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:

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CERTIFICATION 4

CONTRACTOR STATEMENT OF INDEPENDENT TECHNICAL REVIEW

Science Applications International Corporation (SAIC) has prepared this Well Location Selection Report for Jefferson Proving Ground's Depleted Uranium Impact Area, located in Madison, Indiana. Notice is hereby given that an independent technical review has been conducted that is appropriate to the level of risk and complexity inherent in the project, as defined in the Quality Control Plan (QCP). During the independent technical review, compliance with established policy principles and procedures, utilizing justified and valid assumptions, was verified. This included review of assumptions; methods, procedures, and material used in analyses; alternatives evaluated; the appropriateness of data used and level of data obtained; and reasonableness of the results, including whether the product meets the customer's needs consistent with law and existing Corps policy.

For: Joseph N. Skibinski Project Manager Science Applications International Corporation	8/18/07 Date
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Significant concerns and explanation of the resolutions are documented within the project file.

As noted above, all concerns resulting from independent technical review of the project have been considered.

Lisa D. Jones-Bateman Vice President Science Applications International Corporation	8/18/07 Date

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LIST OF ACRONYMS AND ABBREVIATIONS

3-D	Three Dimensional
AGI	Advanced Geosciences, Inc.
ARCPACS	American Registry of Certified Professionals in Agronomy, Crops and Soils
BLS	Below Land Surface
BRAC	Base Realignment and Closure
CPSS	Certified Professional Soil Scientist
CSM	Conceptual Site Model
DGPS	Differential Global Positioning System
DU	Depleted Uranium
Eh	Redox Potential
EI	Electrical Imaging
EOD	Explosive Ordnance Disposal
EPA	U.S. Environmental Protection Agency
ERM	Environmental Radiation Monitoring
FSP	Field Sampling Plan
GIS	Geographic Information System
GPS	Global Positioning System
HASP	Health and Safety Plan
JPG	Jefferson Proving Ground
MOA	Memorandum of Understanding
NAD-83	1983 North American Datum
NARA	U.S. National Archives and Records Administration
NRC	Nuclear Regulatory Commission
NRCS	Natural Resources Conservation Service
NWR	National Wildlife Refuge
OSD	Official Soil Description
PC	Personal Computer
QC	Quality Control
SAIC	Science Applications International Corporation
SSURGO	Soil Survey Geographical Database
SVS	Soil Verification Study
USFWS	U.S. Fish and Wildlife Service
UTM	Universal Transverse Mercator
UXO	Unexploded Ordnance

1. INTRODUCTION

This section provides a brief overview of the site history, characteristics of uranium and depleted uranium (DU), exposure pathways, objectives of the report, and the report organization.

1.1 SITE HISTORY

Jefferson Proving Ground (JPG) was established in 1941 as a proving ground for the test firing of a wide variety of munitions. The facility is approximately 55,264 acres (224 square kilometers) and is located in Jefferson, Jennings, and Ripley Counties in southeastern Indiana (Figure 1-1). A firing line with 268 gun positions used for testing munitions separates JPG into two areas: a 4,000-acre (16.1-square kilometer) southern portion and a 51,000-acre (206-square kilometer) northern portion (SAIC 1997). The area north of the firing line consists of undeveloped and heavily wooded land and contains the Nuclear Regulatory Commission (NRC)-licensed DU Impact Area (SAIC 1997). The DU Impact Area is located entirely in Jefferson County.

The U.S. Army used JPG as a proving ground from 1941 to 1994. The U.S. Army test fired DU projectiles as part of its munitions testing program. DU is uranium from which some fraction of the U-235 isotope has been removed and is used as a component in the manufacturing of a munition that penetrates armor plating. The possession and test firing of DU penetrators were conducted under a license issued by NRC (License SUB-1435). The test firing of DU projectiles occurred between 1983 and 1994 in the DU Impact Area, which is located in the south-central area of the northern portion of JPG, as shown in Figure 1-2. These tests were designed to be nondestructive (i.e., no aerosolization occurred) and were not testing the armor penetrating capability, although the rounds may have fragmented upon impact.

Approximately 220,462 pounds (100,000 kilograms) of DU projectiles were fired at soft targets (i.e., nonarmored targets that are made of materials such as cloth or wood) in the 2,080-acre (8.4-square kilometer) DU Impact Area. A total of approximately 66,139 pounds (30,000 kilograms) of DU projectiles and projectile fragments were recovered at or near the ground surface during periodic collection events to ensure that the total 100,000-kilogram license limit was not exceeded. Approximately 154,323 pounds (70,000 kilograms) of DU remain in the DU Impact Area (SEG 1995 and 1996).

JPG was closed in September 1995 under the Defense Authorization Amendments and Base Realignment and Closure (BRAC) Act of 1988. The NRC license for the DU Impact Area north of the firing line was amended for possession-only of DU in May 1996. Activities documented in this report were conducted in order to refine the conceptual site model (CSM) and address gaps in the current set of site characterization data. Further details concerning site history are presented in the Field Sampling Plan (FSP) (SAIC 2005a).

1.2 EXPOSURE PATHWAYS

Figure 1-3 is a working graphical representation of the CSM, including DU sources, release mechanisms, exposure mediums, potential exposure pathways, and potential receptors at JPG. This working draft of the CSM will be revised as data are collected throughout the 5-year site characterization program. The transport mechanisms and potential exposure pathways are described in further detail below.

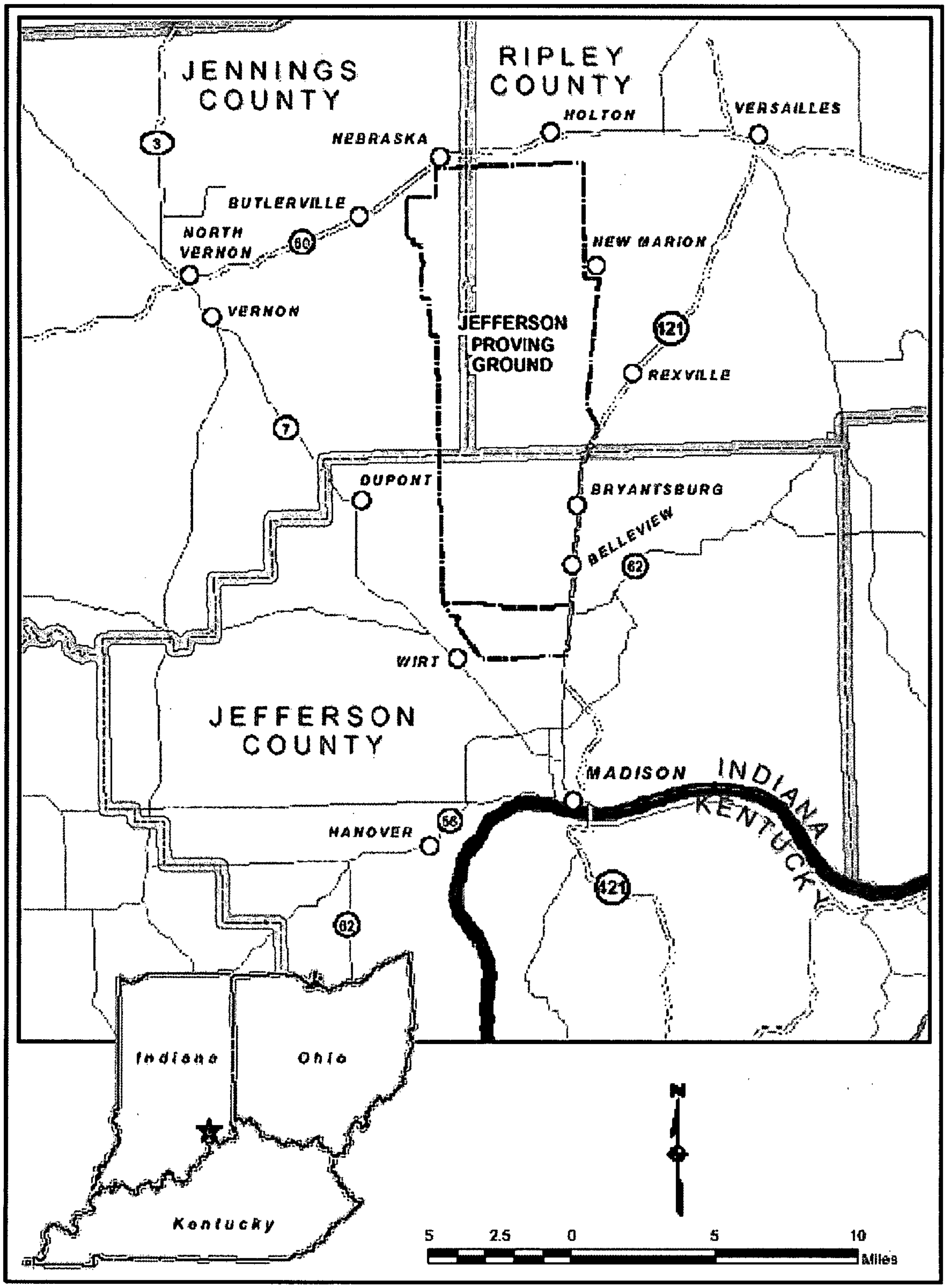


Figure 1-1. Regional Location of Jefferson Proving Ground

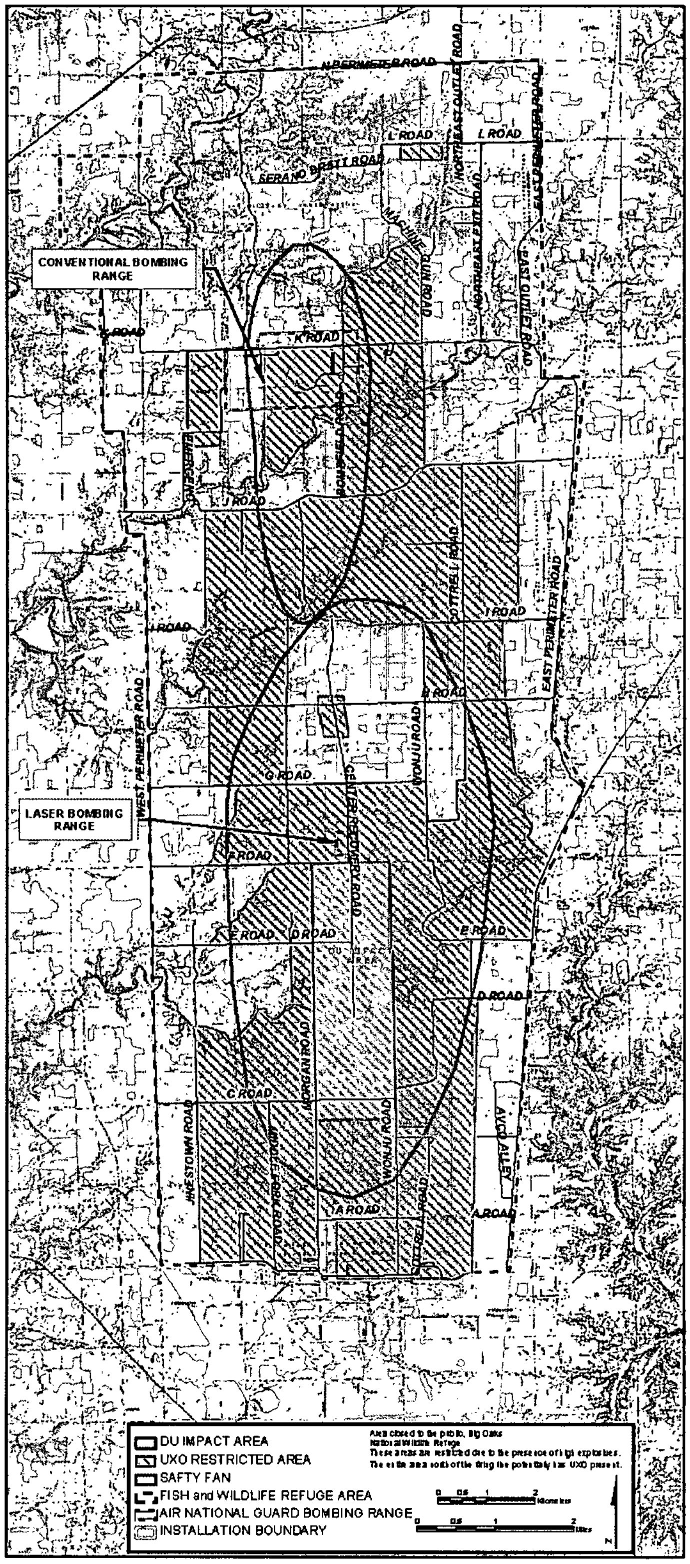


Figure 1-2. Jefferson Proving Ground, Madison, Indiana

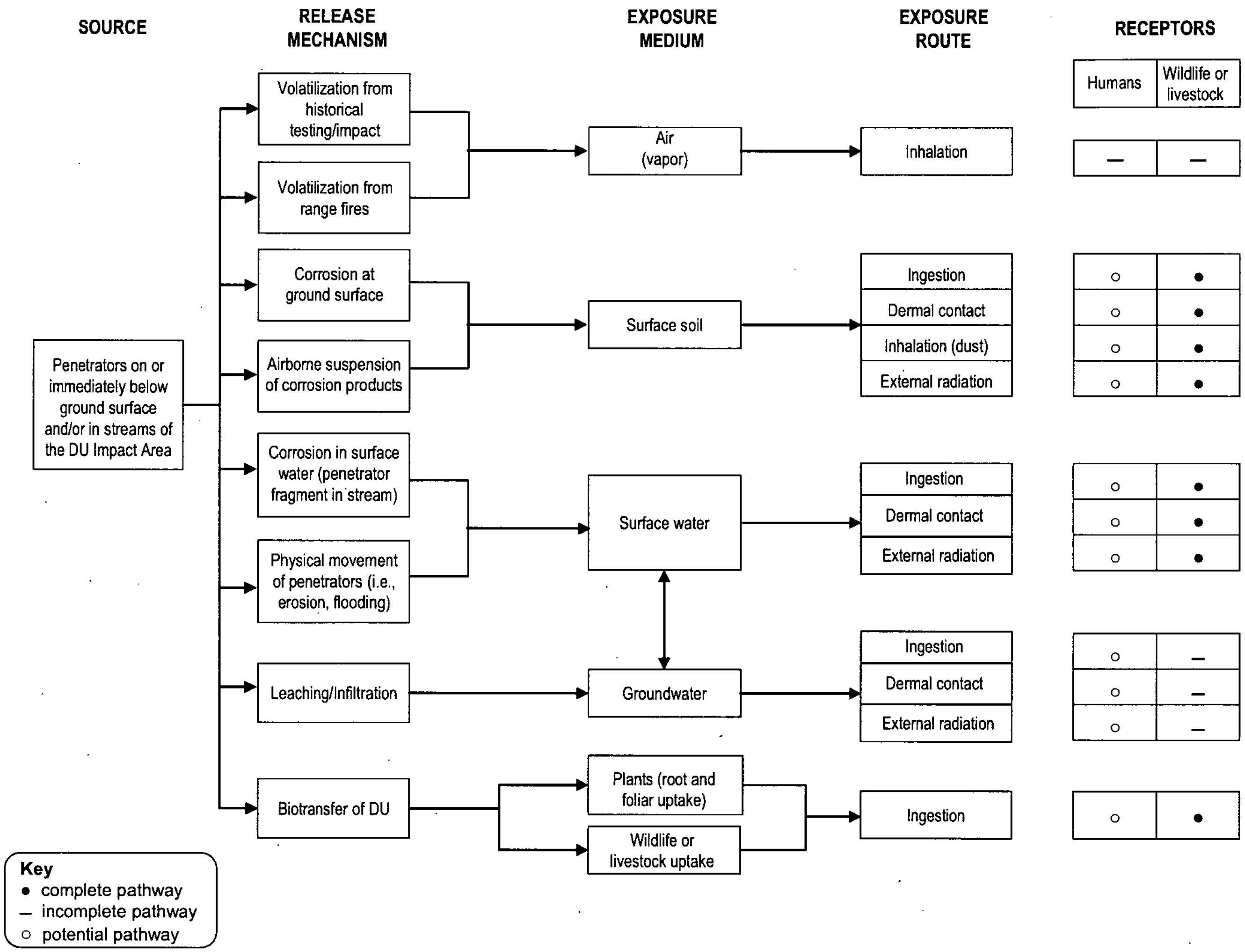


Figure 1-3. Working Conceptual Site Model of DU Transport Through the Environment at and in Close Proximity to the JPG DU Impact Area
Jefferson Proving Ground, Madison, Indiana

The type of release affects the type and amount of DU released into the environment and the potential for exposure of humans and wildlife. In general, during the testing of DU penetrators, DU either can be released as particles in aerosols and residual metallic fragments created upon impacts with targets or nearly intact penetrators that missed their targets. While DU testing had occurred at JPG (between 1983 and 1994), humans and wildlife could have been exposed to DU from inhaling and inadvertently ingesting particles in aerosols released from the DU munitions. However, as testing operations have not been conducted at JPG since 1994, and any aerosols created by the impact of the DU penetrators with the ground surface were limited because the tests were nondestructive testing on soft cloth (nonarmored) targets for trajectory purposes, this pathway is less of a concern than the subsequent inhalation of any resuspended particles from contaminated soil or dust.

DU that had been distributed on or immediately below the ground surface and/or within the surface water (streams) of the DU Impact Area as a result of the testing may be transported throughout the environment by several different processes. DU in the soil or surface water can be subject to physical movement by erosion (during floods and high runoff events), and these processes may cause migration and transport of DU penetrators along the ground surface and along the surface water drainageways. Corrosion of the DU in the surface water or soil could enable soluble forms of DU to be absorbed by plants and incorporated within the plant matter for uptake by wildlife. Although vegetation may be burned as part of a management effort or unintended fires (e.g., from lightning), the levels of DU carried in smoke associated with natural vegetation (such as the controlled burns at JPG) are not likely significant (Williams et al. 1998 and U.S. Army 2001). Leached DU from the penetrators and/or fragments in the surface water potentially could be transported to groundwater and surface water, which in turn could migrate to drinking water sources and be ingested by humans, livestock, and wildlife.

Exposure of wildlife to DU can be highly variable depending on animal behavior and recent diet, in addition to the nature of the DU contamination. Wildlife that traverses the DU Impact Area may be exposed to DU from direct contact with the penetrators and/or fragments and incidental ingestion of DU or DU-impacted soils or water. In addition, wildlife may be exposed to the effects of the external radiation from the DU due to the proximity of DU (in the soil and/or water and/or sediment). Ingestion of contaminated soil could be an important exposure pathway for animals as animals typically eat more soil than humans (i.e., incidentally when licking fur or pelts or as part of their diet).

