827.2008.0331.001

Science Applications International Corporation
An Employee-Owned Company

Dr. Thomas McLaughlin
Materials Decommissioning Branch
Division of Waste Management and Environmental Protection
Office of Nuclear Materials Safety and Safeguard
Two White Flint North
11545 Rockville Pike
Rockville, MD 20852-2738

Dear Dr. McLaughlin:

In accordance with the U.S. Army's request, Science Applications International Corporation (SAIC) is submitting 6 hard copies and 4 electronic copies on compact disk-read only memory (CD-ROM) of the *Well Construction and Surface Water Data Report* with appendixes. This submittal provides the response to action items numbers 4 and 5 from the December 3, 2008, meeting between the NRC headquarters staff, Army and SAIC.

Please contact Mr. Paul Cloud at (410 436-2381, e-mail address: paul.d.cloud@us.army.mil or the undersigned a (703)810-8994, e-mail address: skibinskij@saic.com if you have any questions.

Sincerely,

Joseph N. Skibinski

Encl.: As stated
cc: Paul Cloud, U.S. Army Installation Management Command
Brooks Evens, U.S. Army Corps of Engineers
SAIC Central Records

U.S. Army Corps of Engineers

WELL CONSTRUCTION AND SURFACE WATER DATA REPORT

Depleted Uranium Impact Area Site Characterization: Well Construction Details and Stream, Cave Spring, and Precipitation Gauge Data Presentation Jefferson Proving Ground, Madison, Indiana

FINAL

Prepared for:

U.S. Department of Army
Installation Support Management Activity
5183 Blackhawk Road
Aberdeen Proving Ground, Maryland 21010-5424

and

U.S. Army Corps of Engineers
Louisville District
600 Dr. Martin Luther King, Jr. Place
Louisville, Kentucky 40202-2230

Submitted by:

SAIC
From Science to Solutions™

Science Applications International Corporation
11251 Roger Bacon Drive
Reston, Virginia 20190

Contract No. DACW62-03-D-0003
Delivery Order No. CY07

March 2008

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Delivery Order No. CY07

Nuclear Regulatory Commission License No. 24-32591-01

March 2008

Final

Joseph N. Skibinski Project Manager	(703) 810-8994 Telephone	3/28/08 Date

The work completed and the preparation of this report was accomplished under direction of the undersigned Licensed Indiana Professional Geologist.

Todd D. Eaby Licensed Indiana Professional Geologist (Registration # 2215)	(717) 901-8823 Telephone	3/28/08 Date

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CERTIFICATION 4

CONTRACTOR STATEMENT OF INDEPENDENT TECHNICAL REVIEW

Science Applications International Corporation (SAIC) has prepared this Well Construction and Surface Water Data 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.

Joseph N. Skibinski
Project Manager
Science Applications International Corporation

3/28/08
Date

Joseph E. Peters
Quality Assurance Officer
Science Applications International Corporation

3/28/08
Date

Michael L. Barta
Independent Technical Review
Science Applications International Corporation

3/28/08
Date

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

3/28/08
Date

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LIST OF ACRONYMS AND ABBREVIATIONS

^{234}U	^{234}Uranium
^{235}U	^{235}Uranium
^{238}U	^{238}Uranium
BGL	Below Grade Level
BLS	Below Land Surface
BRAC	Base Realignment and Closure
CD	Compact Disc
cfs	Cubic Feet per Second
CSM	Conceptual Site Model
DGM	Digital Geophysical Mapping
DGPS	Differential Global Positioning System
DQO	Data Quality Objective
DU	Depleted Uranium
EI	Electrical Imaging
EM	Electromagnetic
EOD	Explosive Ordnance Disposal
ERM	Environmental Radiation Monitoring
ET	Evapotranspiration
FSP	Field Sampling Plan
FTA	Fracture Trace Analysis
gpm	Gallons per Minute
HASP	Health and Safety Plan
HPT	Health Physics Technician
IDNR	Indiana Department of Natural Resources
ISPCS	Indiana State Plane Coordinate System
JPG	Jefferson Proving Ground
LEU	Low Enriched Uranium
mV	Millivolt
NaI	Sodium Iodide
NGVD	National Geodetic Vertical Datum
NRC	Nuclear Regulatory Commission
NTU	Nephelometric Turbidity Unit
OD	Outside Diameter
PVC	Polyvinyl Chloride
RAI	Request for Additional Information
RQD	Rock Quality Determination
SAIC	Science Applications International Corporation
SUXOS	Senior UXO Supervisor
SVS	Soil Verification Study
USACE	U.S. Army Corps of Engineers
USCS	Unified Soil Classification System
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
UXO	Unexploded Ordnance

1. INTRODUCTION

This report provides the groundwater monitoring well installation and construction results, surface water stage data, and corresponding flow calculations, as well as the evaluations and conclusions based on the collected data from within and around the Jefferson Proving Ground (JPG) Depleted Uranium (DU) Impact Area, and provides the response to action item numbers 4 and 5 from the December 3, 2007 meeting with the Nuclear Regulatory Commission (NRC) staff at NRC headquarters in Rockville, Maryland. The proposed groundwater monitoring well locations were selected at locations where it was most probable to intersect preferential groundwater pathways within the carbonate aquifer underlying the DU Impact Area. The wells were installed in May, June, November, and December 2007. The surface water stage and flow data were collected from September 2006 to November 2007 from two creeks that flow through the DU Impact Area, as well as at two cave springs within the DU Impact Area. These activities were conducted as part of the Army's phased site characterization. The data are needed to develop the Army's Decommissioning Plan and Environmental Report, both of which are required to be submitted for NRC review and approval by the end of 2011 or earlier (NRC 2006). Additional information about these activities is described in the Field Sampling Plan (FSP) Addendum 3 (SAIC 2006b), FSP Addendum 4 (SAIC 2007b), and Well Location Selection Report (SAIC 2007a).

The surface water stage and flow data are to be used in conjunction with data from the groundwater monitoring wells to develop a water budget for the JPG DU Impact Area and to define the interrelationship between surface water and groundwater. A water budget accounts for the inflow, outflow, and storage changes of water in a hydrologic unit (USGS 2008a). It includes precipitation, irrigation, dew, and capillary rise from groundwater as inputs and evapotranspiration (ET), runoff, and deep percolation as outputs (USGS 2007). Water budgets are tools to quantify the hydrologic cycle (USGS 2007). The water budget for the JPG DU Impact Area will be used to describe the hydrologic cycle as it relates to the conceptual site model (CSM). The hydrologic cycle includes the potential migration mechanisms and potential rates of DU transport through the environment at the DU Impact Area that could result in potential exposures to onsite and offsite receptors currently and in the future.

This section provides a brief overview of the site history (Section 1.1); objectives and approach for the groundwater monitoring well installation, the stream stage, and flow data collection (Section 1.2); and the report organization (Section 1.3).

1.1 SITE HISTORY

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 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 Army test fired DU projectiles as part of its munitions testing program. DU is uranium from which some fraction of the ^{235}U 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. Although the rounds may have fragmented upon impact, these tests were designed to be nondestructive (i.e., no aerosolization occurred) because they were not testing armor penetrating capability.

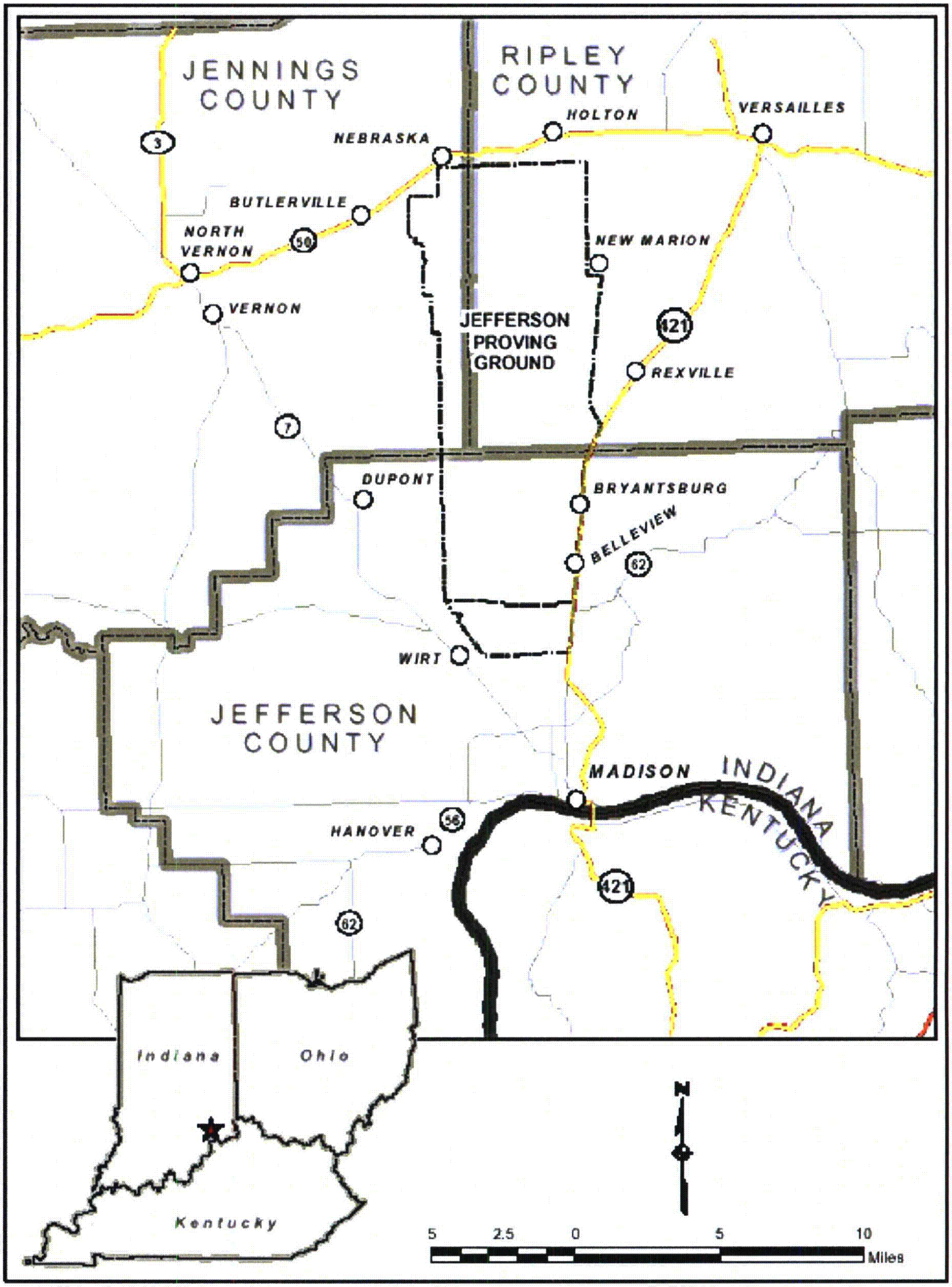

Figure 1-1. Regional Location of Jefferson Proving Ground

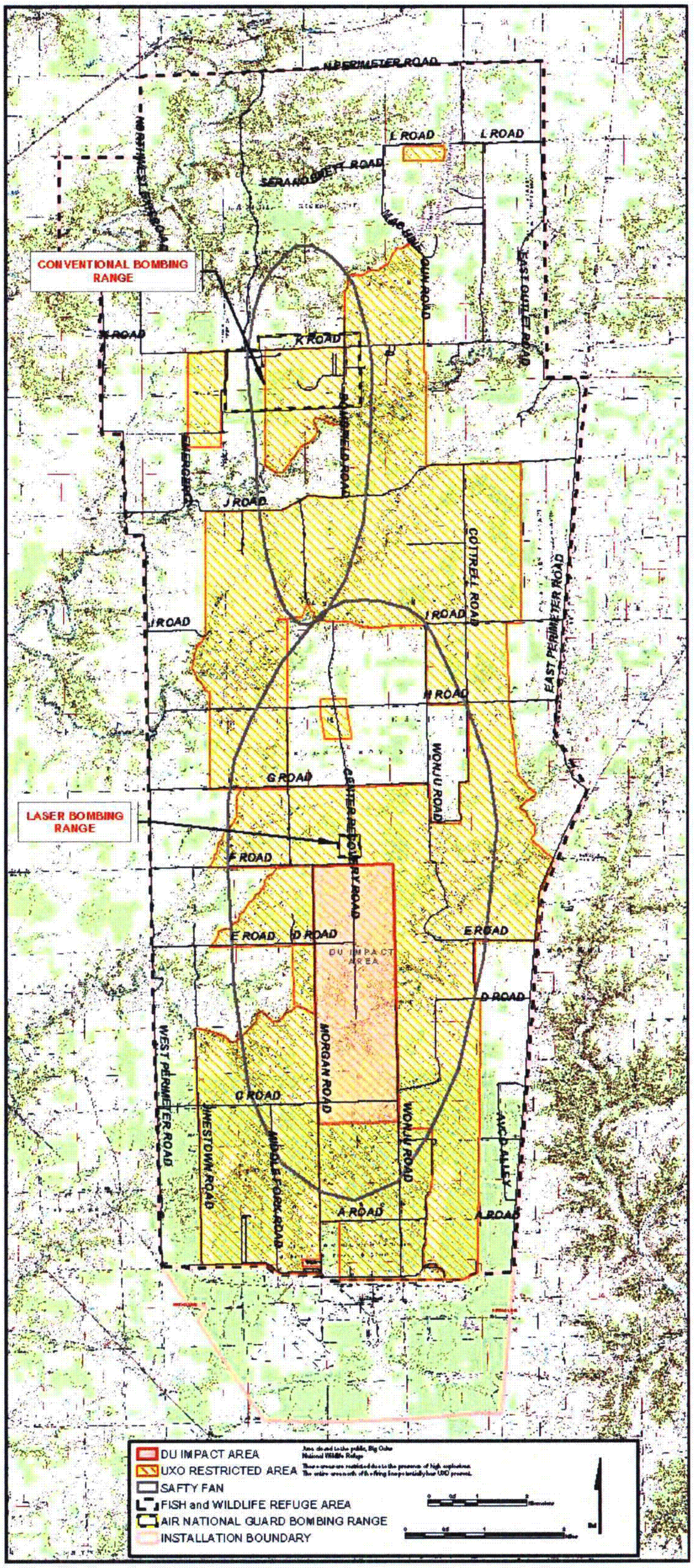

Figure 1-2. Jefferson Proving Ground, Madison, Indiana

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. In 2005, NRC granted a 5-year extension to the Army's license to collect data needed to support the Decommissioning Plan and Environmental Report as stipulated in the following condition 13 (NRC 2006):

> *The Army shall submit a decommissioning plan for NRC review and approval under an alternate schedule identified in its May 25, 2005, Field Sampling Plan, its responses to action items from a September 8, 2005, public meeting by letter dated October 26, 2005, its Field Sampling Plan addendum dated November 2005, and its responses to NRC's request for additional information by letter dated February 9, 2006, by the end of 2011 or earlier. The Army will also submit an Environmental Report using the guidance in NUREG-1748 for NRC to use in preparing an Environmental Impact Statement.*

1.2 OBJECTIVES AND APPROACH

The following sections define the approaches for installing groundwater monitoring wells and collecting stream flow and stage data in terms of the overall project objectives. As explained below, well clusters including 2 or 3 wells were installed at 10 locations and were completed in the overburden soil and bedrock (shallow and deeper). The purpose of installing these well clusters is to evaluate potential groundwater impacts from DU corrosion products that may have migrated through soil to groundwater and could migrate offsite.

In addition, seven automatic stream stage data recorders plus one manual/visual staff gauge and two automatic cave spring stage recorders were installed at Big Creek, Middle Fork Creek, and one unnamed tributary to Big Creek. Surface water stage data have been and will continue to be downloaded to refine the water budget presented in this report for the JPG site. The data from these recorders, along with precipitation data and monitoring well stage data, will be used to evaluate the interrelationships between precipitation, surface water, and groundwater. The information will be used to delineate gaining and losing stream sections and calculate water budget components of surface water runoff and groundwater runoff.

1.2.1 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 and remaining DU penetrators. 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, 2006b, and 2007b) and the Well Location Selection Report (SAIC 2007a). 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 builds 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.

One goal of this phase of the characterization is to identify the most significant groundwater flow pathways. The most significant pathways are believed to be present within fractures and solution enhanced features or "conduits" within the karst aquifer underlying the DU Impact Area. For this reason, this phase focused primarily on placing wells within conduits that are connected to the groundwater flow network of the most likely and expeditious transport pathways for offsite migration of DU in groundwater. These well locations represent the most likely monitoring locations to evaluate if dissolved DU oxidation products are migrating offsite in groundwater. Since other potential pathways may be present, some wells also were installed in saturated overburden material with sufficient permeability that would provide a functional monitoring well. The objective of installing these additional conduit and overburden groundwater monitoring wells is to provide appropriately located and constructed monitoring points that will be used for, but not limited to, the following:

- Collection of groundwater stage data
- Collection of groundwater chemistry samples
- Collection of samples for evaluation of the potential presence of and migration of DU and corrosion products
- Collection of groundwater samples by the U.S. Geological Survey (USGS) for groundwater age-dating analysis and evaluation
- Confirmation of the presence of preferential groundwater flow pathways (conduits)
- Characterization of groundwater flow through the aquifer and groundwater flow pathways
- Evaluation of the connectivity between the aquifer (groundwater) and surface water.

Another goal of this phase of the characterization is to evaluate potential interconnections between groundwater and surface water flow pathways. The "conduits" described above may intersect with stream channels. Groundwater present in the saturated overburden also may migrate toward the stream channels. Therefore, this phase provides data to support the potential for dissolved DU oxidation products to migrate from soil to groundwater to surface water and from surface runoff to streams to groundwater. The objective of installing the surface water gauging stations is to provide appropriately located and constructed monitoring points that will be used for, but not limited to, the following:

- Collection of stream and cave spring stage data
- Evaluation of the connectivity between the aquifer (groundwater) and surface water
- Calculation and monitoring of surface water flows and flow from selected cave streams
- Estimation of recharge quantities and characteristics of the aquifer
- Evaluation of the interrelationships between precipitation, surface water, and groundwater.

The collected data and evaluations will be used for refining the CSM, evaluating the potential for migration of DU from the DU Impact Area to potential receptors, and providing site-specific inputs for the exposure modeling required for preparing the Decommissioning Plan.

1.2.2 Approach

As discussed in Section 1.2.1, 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 2006a and 2006b), Science Applications International Corporation (SAIC) has completed or is conducting the following tasks and studies:

- Stream and cave spring gauge installation (September 2006)
- Continuous stage data collection (September 2006 through present)
- Manual measurements of stream flow monthly for first year (September 2006 through August 2007)
- Well location selection study (SAIC 2007a)
- Thirteen wells installed in May and June 2007
- Manual measurements of stream flow quarterly for second year (November 2007 and February 2008)
- Ten wells installed in November and December 2007
- Manual cross-section measurements for observing stream channel changes and rating curve confirmation (February 2008)
- Nineteen existing wells re-developed (February 2008).

This report presents the results of each of these studies/activities.

1.3 REPORT ORGANIZATION

This Well Installation and Surface Water Data Report is organized to summarize the data from the construction of conduit monitoring wells and evaluation of surface water stage and flow data collected within and near 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 and objectives of the report, as well as summarizes the organization and contents.
- ***Section 2. Well Completion***—This section summarizes the field activities and findings associated with the groundwater monitoring wells that were installed in May, June, November, and December 2007.
- ***Section 3. Surface Water Gauge Measurements***—This section summarizes the findings from the monthly (September 2006 to August 2007) and quarterly (November 2007) data collection activities for the stream and cave spring gauges installed in September 2006.
- ***Section 4. Updated Conceptual Site Model***— This section provides an update of the working CSM and associated exposure pathways and transport mechanisms.
- ***Section 5. Conclusions and Recommendations***—This section summarizes the conclusions and recommendations from the described investigations.
- ***Section 6. References***—This section identifies the documents used to support development of this report.
- ***Appendices***—The following appendices are included in this report:
  - Appendix A. Well Installation and Development Logbook Records
  - Appendix B. Digital Geophysical Mapping for Construction Support

- Appendix C. Well Installation Log Forms and Indiana Department of Natural Resources (IDNR) Record of Water Well Forms
- Appendix D. Rock Coring Photographs
- Appendix E. Surveying Results
- Appendix F. Well Development Forms
- Appendix G Manual Flow Calculation Forms
- Appendix H. Surface Water and Precipitation Data
- Appendix I. USGS Gauge Stations
- Appendix J. PART and RORA Data Base-flow Models Input/Output.

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2. WELL COMPLETION

This section describes the activities related to the installation of 10 multi-level groundwater monitoring well clusters consisting of a total installation of 23 additional groundwater monitoring wells within and around the DU Impact Area. The installation, development, and surveying of these monitoring wells was supervised and directed by SAIC during two separate mobilizations in May-June and November-December 2007. This section also classifies the new and existing wells into hydrostratigraphic units and discusses future aquifer monitoring and testing activities.

2.1 BACKGROUND/EXISTING MONITORING WELLS

Prior to this well installation effort, there were two sets of monitoring wells located within and around the DU Impact Area, consisting of the Environmental Radiation Monitoring (ERM) Program wells (designated as MW-1 to MW-11) and the Range Study wells (designated as MW-RS1 to MW-RS8). The details for these wells and their usefulness in characterizing the potential impacts and migration of DU from the DU Impact Area as well as characterizing the hydrogeology at the site were discussed in the Army's response to Question 2 of the May 2004 NRC's request for additional information (RAI) (Army 2004). The placement of the existing well locations appears to have been selected without the consideration of preferential groundwater flow in bedrock fractures or karst features that have been documented and observed to be present within and surrounding the DU Impact Area (Greeman 1981, Sheldon 1997). In addition, the construction of several of the existing wells is questionable (e.g., two separate screen intervals, screen intervals spanning both overburden and bedrock) for complete use during the hydrogeologic characterization and groundwater monitoring of the DU Impact Area (SAIC 2004).

2.2 METHOD OF SELECTING WELL LOCATIONS

Based on the presence of karst geology and bedrock fractures and jointing, it was 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, the presence of preferential flow pathways needed to be evaluated and wells installed so that screened intervals intersected the potential "conduits." In order to identify potential areas or features that could function as a preferential groundwater flow pathway, two methods consisting of a fracture trace analysis (FTA) and electrical imaging (EI) survey were completed. The results of these two studies and the rationale for well location selection are presented in the FTA Report (SAIC 2006c) and the Well Location Selection Report (SAIC 2007a). The proposed well locations, identified based on fracture traces, EI transect locations, and identified EI anomaly locations, are shown in Figure 2-1. Nine first-choice "conduit well" locations (proposed locations 1 through 9) were selected where it was anticipated that groundwater flow conduits could be intercepted. The selection criteria are summarized below:

- Located on an identified fracture trace from the aerial photograph FTA 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 may be evaluated.

- Located along those features identified and selected so that there is good site coverage in the possible downgradient flow directions (i.e., all well clusters were not concentrated in one portion or side of the study area).

The tenth well cluster location (proposed location 10) was selected to evaluate the potential for permeable materials or a permeable zone at the overburden-bedrock surface. The location for this well pair is at an area that is interpreted from the EI survey results to have a deeper depth to bedrock than was normally interpreted at the majority of the area investigated along the EI transects.

Following drill site preparations at each proposed location consisting of digital geophysical mapping (Section 2.5.1.1) and unexploded ordnance (UXO) construction support (Section 2.5.1.2), all of the "first choice" locations (proposed locations 1 through 10) were able to be accessed and none of the alternately proposed locations was used. The final well locations are shown in Figure 2-2.

2.3 TASK ORGANIZATION AND RESPONSIBILITIES

SAIC, on behalf of the Army, had overall responsibility for the installation of the additional monitoring wells at the site. SAIC and subcontractor personnel were onsite providing direct oversight during drilling, well construction/installation, and well development activities. A representative of the Army was present during the majority of the well installation activities. A representative from NRC made one visit in June 2007 to observe the drilling and well installation activities.

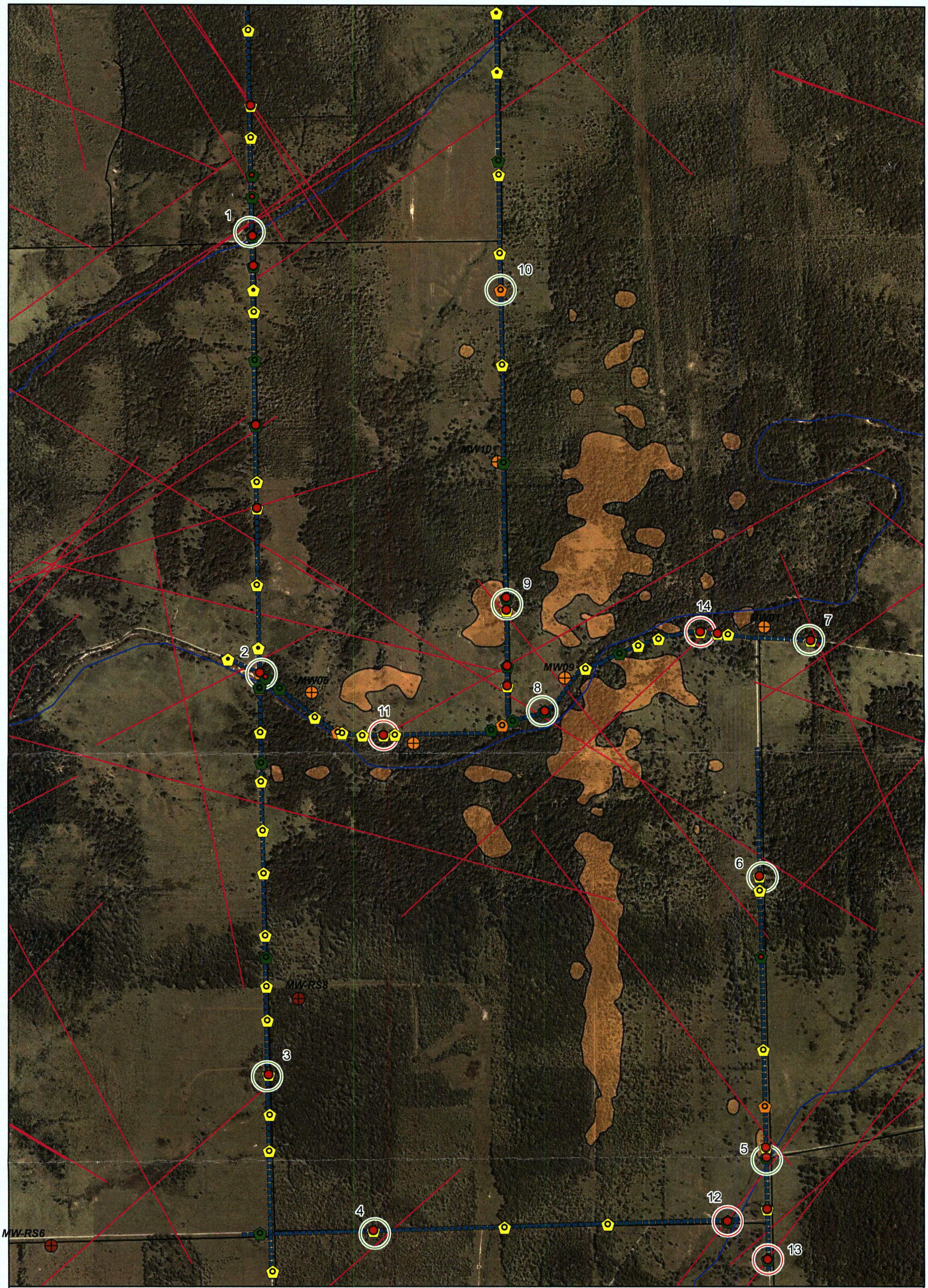
The drilling subcontractor for the installation of the new monitoring wells was Miller Drilling, Inc., which provided an Indiana licensed water well driller, Mr. Ira G. Bilbrey (License #2165). Mr. Bilbrey who was present onsite and completed and/or directed all of the drilling and well installation activities. The survey work was completed by Scholle's Land Surveying of Greensburg, Indiana, an Indiana Registered Land Surveyor (Registration 20400051).

2.4 SUMMARY OF FIELD PROCEDURES

The new monitoring wells were installed following the procedures and guidelines detailed in the FSP Addendum 4 (SAIC 2007b), the Health and Safety Plan (HASP) Addendum 4 (SAIC 2007c), and other relevant project documents (SAIC 2005a and 2005b). Copies of all of the field logbook entries for well installation and well development activities for the new wells are included in Appendix A. The initial plan included the installation of a well pair at each selected location consisting of a "shallow" and "deep" well to be installed in bedrock at each location. In general, each well was to be installed in a similar manner, but each monitoring well construction was adjusted to the actual site conditions, such as depth to the water table, depths and sizes of individual water-bearing zones, and the orientation and/or condition of those zones. The goal was to target high-permeability zones, such as fractures and solution-enhanced zones, for the placement of the screened interval based on field observations by the rig geologist.

During the borehole advancement through the overburden at one of the wells in each pair, continuous split spoon samples were collected for visual characterization and evaluation by the rig geologist. If saturated material with sufficient permeability to provide a functional well was observed, a well with the screen interval within the overburden was considered for installation.

The borehole was advanced using a combination of hollow-stem auger drilling in the overburden followed with diamond rock coring within the bedrock. Following advance of the borehole to total depth, the well was constructed with polyvinyl chloride (PVC) riser and PVC well screen.



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 Locations of GW Montiroring Well Clusters

drawn AGM	checked	approved	Figure no.
date 12/14/06	date	date	**2-1**
job no. 01-1633-04-8527-710		file no.	

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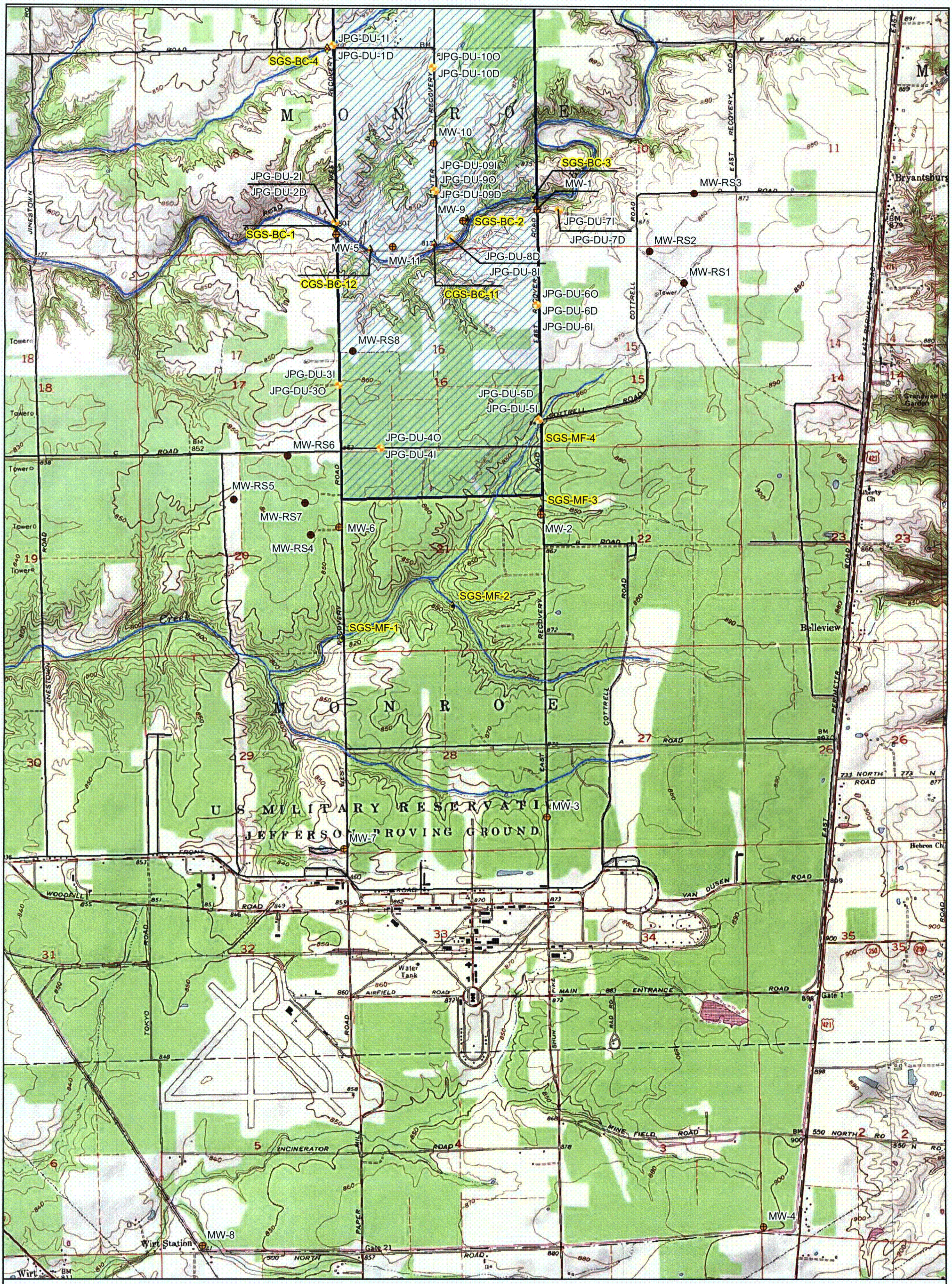

Legend

- DU Well
- Monitoring Well
- Range Well
- Continuous Stream Gauge
- Stream Staff Gauge
- Cave Gauge
- Streams
- Roads
- DU Impact Area

0 1,250 2,500 5,000
SCALE IN FEET

N W E S

NOTE: Base map from the USGS 7.5 min. Clifty Falls and San Jacinto Quadrangle.

Jefferson Proving Ground
Madison, Indiana

Final Location of Newly Installed Monitoring Wells

Drawn	AGM	Checked	Approved	Figure No.
Date	2/9/08			**2-2**
JB #	01-1633-04-8527-710			

SAIC
From Science to Solutions

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2.4.1 *Changes and Modifications to the FSP*

The following sections describe minor changes or significant modifications to the field procedures previously described in the FSP Addendum 4 (SAIC 2007b). The reasons for making the changes and modifications varied and are provided below.

2.4.1.1 Equipment Decontamination

The FSP Addendum 4 (SAIC 2007b) indicated that a single decontamination pad would be built to provide a location for decontaminating the drill tooling and staging the decontamination equipment and supplies. It was determined that a single staging area was not required for the decontamination equipment and minor changes were made relating to equipment decontamination. The decontamination equipment was staged on the drilling equipment along with a portable water tank. The initial equipment decontamination was completed in a gravel area immediately north of the firing line and all subsequent decontamination activity was completed in close proximity to the individual well pair locations prior to moving to the next well pair location. By completing the decontamination in the close proximity to the individual well cluster locations, the decontamination fluids and associated sediments were surface discharged as indicated in the FSP Addendum 4 (SAIC 2007b).

2.4.1.2 Drill Tooling

In order to provide a stable borehole within the anticipated difficult drilling conditions that are normally present within fracture zones and solution enhanced karst features, a PQ-series wire-line diamond drill coring technique and a compatible casing advance system for advancing PWT-series outer casing or similar system was designated in the FSP Addendum 4 (SAIC 2007b). Shortly before mobilizing to begin the drilling, the drilling contractor realized that the specified system was not available and the well installation would be delayed by a minimum of several months to have the drill tooling ordered and manufactured. A suitable replacement was proposed and discussed between SAIC, the Army, and NRC. All parties agreed that the well installation could proceed with the minor change of using a combination of PQ-series wire-line diamond drill coring tooling and HQ-series wire-line diamond drill coring tooling with a compatible casing advance system for advancing HWT-series outer casing when unstable subsurface conditions required the advancement of casing and stabilization of the borehole. The HWT casing has an outside diameter (OD) of 4.5 inches and provided a borehole that meets the Indiana State regulations requiring a borehole of at least 2 inches in diameter greater than the nominal diameter of the finished well casing.

2.4.1.3 Addition of Overburden Wells

The FSP Addendum 4 (SAIC 2007b) planned for one well to be constructed with a screen interval within the overburden materials. The FSP Addendum 4 (SAIC 2007b) did allow the flexibility of constructing additional wells with screen intervals within the overburden materials when saturated material with sufficient permeability to provide a functional well was present. A significant change consisting of the addition of three wells (JPG-DU-04O, JPG-DU-06, and JPG-DU-09, Figure 2-2) was completed. The additional overburden wells were installed at three well clusters with well screen intervals constructed within the overburden materials due to the observation of saturated materials that appeared to have sufficient permeability to provide a functional well. This determination was made by the rig geologist upon examination of the overburden materials retrieved in the split spoon samples during advancement of the borehole through the overburden materials in one borehole at each well cluster location.

2.4.1.4 Cluster at JPG-DU-03 (Overburden and Shallow Bedrock Wells Only)

The observed subsurface conditions during the drilling at well cluster location 3 resulted in a significant modification of the proposed well construction depths and screened intervals from that originally presented in the FSP Addendum 4 (SAIC 2007b). The "deeper" bedrock well was replaced with a well constructed with the screen interval exposed in the apparently saturated, permeable overburden materials. A "deep" borehole was advanced to a total depth of 120.6 feet below grade level (BGL). No features or conditions were observed during the drilling or from the retrieved rock core that indicated the presence of permeability that would provide a functional well within the "deeper" portion of the borehole. The "deep" borehole was abandoned in accordance with requirements in Section 2.2.6 of the FSP Addendum 4 (SAIC 2007b) from the total depth of 62.5 feet BGL where a shallow bedrock depth screen interval was installed.

2.5 WELL INSTALLATION

This section describes the drill site preparation and drilling equipment preparation (Section 2.5.1) and activities during the installation of the groundwater monitoring wells (Section 2.5.2).

2.5.1 Drill Site Preparation and Drilling Equipment Preparation

Since the 23 groundwater wells SAIC installed in 2007 were constructed in locations north of the firing line, precautionary measures were followed to minimize risks associated with working around UXO and DU penetrators. Prior to conducting any activities at any of the 40- by 40-foot drilling areas, explosive ordnance disposal (EOD) technicians under the supervision of a Senior UXO Supervisor (SUXOS) and SAIC's Field Manager conducted a surface survey for UXO using Schonstedt® ordnance locators. In addition, a Health Physics Technician (HPT) conducted a survey for DU penetrators using a Ludlum Model 44-10 2- by 2-inch sodium iodide (NaI) gamma scintillation detector. Vegetation in most of the areas did not hinder drilling operations, but some brush clearance and a few small trees were removed before additional site preparation activities ensued.

Following brush clearance, where needed, SAIC conducted digital geophysical mapping (DGM), which is described in Section 2.5.1.1. The process for investigating anomalies identified during the DGM and UXO destruction operations are summarized in Section 2.5.1.2. Construction support to avoid subsurface UXO during drilling operations is discussed in Section 2.5.1.3. Preparation and decontamination of equipment used in drilling is discussed in Sections 2.5.1.4 and 2.5.1.5, respectively.

2.5.1.1 Digital Geophysical Mapping

SAIC used a Geonics Limited, EM61-MK2® high sensitivity electromagnetic (EM) metal detector to digitally record the subsurface metallic objects and an integrated PRO-XRS differential global positioning system (DGPS) manufactured by Trimble Limited to geo-reference EM data. Data were collected with 1-meter lateral data resolution where access permitted with inline data resolution of 0.15 meters during the week of 11 May 2007. Background responses were measured during EM standardization tests within ±2 millivolts (mVs) and instrument response drift during survey was maintained at a level less than 1 mV.

The survey was conducted with the long-axis of the coils (1- by 0.5-meter) oriented perpendicular to the direction of travel. Since there is some lateral sensitivity outside the coil footprint, data were collected along traverses nominally spaced 3 feet apart where access permitted. In addition, data were collected five times per second as the operator walked along the traverses and was integrated with the DGPS data collected at a rate of one per second. These survey parameters were expected to represent complete coverage and met the objectives of the survey.

During data pre-processing, SAIC performed lag adjustments as appropriate and normalized data to a consistent background response. SAIC used the Geosoft OASIS Montaj™ UX-Detect Module to grid and contour Channels 2 and 3, which represent bottom coil data. Based on preliminary data assessment, SAIC selected data from Channel 3 for interpretation and presentation as it appeared to contain the greater number of interpretable targets and, based on theory of measurement, better represented both near surface features and targets at depth.

Targets were selected based on a 6 mV target threshold, which exceeded the normal noise levels of the EM61-MK2 in dynamic mode and permitted the selection of small targets of interest. After automatic target selection was completed, SAIC posted EM response data on maps and conducted a more detailed review, which resulted in selected additional targets. Following the refined review, SAIC prepared dig sheets along with maps that were provided to the EOD technicians for subsequent target reacquisition, excavation, and disposal. Based on an independent peer review, data were determined to be consistent with quality objectives for this task. Additional details regarding the DGM are provided in Appendix B.

