-008 (CR/Unscraped) | 1,000.3 | 620.2 |
| 5 | Grayford/Ryker | JP-PGR-001 (GR/Scraped) | 1,000.5 | 583.1 |
| 6 | Grayford/Ryker | JP-PGR-001 (GR/Unscraped) | 1,000.1 | 526.4 |
| 7 | Avonburg/Cobbsfork | No penetrator segment | 1,000.4 | 0 |

The simulated weathering cycles followed the ASTM Standard Test Method for Laboratory Weathering of Solid Materials Using a Modified Humidity Cell, D5744-96 (Reapproved 2001). This procedure: 1) enhances reaction product transport in the aqueous leach of a solid material sample of specified mass, and 2) measures rates of weathering-product mass release. The weathering protocol selected simulates the effect of DU weathering in the vadose zone, including periodic intervals of short-term rainfall flooding, and is believed to be more aggressive than weathering induced by actual field metrological conditions. The native soil utilized in this testing includes viable indigenous microbes, so that it was unnecessary to inoculate the solids with *Thiobacillus ferroxidans* (as suggested in the appendix to D5744-96 for testing versus barren rock ore).

The apparatus for this testing is illustrated in Figure 6-33. Following the ASTM D5744 method, the simulated weathering cycle started with an initial water leach. That is, the very first activity after loading the penetrator segments and soil into the humidity cells was to add water to each cell so as to cover the surface of the soil several inches deep in water. In all cases, approximately 900 grams (g) of site rainwater was added to each cell for this purpose. The rain water used was collected from JPG. The as-received rain water had pH value of approximately 5 and correspondingly low total (bicarbonate) alkalinity (approximately 0.5 milligram per liter [mg/L], expressed as calcium carbonate [$CaCO_3$]).

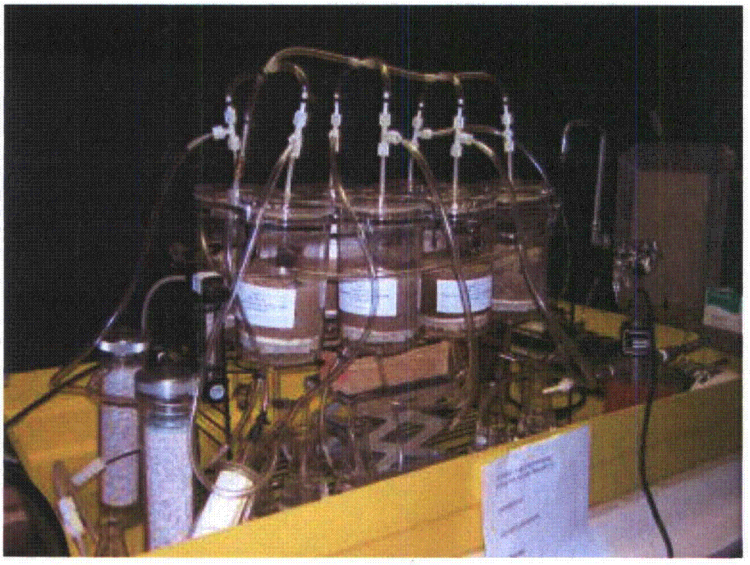


**Figure 6-33. Weathering Apparatus During a Dry Cycle (Courtesy MCLinc)**

After water was added to each cell, the water was allowed to remain in each cell for 3 hours, and then the plug was removed from the bottom of each cell to allow all of the water to drain directly into tared (i.e., pre-weighed) and labeled collection bottles. The seven cells were allowed to drain for 69 hours after opening the drain plugs. The collected water was submitted for total/isotopic uranium analysis. Each cell was re-weighed to record a weight for each wet cell. Then, the dry air manifold was connected to each cell and dry air was passed through each cell at a rate of >1 liter per minute (L/min) for 9 days. Following the dry air cycle, each cell was removed again and re-weighed. All seven cells then were connected to the wet air manifold and wet air was flowed through each cell at >1 L/min for 9 days. After 9 days of the wet air treatment, each cell was re-weighed and approximately 900 g of water was added to each cell to start the next leach cycle. This simulated weathering cycle was repeated numerous times, resulting in 23 leachate sample sets. That is, the initial leachate collection was numbered "00" and the last leachate collection, which followed the 22$^{nd}$ dry air/wet air/leach cycles, was numbered "22" for a total of 23 leachate collection sets with 7 water samples per each collection set. Figure 6-34 illustrates a penetrator segment placed in an accelerated leach testing apparatus cell. The soil containment cell dimensions are approximately 11.7 cm (inside diameter) by 20.5 cm (depth).


**Figure 6-34. Embedded Penetrator Segment in Cell #1 After Drying Cycle (Courtesy MCLinc)**

The uranium oxide phases identified on as-found site corrosion rind were $UO_2$ (uraninite) and $UO_3 \cdot 2H_2O$ (schoepite) as major phases and $UO_4 \cdot 4H_2O$ (uranyl peroxide or studtite) as the minor phase. Whereas uraninite is relatively insoluble, the more oxidized species such as schoepite and studtite should exhibit moderate, pH-dependent, solubility in oxic water. Studtite (uranyl peroxide hydrate) and/or metastudtite (partially dehydrated studtite) are likely produced as very minor phases due to alpha radiolysis of water that forms the peroxide reagent (Douglas et al. 2005, Rey et al. 2009). Studtite and metastudtite have been identified at other sites as an alteration product in casks of spent nuclear fuel (Douglas et al. 2005, Young et al. 2006).

Figure 6-35 illustrates an optical image for a polished cross-section of an as-received penetrator dart segment, which has been embedded in epoxy resin. It shows a thin (~ 1 to 2 millimeter [mm]) rind of corrosion products – a dark gray, near-surface zone (assumed to be predominantly $UO_2$), overlain by a yellow, highly fluorescent material (schoepite). The corrosion products also are encased in an adherent accretion of soil minerals, which likely also serve as a physical barrier to the corrosion and subsequent leaching phenomena. Brock (2003) concludes in her study of DU from an arid site that uranium precipitates as aggregates of tabular, hexagonal schoepite-metaschoepite crystals with silicate clay/silt particles, coated with amorphous silica, and so dissolved uranium does not move quickly and is probably inhibited by the adherent silicate coatings.

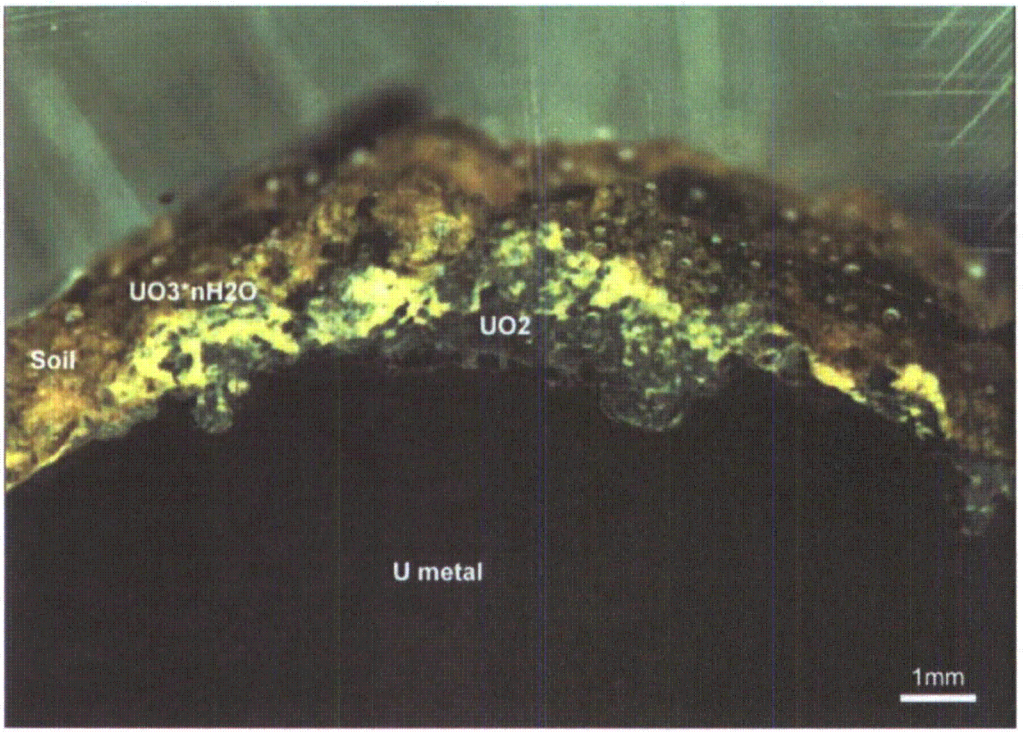



**Figure 6-35. Optical Microscopic Image for Polished Cross-Section of Segment From JP-PAC-005 (Courtesy MCLinc)**

Examination of dry corrosion products on penetrator segments at the conclusion of the accelerated leach study identified meta-schoepite, equivalent to $UO_3 \cdot nH_2O$ (with n <2), yellow, and trace uraninite ($UO_2$), black, as the dominant uranium-bearing phases, as shown in Figure 6-36. Thus, the mineralogy of corrosion products induced during the accelerated weathering procedure is essentially the same as those identified as present on the as-received specimens.

Samples of crushed corrosion products as previously prepared for XRD analysis were examined by the surface-selective technique of XPS. This technique can differentiate between reduced forms of tetravalent uranium ($U^{+4}$) and oxidized hexavalent uranium forms ($U^{+6}$). As Burns (1999) notes, uraninite is probably always at least partially oxidized in nature, especially at the near-surface. Prepared specimens of corrosion scrapings were briefly subjected to argon ion milling, to clean the surfaces (e.g., removing the ubiquitous superficial oxidized uranium from reduced phases such as uraninite [$UO_2$] so that the recorded composition more nearly approximates the bulk phase [Nelson et al. 2003]). In general, the uranium valence state distributions for near-surface corrosion products are similar for as-received and post-weathering specimens (with approximately two-thirds as oxidized $U^{+6}$ and one-third as reduced $U^{+4}$).