Wildlife may be exposed indirectly to DU by ingestion of plants that have taken up DU or where DU has been deposited on the leaves by wind dispersion. Plants are generally poor accumulators of uranium and concentrations of uranium in plants are several orders of magnitude lower than those in the soil in which they grow (Royal Society 2002). However, despite the generally low transfer of uranium from soil to plants, certain plant species (i.e., microbial species such as fungi, yeasts, algae, and other unicellular bacteria [Hu et al. 1996, reported in Royal Society 2002], black spruce and some forest plants [Thomas 2000, reported in Royal Society 2002], sugar beets and sunflowers [Erikkson and Evans 1983 and Dushenkov et al. (1997), reported in Royal Society 2002], and Indian mustard [*Brassica juncea*] [Edenspace 2004]) have been shown to exhibit high uptake of uranium. Nonvascular plants (mosses and lichens) generally accumulate higher concentrations than vascular plants (Cramp et al. 1990, reported in Royal Society 2002). Ingestion of microbial and plant species with accumulation of DU presents a route by which higher trophic levels of wildlife can be exposed. Some accumulation of uranium has been observed in animals. Measurements of uranium in tissues of animals grazing in uranium-contaminated areas have been reported to be higher than those in control areas. Few measurements of uranium in wild animals have been made, but those compiled do not report significant accumulation in tissues (e.g., Clulow et al. 1998), although they are measurable and often elevated in whole animal samples at contaminated sites (Royal Society 2001). Ingestion of animal species with accumulation of DU presents a route by which higher trophic levels of wildlife can be exposed. It should be noted that deer tissue samples collected from JPG in November 2005 through February 2006 do not indicate that DU is accumulating in deer (e.g., no concentrations of uranium detected in deer tissue samples were attributable to DU) (SAIC 2006a).

Humans at JPG also may be exposed to DU from direct contact or incidental ingestion of penetrators and/or fragments from impacted surface water during recreational activities such as hunting. As fishing is not permitted in JPG streams and the nearest fishing is several miles north of the DU Impact Area, humans are not exposed to DU from direct contact while fishing. Possible exposure pathways for humans include ingestion of food (i.e., meat and/or animal products from animals that have ingested DU impacted soil, water, or biota), water, or soil containing DU; inhalation of dust containing DU; or external radiation from the presence of DU.

Insoluble uranium from DU or natural sources that has been inhaled may deposit in the lungs and associated lymph nodes and may remain in the lungs for years. Soluble uranium, once inhaled, may be transported to the gastrointestinal tract. In addition, uranium may be deposited in the intestinal tract of humans or wildlife from ingestion (Royal Society 2001). Once inside the intestinal tract, accumulation may occur in bones, livers, or kidneys. To a lesser degree, the uranium may accumulate in the muscle. Uptake from the stomach gut to the blood is low (0.2 to 5 percent) (IAEA 1989) and most ingested uranium is excreted, where it could be reingested or recycled via the soil into forage. Uptake factors of uranium from the gut to the blood for ruminants (e.g., deer, cattle, or goats) may vary depending upon environmental conditions, but are approximately five times greater than that of humans (Royal Society 2002).

1.3 OBJECTIVES AND APPROACH

The following sections define the objectives and the approach for selecting locations of conduit well pairs in terms of the overall project objectives. As explained below, well pairs are two wells at each location to be completed at anticipated depths of 50 and 120 feet below land surface (BLS). The purpose of installing these well pairs is to evaluate potential groundwater impacts from DU corrosion products that may have migrated through soil to groundwater and could migrate offsite.

1.3.1 Objectives

The site characterization is being completed to document the impacts and the potential exposures to receptors from the DU penetrator testing that occurred at JPG. These tasks, data, and studies will be used to confirm and refine the CSM as well as define follow-on characterization investigations as detailed in the FSP and Addenda (SAIC 2005a, 2006a, and 2006b). The present CSM is discussed in Section 1.2.

The objectives of the JPG site characterization project are three-fold (SAIC 2005a):

- Enhance the understanding of the nature and extent of contamination in the DU Impact Area and the fate and transport of DU in the environment
- Define and verify the CSM
- Provide the basis for modifying the current monitoring program within the next 2 to 3 years and completing a revised Decommissioning Plan in 5 years.

To achieve these overall project objectives within the 5-year timeframe allotted by NRC (NRC 2006), the Army is following a phased characterization approach. The approach was based first on available information and multiple studies that have been completed within and around the DU Impact Area for the past two to three decades. Subsequent phases are completed in a step-wise manner that build upon information collected during previous phases. This concept is crucial to understanding the overall project objectives and how this phase of the study will help meet those objectives.

The goal of this phase of the characterization is to identify the most significant groundwater flow pathways that may be present within fractures and solution enhanced features or "conduits" within the karst aquifer underlying the DU Impact Area. In other words, this phase focuses on placing wells in the most likely and expeditious transport pathways for offsite migration of DU in groundwater. If dissolved DU oxidation products are migrating offsite in groundwater, it will be detected in these wells. The following objectives are defined for this phase of the 5-year site characterization:

- Conduct a soil verification survey (SVS) to determine if the published soil mapping can be used in the process of defining and completing future soil sampling efforts
- Conduct a fracture trace analysis using aerial photographs as a first step in identifying and locating preferential groundwater flow pathways or conduits at the JPG DU Impact Area and use the results to define the locations of the EI survey
- Conduct an EI survey on transects surrounding areas with DU penetrators to identify subsurface features with a nonintrusive technique that can be used in conjunction with the results of the fracture trace analysis to identify where conduit wells should be placed
- Install surface water gauging stations to collect the data to estimate groundwater recharge rates and evaluate the relationships and responses between precipitation and surface water and groundwater flow.

1.3.2 Approach

As discussed in Section 1.3.1, the Army is following a phased characterization approach. In support of this phased site characterization of the DU Impact Area detailed in the FSP (SAIC 2005a) and FSP Addenda (SAIC 2006b and 2006c), SAIC has completed the following tasks and studies:

- An onsite SVS
- Stream and cave spring gauge installation
- Fracture trace analysis
- Electrical imaging (EI) survey
- Well location selection study.

The results of the SVS will be used to define follow-on soil sampling tasks (i.e., K_d studies, soil sampling, corrosion, and dissolution studies) presented in the FSP (SAIC 2005a) that will be used to complete fate and transport analysis. In addition, the results of the SVS will indicate if the published soil mapping can be used in the process of defining and completing future soil sampling efforts. Surface water flow data from the installed stream and cave spring gauges will be used to evaluate the connection between surface water and groundwater and calculate groundwater recharge and the relationships and responses between precipitation and surface water and groundwater flow. The results from the fracture trace analysis and the EI study were used to identify potential "groundwater conduits" and were evaluated in completing this well location selection study. This study provides the rationale for selecting locations of conduit monitoring well pairs to confirm the presence of "groundwater conduits," monitor groundwater stages, provide representative groundwater sampling locations in probable migration pathways, and refine the present CSM. The following report details and presents results of each of these studies/activities.

1.4 REPORT ORGANIZATION

This Well Location Selection Report is organized to summarize the data from activities and the rationale for the selection of locations for conduit monitoring wells at the DU Impact Area. The information provided in each of the following sections of this report is summarized below:

- *Section 1. Introduction*—This section provides a brief overview of the site history exposure pathways and objectives of the report, as well as summarizes the organization and contents.
- *Section 2. Soil Verification*—This section summarizes the findings of the soil verification conducted at JPG on August 29 and 30, 2006.
- *Section 3. Surface Water Gauge Installation*—This section describes the procedures used to install the surface water and cave spring gauging stations that Science Applications International Corporation (SAIC) installed on Big Creek and Middle Fork Creek in September 2006.
- *Section 4. Groundwater Characterization*—This section provides a general description of groundwater in karst systems and summarizes the fracture trace analysis (SAIC 2006d).
- *Section 5. Electrical Imaging*—This section summarizes the EI survey that SAIC completed at the JPG DU Impact Area in July and August 2006.
- *Section 6. Selection of Characterization Well Locations*—This section provides the rationale and proposed locations of conduit monitoring well pairs.
- *Section 7. Conclusions and Recommendations*—This section summarizes the conclusions and recommendations from the described investigations.
- *Section 8. References*—This section identifies the documents used to support development of this report.
- *Appendices*—The following appendices are included in this report:
  - Appendix A. Official Soil Series
  - Appendix B. Soil Profile Descriptions
  - Appendix C. Photographs of Stream and Cave Spring Gauges
  - Appendix D. Electrical Resistivity Background and Theory
  - Appendix E. SAIC Geophysical Procedures
  - Appendix F. Soil Verification Logbook Records
  - Appendix G. Stream and Cave Spring Gauges Installation Logbook Records
  - Appendix H. Electrical Imaging Logbook Records.

2. SOIL VERIFICATION

SAIC completed an initial SVS at the DU Impact Area. The results of SVS will be used to determine the applicability of soil mapping units defined in the Soil Survey Geographical Database (SSURGO) for Jefferson County, Indiana (USDA NRCS 2005). The soil mapping units will be used for selecting appropriate and representative locations for soil sampling to determine site-specific K_d and site-specific corrosion properties that will be used to conduct site-specific fate and transport modeling.

2.1 SOILS BACKGROUND AND GENERAL SITE DESCRIPTION

The DU Impact Area is within the Muscatatuck Plateau physiographic region and is characterized by broad uplands covered by glacial till with entrenched valleys (Gray 2001). The glacial deposits overlie Paleozoic bedrock consisting of interbedded limestone, dolomite, and shale, and overburden thicknesses based on previously installed monitoring wells range from 10 to greater than 65 feet thick (SAIC 2002). According to Franzmeier et al. (2004), the glacial till is Pre-Wisconsinan age and thought to be Illinioan age or older and is covered with a thick (>6 feet thick) mantle of Wisconsinan age loess (wind deposited silt). The soil region that encompasses the DU Impact Area is described as "moderately thick loess over weathered loamy glacial till" and includes the Cincinnati, Avonburg, Vigo, and Ava soil series (USDA NRCS 1999). The DU Impact Area is a broad loess-covered till plain incised by two streams (i.e., Middle Fork Creek and Big Creek and associated tributaries). The surface relief generally is a result of erosion and down cutting associated with the streams and surface water flow to the streams. The surface water drainage of JPG, including the DU Impact Area, is characterized as exhibiting a dendritic pattern that discharges to the streams. The vegetative cover consists of wooded areas containing deciduous trees and open spaces populated with grasses, sedges, and other herbaceous plants. The U.S. Fish and Wildlife Service (USFWS) uses controlled burns (management of vegetation by fire) to manage some of the grassland areas. A wide variety of wildlife inhabits the area, including terrestrial crayfish and other burrowing animals that may cause localized bio-turbation of the soil. The entire DU Impact Area has undergone anthropogenic disturbance of various types and magnitude. Prior to the establishment of JPG, the majority of the land was agricultural and the soils were disturbed in the act of tilling the lands. Following the establishment of JPG, disturbances ranged from installation and maintenance of the infrastructure (e.g., utility trenching, construction of buildings/structures, and road building) to testing operations in impact fields (i.e., disturbance by detonation) for a great number and variety of ordnance between 1941 and 1994.

2.2 METHODS

The following sections describe the methods used for conducting the SVS. Section 2.2.1 presents quality control (QC) measures and Section 2.2.2 presents the field and analysis procedures.

2.2.1 Quality Control

The study was completed in accordance with the FSP (SAIC 2005a) and FSP Addendum 2 (2006a). All of the field work was completed by a Certified Professional Soil Scientist (CPSS) from the American Registry of Certified Professionals in Agronomy, Crops and Soils (ARCPACS). Standard procedures for describing soils as outlined in the "Field Book for Describing and Sampling Soils" (Schoeneberger et al. 2002) were generally followed in conducting this SVS, such as describing soil color using a Munsell® Color Chart. Additional QC measures that were completed as part of the soil verification consisted of comparing the soil scientist's field notes and maps to the published soil descriptions, review of some of the classification decisions with a second ARCPACS CPSS, and second-party verification of global positioning system (GPS) coordinate file input.

2.2.2 Soil Verification Procedure

The existing soil types (series) mapped in the DU Impact Area were reviewed by superimposing the soil mapping units (polygonal area identified as having soil characteristics of a particular soil series) on an aerial photo base map (Plate 2-1). (Plates are presented at the end of Section 2.) Each soil series may include several different soil mapping units. Soil inclusions are part of nearly every soil mapping unit. Soil inclusions are typically too small to be separated and, therefore, can affect the site-specific interpretations for organic coefficients and corrosion. If the inclusions have similar characteristics to the soil mapping unit within which they are located, few differences will be observed.

Different orders of soil surveys are based on the map scale and land area included in a soil mapping unit, ranging from first-order to fifth-order surveys. First-order (2.5 acres or 1 hectare areas) surveys are the most intensive, requiring the most detailed information to map the soils. Fifth-order surveys (15 to 25 mi^2 or 39 to 65 km^2) typically contain data for regional planning. Soil maps are made from second-order surveys (1 to 10 acres) and allow mapping of soil series. The DU Impact area is mapped at second-order detail and, as a result, can include soils of contrasting types. Soil inclusions result more in Type I errors (commission) versus Type II errors (omissions).

The soil mapping units were generated from the latest data provided by the SSURGO data base (USDA NRCS 2005). The resulting soil map was used to identify the location of prospective transects for conducting field soil verification. For each soil series present in the DU Impact Area (Table 2-1), an Official Soil Description (OSD) was printed from the on-line data base maintained by the Natural Resources Conservation Service (NRCS) (Appendix A). 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 (Plate 2-1 and Table 2-1). A detailed description of the typical soil profile for each series is included in Appendix A (NRCS OSDs). Taxonomic descriptions of each soil series are listed in Table 2-2 for comparison and Table 2-3 correlates the map symbol to its respective soil series. The total acreage of each soil series mapped by the NRCS was measured (Table 2-1) using a geographic information system (GIS). The measurements indicate that the majority (>40 percent) of soil mapped is the poorly drained Cobbsfork series.

Table 2-1. 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)

Table 2-2. Taxonomy of Soil Series Found Within the DU Impact Area Jefferson Proving Ground, Madison, Indiana

Soil Series	Taxonomic Classification*
Avonburg	Fine-silty, mixed, active, mesic Aeric Fragic Glossaqualf
Cincinnati	Fine-silty, mixed, active, mesic Oxyaquic Fragiudalf
Cobbsfork	Fine-silty, mixed, active, mesic Fragic Glossaqualf
Grayford	Fine-silty, mixed, active, mesic Ultic Hapludalf
Holton	Coarse-loamy, mixed, active, nonacidic, mesic, Aeric Endoaquept
Rossmoyne	Fine-silty, mixed, superactive, mesic Aquic Fragiudalf
Ryker	Fine-silty, mixed, active, mesic Typic Paleudalf

* Information derived from Soil Survey Staff, NCRS OSD (2006)

Table 2-3. Selected Characteristics of DU Impact Area Soil Series Jefferson Proving Ground, Madison, Indiana

Soil Series	Map Symbol	Slope*	Depth	Drainage Class
Avonburg	Av	0-6%	Very Deep	Somewhat Poorly
Cincinnati	Cn	1-18%	Very Deep	Well Drained
Cobbsfork	Co	0-1%	Very Deep	Poorly
Grayford	Gr	2-35%	Deep	Well Drained
Holton	Ho	0-2%	Very Deep	Somewhat Poorly
Rossmoyne	Ro	0-25%	Very Deep	Moderately Well Drained
Ryker	Ry	0-18%	Very Deep	Well Drained

* Typical soil series range in slope – not site specific
Information derived from Soil Survey Staff, NCRS OSD (2006)

Transects were selected to cross numerous soil series and covered all but one series identified in the DU Impact Area. The Ryker soil series is mapped in the areas recognized as having a high likelihood of penetrators being present but was not included in either transect due to the relative small area and the limited acreage of the series in the DU Impact Area (4.3 percent of total acreage). Following the review of the published soil descriptions and mapping, the transects were selected to provide access to the majority of the soil series present in the study area and most importantly to the soil series where the DU impact trench and secondary DU impacts occurred and where the highest likelihood of DU penetrators is expected. It was determined by the soil scientist that the two transects selected provided sufficient access to the soil series present within the DU Impact Area to evaluate the applicability of the published soil series and mapping for use in following studies. A secondary consideration in selecting the transect location and orientation was for safe access with respect to the presence of unexploded ordnance (UXO) along the transects and at the individual boring locations. The two transects were located parallel to existing roads to minimize the potential for field crew exposure to UXO. The roads consist mostly of dirt with some gravel and often have minimal storm or surface water drainage ditches adjacent. Figures 2-1 and 2-2 identify these two transects.

The field crew completed shallow hand auger soil borings and documented the soil profiles from each of the soil boring locations along both transects in accordance with the FSP (SAIC 2005a), FSP Addendum 2 (SAIC 2006b), Health and Safety Plan (HASP) (SAIC 2005b), and HASP Addendum 2 (SAIC 2006e). The borings were located approximately 30 to 40 feet from the road. At numerous locations, selected hand auger boring locations had to be moved as directed by the UXO specialist to avoid magnetic anomalies detected during the UXO avoidance procedures. Each soil boring location was determined in the field by measuring the coordinates with a portable GPS. The locations were later plotted with ArcGIS on the soil maps using the GPS-measured coordinates.

A soil scientist compared the soil descriptions generated in the field to the typical soil profiles and the associated characteristics for each soil type (as described in the OSD forms) to determine the best fit soil type. In addition, the total acreage of each NRCS mapped soil type (Table 2-1) inside the DU Impact Area was calculated by overlaying the boundary of the DU Impact Area with the NRCS soil mapping units to gain a perspective of the relative percentages of each soil type present in the study area.