The investigation included standard and/or routinely accepted practices of the geophysical industry. SAIC utilized qualified personnel to reduce the number of missed subsurface features, due to burial depth, soil type and condition, feature materials, or other site-specific conditions that may have masked the feature of interest. Field data acquisition and processing were performed consistently with data quality objectives (DQOs) and project schedule and budget. However, by its nature, no subsurface survey is 100 percent accurate and SAIC cannot accept responsibility for inherent survey limitations or unforeseen, site-specific conditions.

2.5.1.2 Anomaly Excavation and UXO Disposal

The DGM identified a total of 308 anomalies for further investigation by EOD technicians. The anomalies were investigated during the week of 10 May 2007 and were destroyed with C4 donor charges in place or moved for consolidated shots on 15 May 2007. Table 2-1 summarizes the numbers of anomalies and UXO destroyed during the site preparation activities.

Table 2-1. Anomalies Identified and UXO Destroyed by Well Construction Site Jefferson Proving Ground, Madison, Indiana

Well Construction Site	Anomalies Identified	UXO Excavated and Destroyed	Description of UXO Items
CW01	19	1	One 155mm projectile, nose down, 0.25 feet BLS
CW02	35	0	Not applicable
CW03	37	0	Not applicable
CW04	19	2	One 105mm and one 106mm projectile
CW05	37	3	One 105mm or 106mm projectile located at surface and two 105mm projectiles, both in flat orientations, recovered at 1 foot BLS
CW06	43	2	One flare candle and one 105mm projectile located at 0.5 feet BLS, both in flat orientations
CW07	31	9	One 57mm, three 105mm, and two 106mm projectiles located at ground surface, all in flat orientations; one 105mm projectile located at 0.5 feet BLS in flat orientation; one 105mm projectile located at 1.5 feet BLS in flat orientation; and one 105mm projectile located at 2 feet BLS in flat orientation
CW08	42	2	Two 37mm projectiles recovered in this area were moved
CW09	31	1	One 105mm projectile located at surface in flat orientation
CW10	14	1	One 105mm projectile, nose down, 1.5 feet BLS
Total	**308**	**21**	

2.5.1.3 UXO Construction Support

Because the entire DU Impact Area is located north of the firing line where the potential to encounter UXO is likely, special UXO-related construction support procedures were used (FSP Addendum 4 [SAIC 2007b], Section 2.2.1.1). Following the UXO construction support activities, an exclusion zone and safe work area were established, as well as routes for ingress and egress. Down-hole UXO detection and avoidance procedures were practiced for the first 15 feet of each borehole. Detection and avoidance were completed by installing an initial pre-boring with a combination of hand auger (shallow, 5 to 6 feet deep) and hollow-stem auger drilling in which the UXO contractor advanced the hole at 2-foot intervals, surveying the boring before advancing to the next interval. After down-hole UXO detection and avoidance were completed at each well location to a depth of 15 feet or auger refusal, whichever occurred first, the drilling contractor completed the remaining borehole drilling and monitoring well installation. Each well location was cleared to a depth of 15 feet below land surface (BLS) unless it was determined during field activities that clearance to a deeper depth was necessary based on the expertise of the onsite UXO subcontractor and SAIC's SUXOS.

2.5.1.4 Equipment Preparation and Health and Safety Inspections

Upon mobilization to the site, SAIC verified that the drilling subcontractor's equipment was acceptable and operable. The two operable kill switches on the rig were tested daily. A Drill Rig Operational Checklist form was completed by the rig geologist and the drilling subcontractor's master driller at the beginning of each 10-day shift. Daily Tailgate Safety Meetings were completed at the beginning of each day. This documentation is in the project file and is available on request.

2.5.1.5 Decontamination

All of the drilling equipment was decontaminated upon mobilization to the site, between wells, and prior to demobilization in accordance with the FSP Addendum 4 (SAIC 2007b), which consisted of a steam or pressurized hot water wash. All of the decontamination fluids were surface discharged in the general area where the materials originated in accordance with Section 3 of the FSP Addendum 4 (SAIC 2007b).

2.5.2 Overburden Evaluation, Rock Coring Methods, and Well Construction

An SAIC rig geologist was onsite during all drilling and well installation activities to provide well installation oversight, catalog subsurface materials (overburden and rock), document drilling observations and conditions, and provide details of the observations to the project hydrogeologist and the Army contact for making drilling and well construction decisions as the well drilling and construction progressed. The rig geologist recorded all of his field observations in the field logbook. The drilling conditions and observations along with the subsurface materials characterization descriptions were recorded in the field on the U.S. Army Corps of Engineers (USACE) Forms MRK55 and MRK55-2. Copies of the rig geologist field logbook and the drilling field log forms are included in Appendix A.

2.5.2.1 Overburden Materials Evaluation Methods

Pre-boring and subsurface anomaly avoidance activities were completed at each well boring location, as described in Section 2.2.1.2 of the FSP Addendum 4 (SAIC 2007b). In addition, at one well boring in each well pair location, anomaly avoidance plus continuous split spoon (2-inch-diameter by 2-foot-long split spoon) collection were completed so that the rig geologist could retrieve soils for visual characterization. The split spoons were completed continuously to the depth of hollow-stem auger refusal (bedrock) or 15 feet BLS, whichever occurred first. All of the field observations were recorded on the USACE Well Drilling Field Form and included the following types of observations:

- Unified Soil Classification System (USCS) classification
- Depositional environment and formation (if known)
- Color (Munsel soil color chart descriptors)
- Plasticity
- Consistency
- Density
- Moisture content
- Structure and orientation
- Grain size and angularity.

Following visual characterization by the rig geologist, every 6-inch section of the retrieved overburden materials from the split spoons were placed in labeled Ziploc® bags or glass sample jars. The containers were labeled with the well boring identifier and the depth of collection. All of the overburden materials that have been collected were stored in a secure building located north of the firing line. These overburden material samples were collected and stored so that intervals could be selected for later submission of overburden materials for laboratory grain size analysis. The selected intervals will be analyzed with the soils collected as part of the Kd study that will be described in the future FSP Addendum 7.

2.5.2.2 Rock Coring Methods

Following auger refusal at the bedrock surface, a temporary surface casing was placed and drilling/borehole advance was resumed with PQ-series wire-line diamond drill coring techniques. In the event that borehole conditions became unstable, it was planned to remove the PQ-series tooling and advance HQ-series wire-line diamond drill coring tooling with a compatible casing advance system for advancing HWT-series outer casing to stabilize the borehole. The observed subsurface conditions were such that the use of the HQ-series tooling with HWT-series outer casing advancer was not required. All of the bedrock wells were successfully drilled and constructed using the PQ-series tooling resulting in a borehole of a nominal diameter of 4.8 inches. The wells were constructed within the PQ-series borehole following removal of the core tooling. The PQ coring system cut and retrieved 3.35-inch (8.51-centimeter) rock cores and was advanced from the top of bedrock to the total target depth.

All of the rock cores were placed in order of collection into labeled and numbered wooden core boxes in such a manner as to preserve their relative positions by depth. The core boxes were labeled so that the determination of the depth of the rock core sequences and depths and heights of voids were documented in the boxes for later observation. Intervals of lost core (e.g., voids, fractured zones) were noted in the core sequence with wooden blocks. Boxes were marked on the cover (both inside and outside) and on the ends to provide project name, borehole number, cored interval, and box number, when there were multiple boxes. The rig geologist recorded observations from the retrieved core onto the well drilling field forms and constructed a lithologic log, including the observations of the drill crew and drilling conditions. The entire core, following placement into the core boxes and photographic documentation of each core box, was placed in a secure building north of the firing line so that it is available for further observation or evaluation or sampling if determined to be necessary at a future time. The core box photographs are included as Appendix D (attached compact disc [CD]).

2.5.2.3 Well Construction

The final well construction depths and screen/filter pack intervals were based on the actual conditions at each well location as observed and recorded by the rig geologist and discussed with the project hydrogeologist, Army, and SAIC Project Manager. The final well construction details are presented in Table 2-2.

Well construction followed the guidelines provided in the FSP Addendum 4 (SAIC 2007b). All of the wells were completed as 2-inch (5.08-centimeter) diameter, schedule 40 PVC, with commercially fabricated 10-slot well screen with openings equal to 0.010 inches (0.0254 centimeters). Filter pack consisted of either conventionally placed filter pack materials surrounding a conventional PVC screen or a pre-packed (filter pack placed inside double-walled screen or U-Pack) screen. The pre-packed screens were used to ensure the proper placement of a continuous filter pack and aided in the proper placement of well screen and filter pack in areas where difficult drilling conditions exist. The actual type of screen and filter pack placement is indicated on the well construction table. Well construction diagrams were completed by the rig geologist and are included in Appendix C. Following completion of the well installation task, Miller Drilling, Inc., the Indiana licensed well driller, completed and submitted the IDNR, Division of Water, Record of Water Well Forms (#35680), which are included in Appendix C.

The overburden wells were completed with total depths ranging from 24.3 to 68.3 feet BLS. The shallow bedrock wells were completed with total depths ranging from 29.2 to 88.3 feet BLS, and the deep bedrock wells were completed with total depths ranging from 83.4 to 136.7 feet BLS. All of the wells were completed with 10-foot screens with the exception of JPG-DU-04O, which was completed with a 20-foot screen to provide additional open screen interval to the saturated materials at this location where the depth to saturated materials was shallow and the depth to bedrock was deeper than the average observed for the site. Some of the borings were initially drilled below the completed depth of the well and the portion of the borehole below the completed depth was abandoned with bentonite to seal the lower portion of the borehole in accordance with requirements specified in Section 2.2.6 of the FSP Addendum 4 (SAIC 2007b). Drilling continued to deeper depths to investigate the presence of permeable intervals, but since such intervals were not identified, the abandonment of the bottom portions of the boreholes was needed to complete the wells.

2.6 SURVEYING

Following the completion of the well installation activities, an Indiana Registered Land Surveyor from Scholle's Land Surveyors of Greensburg, Indiana, conducted a topographic survey of the horizontal and vertical positions of all the existing and newly installed groundwater monitoring wells. In addition, the tops of the surface water gauging station stilling wells, bottoms of the weir notches (cave gauging locations), and the bases of the caves at the two cave gauging locations were surveyed. The horizontal coordinates of each well were surveyed to the nearest 1 foot and were referenced to the Indiana State Plane Coordinate System (ISPCS) NAD83. Locations of the monitoring wells were measured from both the rim of the well casing (PVC) and the protective casing. The elevation of the top of each PVC well casing, protective steel outer casing, ground surface, and concrete pad were surveyed to an accuracy of ±0.01 foot and were referenced to the National Geodetic Vertical Datum (NGVD) of 1988. When the existing concrete pad was flush with the ground surface, only the elevation of the ground surface was measured and reported. The surveyed locations of the existing and newly installed monitoring wells are shown in Figure 2-2. The elevations and coordinates of each monitoring well and surface water/cave spring gauge are included in Table 2-3. A copy of the certified survey results from Scholle's Land Surveyors is included in Appendix E.

2.7 WELL DEVELOPMENT

The development of the newly installed wells was initiated no sooner than 48 hours after nor no longer than 7 days beyond the mortar collar placement or the final grouting of the wells in accordance with the FSP Addendum 4 (SAIC 2007b). The complete well development details were recorded in a combination of both the well development forms and in the field logbooks. Copies of the field logbook pages are included in Appendix A. Copies of the well development forms are included in Appendix F. Due to the lower than expected well yields, the development of the wells was completed by mechanically

Table 2-2. Well Construction Details
Jefferson Proving Ground, Madison, Indiana

Well ID	Date Installed	Ground Surface Elevation	Top of PVC Elevation	Total Depth of Boring	Total Depth of Completed Well	Surface Completion Type	Screen Length	Screen and Riser Diameter	Screen Slot Size	Screened Interval		Sand Pack/Open Interval		Bentonite Seal Interval		Bentonite Borehole Abandonment		Top of Bedrock		Lithology in Exposed Open Interval
		FAMSL	FAMSL							FTBGS	FAMSL	FTBGS	FAMSL	FTBGS	FAMSL	FTBGS	FAMSL	FTBGS	FAMSL	
DU Impact Area Characterization Wells																				
JPG-DU-01D	6/14/2007	838.26	841.15	113.1	113.1	Stick-up	10	2	0.01	102.8 - 112.8	735.46 - 725.46	99.8 - 113.1	738.46 - 725.16	97.6-99.8	740.66 - 737.46	NA	NA	19.5	818.76	Limestone
JPG-DU-01I	6/15/2007	838.06	841.23	41.7	41.7	Stick-up	10	2	0.01	31.4 - 41.4	806.66 - 796.66	28.5 - 41.7	809.56 - 796.36	26 - 28.5	812.06 - 809.56	NA	NA	20	818.06	Limestone
JPG-DU-02D	5/20/2007	800.92	803.83	119.3	119.3	Stick-up	10	2	0.01	108.95 - 118.95	691.97 - 681.97	106.95 - 119.3	693.97 - 681.62	11 - 106.95	789.92 - 693.97	NA	767.93 - 751.93	0.65	800.27	Limestone
JPG-DU-02I	5/21/2007	800.93	803.94	49.0	29.2	Stick-up	10	2	0.01	18.8 - 28.8	782.13 - 772.13	18.2 - 29.2	782.73 - 771.73	5 - 18.2	795.93 - 782.53	33-49	799.64 - 741.54	16	784.93	Limestone, shale
JPG-DU-03I	12/12/2007	862.14	865.6	120.6	60.9	Stick-up	10	2	0.01	50.6 - 60.6	811.54 - 801.24	48.3 - 62.5	813.84 - 799.64	42.3 - 48.3	819.84 - 813.84	62.5 - 120.6	NA	40.6	821.54	Limestone
JPG-DU-03O	12/12/2007	862.1	865.54	25.0	24.3	Stick-up	10	2	0.01	14 - 24	848.1 - 838.1	12 - 25	850.1 - 837.1	7.5 - 12	854.6 - 850.1	NA	762.18 - 743.38	NA	NA	Clay, sand, and gravel
JPG-DU-04D	11/29/2007	864.18	867.13	120.8	100.4	Stick-up	10	2	0.01	90 - 100	774.18 - 764.18	86.7 - 102	777.48 - 762.18	84.85 - 86.7	779.33 - 777.48	102 - 120.8	NA	46.2	817.98	Limestone
JPG-DU-04I	12/3/2007	864.32	867.38	65.5	65.5	Stick-up	10	2	0.01	55.1 - 65.1	809.22 - 799.22	52.6- 65.5	811.72 - 798.82	47 - 52.6	817.32 - 811.22	NA	NA	47	817.32	Limestone
JPG-DU-04O	12/4/2007	864.11	867.28	47.0	47.0	Stick-up	20	2	0.01	26.8 - 46.8	837.31 - 817.31	25 - 47	839.11 - 817.11	20 - 25	844.11 - 839.11	NA	NA	NA	NA	Gravel and clay
JPG-DU-05D	11/19/2007	843.67	847.26	130.7	130.7	Stick-up	10	2	0.01	120.45 - 130.45	723.22 - 713.22	118.1 - 130.7	725.27 - 712.97	110.8 - 118.1	732.87 - 725.57	NA	NA	5.7	837.97	Fossiliferous Limestone
JPG-DU-05I	11/27/2007	843.71	847.21	34.9	34.9	Stick-up	10	2	0.01	24.5 - 34.5	819.21 - 809.21	21.5 - 34.9	822.21 - 808.81	15.3 - 21.5	828.41 - 822.11	NA	771.79 - 754.09	5.8	837.91	Limestone
JPG-DU-06D	6/17/2007	872.79	875.76	118.7	98.3	Stick-up	10	2	0.01	88 - 98	784.79 - 774.49	85.6 - 101	787.19 - 771.79	21.5 - 85.6	851.29 - 786.79	101-118.7	NA	35.7	837.09	Limestone
JPG-DU-06I	6/18/2007	872.91	875.65	48.4	48.2	Stick-up	10	2	0.01	37.8 - 47.8	835.11 - 825.11	36 - 48.4	836.91 - 824.51	22 - 36	850.91 - 836.81	NA	850.56 - 849.56	35.4	837.51	Limestone
JPG-DU-06O	11/13/2007	872.56	876.02	25.0	20.4	Stick-up	10	2	0.01	10 - 20	862.56 - 852.56	6.5 - 22	866.06 - 850.56	5 - 6.5	867.56 - 866.06	22 - 23	NA	NA	NA	
JPG-DU-07D	11/15/2007	842.58	846.53	120.4	120.4	Stick-up	10	2	0.01	110 - 120	732.58 - 722.58	107.3-120.4	735.28 - 722.18	98.25 - 107.3	744.33 - 734.58	NA	NA	5.7	836.88	Fossiliferous Limestone
JPG-DU-07I	11/18/2007	842.39	846.33	60.4	60.4	Stick-up	10	2	0.01	50.05 - 60.05	792.34 - 782.34	48.1-60.4	794.29 - 781.99	43.6 - 48.1	798.79 - 794.29	NA	NA	5.6	836.79	Limestone
JPG-DU-08D	5/23/2007	815.36	818.58	139.3	136.7	Stick-up	10	2	0.01	126.28 - 136.28	689.08 - 679.08	123.8 - 139.3	691.56 - 676.06	120.7 - 123.8	695.66 - 690.71	NA	NA	6	809.36	Limestone
JPG-DU-08I	5/24/2007	815.44	818.59	39.3	36.0	Stick-up	10	2	0.01	25.65 - 35.65	789.79 - 779.79	24.3 - 39.3	791.14 - 776.14	22.2 - 24.3	793.24 - 790.79	NA	760.5 - 726.6	6	809.44	Limestone, dolomite, shale
JPG-DU-09D	6/2/2007	846.1	849.07	119.5	83.4	Stick-up	10	2	0.01	73 - 83	773.1 - 763.1	70 - 85.6	776.1 - 760.5	20 - 70	826.1 - 775.1	85.6-119.5	795.45 - 772.45	34	812.1	Limestone
JPG-DU-09I	6/2/2007	846.45	849.38	74.0	49.4	Stick-up	10	2	0.01	39 - 49	807.45 - 797.45	36.9 - 51	809.55 - 795.45	20-36.9	826.25 - 808.95	51-74	NA	34	812.45	Limestone
JPG-DU-09O	6/3/2007	846.63	849.63	34.0	34.0	Stick-up	10	2	0.01	23.7 - 33.7	822.93 - 812.93	22.2 - 34	824.43 - 812.63	19.7 - 22.2	826.93 - 824.43	NA	780.91 - 751.96	NA	NA	Clay with sand and gravel
JPG-DU-10D	6/6/2007	870.71	873.64	118.75	88.3	Stick-up	10	2	0.01	78 - 88	792.71 - 782.41	75.3 - 89.8	795.41 - 780.91	49.6 - 75.3	821.11 - 794.71	89.8-118.75	802.09 - 798.59	72.5	798.21	Limestone, shaley limestone
JPG-DU-10O	6/7/2007	870.39	873.51	71.8	68.3	Stick-up	10	2	0.01	58 - 68	812.39 - 802.39	55.9 - 71.8	814.49 - 798.59	49.2 - 55.9	821.19 - 814.49	68.3-71.8		71.8	798.59	Sand, silt, clay
ERM Program Wells																				
MW-1	12/6/1983	851.75	853.58	33.2		Stick-up	4.8	2	0.006	8.3 - 13.1 & 28.4 - 33.2	843.45 - 838.65 & 823.35 - 818.55	5 - 33.2	846.75 - 818.55	4 - 3.21	847.75 - 848.54	NA	NA	8	843.75	Limestone
MW-2	12/13/1983	848.25	850.49	23.7		Stick-up	10	2	0.006	13.7 - 23.7	834.55 - 824.55	14.68 - 23.7	833.57 - 824.55	11.5 - 12.5	836.75 - 835.75	NA	NA	9	839.25	Limestone
MW-3	12/13/1983	870.96	873.64	42.8		Stick-up	10	2	0.006	32.8 - 42.8	838.16 - 828.16	33.5 - 42.8	837.46 - 828.16	30 - 31	840.96 - 839.96	NA	NA	NA	NA	Limestone
MW-4	12/14/1983	898.92	902.19	28		Stick-up	5	2	0.006	8.5 - 13.5 & 23 - 28	890.42 - 885.42 & 875.92 - 870.92	9.5 - 28.5	889.42 - 870.42	6 - 7	892.92 - 891.92	NA	NA	12.9	886.02	Siltstone/Limestone
MW-5	12/7/1983	801.91	804.36	33.4		Stick-up	10	2	0.006	23.4 - 33.4	778.51 - 768.51	24.45 - 33.4	777.46 - 768.51	21 - 22	780.91 - 779.91	NA	NA	13.5	788.41	Limestone
MW-6	12/17/1983	858.44	861.22	40		Stick-up	10	2	0.006	30 - 40	828.44 - 818.44	30.72 - 44	827.72 - 814.44	26.5 - 28	831.94 - 830.44	NA	NA	NA	NA	Silty Clay
MW-7	12/8/1983	850.99	853.7	53.7		Stick-up	10	2	0.006	43.7 - 53.7	807.29 - 797.29	44 - 53.7	806.99 - 797.29	41 - 42	809.99 - 808.99	NA	NA	14.3	836.69	Limestone
MW-8	12/9/1983	838.97	841.28	28.2		Stick-up	10	2	0.006	18.2 - 28.2	820.77 - 810.77	19.25 - 28.2	819.72 - 810.77	16 - 17	822.97 - 821.97	NA	NA	14.8	824.17	Limestone
MW-9	9/9/1988	819.85	819.96	38.2		Flush	20	2	UK	18 - 38	801.85 - 781.85	14.98 - 38	804.87 - 781.85	15 - 18	804.85 - 801.85	NA	NA	NA	NA	Limestone & Shale
MW-10	9/18/1988	865.91	866.14	41.3		Flush	20	2	UK	21.3 - 41.3	844.61 - 824.61	25.95 - 41.3	839.96 - 824.61	17.5 - 21	848.41 - 844.91	NA	NA	NA	NA	Sandy to Clayey Silt
MW-11	9/19/1988	809.49	809.89	41.9		Flush	30	2	UK	11.9 - 41.9	797.59 - 767.59	12.16 - 41.9	797.33 - 767.59	2.5 - 12	806.99 - 797.49	NA	NA	NA	NA	Limestone & Shale
Range Study Program Wells																				
MW-RS1	8/20/2002	865.39	867.78	13.5		Stick-up	8	2	0.01	5.5 - 13.5	859.89 - 851.89	6.63 - 13.5	858.76 - 851.89	2.9 - 4.3	862.49 - 861.09	NA	NA	4.5	860.89	Limestone & Clayey Silt
MW-RS2	8/16/2002	873.28	875.83	25.7		Stick-up	10	2	0.01	15.2 - 25.2	858.08 - 848.08	15.53 - 25.2	857.75 - 848.08	4.1 - 12.9	869.18 - 860.38	NA	NA	7	866.28	Limestone
MW-RS3	8/17/2002	879.19	881.57	12.5		Stick-up	5	2	0.01	7.5 - 12.5	871.69 - 866.69	8.55 - 12.5	870.64 - 866.69	4.7 - 6	874.49 - 873.19	NA	NA	18.5	860.69	Silty Clay
MW-RS4	8/19/2002	858.21	860.85	14.8		Stick-up	9	2	0.01	4.8 - 14.8	853.41 - 843.41	7.42 - 14.8	850.79 - 843.41	4.2 - 3.5	854.01 - 854.71	NA	NA	10	848.21	Silty Clay & Fine Sand
MW-RS5	8/18/2002	851.42	853.98	13.1		Stick-up	8	2	0.01	5 - 13.1	846.42 - 838.32	6.32 - 13.1	845.1 - 838.32	2.5 - 3.8	848.92 - 847.62	NA	NA	5.6	845.82	Silty Clay & Fine Sand
MW-RS6	8/18/2002	858.24	860.68	14.8		Stick-up	9	2	0.01	5.4 - 14.4	852.84 - 843.84	6.27 - 14.8	851.97 - 843.44	2.5 - 4	855.74 - 854.24	NA	NA	NA	NA	Silty Clay & Sand
MW-RS7	8/19/2002	859.42	862.02	12.5		Stick-up	5	2	0.01	7.5 - 12.5	851.92 - 846.92	7.52 - 12.5	851.9 - 846.92	3.5 - 5	855.92 - 854.42	NA	NA	26.5	832.92	Silty Clay & Sand
MW-RS8	8/21/2002	865.03	867.14	15.7		Stick-up	10	2	0.01	5.7 - 15.7	859.33 - 849.33	6.83 - 15.7	858.2 - 849.33	2.9 - 3.9	862.13 - 861.13	NA	NA	14.5	850.53	Silty Clay & Sand

Table 2-3. Well and Surface Water/Cave Spring Gauge Locations Jefferson Proving Ground, Madison, Indiana

Well D	X	Y	Concrete Pad Elevation	Ground Surface Elevation	Top of PVC Casing Elevation	Top of Steel Casing Elevation
	Meters	Meters	FTAMSL	FTAMSL	FTAMSL	FTAMSL
Site Characterization Wells						
JPG-DU-01D	636539.995	4306708.642	838.81	838.26	841.15	841.89
JPG-DU-01I	636540.154	4306706.556	838.61	838.06	841.23	841.81
JPG-DU-02D	636565.697	4305279.35	801.61	800.92	803.83	804.47
JPG-DU-02I	636567.214	4305281.137	801.68	800.93	803.94	804.5
JPG-DU-03I	636593.681	4303959.047	862.71	862.14	865.6	866.17
JPG-DU-03O	636593.856	4303960.47	862.65	862.1	865.54	866.14
JPG-DU-04D	636935.686	4303444.371	864.75	864.18	867.13	867.71
JPG-DU-04I	636933.376	4303444.57	864.73	864.32	867.38	867.9
JPG-DU-04O	636931.028	4303444.442	864.58	864.11	867.28	867.73
JPG-DU-05D	638216.278	4303681.567	844.21	843.67	847.26	847.76
JPG-DU-05I	638216.175	4303679.604	844.27	843.71	847.21	847.73
JPG-DU-06D	638199.103	4304614.176	873.47	872.79	875.76	876.35
JPG-DU-06I	638198.972	4304612.403	873.28	872.91	875.65	876.15
JPG-DU-06O	638198.18	4304617.511	873.18	872.56	876.02	876.5
JPG-DU-07D	638367.162	4305382.741	843.1	842.58	846.53	846.76
JPG-DU-07I	638369.497	4305382.771	843.22	842.39	846.33	846.81
JPG-DU-08D	637497.021	4305150.937	816.22	815.36	818.58	819.07
JPG-DU-08I	637495.006	4305149.733	816.15	815.44	818.59	819.06
JPG-DU-09D	637368.414	4305534.945	846.68	846.1	849.07	849.56
JPG-DU-09I	637368.23	4305537.286	847.08	846.45	849.38	849.91
JPG-DU-09O	637368.016	4305538.921	847.26	846.63	849.63	850.19
JPG-DU-10D	637349.415	4306531.094	871.33	870.71	873.64	874.21
JPG-DU-10O	637349.297	4306533.642	871.02	870.39	873.51	874.06
ERM Program Wells						
MW-1	638198.15	4305386.225	NA	851.75	853.58	853.77
MW-2	638231.465	4302916.312	NA	848.25	850.49	850.54
MW-3	638288.107	4300464.406	NA	870.96	873.64	873.74
MW-4	640045.941	4297149.831	899.34	898.92	902.19	902.22
MW-5	636570.126	4305179.455	NA	801.91	804.36	804.44
MW-6	636602.831	4302811.517	NA	858.44	861.22	861.3
MW-7	636647.816	4300202.772	NA	850.99	853.7	853.77
MW-8	635506.6379	4296992.616	838.97	838.97	841.28	841.37
MW-9	637595.429	4305296.982	819.97	819.85	819.96	NA
MW-10	637356.798	4305925.576	866.05	865.91	866.14	NA
MW-11	637027.07	4305080.874	809.94	809.49	809.89	NA
Range Study Program Wells						
MW-RS1	639384.399	4304799.159	NA	865.39	867.78	867.96
MW-RS2	639103.829	4305051.937	NA	873.28	875.83	876.07
MW-RS3	639468.427	4305524.411	NA	879.19	881.57	881.68
MW-RS4	636370.993	4302751.588	NA	858.21	860.85	860.98
MW-RS5	635753.358	4303028.488	NA	851.42	853.98	854.07
MW-RS6	636185.885	4303381.978	NA	858.24	860.68	860.77
MW-RS7	636326.106	4303002.899	NA	859.42	862.02	862.11
MW-RS8	636708.186	4304237.805	NA	865.03	867.14	867.32

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

NA - not applicable

Notes:

Horizontal coordinates are referenced to the North American Datum of 1983 (NAD 83).

The Elevations are referenced to the North American Vertical Datum of 1988 (NAVD 88).

surging the water column in the well with a combination of a surge block and a submersible well pump over the entire screened interval to force water in and out through the screen openings and through the filter pack to agitate and mobilize the particulates around the well screen during the removal of water from the well. Development was achieved by alternating between surging the water column and pumping with an electric submersible pump. Pumping periods following the water column surging were completed to remove the fine particles that had been mobilized and moved into the well bore, where they could be pumped up to the surface and removed from the well. All of the groundwater pumped to the surface during development activities was directed out of the work area and surface discharged, as discussed in Section 3 of the FSP Addendum 4 (SAIC 2007b).

During the development process the following development criteria were achieved for all wells unless specified in the logbooks (Appendix A) and/or well development forms (Appendix F):

- A turbidity with nephelometric turbidity unit (NTU) readings that have stabilized over three successive well volumes, or the water is clear to the unaided eye
- The sediment thickness remaining in the bottom of the well is less than 1.2 inches (0.03 meters)
- A minimum water removal of five times the standing water volume in the well (to include the well screen and casing plus saturated annulus, assuming 30 percent annular porosity) has been achieved
- Indicator parameters (e.g., pH, specific conductivity, and temperature) have stabilized to within 10 percent on three consecutive readings.

The newly installed wells in general have yields that are much lower than expected and the water volume removal criteria was not achieved in the majority of the installed wells. Numerous wells were revisited to continue development on separate days as a result of the low yield and the wells being pumped dry before the criteria were able to be achieved.

The existing ERM and Range Study wells were not developed during the new well installation task, but were re-developed in February/March 2008 due to the limited information with respect to their development and the documented low yields. Re-development of these wells was completed to provide better monitoring points by improving hydraulic communication of the well with the surrounding subsurface materials and providing a well where the collection of a sediment-free sample is more likely. The existing wells in general have low yields and the water volume removal criteria were not achieved in the majority of the existing wells. Numerous wells were revisited to continue development on separate days as a result of the low yields and the wells being pumped dry before the criteria were able to be achieved.

2.8 GROUNDWATER AND SURFACE WATER ELEVATION

Depth to groundwater measurements were completed by SAIC field personnel from the available wells during several field events between August 2007 and February 2008. The entire set of newly installed wells was not available for depth to groundwater measurements until December 2007. The depth to groundwater measurements were used in conjunction with the survey results to calculate the corresponding groundwater elevations and are summarized in Table 2-4. Based on the water level data collected, it appears that several of the newly installed wells have not recovered from being pumped dry during the development activities. These wells that appear to have not fully recovered consist of the following: JPG-DU-01D (not enough data to determine if fully recovered, could be close to static conditions), JPG-DU-02D, JPG-DU-04D, JPG-DU-05D, JPG-DU-07D, JPG-DU-07I, and JPG-DU-08D.

Table 2-4. Water Level Data
Jefferson Proving Ground, Madison, Indiana

Station ID	Reference Elevation	Ground Surface Elevation	Event/Date(s)							
			Quarterly Aug 07		Quarterly Nov 07		Site Wide Jan 08		Quarterly Feb 08	
			8/16/2007		11/15/07-11/16/07		1/23/2008		2/12/2008	
			DTW	GW Elev.	DTW	GW Elev.	DTW	GW Elev.	DTW	GW Elev.
JPG-DU-01D	841.15	838.26	95.76	745.39	54.75	786.4	33.78	807.37	28.51	812.64
JPG-DU-01I	841.23	838.06	1.76	839.47	2.15	839.08	1.7	839.53 F	2.49	838.74 F
JPG-DU-02D	803.83	800.92	119	684.83	118.74	685.09	119	684.83	118.51	685.32
JPG-DU-02I	803.94	800.93	19.39	784.55	19.28	784.66	18.81	785.13	18.39	785.55
JPG-DU-03I	865.6	862.14	NI	NA	NI	NA	7.02	858.58	4.89	860.71
JPG-DU-03O	865.54	862.1	NI	NA	NI	NA	6.26	859.28	5.21	860.33
JPG-DU-04D	867.13	864.18	NI	NA	NI	NA	79	788.13	72.71	794.42
JPG-DU-04I	867.38	864.32	NI	NA	NI	NA	11.77	855.61	10.74	856.64
JPG-DU-04O	867.28	864.11	NI	NA	NI	NA	11.03	856.25	9.95	857.33
JPG-DU-05D	847.26	843.67	NI	NA	NI	NA	121.94	725.32	121.79	725.47
JPG-DU-05I	847.21	843.71	NI	NA	NI	NA	6.32	840.89	6.15	841.06
JPG-DU-06D	875.76	872.79	28.37	847.39	23.28	852.48	23.22	852.54	22.94	852.82
JPG-DU-06I	875.65	872.91	13.69	861.96	15	860.65	9.8	865.85	8.79	866.86
JPG-DU-06O	876.02	872.56	NI	NA	NM	NA	5.69	870.33	4.72	871.3
JPG-DU-07D	846.53	842.58	NI	NA	NM	NA	120.14	726.39	119.78	726.75
JPG-DU-07I	846.33	842.39	NI	NA	NI	NA	60.14	786.19	59.79	786.54
JPG-DU-08D	818.58	815.36	136.89	681.69	136.52	682.06	133.25	685.33	136.09	682.49
JPG-DU-08I	818.59	815.44	35.66	782.93	30.61	787.98	23.69	794.9	22.46	796.13
JPG-DU-09D	849.07	846.1	38.08	810.99	37.49	811.58	37.63	811.44	36.94	812.13
JPG-DU-09I	849.38	846.45	17.11	832.27	17.63	831.75	16.34	833.04	16.21	833.17
JPG-DU-09O	849.63	846.63	12.55	837.08	12.13	837.5	11.29	838.34	11.59	838.04
JPG-DU-10D	873.64	870.71	35.63	838.01	36.61	837.03	36.52	837.12	36.29	837.35
JPG-DU-10O	873.51	870.39	38.74	834.77	39.75	833.76	38.14	835.37	37.66	835.85
MW-1	853.58	851.75	10.49	843.09	9.95	843.63	9.83	843.75	9.71	843.87
MW-2	850.49	848.25	13.59	836.9	13.58	836.91	9.96	840.53	9.51	840.98
MW-3	873.64	870.96	12.49	861.15	14.25	859.39	11.48	862.16	10.95	862.69
MW-4	902.19	898.92	NM	NA	14.71	887.48	6.4	895.79 WF	3.91	898.28
MW-5	804.36	801.91	NM	NA	17.37*	786.99	18.03	786.33	18.19	786.17
MW-6	861.22	858.44	21.54	839.68	9.91	851.31	6.34	854.88	7.02	854.2
MW-7	853.7	850.99	12.39	841.31	12.89	840.81	6.78	846.92	9.42	844.28
MW-8	841.28	838.97	NM	NA	23.72	817.56	23.61	817.67	23.49	817.79
MW-9	819.96	819.85	36.26	783.7	35.9	784.06	32	787.96	31.09	788.87
MW-10	866.14	865.91	9.51	856.63	8.73	857.41	2.62	863.52	1.79	864.35
MW-11	809.89	809.49	18.24	791.65	7.54	802.35	6.64	803.25	6.64	803.25
MW-RS1	867.78	865.39	NM	NA	NM	NA	2.23	865.55 F	2.34	865.44
MW-RS2	875.83	873.28	9.71	866.12	7.71	868.12	4.99	870.84	4.35	871.48
MW-RS3	881.57	879.19	10.89	870.68	11.14	870.43	6.92	874.65	6.59	874.98
MW-RS4	860.85	858.21	NM	NA	4.84	856.01	5.7	855.15	3.61	857.24
MW-RS5	853.98	851.42	NM	NA	9.38	844.6	5.61	848.37	4.95	849.03
MW-RS6	860.68	858.24	10.61	850.07	10.21	850.47	6.93	853.75	6.11	854.57
MW-RS7	862.02	859.42	NM	NA	10.14	851.88	7	855.02	6.05	855.97
MW-RS8	867.14	865.03	12.25	854.89	13.19	853.95	4.36	862.78	3.46	863.68
SGS-BC-01	800.53	NA	NM	NA	NM	NA	NM	NA	17.61	782.92
SGS-BC-03	800.6	NA	NM	NA	NM	NA	NM	NA	10.6	790
SGS-BC-04	837.09	NA	NM	NA	NM	NA	NM	NA	2.02	835.07
SGS-MF-01	811.95	NA	NM	NA	NM	NA	NM	NA	14.59	797.36
SGS-MF-03	846.84	NA	NM	NA	NM	NA	NM	NA	8.81	838.03
SGS-MF-04	849.4	NA	NM	NA	NM	NA	NM	NA	8.6	840.8

Notes:
DTW is depth to water below reference location (PVC @ wells, stilling well @ SW gauges).
GW Elev. Is calculated groundwater elevation feet above mean sea level.
All elevations are feet above mean sea level.
* MW-5 was gauged on 11/20/07.
F is Frozen measurement collected Ice level.
WF is Frozen however a water measurement was collected.
NA is Not Applicable.
NM is not measured.
NI is not installed.

The present water elevation data set is very limited in that there are only two full measurement events of all of the wells and both events were completed in the winter with a short duration between them. Therefore, caution must be exercised in evaluating the limited data set and in making conclusions at this point. Conclusions based on this limited data set are preliminary until additional data are collected and evaluated. Further evaluation will be made following the additional recovery time, collection of additional well gauging events, and automatic collection of water level data with installed pressure transducers and data loggers.

2.8.1 Hydrostratigraphic Layers

The available well, development, and construction logs for the existing wells were evaluated to classify the existing wells by the materials exposed to the open interval of the well screens. Based on the evaluation of the existing lithologic well logs and the 2007 well installation observations, three hydrostratigraphic layers are presently being considered that are intersected by the monitoring wells being gauged. The hydrostratigraphic layers consist of the following:

- "Overburden" or saturated overburden materials
- "Shallow" bedrock consisting of the top 40 to 60 feet
- "Deep" bedrock below the top 40 to 60 feet.

The newly installed wells have been assigned identifiers, which include a portion that identifies in what hydrostratigraphic layer it has been completed, consisting of "O" for the "overburden," "I" for the "shallow" bedrock zone, and "D" for the "deep" bedrock zone. The one exception is for JPG-DU-10D, which is the deeper well at that well pair, but is installed into the top 16 feet of the bedrock in the "shallow" bedrock zone. Nine of the existing wells were installed in the overburden and nine wells were installed in the "shallow" bedrock zone, but none of the existing wells was installed in the "deep" bedrock zone. The wells have been classified into the zones as provided in Table 2-5.

Table 2-5. Summary of Wells by Hydrostratigraphic Unit
Jefferson Proving Ground, Madison, Indiana

Overburden		Shallow Bedrock Zone		Deep Bedrock Zone [b]
JPG-DU-03O	MW-6	JPG-DU-01I	MW-1[a]	JPG-DU-01D
JPG-DU-04O	MW-10	JPG-DU-02I	MW-2	JPG-DU-02D
JPG-DU-06O	MW-RS1	JPG-DU-03I	MW-3	JPG-DU-04D
JPG-DU-09O	MW-RS3	JPG-DU-04I	MW-5	JPG-DU-05D
JPG-DU-10O	MW-RS4	JPG-DU-05I	MW-7	JPG-DU-06D
	MW-RS5	JPG-DU-06I	MW-8	JPG-DU-07D
	MW-RS6	JPG-DU-07I	MW-9	JPG-DU-08D
	MW-RS7	JPG-DU-08I	MW-11	JPG-DU-09D
	MW-RS8	JPG-DU-09I	MW-RS2	
		JPG-DU-10D		

[a] Well MW-1 has two separate screen intervals in the limestone and will require additional consideration following additional data collection to determine if the water levels are usable.
[b] None of the existing wells was installed in the Deep Zone.

The well construction log for MW-4 indicates that the well was constructed with two separate screen intervals with filter pack connecting the two screen intervals. The bottom screen interval is in the carbonate bedrock and the top screen interval extends from the carbonate bedrock into the overburden materials. The open interval is not discretely located in either the overburden or the shallow bedrock zone and, therefore, has not been placed into either the overburden or shallow bedrock classifications.

The groundwater elevations established from the February 12, 2008 measurement round have been posted on a topographic base map of the study area and are included in Figure 2-3. In addition, the

February 2008 water level round was completed during the quarterly surface water gauging event and several surface water elevations were collected during the same event and included in Figure 2-3.