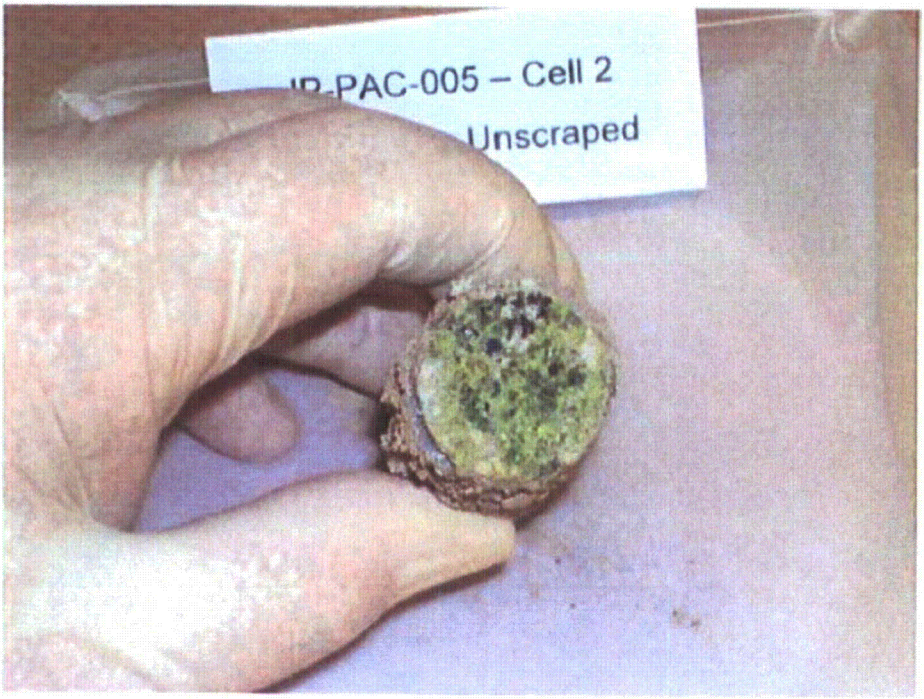



**Figure 6-36. End-View Photograph of Unscraped Segment from JP-PAC-005 (Courtesy MCLinc)**

The post-weathering estimates of uranium valance states show less variability than did the original (as-found) specimens.

#### 6.2.8.3 Sequential Extraction of Soils from the Leachability Tests

Sequential extraction (SE) is often used for evaluating low-level radionuclide partitioning in soils and sediments. This methodology applies operationally defined chemical treatments to selectively dissolve specific classes of macro-scale soil or sediment components (e.g., Tessier et al. 1979). These methods recognize that total soil metal inventory is of limited use in understanding bioavailability or metal mobility, and that it is useful to estimate the amount of metal present in different solid-phase forms.

Many recent studies published in the technical literature have used a selected sequence of extractions from the soil matrix, with each successive lixivant solution increasing in its aggressiveness. The results of these sequential extractions (or "fractionation") often allow a comparison of how tenaciously different metal contaminants partition to different soil and sediment compositions. The partitioning of contaminants to different geochemical fractions is related to the contaminant speciation (or chemical form), as well as other physiochemical factors. Metals deemed least mobile in soil have a relatively small proportion of the total associated with the most readily accessible (or "exchangeable") fraction while having the greatest proportion associated with the most refractory (or "residual") fraction. Metals in the residual fraction are typically locked up within refractory crystalline mineral phases and are not readily accessible to leach into the environment except on an extended time scale.

SE by a modified Tessier protocol has attracted attention as an operational means to aid in the assessment for the potential risk of DU penetrator shards left in war zones, such as the Balkans and the Middle East (e.g., Oliver et al. 2008, Radenković et al. 2003). Details of the modified Tessier SE

procedure performed at MCLinc are presented in Appendix F. The sequence of extractions, and the attributed geochemical components affected, is briefly described below:

- Fraction 1: Exchangeable cations (magnesium chloride lixiviate, pH approximately 7)
- Fraction 2: Carbonate-bound metals (acetate reagent, pH approximately 8.2)
- Fraction 3: Metals associated with hydrous iron- and manganese-oxides (hydroxylamine-acetate reagent)
- Fraction 4: Bound to organic matter (acid and hydrogen peroxide reagent).

For the purpose of mass balance calculations, it is also necessary to determine the total environmentally available metal inventory. Aliquots of the selected soil samples (less than 2 mm size fraction) were extracted in accordance with USEPA Method 3050B. This digestion method, which uses strong nitric acid and hydrogen peroxide, recovers most of the environmentally available heavy metal content, but it does not recover metals locked within a refractory crystalline matrix.

Because the residual fraction is not considered to be available for release to the environment on the time scales of interest, it was not necessary to quantitate this fraction for the purposes of this study. Instead, the proportion of residual metal was estimated by mass balance (i.e., by computing the difference between the total environmentally available metal inventory and the sum of inventories from extraction Fractions 1 through 4).

Inductively coupled plasma-optical emission spectrometry (ICP-OES) is used to quantitate U in soil extract. Results from the sequential extraction of the soils used in the test cells are listed in Table 6-35. By the end of the accelerated soil leaching procedure, the drained soils leached in the presence of penetrator segments (referred to as Cells #1 through #6 in the table) were in contact with aqueous phase containing soluble U at approximately 10 mg/L, largely from dissolution of schoepite (nominally $UO_3 \cdot 2H_2O$) from the surface of the penetrator. Consistent with other investigations of U-contaminated soils (UNEP 2003), most of the test cell soils had the greatest proportion of U in the carbonate and iron/manganese hydrous oxide fractions, with the latter usually predominant.

**Table 6-35. Results From the Sequential Extractions for Uranium in the JPG Test Cells**

| Fraction | Cell #1 Soil (A/C) | | Cell #2 Soil (A/C) | | Cell #3 Soil (C/R) | | Cell #4 Soil (C/R) | | Cell #5 Soil (C/R) | | Cell #6 Soil (C/R) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg/kg | % | mg/kg | % | mg/kg | % | mg/kg | % | mg/kg | % | mg/kg | % |
| Exchangeable | 126 | 9% | 34 | 4% | 211 | 13% | 212 | 11% | 140 | 10% | 133 | 5% |
| Carbonate-Bound | 439 | 30% | 175 | 19% | 438 | 26% | 427 | 22% | 419 | 29% | 463 | 17% |
| Fe/Mn Hydrous Oxide | 739 | 51% | 324 | 36% | 115 | 7% | 629 | 32% | 712 | 48% | 982 | 36% |
| Organic Matter | 80 | 6% | 56 | 6% | 629 | 37% | 123 | 6% | 88 | 6% | 96 | 4% |
| Residual* | 66 | 5% | 313 | 35% | 287 | 17% | 569 | 29% | 111 | 8% | 1,036 | 38% |
| Total | 1,450 | 100% | 902 | 100% | 1,680 | 100% | 1,960 | 100% | 1,470 | 100% | 2,710 | 100% |

* Calculated value (see discussion in text)
A/C = Soil type Avonburg/Cobbsfork, C/R = Soil type Cincinnati/Rossmoyne

The surface complexation reaction of uranyl with iron oxyhydroxide minerals (e.g., goethite) has been shown to have a significant impact on migration of uranium in soil (Sherman, Peacock, and Hubbard 2008). However, formation of uranyl complexes with organic components of the soil also has been found to be important; for example, Oliver et al. (2006) used SE to identify the dominance of organic matter in controlling migration and bioavailability of DU in near-surface soils.

### 6.2.8.4 Corrosion-Dissolution Rate

The soils in the test cells were analyzed to determine the total mass of DU residing in the soil at the end of the leachability tests. When this mass is added to the mass of DU in the leachate, the resulting total represents the total mass of DU corrosion products that dissolved from the surface of the penetrator during the tests. Dividing this mass by the estimated surface area of the penetrator and the duration of the testing period gives the net dissolution rate in grams per square centimeter per year ($g/cm^2$-yr).

Table 6-36 lists the mass of DU in the soil and leachate, the estimated surface area of the penetrator, and the calculated dissolution rate. As shown in the table, the calculated dissolution rate was relatively consistent across the six test cells, ranging from a minimum value of 0.0084 $g/cm^2$-yr to a maximum value of 0.0285 $g/cm^2$-yr, with most values clustered around 0.017 $g/cm^2$-y. The numerical average of the six dissolution rate is approximately 0.018 $g/cm^2$-y. This value is considerably smaller than the conservatively estimated value of 0.15 $g/cm^2$-y used in the DU transport and dose models described elsewhere in this report and the accompanying appendices. (See Section 5 of Appendix C for a derivation of the assumed corrosion-dissolution rate used in these analyses.) This provides further evidence that the analyses of environmental and human health impacts described in this report are likely to significantly overestimate the true impacts of the DU at JPG.

**Table 6-36. Estimated Dissolution Rate of Uranium Corrosion Products Over the 1.3-Year Testing Period**

| Soil Type | Description | Penetrator | Original Mass (g) | Uranium Inventory Lost (g) | | | Nominal Surface Area ($cm^2$) | Mass Loss Rate ($g/cm^2$yr) |
|---|---|---|---|---|---|---|---|---|
| | | | | Aqueous | Soil | Total | | |
| PAC | Cell #1 Soil | Scraped | 701.8 | 0.05 | 1.71 | 1.75 | 80.18 | 0.0172 |
| PAC | Cell #2 Soil | Unscraped | 623.5 | 0.04 | 0.73 | 0.77 | 72.35 | 0.00844 |
| PCR | Cell #3 Soil | Scraped | 577.1 | 0.04 | 1.43 | 1.47 | 65.71 | 0.0177 |
| PCR | Cell #4 Soil | Unscraped | 620.2 | 0.04 | 1.49 | 1.54 | 72.02 | 0.0168 |
| PGR | Cell #5 Soil | Scraped | 583.1 | 0.03 | 1.60 | 1.63 | 68.31 | 0.0188 |
| PGR | Cell #6 Soil | Unscraped | 526.4 | 0.02 | 2.25 | 2.27 | 62.64 | 0.0285 |
| *Average* for Cells #1 through #6 | | | 605.4 | 0.04 | 1.54 | 1.57 | 70.20 | 0.0179 |

### *6.2.9 USGS Age Dating Study*

During 2007 and 2008, USGS, in cooperation with the U.S. Department of the Army, conducted a study to evaluate the relative age of groundwater in Pre-Wisconsinan till and underlying shallow and deep carbonate bedrock units in and near the DU Impact Area (Buszka, Lampe, and Egler 2010). The shallow carbonate unit includes about the upper 40 ft of bedrock below the bedrock-till surface; the deeper carbonate unit includes wells completed at greater depth. Samples collected during April 2008 from 15 wells were analyzed for field water quality parameters, dissolved gases, tritium, and chlorofluorocarbon (CFC) compounds; samples from 14 additional wells were analyzed for tritium only.