2.3 CONSIDERATIONS

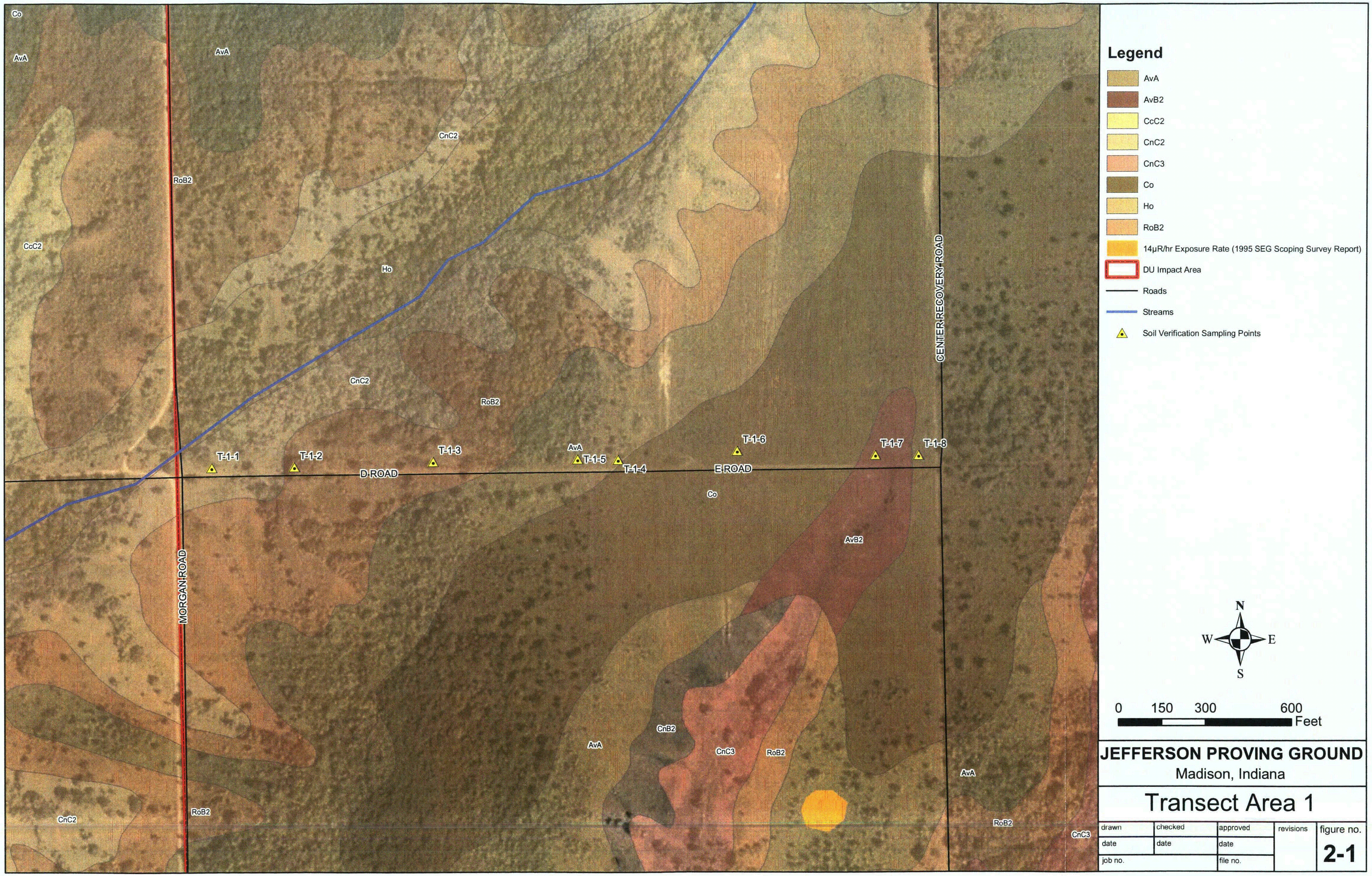
Soils are continuous across the landscape. Although soil mapping unit boundaries are discreet on a map, mapping unit boundaries often have some width associated with the boundary. The change from one soil type to another can range from subtle to abrupt. The difference may be a gradual change, such as a change in relief that affects the wetness of the soil, or an abrupt change due to different parent material or soil forming process. The type of change between two adjacent soil series can affect the relative accuracy to which mapping units can be differentiated by a line on a map. The level of accuracy to which an area is mapped may be determined by the intended use of the resulting map. It is important to determine what soil attributes are of interest and how well they are represented within a special area, such as a soil series, when drafting a map.

The most significant difference among soil series in the DU Impact Area is due to a difference in the types of parent material from which they are derived, and the process from which the soils formed. Soil formed in loess over till is a different parent material from the soil formed on terraces and flood plains and other alluvial (water transported and deposited) parent material. Changes in parent material or depositional processes between mapping units (soil series) are usually more abrupt, resulting in a more accurate boundary between units. An example of this is the Holton Series, which is formed from alluvium and follows the stream courses in the DU Impact Area.

A second factor affecting the resulting soil type in the study area is slope. Slope can vary within a soil series without a change in soil type, but the slope, combined with the position in the landscape (geomorphic landform type), often influences the characteristics and depth of a soil significantly enough to be a different series. The Grayford Series, which forms on the steeper side-slopes of the incised streams and in trough areas with good drainage, tends to be shallower to bedrock than the other associated soil series. However, not all Grayford soil is on steep slopes, and it may gradually grade into another series along a back-slope.

Lastly, there are changes between the soil series at the DU Impact Area based on their moisture regime. The moisture regime is based on the presence or absence of groundwater, seasonal water table, or water holding capacity of the soil in relation to the plant availability of water. The moisture regime can only be qualitatively determined in the field by visual examination. A quantitative determination of the moisture regime is determined by conducting an extensive study involving both field and laboratory exercises that are not necessary for the purpose of this SVS. The moisture regimes assigned by the NRCS allow the grouping of the six soil series at the site into two groups—aquic and udic soil conditions. Aquic soils are commonly saturated and/or ponded (intermittently or seasonally) at a shallow depth, resulting at least for periods in a reducing environment. Udic soils are common soil conditions for temperate, humid climates. Udic soils are generally moist, well-drained, and not dry for lengthy periods of time.

Another useful indication of soil moisture is the NRCS assigned drainage classification. A drainage class is defined as a group of soils having a specific range of relative wetness under natural conditions generally pertaining to the depth to a seasonal or perched water table. The assigned drainage


Legend
AvA
AvB2
CcC2
CnC2
CnC3
Co
Ho
RoB2
14μR/hr Exposure Rate (1995 SEG Scoping Survey Report)
DU Impact Area
Roads
Streams
Soil Verification Sampling Points
MORGAN ROAD
D ROAD
E ROAD
CENTER RECOVERY ROAD
T-1-1
T-1-2
T-1-3
T-1-4
T-1-5
T-1-6
T-1-7
T-1-8
N
W
E
S
0 150 300 600
Feet
JEFFERSON PROVING GROUND
Madison, Indiana
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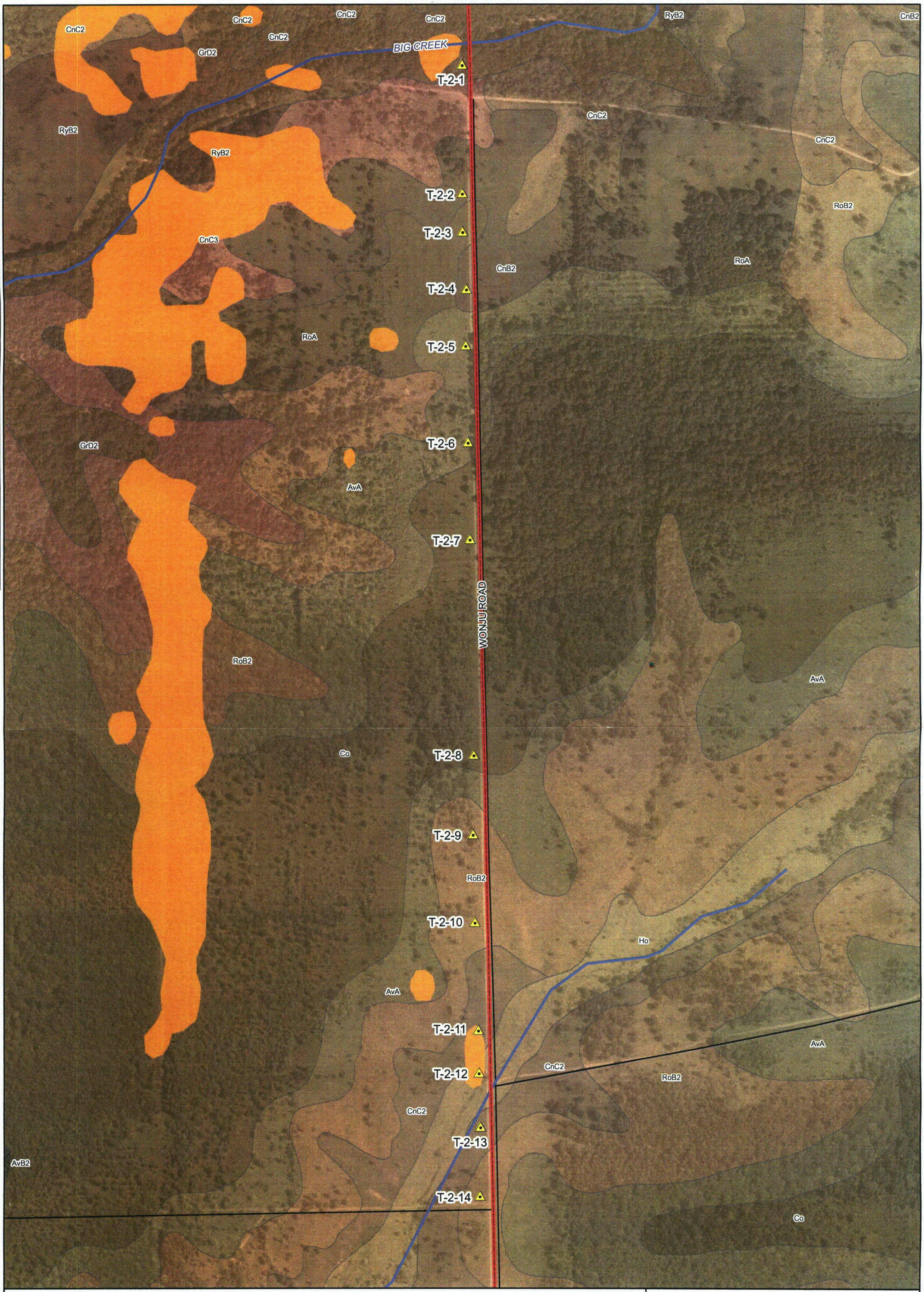

Legend

AvA	Co	RoB2	14µR/hr Exposure Rate (1995 SEG Scoping Survey Report)
CnB2	GrD2	RyB2	DU Impact Area
CnC2	Ho		Soil Verification Sampling Points
CnC3	RoA		Streams
			Roads

Feet
0 300 600 1,200

N

JEFFERSON PROVING GROUND
Madison, Indiana

Transect Area 2

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SAIC Science Applications International Corporation
From Science to Solutions

Figure No.
2-2

classification can be used to separate the soil series at the site as follows: Cincinnati (well-drained), Rossmoyne (moderately well-drained), Avonburg (somewhat poorly drained), and Cobbsfork (poorly drained). Selected soil characteristics, including the drainage class of the soil series present within the DU Impact Area, are listed in Table 2-3. The drainage class may be influenced by micro-topography or other localized influences far too variable to map and delineate for most practical situations, given that one series gradually blends into another. Drainage class can be inferred in the field based on visual observation of redoximorphic features, which indicates the presence of perched water during the growing season. In some soil borings with poorly drained soil, the depth of the boring was limited to less than 3 feet BLS due to the boring filling with water at shallower depths.

2.4 RESULTS

On August 29 and 30, 2006, an SAIC soil scientist observed and described the soil at 22 boring locations along Transect 1 (Figure 2-1) and Transect 2 (Figure 2-2), as illustrated on Plate 2-1. The soil morphology was described from each boring and recorded on soil boring logs (Appendix B) by a CPSS. A comparison of the observed soil characteristics from each boring location was made to the characteristics of the soil series mapped by the NRCS at the same location and to all of the DU Impact Area soil series. The soil series that best fit the observed characteristics was selected for each location and tabulated next to the series mapped by the NRCS to compare the accuracy of mapped versus observed soil types (Table 2-4).

Table 2-4. Soil Boring Location and Soil Series as Mapped by the NRCS and Observed by SAIC in the Field Jefferson Proving Ground, Madison, Indiana

Transect	Boring Number	Mapped Unit*	Observed
1	T-1-1	Cincinnati	Cincinnati
1	T-1-2	Rossmoyne	Rossmoyne
1	T-1-3	Rossmoyne	Rossmoyne
1	T-1-4	Avonburg	Cobbsfork
1	T-1-5	Avonburg	Cobbsfork
1	T-1-6	Cobbsfork	Cobbsfork
1	T-1-7	Avonburg	Avonburg
1	T-1-8	Cobbsfork	Cobbsfork
2	T-2-1	Grayford	Grayford
2	T-2-2	Cincinnati	Cincinnati
2	T-2-3	Rossmoyne	Cobbsfork
2	T-2-4	Cincinnati	Cobbsfork
2	T-2-5	Avonburg	Cobbsfork
2	T-2-6	Avonburg	Cobbsfork
2	T-2-7	Cobbsfork	Cobbsfork
2	T-2-8	Cobbsfork	Cobbsfork
2	T-2-9	Rossmoyne	Rossmoyne
2	T-2-10	Rossmoyne	Avonburg
2	T-2-11	Cincinnati	Cincinnati
2	T-2-12	Holton	Holton
2	T-2-13	Cincinnati	Cincinnati
2	T-2-14	Rossmoyne	Rossmoyne

* SSURGO data base (Jefferson County, Indiana – Interim Product, sv2.7, USDA NRCS 2005)

Along Transect 1, a total of eight locations were bored and characterized (Figure 2-1). At two of the soil boring locations (T-1-4 and T-1-5), the soil characteristics observed indicated the soil was the poorly drained Cobbsfork series instead of the somewhat poorly drained Avonburg series that the NRCS mapped.

A total of 14 borings were completed and observed along Transect 2 (Figure 2-2). From those 14 borings, 5 locations had soil characteristics that matched a soil series with a wetter drainage class than the NRCS series mapped. Four boring locations (T-2-3 through T-2-6) originally mapped as Rossmoyne, Cincinnati, and Avonburg, best fit the Cobbsfork series and one location (T-2-10) mapped as Rossmoyne appeared to be the Avonburg series.

The soil observations were limited by the shallow depth of each boring (3 feet maximum) and the limited number of borings completed during the field verification. The Ryker soil series is mapped in the areas recognized as having a high likelihood of penetrators being present and, due to the limited acreage of the series in the DU Impact Area (4.3 percent of total acreage), it was not included in either transect. It was not necessary to complete a boring in every soil series present within the DU Impact Area to evaluate the applicability of the published soil series and mapping for use in following studies.

2.5 SUMMARY

Based on the results from the field observations, the soil mapping units delineated on the NRCS map were reasonably accurate. From the soil borings observed, the site soil conditions may be wetter than indicated by the NRCS Soil Survey Map. The field data indicate that the somewhat poorly drained Avonburg series may be grouped together with the poorly drained Cobbsfork series for the purpose of interpretation and future site characterization sampling tasks. Combined, these two soil series would comprise approximately 55 percent of the DU Impact Area. The well-drained Cincinnati and Rossmoyne series also may be grouped together, since both have a fragipan subsurface diagnostic horizon, which tends to perch water during parts of the year, and this combination would account for another 32 percent of the DU Impact Area. The well-drained Grayford, Ryker, and somewhat poorly drained Holton series all have somewhat unique soil conditions and are proposed to be treated separately, and combined account for the remaining 13 percent of the DU Impact Area. Plate 2-2 illustrates the proposed soil type groupings. The portion of the DU Impact Area (>55 percent) with somewhat poorly and poorly drained soil exhibits redoximorphic features (soil mottling) that indicate a reducing environment exists in the shallow (<3 feet) subsurface for some period of time during the growing season.

Redoximorphic features or soil drainage mottling are color patterns in the soil formed by the oxidation and reduction of iron and/or manganese caused by saturated or near saturated conditions within the soil. This reducing environment is sufficient to reduce the ferric iron to ferrous iron. The presence of ferrous or ferric iron is an indicator of the oxidative state. No direct measurements of redox potential (Eh) were obtained during this investigation. Corrosion of metals and therefore DU penetrators can be greatly affected by the environment in which it is located. Corrosion rates and processes are much different under reducing conditions than those present under oxidation. The consideration of the presence of the reducing environment will be very important when defining and designing planned future soil sampling and corrosion studies.

The data reviewed during the SVS has enabled the determination that the NCRS established soil series and mapping within the DU Impact Area is applicable and sufficient to be used in defining future sampling efforts and aid in sample location selection. The SVS results have been used to establish a proposed soil grouping of the NRCS established soil series present within the DU Impact Area. These groupings are based on the similar soil conditions and drainage characteristics both observed in the field and defined by the NCRS. When determining sampling locations, frequencies, (e.g., corrosion and K_d studies), particular care should be exercised to ensure that the sample locations are distributed with respect to the soil types groupings presented in this report so that representative results will be determined to capture the different conditions potentially present at the site. In addition, soil properties at sample locations should be verified in the field to determine that appropriate distribution of sample locations at the intended conditions have been achieved.

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THAT CAN BE VIEWED AT THE RECORD TITLED:

"Soils of DU Impact Area Plate No. 2-1."

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D-01

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"Selected Soil Characteristics of DU Impact Area Plate No. 2-2."

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3. SURFACE WATER GAUGE INSTALLATION

SAIC completed the installation of surface water gauging stations in September 2006, consisting 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 un-named tributary of Big Creek (Figure 3-1). The proposed locations of the stream and cave spring gauge locations and general construction are presented in the FSP Addendum 3 (SAIC 2006c). One proposed cave spring gauging station along Middle Fork Creek was not installed and is discussed in Section 3.1.2. The objective of the surface water gauging is to collect surface water stage data at each location. The stage data will be used to calculate corresponding surface water flows by constructing a calibration curve from manual flow measurements collected at each location. The flow data will be used to estimate recharge quantities and characteristics of the aquifer. Along with the stage data, site-specific precipitation data are being downloaded and tabulated from an existing weather station located at JPG. The surface water flow data, along with precipitation data and monitoring well stage data proposed to be collected following the installation of new conduit wells, will be used to evaluate the interrelationships between precipitation, surface water, and groundwater.

3.1 METHODS

The following sections describe the methods used for installing the stream gauges (Section 3.1.1) and cave spring gauges (Section 3.1.2). Section 3.1.3 describes the frequency of data collection. Section 3.1.4 describes the procedures for calibrating gauge stations. Section 3.1.5 includes QC measures.