2.8.2 Shallow Water Table

During the well installation completed in 2007, three locations (JPG-DU-04O, JPG-DU-06O, and JPG-DU-09O) were identified with saturated overburden materials that appeared to have sufficient permeability to provide a functional well. Generally, the majority of the wells completed with screen intervals in the unconsolidated overburden materials exhibited a rise in groundwater levels from the initial measurements collected during 2007, which would normally be expected for this time period of the hydrologic year. The greatest observed water level rise in a single monitored well was 14.52 feet in MW-6. The observed fluctuations with the limited data set may indicate a highly fluctuating shallow groundwater table dependent on precipitation and the season.

Evaluation of the shallow water table is more accurately evaluated within the areas where there are multiple monitoring points screened within the unconsolidated overburden materials, such as in the area of the southwest corner of the DU Impact Area. Based on the water elevations posted in Figure 2-3, it appears that the shallow water table may mimic the surface topography and if determined to be accurate, the localized flow directions and gradients could reasonably be predicted by evaluating the surface topography. The water table in general appears to be relatively close to the ground surface.

2.8.3 Shallow Bedrock Well Water Levels

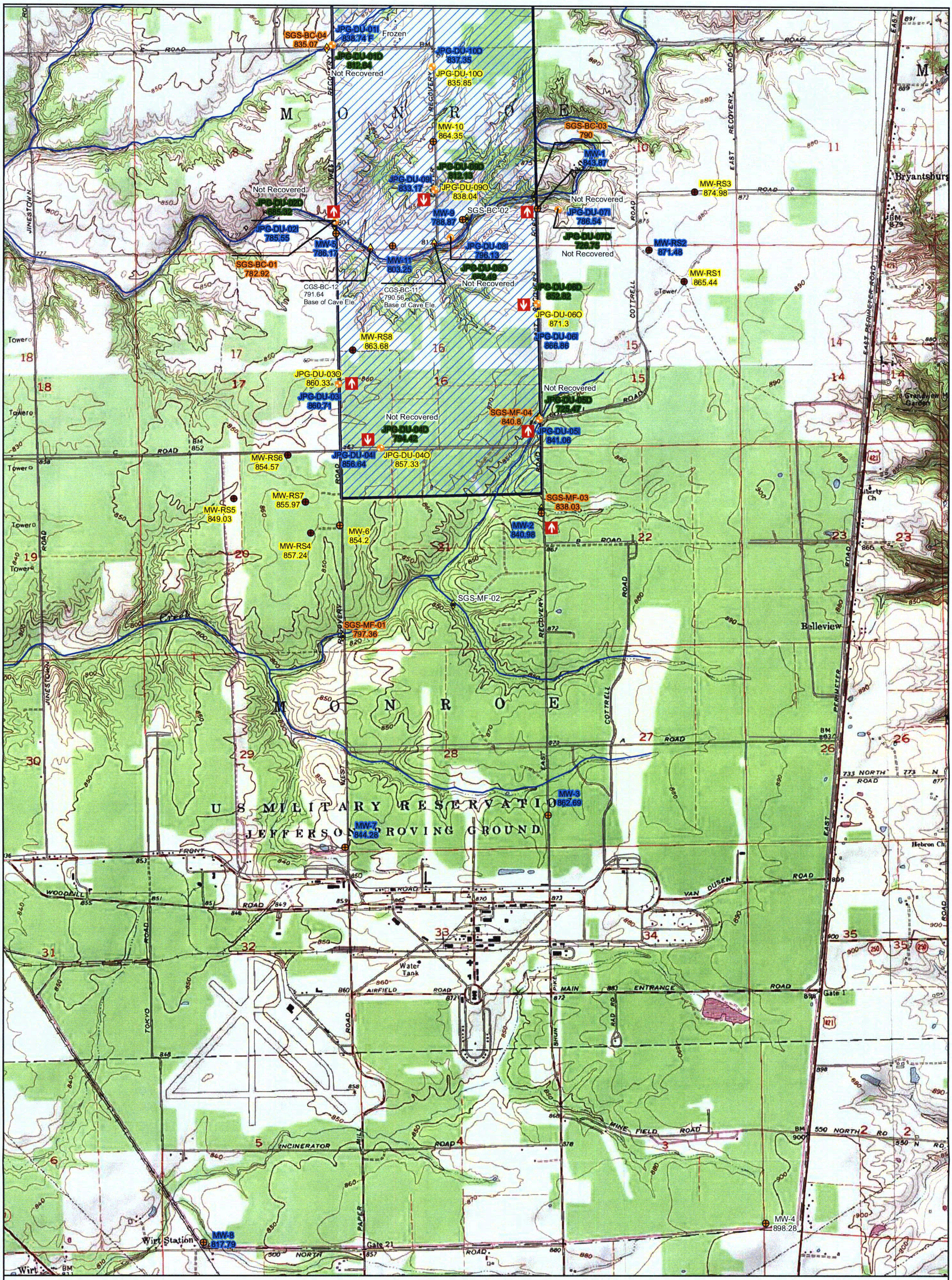
One of the shallow bedrock wells (JPG-DU-07I) appears to not have recovered from the removal of groundwater during well development and will require additional time for recovery and evaluation. The preliminary evaluation of the limited shallow bedrock well water elevation data indicates that the shallow bedrock well water elevations also appear to roughly mimic the surface topography. The water in JPG-DU-01I was frozen in the well during both the January and February 2008 gauging events and the elevation of the ice was measured above the ground surface at that location. The calculated elevations from the measurements to the ice in JPG-DU-01I may not be representative of the actual head potentials at those times.

2.8.4 Deep Bedrock Well Water Levels

As stated earlier, seven of the newly installed deep wells (JPG-DU-01D, JPG-DU-02D, JPG-DU-04D, JPG-DU-05D, JPG-DU-07I, JPG-DU-07D, and JPG-DU-08D) either appear to not have recovered from the removal of groundwater during well development or, with the limited available water level data, it is unclear if the well has completely recovered. The deep borings revealed generally carbonate bedrock that, based on field observations, appears to have a very low permeability. Attempts were made to install the deep wells into the most probable zone (based on field observations) where the most permeability existed within the deeper portion of the boring. Additional time will be required to allow for recovery of the wells from development activities and for additional water level data collection before completing an evaluation of the deep well water levels.

2.8.5 Evaluation of Head Potentials

Using the preliminary water elevation data, the measured head potentials between surface water, overburden, shallow bedrock, and deep bedrock wells were evaluated. Due to conditions discussed previously, such as unrecovered wells, the evaluation only could be completed at several locations. This head potential evaluation should be considered preliminary due to the unrecovered water levels, presence of ice, and the limited water elevation data set available at this time. The following observations also are presented in Figure 2-3 as directional arrows at the respecting locations:



Legend

- DU Well
- Monitoring Well
- Range Well
- Cave Gauge
- Continuous Stream Gauge
- Stream Staff Gauge
- Streams
- Roads
- DU Impact Area
- JPG-DU-04D Deep Monitoring Zone Well
- JPG-DU-04I Intermediate Monitoring Zone Well
- JPG-DU-04O Shallow Monitoring Zone Well
- MW-4 Multiple Monitoring Zone Well
- SGS-MF-01 Surface Water Gauging Station
- Inferred flow direction based on compared head potentials.

0 1,250 2,500 5,000
SCALE IN FEET

NOTE:
1. Water elevations based on 2008 survey completed by Scholle's Land Surveying.
2. All elevations in feet above mean sea level.

N W E S

Jefferson Proving Ground
Madison, Indiana

Groundwater and Surface Water Elevations
12 February 2008

Drawn	AGM	Checked		Approved		Figure No.
Date	2/29/08					**2-3**
JB # 01-1633-04-8527-610						

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- The head potential difference between JPG-DU-01I (ice level) and SGS-BC-04 indicate an upward flow potential from the shallow bedrock zone to the surface water. The water level in JPG-DU-01I was frozen so this result is preliminary. JPG-DU-01D has not recovered and cannot be used at this time in this evaluation.
- JPG-DU-02I, MW-5, and SGS-BC-01 water elevations indicate an upward flow potential from the shallow bedrock zones to the surface water. JPG-DU-02D has not recovered and cannot be used at this time in this evaluation.
- JPG-DU-03O and JPG-DU-03I elevations indicate an upward flow potential from the shallow bedrock zone to the overburden. The water elevations are very close and the upward gradient is small.
- JPG-DU-04O and JPG-DU-04I elevations indicate a downward flow potential from the overburden to the shallow bedrock zone. JPG-DU-04D has not recovered and cannot be used at this time in this evaluation.
- The head potential difference between JPG-DU-05I and SGS-MF-04 indicates an upward flow potential from the shallow bedrock zone to the surface water. JPG-DU-05D has not recovered and cannot be used at this time in this evaluation.
- The head potential differences between JPG-DU-06O, JPG-DU-06I, and JPG-DU-06D indicate a downward flow potential between each zone.
- Neither of the wells at the JPG-DU-07 well pair has recovered and cannot be used in this evaluation.
- JPG-DU-08D has not recovered and cannot be used in this evaluation. Future monitoring events will include surface water elevation measurements at SGS-BC-02 and CGS-BC-11 that can be used in the evaluation of head potentials in this area.
- The head potential differences between JPG-DU-09O, JPG-DU-09I, and JPG-DU-09D indicate a downward flow potential between each zone.
- JPG-DU-10O and JPG-DU-10I elevations indicate an upward flow potential from the shallow bedrock zone to the overburden.
- MW-2 and SGS-MF-03 water elevations indicate an upward flow potential from the shallow bedrock zone to the surface water.
- MW-1 and SGS-BC-03 locations are relatively close and the ground surface is roughly 50 feet higher at MW-1 than at SGS-BC-03. In addition, well construction logs for MW-1 indicate that it was constructed with two separate screen intervals both open to the shallow bedrock zone. Considering these details and the water elevations at the two locations, an upward flow potential is indicated from the shallow bedrock zone to the surface water.

Based on the limited data set and an understanding that additional surface water and groundwater level measurements will be conducted in the future, the following conclusions are made regarding head potentials:

- Four monitoring locations indicate an upward flow potential from the shallow bedrock zone to the surface water
- Two locations indicate an upward flow potential from the shallow bedrock zone to the overburden
- Three locations indicate a downward flow potential between each of the hydrostratigraphic zones.

During planned quarterly monitoring events, additional groundwater and surface water elevation data will be collected along with groundwater stage data from the automatic data recorders that will expand and enhance the evaluation of flow potentials between the three aquifer zones and the surface water.

2.9 FUTURE AQUIFER MONITORING AND TESTING ACTIVITIES

This section describes planned aquifer monitoring and testing activities. Automatic water level data recorders will be installed in several wells and downloaded periodically, as described in Section 2.9.1. Quarterly monitoring for total and isotopic uranium and other water chemistry parameters will commence in April 2008, as described in Section 2.9.2. USGS will collect samples to determine the age of groundwater underlying the site and conduct groundwater flow studies, as described in Section 2.9.3. The Army will conduct one round of rising- and falling-head slug tests, as described in Section 2.9.4. Further evaluation will be completed as required, as described in Section 2.9.5.

2.9.1 Water Level Data Logger Well Selection

Prior to the first quarterly sampling event (planned for April 2008), automatic data recorders will be installed in 12 groundwater wells. The guidelines for selecting wells where the automatic water level recorders are to be installed were presented in Section 5.1.2 of the FSP Addendum 4 (SAIC 2007b) and consisted of the following:

- Two locations where an additional well was installed into the overburden. Recorders will be installed into all three wells at these locations (deep and shallow bedrock, and overburden wells). The locations include JPG-DU-06 cluster (3 wells) and JPG-DU-09 cluster (3 wells).
- At least one well will be selected in a location where minimal permeability was observed in one of the deep wells. The location selected is JPG-DU-04D.
- The remainder of the recorders will be installed into wells where permeability was observed (most likely in shallow bedrock wells) and in previously installed wells to evaluate the connectivity. The selected locations include JPG-DU-01I, JPG-DU-02I, JPG-DU-05I, JPG-DU-08I, and MW-2.

The recorders will operate continuously through the completion of the site characterization, but not necessarily at the same monitoring locations. The data recorder locations will be evaluated and they may be moved for collection of additional data and evaluation of the connectivity of other monitoring locations and responsiveness to precipitation. All of the recorded stage data will be converted to groundwater elevation.

2.9.2 Quarterly Monitoring

Along with the ongoing quarterly manual surface water flow measurements, surface water gauging station data recorder downloads, and weather station downloads, several new quarterly monitoring and sampling tasks will begin starting in April 2008 and consist of the following:

- Site-wide groundwater levels
- Monitoring well sampling
- Surface water and sediment sampling
- Quarterly groundwater stage recorder downloads.

The details and procedures for these tasks are provided in the FSP Addendum 5 (SAIC 2008).

2.9.3 USGS Groundwater Studies

Groundwater samples will be collected from 17 to 20 (depending on the well yield) of the newly installed wells and will be analyzed by USGS for the concentrations of several dissolved gases and age-dating constituents (chlorofluorocarbon compounds, tritium, and helium-3). The dissolved gas data will be used to estimate the recharge temperature of water, which is needed to estimate the age of groundwater samples since the water infiltrated below the water table.

USGS also will measure groundwater flow directions using groundwater flowmeter technologies and compare those measurements to conventionally interpreted flow directions in approximately 20 of the newly installed wells. In addition, USGS will measure borehole geophysical parameters (natural gamma and EM-induction) and use borehole camera logs to provide supporting information with available well log information to refine and target flowmeter measurement intervals. This work will characterize how localized groundwater flow directions in the DU Impact Area at JPG may locally differ from those that would be predicted from mapping of water table or potentiometric surfaces using groundwater elevations measured in wells.

Additional details concerning the scope, objectives, and procedures of the age-dating sampling and flowmeter measurements are presented in the FSP Addendum 6 (USGS 2008b).

2.9.4 Slug Testing

During the well installation and development, it was observed that the aquifer materials that the wells encountered have a lower permeability than what was originally anticipated. Therefore, hydraulic conductivity measurements can be completed with the slug aquifer testing methods. Hydraulic conductivity testing consisting of slug testing will be completed on a representative subset of the wells within the study area. The hydraulic conductivity will be used in the further refinement of the CSM as well as provide site-specific inputs for upcoming modeling efforts. The specific details and slug testing procedures will be described and included in the FSP Addendum 7, which is under development.

2.9.5 Conduit Intersection Confirmation

The newly installed wells will be further evaluated to determine the connectivity and success at intersecting groundwater conduits or preferential groundwater flow pathways. Preliminary portions of this evaluation have been completed and are included in the description of the hydrostratigraphic units of this report, such as 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.

The additional evaluation will be completed as the additional required data are collected and will consist of the following:

- Groundwater 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 sample results for common anions and cations will be evaluated with respect to the relative concentrations of these constituents and would be expected to be higher in nonconduit wells in comparison to conduit wells due to the length of contact time with the aquifer materials
- The results of the USGS groundwater age-dating will be evaluated to determine the connectivity of the wells to preferential flow pathways in the aquifer.

2.10 SUMMARY

SAIC successfully installed 10 monitoring well clusters at locations determined to have a high probability to intersect preferential groundwater flow pathways (i.e., fractures, karst features) as determined from previous studies (FTA and EI survey). The expected karst features were not encountered during the drilling and only one minor solution feature (an approximately 6-inch void) was observed during the drilling of the two wells at the JPG-DU-02 well cluster. Five of the wells were completed with screen intervals in saturated permeable overburden materials and the remaining wells were constructed with screen intervals in the bedrock. Several modifications were made to the field procedures described in the FSP Addendum 4 (SAIC 2007b) and are described in Section 2.4.1. One significant modification consists of the addition of three wells with wells screens located within the overburden materials as well as the replacement of the planned "deep" bedrock well at cluster location 3 with an overburden well. Geophysics to identify UXO "targets" and UXO construction support activities were used to establish a safe work zone at each of the well cluster locations prior to drilling and is described in Section 2.5.1. Following the completion of the well installations, the location and elevation of each well were determined by an Indiana licensed land surveyor and each well was developed to remove fines that may have accumulated during the construction.

The well logs and construction details for the newly installed wells as well as the existing wells (ERM Program and Range Study wells) were reviewed and each well was categorized into one of the three hydrostratigraphic units, as shown in Table 2-5. Groundwater levels were collected in select wells several times in 2007 and a complete round of groundwater levels from the wells and several surface water elevations were collected on 12 February 2008. Several observations have been made from the evaluation of the limited groundwater and surface water elevation data. Overburden water levels have generally risen from the initial 2007 measurements and may represent a highly fluctuating water table that appears to mimic surface topography. Several of the deep wells and one of the shallow bedrock wells appear to have not recovered from pumping during well development. Where differences in water elevations can be evaluated, the head potentials indicate there is an upward flow potential at six of the nine locations. Additional elevation data will be collected during the quarterly monitoring events and from the electronic data loggers that will allow a more complete evaluation of the head potentials within and surrounding the DU Impact Area.

Future planned aquifer monitoring and testing activities include:

- Installation of automatic water level data recorders in monitoring wells
- Quarterly monitoring activities
  - Site-wide groundwater and surface water levels
  - Monitoring well sampling
  - Surface water and sediment sampling
  - Quarterly groundwater stage recorder downloads
- USGS groundwater studies, including age-dating and flowmeter studies
- Hydraulic conductivity aquifer testing by slug test methods.

These activities are scheduled to begin in the spring of 2008 and the first quarterly monitoring event is scheduled to begin in April 2008.

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3. SURFACE WATER GAUGE MEASUREMENTS

SAIC completed the installation of surface water gauging stations in September 2006, which consisted of automatic, continuous, recording stream gauging stations on Big Creek (three locations) and Middle Fork (four locations), selected cave springs along Big Creek (two locations) inside the DU Impact Area, and one visual staff gauge along an unnamed tributary of Big Creek. These locations are shown in Figure 3-1. The installation and monitoring plan were reported in the FSP Addendum 3 (SAIC 2006b). Details and pictures of the gauging station installations are provided in the Well Location Selection Report (SAIC 2007a).

The surface water gauging installations collect stream stage data at each location. Stage data then were used to calculate corresponding surface water flows by constructing a rating curve using manual flow measurements collected at each location (see Appendix G). The rating curves were used to construct hydrographs for each gauge station. These hydrographs were compared to established USGS gauge stations near the site.

Additional surface water flow recordings are planned for a minimum of 2 years. The second year of stream recording will be concurrent with recordings of water levels in monitoring wells across the site. The surface water flow data, along with precipitation data and monitoring well stage data, will be used to evaluate the interrelationships between precipitation, surface water, and groundwater. The information will be used to delineate gaining and losing stream sections and calculate water budget components, surface water runoff, and groundwater runoff.

3.1 CAVE STREAM WEIRS

Two cave streams, both tributaries to Big Creek, were selected for monitoring. CGS-BC-11 is located at the southern end of Center Recovery Road on the north side of Big Creek. CGS-BC-12 is located approximately 2,000 feet downstream from (west of) CGS-BC-11, also on the north side of Big Creek. Both cave stream gauging stations are located between surface water gauging stations SGS-BC-02 and SGS-BC-01. A 60-degree v-notch weir was installed in each location to provide accurate measurement of the anticipated stream flows. The weirs were constructed such that water in the cave streams was captured by, and pooled behind the weir structures, directing all flow in the cave stream over the weir. The stage of the water level behind each weir was calculated from pressure transducer readings. Weir stage data were converted to flows using the formula:

$$Q = 0.9326 \times H^{2.5}$$

Where:

Q = Discharge in millions of gallons per day
H = Head of water behind the weir.

The capacity of the weir at CGS-BC-11 is 648 gallons per minute (gpm) and the capacity of the weir at CGS-BC-12 is 1,131 gpm, or 1.00 foot and 1.25 feet of head behind the weir, respectively. When these values are exceeded, the recorded stage does not accurately reflect the discharge. This occurred when, in the case of CGS-BC-11, Big Creek flooded the weir. In the case of CGS-BC-12, the weir drains into a closed depression in the alluvial sediments and seeps into the stream through the south wall of the depression; during high flows, stormwater backs up and floods the weir. This condition does not negatively impact the usefulness of the data for the purposes of the study, since accurate measurement of stormwater flows is not that critical. Rather, base flow supported by groundwater discharges from the caves are more important to accurately measure, and the weirs effectively record those flows.

Appendices H-1 and H-2 show a hydrograph for each monitored cave stream during the period of record. Excluding the periods of time where flow exceeded the capacity of the weirs, flows from the cave streams ranged from 0 to 646 gpm in BC-11 and 0 to 355 gpm in BC-12. Stage/flow data are included in Appendix H-3.

It is obvious from a review of the cave stream hydrographs that the flow is extremely flashy, meaning that after precipitation events, the flow increases rapidly, and decreases rapidly, causing the spiky nature of the hydrographs. The hydrographs showed periods of no-flow in all months except February through April, interrupted by sharp rises in flow as a result of precipitation events. These observations suggest that the cave stream networks feeding the two monitored streams are above the groundwater table most of the year. The cave streams appear to serve as storm water conduits, capturing surface water runoff, presumably through sink holes and well-drained closed depressions.

3.2 SURFACE STREAM GAUGE STATIONS

After installation of the stage recorder at each location, the flow in the stream was measured manually using an in-stream flow meter. The methodology used to measure the streams is in accordance with the U.S. Environmental Protection Agency's (USEPA's) *Wadeable Stream Assessment Field Operations Manual* (USEPA 2004). Field logbooks and calculation sheets are included in Appendices A and H, respectively.

Measurements were attempted monthly for the first 12 months. During those 12 months, 10 measurements were collected on most stations. During the February 2007 gauging event, measurements were not made on some stations due to high stream flows that were too dangerous to manually measure. The goal of conducting monthly measurements was to collect a range of flow data at different stages, as the streams reacted to seasonal runoff flows. The monthly visits also provided a sufficient maintenance frequency to ensure operation of the recorders.

Figure 3-2 provides an example of the stream flow calculation sheet for 12 December 2006 for SGS-BC-02, located on Big Creek within the DU Impact Area, approximately 1,100 feet upstream and east of Center Recovery Road and between SGS-BC-01 and SGS-BC-03.

The manual flow measurements, corresponding stage measurements, and measured stream cross sections were used to develop a rating curve for discharge, using the Manning equation (Fetter 1988):

$$V = \frac{1.49}{n} R^{2/3} S^{1/2}$$

Where:

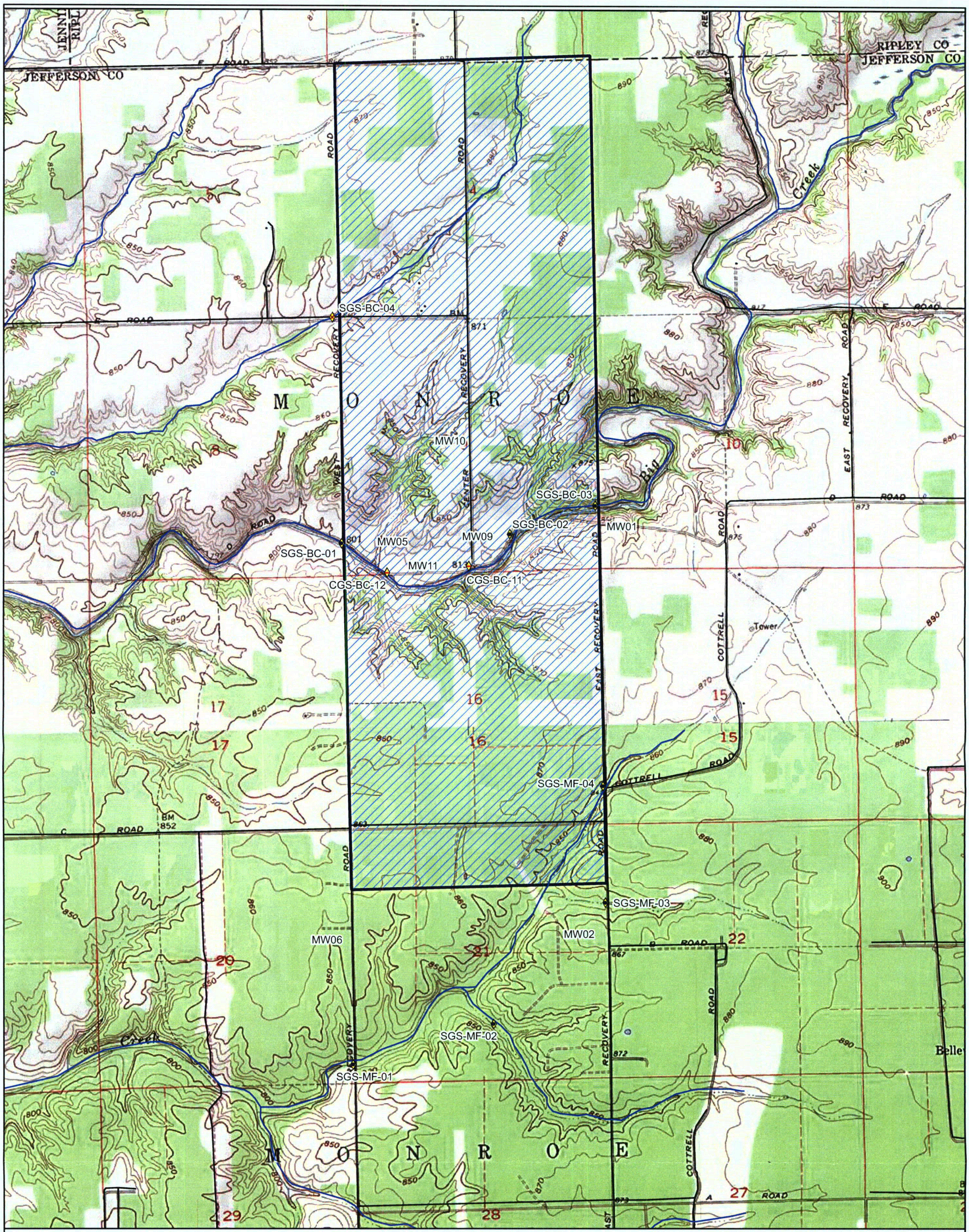
V = Flow velocity in feet per second
n = The Manning roughness coefficient (dimensionless)
R = Hydraulic radius in feet
S = Slope of the water surface (dimensionless).

Discharge Q is defined by:

$$Q = VA$$

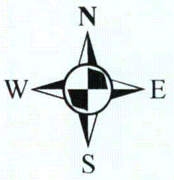
Where Q is discharge in cubic feet per second, and A is the cross-sectional area of the stream in square feet. When we combine this with the Manning equation, we find:

$$Q = \frac{1.49}{n} AR^{2/3} S^{1/2}$$



Legend

- Cave Stream Gauging Station
- Continuous Stream Gauging Station
- Stream Staff Gauging Station
- Streams
- Roads
- DU Impact Area



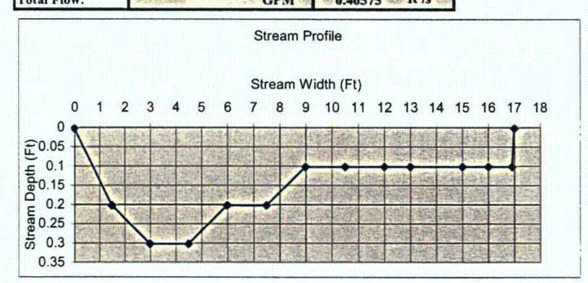
Note: Proposed stream guage locations subject to adjustment based on field observations.

Jefferson Proving Ground Madison, Indiana		
Locations of Stream and Cave Spring Gauges		
JB # 01-1633-04-8527-710	Drawn PAE 04/07/06	Checked
SAIC From Science to Solutions	Revisions: AGM 11/27/06	Figure No. 3-1

Stream Gauging Data Collection Sheet		Page _1_ of _1_
Date: 15-Nov-07	Time : 0845	
Project Name & Location: JPG - Madison, Indiana		
Collected By: AGM	Station Description (circle all that apply)	
Station ID: SGS-BC-02	Stream Bed Description:	Gravelly Sandy Silty Bedrock
Current Weather Conditions:Windy, ~41 degrees F	Flow Description:	Obstructed Turbulent Smooth
Stream Width (ft): 17	Water Clarity:	Very silty Cloudy Clear
Instrument Type & ID: Marsh McBirney	Ice:	None Partially frozen Frozen
Notes:	Heavy Rain in past 7 days	Yes No Unknown
	Carbonate Area	Yes No Unknown

Distance from Bank (Ft)	Depth (ft)	Velocity (ft/s)	Area (ft^2)	Flow (ft^3/s)	Comment
			0.15		
1.5	0.2	0.01	0.375	0.00375	
3	0.3	0.01	0.45	0.0045	
4.5	0.3	0.58	0.375	0.2175	
6	0.2	0.03	0.3	0.009	
7.5	0.2	0.07	0.225	0.01575	
9	0.1	0.39	0.15	0.0585	
10.5	0.1	0.01	0.15	0.0015	
12	0.1	0.31	0.1	0.031	
13	0.1	0.55	0.2	0.11	
15	0.1	0.01	0.1	0.001	
16	0.1	0.14	0.09	0.0126	
16.9	0.1	0.13	0.005	0.00065	
17					
Total Flow:	209.0286 GPM		0.46575 ft^3/s		

Trapezoidal Area		
Distance	Depth	Area (ft^2)
		0.15
1.5	0.2	
1.5	0.2	0.375
3	0.3	
3	0.3	0.45
4.5	0.3	
4.5	0.3	0.375
6	0.2	
6	0.2	0.3
7.5	0.2	
7.5	0.2	0.225
9	0.1	
9	0.1	0.15
10.5	0.1	
10.5	0.1	0.15
12	0.1	
12	0.1	0.1
13	0.1	
13	0.1	0.2
15	0.1	
15	0.1	0.1
16	0.1	
16	0.1	0.09
16.9	0.1	
16.9	0.1	0.005
17		
17		
8		



Notes:

1. All shaded boxes are automatically populated from values entered in un-shaded areas.
2. Zero values entered will show up as blank cells.
3. Average trapeziodal area calculated by following procedures:

http://www.epa.gov/owow/monitoring/volunteer/stream/vms51.html

Figure 3-2. Example Stream Flow Calculation Spreadsheet

Figure 3-3 shows an example of the rating curve development procedure for SGS-BC-02. Because A, R, and the ratio of $S^{1/2}/n$ vary predictably with stage, we can construct Q as a function of stage d, such that:

$$Q(d) = 1.49M(d)A(d)R(d)^{2/3}$$

Where:

$$M(d) = \frac{S(d)^{1/2}}{n(d)}$$

Calculation sheets for all stations are included in Appendix I.

A comparison of the manual flow measurements and the corresponding stage indicates a number of values that do not appear to match well. Some of these measurements were impacted by log jams observed by field staff, and it was reasonable to exclude the data while developing the rating curve. For instance, for SGS-BC-02, (see Figure 3-3) the stages recorded on 10 May 2007 and 16 August 2007 are 1.053 and 1.034 feet, respectively. The measured stream flows were 3.089 and 0.340 cubic feet per second (cfs), respectively. The flows at such similar stages would be expected to be similar. In addition, the calculated discharge using the rating curve formula compared to the measured discharge shows a large percentage of error. In the example given, the August value was not used for calibration.

The poor correlation could be a result of changing stream channel configuration caused by the extreme and frequent storm flows, log and ice jams, and the numerous and changing beaver dams/pools, or, less likely, field measurement error. Additional manual stream flow measurements are required to evaluate these actual stream changes. These additional measurements will potentially improve the accuracy of the rating curves and the calculation of flows from the continuous stage data, and should result in more usable data, even though some impacted flow data will be in the data set.

Daily average stream flow then was calculated for the period of record. This provided a single average stream flow reading for each day. This was necessary to put the data into a compatible format to be used with USGS models that were used to calculate base flow (Section 3.3). The result is a stream flow hydrograph, showing flow in cfs over the period of record from mid-September 2006 to mid-November 2007. Figures 3-4 through 3-10 represent the hydrographs for the gauging stations for the first year of monitoring.

Although the precision of the flow calculations is a concern, observations of the character of the stream flow hydrographs are useful at this point in the project. The following observations from these hydrographs about the stream flow characteristics are offered:

- The streams are extremely flashy, meaning that after precipitation events, the flow increases rapidly, and decreases rapidly, causing the spiky nature of the hydrograph
- The hydrographs showed a period of low- to no-flow for 4 to 6 weeks of the year, during June and July
- The median discharge for the period of record ranges from 0.04 to 0.49 cfs per square mile (see Table 3-1). Two nearby USGS gauging stations are included in this table and discussed in the following paragraphs.

Stream Gauge Calibration for SGS-BC-02

Date and time	Stage	Discharge (CFS)	A	R	S:n ratio	Calculated A	% Error A	Calculated R	% Error R	Calculated S:n	% Error S:n	Calculated discharge	% Error Discharge
9/19/2006 13:21	0.989	1.948	12.021	0.154	0.379	12.249	1.894	0.164	6.557	0.341	10.039	1.863	4.371
10/4/2006 12:30	0.914	0.364	12.360	0.158	0.068	10.811	12.528	0.149	5.468	0.238	250.975	1.076	195.707
11/10/2006 8:36	1.354	16.739	18.956	0.242	1.526	20.137	6.230	0.236	2.545	1.446	5.213	16.567	1.025
12/12/2006 9:25	1.131	5.710	14.719	0.188	0.793	15.146	2.902	0.191	1.757	0.632	20.295	4.738	17.024
1/18/2007 9:00	1.578	41.268	23.616	0.246	2.984	25.658	8.644	0.282	14.430	2.923	2.019	48.060	16.459
3/8/2007 8:25	1.215	9.182	16.315	0.208	1.075	16.965	3.981	0.208	0.201	0.879	18.214	7.798	15.072
5/10/2007 8:05	1.053	3.089	13.237	0.169	0.512	13.527	2.188	0.176	4.106	0.455	11.108	2.882	6.694
6/4/2007 13:55	0.673	0.273	7.363	0.126	0.099	6.661	9.534	0.104	17.022	0.058	41.208	0.128	53.035
8/16/2007 1125	1.034	0.340	12.876	0.164	0.059	13.142	2.068	0.172	4.777	0.419	608.374	2.539	645.874
	11		544.363	2.533									
	19		1391.708	5.684									

Manning's Eqn: Q=1.49/n x A x S^1/2 x R^2/3

Not used for calibration

Q=1.49*(0.3591*A5^4.5968)*(12.465*D^1.5826)*(0.1657*D^1.1657)^(2/3)