Water level gradients in the Pre-Wisconsinan till and the shallow carbonate unit were from topographically higher areas toward Big Creek and Middle Fork Creek, and their tributaries. Vertical gradients were strongly downward from the shallow carbonate unit toward the deep carbonate unit at three of four paired wells where water levels recovered after development, indicating the general lack of flow between the two units. The lack of post development recovery of water levels at four other wells in the deep carbonate unit indicated that parts of that unit have no appreciable permeability.

CFC and tritium-based age dates of Pre-Wisconsinan till groundwater are consistent with infiltration of younger (typically post-1960 age) recharge that "mixes" with older recharge from less permeable or less interconnected strata. Part of the recharge to three till wells dated from the early to mid-1980s (JPG-DU-03O, JPG-DU-09O, and JPG-DU-10O). Age dates of young recharge in water from

two till wells predated 1980 (JPG-DU-04O and JPG-DU-06O). Tritium-based age dates of water from seven other till wells indicated post-1972 age recharge. Most wells in the Pre-Wisconsinan till have the potential to produce groundwater that partially was recharged during or after DU penetrator testing; their water quality can indicate the presence of DU-related contaminants.

The shallow carbonate unit near Big Creek is a karst flow system that may be recharged in part from areas with smaller thicknesses of overlying till or through more permeable parts of the till. This is indicated by CFC- and tritium-based piston-flow (nonmixing) model age dates of early-1980s for water from JPG-DU-02I, similar tritium-based ages of water produced from nearby wells MW-5 and MW-11, and cave development along the creek. The CFC- and tritium-based age dates indicate that water samples from JPG-DU-01I and JPG-DU-03I were best described as mixtures of post-1984 modern recharge and submodern (1953 or older) recharge. These five wells produced groundwater that was recharged, at least partially, during or after DU-penetrator testing and are within or downgradient from the DU Impact Area with respect to groundwater flow directions inferred from water-level contours. Wells with groundwater age dates that are near or after the onset (1984) of DU penetrator testing and that have a plausible connection to a contaminant source can be used to indicate the presence or absence of contaminants from DU penetrator or DU-related corrosion products in groundwater.

Groundwater-age dates indicate that the ages of recharge sampled from shallow carbonate unit wells JPG-DU-04I, JPG-DU-05I, JPG-DU-06I, JPG-DU-09I, and JPG-DU-10D in easternmost (upgradient) and southernmost wells in the shallow carbonate unit are submodern (1953 or older) and predate the DU testing by at least 30 or more years. Water quality data from these five wells are not likely to represent effects from DU projectile testing or corrosion for years.

Well JPG-DU-09D in the deep carbonate unit produced groundwater samples with a submodern (1953 or older) age date. The slow recovery of water levels in most wells in the deep carbonate unit is consistent with slow rates of groundwater flow and very old groundwater ages in that unit.

### 6.2.10 $K_d$ Study

The distribution coefficient ($K_d$) value represents the degree to which a chemical will attach or partition to the geologic matrix during transport in surface water or groundwater. The $K_d$ value is integral to accurate determination of the rate a chemical travels through geologic media relative to the rate of groundwater advection or flow and, therefore, is an important site-related input parameter for contaminant modeling. Values for $K_d$ vary greatly between contaminants and also as a function of aqueous and solid phase chemistry and can fluctuate over six orders of magnitude because they are "a lumped parameter representing a myriad of processes" (NRC 2006a). As a result, NRC encourages licensees to perform site-specific $K_d$ determination when values could be overly conservative or under protective. Development of site-specific $K_d$ values is also the approach recommended by USEPA (1999).

The Army agreed to research and develop site-specific $K_d$ values for applicable geologic substrates in the DU Impact Area. The rationale and procedural basis for the Army's $K_d$ study were developed collaboratively with NRC, culminating in a final design agreed to by NRC on 2 November 2011. The design of the study was based on the detailed understanding of the hydrogeologic setting of JPG and the methods presented in ASTM Method C1733-10, Standard Test Method for Distribution Coefficients of Inorganic Species by the Batch Method (ASTM 2010). Representative soil and aqueous contact solution samples were collected for the $K_d$ study in late March 2012. The batch method analysis of samples over time for uranium occurred from May 2012 to February 2013.

A report in Appendix D presents background on the environmental fate of DU and the $K_d$ term in general. The rationale, design, timing, and implementation of the $K_d$ study are presented. Lastly, results of the $K_d$ study are presented and discussed, with recommended ranges of $K_d$ values presented for use during DU transport simulations.

Clearly, batch results for loess soils indicate a strong potential for DU sorption, whether the processes driving that distribution are partitioning or mineral precipitation/coprecipitation under oxidizing conditions, mineral precipitation under reducing conditions, or a seasonally varying combination of all. With respect to the unsaturated till, given its similar textural and inferred clay mineral composition as loess soils and the weathering or leaching removal of original carbonate, the partitioning potential, or $K_d$ values, should be similar to the loess soils. Once saturated, the influence of the older, more alkaline, mineralized groundwater appears to significantly limit DU partitioning potential, or conversely promotes DU mobilization.

These final $K_d$ values were further statistically analyzed via computer software (ProUCL) to evaluate data in terms of central tendencies by soil type or group and to define, with good statistical certainty, $K_d$ values for input into the other computer models that will simulate DU transport and fate along the various relevant pathways identified in the CSM for the DU Impact Area. Results of the statistical analysis indicate the loess soil sorption $K_d$ value population is normally distributed, at a 0.05 significance level, about a raw mean of 2,044 milliliter per gram (mL/g) between minimum and maximum values of 57 and 4,470 mL/g, with a standard deviation of 1,033 mL/g. The glacial till $K_d$ values also were found to be normally distributed, at a 0.05 significance level, about a raw mean of 8.4 mL/g between minimum and maximum values of 0.93 and 20 mL/g, with a standard deviation of 8.5 mL/g. Finally, the mean of the loess desorption-dissolution values was 429 mL/g, with minimum and maximum values of 189 and 591 mL/g and a standard deviation of 212 mL/g.

Having established the normal bounds of the $K_d$ values within a statistical degree of certainty for each test group, weighted average $K_d$ values then were calculated according to the surface area of respective soils in the DU Impact Area to further connect laboratory determined and plating corrected $K_d$ values to probable DU partitioning potential in the DU Impact Area.

Figure 6-37 shows standard penetration test total blow counts with depth at DU Impact Area monitoring well JPG-DU-06D to illustrate the typical depth profiles of loess and glacial till and depths to rock and groundwater in the DU Impact Area. The figure serves to show conceptually the distribution of $K_d$ values for the different geologic media and locations important for DU migration and subsequent transport simulation using Residual Radiation (RESRAD)-Offsite Version 2.6 (Yu et al. 2010), as follows:

- ***Contaminated Zone (0 to 1 m BGS):*** 354 mL/g, which is an equivalent $K_d$ determined from the weighted average of loess soil desorption-dissolution tests
- ***Vadose Zone 1 Base of Loess Soil (1 to 2.3 m BGS):*** 2,116 mL/g, which is the weighted average for the three loess soil groups determined from sorption tests
- ***Vadose Zone 2 – Top of Till (2.3 to 6 m BGS):*** 2,123 mL/g, which is the weighted average for the loess soils and till combined from the sorption tests
- ***Saturated Till (6m +):*** 6 mL/g, which is the weighted average from the till sorption tests.

## 6.3 ECOLOGICAL MONITORING

As shown in Tables 6-37 and 6-38, vegetation and animal sampling also was conducted (Ebinger and Hansen 1996a,b); however, the data set was not as complete as for the abiotic media. The reported data there do not appear to show an adverse impact on the vegetation and animals. One lichen sample indicated a high concentration, probably from DU in resuspended soil collecting on the lichen surface. Little uranium, either natural or from DU, was found to be present in deer, raccoon, and freshwater clam tissue samples.

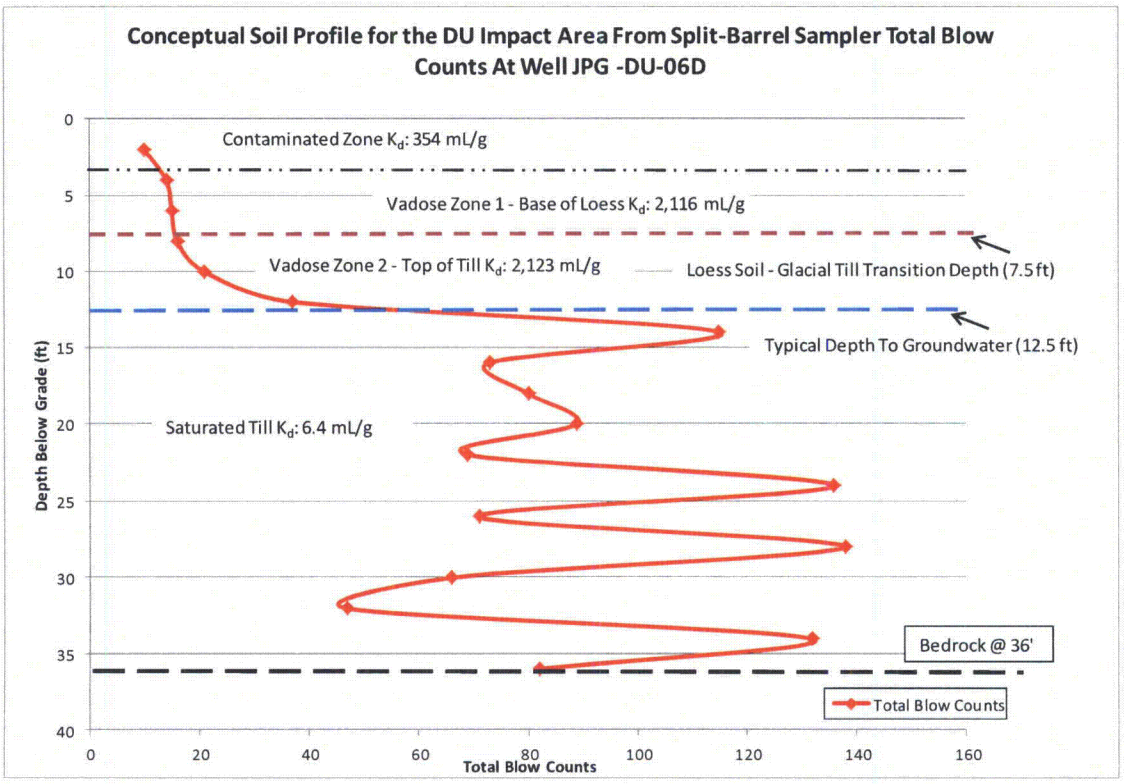



**Figure 6-37. Conceptual Soil Profile Showing Variation of $K_d$ Values in Loess Soils and Till**

**Table 6-37. Scoping Survey Sample Results Jefferson Proving Ground, Madison, Indiana**

| Sample Location | Number of Samples | Total Uranium Range in Concentration |
|---|---|---|
| **DU Impact Area and Environs** Vegetation | 14 | 0.01-0.50 pCi/g |
| **Trajectory Locations** Vegetation | 6 | 0.06-0.65 pCi/g |