3.1.1 Stream Gauge Installations

A total of eight (four on Big Creek and four on Middle Fork) stream gauge locations were installed. The construction of each gauging location was modified in the field to use and work around the existing site features at the selected locations. Seven of the eight gauge stations are continuous electronic recording stations with the remaining station consisting of a staff gauge for visual stage readings. Pictures of the final installation are included in Appendix C. Generally, the gauge stations consist of a stilling well and a pressure transducer/electronic data logger. Manual flow measurement locations were selected close to the stilling well locations in areas that had stream bank and bottom flow conditions (e.g., flat bottom, clear of obstructions) that were conducive to collecting manual flows. Individual installation details for the stream gauge locations are as follows:

- *SGS-BC-01*—The stilling well was attached to the downstream side of the bridge at the intersection of Morgan Road and Big Creek. Manual flow measurements are collected approximately 50 to 60 feet upstream of the bridge so that the turbulence from the bridge piers does not interfere with measurements.
- *SGS-BC-02*—The stilling well protector pipe is attached to a tree along the stream approximately 50 feet upstream of the concrete arched bridge on D Road, where it crosses Big Creek in the interior of the DU Impact Area. The stilling well consists of 2-inch black coil pipe that extends from the bottom of the steel protector pipe into the stream and is anchored to the bank and stream bottom with concrete. The end of the coil pipe is capped with a perforated metal pipe and screw cap. The manual measurements are collected approximately 20 feet downstream from the stilling well and approximately 30 feet upstream of the bridge.
- *SGS-BC-03*—The stilling well is attached to a tree along the bank of Big Creek near the eastern boundary of the DU Impact Area. The manual flow measurements are collected approximately 50 feet downstream from the stilling well.
- *SGS-BC-04*—This location is located along an un-named tributary of Big Creek close to the intersection of Morgan and E Roads. The station consists of an incremented staff gauge for

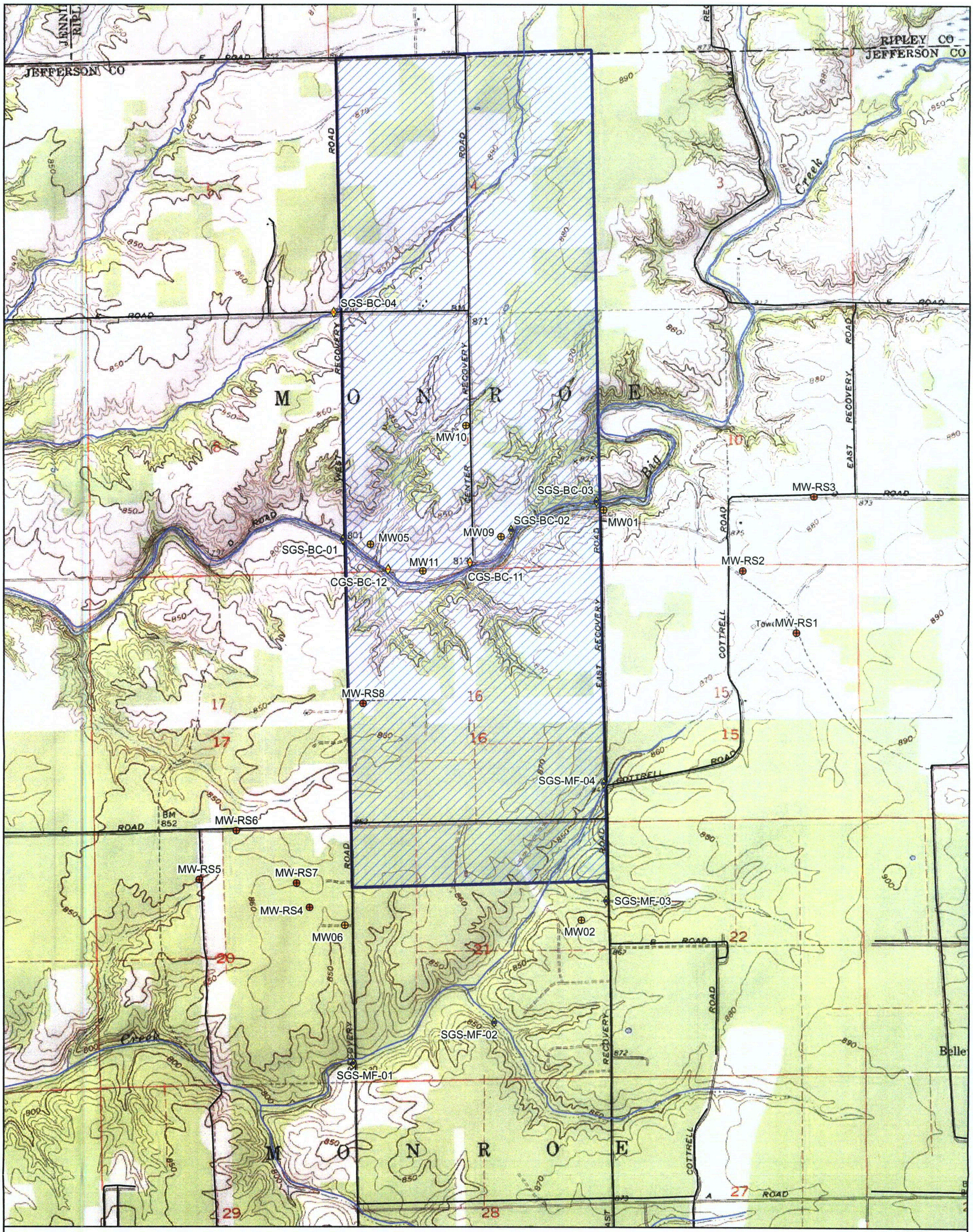
manual/visual stage measurements and does not include a continuous recording data logger. Manual flow measurements are collected approximately 10 feet downstream from the staff gauge.

- *SGS-MF-01*—The stilling well was attached to the downstream side of the bridge at the intersection of Morgan Road and Middle Fork Creek. The manual flow measurements are collected approximately 40 feet downstream from the stilling well.
- *SGS-MF-02*—This gauge was moved from the proposed location at the intersection of Wonju Road and Middle Fork Creek to a location approximately 3,000 feet downstream due to the presence of ponded water that appeared to be attributable to beaver activity. The stilling well is attached to a tree along the stream bank and extends into the main channel of the stream. The manual flow measurements during low flow conditions are collected approximately 50 feet downstream from the stilling well by using the neutral buoyant object procedure as described in the U.S. Environmental Protection Agency (EPA) document entitled "Wadeable Streams Assessment: Field Operations Manual" (EPA 2004). During higher flow periods, the stream flow is measured within several feet of the stilling well using the velocity-area procedure as completed at the other gauge stations.
- *SGS-MF-03*—This gauge is located at the intersection of the tributary of Middle Fork Creek and Wonju Road approximately 1,000 feet north of B Road. The stilling well was attached to the bridge abutment and the railing. The manual flow measurements are collected approximately 40 feet upstream of the bridge.
- *SGS-MF-04*—This gauge was installed at the bridge along Wonju Road immediately north of the intersection with Cottrell Road. The stilling well was attached to the bridge abutment. The manual flow measurements are collected approximately 120 feet upstream of the bridge. The area immediately below and above the bridge is slightly ponded due to a narrowing of the stream channel below the bridge, vegetation growing in the stream channel, and an accumulation of debris.

3.1.2 Cave Spring Gauge Installations

Three cave spring gauge locations were proposed to be installed, two along Big Creek inside the DU Impact Area and one along Middle Fork Creek south of the DU Impact Area. The cave location (MF-02) along Middle Fork Creek was indicated in the 1997 karst study (Sheldon 1997) to include a discharging spring. The cave location was visited during the installation task and was found to not have a spring discharge. Precipitation events had occurred during the first week prior to observing the cave location MF-02 and were significant to cause rises in Big Creek and slight rises in Middle Fork Creek, as well as visually apparent increases in the discharges at BC-11 and BC-12. The cave entrance and initial cave passage evidence (e.g., dry loose leaves, light debris) indicate that spring discharges from the cave have not occurred in some time. Based on these observations, instruments with stilling wells and data recorders would be installed only at the two cave springs locations along Big Creek and would be instrumented with stilling wells and data recorders (CGS-BC-11 and CGS-BC-12).

Each gauging location was unique and construction practices were modified in the field to use the existing site features at the selected locations. Pictures of the final installation are included in Appendix C. Generally, the gauge stations consist of a V-notch weir backing up water in the upstream direction, a stilling well, and a pressure transducer/electronic data logger. Manual flow measurements are collected at the weir by a combination of methods consisting of timed bucket yield of water topping the V-notch weir and measurement of the height of the water topping the weir used for calculation of flow by using the V-notch weir flow calculations. The V-notch was cut into the plywood with a 60-degree opening to provide a flow calibration range that will provide calculable measurable flow that is both low



Legend

- Cave Stream Gauging Station
- Continuous Stream Gauging Station
- Stream Staff Gauging Station
- Monitoring Well Locations
- Range Monitoring Well Locations
- Streams
- Roads
- DU Impact Area

N
W E
S

Note: Proposed stream guage locations subject to adjustment based on field observations.

0 1,000 2,000 4,000
SCALE IN FEET

Jefferson Proving Ground Madison, Indiana		
Surface Water Gauging Station Locations		
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SAIC From Science to Solutions	Revisions: AGM 11/27/06	Figure No. 3-1

K:\GIS_Data\JPG\Projects\Surface_Water Gauging Stations.mxd and high enough for the anticipated discharges from the cave springs. The stilling well was constructed so that the pressure transducer could be placed approximately 4 feet away from the weir to provide accurate water heights above the bottom of the V-notch for calculating the flows. Individual installation details for the cave spring gauge locations are as follows:

- *CGS-BC-11*—This station is located at cave BC-11 on the northern side of Big Creek along D Road approximately 1,000 feet east of Morgan Road. The weir is constructed of marine-grade plywood, which was placed into a trench dug into the ground at the entrance of the cave and concreted in place. The stilling well was secured to an adjacent tree and constructed with an elbow so that the pressure transducer could be placed the proper distance from the weir for accurate measurements.
- *CGS-BC-12*—This station is located at cave BC-12 on the northern side of Big Creek near the intersection of D and Center Recovery Roads. Given the configuration of the cave opening and the drainage to the creek, construction of the weir and the containment of water behind the weir in the upstream direction were more difficult to execute. Initially, the weir was placed into a trench dug to bedrock and concreted in place. Following placement of the weir, water was observed to be short cutting the weir by way of the undercut banks of the drainage swale. Several attempts were made to block or plug the undercut portions. It appeared that the majority of the banks along the spring drainageway were undercut and water was able to flow through openings and gravel and cobbles on the bedrock surface. To remedy the problem and direct all of the cave spring discharge, a 22-mil plastic liner was placed from within the cave entrance, lining the drainage swale and the plywood weir. The edges of the liner were secured in place with a combination of shallow trenching, concrete, roofing mastic, and staples. The installation of the liner successfully directs all of the cave spring discharge through the weir. Due to the large volume of water behind the weir, angle iron was secured to the top to keep the weir from bowing under the weight of the water. Following the successful installation of the weir and containment of water upstream of the weir, the stilling well protector pipe was secured to a nearby tree above the expected Big Creek flood level. The stilling well consists of 2-inch black coil pipe that extends from the bottom of the steel protector pipe into position above the weir and was secured with a bag of concrete. The end of the coil pipe is capped with a perforated metal pipe and screw cap. The placement of the stilling well end is configured so that the pressure transducer could be placed the proper distance from the weir for accurate measurements.

3.1.3 Data Collection Frequency

Initially, manual flow and stage measurements were collected at each gauging station at the time of installation. The data loggers were established to collect water level stage data at the individual stilling wells (at the stream gauge locations) and behind the weir (at the cave spring gauge locations) at a frequency of every 2 minutes. The data recording frequency may be reduced following the collection of several months of data if it is determined that the 2-minute frequency is not necessary. The electronic recording gauging stations are being downloaded along with the collection of manual flow measurements monthly for the first year. Data downloads and manual flow measurements will be completed quarterly for the second year of data collection. The gauging stations presently are planned to be operated for 2 years.

3.1.4 Gauging Station Calibration

Following the first year of data collection, the calibration curves will be constructed for each gauging station location. Individual calibration curves for each gauging station will be constructed by comparing and graphing the recorded surface water stage (level) and the manually measured surface water flow. The construction of the calibration curve will allow the calculation of respective flows for different levels of stage as recorded at each gauging station location.

3.1.5 Quality Control

Function of the field equipment was assessed by several methods during the installation of the gauging stations, as described below:

- Following the installation of the pressure transducer and the electronic stage data recorder, a manual measurement was collected and the level of submergence of the pressure transducer was computed. This level of submergence was compared to the submergence indicated on the pressure transducer to ensure accurate stages were being calculated by the pressure transducer/data recorder.
- Following the V-notch weir installation, the height of the water cresting at the notch was visually recorded, the height of the water cresting the weir as measured by the pressure transducer was recorded, and the flow of water through the notch was measured by completing a timed bucket yield. Flows will be calculated from the two separate cresting water heights above the notch using industry standard V-notch weir formulas, as presented in the FSP Addendum 3 (SAIC 2006c) and compared to the flow as calculated by the timed bucket yield. These comparisons will be evaluated during the calibration curve construction.

Data quality also will be assessed throughout the data collection period using several methods, as described below:

- The level of submergence will be routinely evaluated to determine consistency between the pressure transducer and manual measurements.
- Flow measurement at the V-notch weirs will be routinely evaluated following the methods used during the installation and detailed above.
- Manual flow measurements in the streams will be routinely evaluated by completing replicate measurements. These replicate measurements will be completed by starting on opposite sides of the stream. The manual flow measurements will be compared for reproducibility.

Data download procedures, data collection methodology and frequency are all being completed in accordance with the FSP Addendum 3 (SAIC 2006c). Manual flow measurements are being completed in accordance with the methods presented in the appropriate sections of the "Wadeable Streams Assessment Field Operations Manual" (EPA 2004). All field manual flow measurements are being recorded on standardized field data sheets maintained in the project file.

3.2 SUMMARY

With the exception of the cave spring gauging station at cave MF-02, all of the proposed gauging stations were installed. The gauge at cave MF-02 was not installed due to the absence of a spring at that location and indications that a spring has not flowed from the cave in some time. The stream gauge at SGS-MF-02 was installed approximately 3,000 feet downstream from the proposed location due to the presence of beaver dams and lack of measurable flow at the proposed location. In addition to beaver activity and lack of stream flow, a high concentration of UXO and magnetic anomalies as determined by the UXO specialist during anomaly avoidance procedures was present in areas along this tributary and surrounding areas. The high concentration of UXO caused the selection of a gauging station farther from the road than initially proposed to be able to locate an area that could be safely accessed for installation and manual flow measurement collection. The movement of the gauge location will not have any negative impacts to the data collected or the intended use, since it is still located to adequately record the stage (for flow calculation) for the originally proposed tributary of Middle Fork Creek.

Initial manual flow measurements have been collected, the data recorders are all functioning properly, and initial stage data have begun to be recorded.

4. GROUNDWATER CHARACTERIZATION

Groundwater flow characteristics and flow pathways need to be evaluated in the DU Impact Area. Previous reports and studies at JPG focused on groundwater within the overburden (unconsolidated soil and sediments) above the bedrock and, in a few cases, in shallow bedrock. There was no specific acknowledgement of the unique properties of groundwater flow in a karst environment, such as exists at JPG. In such an environment, the most significant groundwater flow pathway may be present within fractures and solution enhanced features or "conduits" within the carbonate bedrock and along the contact surface between the overburden and the bedrock. In order to complete the groundwater characterization, preferential groundwater flow pathways need to be identified and located. In addition, monitoring wells need to be installed with open screen intervals within the preferential flow pathway features. During the installation of the "conduit" wells, the presence of other potential flow pathways will be evaluated such as the presence of permeable materials and layers within the overburden materials as well as permeable materials or a permeable zone at the overburden-bedrock surface.

4.1 GENERAL DESCRIPTION

Groundwater is the result of precipitation infiltrating the ground surface and migrating vertically through the regolith (soil and decomposed rock layer) to the water table and the bedrock aquifer. Paleozoic bedrock consisting of interbedded Devonian and Silurian limestone, dolomite, with lesser amounts of shale underlie JPG and specifically the DU Impact Area. Overburden thicknesses based on previously installed monitoring wells range from 10 to greater than 65 feet thick (SAIC 2002). The soils at the site have been characterized as generally having a low permeability (SAIC 2002) and the present Environmental Radiation Monitoring (ERM) program monitoring wells (MW-1 through MW-11) and Range Study Wells (RS-1 through RS-8) that are installed into the overburden materials have low yields. Some of the monitoring well logs indicated that sand and fine sands were present, but based on the lack of well yield, it appears that sufficient fine-grained materials reduce the permeability or the sands are not very extensive or hydraulically well-connected. This would suggest that groundwater flow may be concentrated in either the zone at the overburden/bedrock contact or within solution-enhanced discontinuities in the bedrock. The top of bedrock in solution-prone materials is often weathered and has significant permeability that can provide either a separate flow pathway or a pathway that recharges the bedrock discontinuities.

Discontinuities in the bedrock (e.g., faults, fractures, joints, and bedding planes) are avenues for movement of groundwater through the bedrock. Bedrock along these discontinuities slowly dissolves, enlarging the openings. Some of these features become preferentially enlarged with respect to smaller features. In carbonate rocks, such as those that underlie the project area, solution mechanisms favor the development of a few larger openings rather than smaller ones (Fetter 1988). The permeability (capacity for fluid flow) due to the presence of groundwater conduits is often several orders of magnitude greater than the permeability of the unaltered bedrock. Therefore, the majority of the flow through the aquifer occurs within the groundwater conduits. To accurately characterize groundwater flow characteristics in a fractured and solution enhanced (karst) aquifer, these groundwater conduits need to be identified and targeted for the installation of monitoring wells.

The proposed method for locating and identifying preferential groundwater flow paths has been presented in the FSP (SAIC 2005a) and consists of a phased approach of fracture trace analysis, completion of an EI survey, site selection of well pairs, installation of well pairs, collection of stage data, comparison of groundwater stage, precipitation and surface water flow data to evaluate connectivity of the installed wells, and groundwater chemistry sampling. The fracture trace analysis, EI survey, and site selection of well pairs will be completed in that order, since each of the studies uses the previous in defining the successive study. The fracture trace analysis was completed in June 2006 (SAIC 2006d) and is presented in the following sections. The EI survey was competed in July and August 2006 and is presented in Section 5. The site selection of well pair locations is included in Section 6.

4.1.1 Fracture Trace Analysis

An aerial photo fracture trace analysis was completed for JPG to identify possible fracture locations and fracture orientation in the carbonate limestone aquifer in the DU Impact Area. A photogeologic fracture trace is defined by Lattman (1958) as a "natural linear feature consisting of topographic (including straight stream segments), vegetal, or soil tonal alignments, visible primarily on aerial photographs, and expressed continuously for less than one mile. Only natural linear features not obviously related to outcrop pattern or tilted beds, lineation and foliation, and stratigraphic contacts are classified as fracture traces."