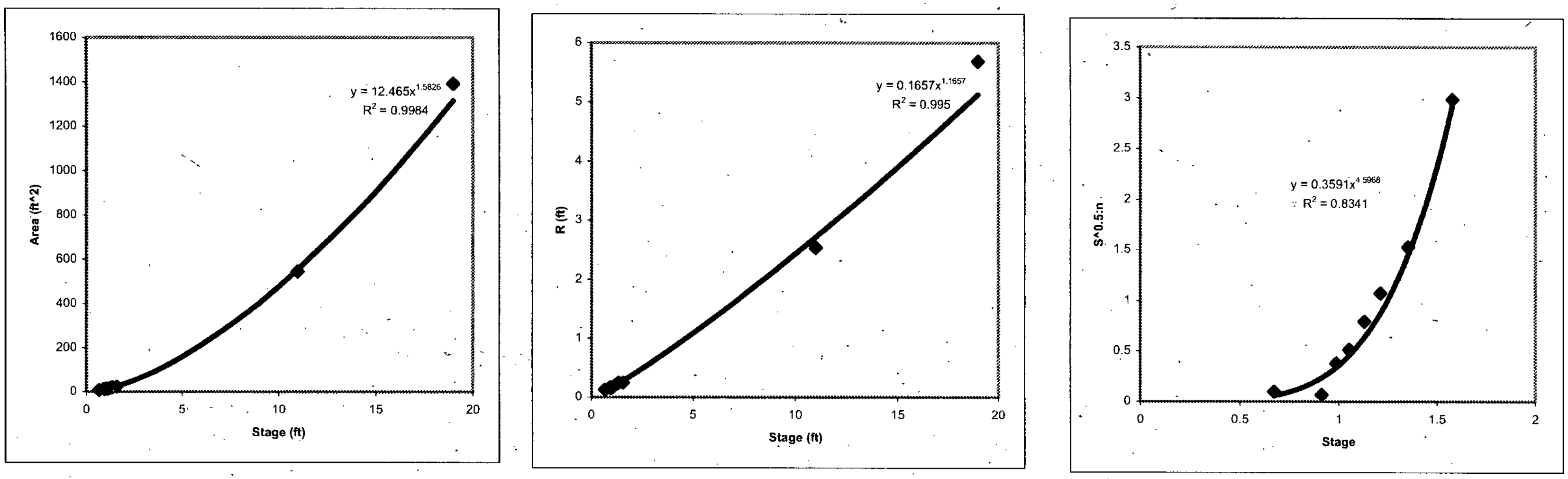


Figure 3-3. Example Rating Curve for SGS-BC-02

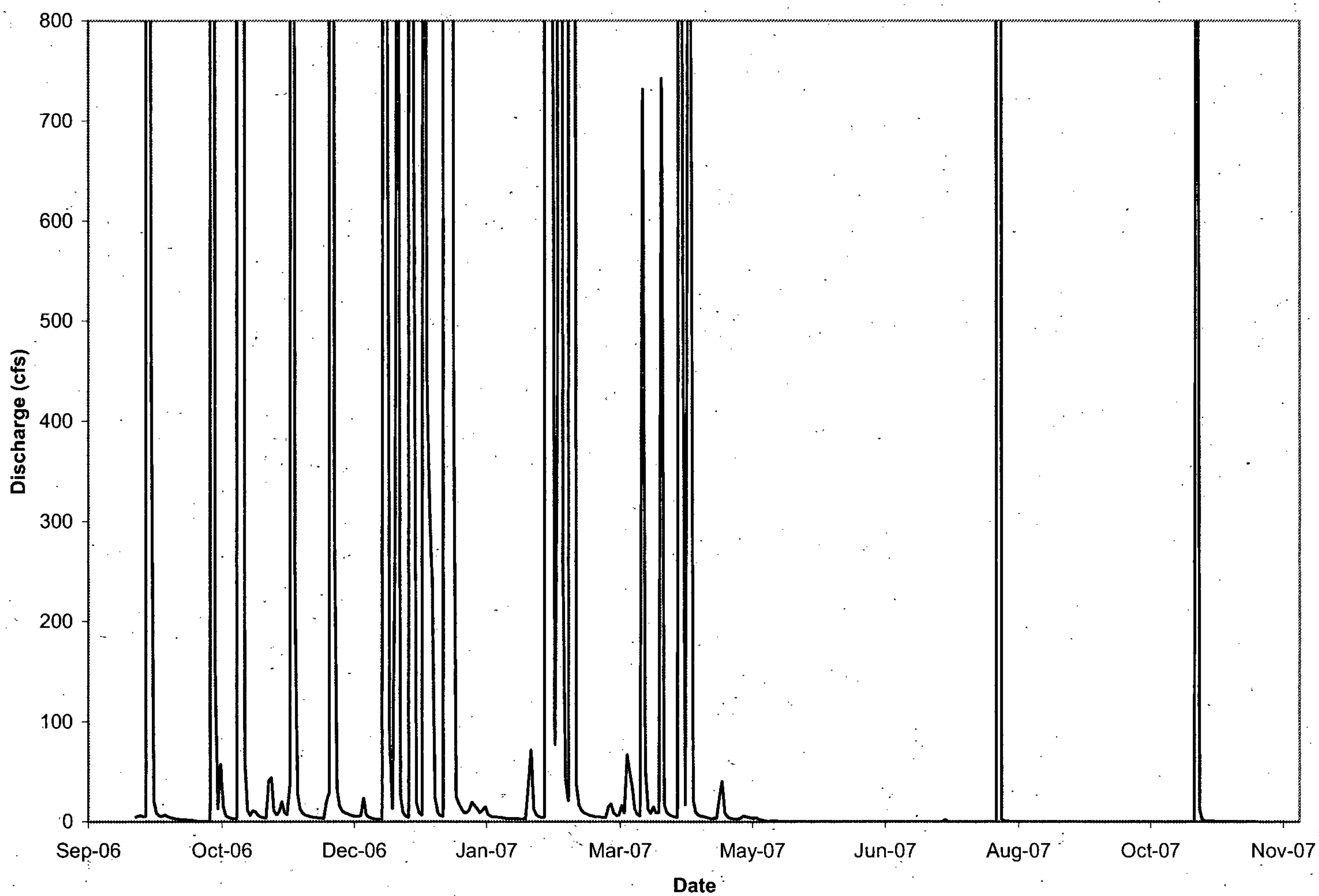


Figure 3-4. Stream Hydrograph for SGS-BC-01

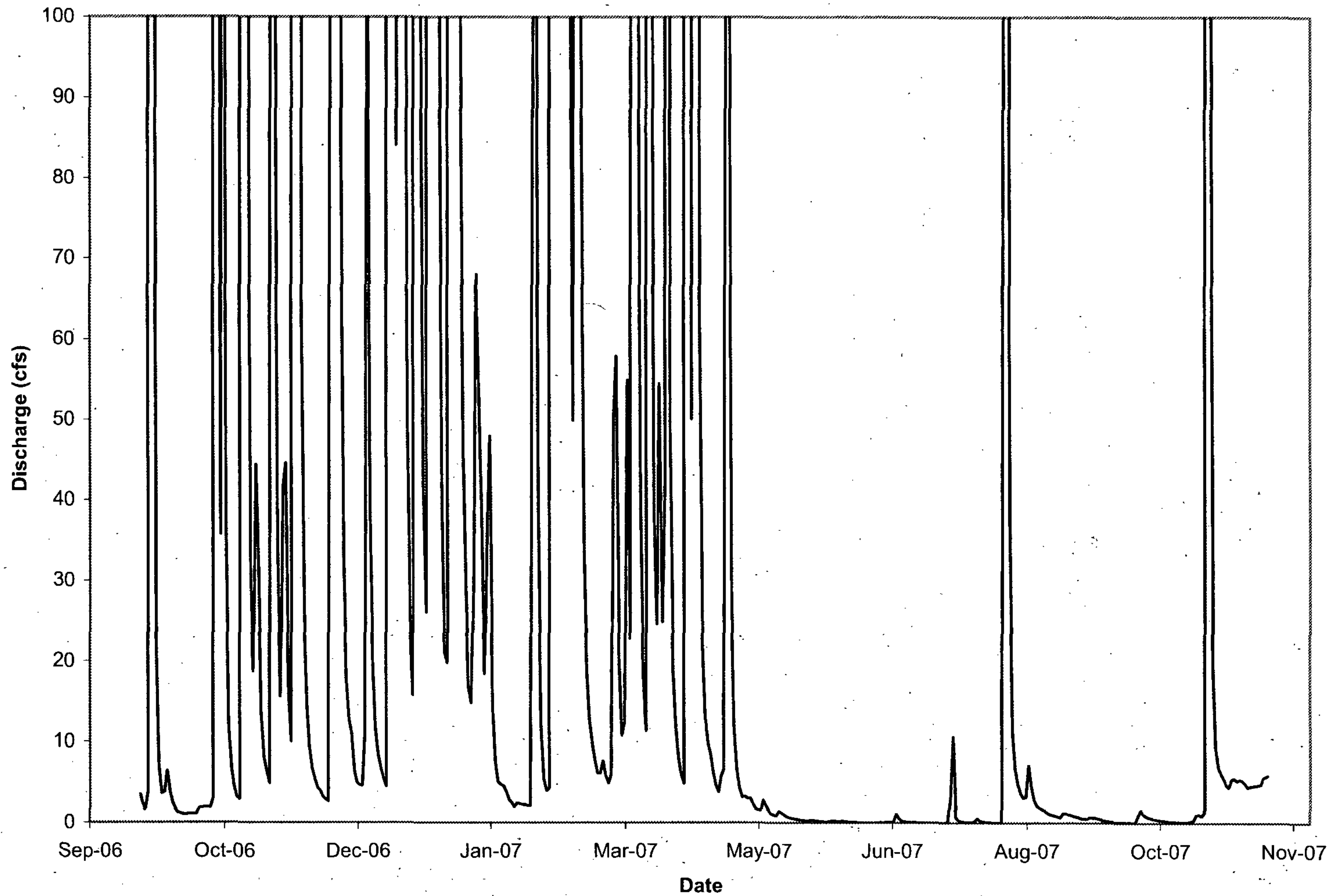


Figure 3-5. Stream Hydrograph for SGS-BC-02

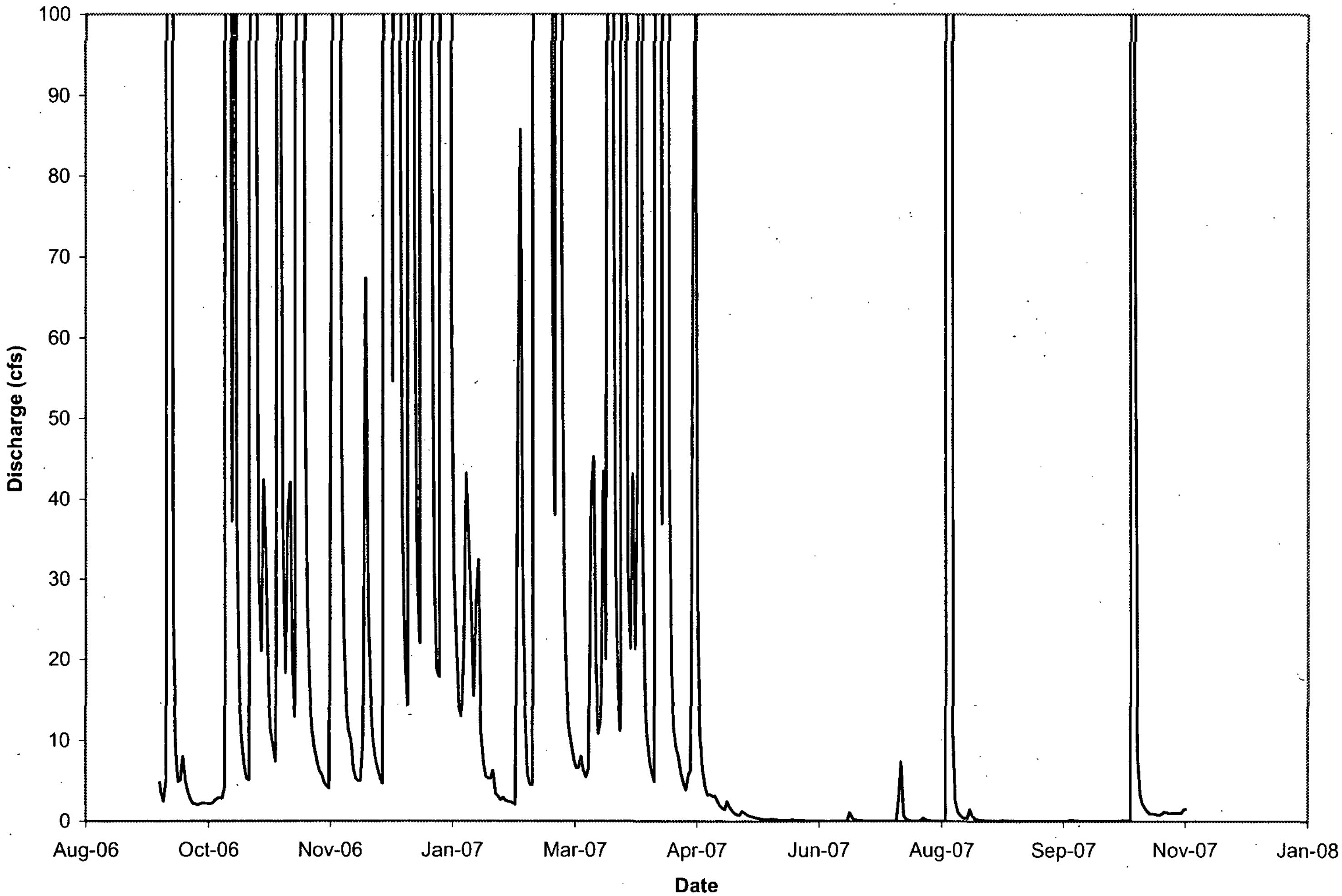


Figure 3-6. Stream Hydrograph for SGS-BC-03

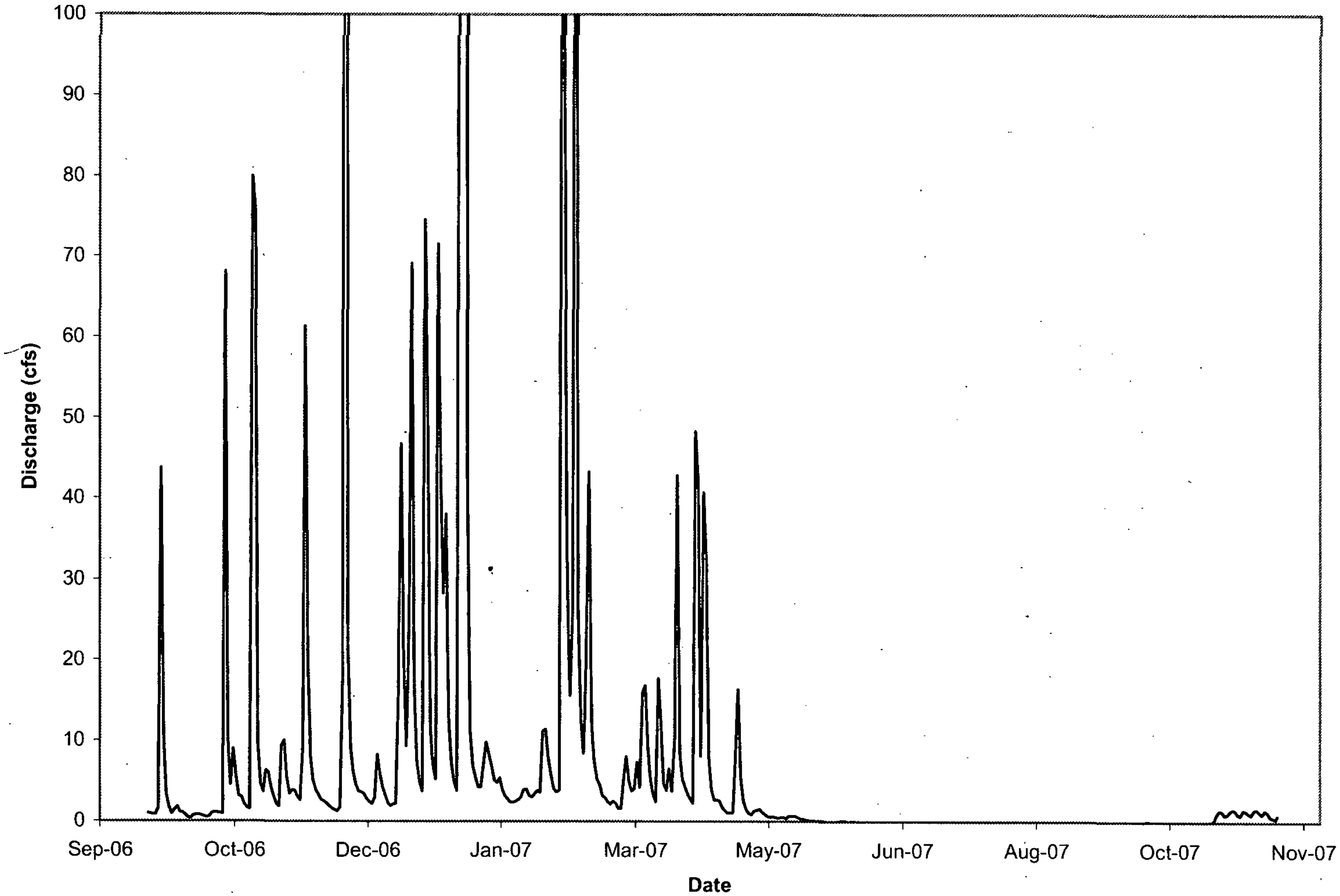


Figure 3-7. Stream Hydrograph for SGS-MF-01

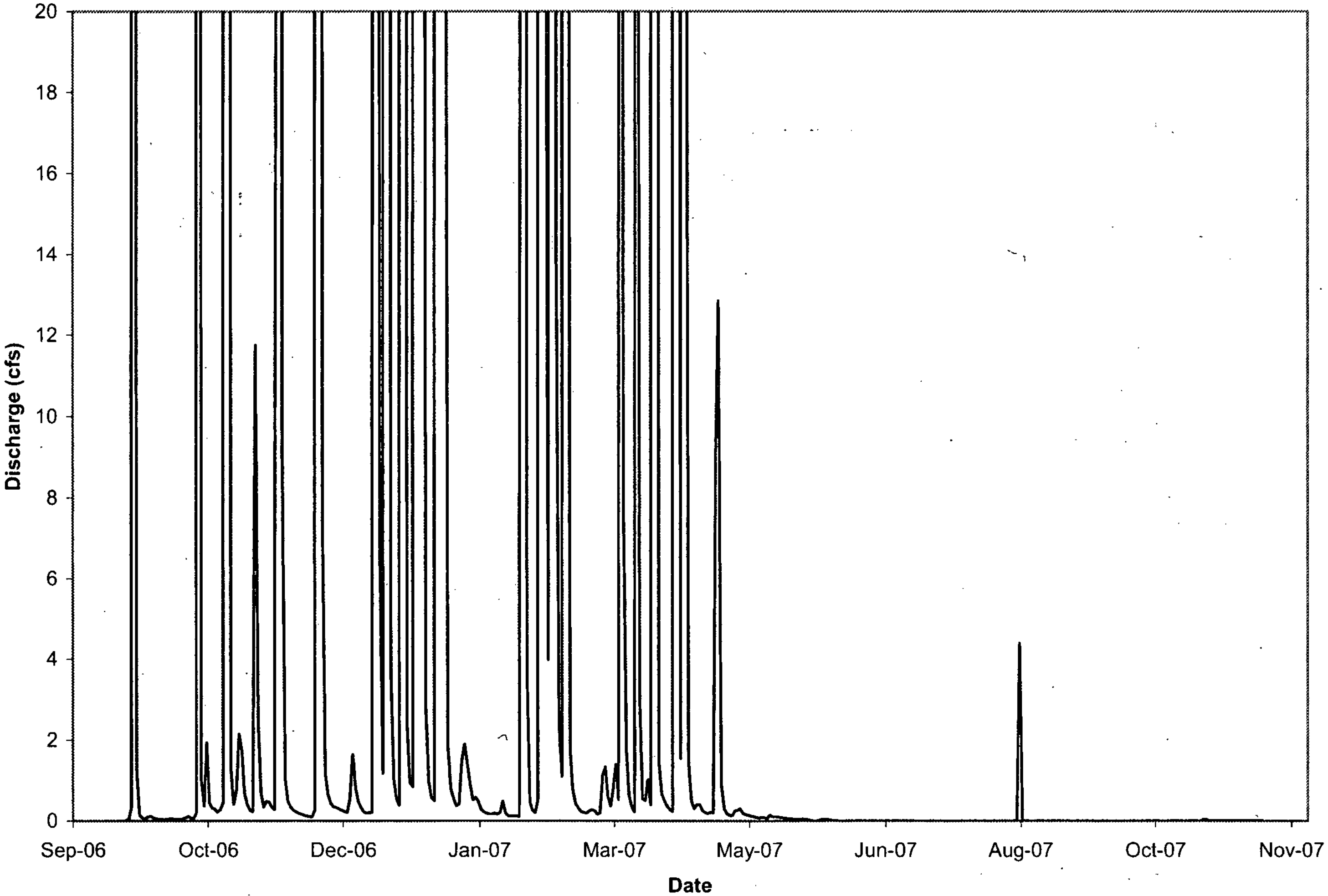


Figure 3-8. Stream Hydrograph for SGS-MF-02

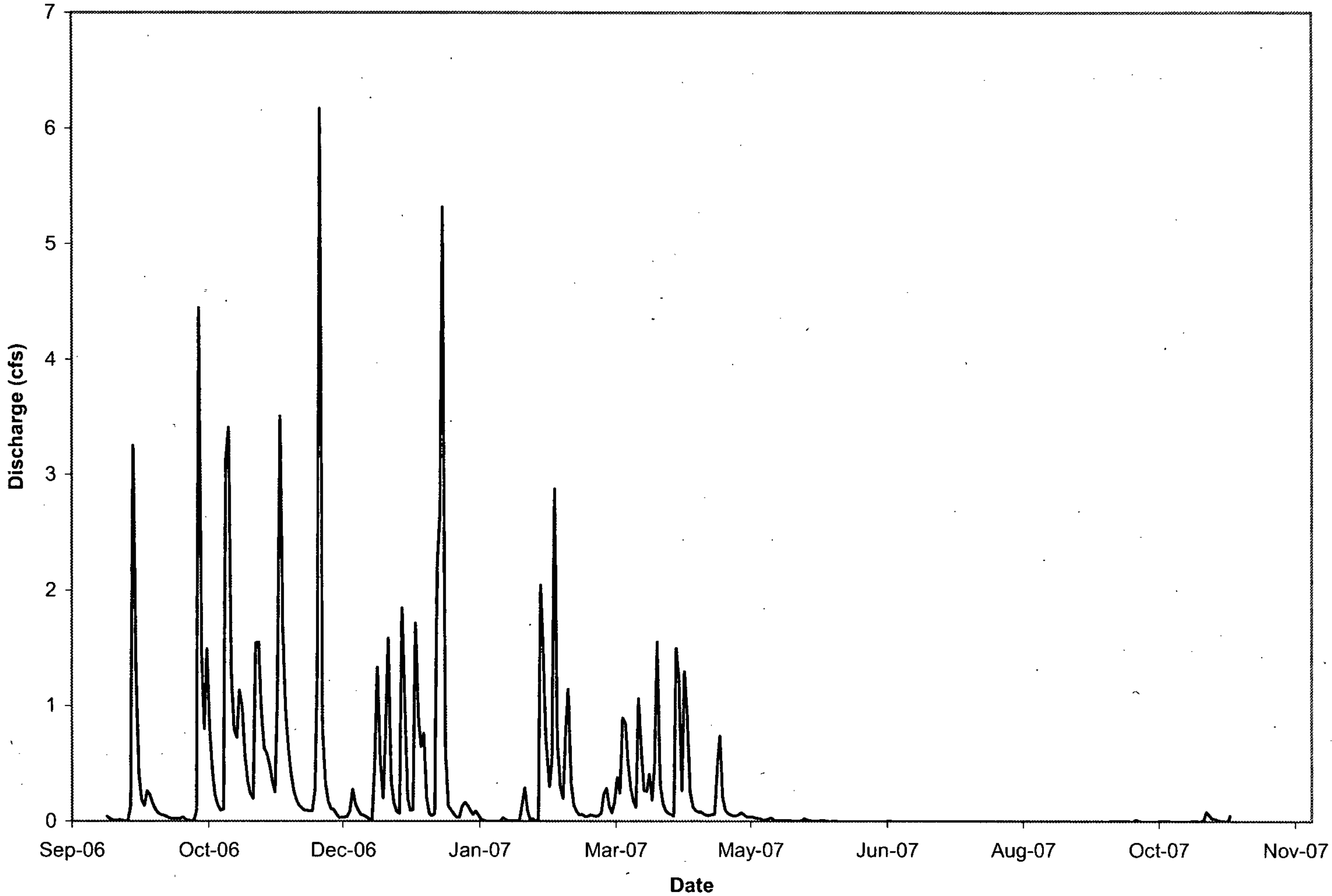


Figure 3-9. Stream Hydrograph for SGS-MF-03

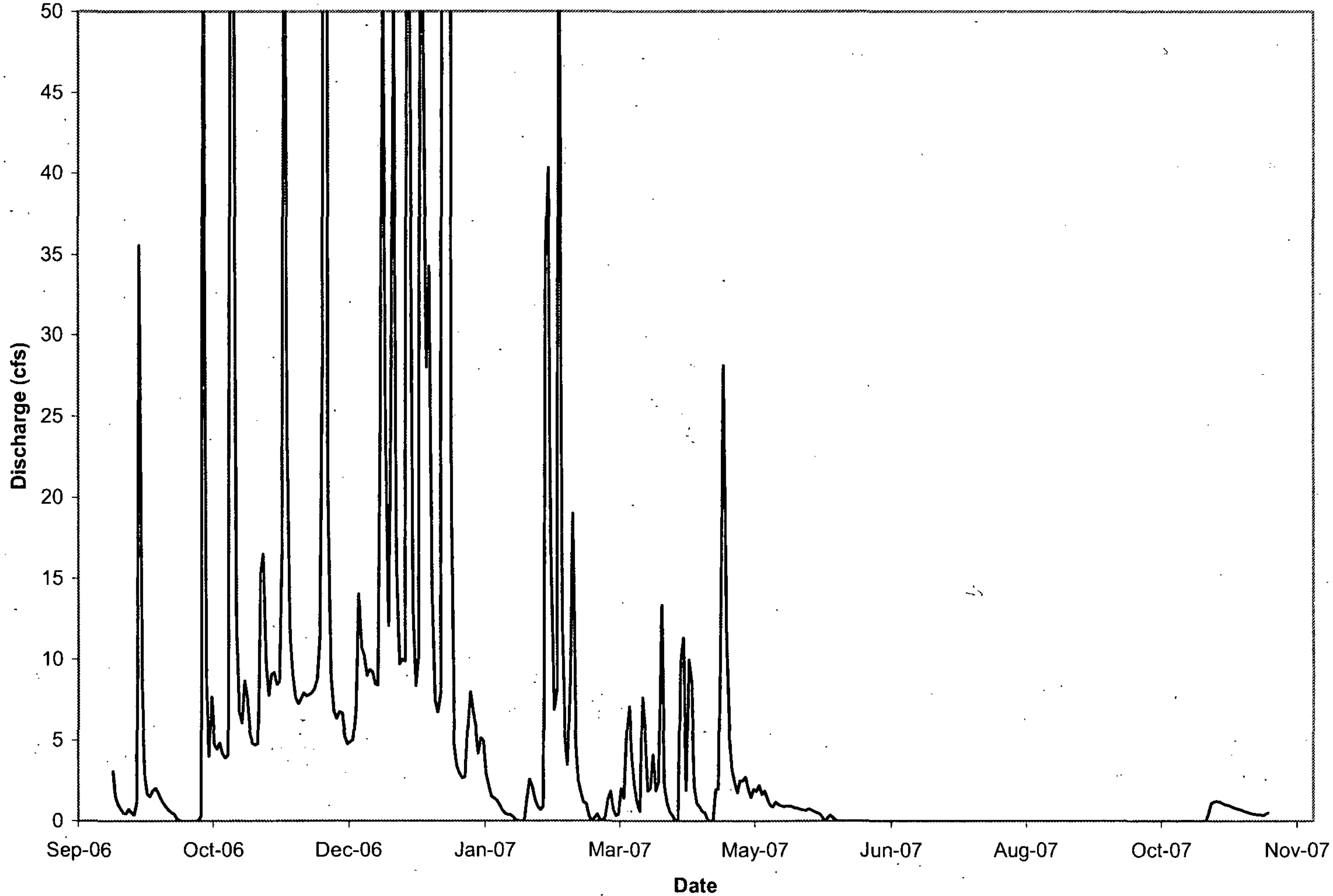


Figure 3-10. Stream Hydrograph for SGS-MF-04

Table 3-1. Median Flow Rates Observed at JPG and USGS Gauging Stations Jefferson Proving Ground, Madison, Indiana

Station	Drainage Area	Median Flow	
		cfs	cfs/mi^2
BC-01	21.84	2.99	0.14
BC-02	20.45	4.40	0.22
BC-03	20.08	3.31	0.16
MF-01	4.71	1.30	0.28
MF-02	1.27	0.11	0.08
MF-03	0.69	0.03	0.04
MF-04	1.62	0.79	0.49
Brush Creek	11.40	2.10	0.18
Muscatatuck	296.00	83.00	0.28

Onsite stream hydrographs were compared to hydrographs from USGS gauging stations for the same time period:

- Station 03368000 is located 11.3 miles northwest of the JPG DU Impact Area boundary near Nebraska, Indiana. The gauge is on Brush Creek, with a drainage area of 11.40 square miles. From a review of topographic maps and aerial photographs, the drainage basin topography and land use/cover appear to be very similar to Big Creek, with mostly agricultural and wooded land use. The geology in both basins is nearly identical (Indiana Geological Survey 2002). The station has continuously recorded discharge from 1 June 1955 through the present day. The geology and topography of the basin are very comparable to the Big Creek and Middle Creek basins onsite. Figure 3-11 shows the hydrograph of station 03368000 for the same period of record. The basin had a median flow of 2.1 cfs (0.18 cfs/mi^2) for the period of interest, nearly identical on a unit area basis to the median flow measured in the three Big Creek gauges in the DU Impact Area (0.14 to 0.22 cfs/mi^2). The median flow for the entire period of record is 2.3 cfs (0.20 cfs/mi^2). Periods of low- to no-flow were common in late June through November. Figure 3-11 is a stream flow hydrograph of the Brush Creek station for September 2006 through November 2007, the period of record for the JPG stations. The hydrograph of this stream shows the same flashy nature as the hydrographs on Big Creek in the DU Impact Area.
- Station 03366500 is located 14 miles southwest of the JPG DU Impact Area, on the Muscatatuck River near Deputy, Indiana. This station is downstream from and includes the JPG area and Brush Creek, and has been continuously recording discharge from 1 April 1948 through the present day. From a review of topographic maps and aerial photographs, the drainage basin topography and land use/cover appear to be very similar to Big Creek, with mostly agricultural and wooded land use. The geology of this basin compared to the Big Creek basin in and upgradient of the DU Impact Area appears to be very similar. The larger basin is underlain by bedrock units somewhat above and below the units exposed in the Big Creek Basin, but the rock types are very similar and should have similar hydrogeologic properties. The 296-square-mile basin had a median flow of 83 cfs (0.28 cfs/mi^2) for the period of interest, slightly higher than measured in the three Big Creek gauges in the DU Impact Area (0.14 to 0.22 cfs/mi^2). The median flow for the entire period of record is 82 cfs (0.28 cfs/mi^2), nearly identical to the period of interest. Periods of no flow were observed during July through November. Figure 3-12 is a stream flow hydrograph of the Muscatatuck River station for September 2006 through November 2007, the period of record for the JPG stations. The hydrograph of this stream shows the same flashy nature as the hydrographs on Big Creek in the DU Impact Area.

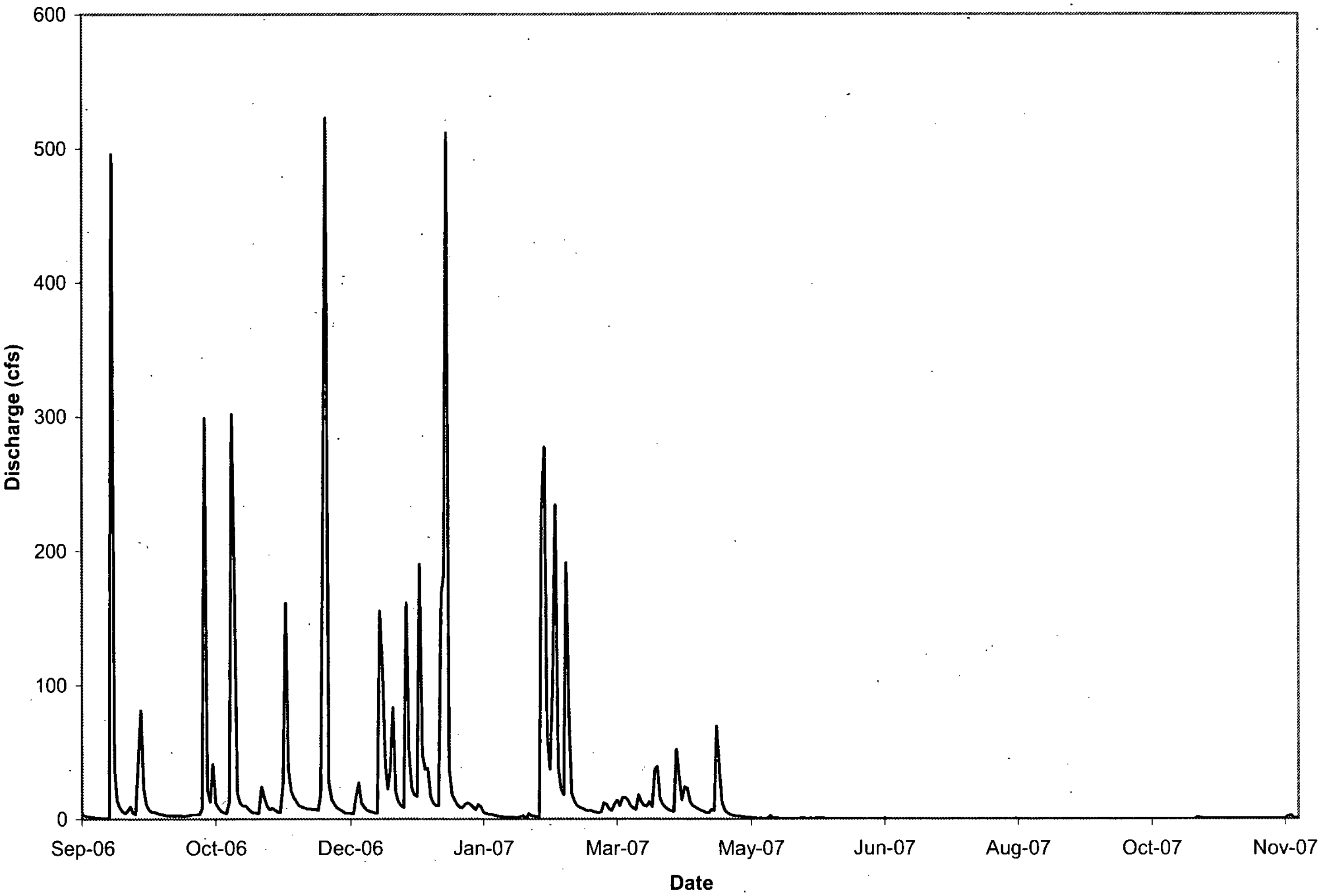


Figure 3-11. Stream Hydrograph for USGS Station 03368000 on Brush Creek

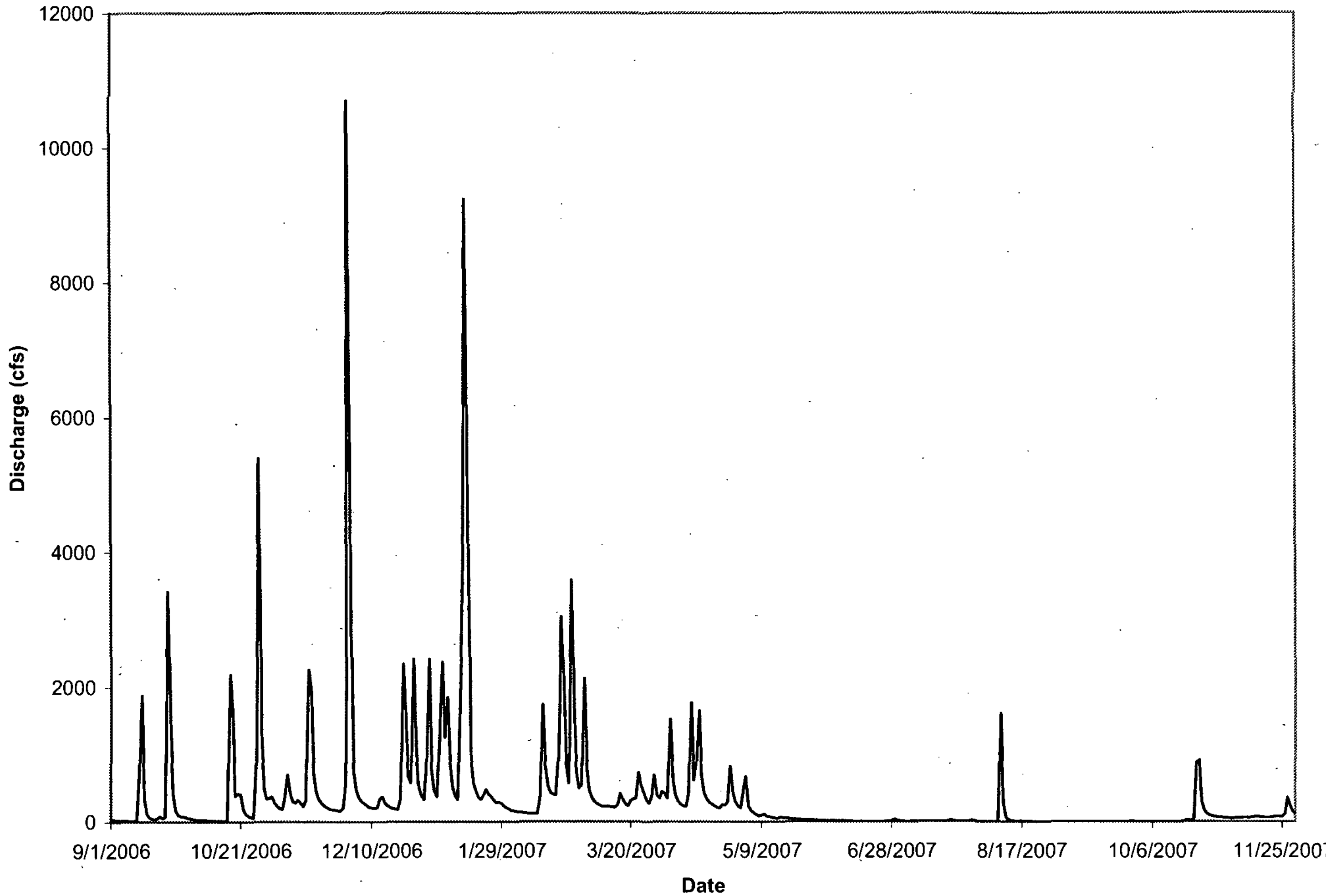


Figure 3-12. Stream Hydrograph for USGS Station 03366500 on Muscatatuck Creek

During the first year of stream data collection, the goal of the study was to establish working stream gauges and develop rating curves. The development of the rating curves have proven to be problematic and will require additional manual flow measurements to improve the rating curves. Data collected over the next year, in conjunction with the groundwater stage data, will be used to measure basin characteristics and the interrelationship between groundwater and surface water. However, an analysis of the available data at this time is useful, and a "first cut" at certain water budget characteristics will be used to provide preliminary input parameters to the dose models. In addition, the importance of various potential pathways of DU migration is more clearly evident as a result of the refinements provided by the ongoing study, which may result in changes to the investigation.

3.3 WATER BUDGET

An important purpose of much of the study regarding stream flows is to develop a water budget for the JPG site. Water budget components are used as input data for the fate and transport models to be used to calculate the potential for migration of DU. As described in Section 3.2, a water budget was calculated using published, Federal, and state precipitation and stream gauge data from Brush Creek and Muscatatuck River. The primary purpose of this calculation was to estimate the surface water and groundwater flow components of the water budget such that the volume of each pathway flowing through the site can be determined and considered for dose assessment calculations. A secondary purpose was to establish the quality of the available hydrologic data and evaluate the need for additional site-specific information. This method offers a basic check on the understanding of the site hydrogeology and is helpful in defining the conceptual geologic model. The general water budget formula accounts for the fate of total precipitation in the following manner:

$$P = Q_{GW} + Q_S + ET \pm \Delta S$$

Where:

- P = Average annual precipitation.
- Q_{GW} = Groundwater component of average annual runoff (groundwater runoff). Groundwater runoff is equal to groundwater recharge, the amount of precipitation that becomes groundwater.
- Q_S = Surface water component of average annual runoff (surface water runoff).
- ET = Average annual evapotranspiration.
- ΔS = Change in the storage of water, both surface water and groundwater (over a hydrologic year, this is generally assumed to be zero).

The total average annual water budget consists of 46.97 inches of rain, as recorded by the U.S. Fish and Wildlife Service (USFWS) station located approximately 2.8 miles northeast of the JPG DU Impact Area. Rainfall for the period of record (1 October 2006 through 30 September 2007) equaled 45.21 inches. The distribution is shown in Figure 3-13, and site weather data are included as Appendix I-8.

3.3.1 Thornthwaite Evapotranspiration Calculation

ET is a very large component of the water budget. Accurate measurements of ET are difficult, but to gain a general understanding of the hydrologic system, potential ET was calculated using the method developed by Thornthwaite (1948). The calculation was completed using climatological data for the USFWS station and is shown in Appendices I-9 and I-10. Monthly potential ET was subtracted from monthly mean precipitation to calculate runoff.

The Thornthwaite calculation shows that 56 percent of 47.0 inches of annual precipitation, or 26.3 inches, is returned to the atmosphere by ET. Forty-four percent (20.7 inches of precipitation) remains as runoff, of which part runs off as surface water (Q_S) and part runs off as groundwater (Q_{GW}).

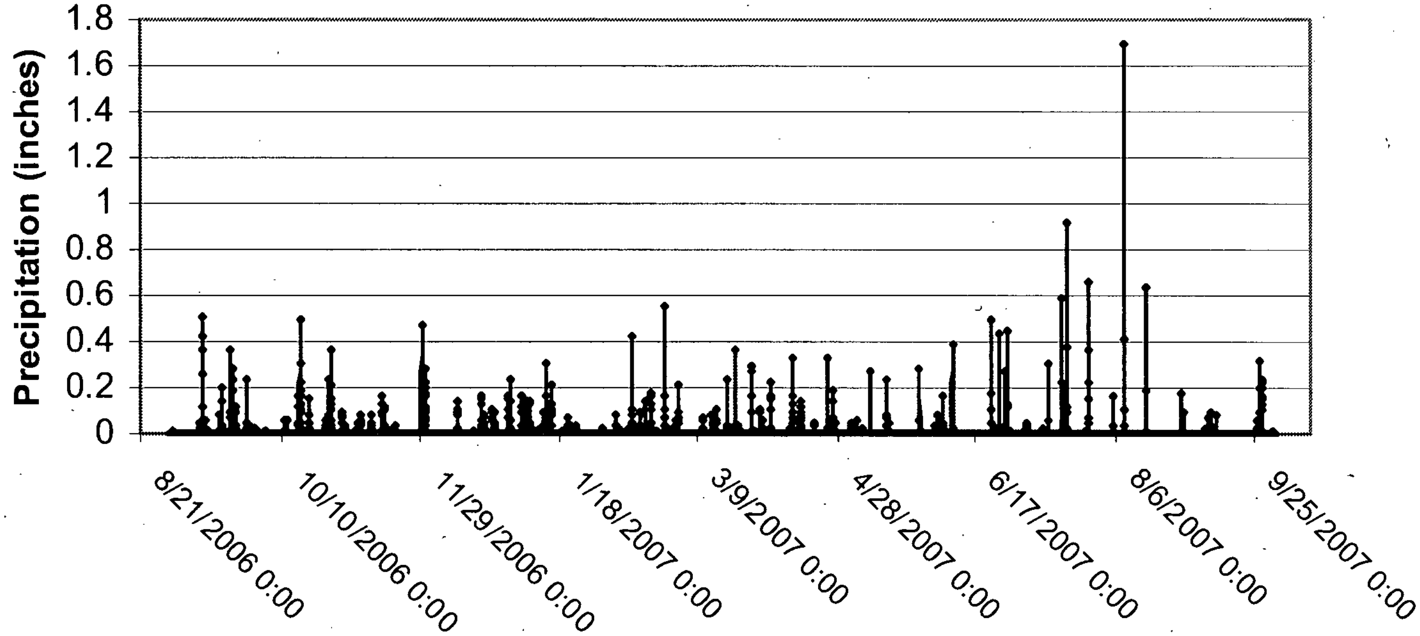


Figure 3-13. Rainfall Data for Period from 1 October 2006 through 30 September 2007

3.3.2 Runoff

Runoff is of most interest to the characterization of the JPG DU Impact Area site study because surface water runoff and groundwater runoff have been identified as the major potential mechanisms for DU migration. A portion of the DU that could migrate from the site would be transported as dissolved or particulate material with surface water runoff. Another portion may be transported as a dissolved component and migrate to groundwater. A third hybrid pathway is the result of surface water that is captured by or enters the shallow karst network of sinkholes and closed depressions that occurs over a portion of the site. This karst route has characteristics of both surface water and groundwater runoff. Determining the proportion of these three runoff components will drive certain components of the dose calculation. As the importance of these runoff components is revealed, where to place efforts in evaluating the site to improve the CSM may be modified.

The following section discusses the separation of these components of runoff. Total runoff is determined by subtracting ET (26.3 inches or 56 percent) from total precipitation (47 inches or 100 percent), which leaves 20.7 inches or 44 percent of the water budget. Groundwater runoff, which is equivalent to infiltration or the amount of precipitation that reaches the groundwater table, will be determined from the stream flow hydrographs in the following section.

Few water budget studies are available in the literature for this section of Indiana. Bechert and Heckard (1966) reported 8 to 16 percent of precipitation in the entire State of Indiana finds its way into the subsurface, becoming groundwater. This would equate to 4 to 8 inches of the 47 inches of rainfall for the site. This literature reference provides the expected range of base-flow values for this study.

Winslow (1960) reported on the drainage characteristics of the Muscatatuck River basin. He reported that the very steep,

> "flow duration curve, as determined from records at the gauging station on the East Fork of the Muscatatuck River near Deputy for the years 1949-55 reflects rapid surface drainage, rapid subsurface drainage through solution channels in the carbonate bedrock (limestone and dolomite), and the thin cover of unconsolidated material over the bedrock. In addition, the clay subsoil that has been formed on the loess deposits and on the carbonate rocks is dense and relatively impermeable so that the infiltration capacity of the soil probably is very low. The low-flow index of the stream is less than 1.0 cfs: this fact indicates that the contribution of ground-water discharge to streamflow is very small. The loessial soils erode readily and probably are the source of much of the silt and clay that muddy the streams more or less continually."

This information does not quantitatively provide any water budget components, but it does indicate that surface water runoff would be expected to be high, while groundwater runoff would be expected to be low.

3.3.3 Calculation of Base Flow

Various methods are used by hydrographers to estimate the component of stream flow that has taken the route across the surface versus infiltrated below the ground surface and entered the stream as groundwater. Two models, called PART and RORA, have been used by USGS for this purpose. Both models use daily stream flow data and separate the surface runoff component from the groundwater runoff component using quantitative methods. PART automates the separation of surface water and interflow from groundwater base flow. RORA uses a recession-curve displacement method to estimate groundwater recharge from storm periods recorded on the stream flow hydrographs. The methodology used by these models is detailed in Rutledge (1998).