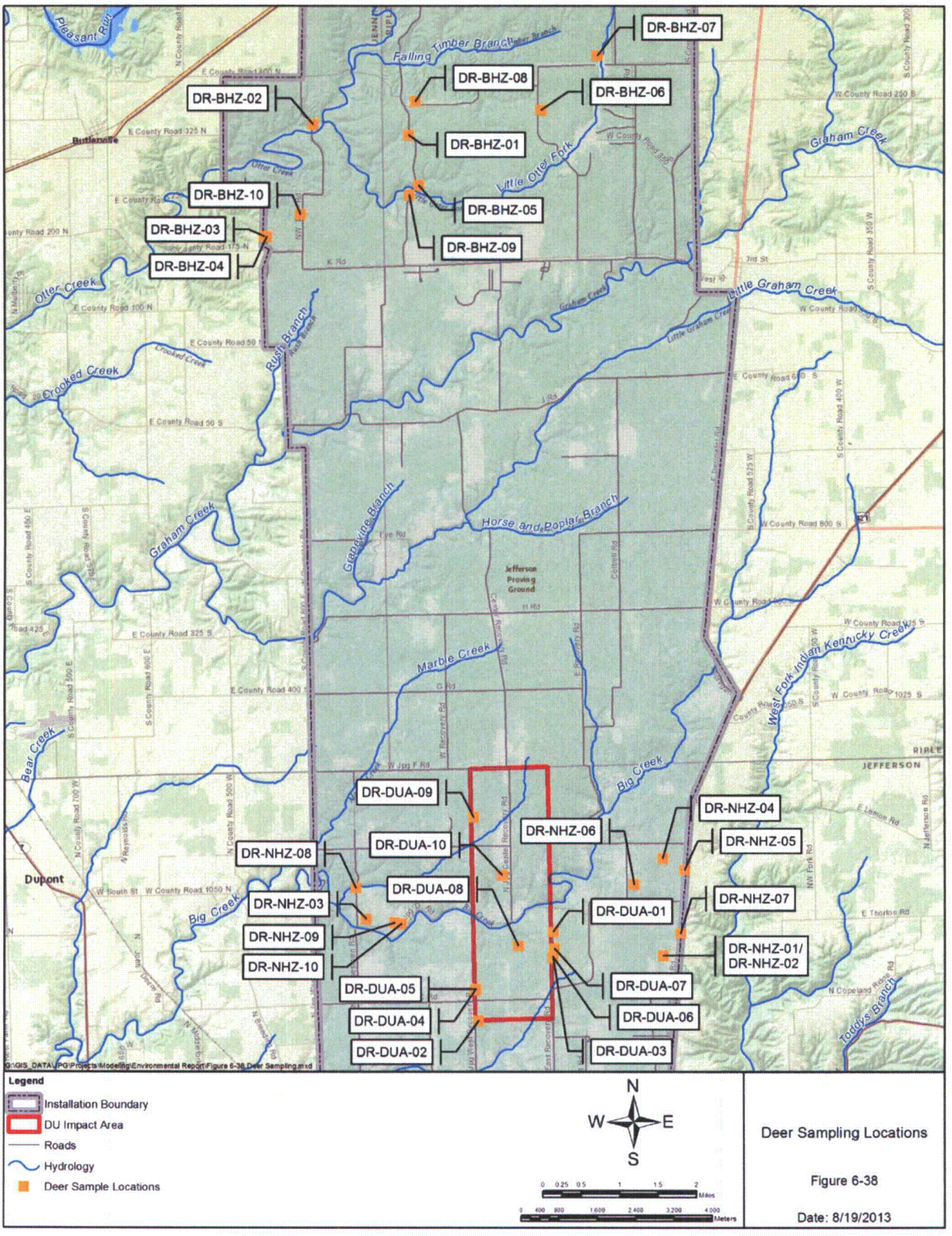
Source: Compiled from SEG 1995
DU = depleted uranium
pCi/L = picocuries per liter
pCi/g = picocuries per gram

## Table 6-38. Summary of Characterization Survey Results Jefferson Proving Ground, Madison, Indiana

| Environmental Medium/ Tissue Type | Number of Samples | Total Uranium | Average Concentration (pCi/g) |
|---|---|---|---|
| | | Range in Concentration (pCi/g) | |
| Vegetation | 10 | 17.0-3,447 | 627.5 |
| Vegetation Root Wash | 10 | 46.1-14,258 | 2,868.8 |
| Deer Liver | 1 | 0.091 | — |
| Deer Kidney | 1 | 0.151 | — |
| Deer Bone | 1 | 0.416 | — |
| Freshwater Clams | 1 | 0.774 | — |
| Freshwater Clams | 1 | 0.334 | — |
| Fish | 1 | 0.150 | — |
| Fish | 1 | 0.282 | — |
| Soft Shelled Turtle | 1 | 0.245 | — |

Source: Compiled from SEG 1996
— = Average not calculated for single sample result
BGS = below ground surface
pCi/g = picocuries per gram

Given that extensive hunting has taken place on JPG in areas outside DU and UXO exclusion zones; deer routinely use the habitat and cross the DU Impact Area; and the potential for ingestion and uptake of uranium by deer present on the installation; the Army implemented a comprehensive program to evaluate the uptake of uranium by deer present on the installation. The evaluation consisted of the collection and laboratory analysis of 132 tissue samples from 30 deer present on the installation with sample collection (Figure 6-38) taking place during the winter of 2005/2006. DU was not detected in any tissue sample during laboratory analysis. As such, the conclusion is drawn that uptake of uranium as a result of the intake of deer meat by hunters does not represent a potentially significant exposure pathway at JPG. This was substantiated through NRC testimony at the Administrative Hearing of 22 October 2007, which indicated that if all the beef in a person's diet were replaced by deer meat with the highest reading obtained from these 30 samples for a year, the increased exposure would be less than 1 mrem (Ridge 2007).


DR-BHZ-07
DR-BHZ-08
DR-BHZ-06
DR-BHZ-02
DR-BHZ-01
DR-BHZ-10
DR-BHZ-05
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DR-BHZ-09
DR-BHZ-04
DR-DUA-09
DR-NHZ-04
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DR-NHZ-05
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DR-NHZ-03
DR-NHZ-09
DR-NHZ-01/
DR-NHZ-02
DR-NHZ-10
DR-DUA-05
DR-DUA-07
DR-DUA-04
DR-DUA-06
DR-DUA-02
DR-DUA-03
Pleasant Run
Falling Timber Branch
Graham Creek
Little Otter Fork
Otter Creek
Little Graham Creek
Crooked Creek
Rush Branch
Grassyard Branch
Horse and Poplar Branch
Marble Creek
West Fork Indian Kentucky Creek
Bear Creek
Big Creek
Toddys Branch
Butlerville
Dupont
Jefferson Proving Ground
JEFFERSON
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Legend
Installation Boundary
DU Impact Area
Roads
Hydrology
Deer Sample Locations
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Deer Sampling Locations
Figure 6-38
Date: 8/19/2013

# 7. COST BENEFIT ANALYSIS

This section presents an analysis of the costs and benefits associated with the No Action alternative and Proposed Action. Both economic and environmental costs and benefits are considered. However, no long-term irreversible and irretrievable loss to the environmental resources is expected, so the following cost-benefit analysis focuses on the economics only.

The as low as reasonably achievable (ALARA) analysis is presented in Section 4.3 of the Decommissioning Plan (U.S. Army 2013a). The total ALARA cost for the major elements of remediation of the Jefferson Proving Ground (JPG) Depleted Uranium (DU) Impact Area to meet requirements for unrestricted use ranged from $2,500,000 to $11,000,000,000, as shown in Table 7-1. The ALARA costs are dominated by the direct costs for detection, removal, and disposition of the unexploded ordnance (UXO) and the DU-contaminated soil and penetrators/fragments.

**Table 7-1. Summary of Major Cost Elements of License Termination for Unrestricted Use Jefferson Proving Ground, Madison, Indiana**

| Remediation Activity | Estimate ($) |
|---|---|
| UXO and DU Remediation Cost[a] | 2,500,000-11,000,000,000 |
| Occupational and Public Radiological Exposure | 27-410,000 |
| Occupational Nonradiological Risk | 130-2,000,000 |
| Nonradiological Transportation Risk | 3,100-47,000,000 |
| Environmental Degradation | 0[b] |
| **Total[c]** | **2,500,000-11,000,000,000** |

[a] Cost breakdown presented in Table 4-2 of the Decommissioning Plan (U.S. Army 2013a).
[b] No environmental degradation costs are anticipated over the long-term.
[c] Total cost rounded to two significant figures.

This cost-benefit analysis was conducted to determine if the residual DU contamination in the DU Impact Area is consistent with the ALARA analysis. The ALARA analysis concluded that further reduction of residual radioactivity is prohibitively expensive based on the major costs elements (i.e., UXO clearance, radiological soil treatment, and transportation and disposal of low-level radiological waste [LLRW]). Even for a scenario created to remove the smallest amount of residual DU to meet unrestricted release requirements, the minimal, low-end UXO and DU remediation costs were prohibitively expensive. As shown in Section 4 of the Decommissioning Plan (U.S. Army 2013a), the cost-benefit ratio for this minimal remediation effort is 3.7 (i.e., ratios greater than 1 are considered prohibitively expensive; U.S. Nuclear Regulatory Commission Regulation [NUREG]-1757, Volume 2, Appendix N [NRC 2006b]).