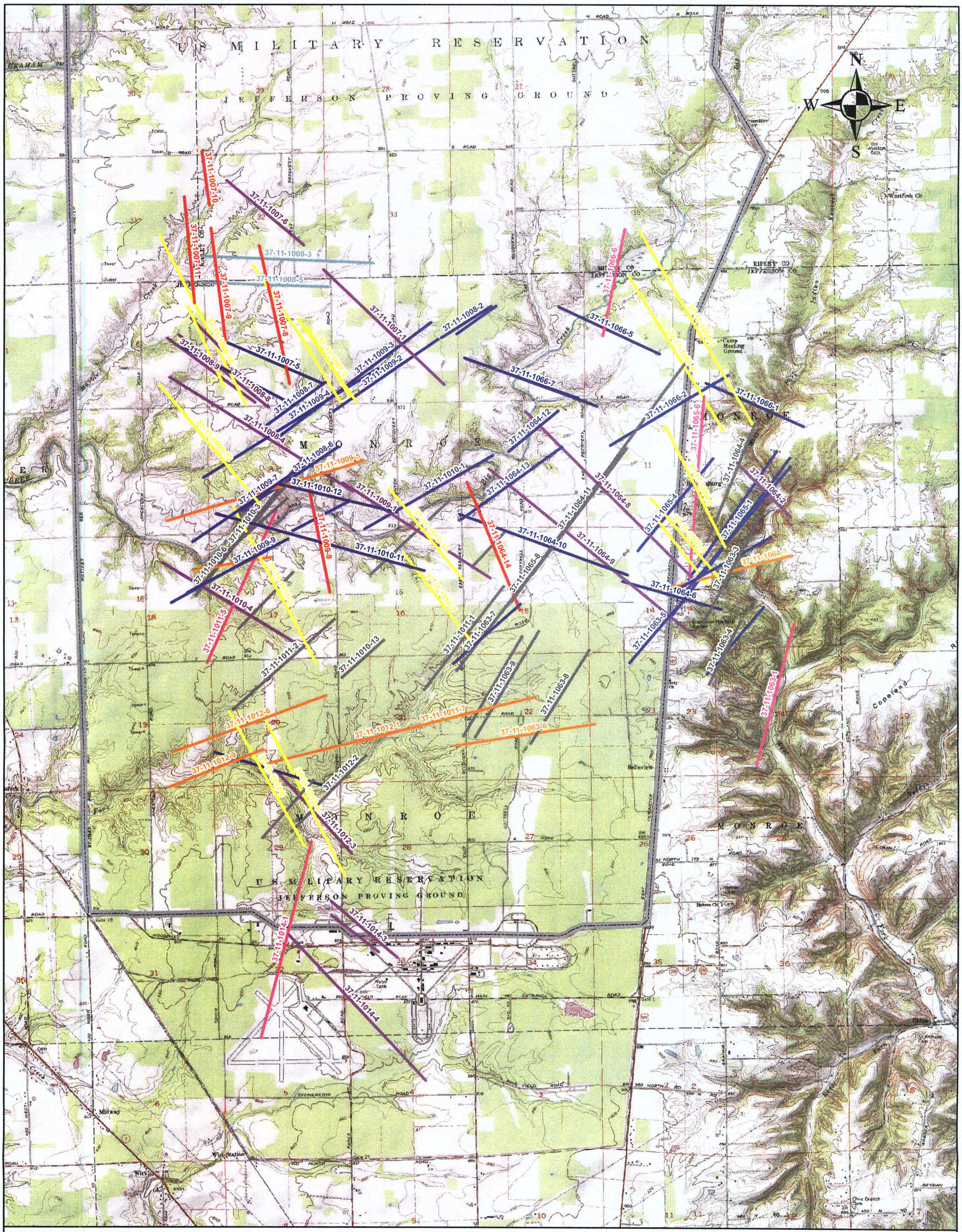
Stereo-paired aerial photographs were obtained from the U.S. National Archives and Records Administration (NARA) showing the site prior to construction of JPG and the DU testing range. Black and white 10- by 10-inch contact prints of photographs taken in November 1937 were obtained at a scale of 1:20,000. The historical aerial photographs were used to map fracture traces and lineaments to help identify enhanced groundwater flow pathways in the aquifer. An area of approximately 22 square miles including the DU Impact Area and immediate surrounding area was analyzed (SAIC 2006d).

The photographs were viewed obliquely and in stereo at various magnifications. Fracture traces were mapped and marked directly on the photographs. The photographs were digitally scanned, imported into Arcview® and superimposed on the site map, rotated, and scaled for best-fit. Straight line segments were aligned with the mapped fractures on the photographs and saved as an Arcview® shape file. Each fracture trace line was assigned an identification number that represents the year of the aerial photograph, the month the photograph was taken, the photograph frame number, and a unique numeral for the fracture trace on that frame, starting with 1, generally in the southwest corner of the frame.

4.1.2 Quality Control

Field correlation or visual verification was completed by the analyst in July 2006 of the fracture trace locations that could be readily accessed along the roads surrounding and bisecting the DU Impact Area. The field verification was restricted to observation from the roadways such that the verification could be completed reasonably safely with consideration for the presence of UXO off the roadways. Field verification of fracture traces was restricted to the area immediately surrounding and within the DU Impact Area, and within the area where characterization wells will be constructed. The verification was completed by viewing the surface topography and surrounding landforms to determine if the conditions (i.e., linear sag or trough) represent that which would be expected with the presence of a fracture(s). Twenty-four fracture traces were field checked with 22 having good (readily apparent/numerous supporting landforms), 1 having fair (less obvious/scarce supporting landforms), and 1 having poor (faint or no supporting landforms) correlating field features.

Mapped fracture traces location and orientation are illustrated in Figure 4-1, overlying the site topographic base map. Each illustrated fracture trace is labeled with the identification number for reference. Because of the registration and distortion associated with the aerial photographs, compounded by the paucity of useful features that survived since 1937, the accuracy of the fracture trace locations is approximately ±200 feet. The error was estimated by comparing fracture trace positions with the positions of topographic features, such as breaks in the ridges, which were caused by fracture traces, and the difference in the position of a single fracture trace mapped on two different photographs.



Legend

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

0 2,050 4,100 8,200

Scale in Feet

Jefferson Proving Ground
Madison, Indiana

Fracture Trace Prevalent Directions

Drawn	Checked
PAE 05/04/06	SMS 05/17/06
Revisions:	Figure No:
	4-1

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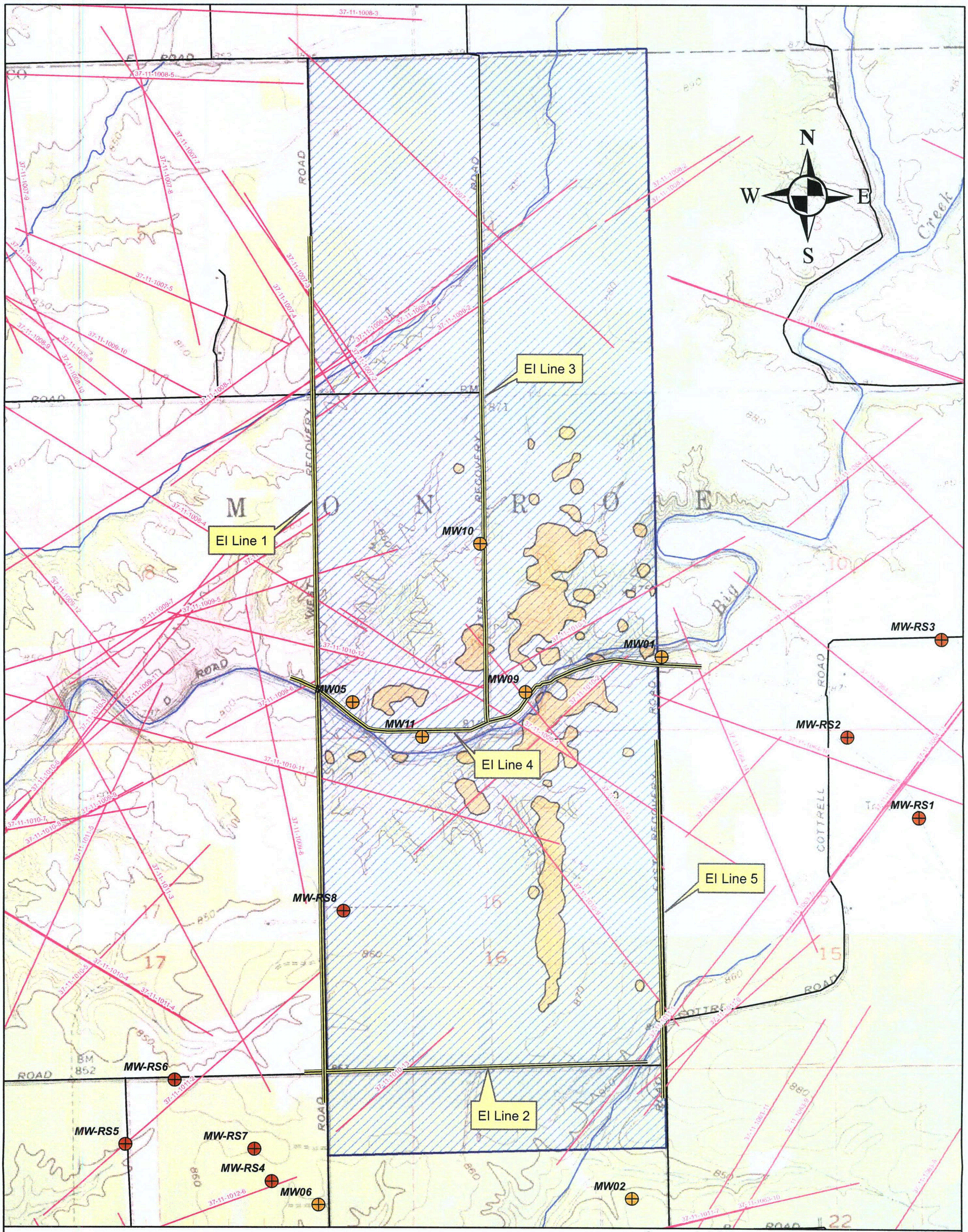
Fracture traces were grouped based on similar orientation and color coded into nine groups, as illustrated in Figure 4-1. Seventy percent of the mapped traces were oriented either North 27 to 59° West (33 fracture traces) or North 31 to 56° East (43 fracture traces). These two orientations are generally 90° apart and are considered one joint set, most likely caused by a single episode of orogenic (mountain-building) deformation or multiple episodes from the same direction.

During the mapping process, fracture traces were given a quality ranking, which is a relative value indicating how distinct the fracture trace appeared when viewed obliquely and in stereo on the aerial photographs. In the case of the JPG fracture trace analysis, most of the fracture traces were faint to moderately distinct, and compared to other karst areas mapped, fracture traces were somewhat generally less distinct. Aerial photograph quality, ground cover, and season in which the photograph was taken can impact this assessment considerably. The mapped traces are not considered to be any less indicative of fracture features based on these constraints.

4.2 SUMMARY

A total number of 110 numbered fracture trace lines were identified from the aerial photographs. The distribution of fracture traces was used to select the location and extent of EI geophysical survey traverse lines that was completed in July and August 2006. The EI results are discussed in Section 5. The fracture traces were used in conjunction with the results of the EI survey to select locations to drill and install paired groundwater monitoring wells in groundwater conduits and is discussed in Section 6. Figure 4-2 shows the identified fracture traces and the proposed EI geophysical survey traverse lines.



Legend

- ERM Monitoring Well
- Range Monitoring Well Locations
- Electrical Imaging Locations
- Fracture Traces
- Streams
- Roads
- DU Impact Area
- 14 µR/hr Exposure Rate (1995 SEG Scoping Survey Report)

Jefferson Proving Ground Madison, Indiana	
Fracture Trace Locations and Electrical Imaging Traverses	
Drawn SMS 10/09/06	Checked TDE 10/09/06
SAIC From Science to Solutions™ Revisions:	Figure No: 4-2

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5. ELECTRICAL IMAGING

The objective of the EI survey was to provide data on potential preferred groundwater flow pathways to support site selection of groundwater characterization well pairs. The results of this study will be used in conjunction with the fracture trace analysis results and the known suspected areas containing DU penetrators to assist in the site selection of monitoring well pair locations, which will be detailed in Section 6. The results of the EI survey also will be used to refine the CSM along with the monitoring well data collected after the installation of the proposed monitoring wells. The survey was conducted in accordance with the FSP (SAIC 2005a) and FSP Addendum 3 (SAIC 2006c).

5.1 BACKGROUND

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). Through the use of multiple electrodes placed in the ground at the same time, advances in inversion theory, computer directed electrode selection and switching, and use of personal computers, this method of geophysical investigation can be completed more efficiently and accurately than previously and has experienced increased use during the last 5 years.

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 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. Background information on subsurface resistivities is presented in Appendix D.

5.2 METHODS

The following sections summarize the methods used for conducting the EI survey (Section 5.2.1), steps to prepare the site to conduct the EI (Section 5.2.2), descriptions of field equipment (Section 5.2.3), description of data collection activities (Section 5.2.4), and QC measures (Section 5.2.5).

5.2.1 EI Field Activities

EI field activities were conducted between July 17 and August 22, 2006. All geophysical measurements were conducted along existing roads in the DU Impact Area. Proposed EI survey lines were selected following the completion of the fracture trace analysis and are illustrated in Figure 4-2. Portions of line 2 were proposed to extend east of the road intersection; however, during anomaly avoidance procedures (see Section 5.2.4), a large number of metallic materials in the subsurface just beyond the end of the road was detected and indicated the potential presence of numerous UXO. A field decision was made to terminate EI survey line 2 at the road to prevent exposure of field personnel to potential UXO hazards.

5.2.2 Field Preparation

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

Initiating the EI survey, individual traverses were marked with push flags by the field crew, using 300-foot measuring tapes relative to road intersections and interpreted fracture traces of interest indicated in aerial photographs. The proposed stake locations were examined for any surface indications of cultural interferences and the presence of location reference points. 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.

5.2.3 Principal Field Equipment

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 contain fixed cylindrical stainless steel switches that attach to the stainless steel electrode stakes placed into the ground. The SuperSting® system, a multi-electrode switching system, passes an electrical current automatically along multiple paths at various depths and measures the resulting associated voltages. This system utilizes two arrays of multicore cables, which extend 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.

5.2.4 Data Collection Activities

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 feet. Elevations were measured in feet, and converted to meters using a conversion factor of 1 meter equals 3.281 feet. Therefore, all site data were collected (or converted) in meters so all resistivity values are presented in ohm-meters.

Due to the remote potential for fuse detonation of UXO, 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®, that 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 ordnance present, a safe distance established by EOD personnel was 1,000 meters (6/10 mile) 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 could observe when the end of the command file was reached, and turn off the SuperSting® prior to re-entering the area.

In the event a wireless bridge link could not be attained due to equipment issues, topography, or vegetation interference, all personnel except the operator were removed from the area. During a roll, the newly placed electrodes are sensing subsurface voltage and not injecting current. Therefore, SAIC determined that the SuperSting® could be located at or near the end of the line of electrodes, and the survey could be initiated followed by an immediate withdraw from the area. Return time was estimated by doubling the normal time required to collect the data, providing for automated re-measurement for electrode results beyond the bounds of acceptability established when programming the SuperSting®.

5.2.4.1 Contact Resistance Check

Prior to collecting data, the operator performed a contact resistance check across the electrodes to ensure acceptable resistance (electrical contact) was present between the earth and the electrode. In the event an abnormally high contact resistance was measured (greater than 2000 ohm-meters), indicating potentially poor electrical contact between the stake and the soil, a salt/water solution was re-applied to the ground surface immediately surrounding the stake or electrode to reduce the contact resistance.

Generally, the contact resistances were very good or in an acceptable range at the site. Shallow bedrock was present near Big Creek, and contact resistances were elevated due to the lack of soils and the naturally resistive bedrock. Following rainfall events, or during early morning hours on days when dew was present, contact resistances were unusually low. These low readings were attributable to the presence of fine-grained material in the silt loam soils.

Intermittently, contact resistance tests would indicate unusual conditions. High contact resistance following the application and re-application of saltwater and replacement of the electrode stake were indications for concern. These conditions typically occurred during a hot afternoon, when an electrode was located in a sunny location. These conditions led to other equipment testing to determine if the cause of the high contact resistance was a result of the switch "sticking" or complete switch failure. Several sections of cables and electrodes were swapped out with functional replacement cable sections during the survey following the identification of switch failures.

5.2.4.2 EI Data Collection

The data were collected with a dipole-dipole electrode arrangement. With this survey method, two electrodes were used to provide current to the subsurface in one location, while two other electrodes some distance away were used to measure the voltage. The dipole-dipole array is useful for deeper investigations where a long layout of electrodes may be difficult. During this survey, the cables used included 84 switches that were attached to the electrode stakes to complete the electrical circuits between the electrical switching box and the earth. The SuperSting® system was programmed (command file) to use 84 electrodes (4 at a time—2 current and 2 potential), with 12-electrode "rolls." The command file in the SuperSting® system directed the automatic selection of individual sets of four switches and electrodes at a time for each measurement. The SuperSting® system continued selecting sets of 4 switches and electrodes until all dipole-dipole arrangement selections were completed using all of the 84 installed electrodes. Then, the first 12 electrodes were picked up from the start of the line and "rolled" or placed at the end of the line to electrode locations 85 through 96. After the command file has completed recording data with these new electrode locations, the next "roll" is completed by moving electrodes 13 through 24 to locations 97 through 108. Therefore, by repeating this process of "rolls," an EI line can be extended to any length required.

For the purpose of this EI survey and the desired depth of approximately 150 feet BLS, individual stainless steel electrode stakes were placed into the ground at a spacing of 9.8 feet (4 meters) along each traverse. A minimum of 30 resistivity measurements were made at 1-second intervals at each location that was surveyed.

5.2.5 Quality Control

The data collection and processing was conducted in accordance with the FSP (SAIC 2005a), FSP Addendum 3 (SAIC 2006c), and the geophysical procedures included in Appendix E. Portions of the geophysical procedures are summarized in the applicable sections of this report, and any additions or modifications to the procedures are discussed. In addition, procedures specific to this investigation, such as digital field-file naming conventions, are discussed.

In preparation for data collection, a command file was prepared to permit consistent data collection. The command file identifies the electrodes to be used as current electrodes (electric current induction points) and potential electrodes (electric current measurement points) for each measurement to be performed. The use of a command file ensures that the method of data collection (e.g., electrode array, electrode sequence) is consistent throughout the entire data collection.

Data processing involves four distinct steps, using three separate software packages. Data processing typically included tracking files, data editing, forward modeling the data, contouring and presenting traverse profiles, and compiling the data for the site. To minimize errors and provide an audit trail of the geophysical data processing, a series of data tracking and data processing forms was used. Examples of the forms used for the survey are included in the geophysical procedures provided in Appendix E. Completed forms are retained in the project files.

The apparent resistivity measurements were determined to have a number of spurious values that created an added degree of complexity during the editing and processing steps. Editing was completed and repeated a number of times, and the modeled resistivity values for different levels of editing were compared for model stability, error, and consistency. The number and location of data values in addition to model consistency and stability were all considered during data interpretation and presentation.

5.2.6 Data Processing

The following sections describe the processing of GPS data (Section 5.2.6.1) and EI data processing (Section 5.2.6.2). Section 5.2.6.3 explains how EI data are prepared for presentation.

5.2.6.1 GPS Data Processing

GPS data were downloaded via computer using Trimble's GPS Pathfinder® Office software in accordance with the manufacturer's instructions. Once the data were downloaded, a GPS track map was viewed for inconsistency. In most cases, the GPS position filters automatically removed erroneous data points. In such cases where multi-path errors were observed as a result of reflection of the GPS signal from nearby structures or trees, erroneous data points were removed manually and automatic interpolation was made between good measurements. Once GPS information was verified to be true and accurate, GPS information was exported from the Pathfinder® Office software in required formats to be used in other software packages during the data processing and mapping.

5.2.6.2 EI Data Processing

The data processing was conducted in accordance with the geophysical procedures included in Appendix E and FSP Addendum 3 (SAIC 2006c). Data processing involves four distinct steps, using three separate software packages. Data processing typically included tracking files, data editing, forward modeling the data, contouring and presenting traverse profiles, and compiling the data for the site. To minimize errors and provide an audit trail of the geophysical data processing, a series of data tracking and data processing forms was used. Examples of the forms used for the survey are included in the geophysical procedures included in Appendix E. Completed forms are retained in the project files.