SAIC stated as a response to NRC's 18 January 2006 RAI Question 3 (Army 2006) that they intend to run PART and RORA on the gauging station data obtained from the recently installed gauge stations in and surrounding the DU Impact Area. Preliminary runs have been problematic, probably because of the short period of record. PART and RORA models were designed to rapidly determine base flow of a basin for USGS gauge stations with multiple years of record and, therefore, have the advantage of averaging many hydrologic years of data to develop a dependable average value.

As a check on the methodology, and to determine a reasonable regional value of base flow, SAIC applied these models to hydrograph data from the two previously mentioned USGS gauging stations, as shown in Table 3-2. PART and RORA results are included in Appendix H. As discussed earlier, both of these stations drain basins with similar geology, topography, and land use characteristics and, therefore, should provide accurate estimates of the stream base flow for the JPG DU Impact Area site.

Table 3-2. PART and RORA Results for Water Bodies with USGS Gauges Jefferson Proving Ground, Madison, Indiana

Station	PART Base Flow Estimate (in/yr)	RORA Base Flow Estimate (in/yr)
Brush Creek	4.04	3.98
Muscatatuck River	4.65	3.59

These estimates of base flow are at the lower range of published results referenced earlier. During the model run using the RORA model, a warning was received indicating that the length of recession periods was shorter than required by the model assumptions, and indicated that results may be questionable. In other words, when stream flow increases as a result of a precipitation event, the amount of time for the flows to return to pre-precipitation condition is faster than assumed by the model. The significance of this warning is that this is another indication of the very flashy nature of the basin, resulting in very low infiltration rates (low groundwater recharge). Because the values calculated by RORA are so similar to PART, and within the range of published results, it is expected that the results are reasonable, in these cases.

Based on these results, SAIC estimates that groundwater of runoff (Q_{GW}) equals 4 inches or 8 percent of the total water budget. By subtracting that value from total runoff (20.7 inches or 44 percent), surface water runoff (Q_S) is determined to be 16.7 inches or 36 percent of the total water budget.

PART and RORA were run on the hydrograph data from the JPG DU Impact Area gauge stations collected to date. A similar warning message was received for the RORA runs. However, possibly due to the short period of record (the programs were run on the entire 50+ years of records for the USGS stations versus 12 months of JPG DU Impact Area data), a more severe violation of assumptions, or the rating curve problems experienced with the local installed gauge stations, the results were extremely erratic, and did not match the results of USGS gauge stations or the published data. Those trial runs are not included in this report.

Although it is expected that data quality from the locally installed gauging stations will improve somewhat with continued stage and manual flow measurements, the use of the nearby USGS gauge stations data to determine groundwater recharge (base-flow) values to be used for dose modeling is expected to be superior due to the much longer period of record. The Army had intended to use the locally installed gauge stations to evaluate variations in recharge across the DU Impact Area and to identify gaining and losing stream segments. In light of the difficulties with the gauge stations, the Army intends to conduct a seepage run survey on Big Creek, to identify gaining and losing stream sections. The seepage run survey will focus on Big Creek, during which three teams will measure the stream flows simultaneously. Starting at three locations on Big Creek, the evenly spaced crews will progress along the stream in such a manner that the stream segment as it passes into, through, and out of the DU Impact Area is measured within a few hours. The measurements will occur during a time of minimal surface water runoff (during a time when groundwater runoff makes up the flow in the stream). The teams will each measure a single stream channel location as a calibration/check on accuracy and will repeat measurements at one or more of the first stations to evaluate the changes that occurred during the period of measurement.

3.4 SUMMARY

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 unnamed tributary of Big Creek. Approximately 1 year of stage data has been collected on the gauges. Stream flows at the gauge stations were measured monthly to collect a range of flow data at different stages. Rating curves were developed using the manual measurements. Flows higher than the manually measured rates were extrapolated using the Manning equation and surveyed cross sections of the streams at the gauging stations. A poor correlation between automatic stream stage measurements and manual stream flow measurements has been experienced. Additional manual stream flow measurements are required to evaluate the problems causing these anomalies. The additional measurements will potentially improve the accuracy of the rating curves and the calculation of flows from the continuous stage data, and should result in more usable data, even though some impacted flow data will be in the data set. If the condition is determined to be stream channel impacts that continue to occur (e.g., changes as a result of stormwater flow, ice jams, log jams, beaver dams), the use of the local flow data will have to be limited.

Stream flow hydrographs, showing a graph of daily flow in cfs for a period of approximately 1 year, were constructed for the installed gauge stations, and compared to established USGS gauging stations on streams near the JPG DU site, and in similar topographic and geologic conditions. All gauges appear to reflect very flashy streams, meaning that after precipitation events, the flow increases rapidly, and decreases rapidly, causing the spiky nature of the hydrograph. The hydrographs showed a period of low- to no-flow for much of the summer months. Both conditions are indicative of a hydrologic system in which surface water runoff is unusually high and groundwater recharge is unusually low.

A "first cut" water budget was developed for the JPG DU Impact Area site, segregating all of the water that falls on the site as precipitation (47 inches [100 percent]) into ET (26 inches [56 percent]), surface water runoff (17 inches [36 percent]) and groundwater runoff (4 inches [8 percent]).

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4. UPDATED CONCEPTUAL SITE MODEL

A CSM is a description of a site and its environment that is based on existing knowledge. It describes sources; complete, potentially complete, and incomplete transport mechanisms and exposure pathways; current or reasonable proposed use of property; and potential receptors. The CSM serves as a planning instrument, a modeling and data interpretation aid, and a communication device. A central concept to understanding the site-specific problem at the JPG DU Impact Area (Army 2002) is that doses to humans and ecosystem receptors can come from any number of exposure pathways beginning when the munitions are tested and lasting until the DU is removed from the system. Thus, the dose to humans from DU must be assessed for a variety of pathways, and for a relatively long time due to slow transport through the soils (Army 2002).

This section discusses the general CSM that was presented in the original FSP (SAIC 2005a) based on historical studies. In addition, it includes enhancements made based on the conclusions of the groundwater well installations and surface water gauge measurements. Updating the CSM is consistent with the following basic project goals identified in the original FSP (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.

The CSM for the JPG DU Impact Area is based on the DU penetrators that have been deposited on, or immediately below, the ground surface and/or within the surface water (streams). Once the DU has been deposited within the soil or surface water, it is available for transport through the environment by several different processes. DU in the soil or surface water can be subject to physical movement by erosion, flooding/high-water conditions, and dust movement by wind or fire and leaching. Processes of erosion could cause migration and transport of DU penetrators or fragments (during floods and high runoff events) along the ground surface and along surface water drainageways. DU corrosion products from the penetrators and related secondary byproducts (e.g., uranium carbonates) in the soil and surface runoff could be transported to groundwater and surface water. These DU corrosion products and related byproducts could be absorbed by plants and incorporated within the plant matter. The simplest and most direct exposure pathway to wildlife and humans would be from direct contact with the penetrators and/or fragments and incidental ingestion of DU or DU-impacted soils. Impacted surface water and groundwater could migrate to drinking water sources. The drinking and surface water could be ingested by humans, livestock, and wildlife. Meat and/or animal products from animals ingesting DU-impacted media (i.e., vegetation, soil, water) could be ingested by humans. Humans could have contact with, and incidental ingestion of, impacted surface water during recreational activities such as fishing and hunting.

4.1 CHARACTERISTICS OF URANIUM AND DEPLETED URANIUM

As stated earlier, approximately 220,462 pounds (100,000 kilograms) of DU projectiles were fired at soft targets, approximately 66,139 pounds (30,000 kilograms) of the projectiles and fragments were recovered at or near the ground surface periodically to ensure that the total 100,000-kilogram license limit was not exceeded, and approximately 154,323 pounds (70,000 kilograms) of DU is believed to remain in the DU Impact Area (SEG 1995 and 1996). The following sections describe characteristics of uranium and DU.

4.1.1 Uranium

Uranium is a naturally occurring metal that can be found throughout the environment in rocks, soil, water, plants, and animals. Natural uranium has three primary isotopes (forms): ^{234}uranium (^{234}U), ^{235}uranium (^{235}U), and ^{238}uranium (^{238}U). ^{235}U and ^{238}U are the two most abundant isotopes. ^{234}U is formed during the natural radioactive decay of ^{238}U. Naturally occurring uranium consists of approximately 99.27 percent ^{238}U, approximately 0.72 percent ^{235}U, and approximately 0.0055 percent ^{234}U (Royal Society 2001). Humans and wildlife are exposed to natural uranium on a daily basis primarily in their food and water (Royal Society 2002). As a result, humans ingest approximately 2 micrograms of natural uranium each day in food and fluids. A similar quantity is excreted each day in the feces and urine (DOE 2000). This presents a uranium balance in which uranium is always present in the tissues.

The range of intake and losses has been observed to vary over several orders of magnitude, depending upon the uranium concentration in foods and in the water supply (DOE 2000). This condition also may occur in wildlife. As a result of this potential exposure, it is possible that uranium may be detected in tissue samples from humans or wildlife.

4.1.2 Depleted Uranium

A modified form of uranium metal can be used as fuel in nuclear power plants. For use as a nuclear fuel, it is necessary to have uranium with a higher content of ^{235}U; therefore, uranium undergoes an enrichment process to convert natural uranium into low enriched uranium (LEU). The ^{235}U content of LEU is approximately 3 percent by mass. DU is created as a byproduct of the uranium enrichment process. However, because of its high density, DU can have other uses, such as radiation shielding. DU also is used by the military for tank armor, armor-piercing projectiles, and counterweights in missiles and aircraft.

DU contains approximately 0.2 percent of ^{235}U by mass, with the remainder being ^{238}U and a very small type amount of ^{234}U by mass. The difference in ^{235}U content (by mass) can be used to distinguish natural uranium from DU (DOE 2000). The percent by mass of ^{235}U for each type of uranium is provided in Table 4-1.

Table 4-1. Percent ^{235}U by Mass in Different Types of Uranium
Jefferson Proving Ground, Madison, Indiana

Type of Uranium	Percent ^{235}U by Mass
Natural Uranium	0.72
Low Enriched Uranium (LEU)	3
Depleted Uranium (DU)	Approximately 0.2

Source: DOE 2000

The decay of each atom of uranium gives off radiation that, to some degree and efficiency, can be detected by laboratory instruments. Each isotope of uranium (^{238}U, ^{235}U, and ^{234}U) decays at its own characteristic rate. Since the rate of decay of ^{234}U is much faster than ^{238}U or ^{235}U, the amount of radiation that is available to be detected from ^{234}U is nearly equal to that available from ^{238}U, even though the mass of ^{234}U present is much smaller. The contributions for each isotope of uranium in a natural uranium mixture are provided in Table 4-2.

Table 4-2. Amount of Isotope Present by Activity in Natural Uranium
Jefferson Proving Ground, Madison, Indiana

Isotope	Percent
^{238}U	47.3
^{235}U	2.3
^{234}U	50.4

Source: Army 1995

Since the radiation from the radioactive decay of uranium isotopes is relatively easy to detect, the levels of activity in a sample are used to determine the relative amounts of the individual isotopes in the sample. In other words, the activity values of the uranium isotopes are used to determine the amounts of the uranium isotopes present, and hence the levels of enrichment.

When uranium is enriched, the level of ^{235}U is increased in the product. Because the mass of the ^{234}U atom is very close to the mass of the ^{235}U atom, the levels of ^{234}U also are increased in LEU. That also means that the levels of ^{234}U are decreased in DU. The result is that DU exhibits roughly 60 percent of the alpha radiation as naturally occurring uranium (Army 1995). The contributions for each isotope of uranium in DU is provided in Table 4-3.

Table 4-3. Amount of Isotope Present by Activity in DU
Jefferson Proving Ground, Madison, Indiana

Isotope	Percent
^{238}U	84.7
^{235}U	1.1
^{234}U	14.2

Source: WISE 2006

Because natural uranium and DU are identical except for their isotopic composition (percentage of ^{234}U, ^{235}U, and ^{238}U), their chemical characteristics are the same. Thus, their biochemical action is also the same (Royal Society 2001 and 2002).

4.1.3 Radioactivity

DU exhibits approximately 60 percent of the alpha radiation as natural uranium because some of the ^{235}U and much of the ^{234}U has been removed. The radioactive decay of DU gives off predominantly alpha-particles along with beta-particles and gamma-rays. Alpha-particles are high energy and massive and, therefore, are more biologically harmful than beta-particles or gamma-rays if they are introduced internally (ingested or inhaled). Their large size, however, prevents alpha-particles from penetrating dead skin. Beta-particles are highly energetic and can penetrate tissues up to approximately 1 centimeter compared to alpha-particles. Gamma-rays are extremely penetrating and can penetrate through several feet of concrete or a few inches of lead (USEPA 1998). The biological damage from either beta-particles or gamma-rays passing through cells is much less than alpha-rays (Royal Society 2001).

4.2 TRANSPORT MECHANISMS

Figure 4-1 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 site characterization program. The transport mechanisms are described in further detail below.

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.

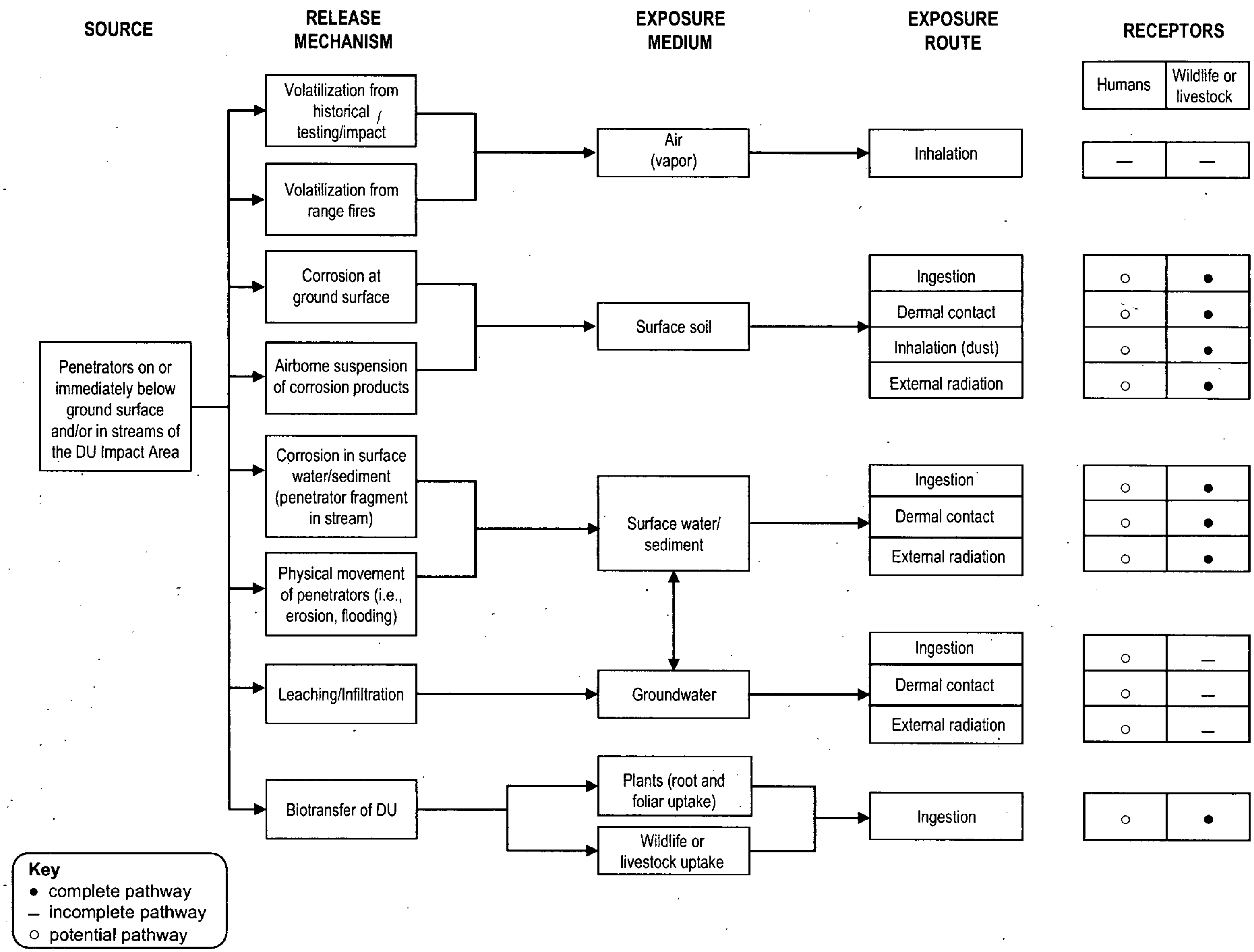

Figure 4-1. Revised Conceptual Site Model of DU Transport Through the Environment at and in Close Proximity to the JPG DU Impact Area

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) is not likely significant (Williams et al. 1998, 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.

4.2.1 Groundwater Pathway

As discussed in Section 2.8, based on the observations from the wells installed during 2007 and the available logs for the existing wells, the subsurface materials can be categorized into three hydrostratigraphic layers consisting of the following: "overburden," "shallow" bedrock zone, and "deep" bedrock zone. A description of the zones is provided below.

4.2.1.1 Overburden

The overburden consists of the unconsolidated materials or overburden present above the bedrock. As determined from the well installation and well logs, the depth of the overburden materials range from 0.65 to 72.5 feet, with an average depth to bedrock of 20.8 feet. The overburden materials consist of glacial tills and loess. A soil verification study (SVS) was completed and the results of the study are provided in Section 2 of the Well Location Selection Report (SAIC 2007a) in which the soils present within the DU Impact Area are described in detail.

The soil in the study area is composed of mostly fine-grained materials, which appear to have a low permeability. At five well locations, sufficiently permeable materials were observed that would provide sufficient well yield to provide a suitable groundwater monitoring and sampling point. The majority of the existing monitoring wells that were completed in the overburden have been observed or documented in previous reports to have low well yields.

4.2.1.2 Shallow Bedrock Zone

The shallow bedrock zone consists of the top 40 to 60 feet of the carbonate bedrock. Generally, the bedrock encountered consisted of nearly horizontally bedded limestone, shaley interbedded limestone, dolostone, and shaley interbedded dolostone. As evident from the observations from the well installations and from the logs for the existing monitoring wells, there is limited secondary porosity consisting of weathering near the bedrock surface, fractures, and very limited solution features. In addition, there was very little evidence of weathering along observed fracture surfaces. The amount and severity of the fractures generally decreased with depth. The only void of significance that was observed during the recent well installation was approximately 6 inches in size at a depth of 23 feet BLS in the boreholes for both JPG-DU-02I and JPG-DU-02D.

4.2.1.3 Deep Bedrock Zone

The deep bedrock zone consists of the bedrock below the permeability observed in the shallow bedrock zone, below 40 to 60 feet BLS. The bedrock in the deep zone consisted generally of the same bedrock types of the shallow bedrock zone. Within the deep zone the fractures observed were extremely limited and fresh (e.g., practically nonexistent weathering). No evidence of solution features were observed within the deep zone. The minimum rock core recoveries for all of the core holes was 93.1 percent and all but two were greater than 95 percent. In the deep zone, the measured and calculated Rock Quality Determination (RQD) was very high, indicating competent bedrock with little fracturing or weathering. The deep bedrock wells were constructed with screen intervals located within the interval that appeared to have the highest potential for permeability. After several months, a number of the deep bedrock wells were still recovering from pumping that occurred during the well development activities. The hydraulic conductivities that will be calculated from the planned slug tests are expected to be very low.

4.2.1.4 Karst Development

Karst features have been observed at JPG and specifically within the DU Impact Area consisting of surface expressions of sinkholes, caves along Big Creek, and weathered jointing (fracturing) of bedrock observed at outcrops along Big Creek. As a result of these observations, the SAIC CSM included a karstified aquifer. Wells were located on fracture traces and using geophysical techniques to selectively test areas where karst development would be greatest. However, as a result of the well drilling, the following field observations and an analysis of published reports and previous studies demonstrate why it appears that karst activity within and immediately surrounding the DU Impact Area is limited in depth and lateral extent:

- Of all of the new wells installed, only a single very minor solution feature was observed in each of the borings at the JPG-DU-02 well pair location (along Big Creek) during the well installation. The solution feature was located at a depth of 23 to 23.5 feet BLS. The absence of karst/weathered conditions in 19 borings cored in 10 locations that were expected to be preferentially developed demonstrates that karst weathering is not a predominant feature onsite.
- Karst development and the presence of a karst controlled groundwater flow network appears to be limited to within the narrow erosional plain along Big Creek and offsite along lower sections of Middle Fork Creek. Observations by SAIC soil scientists and geologists indicate no sinkholes or closed depressions in the elevated areas above this plain. Sheldon (1997) reported on extensive field reconnaissance work completed between January 1994 to April 1997 in and surrounding the DU Impact Area, in which caves, sinkholes, and karst features were recorded and catalogued. Sheldon's only reported, observed, and documented cave locations within the DU Impact Area were only along Big Creek (Sheldon 1997).
- The observations of karst features and weathering onsite concur with the following statements by Herring (2004) "the majority of sinkholes or depressions occur along the larger stream valleys (especially Big Creek)," "water well records...indicate a few feet of crevices, broken limestone, or mud seams within the limestone bedrock, generally at depths less than 50 feet below land surface" and "The Silurian carbonates...show limited karst development in Jefferson County. These rocks contain thinner limestones and more layers of shale, conditions that significantly limit karst development."

As a result of these observations, the CSM has been modified to limit the location of shallow karst features (caves and sink holes) to a narrow plain along Big Creek. Caves and solution features appear to be most commonly above the groundwater table, and above the elevation of Big Creek, and limited to depths of less than 50 feet below the land surface. SAIC will continue to evaluate these observations during future field activities, including stream surveys and soil and sediment sampling.

4.2.1.5 Recharge and Groundwater Flow

Recharge to the aquifer is extremely limited by the low permeability overburden (soil) materials present within the study area, very tight bedrock (horizontal bedding, shaley interbedding, fresh, unweathered) observed during the 2007 well installation, and further limited by collection of surface water/infiltration/interflow by the limited shallow karst/cave system, which is at or above the water table, and discharges through open channel flow to the surface water. The majority of the limited groundwater flow within and from the DU Impact Area is expected to occur within the overburden and shallow bedrock zone, whereas the deeper bedrock zone is tight and groundwater flows are expected to be extremely limited. In addition, based on the preliminary data set available, it appears that the groundwater elevations within the overburden and possibly the shallow bedrock zones generally mimic the surface topography and groundwater flow directions appear to be toward the local surface water drainages. Also, based on the head potentials observed, the majority of the data suggests that the overburden and shallow bedrock zones exhibit the potential for flow toward and discharge to the local surface water. These observations and the expected limited potential for any significant deep migration of groundwater will be further evaluated after completion of the permeability testing in the wells, and using water level recordings in streams and wells.

4.2.2 Surface Water Pathway

Based on the limited recharge to the aquifer, limited observed permeability with depth, and the expected low hydraulic conductivity with depth, the surface water pathway may be the most significant potential migration pathway from the DU Impact Area. The hydrographs from nearby USGS stream gauges and preliminary results from stream gauges onsite indicate that surface runoff after a precipitation event spikes rapidly and dissipates quickly. This may be an indication that the majority of sediment moved from the DU Impact Area could occur during short durations during peak runoff conditions. These would be times when considerable flows in the streams would potentially carry particulates, either sediments with DU attached or DU particles, and deposit them downstream when flow velocities dissipate. Combined with the highly erodible soils within the DU Impact Area, this pathway appears to be potentially significant.

4.2.3 Biotransfer Pathways

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, Norman, and Faison 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.

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.

4.3 EXPOSURE PATHWAYS

Humans at JPG 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) 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 (i.e., deer, cattle, or goats) may vary depending upon environmental conditions, but are approximately five times greater than that of humans (Royal Society 2002).

5. CONCLUSIONS AND RECOMMENDATIONS

This section summarizes the results and conclusions from the completed monitoring well installation, surface water stage data collection, and flow analysis. This section also includes recommendations for follow-on investigations.

5.1 WELL COMPLETION

The primary purpose of installing the 23 individual monitoring wells at the 10 well cluster locations described in this report was to evaluate and characterize preferential groundwater flow conduits or zones of fracturing and/or solution-enhanced fractures present in the karst system that was suspected to underlie the JPG DU Impact Area. A secondary purpose of installing the 23 wells was to evaluate the permeable materials or permeable zones at the overburden-bedrock surface (e.g., EI survey results showing deeper depths to bedrock, drilling observations).

An FTA and EI survey were completed previously (SAIC 2006c and SAIC 2007a) to identify locations of preferential groundwater flow pathways prior to commencing drilling operations. These studies, in conjunction with a visual reconnaissance, formed the basis for identifying well locations. The locations for installing the wells included additional selection criteria that were presented in the Well Location Selection Report (SAIC 2007a).

Results from the wells SAIC installed in 2007 are to be used in conjunction with the 11 ERM Program wells and 8 Range Study wells that existed in the DU Impact Area prior to May 2007. The majority of the newly installed wells and the existing wells have low well yields, as observed during pumping during well development, purging during ERM well sampling, or documented in previous reports. The ERM Program and Range Study wells were re-developed in February 2008 to ensure that the wells produce water representative of local geologic formations and provide data of sufficient quality to support this site characterization.

Based on the evaluation of the existing lithologic well logs and the 2007 well installation observations, three hydrostratigraphic layers are presently being considered that are intersected by the monitoring wells being gauged. The hydrostratigraphic layers consist of the following: the "overburden" or saturated overburden materials, "shallow" bedrock consisting of the top 40 to 60 feet of bedrock, and "deep" bedrock below the top 40 to 60 feet.

During the well installation, the overburden and the bedrock materials were visually characterized. The depths of the overburden materials from all of the wells installed by SAIC in 2007, ERM Program wells, and Range Study wells range from 0.65 to 72.5 feet, with an average depth to bedrock of 20.8 feet. The majority of the overburden materials observed consist of fine-grained, low-permeability materials consistent with published and observed soil descriptions of glacial (till) and wind blown (loess) origins presented in the SVS (SAIC 2007a). At a total of five locations (JPG-DU-03O, JPG-DU-04O, JPG-DU-06O, JPG-DU-09O, and JPG-DU-10O) during the 2007 well installation task, permeable materials were observed that would provide sufficient well yield to provide a suitable groundwater monitoring and sampling point. The presence of materials with sufficiently permeable materials to provide sufficient well yield for monitoring purposes appears to not be widespread or consistent within the study area. Materials that would be characterized as residuum from the carbonate bedrock were not observed during the well installation task. Consistent with the observation of the lack of residuum materials on bedrock, the pre-Wisconsinan glacial tills are typically thin and are present directly on the bedrock (USGS 1994).

The observed nearly horizontally bedded limestone, shaley interbedded limestone, dolostone, and shaley interbedded dolostone is consistent with the mapped bedrock formations for the study area (USGS 1994). Within the bedrock, an overall lack of secondary porosity and presence of solution features was observed during the well drilling and installation activities and decreased with depth below the top of the bedrock surface. Generally, the bedrock aquifer can be classified into two hydrostratigraphic units consisting of the "shallow" bedrock (top 40 to 60 feet) and the "deep" bedrock (deeper than the 40 to 60 feet zone). The shallow bedrock has limited secondary porosity that was observed consisting of fractures (minor weathering) and one shallow solution feature (23 feet BLS in the JPG-DU-02 well pair). The deep bedrock had very limited secondary porosity that was observed consisting of very limited fractures and practically nonexistent weathering. The un-weathered rock matrix is very tight and based on observations from pumping during well development, has a very low hydraulic conductivity. For these reasons and additional discussion in Section 4.2.1.4, it appears that the karst development at the site is limited and may be primarily restricted within the erosional plain along Big Creek. The width of the erosional plane is variable along Big Creek and ranges from approximately 100 to nearly 1,000 feet along some portions of the creek. The width of the plane also often is not equal on either side of the creek as in the central potion of the DU Impact Area where Center Recovery Road extends to Big Creek. In this area, the erosional plane appears to extend nearly 1,000 feet to the north of Big Creek while extending only approximately 100 feet or less on the southern side of Big Creek.

Based on the limited water elevation data available at this time as discussed in Section 2.8.5, the head potentials observed for the majority of the locations where a comparison could be made suggests that the overburden and shallow bedrock zones exhibit the potential for flow toward and discharge to the local surface water. Based on the observations from the drilling, characteristics of the hydrostratigraphic units, and the head potential evaluation, the potential for migration to deep groundwater is limited. This observation is preliminary and additional data are needed to complete the evaluation of the groundwater pathway.

There are several key elements of the evaluation of the groundwater pathway in which the monitoring wells and surface water monitoring will be used during the future characterization tasks and include:

- Determining the active components of the groundwater pathway
- Determining the interconnectivity of the surface water and groundwater
- Determining if DU is or has the potential for migrating to groundwater
- Determining if DU is present in the groundwater.

The planned tasks where these wells will be used are discussed in Section 2.9 and include groundwater sampling, groundwater stage monitoring, USGS groundwater age-dating and down hole flowmeter measurements, conduit intersection confirmation and connectivity evaluation, and hydraulic conductivity aquifer testing (slug testing). Additional surface water, groundwater, and precipitation data will be collected and evaluated before a more thorough determination of head potentials, flow directions, gradients, connectivity of groundwater and surface water, reactions of groundwater and surface water to precipitation, and seasonal variability can be completed. The collection of the required water elevation and precipitation data from the automatic data recorders for these evaluations is planned during the quarterly monitoring events downloads (manual measurements also will be collected quarterly). Some of the data collected from the wells also will be used in completing the evaluation of the interaction between precipitation, groundwater, and surface water (Section 5.2), as well as evaluating groundwater flow direction potentials.

5.2 SURFACE WATER GAUGE MEASUREMENTS

The purpose of installing and monitoring stream gauges and cave spring gauges was to collect surface water stage data and manual flow measurements to calculate surface water flows and estimate recharge to the aquifer at the JPG DU Impact Area. Precipitation and temperature data were obtained from an automated weather station maintained by USFWS on the eastern side of the JPG facility. SAIC installed 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. Electronic data recorders and pressure transducers were installed to continuously and automatically record water levels (or stage) within the stilling wells. Each stream gauging station was calibrated by manually measuring stream flows using a Gurley® flow meter or equivalent. Weirs were used to measure cave stream flows. Continuous stage data were collected from all the gauges from September 2006 through present. Manual measurements of stream flow were made when data were downloaded from the gauge recorders: monthly for the first year (September 2006 to August 2007) and quarterly thereafter (beginning in November 2007). In addition, stream cross-section measurements were collected in February 2008. Rating curves were developed for the stream gauges using the stage data from the automatic data recorders, manual flow measurements, and cross-section measurements. Flows higher than the manually measured rates were extrapolated using the Manning equation and cross-section measurements of the streams at the gauging stations. The development of the rating curves has proven to be problematic because of the lack of correlation observed between the stage data from the automatic stream gauge data recorders and the manual flow measurements. The poor correlation could be a result of naturally changing stream channel configuration caused by the extreme and frequent storm flows, log and ice jams, and the numerous and changing beaver dams/pools, or, less likely, field measurement errors..

The rating curves were used to calculate stream flows from the automatically recorded stage data, and construct stream flow hydrographs, which show daily flows in cfs. Hydrographs were constructed for the installed gauge stations and compared to established USGS gauging stations on streams near the JPG DU site and which are located in similar topographic and geologic conditions (Brush Creek and Muscatatuck River near Deputy, Indiana). All gauges at and around the JPG DU Impact Area appear to reflect very flashy streams, meaning that after precipitation events, the flow increases rapidly, and decreases rapidly, causing the spiky nature of the hydrographs. The hydrographs showed a period of low- to no-flow for many of the summer months. Both conditions are indicative of a hydrologic system in which surface water runoff is unusually high and groundwater recharge is unusually low.

The flow data from the USGS gauging stations were processed by two computer programs to estimate recharge to the aquifer using stream flow hydrograph analysis methods:

- PART automated the separation of surface water and interflow from groundwater base flow
- RORA used a recession-curve displacement method to estimate groundwater recharge from storm periods recorded on the stream flow hydrographs.

Based on these models and the Thornthwaite equation (1948), a preliminary water budget includes 56 percent of annual onsite precipitation returning to the atmosphere via evapotranspiration and the remaining 44 percent leaving the site as runoff. The 44 percent of precipitation included in runoff (Q) is composed of surface water runoff (Q_S) and groundwater runoff (Q_{GW}). The Q_{GW} component was calculated by running PART and RORA models on records from two nearby USGS gauge stations in Indiana, which suggests that the component of the water budget that infiltrates the ground surface and becomes groundwater would be quite small, on the order of 8 percent of total precipitation. The remaining 36 percent of annual precipitation that falls on the site is believed to leave the site as surface water runoff. This information qualitatively and preliminarily supports that surface water runoff might be a more important transport mechanism for DU than groundwater runoff at the DU Impact Area.

Based on the results of the cave stream gauges, it appears that water discharging from cave streams, enters the shallow karst network, and discharges very quickly through caves and voids located in the banks and floor of local surface water features, in the same timeframe as surface water. A small component of the cave stream discharge is derived from groundwater during certain times of the year, based on the intermittent flows recorded from the cave streams. Based on the drilling, the results of historical studies of the karst at JPG, and observations by SAIC geologists and field technicians, karst development in the DU Impact Area is more pronounced near Big Creek. Along Middle Fork Creek, karst features have only been observed outside the DU Impact Area. Combined with the observation that most groundwater appears to take a shallow route through the aquifer, discharging to the local streams, and the flashy nature of the stream flow in the surface water courses, surface water in Big Creek appears to be the greatest avenue of potential DU migration from the DU Impact Area.

The discharges from subsurface to surface water is a condition that will be more closely examined by comparing the water levels in surface streams and wells with cave stream flows during storm and non-storm events over the next year. Additional effort is necessary to improve the accuracy of stream gauge rating curves. Therefore, the Army is planning to collect additional manual stream flow data. The additional measurements will potentially improve the accuracy of the rating curves and the calculation of flows from the continuous stage data, and should result in more usable data, even though some impacted flow data will be in the data set. If the condition is determined to be stream channel impacts that continue to occur (e.g., changes as a result of stormwater flow, ice jams, log jams, beaver dams), the use of the local flow data will have to be limited.

In addition, the Army plans to conduct a seepage run survey to confirm that stream flow changes are not related to gaining or losing stream sections. The seepage run survey will focus on Big Creek during which three teams will measure the stream flows simultaneously. Starting at three locations on Big Creek, the evenly spaced crews will progress along the stream in such a manner that the stream segment as it passes into, through, and out of the DU Impact Area is measured within a few hours. The measurements will occur during a time of minimal surface water runoff (during a time when groundwater runoff makes up the flow in the stream). The teams will each measure a single stream channel location as a calibration/check on accuracy and will repeat measurements at one or more of the first stations to evaluate the changes that occurred during the period of measurement.

The relationship between groundwater and surface water will continue to be investigated with planned studies. Surface water stage data collected over the next year, in conjunction with the groundwater stage data, will be used to measure basin characteristics and confirm the suspected interrelationships between groundwater and surface water that were presented in this report.

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APPENDIX A

WELL INSTALLATION AND DEVELOPMENT LOGBOOK RECORDS

(Provided on CD only)

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APPENDIX B

DIGITAL GEOPHYSICAL MAPPING FOR CONSTRUCTION SUPPORT

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From Science to Solutions

June 12, 2007

Mr. Joe Skibinski
Science Applications International Corporation
11251 Roger Bacon Drive
Reston, VA 20190

Re: Anomaly Avoidance Investigation
Jefferson Proving Grounds – Madison, IN
SAIC Project 01-1633-04-3211-100

Dear Joe:

Science Applications International Corporation (SAIC) Center for Geophysical Excellence is pleased to present this letter report documenting the results of digital geophysical mapping services for the detection of potential munitions and explosives of concern (MEC) at Jefferson Proving Grounds (JPG) near Madison, Indiana. This investigation was conducted prior to the installation of characterization wells (CWs). SAIC utilized an EM61-MK2 high sensitivity metal detector to determine the location of metallic objects. This survey was performed over the footprint designated for well construction activities. The footprint included the proposed well location and the area designated for drilling equipment, support equipment and personnel movement during well construction activities.

Data quality objectives for this project include:

- Measure background response during EM standardization tests within +/-2 millivolt (mV)
- Ensure instrument response drift during survey is less than 1 mV.
- Optimize positional accuracy through appropriate lag corrections applied to data to eliminate "chevron" effect within contoured data.
- Establish one meter lateral data resolution where access permits with inline data resolution of 0.15 meters.

SITE DESCRIPTION AND PREPARATION

A total of 10 proposed characterization well sites (CW01 – CW10) were surveyed as part of this investigation. These sites were situated along site access roads and generally consisted of flat topography with the exception of CW09 which was situated on a slope. Vegetation within open areas consisted of ankle high grass, whereas sites CW04 and CW07 contained a few small trees with some tree canopy present.

Work plans proposed establishing a 40-foot survey grid over the proposed well location. The proposed well location was identified in accordance with SAIC's Geophysical Procedures GP-007 *Field Mapping With Global Positioning Systems* using a submeter PRO-XRS Differential Global Positioning System (DGPS) manufactured by Trimble Limited® of Sunnyvale, California. Once the proposed well location was identified, a survey grid was demarcated by qualified explosive ordnance disposal (EOD) staff. All grids met the 40-foot survey grid requirement with the exception of CW04, which was situated adjacent to a dense tree zone. This grid was modified to encompass an area of approximately 40 feet by 20 feet. At all locations, a portion of the access road immediately adjacent to the survey grid was added to the investigation.

Prior to initiating digital geophysical mapping (DGM) surveys, EOD staff performed surface sweeps using a magnetic locator. EOD staff flagged remarkable targets of interest using polyvinyl chloride (PVC) pin flags. Inert metallic objects identified were removed from the grid by EOD staff, whereas potentially fused ordnance items were left in place for safe disposition during removal activities. Extreme caution was exercised by geophysical personnel while working around potentially fused items.

Prior to DGM, radiological surface sweeps were also performed. Any impacted areas identified were marked with different colored PVC flagging. Access to these areas was minimized during DGM surveys.

All geophysical data for this project is referenced in the Universal Transverse Mercator (UTM) coordinate system, Zone 16 North, NAD 83 (CONUS) datum, meters.

EM61 HIGH SENSITIVITY METAL DETECTOR

SAIC utilized an EM61-MK2 manufactured by Geonics Limited of Mississauga, Ontario, Canada, to collect high sensitivity metal detector data. The EM61-MK2 is able to discriminate between conductive earth materials and highly conductive metallic targets such as underground storage tanks (USTs), drums, MEC, and buried metallic waste.

The EM61-MK2 is a time domain electromagnetic (EM) instrument that transmits a high frequency electromagnetic pulse 150 times per second and measures during the off-time between pulses. After each pulse, secondary EM fields are induced briefly in moderately conductive soils and for a longer time in metallic objects. Between each pulse, the EM61-MK2 waits until the response from the conductive earth dissipates and then measures the prolonged buried metal response. Four separate response measurements are recorded. Conventional inductive metal detectors are generally limited in depth of exploration due to design factors idealized for detecting small objects at shallow depths. The EM61-MK2 can distinguish near-surface metals from metal objects buried at depths by using two separate coils. The design of the second coil is such that the near-surface response can be made virtually zero, increasing the detection of deeper targets.

EM 61-MK2 DATA COLLECTION

During the week of May 11, 2007, SAIC performed a high sensitivity metal detector survey over the 10 areas of interest following SAIC Geophysical Procedure GP-002 *Surface Electromagnetic Surveys* and in accordance with U.S. Army Corps of Engineers *Geophysical Investigation Plan,* DID MR-005-05. The dimensions of the EM61-MK2 coil are 1.0 meters by 0.5 meters. The survey was conducted with the long axis of the coils oriented perpendicular to the direction of travel. Since there is some lateral sensitivity outside the coil footprint, data was collected along traverses nominally spaced three feet apart where access permitted. Additionally data was collected five times per second as the operator walked along the traverses and was integrated with DGPS data collected every one second. These survey parameters are expected to represent complete coverage and are suitable for the survey objective.

Prior to initiating the field investigation, SAIC performed a six line test to determine the optimal lag correction factor. Additionally, per survey and post survey static tests were performed to calibrate the EM61-MK2 and monitor background noise and any instrument drift.

The data was digitally recorded and periodically downloaded to a field computer for quality assurance and in field data interpretation.

SAIC utilized DGPS to map features marked during EOD surface sweeps. These mapped features were integrated with the processed data to provide enhanced data interpretation.