## 7.1 ALTERNATIVE 1: LICENSE CONTINUATION (NO ACTION)

Although there would be institutional controls (e.g., continued Army ownership of the property north of the firing line, facility maintenance, site security) and continued Environmental Radiation Monitoring (ERM) costs associated with the No Action alternative, these costs are not estimated because the No Action alternative does not meet the U.S. Nuclear Regulatory Commission (NRC) regulatory requirements defined in Title 10 Code of Federal Regulations (CFR) Part 40, Section 42(d)(2) for license termination. Since the principal activities required by the Army's license termination ceased in 1994, the Army is required to terminate their NRC Materials License SUB-1435. In addition, most of the institutional controls currently in place also are a component of the Proposed Action. As such, the costs are considered in Section 7.2.

The economic and environmental benefits are described in Section 4. As described in Section 2.1.1, there are no benefits associated with the continuation of the ERM program for the following reasons:

- There have been no releases of DU outside of the DU Impact Area, as evidenced by ERM sampling that commenced in 1983 to ensure that DU does not pose a threat to human health and the environment through inadvertent or unanticipated release or migration.
- The results of Residual Radiation (RESRAD)-OFFSITE modeling for the next 1,000 years conclude that the total effective dose equivalents (TEDEs) for the average member of the critical group to residual DU are well below the dose limits for restricted release, as specified in 10 CFR 20.1403.
- The results of the fate and transport modeling utilizing the derived site-specific partition coefficient for JPG predict negligible amounts of DU reach groundwater and peak concentrations of DU in Big Creek and Middle Fork Creek surface water and sediment are low (i.e., surface water less than 5 µg/L and sediment less than 5 milligrams per kilogram [mg/kg]); therefore, there is no evidence of future threats from DU to human health and the environment through inadvertent or unanticipated release or migration.

The benefits associated with the No Action alternative are not expected to be significant and remain identical to the baseline conditions described in Section 3 and the Proposed Action described in Section 4.

## 7.2 ALTERNATIVE 2: LICENSE TERMINATION UNDER RESTRICTED CONDITIONS (PROPOSED ACTION)

The Army expects to incur approximately $268,000 annually for maintaining the institutional controls currently in place for the 50,950-acre (ac) (206-square kilometer [$km^2$]) area at JPG, as detailed in Section 2. Only a small fraction of the $268,000 is associated with the administrative controls, facility maintenance, and security associated with the 2,080-ac (8.4-$km^2$) DU Impact Area. Please note that these are the costs if the Army needs to carry out the functions of the Memorandum of Agreement (MOA) in the event that both the Indiana Air National Guard (INANG) and U.S. Fish and Wildlife Service (FWS) decide to terminate their respective agreements in the MOA. If one or both agencies remain, the costs to the Army would decrease, but the overall costs would remain the same.

Replacement of the installation security fence (55 miles [mi] [88 kilometers (km)] of 6-foot (ft) [2.11-meter (m)] chain-link fence topped with barbed wire surrounding the installation) may need to occur every 25 to 35 years based on discussions with fencing contractors in the Southern Indiana region. The periodic replacement of the installation security fence was not included in the annual institutional control costs above as it is unknown how often the fencing would need to be replaced for the foreseeable future. In 2013, the replacement of the installation security fence is estimated between $7,500,000 and $18,500,000. The estimate was generated using regional vendor information and Remedial Action Cost Engineering and Requirements (RACER™) version 11.1 (AECOM 2012) cost estimation software.

The economic and environmental benefits are described in Section 4. The benefits associated with the Proposed Action alternative are not expected to be significant and remain identical to the baseline conditions described in Section 3.

# 8. SUMMARY OF ENVIRONMENTAL CONSEQUENCES

This section summarizes the following environmental impacts, as applicable, for each of the alternatives:

- Unavoidable adverse environmental impacts
- Irreversible and irretrievable commitments of resources used in project construction, operation, and decommissioning
- Short- and long-term impacts
- Short-term uses of the environment and the maintenance and enhancement of long-term productivity.

## 8.1 NO ACTION ALTERNATIVE

Under the No Action alternative, which does not meet the U.S. Nuclear Regulatory Commission (NRC) regulatory requirements defined in Title 10 Code of Federal Regulations (CFR) Part 40, Section 42(d)(2) for license termination, the depleted uranium (DU) would remain as-is indefinitely and the Army would maintain an NRC materials license consistent with requirements in 10 CFR 40. The potential for unavoidable adverse environmental impacts appears minimal. The unavoidable commitments of resources include the Army maintaining their possession only materials license (e.g., Environmental Radiation Monitoring [ERM], inspections) or alternative (e.g., long-term control [LTC] license), but there does not appear to be any potential for future adverse impacts to public health and the environment for the No Action alternative.

## 8.2 LICENSE TERMINATION UNDER RESTRICTED CONDITIONS (PROPOSED ACTION)

This alternative would result in the long-term presence of the radioactively contaminated materials under the protective conditions offered by the terms of legally enforceable and durable institutional controls maintained in effect by the U.S. Army and agency of the Federal Government and an enduring entity. No unavoidable adverse environmental impacts were identified as natural onsite environmental conditions minimize the corrosion, dissolution, and transport of DU to average members of the critical group. Irreversible and irretrievable commitments of resources associated with this alternative include the commitment of approximately $268,000 for implementing institutional control costs at the Jefferson Proving Ground (JPG), as detailed in Appendix F of the Decommissioning Plan (U.S. Army 2013a). Short-term impacts are negligible because no construction is planned (e.g., noise, traffic levels, air emissions) and many of the legally enforceable controls have already been implemented (U.S. Army 2000a). Long-term impacts also are expected to be negligible based on modeling of future doses to the average member of critical groups as well as predicted concentrations of uranium in surface water and groundwater. There are no planned short- or long-term uses of the DU Impact Area nor are any maintenance activities planned to enhance long-term productivity other than U.S. Fish and Wildlife Service (FWS) prescribed burns. Enhancement activities would be difficult to implement given the presence of unexploded ordnance (UXO) and DU in the DU Impact Area. Table 8-1 summarizes the anticipated environmental consequences, actions to mitigate adverse impacts, and unavoidable adverse/irreversible and irretrievable commitments of resources/short- and long-term impacts for each environmental impact category discussed in Section 4.

## Table 8-1. Summary of Environmental Consequences
## Jefferson Proving Ground, Madison, Indiana

| Environmental Impact | Adverse Impacts Based on Alternative 2: License Termination Under Restricted Conditions (Proposed Action) | Actions to Mitigate Impacts | Unavoidable Adverse/Irreversible and Irretrievable Commitments of Resources/ Short- and Long-Term Impacts |
|---|---|---|---|
| Land Use | No impacts anticipated as land use will remain restricted due to presence of UXO and DU. | No actions needed. | Land use of the DU Impact Area will remain restricted. |
| Transportation | No impacts anticipated. | No actions needed. | No impacts. |
| Geology and Soil | No short-term impacts. Possible long-term impacts associated with uranium migration with soil depth. | Conducted fate and transport modeling presented in Section 3. | No direct or indirect adverse impacts. |
| Water Resources | No short-term impacts to either surface water or groundwater. Over the long-term, there could be localized fluctuations of uranium concentrations in surface water from uranium migration. | Conducted fate and transport modeling (Section 3) to assess magnitude of direct and indirect impacts of uranium fluctuations in surface water and confirm no impacts to groundwater resources. | No direct or indirect adverse impacts. |
| Ecological Resources | No short-term impacts to biotic resources. Over the long-term, uranium could accumulate in biotic resources. | Conducted deer sampling (Section 6). | Results from deer sampling study suggest that accumulation is unlikely. |
| Air Quality | Possible short-term, local impacts with re-suspension of DU particulates and oxides (low-probability event). | Conducted residual dose analysis. | Residual doses associated with the inhalation pathway are negligible (Section 4 of Decommissioning Plan). |
| Noise | No impacts. | No actions needed. | No impacts. |
| Historic and Cultural Resources | No impacts. | No actions needed. | DU Impact Area previously was disturbed by ammunition testing. No historic or cultural resources are within the DU Impact Area. |
| Visual/Scenic Resources | No impacts. | No actions needed. | No impacts. |
| Socioeconomic Impacts | No impacts. | No actions needed. | No impacts. |
| Environmental Justice | No impacts. | No actions needed. | No impacts. |
| Public and Occupational Health | UXO hazards predominate and could result in injuries or fatalities. Radiological impacts to site workers and members of the public in the short-term would be a few mrem/y, but below NRC restricted release criterion (25 mrem/y). With loss of institutional controls, potential for health effects would increase, but radiological impacts would be less than 100 mrem/y. | Maintain land use restrictions in DU Impact Area in accordance with approved Decommissioning Plan. | If institutional controls are maintained, adverse short- and long-term impacts from UXO and radiological hazards would be minimized. |
| Waste Management | No impacts. | No actions needed. | No impacts. |

DU = Depleted Uranium
mrem/y = Millirems per Year
NRC = U.S. Nuclear Regulatory Commission
UXO = Unexploded Ordnance

# 9. REFERENCES


AECOM. 2012. Remedial Action Cost Engineering and Requirements System (RACER™), version 11.1.

ANG (Air National Guard). 2001. Final Environmental Assessment, Proposed Air National Guard Actions in Ohio and Indiana, Ohio Air National Guard and Indiana Air National Guard. Air National Guard, Environmental Division, 3500 Fetchet Avenue, Andrews Air Force Base, Maryland, 20762-5157. March.

ASTM (American Society for Testing and Materials). 2010, ASTM Method C1733-10, Standard Test Method for Distribution Coefficients of Inorganic Species by the Batch Method.

BBC (British Broadcasting Company). 2001. Kosovo DU Rounds Contained Plutonium. BBC News SCI/TECH. http://news.bbc.co.uk/low/english/sci/tech/newsid_1173000/1173746.stm.

Bechert, C.H. and J.M. Heckard. 1966. In Lindsey, A.A., ed, Natural features of Indiana: Indianapolis, Indiana Academy on Science, p. 100-115.

BOCS (Big Oaks Conservation Society). 2003. Big Oaks Newsletter of Big Oaks National Wildlife Refuge and Big Oaks Conservation Society. Spring.

BOCS. 2012. Big Oaks Newsletter of Big Oaks National Wildlife Refuge and Big Oaks Conservation Society. Fall.