Modeling of the data was performed using RES2DINV® commercially available from GeoTomo Software of Penang, Malaysia. Modeled apparent resistivity can be compared to the measured apparent resistivity in order to estimate the goodness of the model. As a means to evaluate the data quality, the model blocks were plotted with a relative evaluation of the model sensitivity. Lower sensitivities indicate a lower confidence in the model in this area. Higher sensitivities are present along the sides and bottom of the model as a means of constraining the model, and do not indicate data redundancy or quality. This information is considered during the interpretation of the EI results. In addition, the model uncertainty was examined. Goodness-of-fit between the model and measured apparent resistivity also were used to generate minimum resistivity and maximum resistivity profiles of the data. These profiles were used to verify the reasonableness of the data and the appropriateness of the inversion model. These profiles are discussed further in Section 5.3.

5.2.6.3 Preparation of Data Presentation

At the conclusion of modeling, data files were exported in Surfer® format for final data processing and generation of figures for presentation. These Exported Surfer® files contain depth, distance, and modeled resistivity, and are identified with the addition of "_toporeslinearXYZ.dat" to the file name indicating that topography is present, inline distances are linear, and XYZ data are present.

Final data processing involved the generation of color-enhanced contour cross-sections of the data using Surfer® mapping and processing system, commercially available from Golden Software, of Golden Colorado. This activity was completed to allow flexibility (e.g., different scales) in the data presentation, and the annotation of surface cultural features that may be relevant to the interpretation of the data. Surfer® was used to grid the data using a kriging grid method with a 1.6-foot (0.5-meter) grid. Finally, Surfer® was used as an annotation tool to convey interpretation information.

All files generated during the data processing sequence, including control files used to drive the various program modules, were documented on Surfer® Data Processing Forms. These forms are retained in the project files.

5.3 RESULTS

Data interpretation was formulated based upon detailed examination of the data presented on the line profiles. Top of bedrock was not correlated with well data; however, based upon examination of the resistivity data, gradient changes can be interpreted to be near a resistivity of 500 ohm-meters. Sags in the top of bedrock can serve as collection locations for infiltrating surface water and represent the first preferential groundwater flow pathways for groundwater. Sags also may represent locations of weathering and bedrock fractures, which are inadequately developed or too small to discern directly. Vertical and near vertical discontinuities in high-resistivity bedrock can be interpreted to represent significant bedrock fractures, which represent the second preferential groundwater flow pathways. Bedrock fractures are interpreted as fractures, where a clear decrease is present in the resistivities, or possible fractures, where the resistivity decrease is less pronounced.

Finally, low-resistivity features within the bedrock can represent water or mud-filled solution cavities or highly weathered zones 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 that represent the third potential preferential groundwater flow pathway. Similar low resistivity features may exist at a number of locations within the data; however, the data quality or model block sensitivity is not adequate to warrant significant emphasis on these features.

As a final note, the data were found to be somewhat noisy at the site. Due to the presence of noise at the maximum design depth (150 feet BLS), deeper data were interpreted with caution. Unusually high or low resistivities in the deeper portions of any cross section were treated with caution, and commonly found to be related to noisy data. Two sources of noise have been identified. First, highly variable surface contact resistances were found to be present. When bedrock is present near the surface (such as found along the creek or stream along EI Traverse 4, Figure 4-2), high contact resistance is to be expected. Outside the creek or stream areas, the soils were found to be very conductive, and very low contact resistances were commonly found. However, the contact resistances were found to be sensitive to soil moisture, and quickly fell following a precipitation event and rose within hours as the soils dried. Therefore, the surface resistivities were found to be variable.

The second noise contributor appears to be related to heat during data collection. Temperatures during afternoon hours of data collection frequently climbed into the upper 90°F range. Particularly for electrodes that were exposed to long periods of direct sunlight, the stainless steel cylinder containing the electrode switch would become very hot to the touch. Intermittent electrode switch failure was observed during normal field checks, and appropriate corrections were made. Prior to failure, some switches may have occasionally "stuck," resulting in erroneous data being collected. While many of these resulted in measurements that were removed during the editing process, some of these measurements may have remained and contributed to the noise present.

Given the interpretation constraints and data limitations recognized in the preceding paragraphs, the data are adequate to use for the intended purposes (i.e., for the identification of fractures and solution-enhanced zones within the bedrock). All EI data traverses are presented without distortion. Horizontal and vertical scales have been prepared and presented at 200 feet per inch. For convenience of presentation, sections have been broken every 3000 feet, with the left edge of the lower section representing a continuation of the right edge of the upper section. Interpreted anomalies are indicated as "possible" or "probable" fractures or features of interest (e.g., potential sediment-filled void, caves). The following sections provide details for each transect, data point volume collected, and interpretation results of the data.

5.3.1 Line 1

Line 1 is oriented south to north along the eastern edge of Morgan Road (Figure 4-2). The line was proposed to be 14,085 feet long. Data were collected over a distance of 14,161 feet (4,316 meters or 1,080 stations). Thirty-one anomalies were identified as 29 probable or possible fractures and two features of interest. Their locations are identified on Figure 5-1. Depth to bedrock across the traverse is estimated to range from 10 to 20 feet, except in zones of deeper weathering, usually corresponding to interpreted fractures.

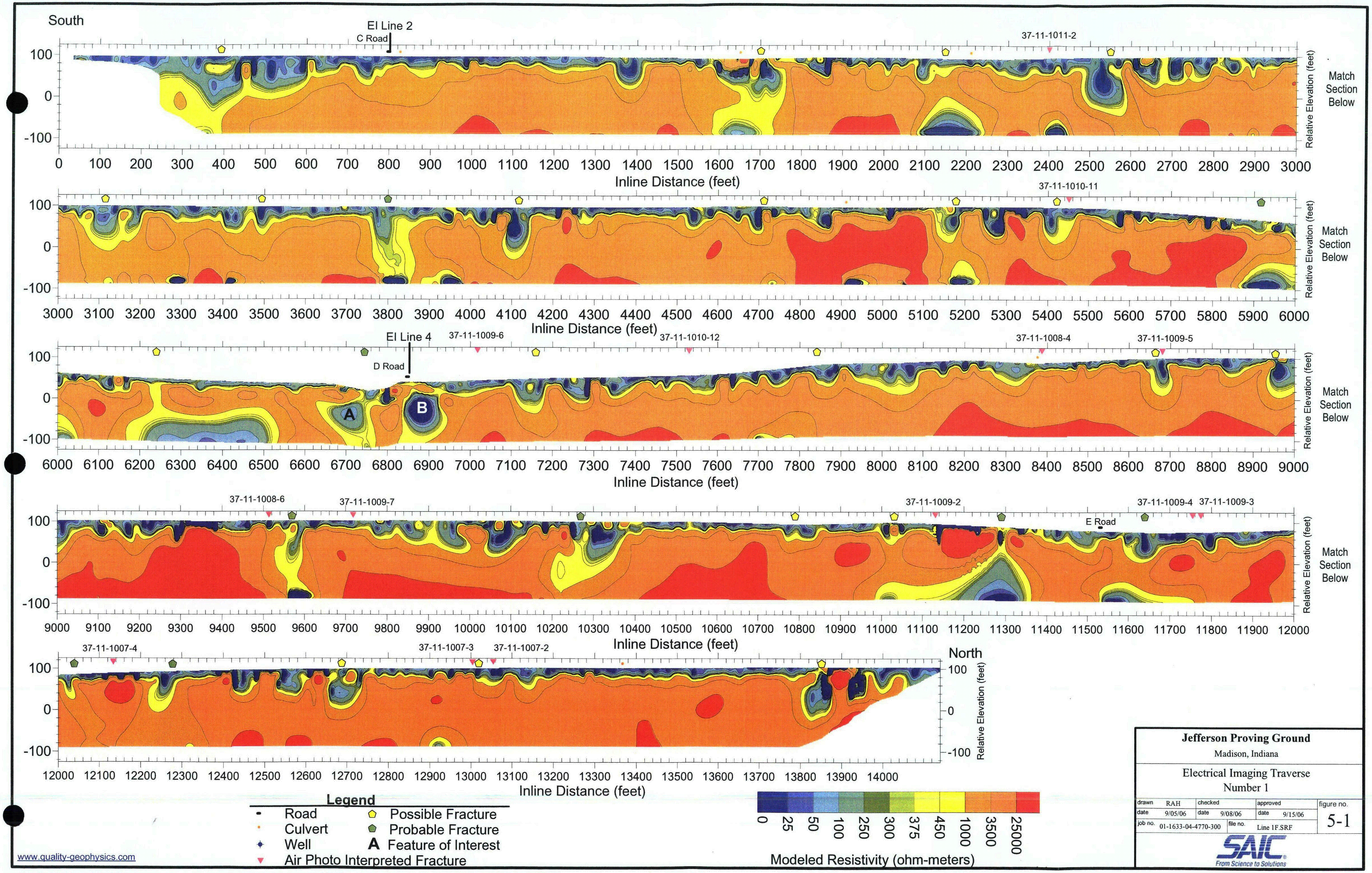
5.3.2 Line 2

Line 2 is oriented west to east along the southern edge of "C" Road (Figure 4-2). The line was proposed to be 6,700 feet long. The portion of line 2, proposed to extend east of the road intersection, was not completed given the presence of and safety concerns associated with a large number of metallic materials in the subsurface just beyond the end of the road. Therefore, only 5,813 feet (1,772 meters or 444 stations) of data were collected.

Five anomalies were identified as probable or possible fractures. Their locations are identified in Figure 5-2. Depth to bedrock across the traverse is estimated to range from 20 to 30 feet, except in zones of deeper weathering, usually corresponding to interpreted fractures.

5.3.3 Line 3

Line 3 is oriented south to north along the western edge of Center Recovery Road (Figure 4-2), north of Big Creek. The line was proposed to be 8,650 feet long. Data were collected over a distance of 8,649 feet (2,636 meters or 660 stations).


South
North
El Line 2
C Road
El Line 4
D Road
E Road
37-11-1011-2
37-11-1010-11
37-11-1009-6
37-11-1010-12
37-11-1008-4
37-11-1009-5
37-11-1008-6
37-11-1009-7
37-11-1009-2
37-11-1009-4
37-11-1009-3
37-11-1007-4
37-11-1007-3
37-11-1007-2
A
B
Match Section Below
Relative Elevation (feet)
Inline Distance (feet)
Legend
Road
Culvert
Well
Air Photo Interpreted Fracture
Possible Fracture
Probable Fracture
A Feature of Interest
0 25 50 100 250 300 375 450 1000 3500 25000
Modeled Resistivity (ohm-meters)
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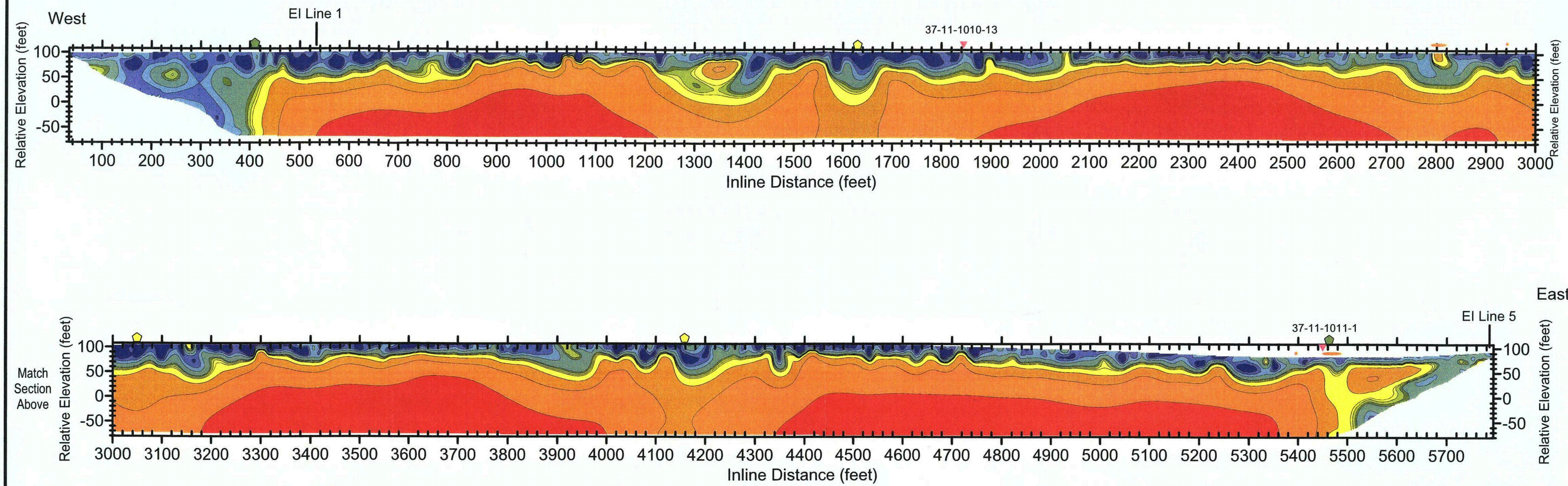

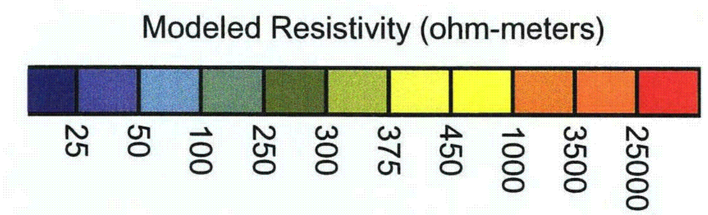

Legend

- Road
- Culvert
- Well
- Air Photo Interpreted Fracture
- Possible Fracture
- Probable Fracture
- A Feature of Interest

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Twelve anomalies were identified as probable or possible fractures. The anomaly locations are identified in Figure 5-3. Depth to bedrock across the traverse was more variable than other traverses and ranged from 10 to 75 feet. A few large broad areas of deeper bedrock (and corresponding thicker unconsolidated materials occur along this traverse.

5.3.4 Line 4

Line 4 is oriented west to east along the northern edge of "D" Road (Figure 4-2). The line was proposed to be approximately 7,200 feet long, following the turns of the roadway. A total of 7,546 feet (2,300 meters or 576 stations) of data were collected.

Twenty-one anomalies were identified as probable or possible fractures. The anomaly locations are identified in Figure 5-4. Depth to bedrock across the traverse is estimated to range from 0 to 30 feet, except in zones of deeper weathering, usually corresponding to interpreted fractures.

5.3.5 Line 5

Line 5 is oriented south to north along the eastern edge of East Recovery Road, south of Big Creek (Figure 4-2). The line was proposed to be 7,000 feet long. A total of 7,074 feet (2,156 meters or 540 stations) of data were collected; however, only 6,108 feet (1,860 meters or 466 stations) of digital data were able to be recovered due to a damaged cable that was not discovered until the equipment and team were demobilized from the site.

Nine anomalies were identified as probable or possible fractures. The anomaly locations are identified in Figure 5-5. Depth to bedrock across the traverse is estimated to range from 0 to 50 feet, except in zones of deeper weathering, usually corresponding to interpreted fractures.

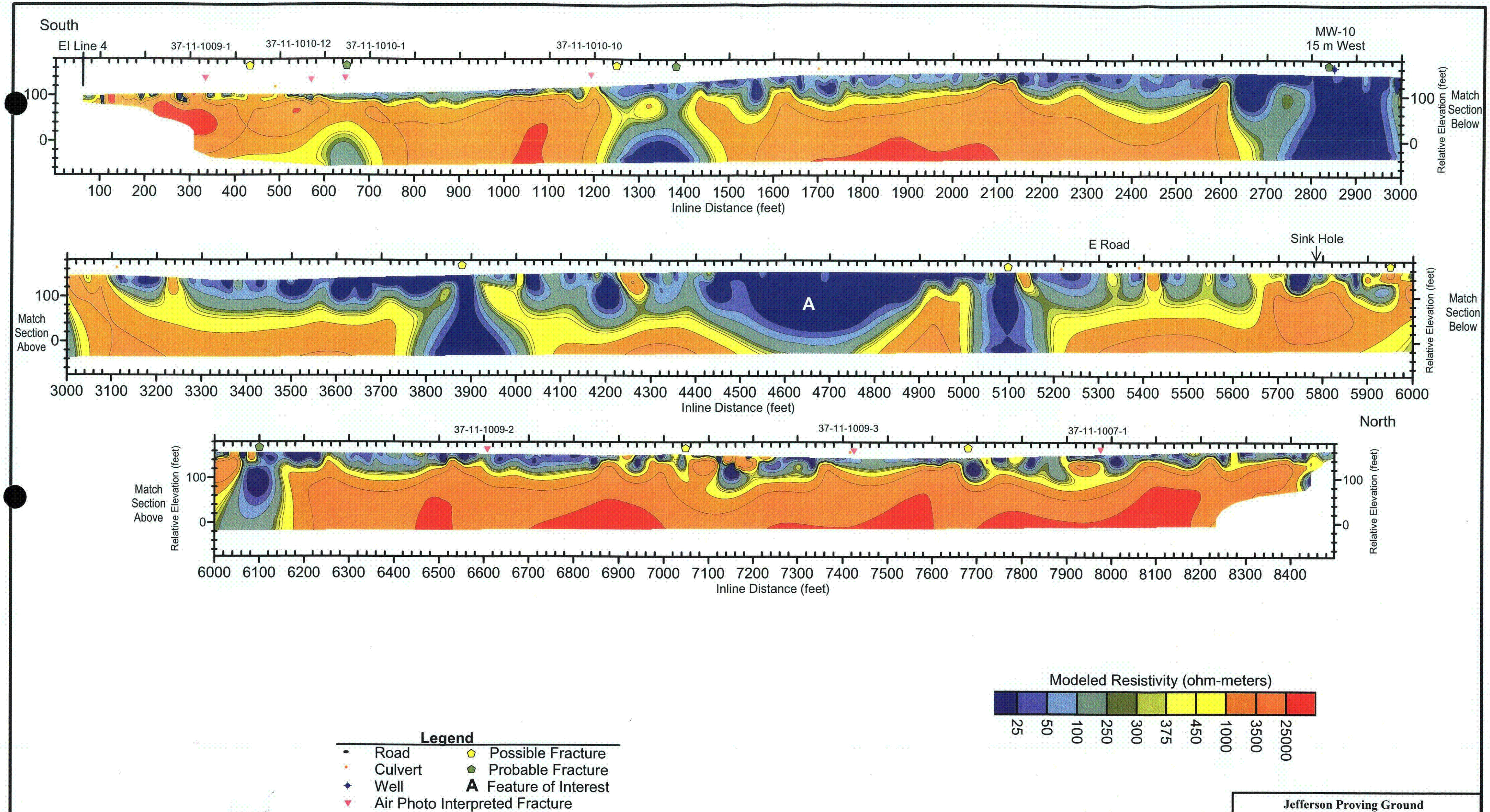
5.4 SUMMARY

There are limitations to all remote-sensing methods. Common electrical resistivity limitations that SAIC considered during interpretation and presentation include the following:

- ***Nonuniqueness***—It is well-recognized that with the inversion of apparent resistivity data that slightly different geologic models can result in similar computed apparent resistivities.
- ***3-D Geology***—A basic limitation of two-dimensional data is the effects from nearby three dimensional (3-D) features that may serve to bias the data. If there are significant variations in the subsurface resistivity in a direction perpendicular to the survey line, distortions in the model can result.
- ***Unusual Ground Conditions***—If a very conductive or resistive near surface layer is present, it may be difficult to place enough current into the subsurface to be detected, or the voltage difference may not be large enough to be detected easily. Caution should be exercised when interpreting information near the locations of underground utilities. Culverts are the only known underground utilities present within the EI survey area and were documented when observed in the field. The locations of the culverts are illustrated on the presentations of the individual EI lines and their presence was considered during the interpretation.