EM 61-MK2 DATA PROCESSING AND ANALYSIS

During data preprocessing, SAIC performed lag adjustment as appropriate and normalized data results to a consistent background response. SAIC utilized the Geosoft OASIS Montaj™ UX Detect module to grid and contour Channels 2 and 3 representing bottom coil data. Based on preliminary data assessment, SAIC selected data from Channel 3 for interpretation and presentation as it appeared to contain the greater number of interpretable targets and based on theory of measurement, better represented both near surface features and targets at depth.

As a quality check, SAIC reviewed the nominal traverse spacing and data density results. Based on this review, it was determined that density data quality objectives were met as defined in the work plans except in those areas that had limited site access due to tree clusters. Areas where access was limited are represented by blanked regions within the survey grid.

A geophysical prove-out was not required under this task order; therefore, SAIC relied upon collective knowledge of GPO results from similar projects in determining a basis for target selection criteria. Targets were selected based on a six millivolt target threshold, as this threshold would be above normal noise levels of an EM61-MK2 in dynamic mode, and permit the selection of small targets of interest. After automated target selection was performed, SAIC posted EM response on each of the data maps and performed a detail review of these data. Supplemental targets were selected based on this refined review. Subsequent to review, comprehensive dig sheets were prepared. No efforts were made to discriminate fragments from intact items as any foreign object was considered a potential hazard during drilling activities. Dig sheets along with data maps were provided to EOD field crews for subsequent target reacquisition and removal action. These dig sheets and maps are presented as Attachments.

EM 61-MK2 DATA PEER REVIEW

As a quality check, SAIC reviewed the nominal traverse spacing and data density results. Based on this review, it was determined that data density data quality objectives were met as defined in the work plans except in those areas that had limited site access due to tree cluster. Areas where access was limited are represented by blanked regions within the survey grid.

On a daily basis, the SAIC field team posted raw and processed data on the geophysical network drive for independent data peer review by a senior geophysicist. Preliminary field interpretation was reviewed and feedback provided. Since a low target threshold was used for target selection, no additional targets were added to the dig sheet as a result of independent data peer review.

Based on the independent peer review, data was determined to be consistent with data quality objectives for this task.

GEOPHYSICAL SURVEY LIMITATIONS

The investigation performed included standard and/or routinely accepted practices of the geophysical industry. SAIC utilize qualified personnel to reduce the risk of missing a subsurface feature, due to the depth it is buried, the soil type and conditions, the feature materials, or other site-specific conditions that may mask the feature of interest. Field data acquisition and processing were performed consistent with data quality objectives, project schedule, and within budget. However, by its nature, no subsurface survey is 100 percent accurate and SAIC cannot accept responsibility for inherent survey limitations or unforeseen, site-specific conditions.

SUMMARY

A total of 10 grids were investigated and dig sheets prepared. Acquired and processed data were submitted for peer review in advance of intrusive field activities. Dig sheets were provided to EOD staff for target reacquisition subsequent removal action. These final results represent satisfactory completion of data quality objectives proposed for this project and permitted subsequent drilling activities to commence on schedule.

SAIC Center for Geophysical Excellence appreciates this opportunity to support the JPG project team. We look forward to your favorable review of this letter report and successful completion of the drilling program. If you have any questions or require any further information, please feel free to contact the undersigned at your convenience.

Respectfully submitted,

SCIENCE APPLICATIONS INTERNATIONAL CORPORATION

Jeffrey J. Warren, P.G.
Geophysicist

Richard A. Hoover P. G.
Senior Geophysicist

JJW:dlp
Attachments

References

Science Applications International Corporation, 2005, Geophysical Procedure GP-002 Surface Electromagnetic Survey.

Science Applications International Corporation, 2005, Geophysical Procedure GP-007 Field Mapping With Global Positioning Systems.

U.S. Army Corps of Engineers. 2003b. Geophysical Investigation Plan. DID MR-005-05 Activity, Savanna, Illinois. March.

ATTACHMENT A

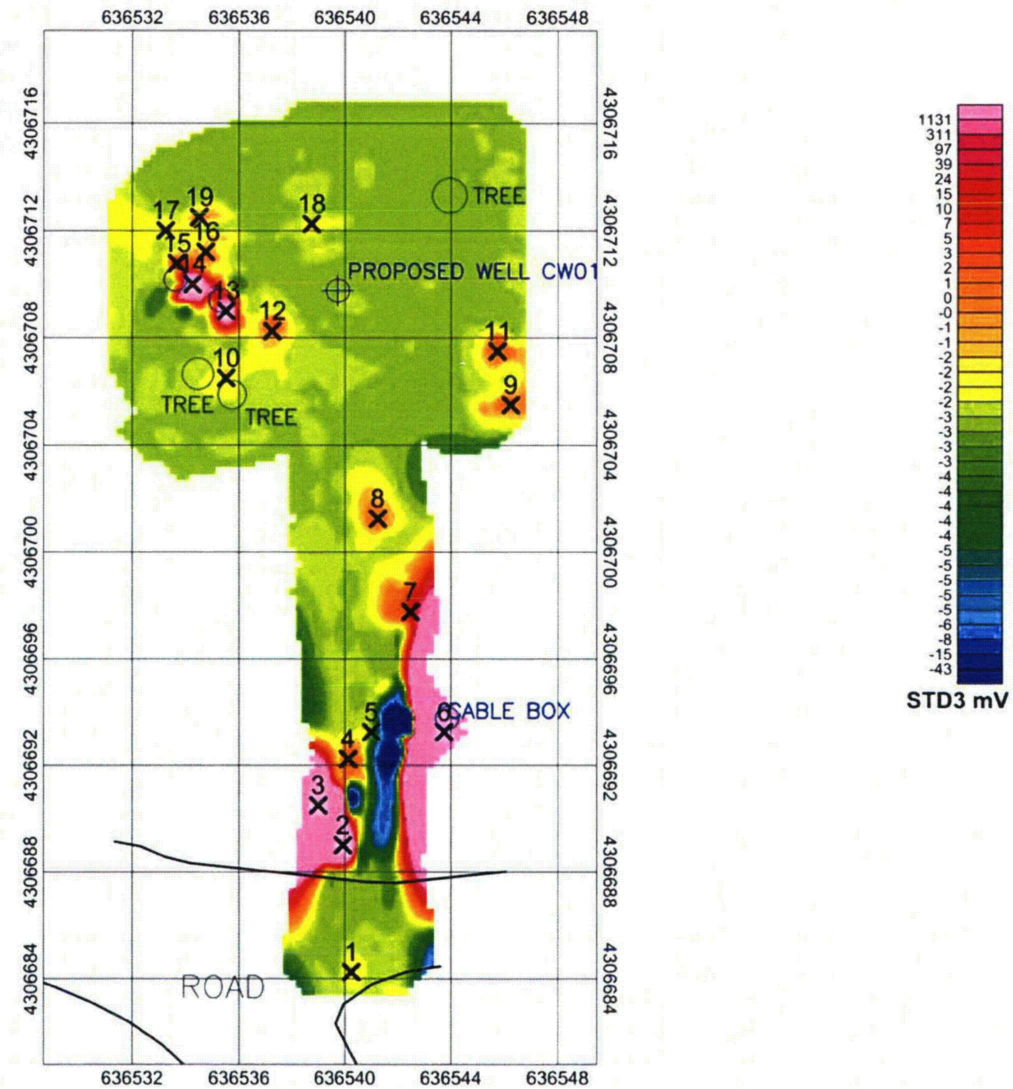
DIGITAL GEOPHYSICAL MAPPING RESULTS

Survey Grid ID CW01

Project Name: Jefferson Proving Ground - Anomaly Avoidance Surveys
Project Location: Madison, Indiana
Date: 19-May-07
Coordinate System: Universal Transverse Mercator
Zone 16 North, NAD 83, meters

Geophysical Contractor: SAIC
Project Geophysicist: Jeffrey J. Warrren P.G.
EOD Support: Seth Stephenson
Radiological Support Clark Evers
Project Manager Joe Skibinski

Target_ID	X	Y	STD2Grid_value	STD3Grid_value	Description	Depth	Orientation	Comment
1	636540.3	4306684.3	40.0	26.9				
2	636539.9	4306689.0	1770.5	992.2				
3	636539.0	4306690.5	4993.2	2434.0				
4	636540.1	4306692.2	88.6	37.4				
5	636541.0	4306693.3	15.7	26.1				
6	636543.8	4306693.3	11404.0	7699.7				
7	636542.5	4306697.8	156.2	89.2				
8	636541.3	4306701.3	86.9	55.5				
9	636546.3	4306705.5	83.8	51.3				
10	636535.5	4306706.5	33.0	18.8				
11	636545.8	4306707.5	121.6	67.8				
12	636537.3	4306708.3	76.2	32.8				
13	636535.5	4306709.0	842.6	510.1				
14	636534.3	4306710.0	803.2	555.7				
15	636533.7	4306710.8	154.3	93.3				
16	636534.7	4306711.2	70.9	40.6				
17	636533.3	4306712.0	31.6	18.8				
18	636538.8	4306712.3	12.8	8.3				
19	636534.5	4306712.5	77.2	44.8				



LEGEND

× Target Location and Identifier (2)

○ Surface Sweep Anomaly

JPG ANOMALY AVOIDANCE

CW-01

5 0 5

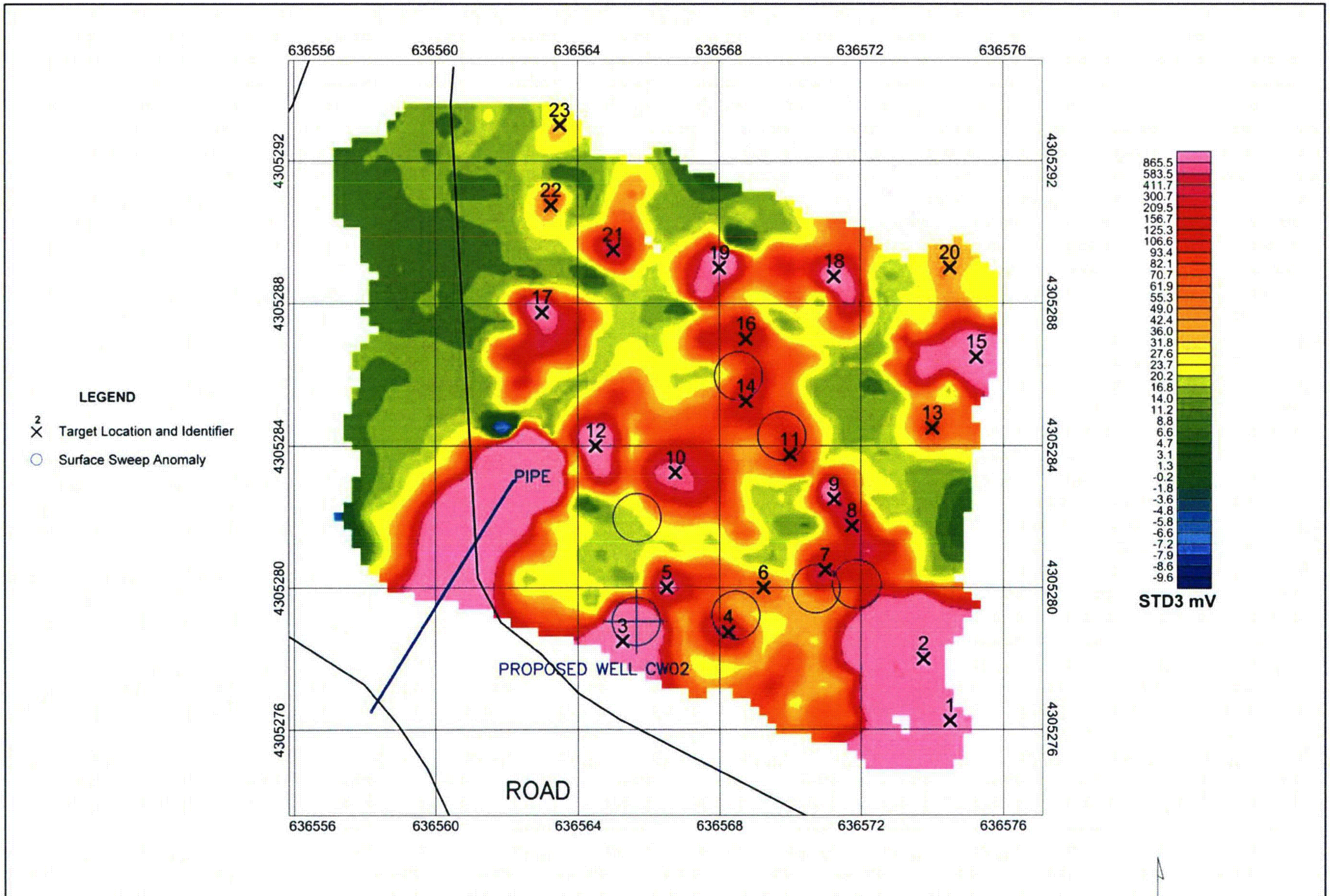
metres

Survey Grid ID CW02

Project Name: Jefferson Proving Ground - Anomaly Avoidance Surveys
Project Location: Madison, Indiana
Date: 19-May-07
Coordinate System: Universal Transverse Mercator
Zone 16 North, NAD 83, meters

Geophysical Contractor: SAIC
Project Geophysicist: Jeffrey J. Warrren P.G.
EOD Support: Seth Stephenson
Radiological Support Clark Evers
Project Manager Joe Skibinski

Target_ID	X	Y	STD2Grid_value	STD3Grid_value	Description	Depth	Orientation	Comment
1	636574.5	4305276.3	1252.3	749.7				
2	636569.5	4305277.2	147.4	75.1				
3	636572.9	4305277.3	898.7	559.9				
4	636573.8	4305278.0	2168.0	1194.1				
5	636565.3	4305278.5	1932.3	1173.1				
6	636568.3	4305278.8	282.0	165.2				
7	636566.5	4305280.0	414.6	241.1				
8	636569.3	4305280.0	92.8	46.8				
9	636571.0	4305280.5	267.1	160.6				
10	636572.2	4305281.0	291.8	117.3				
11	636568.6	4305281.6	68.8	41.5				
12	636571.8	4305281.8	286.9	164.7				
13	636571.3	4305282.5	351.6	195.6				
14	636566.8	4305283.3	322.8	140.8				
15	636570.0	4305283.8	185.7	124.1				
16	636564.5	4305284.0	885.3	475.8				
17	636566.0	4305284.5	100.3	59.4				
18	636574.0	4305284.5	163.9	88.4				
19	636568.8	4305285.3	236.4	128.7				
20	636565.0	4305285.4	140.5	86.0				
21	636562.4	4305285.6	143.4	81.9				
22	636575.3	4305286.5	760.6	464.2				
23	636562.9	4305286.8	263.1	158.9				
24	636567.6	4305286.9	171.4	108.5				
25	636568.8	4305287.0	199.2	121.2				
26	636563.0	4305287.8	426.6	252.2				
27	636571.6	4305287.8	230.2	127.4				
28	636571.3	4305288.8	465.5	256.8				
29	636568.0	4305289.0	570.6	280.7				
30	636574.5	4305289.0	55.6	26.8				
31	636569.7	4305289.1	150.0	90.4				
32	636565.0	4305289.5	274.1	146.8				
33	636563.3	4305290.8	77.9	27.3				
34	636565.5	4305291.1	55.6	29.9				
35	636563.5	4305293.0	35.9	21.0				



JPG ANOMALY AVOIDANCE

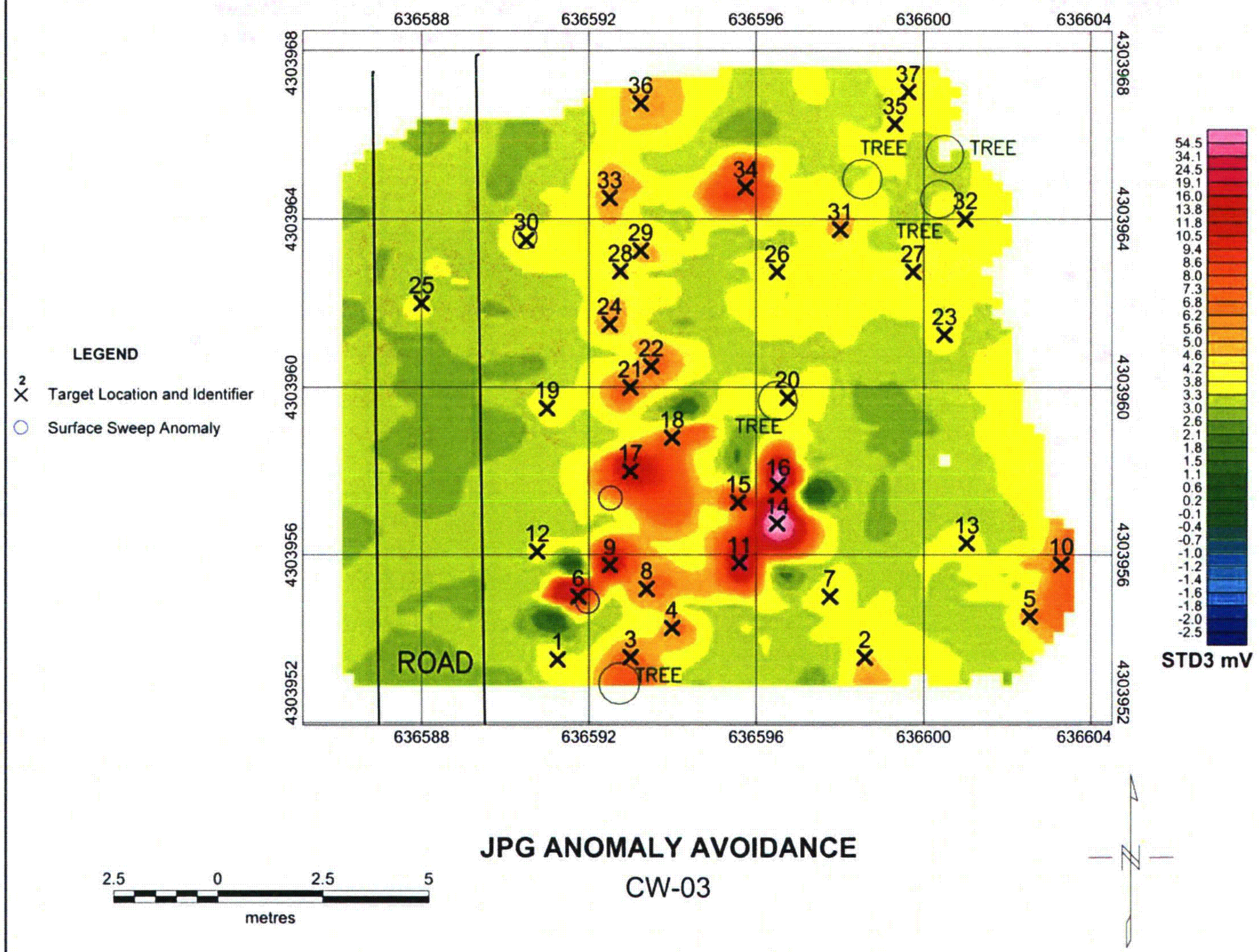
CW-02

Survey Grid ID CW03

Project Name: Jefferson Proving Ground - Anomaly Avoidance Surveys
Project Location: Madison, Indiana
Date: 9-May-07
Coordinate System: Universal Transverse Mercator
Zone 16 North, NAD 83, meters

Geophysical Contractor: SAIC
Project Geophysicist: Jeffrey J. Warrren P.G.
EOD Support: Seth Stephenson
Radiological Support Clark Evers
Project Manager Joe Skibinski

Target_ID	X	Y	STD2Grid_value	STD3Grid_value	Description	Depth	Orientation	Comment
1	636591.3	4303953.5	17.1	8.4				
2	636598.6	4303953.5	35.8	19.1				
3	636593.0	4303953.6	63.6	30.2				
4	636594.0	4303954.3	58.7	26.5				
5	636602.6	4303954.5	57.2	31.7				
6	636591.8	4303955.0	199.2	124.5				
7	636597.8	4303955.0	21.8	12.4				
8	636593.4	4303955.2	58.4	27.5				
9	636592.5	4303955.8	241.6	121.6				
10	636603.3	4303955.8	74.6	43.2				
11	636595.6	4303955.8	259.3	119.0				
12	636590.8	4303956.1	20.8	11.1				
13	636601.0	4303956.3	15.9	7.7				
14	636596.5	4303956.8	534.9	273.0				
15	636595.6	4303957.3	158.3	78.6				
16	636596.5	4303957.7	334.1	172.7				
17	636593.0	4303958.0	208.0	100.8				
18	636594.0	4303958.8	63.9	31.2				
19	636591.0	4303959.5	28.3	14.5				
20	636596.8	4303959.8	21.7	11.2				
21	636593.0	4303960.0	66.9	28.9				
22	636593.5	4303960.5	63.3	28.4				
23	636600.5	4303961.3	18.2	9.6				
24	636592.5	4303961.5	53.0	22.8				
25	636588.0	4303962.0	13.9	8.8				
26	636596.5	4303962.8	19.1	9.9				
27	636599.8	4303962.8	37.6	18.9				
28	636592.8	4303962.8	38.4	18.5				
29	636593.3	4303963.3	39.3	17.3				
30	636590.5	4303963.5	20.1	10.3				
31	636598.0	4303963.8	45.8	27.5				
32	636601.0	4303964.0	21.2	12.6				
33	636592.5	4303964.5	48.4	23.3				
34	636595.8	4303964.8	105.7	61.9				
35	636599.3	4303966.3	34.3	19.2				
36	636593.3	4303966.8	45.5	19.6				
37	636599.6	4303967.0	23.0	12.7				



JPG ANOMALY AVOIDANCE

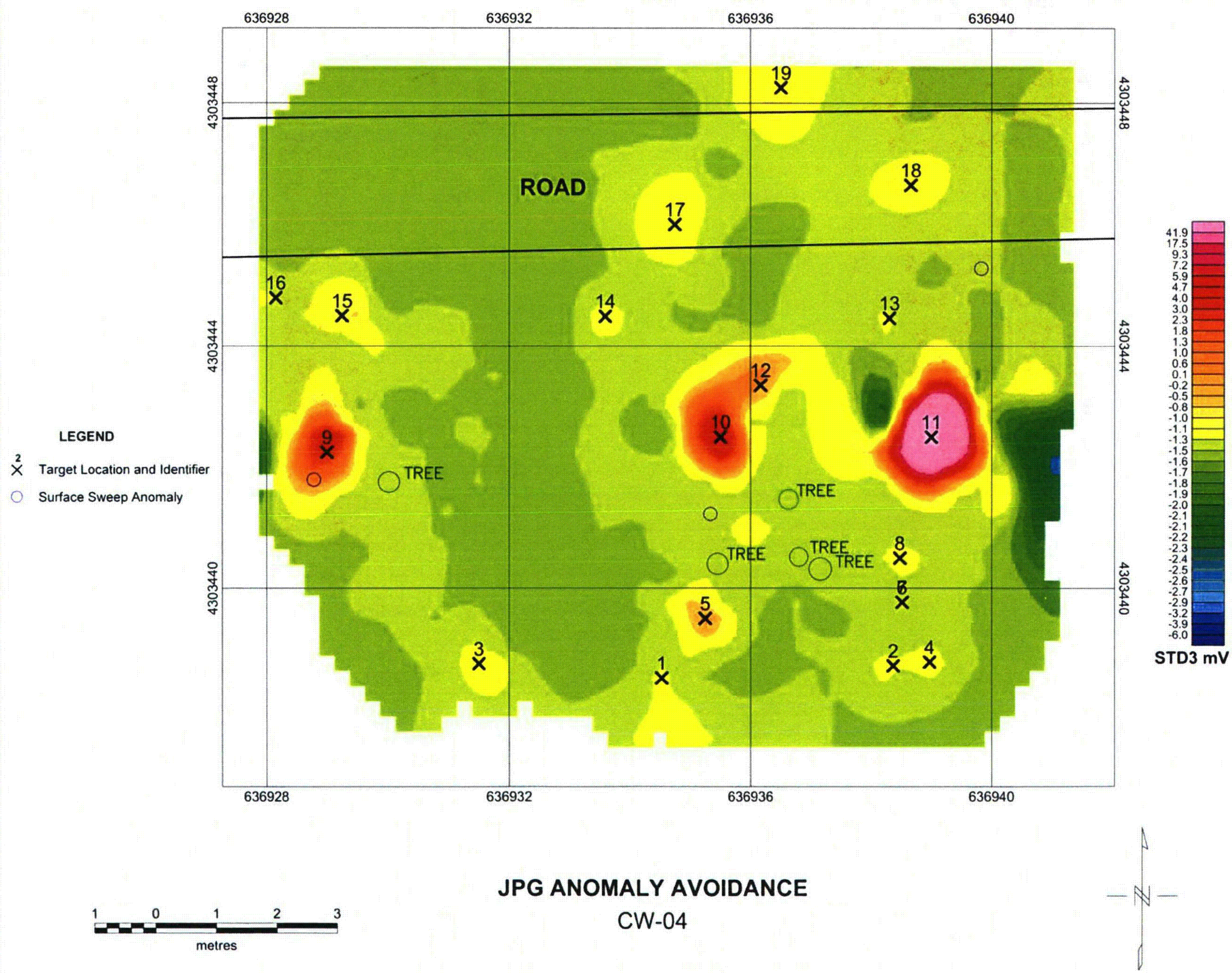
CW-03

Survey Grid ID CW04

Project Name: Jefferson Proving Ground - Anomaly Avoidance Surveys
Project Location: Madison, Indiana
Date: 9-May-07
Coordinate System: Universal Transverse Mercator
Zone 16 North, NAD 83, meters

Geophysical Contractor: SAIC
Project Geophysicist: Jeffrey J. Warrren P.G.
EOD Support: Seth Stephenson
Radiological Support Clark Evers
Project Manager Joe Skibinski

Target_ID	X	Y	STD2Grid_value	STD3Grid_value	Description	Depth	Orientation	Comment
1	636934.5	4303438.5	12.5	7.6				
2	636938.4	4303438.7	11.4	6.4				
3	636931.5	4303438.8	17.2	8.2				
4	636939.0	4303438.8	14.5	8.0				
5	636935.3	4303439.5	66.7	42.8				
6	636938.5	4303439.8	9.6	4.8				
7	636938.5	4303439.8	9.6	4.8				
8	636938.5	4303440.5	14.5	7.7				
9	636929.0	4303442.3	165.0	96.5				
10	636935.5	4303442.5	250.1	132.3				
11	636939.0	4303442.5	1284.1	666.7				
12	636936.2	4303443.4	54.8	32.4				
13	636938.3	4303444.5	10.0	4.2				
14	636933.6	4303444.5	14.4	7.4				
15	636929.3	4303444.5	30.1	16.3				
16	636928.2	4303444.8	8.7	5.2				
17	636934.8	4303446.0	18.9	9.3				
18	636938.7	4303446.6	14.9	7.0				
19	636936.5	4303448.3	22.7	13.2				



JPG ANOMALY AVOIDANCE

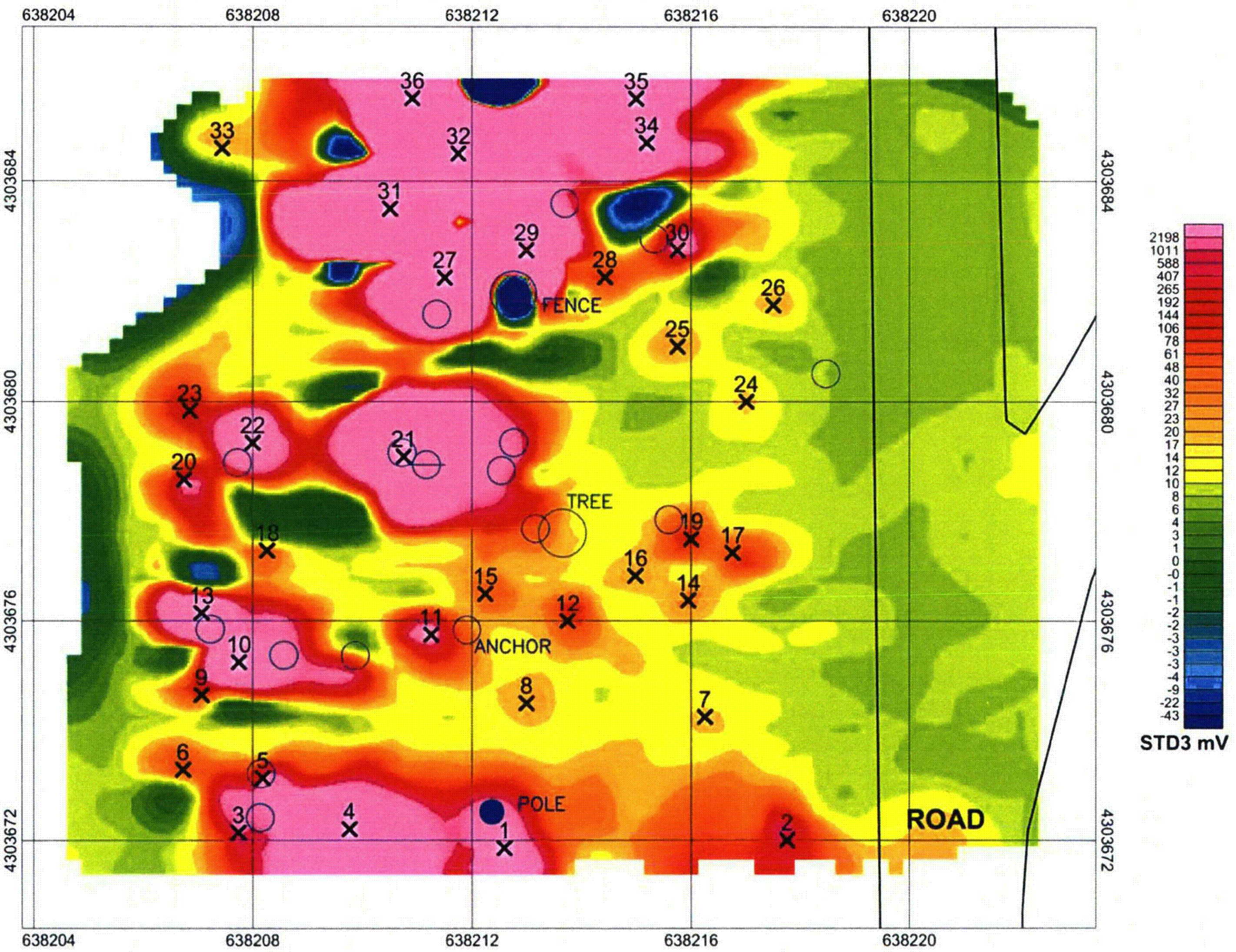
CW-04

Survey Grid ID CW05

Project Name: Jefferson Proving Ground - Anomaly Avoidance Surveys
Project Location: Madison, Indiana
Date: 9-May-07
Coordinate System: Universal Transverse Mercator
Zone 16 North, NAD 83, meters

Geophysical Contractor: SAIC
Project Geophysicist: Jeffrey J. Warrren P.G.
EOD Support: Seth Stephenson
Radiological Support Clark Evers
Project Manager Joe Skibinski

Target_ID	X	Y	STD2Grid_value	STD3Grid_value	Description	Depth	Orientation	Comment
1	638212.6	4303671.9	786.6	445.0				
2	638217.8	4303672.0	253.4	135.1				
3	638207.7	4303672.1	303.8	191.5				
4	638209.8	4303672.2	1125.3	634.8				
5	638208.2	4303673.1	289.1	176.4				
6	638206.7	4303673.3	115.6	71.9				
7	638216.3	4303674.3	39.3	21.8				
8	638213.0	4303674.5	53.8	33.9				
9	638207.1	4303674.7	132.7	82.8				
10	638207.8	4303675.3	1629.2	938.3				
11	638211.3	4303675.8	376.5	239.3				
12	638213.8	4303676.0	125.8	71.5				
13	638207.1	4303676.1	1005.1	584.3				
14	638215.9	4303676.4	57.4	29.4				
15	638212.3	4303676.5	84.5	53.0				
16	638215.0	4303676.8	49.4	30.4				
17	638216.8	4303677.3	104.9	61.5				
18	638208.3	4303677.3	66.8	35.1				
19	638216.0	4303677.5	145.9	81.3				
20	638206.8	4303678.6	272.9	159.5				
21	638210.8	4303679.0	5763.9	3128.6				
22	638208.0	4303679.3	1015.9	582.8				
23	638206.9	4303679.8	196.5	114.4				
24	638217.0	4303680.0	43.6	21.2				
25	638215.8	4303681.0	49.8	26.3				
26	638217.5	4303681.8	50.5	30.8				
27	638211.5	4303682.3	3718.1	1909.2				
28	638214.4	4303682.3	123.8	75.5				
29	638213.0	4303682.8	4358.5	2181.1				
30	638215.8	4303682.8	384.0	250.9				
31	638210.5	4303683.5	13640.4	11527.3				
32	638211.8	4303684.5	13313.9	10321.5				
33	638207.4	4303684.6	39.0	21.8				
34	638215.2	4303684.7	1157.2	706.5				
35	638215.0	4303685.5	5590.6	2952.0				
36	638210.9	4303685.5	7025.8	4189.3				



LEGEND

× Target Location and Identifier

○ Surface Sweep Anomaly

2.5 0 2.5

metres

JPG ANOMALY AVOIDANCE

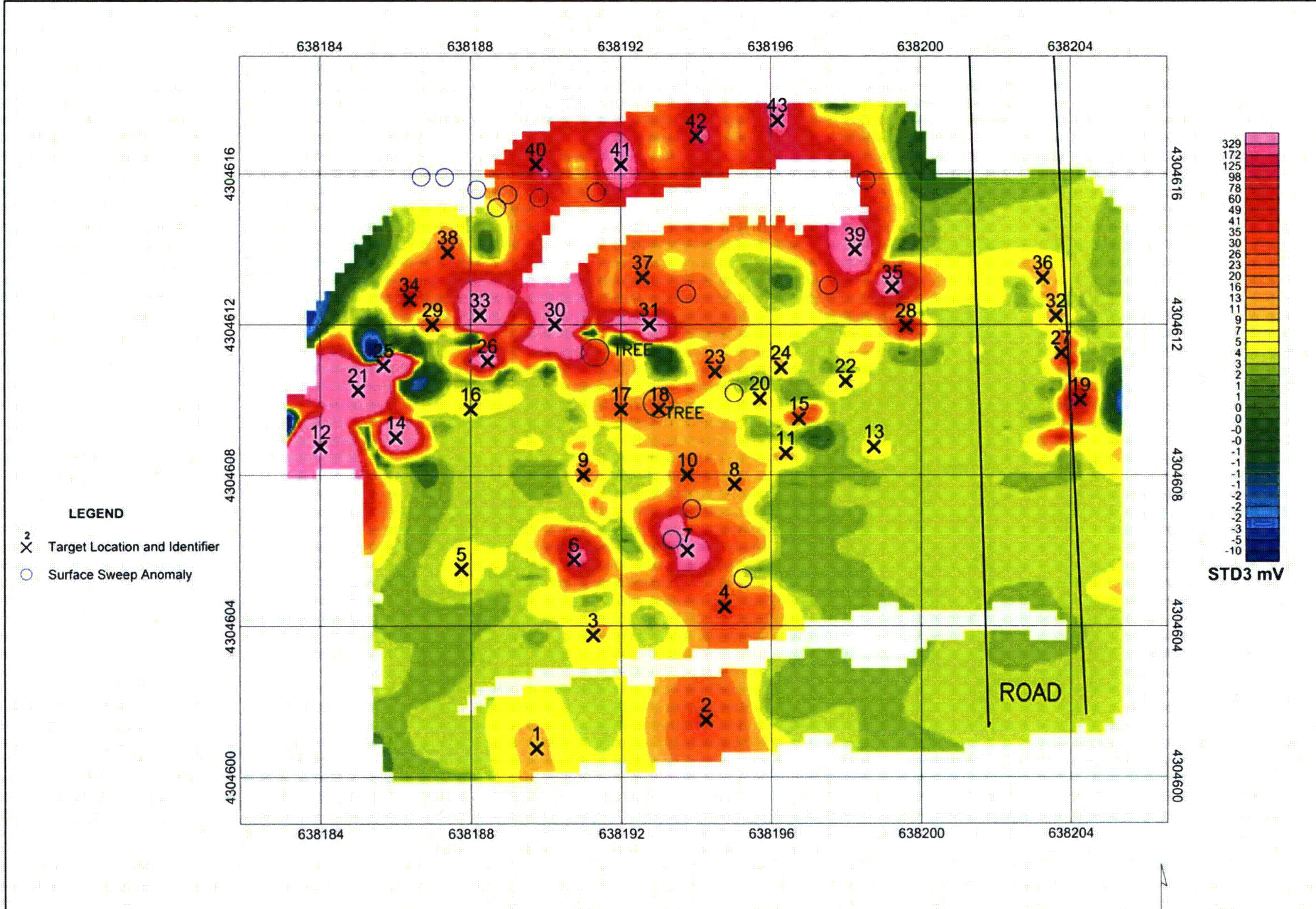
CW-05

Survey Grid ID CW06

Project Name: Jefferson Proving Ground - Anomaly Avoidance Surveys
Project Location: Madison, Indiana
Date: 19-May-07
Coordinate System: Universal Transverse Mercator
Zone 16 North, NAD 83, meters

Geophysical Contractor: SAIC
Project Geophysicist: Jeffrey J. Warrren P.G.
EOD Support: Seth Stephenson
Radiological Support Clark Evers
Project Manager Joe Skibinski

Target_ID	X	Y	STD2Grid_value	STD3Grid_value	Description	Depth	Orientation	Comment
1	638189.8	4304600.8	22.5	22.5				
2	638194.3	4304601.5	59.0	59.0				
3	638191.3	4304603.8	20.6	20.6				
4	638194.8	4304604.5	63.7	63.7				
5	638187.8	4304605.5	18.1	18.1				
6	638190.8	4304605.8	193.0	193.0				
7	638193.8	4304606.0	272.4	272.4				
8	638195.0	4304607.8	39.1	39.1				
9	638191.0	4304608.0	45.6	45.6				
10	638193.8	4304608.0	67.8	67.8				
11	638196.4	4304608.6	23.6	23.6				
12	638184.0	4304608.8	1530.3	1530.3				
13	638198.8	4304608.8	10.6	10.6				
14	638186.0	4304609.0	721.2	721.2				
15	638196.8	4304609.5	59.1	59.1				
16	638188.0	4304609.8	10.0	10.0				
17	638192.0	4304609.8	45.0	45.0				
18	638193.0	4304609.8	38.0	38.0				
19	638204.3	4304610.0	130.4	130.4				
20	638195.7	4304610.0	21.1	21.1				
21	638185.0	4304610.3	1276.4	1276.4				
22	638198.0	4304610.5	21.0	21.0				
23	638194.5	4304610.8	43.7	43.7				
24	638196.3	4304610.9	24.6	24.6				
25	638185.7	4304610.9	384.5	384.5				
26	638188.5	4304611.0	295.8	295.8				
27	638203.8	4304611.3	43.5	43.5				
28	638199.6	4304612.0	115.9	115.9				
29	638187.0	4304612.0	69.6	69.6				
30	638190.3	4304612.0	823.8	823.8				
31	638192.8	4304612.0	355.8	355.8				
32	638203.6	4304612.2	31.9	31.9				
33	638188.3	4304612.3	667.9	667.9				
34	638186.4	4304612.7	97.9	97.9				
35	638199.3	4304613.0	241.8	241.8				
36	638203.3	4304613.3	27.6	27.6				
37	638192.6	4304613.3	60.6	60.6				
38	638187.4	4304613.9	53.7	53.7				
39	638198.3	4304614.0	300.8	300.8				
40	638189.8	4304616.3	160.9	160.9				
41	638192.0	4304616.3	280.3	280.3				
42	638194.0	4304617.0	167.4	167.4				
43	638196.2	4304617.4	194.6	194.6				