Brock, A.L. 2003. "Corrosion of Depleted Uranium in an Arid Environment: Characterization With XRD, Sem/Eds And Microprobe Analyses," Presented to The Geological Society of America, Annual Meeting (November 2-5, 2003) (http://gsa.confex.com/gsa/2003AM/finalprogram/abstract_58213.htm)

Burns, P.C. 1999. "The Crystal Chemistry of Uranium," Chapter 2 in Burns, P.C.; Finch, R. (eds.) Reviews in Mineralogy, Vol. 38, Uranium: Mineralogy, Geochemistry and the Environment, Mineralogy Society of America.

Buszka, P.M., D.C. Lampe, and A.L. Egler. 2010. Estimates of groundwater age from till and carbonate bedrock hydrogeologic units at Jefferson Proving Ground, Southeastern Indiana, 2007-08: U.S. Geological Survey Scientific Investigations Report 2010-5178, 67 p.

CHPPM (U.S. Army Center for Health Promotion and Preventive Medicine). 2001. Industrial and Environmental Radiation Survey No. 26-MF-8260-R2-01, U.S. Army Jefferson Proving Ground, Madison, Indiana, 9-10 April 2001. 25 June.

CHPPM. 2002a. Industrial and Environmental Radiation Survey No. 26-MF-8260-R2-01, U.S. Army Jefferson Proving Ground, Madison, Indiana, 22-23 October 2001. 2 January.

CHPPM. 2002b. Industrial and Environmental Radiation Survey No. 26-MF-8260-R2-01, U.S. Army Jefferson Proving Ground, Madison, Indiana, 15-18 April 2002. 13 June.

Clark, D. 1993. Personal Communication with Dennis Clark, IDEM. July.

Das, B.M. 1998. Principles of Geotechnical Engineering. Fourth Edition. PWS Publishing Company. Boston, MA 02116-4324. p. 667.

Deere, D.U., A.J. Hendron Jr., F.D. Patton, and E.J. Cording. 1967. Design of Surface and Near Surface Construction In Rock. The 8th U.S. Symposium on Rock Mechanics (USRMS), 15 to 17 September 1966. Minneapolis, Minnesota.

DOD (U.S. Department of Defense). 1996. Department of Defense Instruction Number 4715.3, Environmental Conservation Program. Under Secretary of Defense for Acquisition and Technology (DUSD(A&T)). 3 May.

DOD. 2008. Department of Defense Instruction 4715.16, Cultural Resources Management. 18 September.

DOE (U.S. Department of Energy). 2000a. Letter from Mr. David Michaels, U.S. Department of Energy, Environment, Safety, and Health (ESH), to Ms. Tara Thornton, Military Toxics Project, Regarding "Concentrations of Plutonium in Depleted Uranium." 20 January.

DOE. 2000b. Guide of Good Practices for Occupational Radiological Protection in Uranium Facilities, DOE-STD-1136-2000, U.S. Department of Energy. August.

Douglas, M., S.B. Clark, J.L. Freise, B.W Arey, E.C. Buck, and B.D. Hanson. 2005. "Neptunium(V) partitioning to uranium(VI) oxide solids," Environ. Sci. Technol., 39, 4117-4124.

Ebinger and Hansen. 1996a. JPG Data Summary and Risk Assessment. Submitted to the U.S. Army Test and Evaluation Command by Los Alamos National Laboratory, New Mexico.

Ebinger and Hansen. 1996b. DU Risk Assessment for JPG using Data from Environmental Monitoring and Site Characterization. Submitted to the U.S. Army Test and Evaluation Command by Los Alamos National Laboratory, New Mexico. LA-UR-96-835.

Ebinger. 2001. Evaluation of JPG for Restricted Release: Risk Assessment Supporting NRC License Termination.

EG&G (EG&G Mound Applied Technologies Corporation). 1988. A Review of the Radiological Environmental Monitoring Data at the U.S. Army JPG, Madison, Indiana. 14 July.

Fetter, C.W. 1988. Applied Hydrogeology. Second Edition. Merrill Publishing Company. Columbus, Ohio, 43216. P. 285-295.

Freeze, R.L. and J.A. Cherry. 1979. Groundwater. Prentice-Hall, Inc., Englewood, New Jersey, 07632.

FWS (U.S. Fish and Wildlife Service). 1994. Fish and Wildlife Plan. September.

FWS. 2001a. Part 1 of the Public Information Packet. Interim Comprehensive Conservation Plan for the Proposed Big Oaks National Wildlife Refuge. Madison, Indiana.

FWS. 2001b. Part 2 of the Public Information Packet. Big Oaks Interim Hunting and Fishing Plan for the Proposed Big Oaks National Wildlife Refuge. Madison, Indiana.

FWS. 2001c. Part 3 of the Public Information Packet. Interim Compatibility Determination for the Proposed Big Oaks National Wildlife Refuge. Madison, Indiana.

FWS. 2001d. Environmental Assessment for the Big Oaks National Wildlife Refuge Fire Management Plan. Madison, Indiana. March.

FWS. 2001e. Finding of No Significant Impact, Facility: Big Oaks National Wildlife Refuge; Title: Fire Management Plan Environmental Assessment. Signed by Regional Director, FWS, Region 3. 2 March.

FWS. 2002. 2001 Fisheries Management Report, Big Oaks National Wildlife Refuge. USFWS-Carterville Fisheries Resource Office.

FWS. 2006. Wildland Fire Management Plan, Big Oaks National Wildlife Refuge, Great Lakes-Big Rivers Region. Department of The Interior, U.S. Fish & Wildlife Service. February.

FWS. 2010a. Biological Assessment for Modification of Prescribed Fire Dates for Big Oaks National Wildlife Refuge. December.

FWS. 2010b. National Wetlands Inventory Program. Image Year 2000. Online: http://www.fws.gov/wetlands/Data/index.html

FWS. 2012. Public Access Plan for Big Oaks National Wildlife Refuge. Prepared by Joseph R. Robb, Big Oaks National Wildlife Refuge, 23 March 2012. Reviewed by Lieutenant Colonel (LTC) Ken Stone, Commander, Jefferson Range, 27 March 2012. Approved by Yvette Hayes, Commanders Representative, Jefferson Proving Ground, 26 March 2012.

FWS. 2013. Big Oaks National Wildlife Refuge Website. As Viewed February 28. Online: http://www.fws.gov/midwest/bigoaks/. Updated 25 January.

Geo-Marine. 1996. Cultural Resources Management Plan. Prepared for the U.S. Army Corps of Engineers, Fort Worth District, Texas. August.

Gray, H.H. 2001. Miscellaneous Map 69 modified from Gray, H.H. 2000. Physiographic Divisions of Indiana, Indiana Geological Survey Special Report 61, Plate 1.

Hawkins, R.A. and S.A. Walley. 1995. Chert Source and Phase I Archaeological Surveys on the U.S. Army Jefferson Proving Ground, Jefferson, Jennings, and Ripley Counties, Indiana. Draft Report. Algonquin Archaeological Consultants, Inc.

Herring, W.C. 2004. Karst Features and the Dissolution of Carbonate Rocks in Jefferson County. Division of Water, Resource Assessment Section. April.

IDNR (Indiana Department of Natural Resources). 1993. An Inventory of Special Plants and Natural Areas Within JPG. March.

IDNR. 1996. Letter from Mr. Patrick Ralston, IDNR, to Ken Knouf, U.S. Army, JPG, regarding "NRHP sites at JPG." 29 August.

IDNR. 1999. An Inventory of Special Plants within the U.S. Army Jefferson Proving Ground. Phase II. April.

IDNR. 2010a. List of Endangered, Threatened, and Rare Species by County. Indiana Department of Natural Resources. http://www.in.gov/dnr/naturepreserve/4666.htm. Revised 1 June.

IDNR. 2010b. Endangered, Threatened, & Rare Vascular Plants of Indiana. Indiana Department of Natural Resources. http://www.in.gov/dnr/naturepreserve/4725.htm.

IDNR. 2012. "Indiana's Endangered Wildlife," Indiana Endangered Species. http://www.in.gov/dnr/fishwild/files/fw-State_Endangered_Species_list.pdf. Revised April.

INANG (Indiana Air National Guard). 2010. Jefferson Range Comprehensive Range Plan, 2010. Indiana Air National Guard, Joint Forces Air Component Headquarters Detachment 2, 1661 West Niblo Road, Madison, Indiana, 47250. LTC. Matthew J. Sweeney, Commander, Jefferson Range.

INANG. 2011. Integrated Cultural Resource Management Plan for the Jefferson Proving Ground/Jefferson Range, Indiana Air National Guard. Prepared for the Indiana Air National Guard and Air National Guard Readiness Center, National Guard Bureau through Air Force Center for Engineering and the Environment under USAMRAA Cooperative Agreement No. W81XWH-05-2-0050, Delivery Order No. 0009. January.

INANG. 2013. An Integrated Natural Resources Plan for Jefferson Range, Ripley County, Indiana. Final. 8 March.

Indiana Geological Survey. 2002. Bedrock Geology of Indiana (Indiana Geological Survey, 1:500,000, Polygon Shapefile), Bloomington, Indiana. This shapefile was derived and modified from a pre-existing published paper map: Gray, H.H., C.H. Ault, and S.J. Keller, 1987, Bedrock Geologic Map of Indiana, Indiana, Geological Survey Miscellaneous Map 48.

Inman, D.L. and S.A. Douglas. 2002. Scour and Burial of Bottom Mines: A Primer for Fleet Use. Integrative Oceanography Division, Scripps Institution of Oceanography, University of California, San Diego, La Jolla, California, 92093-0209. Scripps Institution of Oceanography (SIO) Reference Series No. 02-8. September.

Johansen, M.P., T.E. Hakonson, F.W. Whicker, J.R. Simmanton, and J.L Stone. 2001. "Hydrologic response and radionuclide transport following fire at semiarid sites." Journal of Environmental Quality 30:2010–2017.

Kraig, D.H., T.E. Buhl, C.F. Eberhart, and E.S. Gladney. 2001a. Updated Calculation of the Inhalation Dose from the Cerro Grande Fire Based on Final Air Data. Los Alamos National Laboratory Report LU-UR-01-1132, Los Alamos, New Mexico.

Kraig, D.H., R. Ryti, D. Katzman, T. Buhl, B. Gallaher, and P. Fresquez. 2001b. Radiological and Nonradiological Effects after the Cerro Grande Fire. Los Alamos National Laboratory Report LA-UR-01-6868, Los Alamos, New Mexico.

Kresic, N. 2007. Quantitative Solutions in Hydrogeology and Groundwater Modeling, Second Edition. LAW Engineering and Environmental Services, Inc. © 1997 by CRC Press LLC. Lewis Publishers is an imprint of CRC Press.