The survey undertaken includes standard and/or routinely accepted practices of the geophysical industry. SAIC utilized and modeled the EI data collected to reflect the subsurface conditions at the site. However, no subsurface survey is 100 percent accurate and SAIC cannot accept responsibility for inherent survey limitations or unforeseen site-specific conditions. 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 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 feet 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. An assessment of these features should be considered following correlation to drilling features and activities.



Jefferson Proving Ground
Madison, Indiana

Electrical Imaging Traverse
Number 3

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job no. 01-1633-04-4770-300	file no. Line 3F.SRF		

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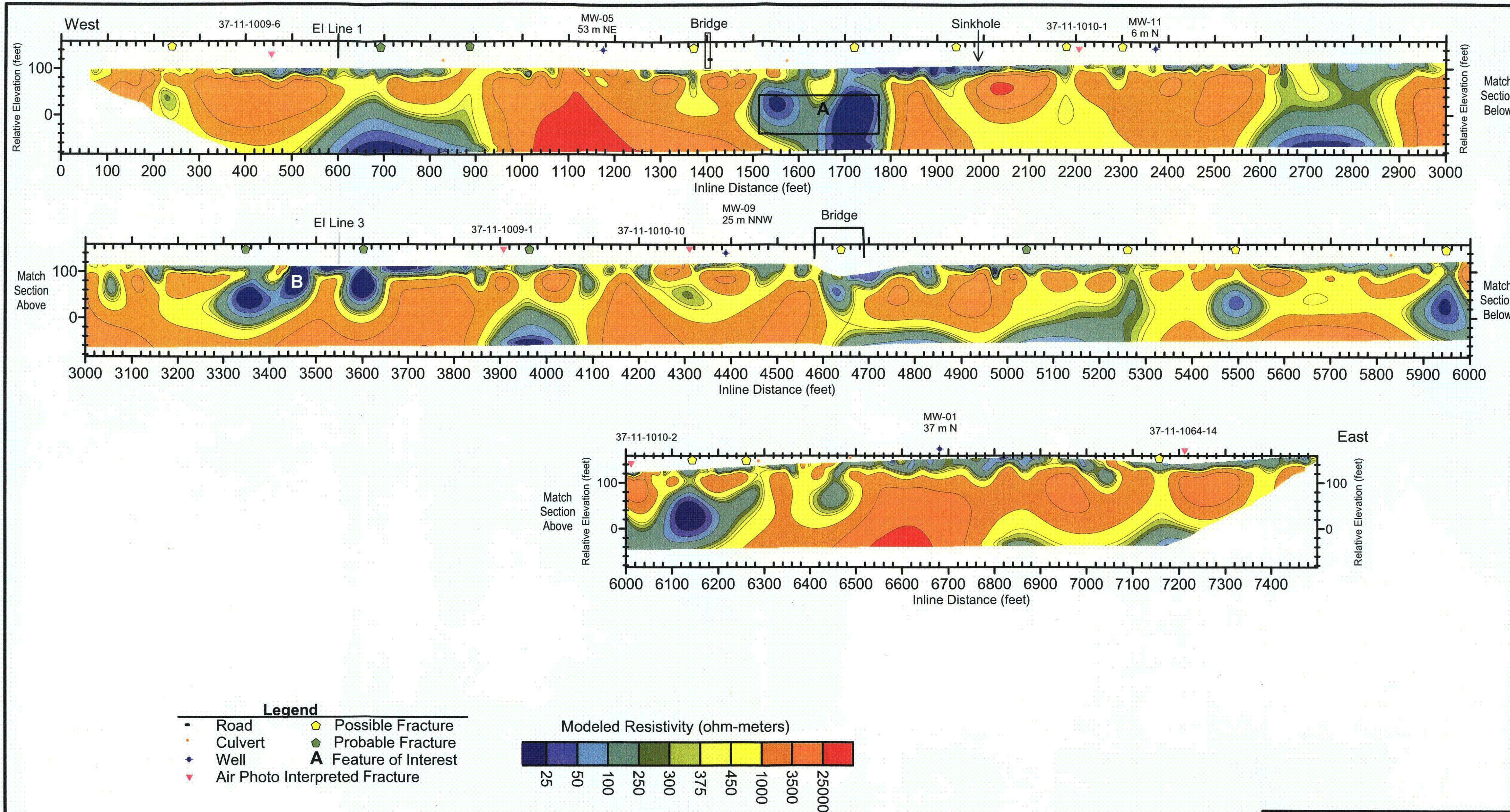

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Jefferson Proving Ground

Madison, Indiana

Electrical Imaging Traverse
Number 4

drawn RAH	checked	approved	figure no.
date 9/05/06	date 9/08/06	date 9/15/06	5-4
job no. 01-1633-04-4770-300	file no. Line 4F.SRF		

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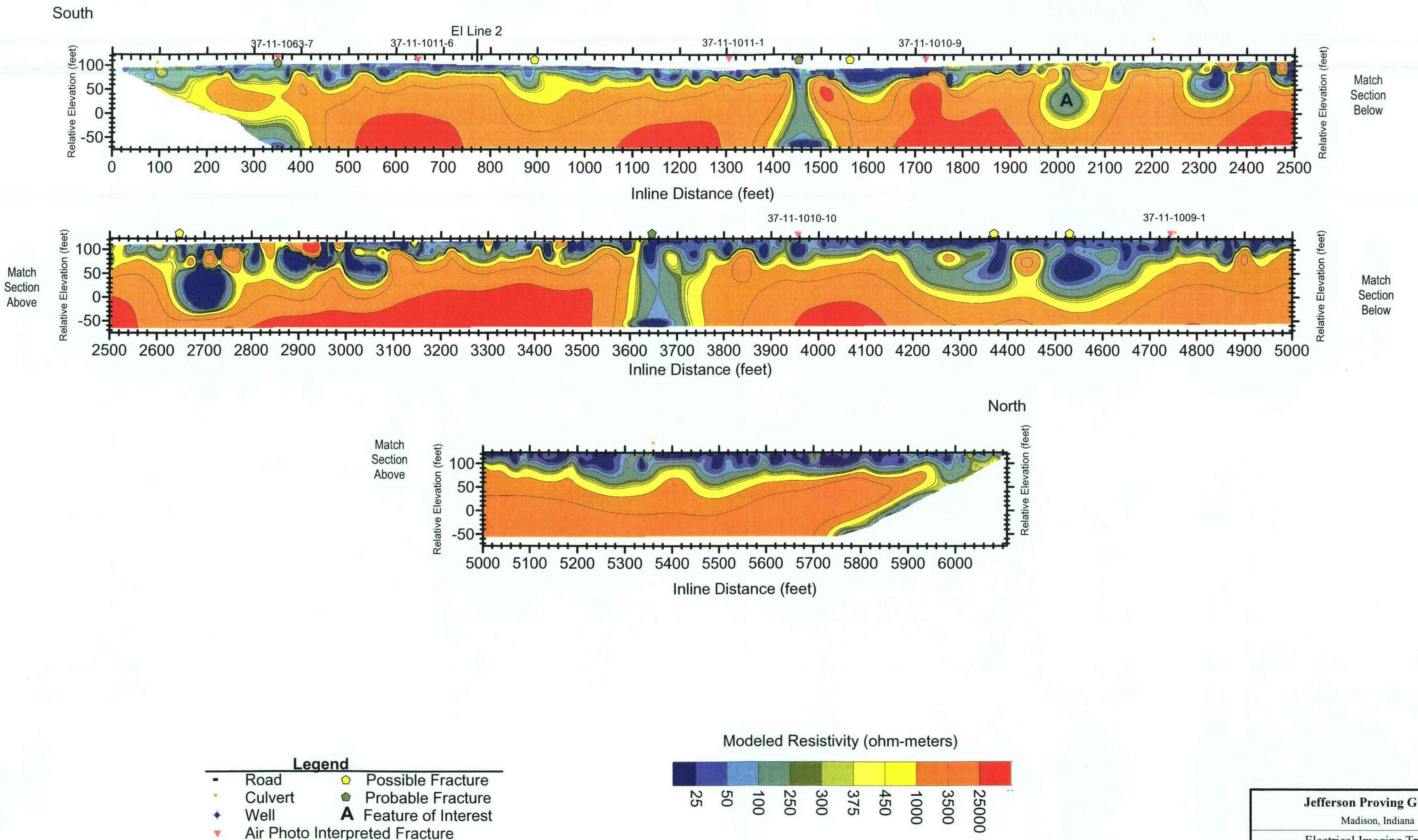

Jefferson Proving Ground

Madison, Indiana

Electrical Imaging Traverse Number 5

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6. SELECTION OF CHARACTERIZATION WELL LOCATIONS

Based on the present CSM and the preliminary information presented in previous JPG reports and published materials, it is anticipated that a significant portion of groundwater flow from the DU Impact Area occurs within preferential flow pathways or conduits within the bedrock aquifer. To evaluate DU presence in the groundwater or the potential for DU migration, these preferential flow pathways need to be located and wells installed so that screened intervals intersect the "conduits." The proposed "conduit" well pair locations will support the refinement of the CSM, characterize the bedrock groundwater flow in the area of the DU Impact Area, confirm the presence of the preferential flow pathways (conduits), and provide the basis for monitoring points for groundwater stage monitoring and groundwater quality sample collection.

6.1 METHODS

The locations of features of interest and probable and possible fractures as identified in the results of the EI survey were plotted (Figure 6-1) using GIS and overlain with the site aerial photograph and the fractures established during the fracture trace analysis. The correlation between the locations of fractures identified during the fracture trace analysis and the EI fracture locations were reviewed to determine how well the locations from the two methods correlate. The correlation of the locations between the two methods were ranked for each fracture location identified with EI and assigned rankings of excellent (within 200 feet of each other), probable, possible, or none; the rankings are illustrated at the locations in Figure 6-2. The quality ranking of the match between the fracture trace and the EI feature was downgraded to probable or possible if multiple features match with a single fracture trace.

6.2 RESULTS

The following sections presents the results associated with selection of conduit well location evaluations. The rationale is presented in Section 6.2.1. The evaluation of downgradient flow directions with respect to conduit well coverage is presented in Section 6.2.2. The confirmation that recommended well locations intersect with subsurface conduits is presented in Section 6.2.3.

6.2.1 Rationale for Selection of Monitoring Well Pair Locations

The following sections present recommended locations for "conduit" well pairs (Section 6.2.1.1) and overburden well pairs (Section 6.2.1.2).

6.2.1.1 "Conduit" Well Pair Locations

Nine candidate "conduit well" pair locations were selected based on the results of the studies and the likelihood that conduits of groundwater flow could be intercepted at those locations. Four alternate well pair locations (Numbers 11-14, Table 6-1) were selected in the event actual site conditions at the candidate locations are such that drilling activities can not be completed at those locations. Examples of conditions that would prohibit drilling could consist of excessively uneven or sloped ground surface, saturated ground surface material, or high concentration of UXO. Several of the alternate locations are located nearby or adjacent to candidate locations and would represent replacement locations. If an alternate location would need to be selected, considerations for good site coverage of well locations would be revisited. The candidate well pair locations represent the preferred or "first choice" "conduit" well pair locations. The candidate and alternate well pair locations are illustrated in Figure 6-3. Proposed well pair locations were selected based on the following criteria:

- Located on an identified fracture trace from the aerial photograph fracture trace analysis that extends through or from the DU Impact Area.

- Located at areas along the EI traverse where the results indicated the potential presence of fractures as represented by apparent greater depth to bedrock and zones of weathered bedrock.
- Located where strong correlation was evident between a mapped fracture trace and the EI anomalies (probable and possible fractures).
- Located along potential conduit features identified with the EI results and/or along fracture traces in the expected downgradient direction from areas identified previously as demonstrating elevated radiation exposure rates above background (SEG 1996). Those areas are assumed to represent the area of highest density of DU penetrators. Downgradient locations along these conduit locations were favored so that migration of DU and potential impacts to groundwater will be evaluated.
- Located along those features identified and selected so that there is good site coverage in the possible downgradient flow directions (i.e., not concentrated in one portion or side of the study area).

The criteria evaluated for selecting conduit monitoring well locations are summarized in Table 6-1.

6.2.1.2 Deep Overburden Well Pair Location

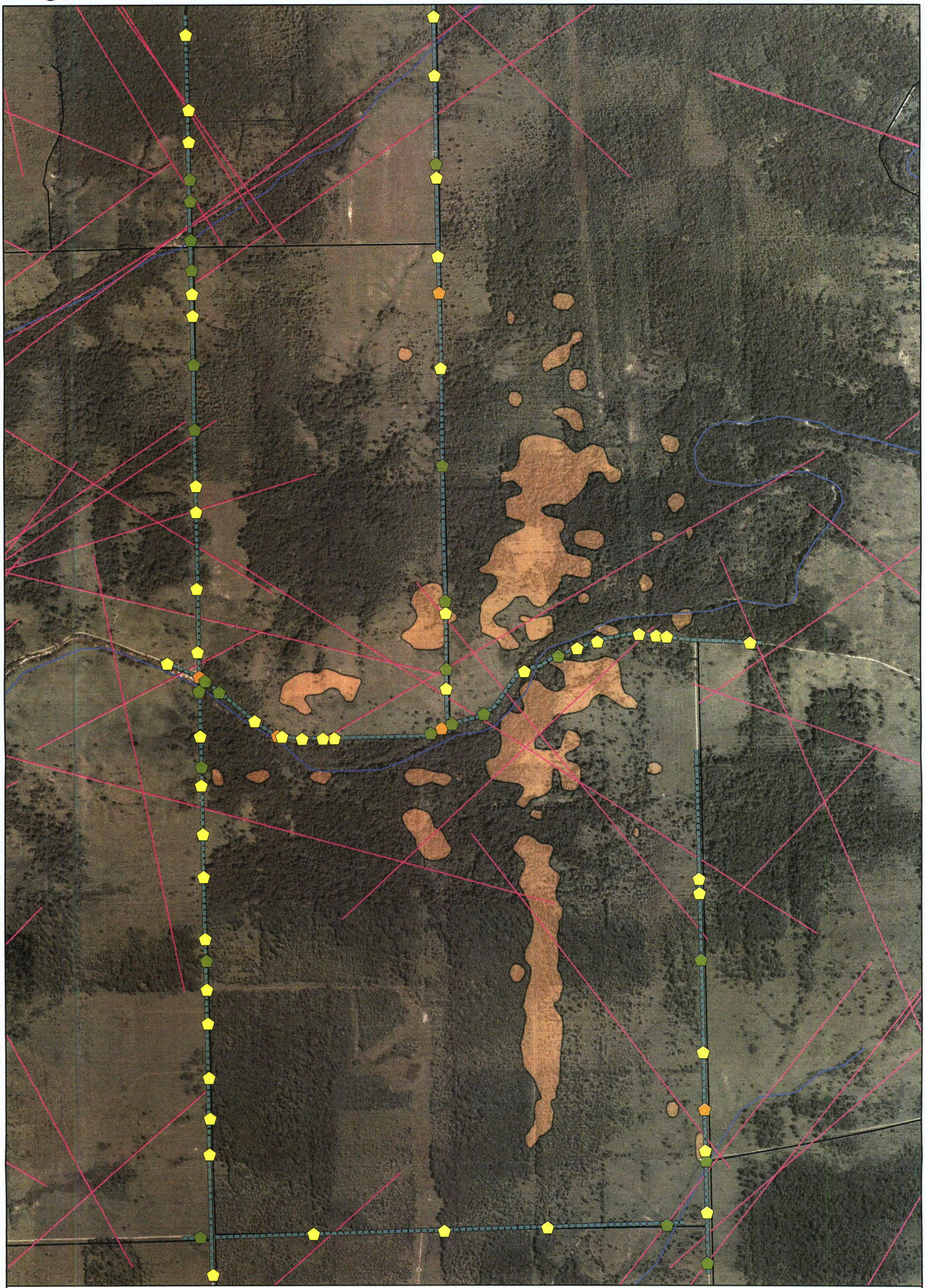
One well pair location (Number 10, Table 6-1) was selected to evaluate permeable materials or a permeable zone at the overburden-bedrock surface. The location (Figure 6-3) for this well pair is at an area that is interpreted from the EI survey results to have a deeper depth to bedrock than what was normally interpreted at the EI transects. The overburden materials will be evaluated visually during drilling for the presence of permeable materials. In addition, the zone of soil/bedrock surface will be evaluated visually during drilling for permeability and potential for groundwater flow.

6.2.2 Downgradient Flow Directions and Conduit Well Coverage

Several potential flow directions will be evaluated following the installation of wells at the selected locations. The potential flow direction or flow component that will be evaluated at each proposed well pair location is indicated in Table 6-1. Several of the proposed locations have the potential for intersecting flow in more than one direction (i.e., Big Creek or Middle Fork) and, following installation, the flow direction or component monitored will be further evaluated. The potential flow directions currently being considered are presented below along with the proposed well locations potentially monitoring or intersecting those potential flow pathways:

- Shallow flow:
  - To Big Creek (Proposed well pair locations 1, 2, 3, 6, 7, 8, 9, and 10, and alternate locations 11 and 14)
  - To Middle Fork Creek (Proposed well pair locations 3, 4, 5, and 6, and alternate locations 12 and 13)
- Deeper flow, possibly flowing under the local creeks, crossing the site:
  - South and southeast along the general course of Big Creek generally toward the Ohio River (Proposed well pair locations 1, 2, 3, 4, 8, 9, and 10, and alternate location 12)
  - Southeast to the West Branch of the Indiana-Kentuck Creek (Proposed well pair locations 5, 6, 7, 8, 9, and 10, and alternate locations 12, 13, and 14).

As part of the well site selection process, well pair locations were chosen to provide good coverage so that all general downgradient directions would be evaluated.