JPG ANOMALY AVOIDANCE

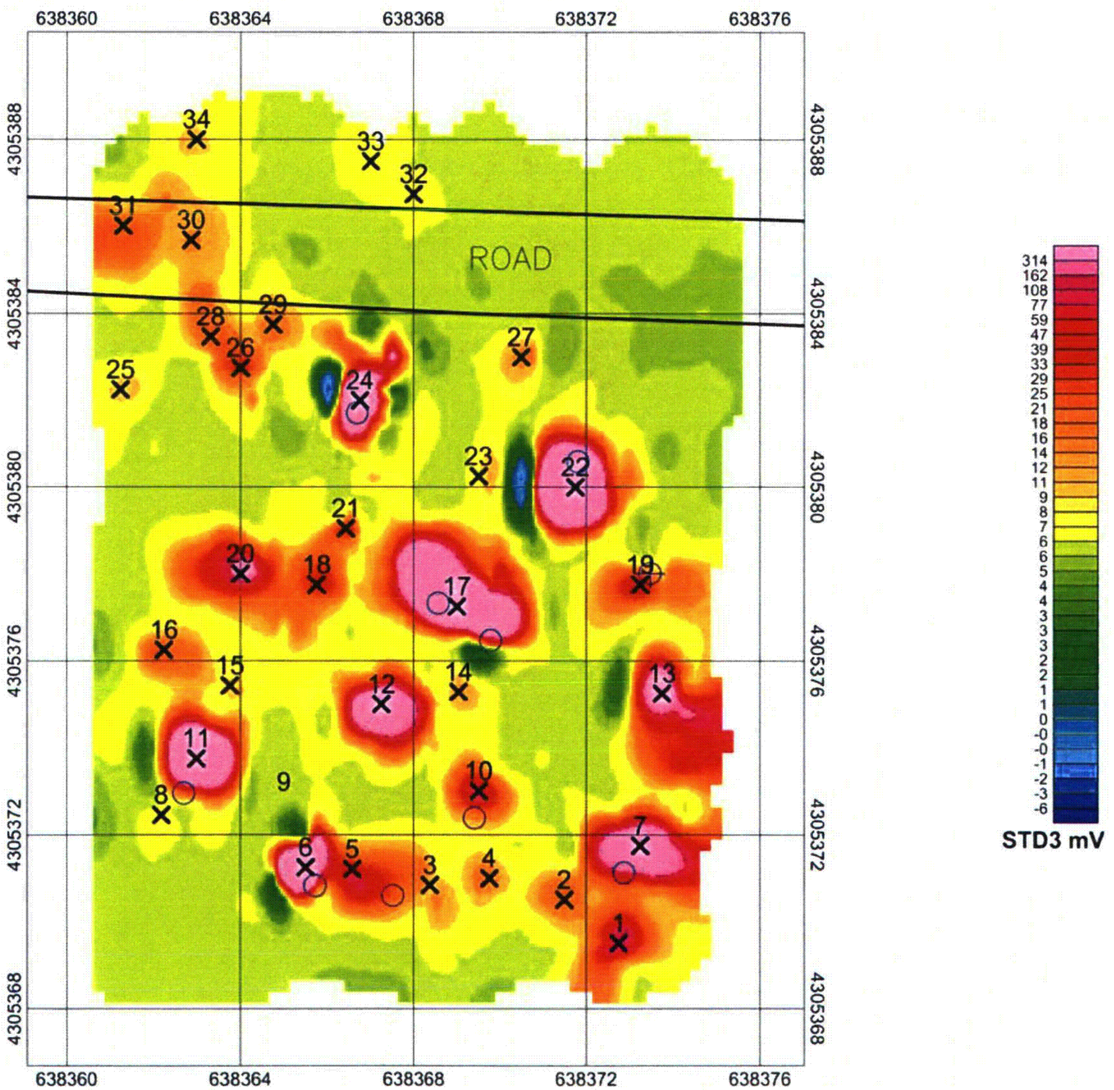
CW-06

Survey Grid ID CW07

Project Name: Jefferson Proving Ground - Anomaly Avoidance Surveys
Project Location: Madison, Indiana
Date: 19-May-07
Coordinate System: Universal Transverse Mercator
Zone 16 North, NAD 83, meters

Geophysical Contractor: SAIC
Project Geophysicist: Jeffrey J. Warrren P.G.
EOD Support: Seth Stephenson
Radiological Support Clark Evers
Project Manager Joe Skibinski

Target_ID	X	Y	STD3Grid_value	STD2Grid_value	Description	Depth	Orientation	Comment
1	638372.8	4305369.5	286.5	172.5				
2	638371.5	4305370.5	88.6	54.7				
3	638368.4	4305370.8	51.9	31.9				
4	638369.8	4305371.0	80.1	47.9				
5	638366.6	4305371.2	176.3	113.3				
6	638365.5	4305371.3	2352.9	1347.9				
7	638373.3	4305371.8	570.4	327.4				
8	638362.2	4305372.5	17.4	12.0				
9	638365.0	4305372.8	2.5	13.5				
10	638369.5	4305373.0	272.6	149.2				
11	638363.0	4305373.8	1678.5	895.9				
12	638367.3	4305375.0	734.4	432.9				
13	638373.8	4305375.3	619.9	348.9				
14	638369.0	4305375.3	58.4	34.4				
15	638363.8	4305375.4	36.1	20.0				
16	638362.3	4305376.3	98.8	62.8				
17	638369.0	4305377.3	1727.4	1051.4				
18	638365.8	4305377.8	161.0	90.7				
19	638373.3	4305377.8	261.8	152.3				
20	638364.0	4305378.0	337.5	189.7				
21	638366.4	4305379.0	161.3	94.3				
22	638371.8	4305380.0	2007.1	1140.5				
23	638369.5	4305380.3	31.0	13.3				
24	638366.8	4305382.0	1187.9	652.1				
25	638361.3	4305382.3	39.7	22.6				
26	638364.0	4305382.8	153.8	91.8				
27	638370.5	4305383.0	70.9	40.9				
28	638363.3	4305383.5	91.4	54.2				
29	638364.8	4305383.8	71.7	46.2				
30	638362.9	4305385.7	55.9	34.8				
31	638361.3	4305386.0	89.2	54.6				
32	638368.0	4305386.8	17.9	12.8				
33	638367.0	4305387.5	17.6	12.9				
34	638363.0	4305388.0	40.4	23.3				



LEGEND

2 ✕ Target Location and Identifier

○ Surface Sweep Anomaly

2.5 0 2.5 5

metres

JPG ANOMALY AVOIDANCE

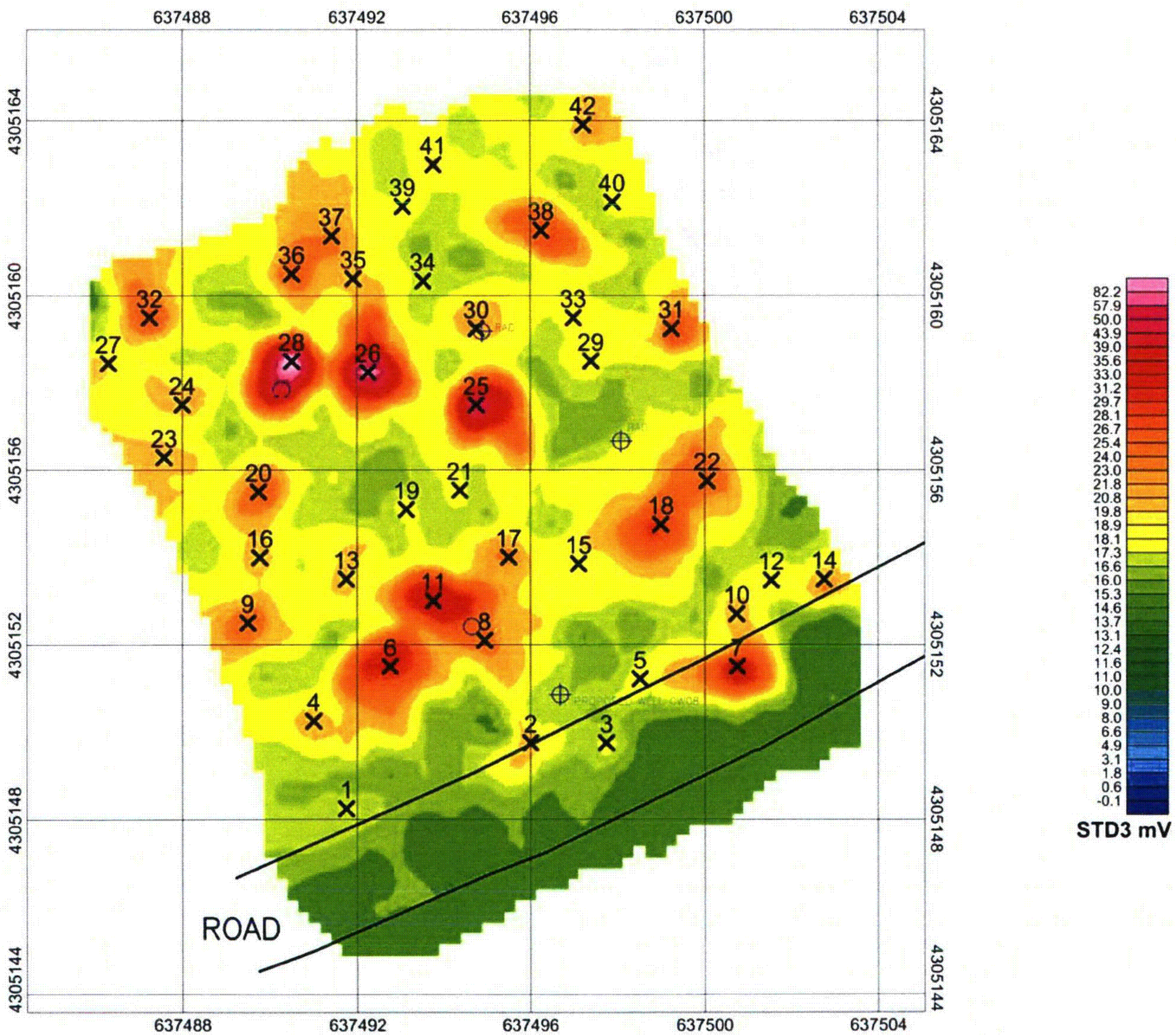
CW-07

Survey Grid ID CW08

Project Name: Jefferson Proving Ground - Anomaly Avoidance Surveys
Project Location: Madison, Indiana
Date: 9-May-07
Coordinate System: Universal Transverse Mercator
Zone 16 North, NAD 83, meters

Geophysical Contractor: SAIC
Project Geophysicist: Jeffrey J. Warrren P.G.
EOD Support: Seth Stephenson
Radiological Support Clark Evers
Project Manager Joe Skibinski

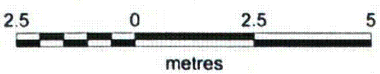
Target_ID	X	Y	STD2Grid_value	STD3Grid_value	Description	Depth	Orientation	Comment
1	637491.8	4305148.3	31.1	15.8				
2	637496.0	4305149.8	69.8	35.8				
3	637497.8	4305149.8	35.9	16.4				
4	637491.0	4305150.3	75.5	34.9				
5	637498.5	4305151.2	43.1	21.7				
6	637492.8	4305151.5	169.5	97.4				
7	637500.8	4305151.5	203.9	117.0				
8	637494.9	4305152.1	95.0	49.7				
9	637489.5	4305152.5	101.0	53.0				
10	637500.7	4305152.7	69.3	35.2				
11	637493.8	4305153.0	226.0	137.8				
12	637501.5	4305153.5	56.4	29.6				
13	637491.8	4305153.5	59.8	30.6				
14	637502.8	4305153.5	73.9	38.5				
15	637497.1	4305153.8	52.6	25.2				
16	637489.8	4305154.0	69.0	33.7				
17	637495.5	4305154.0	89.0	51.3				
18	637499.0	4305154.8	137.4	74.0				
19	637493.1	4305155.1	35.2	16.2				
20	637489.8	4305155.5	98.3	50.2				
21	637494.4	4305155.5	34.1	16.0				
22	637500.1	4305155.8	94.5	49.8				
23	637487.6	4305156.3	64.9	33.6				
24	637488.0	4305157.5	66.7	34.7				
25	637494.8	4305157.5	303.8	169.7				
26	637492.3	4305158.3	345.6	190.9				
27	637486.3	4305158.4	58.9	29.9				
28	637490.5	4305158.5	423.0	244.6				
29	637497.4	4305158.5	44.0	19.6				
30	637494.8	4305159.3	79.5	46.2				
31	637499.3	4305159.3	123.1	56.3				
32	637487.3	4305159.5	113.3	67.0				
33	637497.0	4305159.5	47.1	23.4				
34	637493.5	4305160.3	29.4	14.5				
35	637491.9	4305160.4	64.5	32.3				
36	637490.5	4305160.5	102.6	60.8				
37	637491.4	4305161.4	81.2	42.7				
38	637496.3	4305161.5	112.9	66.5				
39	637493.0	4305162.0	49.7	24.2				
40	637497.9	4305162.1	35.9	17.2				
41	637493.8	4305163.0	61.1	35.6				
42	637497.2	4305163.9	70.7	36.7				



LEGEND

× (2) Target Location and Identifier

○ Surface Sweep Anomaly



JPG ANOMALY AVOIDANCE

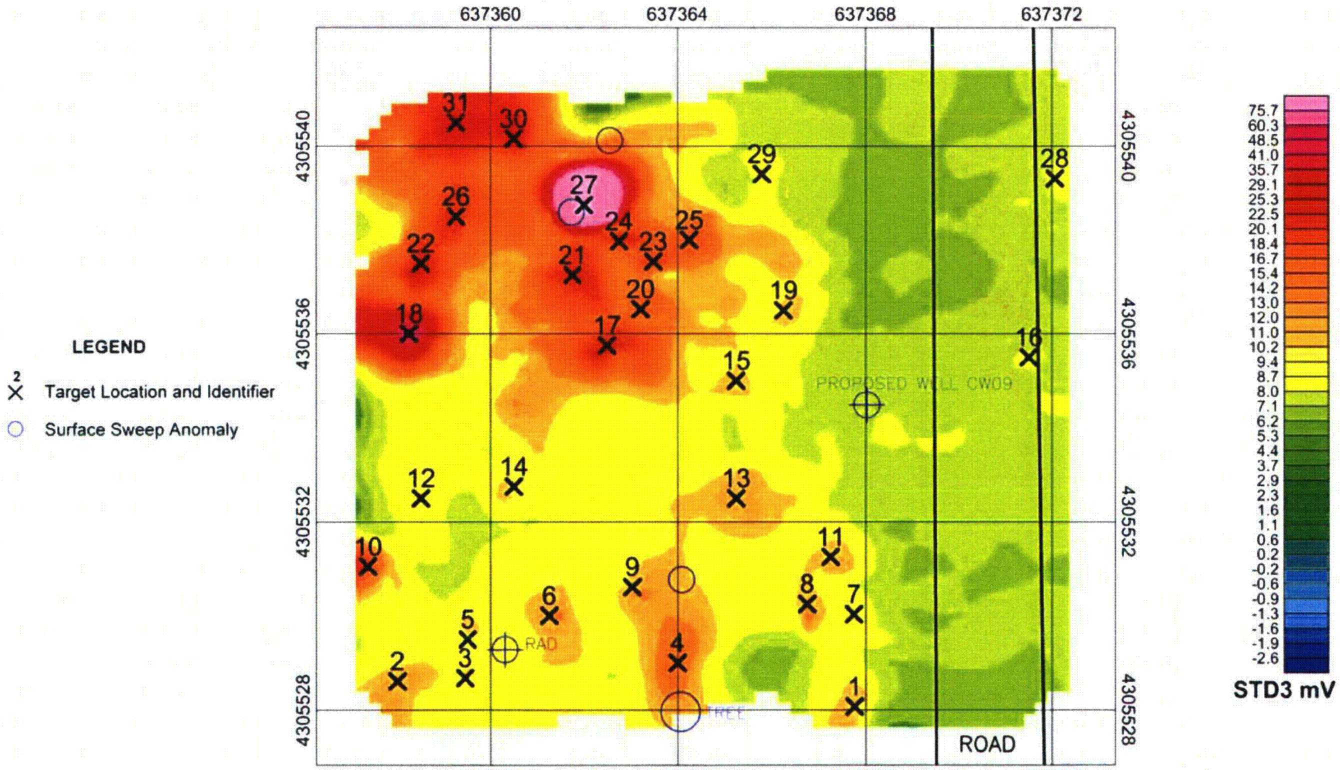
CW-08

Survey Grid ID CW09

Project Name: Jefferson Proving Ground - Anomaly Avoidance Surveys
Project Location: Madison, Indiana
Date: 9-May-07
Coordinate System: Universal Transverse Mercator
Zone 16 North, NAD 83, meters

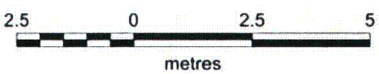
Geophysical Contractor: SAIC
Project Geophysicist: Jeffrey J. Warrren P.G.
EOD Support: Seth Stephenson
Radiological Support Clark Evers
Project Manager Joe Skibinski

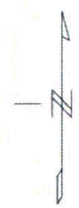
Target_ID	X	Y	STD2Grid_value	STD3Grid_value	Description	Depth	Orientation	Comment
1	637367.8	4305528.1	42.7	21.8				
2	637358.0	4305528.6	48.8	27.2				
3	637359.4	4305528.7	32.7	14.4				
4	637364.0	4305529.0	73.1	35.2				
5	637359.5	4305529.5	30.1	14.7				
6	637361.3	4305530.0	57.5	33.1				
7	637367.7	4305530.0	32.5	14.8				
8	637366.8	4305530.3	51.7	21.9				
9	637363.0	4305530.6	48.5	23.1				
10	637357.4	4305531.0	118.8	51.1				
11	637367.3	4305531.3	44.4	19.7				
12	637358.5	4305532.5	30.2	19.1				
13	637365.3	4305532.5	47.2	28.7				
14	637360.5	4305532.8	33.0	18.4				
15	637365.3	4305535.0	38.5	22.6				
16	637371.5	4305535.5	12.5	8.2				
17	637362.5	4305535.8	141.6	70.3				
18	637358.3	4305536.0	259.8	141.2				
19	637366.3	4305536.5	39.4	19.6				
20	637363.2	4305536.5	93.0	46.2				
21	637361.8	4305537.3	146.7	75.7				
22	637358.5	4305537.5	154.9	83.6				
23	637363.5	4305537.5	115.7	52.2				
24	637362.8	4305538.0	145.7	80.5				
25	637364.3	4305538.0	103.6	54.2				
26	637359.3	4305538.5	137.4	65.9				
27	637362.0	4305538.8	1425.4	798.1				
28	637372.1	4305539.3	12.3	8.2				
29	637365.8	4305539.4	12.4	6.6				
30	637360.5	4305540.2	165.3	76.3				
31	637359.3	4305540.5	158.8	79.8				



JPG ANOMALY AVOIDANCE

CW-09



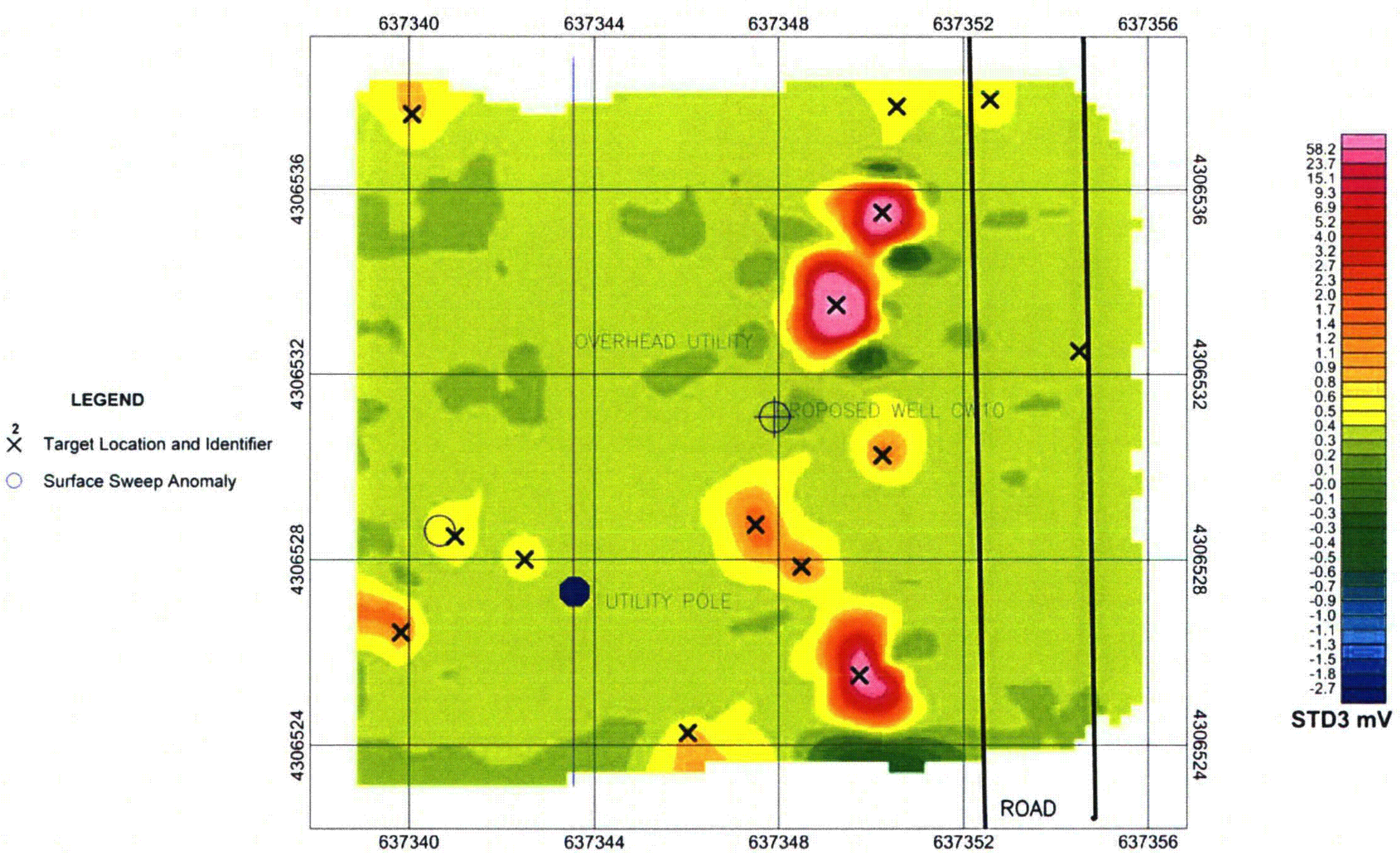


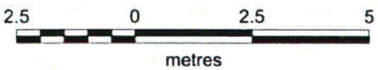
Survey Grid ID CW10

Project Name: Jefferson Proving Ground - Anomaly Avoidance Surveys
Project Location: Madison, Indiana
Date: 19-May-07
Coordinate System: Universal Transverse Mercator
Zone 16 North, NAD 83, meters

Geophysical Contractor: SAIC
Project Geophysicist: Jeffrey J. Warrren P.G.
EOD Support: Seth Stephenson
Radiological Support Clark Evers
Project Manager Joe Skibinski

JPG Dig Sheet - CW10								
Target_ID	X	Y	STD2Grid_value	STD3Grid_value	Description	Depth	Orientation	Comment
1	637346.0	4306524.3	41.2	27.4				
2	637349.8	4306525.5	394.9	213.4				
3	637339.8	4306526.4	59.6	23.2				
4	637348.5	4306527.8	61.8	32.6				
5	637342.5	4306528.0	15.6	8.9				
6	637341.0	4306528.5	17.9	10.0				
7	637347.5	4306528.8	66.0	36.6				
8	637350.3	4306530.3	63.9	40.4				
9	637354.5	4306532.5	11.3	8.5				
10	637349.3	4306533.5	1125.8	610.0				
11	637350.3	4306535.5	607.5	377.6				
12	637340.1	4306537.6	36.2	23.1				
13	637350.6	4306537.8	16.6	9.2				
14	637352.6	4306537.9	18.0	10.3				





JPG ANOMALY AVOIDANCE

CW-10

APPENDIX C

WELL INSTALLATION LOG FORMS AND INDIANA DEPARTMENT OF NATURAL RESOURCES (IDNR) RECORD OF WATER WELL FORMS

(Provided on CD only)

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APPENDIX D
ROCK CORING PHOTOGRAPHS
(Provided on CD only)

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APPENDIX E
SURVEYING RESULTS

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Location_ID	Surveyors_Point Number	Y_m	X_m	Elev_m	Surveyor_PT_loc
JPG-DU-01I (top of lid)	164	4306706.55900	636540.15900	256.584	LID
JPG-DU-01I (PVC)	165	4306706.55600	636540.15400	256.408	RIM
JPG-DU-01I (concrete pad)	163	4306706.48500	636540.09700	255.608	CONC
JPG-DU-01I (Ground Surface)	162	4306706.15800	636540.18700	255.44	GND
JPG-DU-01D (top of lid)	167	4306708.64900	636539.98800	256.609	LID
JPG-DU-01D (PVC)	166	4306708.64200	636539.99500	256.382	RIM
JPG-DU-01D (concrete pad)	168	4306708.63500	636539.92700	255.668	CONC
JPG-DU-01D (Ground Surface)	169	4306708.30100	636539.91800	255.502	GND
JPG-DU-02I (top of lid)	106	4305281.20700	636567.18200	245.213	LID
JPG-DU-02I (PVC)	105	4305281.13700	636567.21400	245.04	RIM
JPG-DU-02I (concrete pad)	107	4305281.12100	636567.23000	244.352	CONC
JPG-DU-02I (Ground Surface)	108	4305280.80700	636567.14500	244.124	GRD
JPG-DU-02D (top of lid)	103	4305279.34200	636565.75200	245.202	LID
JPG-DU-02D (PVC)	104	4305279.35000	636565.69700	245.007	RIM
JPG-DU-02D (concrete pad)	102	4305279.35400	636565.68300	244.33	CONC
JPG-DU-02D (Ground Surface)	101	4305279.46700	636565.40500	244.12	GROUND
JPG-DU-03O (top of lid)	95	4303960.47400	636593.84000	264	LID
JPG-DU-03O (PVC)	94	4303960.47000	636593.85600	263.818	RIM
JPG-DU-03O (concrete pad)	96	4303960.49200	636593.83500	262.935	CONC
JPG-DU-03O (Ground Surface)	97	4303960.98800	636593.91800	262.769	GND
JPG-DU-03I (top of lid)	92	4303958.99800	636593.66200	264.008	LID
JPG-DU-03I (PVC)	93	4303959.04700	636593.68100	263.836	RIM
JPG-DU-03I (concrete pad)	91	4303959.06000	636593.65700	262.953	CONC
JPG-DU-03I (Ground Surface)	90	4303958.73500	636593.70100	262.781	GROUND
JPG-DU-04O (top of lid)	56	4303444.40800	636931.04200	264.483	LID
JPG-DU-04O (PVC)	57	4303444.44200	636931.02800	264.347	RIM
JPG-DU-04O (Concrete pad)	55	4303444.56100	636931.00000	263.524	CONC
JPG-DU-04O (Ground Surface)	54	4303444.86500	636931.00100	263.382	GROUND
JPG-DU-04I (top of lid)	52	4303444.57200	636933.40100	264.537	LID
JPG-DU-04I (PVC)	53	4303444.57000	636933.37600	264.377	RIM
JPG-DU-04I (concrete pad)	51	4303444.69300	636933.40500	263.571	CONC
JPG-DU-04I (Ground Surface)	50	4303445.03800	636933.45000	263.445	GROUND
JPG-DU-04D (top of lid)	46	4303444.38200	636935.65200	264.478	LID
JPG-DU-04D (PVC)	47	4303444.37100	636935.68600	264.302	RIM

JPG-DU-04D (concrete pad)	48	4303444.51000	636935.64800	263.575	CONC
JPG-DU-04D (Ground Surface)	49	4303444.82900	636935.75900	263.403	GROUND
JPG-DU-05I (top of lid)	7	4303679.62900	638216.17000	258.387	LID
JPG-DU-05I (PVC)	6	4303679.60400	638216.17500	258.23	RIM
JPG-DU-05I (concrete pad)	9	4303679.52000	638216.27000	257.334	CONCRETE
JPG-DU-05I (Ground Surface)	8	4303679.58200	638216.54000	257.162	GROUND
JPG-DU-05D (top of lid)	12	4303681.56300	638216.29100	258.396	LID
JPG-DU-05D (PVC)	13	4303681.56700	638216.27800	258.245	RIM
JPG-DU-05D (concrete pad)	10	4303681.43500	638216.37600	257.316	CONCRETE
JPG-DU-05D (Ground Surface)	11	4303681.45700	638216.69100	257.151	GROUND
JPG-DU-06O (top of lid)	17	4304617.48000	638198.13800	267.158	LID
JPG-DU-06O (PVC)	18	4304617.51100	638198.18000	267.011	RIM
JPG-DU-06O (concrete pad)	16	4304617.38800	638198.29900	266.145	CONC
JPG-DU-06O (Ground Surface)	15	4304617.39500	638198.60600	265.957	GROUND
JPG-DU-06I (top of lid)	25	4304612.43900	638198.95800	267.051	LID
JPG-DU-06I (PVC)	26	4304612.40300	638198.97200	266.897	RIM
JPG-DU-06I (concrete pad)	24	4304612.49200	638199.07900	266.175	CONC
JPG-DU-06I (Ground Surface)	23	4304612.47300	638199.45000	266.062	GROUND
JPG-DU-06D (top of lid)	20	4304614.18000	638199.11300	267.112	LID
JPG-DU-06D (PVC)	19	4304614.17600	638199.10300	266.933	RIM
JPG-DU-06D (concrete pad)	21	4304614.27800	638199.20400	266.235	CONC
JPG-DU-06D (Ground Surface)	22	4304614.29200	638199.47300	266.025	GROUND
JPG-DU-07I (top of lid)	30	4305382.77600	638369.57500	258.107	LID
JPG-DU-07I (PVC)	29	4305382.77100	638369.49700	257.962	RIM
JPG-DU-07I (concrete pad)	31	4305382.77300	638369.53000	257.012	CONC
JPG-DU-07I (Ground Surface)	32	4305382.60000	638369.26600	256.76	GRD
JPG-DU-07D (top of lid)	36	4305382.83200	638367.15300	258.091	LID
JPG-DU-07D (PVC)	35	4305382.74100	638367.16200	258.022	RIM
JPG-DU-07D (concrete pad)	34	4305382.79600	638367.11000	256.976	CONC
JPG-DU-07D (Ground Surface)	33	4305382.85400	638366.79900	256.817	GRD
JPG-DU-08I (top of lid)	152	4305149.76000	637494.99300	249.65	LID
JPG-DU-08I (PVC)	153	4305149.73300	637495.00600	249.506	RIM
JPG-DU-08I (concrete)	151	4305149.79800	637494.94400	248.763	CONC
JPG-DU-08I (Ground Surface)	150	4305149.66900	637494.64700	248.545	GND
JPG-DU-08D (top of lid)	155	4305150.99000	637497.06200	249.653	LID
JPG-DU-08D (PVC)	154	4305150.93700	637497.02100	249.504	RIM

E-2

JPG-DU-08D (concrete pad)	156	4305150.86400	637497.07600	248.785	CONC
JPG-DU-08D (Ground Surface)	157	4305150.68900	637496.82800	248.522	GND
JPG-DU-09O (top of lid)	133	4305538.83100	637368.00900	259.137	LID
JPG-DU-09O (PVC)	134	4305538.92100	637368.01600	258.966	RIM
JPG-DU-09O (concrete pad)	132	4305538.81800	637368.08100	258.244	CONC
JPG-DU-09O (Ground Surface)	131	4305538.79400	637368.41100	258.053	GROUND
JPG-DU-09I (top of lid)	128	4305537.30600	637368.20700	259.054	LID
JPG-DU-09I (PVC)	127	4305537.28600	637368.23000	258.891	RIM
JPG-DU-09I (concrete pad)	129	4305537.31700	637368.27800	258.191	CONC
JPG-DU-09I (Ground Surface)	130	4305537.21700	637368.60000	257.999	GROUND
JPG-DU-09D (top of lid)	125	4305534.93300	637368.36100	258.946	LID
JPG-DU-09D (PVC)	126	4305534.94500	637368.41400	258.797	RIM
JPG-DU-09D (concrete)	124	4305535.02400	637368.49700	258.068	CONC
JPG-DU-09D (Ground Surface)	123	4305534.97600	637368.82900	257.892	GROUNDS
JPG-DU-10O (top of lid)	143	4306533.54900	637349.27100	266.415	LID
JPG-DU-10O (PVC)	142	4306533.64200	637349.29700	266.246	RIM
JPG-DU-10O (concrete pad)	144	4306533.42400	637349.37200	265.488	CONC
JPG-DU-10O (Ground Surface)	145	4306533.53000	637349.67900	265.294	GND
JPG-DU-10D (top of lid)	140	4306531.06100	637349.41300	266.46	LID
JPG-DU-10D (PVC)	141	4306531.09400	637349.41500	266.285	RIM
JPG-DU-10D (concrete pad)	139	4306531.08000	637349.45000	265.58	CONC
JPG-DU-10D (Ground Surface)	138	4306531.16800	637349.75400	265.393	GROUND
MW-1 (top of lid)	28	4305386.16900	638198.13900	260.23	LID
MW-1 (PVC)	69	4305386.22500	638198.15000	260.172	RIM
MW-1 (Ground Surface)	27	4305386.13100	638198.05000	259.612	GROUND
MW-2 (top of lid)	5	4302916.28100	638231.49500	259.244	LID
MW-2 (PVC)	4	4302916.31200	638231.46500	259.228	RIM
MW-2 (Ground Surface)	3	4302916.37700	638231.52400	258.548	GRD
MW-3 (top of lid)	63	4300464.46800	638288.12800	266.316	LID
MW-3 (PVC)	64	4300464.40600	638288.10700	266.285	RIM
MW-3 (Ground Surface)	62	4300464.51500	638288.02800	265.47	GRD
MW-4 (top of lid)	183	4297149.77100	640045.90628	274.996	LID
MW-4 (PVC)	184	4297149.83078	640045.94102	274.987	RIM
MW-4 (Concrete pad)	181	4297149.74149	640045.96780	274.119	CONC
MW-4 (Ground Surface)	182	4297148.89182	640045.82256	273.992	GRD

MW-5 (top of lid)	111	4305179.45300	636570.15200	245.194	LID
MW-5 (PVC)	113	4305179.45500	636570.12600	245.169	RIM
MW-5 (Ground Surface)	112	4305179.38600	636570.16100	244.423	GND
MW-6 (top of lid)	74	4302811.46200	636602.83500	262.525	LID
MW-6 (PVC)	76	4302811.51700	636602.83100	262.5	RIM
MW-6 (Ground Surface)	75	4302811.42500	636602.85200	261.652	GND
MW-7 (top of lid)	67	4300202.82700	636647.84100	260.23	LID
MW-7 (PVC)	66	4300202.77200	636647.81600	260.209	RIM
MW-7 (Ground Surface)	65	4300202.77300	636647.71000	259.382	GROUND
MW-8 (top of lid)	177	4296992.56842	635506.66920	256.45	LID
MW-8 (PVC)	178	4296992.61577	635506.63789	256.421	RIM
MW-8 (concrete pad)	176	4296992.70484	635506.65473	255.719	CONC
MW-8 (Ground Surface)	175	4296991.73152	635506.27056	255.625	GRD
MW-9 (PVC)	158	4305296.98200	637595.42900	249.923	RIM
MW-9 (concrete pad)	159	4305297.02900	637595.49000	249.927	CONC
MW-9 (Ground Surface)	160	4305297.23000	637595.57200	249.891	GND
MW-10 (PVC)	135	4305925.57600	637356.79800	263.999	RIM
MW-10 (concrete pad)	136	4305925.55500	637356.83000	263.973	CONC
MW-10 (Ground Surface)	137	4305925.53200	637357.03500	263.93	GROUND
MW-11 (PVC)	119	4305080.87400	637027.07000	246.854	RIM
MW-11 (concrete pad)	120	4305080.79400	637027.07100	246.87	CONC
MW-11 (Ground Surface)	121	4305080.63600	637027.09500	246.733	GROUND
MW-RS1 (top of lid)	40	4304799.17900	639384.41700	264.555	LID
MW-RS1 (PVC)	41	4304799.15900	639384.39900	264.499	RIM
MW-RS1 (Ground Surface)	39	4304799.29900	639384.32800	263.77	GRD
MW-RS2 (top of lid)	38	4305051.92600	639103.79900	267.026	LID
MW-RS2 (PVC)	42	4305051.93700	639103.82900	266.952	RIM
MW-RS2 (Ground Surface)	37	4305051.77700	639103.66900	266.176	GRD
MW-RS3 (top of lid)	45	4305524.42300	639468.39100	268.735	LID
MW-RS3 (PVC)	44	4305524.41100	639468.42700	268.704	RIM
MW-RS3 (Ground Surface)	43	4305524.42000	639468.30400	267.977	GRD
MW-RS4 (top of lid)	78	4302751.58400	636370.95600	262.427	LID
MW-RS4 (PVC)	77	4302751.58800	636370.99300	262.386	RIM
MW-RS4 (Ground Surface)	79	4302751.68400	636371.00100	261.581	GROUND
MW-RS5 (top of lid)	87	4303028.50500	635753.39900	260.32	LID

MW-RS5 (PVC)	88	4303028.48800	635753.35800	260.293	RIM
MW-RS5 (Ground Surface)	86	4303028.48900	635753.29700	259.514	GRD
MW-RS6 (top of lid)	84	4303381.94700	636185.90900	262.364	LID
MW-RS6 (PVC)	83	4303381.97800	636185.88500	262.334	RIM
MW-RS6 (Ground Surface)	85	4303382.05200	636185.92900	261.592	GRD
MW-RS7 (top of lid)	81	4303002.93400	636326.13100	262.772	LID
MW-RS7 (PVC)	82	4303002.89900	636326.10600	262.744	RIM
MW-RS7 (Ground Surface)	80	4303003.06000	636326.23500	261.95	GROUND
MW-RS8 (top of lid)	99	4304237.81000	636708.14000	264.36	LID
MW-RS8 (PVC)	100	4304237.80500	636708.18600	264.305	RIM
MW-RS8 (Ground Surface)	98	4304237.91700	636708.15800	263.661	GND
CGS-BC-11(top of lid)	147	4305099.36687	637364.43060	243.436	LID
CGS-BC-11(bottom of weir notch)	148	4305096.95904	637368.95504	240.494	NOTCH
CGS-BC-11(base of cave where spring exits)	149	4305101.12402	637368.96596	240.963	FLOWLINE
CGS-BC-12 (top of lid)	116	4305058.42189	636847.08947	243.192	LID
CGS-BC-12 (bottom of weir notch)	117	4305057.37139	636845.93009	241.392	NOTCH
CGS-BC-12 (base of cave where spring exits)	118	4305059.95126	636846.07890	241.292	FLOWLINE
SGS-BC-01 (top of lid)	110	4305244.03700	636557.22800	244.001	LID
SGS-BC-02 (top of lid)	161	4305304.52900	637627.10600	244.477	LID
SGS-BC-03 (top of lid)	73	4305487.16617	638168.74732	244.024	LID
SGS-BC-04 (Top of Steel post)	170	4306681.68600	636495.18100	255.385	GAUGE POST
SGS-BC-04 (Top of Staff Gauge @ 3.32 Feet on gauge)	171	4306681.61700	636495.30800	255.145	GAUGE POST
SGS-MF-01 (top of lid)	72	4301916.06800	636628.43100	247.482	LID
SGS-MF-02 (top of lid)	61	4302177.44182	637519.80448	248.245	LID
SGS-MF-03 (top of lid)	58	4302952.03000	638232.97700	258.117	LID
SGS-MF-04 (top of lid)	14	4303695.69200	638217.45900	258.896	LID

BENCH MARK INFORMATION:
Marker: I = Metal Rod
Setting: 59 = Stainless Steel Rod in Sleeve (10 FT.+)
Stamping: JPG 1 1997
Projection: Flush
Magnetic: N = No Magnetic Material

UTM 16 – North (Y) = 4,298,943.882 meters
East (X) = 640,451.259 meters
Elevation (Z) = 273.2 meters

The Horizontal coordinates are referenced to the North Atlantic Datum of 1983 (NAD 83). The Elevations are referenced to the North American Vertical Datum of 1988 (NAVD 88). This bench mark information was found on the NGS website (www.ngs.noaa.gov) under data sheets and has a file number of AE8506.

SURVEYOR'S CERTIFICATE

I, Andrew P. Scholle, do hereby certify to Science Applications International Corporation (SAIC) that these coordinate values were prepared from a field survey in accordance with the rules of 865 IAC Rule 12 for Land Surveyors. Assumed bearings were used and measurements are shown in meters. I hereby certify that I am a Land Surveyor holding Indiana Registration 20400051 this 6 day of February, 2008.