Mason and Hanger, Silas Mason Co., Inc. 1992. Final Study Cleanup and Reuse Options, Jefferson Proving Ground, Madison, Indiana. 15 October.

Mbutu, S.K., P.R. Waite, D.E. Peter, and F.B. Largent, Jr. 1996. Jefferson Proving Ground Cultural Resources Management Plan. Prepared by Geo-Marine, Plano, Texas for Jefferson Proving Ground under contract with U.S. Army Corps of Engineers, Fort Worth District. August.

Materials and Chemistry Laboratory, Inc. (MCL)-7708: MCL Electron Microscopy Operation Guide, Materials and Chemistry Laboratory, Inc.

MCL-7712: MCL X-Ray Diffraction Operation Guide, Materials and Chemistry Laboratory, Inc.

Monsanto. 1984. Review of the Environmental Quality Aspects of the U.S. Army Test and Evaluation Command (TECOM) DU Program at JPG, Indiana.

MRLC (Multi-Resolution Land Characteristics Consortium). 2006. National Land Cover Database. http://www.mrlc.gov. November.

MWH (Montgomery Watson Harza). 2002. Draft Final Remedial Investigation, JPG. Prepared for USACE Louisville District under Contract DACW27-97-D-0015, Task Order 008. March.

Nelson, A.J., T.C. Meier, C.K. Saw, L.V. Griffith. 2003. Surface and bulk chemistry of calcined UO2 powders, Journal of Vacuum Science & Technology A: Vacuum, Surfaces, and Films, 21(3), 762-765.

NRC (U.S. Nuclear Regulatory Commission). 1985. License Number SUB-1435, Jefferson Proving Ground, Madison, Indiana. U.S. Army, TECOM, Aberdeen Proving Ground, Maryland.

NRC. 2003. Environmental Review Guidance for Licensing Actions Associated with NMSS Programs. Final Report. NUREG-1748. U.S. Nuclear Regulatory Commission, Division of Waste Management, Office of Nuclear Material Safety and Safeguards, Washington, DC 20555-0001. Manuscript Completed: July 2003. Date Published: August 2003.

NRC. 2004a. Request for Additional information to Support NRC's Evaluation of the Proposed Changes to the Environmental Radiation Monitoring Program Plan for Jefferson Proving Ground (License SUB-1435). Letter from Tom McLaughlin, Project Manager, Materials Decommissioning Branch, NRC to Colonel Mike Mullins, Rock Island Arsenal, U.S. Army. 20 May.

NRC. 2004b. Request for Details About Parameters Needed for Offsite Transport Models for Jefferson Proving Ground (SUB-1435). 4 October.

NRC. 2006. Consolidated Decommissioning Guidance, Decommissioning Process for Materials Licensees. Final Report. NUREG-1757, Vol. 1, Rev. 2. U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards, Washington, DC 20555-0001. Prepared by K.L. Banovac, J.T. Buckley, R.L. Johnson, G.M. McCann, J.D. Parrott, D.W. Schmidt, J.C. Shepherd, T.B. Smith, P.A. Sobel, B.A. Watson, D.A. Widmayer, and T.H. Youngblood. Manuscript Completed: September 2006. Date Published: September 2006.

NRC. 2006a. Consolidated Decommissioning Guidance, Decommissioning Process for Materials Licensees. Final Report. NUREG-1757, Vol. 1, Rev. 2. Division of Waste Management and Environmental Protection, Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission, Washington, DC 20555-0001. Prepared by K.L. Banovac, J.T. Buckley, R.L. Johnson, G.M. McCann, J.D. Parrott, D.W. Schmidt, J.C. Shepard, T.B. Smith, P.A. Sobel, B.A. Watson, D.A. Widmayer, T.H. Youngblood. Manuscript Completed: September 2006. Date Published: September 2006.

NRC. 2006b. Consolidated Decommissioning Guidance, Characterization, Survey, and Determination of Radiological Criteria. Final Report. NUREG-1757, Vol. 2, Rev. 1. Division of Waste Management and Environmental Protection, Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission, Washington, DC 20555-0001. Prepared by D.W. Schmidt, K.L. Banovac, J.T. Buckley, D.W. Esh, R.L. Johnson, J.J. Kottan, C.A. McKenney, T.G. McLaughlin, S. Schneider. Manuscript Completed: September 2006. Date Published: September 2006.

NRC. 2007. Tornado Climatology of the Contiguous United States. NUREG/CR-4461, Rev. 2; PNNL-15112, Rev. 1. Prepared for Division of Risk Assessment and Special Projects, Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission, Washington, DC 20555-0001, NRC Job Code N6337. Prepared by J.V. Ramsdell, Jr. and J.P. Rishel, Pacific Northwest National Laboratory, P.O. Box 999, Richland, Washington, 99352. Manuscript Completed: December 2006. Date Published: February 2007.

NRC. 2008. NRC Atomic Safety and Licensing Board Hearing Initial Decision, ASLBP No. 00-766-04-MLA, dated 28 February.

Oliver, I.W., A.B. Mackenzie, R.M. Ellam, M.C. Graham, and J.G. Farme. 2006. "Determining the extent of depleted uranium contamination in soils at a weapons test site: An isotopic investigation," *Geochimica et Cosmochimica Acta*, Volume 70, Issue 18, Supplement 1, August-September 2006, p. 457.

Oliver, I.W., M.C. Graham, A.B. MacKenzie, R.M. Ellam and J.G. Farmer. 2008. "Distribution and partitioning of depleted uranium (DU) in soils at weapons test ranges – Investigations combining

the BCR extraction scheme and isotopic analysis," *Chemosphere*, Volume 72, Issue 6, June 2008, p. 932-939.

Personal Communication. 2013a. Communication between Mr. Michael Barta, SAIC, and Mr. Andy King, Indiana Bat Specialist, FWS Bloomington Ecological Services Field Office. 26 June.

Personal Communication. 2013b. Personal communication between Mr. Paul Cloud (former JPG Radiation Safety Officer and RAC Environmental Coordinator) with Mr. Joseph Skibinski, SAIC Project Manager. Electronic mail message subject: RE: Just the Facts. 24 April.

Personal Communication. 2013c. Communication between Mr. Dennis Chambers, SAIC, and Tanya Palmateer-Oxenberg, former Army RSO/Health Physicist for JPG. 17 March 2013.

Radenković, R., D. Djordjević, J. Joksić, S. Djogo, P. Pfendt, and J. Raičević. 2003. "Uranium Mobility in Soils Contaminated with Depleted Uranium," *CEJOEM 2003*, Vol. 9. No. 4.: 327-331.

Ralston, M.R. and I.S. Oweis. 1999. Geotechnical Engineering Considerations for Stormwater Management in Karst Terrain. Proceedings of the 1999 Southeastern Pennsylvania Stormwater Management Symposium. Villanova University, Villanova, Pennsylvania.

Rey, A. et al. 2009. "Stability of uranium(VI) peroxide hydrates under ionizing radiation," Amer. Mineralogist, 94, 229-235

Ridge, C. 2007. Prefiled Testimony of A. Christianne Ridge before the Atomic Safety and Licensing Board of the United States of America Nuclear Regulatory Commission, Docket No. 40 8838-MLA, pp. 17-18. 17 August.

Rust E&I (Rust Environment and Infrastructure). 1998. JPG South of the Firing Line Phase II Draft Remedial Investigation. Prepared for U.S. Army Environmental Corps, Aberdeen Proving Ground, Maryland. August.

SAIC (Science Applications International Corporation). 1997. Base Realignment and Closure Cleanup Plan. Version 3. Prepared for the U.S. Army Environmental Corps under Contract DACA31-94-D-0066, DO 0001. June.

SAIC. 2005. Field Sampling Plan, Site Characterization of the Depleted Uranium Impact Area. Final. May.

SAIC. 2006a. Deer Tissue Sampling Results, Depleted Uranium Impact Area Site Characterization, Jefferson Proving Ground, Madison, Indiana. August.

SAIC. 2006b. Field Sampling Plan Addendum 2, Depleted Uranium Impact Area Site Characterization – Soil Verification, Jefferson Proving Ground, Madison, Indiana. Final. July.

SAIC. 2006c. Field Sampling Plan Addendum 3, Depleted Uranium Impact Area Site Characterization – Other Monitoring Equipment Installation, Other Monitoring (Precipitation, Cave, and Stream/Cave Spring Gauges) and Electrical Imaging Survey, Jefferson Proving Ground, Madison, Indiana. Final. July.

SAIC. 2007a. Well Location Selection Report. Depleted Uranium Impact Area Site Characterization: Soil Verification, Surface Water Gauge Installation, Fracture Trace Analysis, and Electrical Imaging, Jefferson Proving Ground, Madison, Indiana. Final. Prepared for U.S. Department of Army Contract No. W912QR-04-D-0019. January.

SAIC. 2007b. Field Sampling Plan Addendum 4, Depleted Uranium Impact Area Site Characterization – Monitoring Well Installation, Jefferson Proving Ground, Madison, Indiana. Final. January.

SAIC. 2008a. Well Construction and Surface Water Data Report. Prepared for U.S. Department of Army Contract No. DACW62-03-D-0003.

SAIC. 2008b. Field Sampling Plan Addendum 5, Depleted Uranium Impact Area Site Characterization – Data Quality Objectives for Groundwater, Surface Water, and Sediment Sampling and Analysis, Jefferson Proving Ground, Madison, Indiana. Final. January.

SAIC. 2008c. Field Sampling Plan Addendum 6, Depleted Uranium Impact Area Site Characterization – Water Chemistry Sampling for Ground-Water Age Estimates and Comparison of Flowmeter-Based and Water-Level-Based Directions of Ground-Water Flow in a Karst Hydrogeologic Framework, Jefferson Proving Ground, Madison, Indiana. Final. March.

SAIC. 2008d. Field Sampling Plan Addendum 7, Depleted Uranium Impact Area Site Characterization – Soil Sampling and Analysis, Corrosion Study, Partition Coefficient Study, Modeling Overview and Slug Testing. Jefferson Proving Ground, Madison Indiana. Final. October.

SAIC. 2009. Field Sampling Plan Addendum 8, Depleted Uranium Impact Area Site Characterization – Soil Sampling and Analysis using Direct-Push Technology, Partition Coefficient Study for Glacial Till Stratigraphic Layer, Jefferson Proving Ground, Madison, Indiana. Final. October.