Legend

- Feature of Interest
- Probable Fracture
- Possible fracture
- Fracture Traces
- Streams
- Roads
- EI Lines
- uR/hr Exposure Rate

0 500 1,000 2,000

Scale in Feet

N
W E
S

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Fracture Trace and EI Results				
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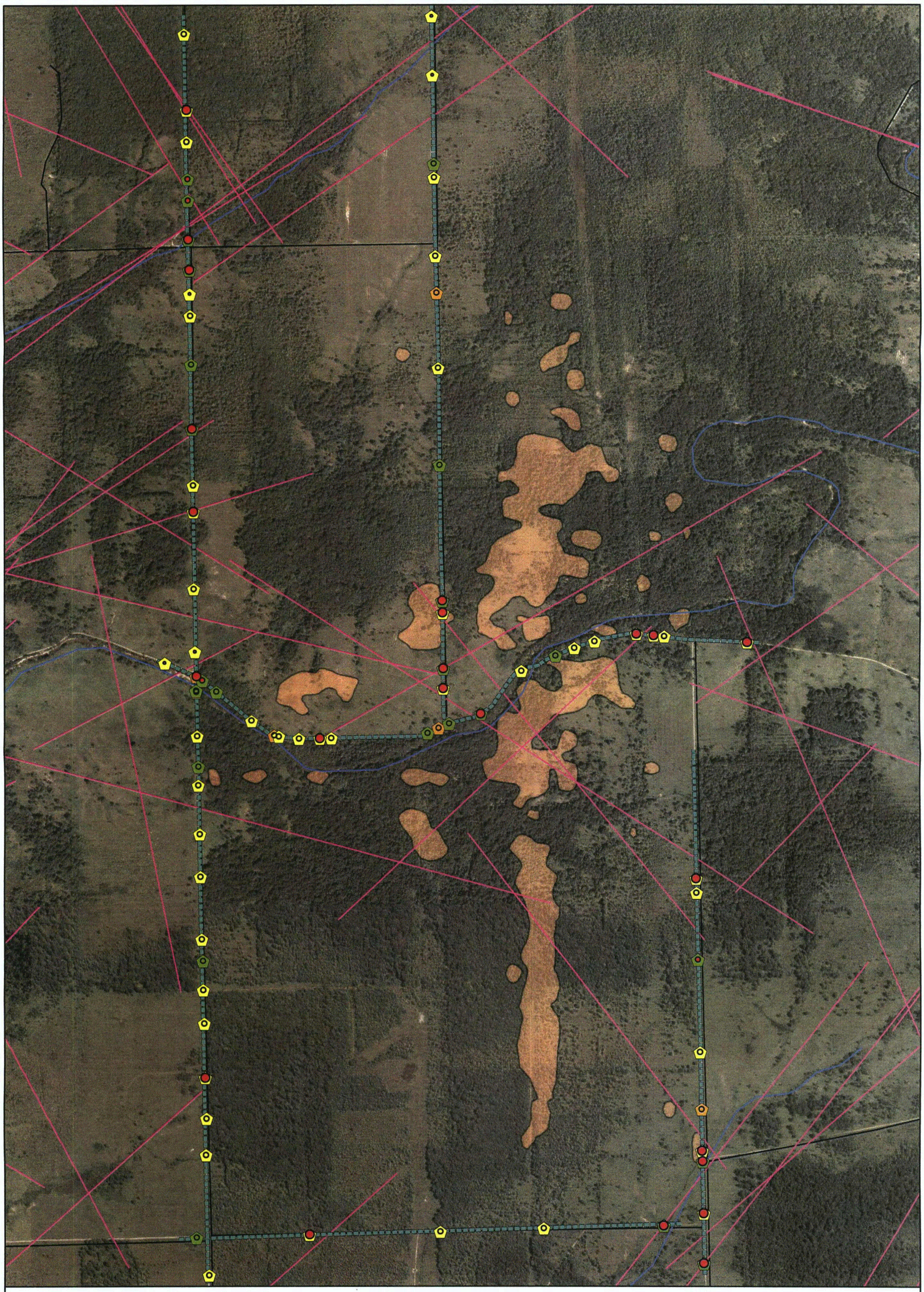

Legend

- Feature of Interest
- Probable Fracture
- Possible fracture
- Fracture Traces
- Streams
- Roads
- EI Lines
- Excellent
- Probable
- Possible
- None
- uR/hr Exposure Rate

0 500 1,000 2,000
Scale in Feet

N
W E
S

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EI/ Fracture Trace Correlation Rankings				
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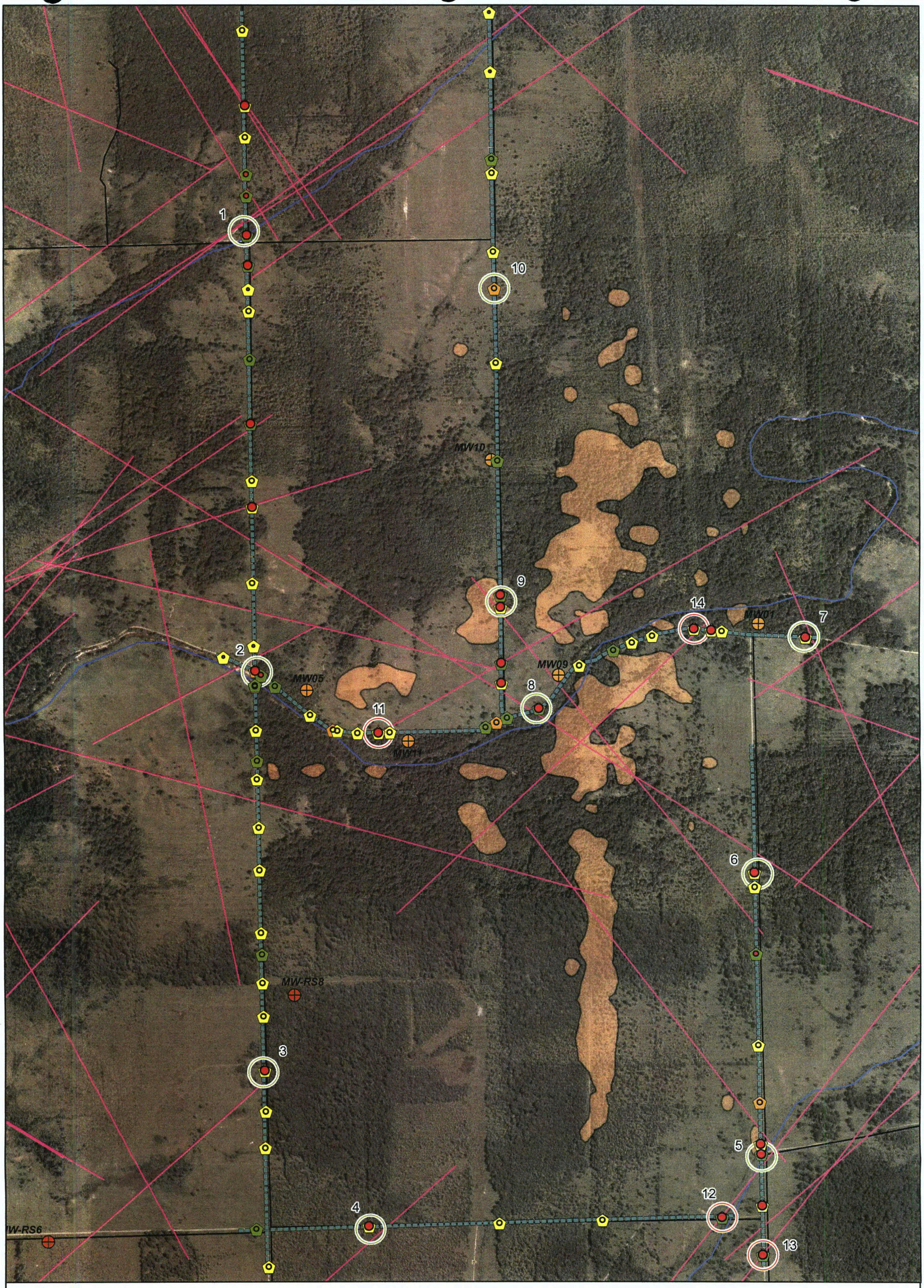

Legend

- Excellent
- Probable
- Possible
- None
- Feature of Interest
- Probable Fracture
- Possible fracture
- EI Lines
- Fracture Traces
- Streams
- Roads
- uR/hr Exposure Rate
- Candidate Well Pair Location
- Alternate Well Pair Location
- Monitoring Well Locations
- Range Monitoring Well Locations

N W E S

0 500 1,000 2,000
Scale in Feet

JEFFERSON PROVING GROUND
Madison, Indiana

Proposed Well Pair Locations

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Table 6-1. Criteria for Selection of Conduit Well Locations Jefferson Proving Ground, Madison, Indiana

Proposed Well Pair Location	Fracture Trace		Geophysical Transect Number	Inline Distance Along Electrical Imaging Transect (Feet)	Flow Direction/Component
	Fracture Trace Number	Field Verification			
1	37-11-1009-3 and 37-11-1009-4	Good	1	11,620	Shallow migration toward northern tributary of Big Creek, deeper/general flow toward the southwest and the Ohio River
2	37-11-1009-6	Not Field Checked	1	6,890	Shallow migration toward Big Creek, deeper/general flow toward the southwest and the Ohio River
3	37-11-1011-2	Good	1	2,550	Shallow flow toward either Big Creek or Middle Fork Creek, and deeper/general flow toward the southwest and the Ohio River
4	37-11-1010-13	Good	2	1,630	Shallow flow toward Middle Fork Creek, deeper/general flow toward the southwest and/or south and the Ohio River
5	37-11-1011-1	Good	5	1,450	Shallow flow toward the Middle Fork Creek, deeper/general flow toward the south-southeast toward the West Branch of the Indiana-Kentuck Creek
6	37-11-1009-1	Good	5	4,530	Shallow flow toward Big Creek and/or Middle Fork Creek, deeper/general flow toward the south-southeast toward the West Branch of the Indiana-Kentuck Creek
7	37-11-1064-14	Good	4	7,160	Shallow flow toward Big Creek, deeper/general flow toward the east-southeast toward the West Branch of the Indiana-Kentuck Creek
8	37-11-1009-1	Good	4	3,960	Shallow flow toward Big Creek, deeper general flow direction either toward the Ohio River or toward the West Branch of the Indiana-Kentuck Creek
9	37-11-1010-10	Good	3	1,250, 1,380*	Shallow flow toward Big Creek, deeper general flow direction either toward the Ohio River or toward the West Branch of the Indiana-Kentuck Creek
10	NA	NA	3	4,650	Shallow flow toward Big Creek, deeper general flow direction either toward the Ohio River or toward the West Branch of the Indiana-Kentuck Creek
11	37-11-1010-1	Good	4	2,180	Shallow migration toward Big Creek, deeper/general flow toward the southwest and the Ohio River
12	37-11-1011-1	Good	2	5,460	Shallow flow toward the Middle Fork Creek, deeper/general flow toward the south-southeast toward the West Branch of the Indiana-Kentuck Creek
13	37-11-1063-7	Good	5	350	Shallow flow toward the Middle Fork Creek, deeper/general flow toward the south-southeast toward the West Branch of the Indiana-Kentuck Creek
14	37-11-1010-2	Good	4	5,950	Shallow flow toward Big Creek, deeper/general flow toward the east-southeast toward the West Branch of the Indiana-Kentuck Creek

* Two closely spaced features as indicated with EI

6.2.3 Conduit Intersection Confirmation

During and following the installation of the "conduit" well pairs, a preliminary evaluation will be completed to determine if placing the well screen into a preferential flow pathway or "conduit" was successful. The evaluation will consist of the following:

- Observations by the rig geologist of drilling conditions and evidence of high groundwater yields; fractured, broken or weathered zones; drill fluid loss; tool-drop; and other evidence of the presence of subsurface voids.
- Review of the rig geologist-prepared drilling and well construction log for evidence of fractures, voids, and other conduit features.
- Following the collection of groundwater stage data from the newly installed wells, the stage data will be evaluated along with precipitation and surface water stage/flow data to further evaluate the degree to which the well is connected to preferential flow pathways in the aquifer.
- Groundwater samples will be analyzed for common anions and cations. Relative concentrations of these constituents will be higher in nonconduit wells in comparison to conduit wells due to the length of contact time with the aquifer materials.

6.3 SUMMARY

The evaluation of the fracture trace analysis and EI survey results was completed and both support the potential for the presence of preferential flow pathways in the aquifer underlying the DU Impact Area. Fourteen sites (13 "fracture" sites and 1 deep overburden site) for locations of well pairs have been selected based on the fracture trace and EI survey results and are illustrated in Figure 6-3. The first nine sites have been selected to provide locations that are anticipated to provide coverage in possible flow directions from the DU Impact Area and areas suspected to contain DU penetrators. Four additional sites (Numbers 11-14, Table 6-1) are provided as alternate well pair locations for the first nine sites in the event that physical site conditions such as uneven ground (e.g., steep slopes preclude the placement) or access of drilling equipment or the presence of unavoidable UXO would present unsafe working conditions. The tenth well pair location was selected to evaluate an area identified in the EI results with a greater than average depth to bedrock. This location will provide additional information by evaluating unconsolidated materials and the zone of bedrock soil interface in an area where deep bedrock weathering appears to have occurred.

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7. CONCLUSIONS AND RECOMMENDATIONS

This section summarizes the results and conclusions from the completed SVS, surface water gauge installations, fracture trace analysis, EI survey, and well location selection task. This section also includes recommendations for follow-on investigations.

7.1 SOIL VERIFICATION

The proposed 5-year site characterization study includes plans for numerous soil sampling tasks for characterizing the impacts from the testing of DU penetrators at JPG and for determining site-specific soil characteristics that will be used in fate and transport analysis. The SVS was completed to determine if the published soil mapping is applicable to be used in the process of defining and completing these future soil sampling efforts.

7.1.1 Results and Conclusions

Based on the results from the field observations and the data reviewed, the soil mapping units delineated on the NRCS map were reasonably accurate and are applicable and sufficient to be used in defining future sampling efforts and aid in sample location selection. For the purpose of interpretation and future site characterization sampling tasks, the mapped soil series can be grouped based on their drainage classes and soil conditions both observed and defined by the NRCS. The proposed groupings of the NRCS established soil series present within the DU Impact Area are illustrated on Plate 2-2.

The majority of proposed soil grouping with somewhat poorly and poorly drained soil exhibits redoximorphic features that indicate a reducing environment exists in the shallow (<3 feet BLS) 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 conditions than those present under oxidation. The consideration of the presence of the reducing environment will be very important when defining and designing planned future soil sampling and corrosion studies.

7.1.2 Recommendations

When determining sampling locations, frequencies, and distributions (e.g., corrosion and K_d studies), samples should be distributed with respect to the soil types presented in this report to capture the different conditions potentially present at the site. In addition, soil properties at sample locations should be verified in the field to determine that appropriate distribution of sample locations at the intended conditions have been achieved.

7.2 SURFACE WATER GAUGE INSTALLATION

The 5-year site characterization study includes the estimation of groundwater recharge and evaluation of the relationships and responses between precipitation, surface water, and groundwater. The surface water gauging stations were installed to collect the data necessary to calculate surface water flows at stream and cave spring locations within and surrounding the DU Impact Area. These surface water data will be used in the process of estimating groundwater recharge and the evaluation of the relationships and responses between precipitation, and surface water and groundwater.

7.2.1 Results and Conclusions

With the exception of one cave spring location, all planned gauging stations were able to be established. Stream gauge location SGS-MF-02 was required to be moved downstream approximately 3.000 feet due to ponding and lack of flow from beaver activity and the high density of UXO near the planned location. Observations at cave MF-02 indicated that spring flows have not occurred out of the cave recently, even though rain events occurred during the first days of gauge installation prior to visiting cave MF-02. As a result, a gauge station was not installed at cave MF-02. The gauge stations that were established are functional and will provide sufficient data to complete the estimation of groundwater recharge and evaluations proposed in characterizing the DU Impact Area.

Stage data have been downloaded from the nine automatic gauges and manual flow has been measured monthly since October 2006. Results are too preliminary at this time to formulate conclusions concerning groundwater recharge and relationships between precipitation, and surface water and groundwater

7.2.2 Recommendations

The Army recommends continuing to download automatic monitoring stage data and performing manual flow measurements on a monthly basis until October 2007 and quarterly for the subsequent year until October 2008. The Army will evaluate the data periodically to ensure the data continue to meet the project objectives. At the completion of the second year of monitoring, the Army will determine if sufficient data are available to meet project requirements or if additional monitoring is needed.

7.3 GROUNDWATER CHARACTERIZATION

The 5-year site characterization study includes the characterization of groundwater flow from the DU Impact Area to potential receptors. Previous reports and studies at JPG focused on groundwater within the overburden (unconsolidated soil and sediments) above the bedrock and, in a few cases, in shallow bedrock. There was no specific acknowledgement of the unique properties of groundwater flow in a karst environment. In such an environment, the most significant groundwater flow pathway may be present within fractures and solution enhanced features or "conduits" within the carbonate bedrock and along the contact surface between the overburden and the bedrock.

Groundwater characterization is a phased task and follows a progression of identifying flow pathways and installing wells to intercept and to be used to characterize the flow pathways. Each step or task builds on the previous and the results of each are used to further evaluate the presence of the flow pathways. The fracture trace analysis is the first step in identifying and locating preferential groundwater flow pathways or conduits at the site and is used to help define the EI survey. Following the completion of the EI survey, the results from both the fracture trace analysis and EI survey are evaluated together to select sites for installing conduit well pairs.

7.3.1 Results and Conclusions

Section 7.3.1.1 and 7.3.1.2 summarize the results and conclusions of the fracture trace analysis and the EI survey, respectively.

7.3.1.1 Fracture Trace Analysis

An area of approximately 22 square miles, including the DU Impact Area and immediate surrounding area, was analyzed (SAIC 2006d). A total number of 110 fracture trace lines (Figure 4-2) 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), 1 having fair (less obvious/scarce supporting landforms), and 1 having poor (faint or no supporting landforms) correlating field features.

7.3.1.2 Electrical Imaging

A total of 42,277 feet of EI data was 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). The results of the EI survey transects are illustrated in Figures 6-1 and 6-2. The intersections between the fracture traces and the EI transects are indicated for the purpose of correlation.

7.3.2 Recommendations

The evaluation of the fracture trace analysis and EI survey results was completed and both support the potential for the presence of preferential flow pathways in the aquifer underlying the DU Impact Area. Fourteen sites (13 "fracture" or "conduit," 1 deep overburden) for locations of well pairs have been selected based on the fracture trace and EI survey results and are illustrated in Figure 6-3. The first nine sites have been selected to provide locations that are anticipated to provide coverage in possible flow directions from the DU Impact Area and areas suspected to contain DU penetrators. Four additional sites (Numbers 11-14, Table 6-1) are provided as alternate well pair locations for the first nine sites in the event that physical site conditions, such as uneven ground (e.g., steep slopes preclude the placement), limited access of drilling equipment, or the presence of unavoidable UXO would present unsafe working conditions. The tenth well pair location was selected to evaluate an area identified in the EI results with a greater than average depth to bedrock. This location will provide additional information by evaluating unconsolidated materials and the zone of bedrock soil interface in an area where deep bedrock weathering appears to have occurred.

Following the installation of the proposed well pairs, survey of well coordinates and elevations for newly installed well pairs, ERM wells, and range study wells, and collection of initial groundwater stage data, an evaluation will be completed. This evaluation will assess the newly installed well pairs and the existing ERM wells and range study wells. The evaluation will determine which, if any, of the existing wells are appropriately constructed and located for inclusion in ongoing characterization activities. The data also will be used to select wells for the installation of recorders that collect groundwater stage data. In addition to determining if appropriate to be included, the types of uses (e.g., chemistry sampling, stage gauging) of the wells also will be evaluated. Following this evaluation, recommendations for any necessary rehabilitation or redevelopment also will be provided.

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