SAIC. 2010. Slug Testing Report, Depleted Uranium Impact Area Site Characterization: Aquifer Testing for Hydraulic Conductivity, Jefferson Proving Ground, Madison, Indiana. Final. Prepared for U.S. Department of Army, Installation Support Management Activity, Aberdeen Proving Ground, Maryland and U.S. Army Corps of Engineers, Louisville District, Louisville, Kentucky. Submitted by Science Applications International Corporation under Contract No. DACW62-03-D-0003, Delivery Order No. CY07. August.

SEC Donohue, Inc. 1992. Letter Report of Site Specific Sampling and Analysis Program Results. Prepared for U.S. Army Toxic and Hazardous Materials Agency. August.

SEG (Scientific Ecology Group). 1995. Jefferson Proving Ground Depleted Uranium Impact Area, Scoping Survey Report, Volumes 1-3. Scientific Ecology Group, Oak Ridge, Tennessee. March.

SEG. 1996. Jefferson Proving Ground Depleted Uranium Impact Area Characterization Survey Report, Vol. 1 and 2. Scientific Ecology Group, Inc., Radiological Engineering and Decommissioning Service, February.

Sheldon, R. 1997. Jefferson Proving Ground Karst Study. Report to Jefferson Proving Ground, unnumbered pages.

Sherman, D.M., C.L. Peacock, and C.G. Hubbard. 2008. "Surface complexation of U(VI) on goethite (α-FeOOH)," *Geochimica et Cosmochimica Acta*, Volume 72, 2008, pp. 298-310.

Telford, W.M, R.E. Sheriff, and L.P. Geldart. 1990. Applied Geophysics, Second Edition. © Cambridge University Press.

Tessier, A., C. Campbell, and M. Bisson. 1979. "Sequential extraction procedure for the speciation of particulate trace metals," *Anal. Chem.*, 1979, *51* (7), pp. 844-851.

U.S. Army. 1988. Environmental Assessment (EA) for Renewal of NRC License for Testing DU at JPG.

U.S. Army. 1995a. Final Environmental Impact Statement for Disposal and Reuse of the Jefferson Proving Ground. U.S. Army Materiel Command (AMCSO). Alexandria, Virginia. September.

U.S. Army. 1995b. Letter from the Deputy Assistant Secretary of the Army to the Governor of the State of Indiana regarding "Retrocession." 4 April.

U.S. Army. 1995c. Health and Environmental Consequences of Depleted Uranium Use in the U.S. Army: Technical Report. June.

U.S. Army. 1996a. Record of Decision on the Final Environmental Impact Statement (FEIS), on the Disposal and Reuse of Jefferson Proving Ground, Madison, Indiana. Federal Register Vol. 61, No. 7. 10 January.

U.S. Army. 1996b. Environmental Radiation Monitoring Plan at JPG. U.S. Army Test and Evaluation Command.

U.S. Army. 1999. Decommissioning Plan and Environmental Report for the DU Impact Area. Prepared for the U.S. Army Test and Evaluation Command by Los Alamos National Laboratory. LA-UR-94-3376. June.

U.S. Army. 2000a. Memorandum of Agreement between the U.S. Army, U.S. Air Force, and U.S. Fish and Wildlife Service.

U.S. Army. 2000b. "Standard Operating Procedure (SOP). Depleted Uranium Sampling Program, Environmental Radiation Monitoring Program, JPG, Indiana." SOP No. OHP 40-2. 10 March.

U.S. Army. 2001. License SUB-1435 Decommissioning Plan, No. 26-MA-5970-01, Jefferson Proving Ground, Madison, Indiana. Center for Health Promotion and Preventive Medicine (CHPPM), Aberdeen Proving Ground, Maryland. June.

U.S. Army. 2002a. License SUB-1435 Decommissioning Plan, No. 26-MA-5970-01, Jefferson Proving Ground, Madison, Indiana. Center for Health Promotion and Preventive Medicine (USACHPPM), Aberdeen Proving Ground, Maryland. June.

U.S. Army. 2002b. Decommissioning Plan for License SUB-1435. Jefferson Proving Ground, Madison, Indiana. Prepared for the U.S. Army SBCCOM by SAIC. June.

U.S. Army. 2002c. Environmental Report, JPG, Madison, Indiana. Prepared for the U.S. Army SBCCOM by SAIC. June.

U.S. Army. 2003a. The Training Range Site Characterization and Risk Screening Regional Range Study, Jefferson Proving Ground, Madison, Indiana. August.

U.S. Army. 2003b. Environmental Radiation Monitoring Program Plan for License SUB-1435, Jefferson Proving Ground. Prepared by SAIC for the U.S. Army. September.

U.S. Army. 2004a. Responses to the NRC May 20, 2004 Request for Additional Information Regarding the Environmental Radiation Monitoring Plan. Prepared by SAIC for the U.S. Army. November.

U.S. Army. 2004b. ERM Program Plan For License Sub-1435 JPG Addendum, Jefferson Proving Ground. Prepared by SAIC for the U.S. Army. April.

U.S. Army. 2005. Jefferson Proving Ground (License SUB-1435). Letter from Alan G. Wilson, Garrison Manager, Department of the Army, United States Army Garrison-Rock Island Arsenal, 1 Rock Island Arsenal, Rock Island, Illinois 61299-5000 to Tom McLaughlin, Materials Decommissioning Branch, Division of Waste Management and Environmental Protection, Office of Nuclear Material Safety and Safeguards, Two White Flint North, 11545 Rockville Pike, Rockville, Maryland, 20852-2738. 31 January.

U.S. Army. 2006. Radiation Monitoring Report For License SUB-1435, Jefferson Proving Ground, Summary of Results for April 10-13, 2006 Sampling Event. Final. Prepared by SAIC for U.S. Army. October.

U.S. Army. 2013a. Decommissioning Plan for Materials License SUB-1435, Depleted Uranium Impact Area, Jefferson Proving Ground, Madison, Indiana. August.

U.S. Army. 2013b. Radiation Safety Plan for Jefferson Proving Ground Depleted Uranium Impact Area. 20 June.

U.S. Army. 2013c. Radiation Monitoring Report for License SUB-1435, Jefferson Proving Ground, Summary of Results for the March-April 2012 Sampling Event. Final. Submitted to U.S. Department of Army, U.S. Army Garrison, Rock Island Arsenal, Rock Island, Illinois. Prepared by Science Applications International Corporation, McLean, Virginia. January.

U.S. Army. 2013d. Radiation Monitoring Report For License SUB-1435, Jefferson Proving Ground, Summary of Results for October 2012 Sampling Event. Final. Prepared by SAIC for U.S. Army. April.

U.S. Census Bureau. 2013. U.S. Census Bureau, American FactFinder. http://factfinder2.census.gov/faces/nav/jsf/pages/index.xhtml. 8 July.

UNEP (United Nations Environmental Programme). Depleted Uranium in Bosnia and Herzegovina, Post-Conflict Environmental Assessment. 2003.

USACE (U.S. Army Corps of Engineers). 2004. Munitions and Explosives of Concern (MEC) Support During Hazardous, Toxic, and Radioactive Waste (HTRW) and Construction Activities. Engineer Pamphlet (EP) 75-1-2. Department of the Army, U.S. Army Corps of Engineers, Washington, DC, 20314-1000. 1 August.

USAF (U.S. Air Force). 2004. Air Force Instruction 32-7065, Cultural Resources Management Program. Civil Engineering. 1 June.

USATHAMA (U.S. Army Toxic and Hazardous Materials Agency). 1988. Remedial Investigation at Jefferson Proving Ground, Technical Plan Data Item A005. Environmental Science and Engineering, Inc., Gainesville, Florida, 32602. May.

USDA NRCS (U.S. Department of Agriculture Natural Resources Conservation Service). 2005. Soil Survey Geographic Database (SSURGO) for Jefferson County, Indiana – Interim Product, SV 2.7.

USEPA (U.S. Environmental Protection Agency). 1999. Understanding Variation In Partition Coefficient, $K_d$, Values, Volumes I, II and III. EPA Office of Air and Radiation, EPA 402-R-99-004A. August.

USEPA. 2004. Wadeable Streams Assessment: Field Operations Manual. EPA841-B-04-004. U.S. Environmental Protection Agency, Office of Water and Office of Research and Development, Washington DC. Final. July.

USEPA. 2007. ProUCL Version 4.00.02 User Guide. EPA/600/R-07/038. U.S. Environmental Protection Agency, Office of Research and Development, Washington, DC 20460. April.

USGS (U.S. Geological Survey). 2007. Water Budgets: Foundations for Effective Water-Resources and Environmental Management. Circular 1308. By R.W. Healy, T.C. Winter, J.W. LaBaugh, and O.L. Franke, U.S. Department of the Interior, U.S. Geological Survey. Reston, Virginia.

USGS. 2008a. Hydrologic Investigations Concerning Lead Mining Issues in Southeastern Missouri. Scientific Investigations Report 2008-5140. By M.J. Kleeschulte, C.M. Seeger, L. Lee, G.W. Krizanich, S.R. Femmer, and G. Schumacher. U.S. Department of the Interior, U.S. Geological Survey. Reston, Virginia.

USGS. 2008b. Definition of water budget: http://www.usgs.gov/science/science.php?term=1297.

USGS. 2009. Geohydrologic Investigations and Landscape Characteristics of Areas Contributing Water to Springs, The Current River, and Jacks Fork, Ozark National Scenic Riverways, Missouri. Scientific Investigations Report 2009-5138. By D.N. Mugel and J.M. Richards, J.G. Schumacher. U.S. Department of the Interior, U.S. Geological Survey. Reston, Virginia.

Williams, G.P., A.M. Hermes, A.J. Policastro, H.M. Hartmann, and D. Tomasko. 1998. Potential Health Impacts from Range Fires at Aberdeen Proving Ground. Report ANL/EAD/TM-79, Argonne National Laboratory, Argonne, Illinois.

Young, C.M., K.A. Nelson, G.T. Stevens, V.J. Grassi (2006), Occurrence of Metastudtite (Uranium Peroxide Dihydrate) at a FUSRAP Site, WM'06 Conference, February 26-March 2, 2006, Tucson, Arizona.

Yu, C. et al. 2010. RESRAD-OFFSITE (Version 2.6) [Computer Program]. Available at http://web.ead.anl.gov/resrad/RESRAD_Family/ (Accessed 23 May 2013). July.

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