Andrew P. Scholle

ANDREW P. SCHOLLE REGISTERED 20400051 STATE OF INDIANA LAND SURVEYOR

Andrew P. Scholle, L.S.
Scholle's Land Surveying
122 West Main Street, Suite B
Greensburg, Indiana 47240
Telephone: 812-663-6526

I affirm under penalties for perjury that I have taken reasonable care to redact each Social Security Number in this document unless required by law. Andrew P. Scholle

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APPENDIX F

WELL DEVELOPMENT FORMS

(Provided on CD only)

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APPENDIX G
MANUAL FLOW CALCULATION FORMS
(Provided on CD only)

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APPENDIX H
SURFACE WATER AND PRECIPITATION DATA

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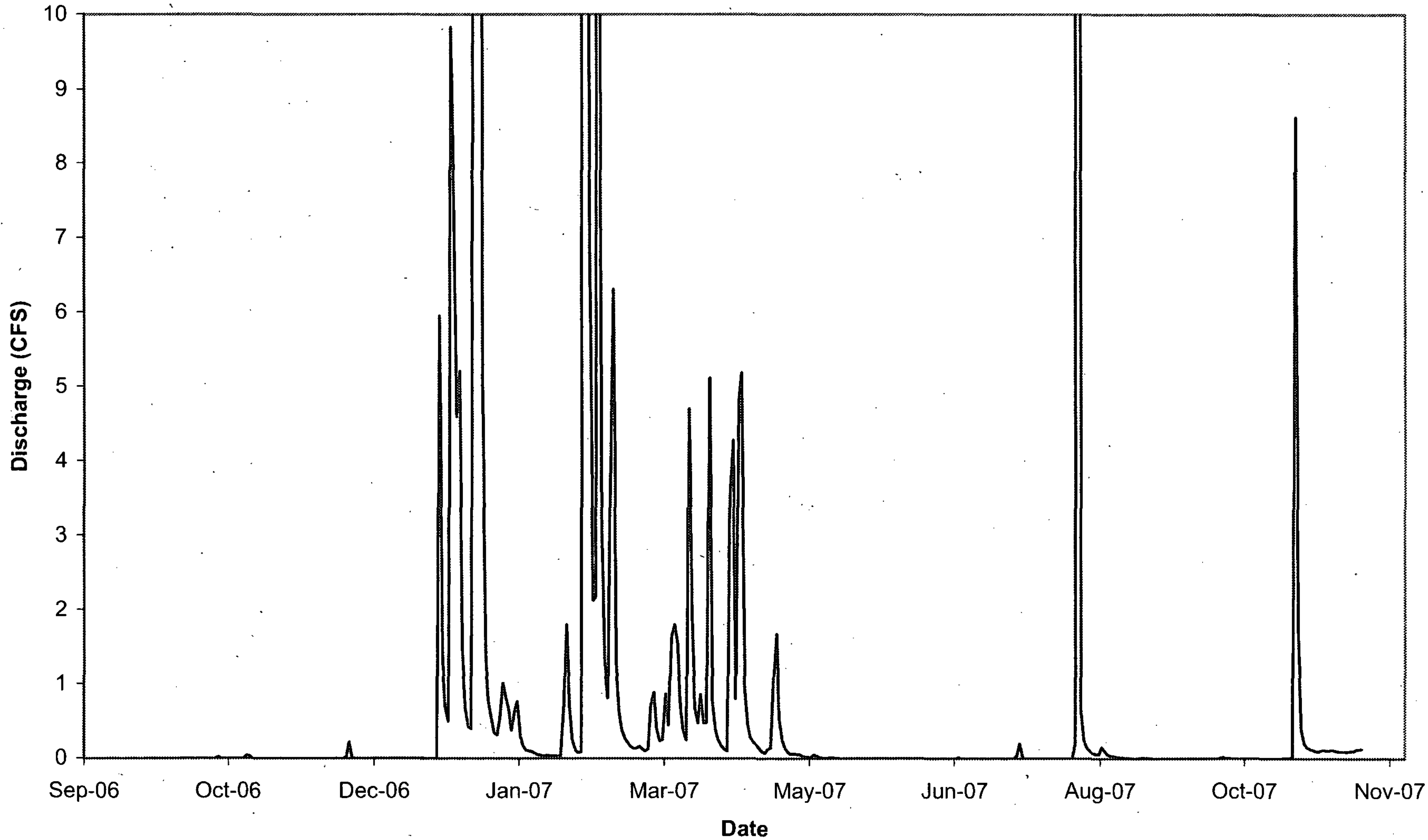
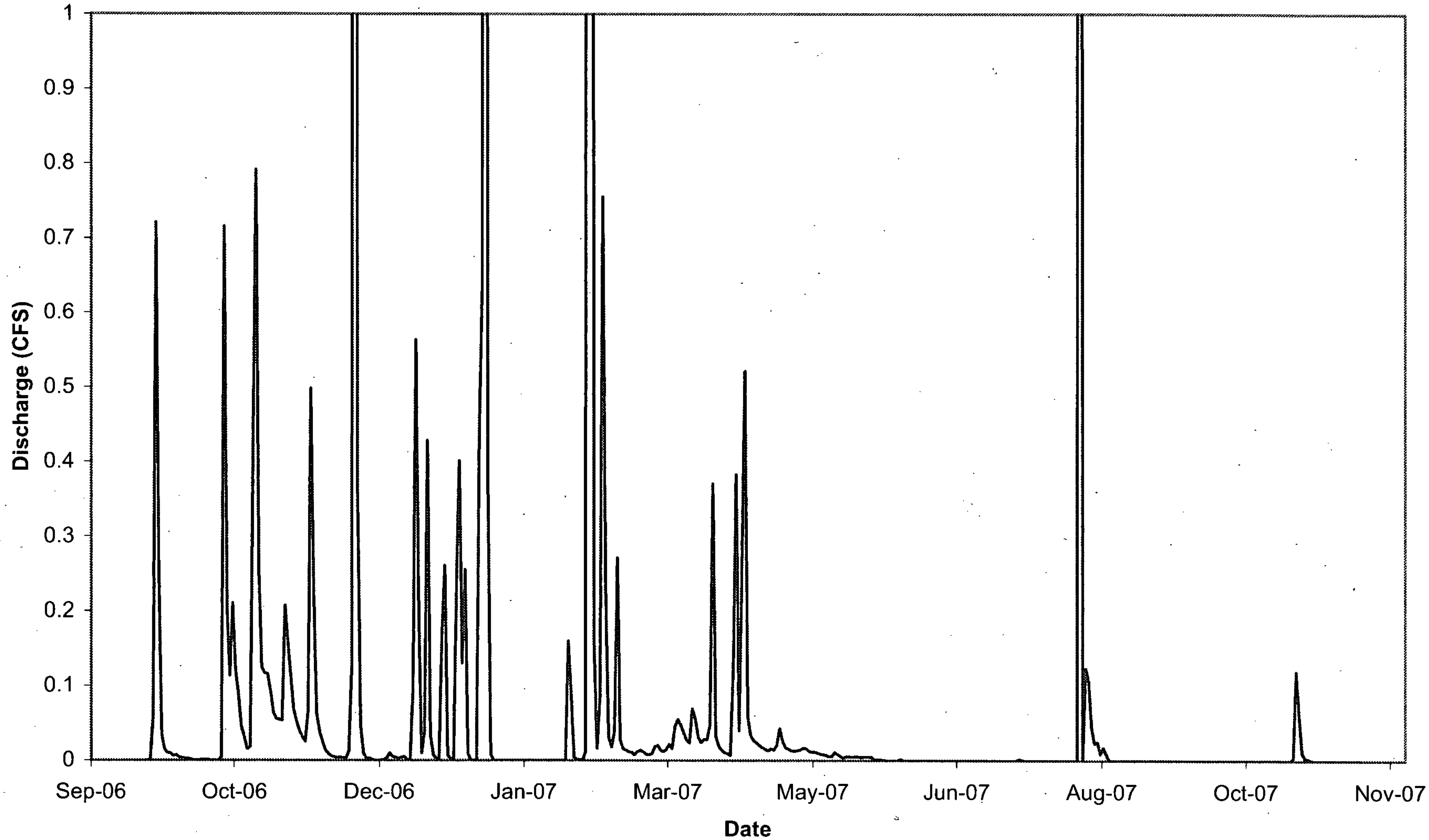
APPENDIX H-1
HYDROGRAPH FOR CGS-BC-11



APPENDIX H-2
HYDROGRAPH FOR CGS-BC-12



APPENDIX H-3
FLOW DATA FOR CAVE STREAMS CGS-BC-11 AND CGS-BC-12, MARCH 2006-NOVEMBER 2007

Date	CGS-BC-11		CGS-BC-12	
	Discharge (GPM)	Discharge (CFS)	Discharge (GPM)	Discharge (CFS)
9/19/2006			0.00	0.00
9/20/2006			0.00	0.00
9/21/2006			0.00	0.00
9/22/2006			25.49	0.06
9/23/2006			323.62	0.72
9/24/2006			110.43	0.25
9/25/2006			15.22	0.03
9/26/2006			6.43	0.01
9/27/2006			4.47	0.01
9/28/2006			4.23	0.01
9/29/2006			2.60	0.01
9/30/2006			3.22	0.01
10/1/2006			1.90	0.00
10/2/2006			1.50	0.00
10/3/2006			1.08	0.00
10/4/2006	0.00	0.00	0.98	0.00
10/5/2006	0.00	0.00	0.79	0.00
10/6/2006	0.00	0.00	0.13	0.00
10/7/2006	0.00	0.00	0.12	0.00
10/8/2006	0.00	0.00	0.17	0.00
10/9/2006	0.00	0.00	0.32	0.00
10/10/2006	0.00	0.00	0.32	0.00
10/11/2006	0.00	0.00	0.55	0.00
10/12/2006	0.00	0.00	0.00	0.00
10/13/2006	0.00	0.00	0.00	0.00
10/14/2006	0.00	0.00	0.00	0.00
10/15/2006	0.00	0.00	0.00	0.00
10/16/2006	0.00	0.00	2.05	0.00
10/17/2006	8.18	0.02	321.33	0.72
10/18/2006	0.00	0.00	91.52	0.20
10/19/2006	0.00	0.00	50.75	0.11
10/20/2006	0.00	0.00	94.43	0.21
10/21/2006	0.00	0.00	54.38	0.12
10/22/2006	0.00	0.00	40.29	0.09
10/23/2006	0.00	0.00	20.28	0.05
10/24/2006	0.00	0.00	14.08	0.03
10/25/2006	0.00	0.00	6.70	0.01
10/26/2006	0.00	0.00	8.21	0.02
10/27/2006	17.97	0.04	184.02	0.41
10/28/2006	12.77	0.03	355.31	0.79
10/29/2006	0.00	0.00	113.26	0.25
10/30/2006	0.00	0.00	55.72	0.12
10/31/2006	0.00	0.00	52.45	0.12
11/1/2006	0.00	0.00	51.96	0.12
11/2/2006	0.00	0.00	41.31	0.09
11/3/2006	0.00	0.00	28.44	0.06

APPENDIX H-3
FLOW DATA FOR CAVE STREAMS CGS-BC-11 AND CGS-BC-12, MARCH 2006-NOVEMBER 2007

	CGS-BC-11		CGS-BC-12	
Date	Discharge (GPM)	Discharge (CFS)	Discharge (GPM)	Discharge (CFS)
11/4/2006	0.00	0.00	24.84	0.06
11/5/2006	0.00	0.00	24.57	0.05
11/6/2006	0.00	0.00	23.90	0.05
11/7/2006	0.00	0.00	93.00	0.21
11/8/2006	0.00	0.00	70.33	0.16
11/9/2006	0.00	0.00	50.80	0.11
11/10/2006	0.00	0.00	30.53	0.07
11/11/2006	0.00	0.00	23.48	0.05
11/12/2006	0.00	0.00	17.81	0.04
11/13/2006	0.00	0.00	14.14	0.03
11/14/2006	0.00	0.00	11.20	0.02
11/15/2006	0.00	0.00	29.38	0.07
11/16/2006	1.47	0.00	223.50	0.50
11/17/2006	0.00	0.00	98.38	0.22
11/18/2006	0.00	0.00	27.77	0.06
11/19/2006	0.00	0.00	17.22	0.04
11/20/2006	0.00	0.00	11.34	0.03
11/21/2006	0.00	0.00	6.08	0.01
11/22/2006	0.00	0.00	4.04	0.01
11/23/2006	0.00	0.00	2.64	0.01
11/24/2006	0.00	0.00	1.95	0.00
11/25/2006	0.00	0.00	1.62	0.00
11/26/2006	0.00	0.00	1.71	0.00
11/27/2006	0.00	0.00	1.59	0.00
11/28/2006	0.00	0.00	1.21	0.00
11/29/2006	0.00	0.00	5.30	0.01
11/30/2006	10.49	0.02	55.93	0.12
12/1/2006	97.67	0.22	1838.55	4.10
12/2/2006	0.82	0.00	160.19	0.36
12/3/2006	0.00	0.00	21.06	0.05
12/4/2006	0.00	0.00	4.08	0.01
12/5/2006	0.00	0.00	1.06	0.00
12/6/2006	0.00	0.00	1.28	0.00
12/7/2006	0.00	0.00	0.34	0.00
12/8/2006	0.00	0.00	0.00	0.00
12/9/2006	0.00	0.00	0.02	0.00
12/10/2006	0.00	0.00	0.06	0.00
12/11/2006	0.00	0.00	0.24	0.00
12/12/2006	0.00	0.00	1.43	0.00
12/13/2006	0.00	0.00	4.35	0.01
12/14/2006	0.00	0.00	2.23	0.00
12/15/2006	0.00	0.00	1.81	0.00
12/16/2006	0.00	0.00	0.97	0.00
12/17/2006	0.00	0.00	1.80	0.00
12/18/2006	0.00	0.00	2.20	0.00
12/19/2006	0.00	0.00	0.58	0.00

APPENDIX H-3
FLOW DATA FOR CAVE STREAMS CGS-BC-11 AND CGS-BC-12, MARCH 2006-NOVEMBER 2007

	CGS-BC-11		CGS-BC-12	
Date	Discharge (GPM)	Discharge (CFS)	Discharge (GPM)	Discharge (CFS)
12/20/2006	0.00	0.00	0.26	0.00
12/21/2006	0.86	0.00	42.20	0.09
12/22/2006	0.87	0.00	252.38	0.56
12/23/2006	0.06	0.00	88.33	0.20
12/24/2006	0.00	0.00	4.28	0.01
12/25/2006	0.36	0.00	17.96	0.04
12/26/2006	1.74	0.00	192.34	0.43
12/27/2006	0.00	0.00	15.24	0.03
12/28/2006	0.00	0.00	3.02	0.01
12/29/2006	0.00	0.00	1.30	0.00
12/30/2006	0.00	0.00	0.77	0.00
12/31/2006	1.62	0.00	74.24	0.17
1/1/2007	2671.08	5.95	117.20	0.26
1/2/2007	588.68	1.31	2.90	0.01
1/3/2007	314.08	0.70	0.86	0.00
1/4/2007	224.23	0.50	0.72	0.00
1/5/2007	4410.90	9.83	105.41	0.23
1/6/2007	3306.35	7.37	179.99	0.40
1/7/2007	2058.13	4.59	58.31	0.13
1/8/2007	2337.36	5.21	114.53	0.26
1/9/2007	646.21	1.44	4.12	0.01
1/10/2007	302.62	0.67	0.11	0.00
1/11/2007	189.88	0.42	0.04	0.00
1/12/2007	179.24	0.40	0.32	0.00
1/13/2007	7294.93	16.25	195.97	0.44
1/14/2007	8751.06	19.50	286.16	0.64
1/15/2007	25203.24	56.15	4043.49	9.01
1/16/2007	2211.90	4.93	167.09	0.37
1/17/2007	600.20	1.34	3.46	0.01
1/18/2007	345.85	0.77	0.06	0.00
1/19/2007	242.39	0.54	0.03	0.00
1/20/2007	156.36	0.35	0.00	0.00
1/21/2007	140.35	0.31	0.00	0.00
1/22/2007	237.50	0.53	0.00	0.00
1/23/2007	453.14	1.01	0.00	0.00
1/24/2007	376.86	0.84	0.00	0.00
1/25/2007	293.88	0.65	0.00	0.00
1/26/2007	168.83	0.38	0.00	0.00
1/27/2007	279.60	0.62	0.00	0.00
1/28/2007	344.24	0.77	0.00	0.00
1/29/2007	137.81	0.31	0.00	0.00
1/30/2007	73.19	0.16	0.00	0.00
1/31/2007	47.21	0.11	0.00	0.00
2/1/2007	43.66	0.10	0.00	0.00
2/2/2007	41.50	0.09	0.00	0.00
2/3/2007	33.39	0.07	0.00	0.00

APPENDIX H-3
FLOW DATA FOR CAVE STREAMS CGS-BC-11 AND CGS-BC-12, MARCH 2006-NOVEMBER 2007

	CGS-BC-11		CGS-BC-12	
Date	Discharge (GPM)	Discharge (CFS)	Discharge (GPM)	Discharge (CFS)
2/4/2007	22.24	0.05	0.00	0.00
2/5/2007	18.85	0.04	0.00	0.00
2/6/2007	12.48	0.03	0.00	0.00
2/7/2007	18.00	0.04	0.00	0.00
2/8/2007	16.94	0.04	0.00	0.00
2/9/2007	15.85	0.04	0.00	0.00
2/10/2007	15.33	0.03	0.00	0.00
2/11/2007	14.14	0.03	0.00	0.00
2/12/2007	14.34	0.03	0.04	0.00
2/13/2007	311.24	0.69	71.83	0.16
2/14/2007	803.99	1.79	39.30	0.09
2/15/2007	304.93	0.68	1.69	0.00
2/16/2007	114.83	0.26	0.70	0.00
2/17/2007	50.84	0.11	0.48	0.00
2/18/2007	35.22	0.08	0.17	0.00
2/19/2007	38.72	0.09	5.07	0.01
2/20/2007	16459.27	36.67	6925.65	15.43
2/21/2007	10610.70	23.64	1936.96	4.32
2/22/2007	3238.21	7.21	69.30	0.15
2/23/2007	950.53	2.12	7.16	0.02
2/24/2007	975.10	2.17	37.07	0.08
2/25/2007	9770.84	21.77	338.97	0.76
2/26/2007	1605.32	3.58	99.79	0.22
2/27/2007	596.24	1.33	14.13	0.03
2/28/2007	364.20	0.81	7.96	0.02
3/1/2007	1723.47	3.84	17.18	0.04
3/2/2007	2832.34	6.31	121.69	0.27
3/3/2007	558.99	1.25	12.21	0.03
3/4/2007	272.97	0.61	7.06	0.02
3/5/2007	172.02	0.38	6.13	0.01
3/6/2007	119.70	0.27	5.16	0.01
3/7/2007	95.23	0.21	4.79	0.01
3/8/2007	73.50	0.16	3.20	0.01
3/9/2007	59.21	0.13	5.48	0.01
3/10/2007	59.20	0.13	6.07	0.01
3/11/2007	74.65	0.17	5.03	0.01
3/12/2007	55.75	0.12	3.61	0.01
3/13/2007	45.72	0.10	3.44	0.01
3/14/2007	56.79	0.13	4.10	0.01
3/15/2007	317.76	0.71	8.31	0.02
3/16/2007	398.72	0.89	9.08	0.02
3/17/2007	181.96	0.41	6.23	0.01
3/18/2007	104.77	0.23	5.20	0.01
3/19/2007	114.71	0.26	6.70	0.01
3/20/2007	388.38	0.87	9.59	0.02
3/21/2007	201.08	0.45	7.02	0.02

APPENDIX H-3
FLOW DATA FOR CAVE STREAMS CGS-BC-11 AND CGS-BC-12, MARCH 2006-NOVEMBER 2007

	CGS-BC-11		CGS-BC-12	
Date	Discharge (GPM)	Discharge (CFS)	Discharge (GPM)	Discharge (CFS)
3/22/2007	733.03	1.63	20.31	0.05
3/23/2007	804.28	1.79	24.53	0.05
3/24/2007	693.01	1.54	21.36	0.05
3/25/2007	304.76	0.68	16.60	0.04
3/26/2007	170.98	0.38	12.25	0.03
3/27/2007	110.07	0.25	10.41	0.02
3/28/2007	2108.49	4.70	30.85	0.07
3/29/2007	821.45	1.83	25.06	0.06
3/30/2007	304.72	0.68	13.94	0.03
3/31/2007	213.89	0.48	10.69	0.02
4/1/2007	386.21	0.86	12.81	0.03
4/2/2007	212.74	0.47	12.63	0.03
4/3/2007	213.55	0.48	21.42	0.05
4/4/2007	2294.04	5.11	166.26	0.37
4/5/2007	351.09	0.78	14.44	0.03
4/6/2007	175.66	0.39	8.58	0.02
4/7/2007	113.23	0.25	6.13	0.01
4/8/2007	77.41	0.17	4.65	0.01
4/9/2007	57.90	0.13	4.02	0.01
4/10/2007	44.97	0.10	3.05	0.01
4/11/2007	1599.16	3.56	56.10	0.12
4/12/2007	1918.40	4.27	171.91	0.38
4/13/2007	360.58	0.80	17.83	0.04
4/14/2007	2161.57	4.82	122.09	0.27
4/15/2007	2328.20	5.19	233.84	0.52
4/16/2007	428.98	0.96	26.02	0.06
4/17/2007	199.27	0.44	14.98	0.03
4/18/2007	125.90	0.28	11.99	0.03
4/19/2007	96.04	0.21	10.58	0.02
4/20/2007	82.89	0.18	8.92	0.02
4/21/2007	59.00	0.13	7.72	0.02
4/22/2007	42.81	0.10	6.75	0.02
4/23/2007	33.03	0.07	5.84	0.01
4/24/2007	55.07	0.12	7.11	0.02
4/25/2007	63.31	0.14	6.23	0.01
4/26/2007	461.65	1.03	9.15	0.02
4/27/2007	749.33	1.67	19.17	0.04
4/28/2007	238.28	0.53	11.44	0.03
4/29/2007	111.22	0.25	7.63	0.02
4/30/2007	63.60	0.14	6.89	0.02
5/1/2007	38.48	0.09	5.85	0.01
5/2/2007	26.52	0.06	5.68	0.01
5/3/2007	27.22	0.06	5.89	0.01
5/4/2007	24.70	0.06	6.36	0.01
5/5/2007	25.24	0.06	7.40	0.02
5/6/2007	17.34	0.04	7.16	0.02

APPENDIX H-3
FLOW DATA FOR CAVE STREAMS CGS-BC-11 AND CGS-BC-12, MARCH 2006-NOVEMBER 2007

Date	CGS-BC-11		CGS-BC-12	
	Discharge (GPM)	Discharge (CFS)	Discharge (GPM)	Discharge (CFS)
5/7/2007	10.31	0.02	5.64	0.01
5/8/2007	8.63	0.02	4.95	0.01
5/9/2007	7.51	0.02	4.97	0.01
5/10/2007	22.18	0.05	4.53	0.01
5/11/2007	14.41	0.03	3.88	0.01
5/12/2007	7.69	0.02	3.58	0.01
5/13/2007	3.71	0.01	3.22	0.01
5/14/2007	2.50	0.01	2.28	0.01
5/15/2007	1.84	0.00	2.50	0.01
5/16/2007	6.72	0.01	4.78	0.01
5/17/2007	4.48	0.01	3.77	0.01
5/18/2007	2.31	0.01	2.52	0.01
5/19/2007	0.97	0.00	1.57	0.00
5/20/2007	0.39	0.00	2.30	0.01
5/21/2007	0.15	0.00	2.44	0.01
5/22/2007	0.03	0.00	2.14	0.00
5/23/2007	0.00	0.00	2.28	0.01
5/24/2007	0.00	0.00	2.35	0.01
5/25/2007	0.00	0.00	1.89	0.00
5/26/2007	0.00	0.00	1.97	0.00
5/27/2007	0.00	0.00	2.30	0.01
5/28/2007	0.00	0.00	2.17	0.00
5/29/2007	0.00	0.00	1.96	0.00
5/30/2007	0.00	0.00	0.23	0.00
5/31/2007	0.00	0.00	0.71	0.00
6/1/2007	0.00	0.00	0.50	0.00
6/2/2007	0.00	0.00	0.24	0.00
6/3/2007	0.00	0.00	0.02	0.00
6/4/2007	0.00	0.00	0.10	0.00
6/5/2007	0.00	0.00	0.03	0.00
6/6/2007	0.00	0.00	0.06	0.00
6/7/2007	0.00	0.00	0.06	0.00
6/8/2007	0.00	0.00	0.78	0.00
6/9/2007	0.00	0.00	0.02	0.00
6/10/2007	0.00	0.00	0.00	0.00
6/11/2007	0.00	0.00	0.00	0.00
6/12/2007	0.00	0.00	0.00	0.00
6/13/2007	0.00	0.00	0.00	0.00
6/14/2007	0.00	0.00	0.00	0.00
6/15/2007	0.00	0.00	0.00	0.00
6/16/2007	0.00	0.00	0.00	0.00
6/17/2007	0.00	0.00	0.00	0.00
6/18/2007	0.00	0.00	0.00	0.00
6/19/2007	0.00	0.00	0.00	0.00
6/20/2007	0.00	0.00	0.00	0.00
6/21/2007	0.00	0.00	0.00	0.00

APPENDIX H-3
FLOW DATA FOR CAVE STREAMS CGS-BC-11 AND CGS-BC-12, MARCH 2006-NOVEMBER 2007

	CGS-BC-11		CGS-BC-12	
Date	Discharge (GPM)	Discharge (CFS)	Discharge (GPM)	Discharge (CFS)
6/22/2007	0.00	0.00	0.00	0.00
6/23/2007	0.00	0.00	0.00	0.00
6/24/2007	0.00	0.00	0.00	0.00
6/25/2007	0.00	0.00	0.00	0.00
6/26/2007	0.00	0.00	0.00	0.00
6/27/2007	0.00	0.00	0.00	0.00
6/28/2007	0.00	0.00	0.00	0.00
6/29/2007	5.78	0.01	0.00	0.00
6/30/2007	0.40	0.00	0.00	0.00
7/1/2007	0.00	0.00	0.00	0.00
7/2/2007	0.00	0.00	0.00	0.00
7/3/2007	0.00	0.00	0.00	0.00
7/4/2007	0.00	0.00	0.00	0.00
7/5/2007	0.00	0.00	0.00	0.00
7/6/2007	0.00	0.00	0.00	0.00
7/7/2007	0.00	0.00	0.00	0.00
7/8/2007	0.00	0.00	0.00	0.00
7/9/2007	0.00	0.00	0.00	0.00
7/10/2007	0.00	0.00	0.00	0.00
7/11/2007	0.00	0.00	0.00	0.00
7/12/2007	0.00	0.00	0.00	0.00
7/13/2007	0.00	0.00	0.00	0.00
7/14/2007	0.00	0.00	0.00	0.00
7/15/2007	0.00	0.00	0.00	0.00
7/16/2007	0.00	0.00	0.00	0.00
7/17/2007	0.00	0.00	0.00	0.00
7/18/2007	0.00	0.00	0.00	0.00
7/19/2007	20.02	0.04	0.87	0.00
7/20/2007	87.96	0.20	0.20	0.00
7/21/2007	1.28	0.00	0.00	0.00
7/22/2007	0.00	0.00	0.00	0.00
7/23/2007	0.00	0.00	0.00	0.00
7/24/2007	0.00	0.00	0.00	0.00
7/25/2007	0.00	0.00	0.00	0.00
7/26/2007	0.00	0.00	0.00	0.00
7/27/2007	0.00	0.00	0.00	0.00
7/28/2007	0.00	0.00	0.00	0.00
7/29/2007	0.35	0.00	0.00	0.00
7/30/2007	0.00	0.00	0.00	0.00
7/31/2007	0.00	0.00	0.00	0.00
8/1/2007	0.00	0.00	0.00	0.00
8/2/2007	0.00	0.00	0.00	0.00
8/3/2007	0.00	0.00	0.00	0.00
8/4/2007	0.00	0.00	0.00	0.00
8/5/2007	0.00	0.00	0.00	0.00
8/6/2007	0.00	0.00	0.00	0.00

APPENDIX H-3
FLOW DATA FOR CAVE STREAMS CGS-BC-11 AND CGS-BC-12, MARCH 2006-NOVEMBER 2007

	CGS-BC-11		CGS-BC-12	
Date	Discharge (GPM)	Discharge (CFS)	Discharge (GPM)	Discharge (CFS)
8/7/2007	0.00	0.00	0.00	0.00
8/8/2007	79.32	0.18	0.10	0.00
8/9/2007	44308.46	98.72	9991.50	22.26
8/10/2007	288.25	0.64	1.01	0.00
8/11/2007	109.68	0.24	55.40	0.12
8/12/2007	65.53	0.15	47.69	0.11
8/13/2007	45.08	0.10	20.13	0.04
8/14/2007	31.94	0.07	10.23	0.02
8/15/2007	25.01	0.06	11.14	0.02
8/16/2007	26.42	0.06	3.95	0.01
8/17/2007	68.17	0.15	7.71	0.02
8/18/2007	40.45	0.09	3.75	0.01
8/19/2007	22.15	0.05	0.00	0.00
8/20/2007	14.39	0.03	0.00	0.00
8/21/2007	11.33	0.03	0.09	0.00
8/22/2007	9.79	0.02	0.02	0.00
8/23/2007	7.74	0.02	0.00	0.00
8/24/2007	5.32	0.01	0.00	0.00
8/25/2007	3.75	0.01	0.00	0.00
8/26/2007	2.72	0.01	0.00	0.00
8/27/2007	1.91	0.00	0.00	0.00
8/28/2007	1.34	0.00	0.00	0.00
8/29/2007	0.76	0.00	0.00	0.00
8/30/2007	4.75	0.01	0.00	0.00
8/31/2007	4.45	0.01	0.00	0.00
9/1/2007	3.46	0.01	0.00	0.00
9/2/2007	2.61	0.01	0.00	0.00
9/3/2007	1.78	0.00	0.00	0.00
9/4/2007	1.17	0.00	0.00	0.00
9/5/2007	0.61	0.00	0.00	0.00
9/6/2007	0.19	0.00	0.00	0.00
9/7/2007	0.05	0.00	0.00	0.00
9/8/2007	0.29	0.00	0.00	0.00
9/9/2007	0.83	0.00	0.00	0.00
9/10/2007	0.55	0.00	0.00	0.00
9/11/2007	0.53	0.00	0.00	0.00
9/12/2007	0.24	0.00	0.00	0.00
9/13/2007	0.03	0.00	0.00	0.00
9/14/2007	0.00	0.00	0.00	0.00
9/15/2007	0.00	0.00	0.00	0.00
9/16/2007	0.00	0.00	0.00	0.00
9/17/2007	0.00	0.00	0.00	0.00
9/18/2007	0.00	0.00	0.00	0.00
9/19/2007	0.00	0.00	0.00	0.00
9/20/2007	0.00	0.00	0.00	0.00
9/21/2007	0.00	0.00	0.00	0.00

APPENDIX H-3
FLOW DATA FOR CAVE STREAMS CGS-BC-11 AND CGS-BC-12, MARCH 2006-NOVEMBER 2007

Date	CGS-BC-11 Discharge (GPM)	CGS-BC-11 Discharge (CFS)	CGS-BC-12 Discharge (GPM)	CGS-BC-12 Discharge (CFS)
9/22/2007	0.00	0.00	0.00	0.00
9/23/2007	0.00	0.00	0.00	0.00
9/24/2007	0.00	0.00	0.00	0.00
9/25/2007	0.00	0.00	0.00	0.00
9/26/2007	0.00	0.00	0.00	0.00
9/27/2007	3.71	0.01	0.00	0.00
9/28/2007	8.58	0.02	0.00	0.00
9/29/2007	3.77	0.01	0.00	0.00
9/30/2007	1.74	0.00	0.00	0.00
10/1/2007	0.88	0.00	0.00	0.00
10/2/2007	0.40	0.00	0.00	0.00
10/3/2007	0.12	0.00	0.00	0.00
10/4/2007	0.01	0.00	0.00	0.00
10/5/2007	0.00	0.00	0.00	0.00
10/6/2007	0.00	0.00	0.00	0.00
10/7/2007	0.00	0.00	0.00	0.00
10/8/2007	0.00	0.00	0.00	0.00
10/9/2007	0.00	0.00	0.00	0.00
10/10/2007	0.00	0.00	0.00	0.00
10/11/2007	0.00	0.00	0.00	0.00
10/12/2007	0.00	0.00	0.00	0.00
10/13/2007	0.00	0.00	0.00	0.00
10/14/2007	0.00	0.00	0.00	0.00
10/15/2007	0.00	0.00	0.00	0.00
10/16/2007	0.00	0.00	0.00	0.00
10/17/2007	0.00	0.00	0.00	0.00
10/18/2007	0.00	0.00	0.00	0.00
10/19/2007	2.97	0.01	0.00	0.00
10/20/2007	3.03	0.01	0.00	0.00
10/21/2007	1.70	0.00	0.00	0.00
10/22/2007	6.24	0.01	1.64	0.00
10/23/2007	3872.59	8.63	53.52	0.12
10/24/2007	760.29	1.69	27.99	0.06
10/25/2007	179.82	0.40	5.00	0.01
10/26/2007	90.05	0.20	1.32	0.00
10/27/2007	66.45	0.15	1.25	0.00
10/28/2007	58.68	0.13	0.27	0.00
10/29/2007	51.93	0.12	0.00	0.00
10/30/2007	43.19	0.10	0.00	0.00
10/31/2007	40.26	0.09	0.00	0.00
11/1/2007	51.66	0.12	0.00	0.00
11/2/2007	52.32	0.12	0.00	0.00
11/3/2007	49.15	0.11	0.00	0.00
11/4/2007	51.00	0.11	0.00	0.00
11/5/2007	49.57	0.11	0.00	0.00
11/6/2007	45.92	0.10	0.00	0.00

APPENDIX H-3
FLOW DATA FOR CAVE STREAMS CGS-BC-11 AND CGS-BC-12, MARCH 2006-NOVEMBER 2007

	CGS-BC-11		CGS-BC-12	
Date	Discharge (GPM)	Discharge (CFS)	Discharge (GPM)	Discharge (CFS)
11/7/2007	40.24	0.09	0.00	0.00
11/8/2007	41.74	0.09	0.00	0.00
11/9/2007	42.30	0.09	0.00	0.00
11/10/2007	42.52	0.09	0.00	0.00
11/11/2007	43.73	0.10	0.00	0.00
11/12/2007	44.27	0.10	0.00	0.00
11/13/2007	53.49	0.12	0.00	0.00
11/14/2007	55.34	0.12	0.00	0.00
11/15/2007	56.72	0.13		

APPENDIX I

USGS GAUGE STATIONS

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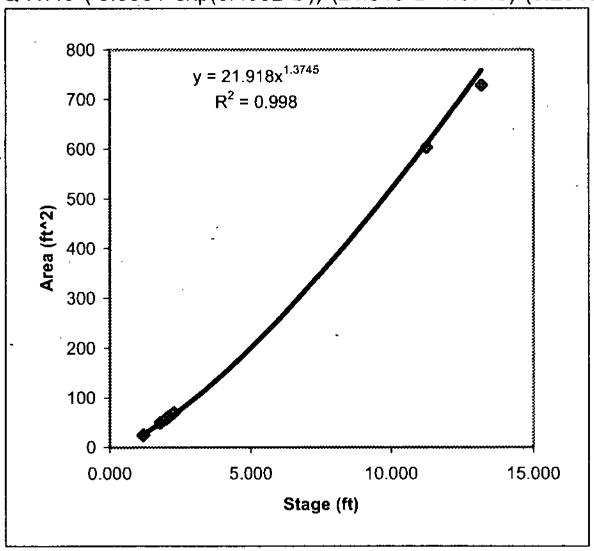
APPENDIX I-1
Stream Gauge Calibration for SGS-BC-01

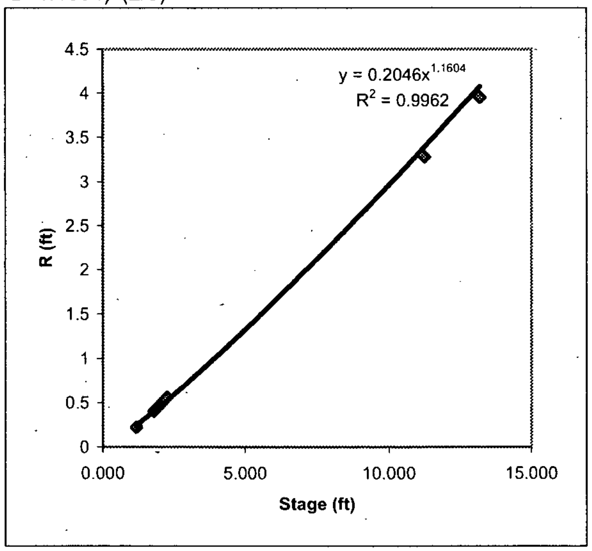
Date and Time	Stage	Discharge (CFS)	A	R	S:n ratio	Calculated A	% Error A	Calculated R	% Error R	Calculated S:n	% Error S:n	Calculated discharge	% Error Discharge
9/18/2006 12:16	1.965	2.218	57.253	0.462	0.044	55.466	3.120	0.448	3.002	0.089	105.391	4.325	94.980
10/4/2006 15:30	1.779	1.201	49.348	0.398	0.030	48.380	1.960	0.399	0.272	0.047	55.633	1.836	52.859
11/10/2006 13:40	2.095	19.539	62.778	0.506	0.329	60.572	3.514	0.483	4.712	0.140	57.385	7.780	60.184
12/12/2006 13:40	2.009	9.202	59.123	0.477	0.171	57.180	3.285	0.460	3.625	0.104	39.186	5.281	42.613
1/17/2007 13:45	2.252	37.281	69.450	0.560	0.530	66.897	3.676	0.525	6.333	0.241	54.513	15.638	58.055
3/8/2007 12:10	2.041	8.243	60.483	0.488	0.148	58.436	3.384	0.468	4.048	0.116	21.236	6.102	25.969
5/10/2007 11:25	2.026	4.679	59.845	0.483	0.085	57.846	3.340	0.464	3.853	0.110	29.437	5.703	21.880
6/4/2007 12:06	1.170	0.164	24.978	0.223	0.012	27.197	8.886	0.245	10.042	0.006	52.392	0.091	44.747
8/16/2007 10:05	1.162	0.383	24.660	0.220	0.029	26.942	9.255	0.244	10.577	0.006	80.542	0.087	77.268
	11.250		603.373	3.278									
	13.180		727.858	3.954									

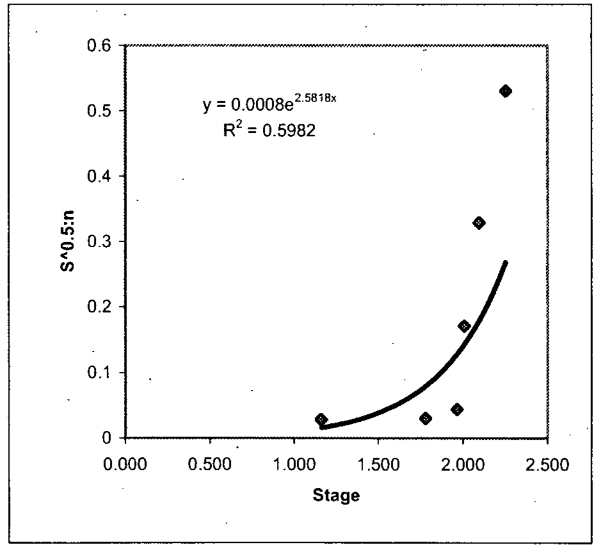
Manning's Eqn: Q=1.49/n x A x S^1/2 x R^2/3

Affected by log jam

Q=1.49*(0.0001*exp(3.4582*D))*(21.918*D^1.3745)*(0.2046*D^1.1604)^(2/3)







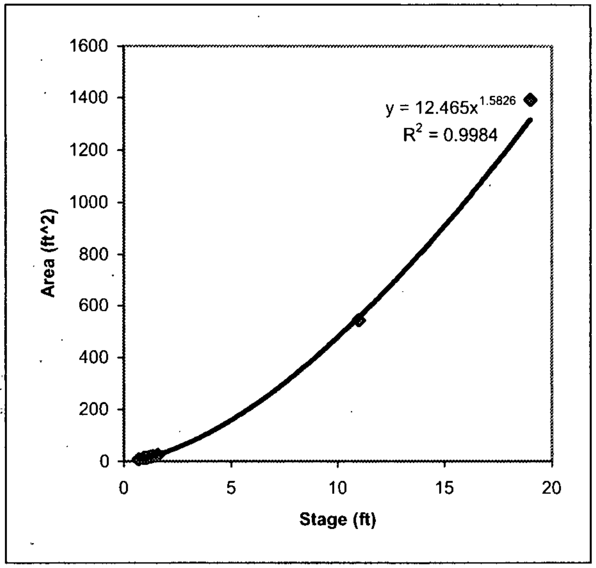
APPENDIX I-2
Stream Gauge Calibration for SGS-BC-02

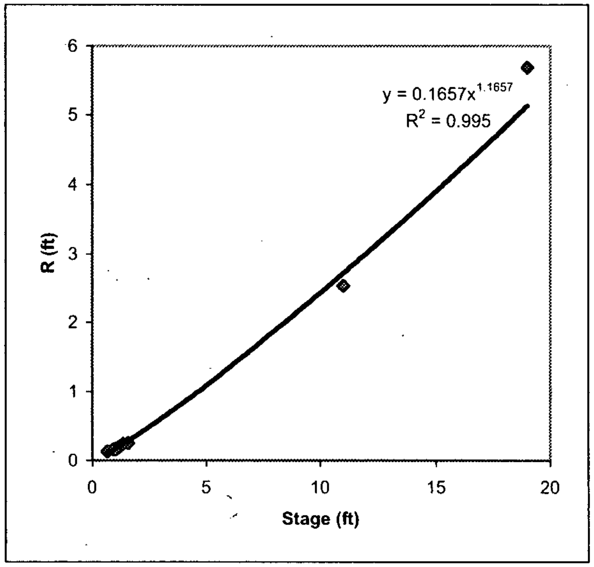
Date and time	Stage	Discharge (CFS)	A	R	S:n ratio	Calculated A	% Error A	Calculated R	% Error R	Calculated S:n	% Error S:n	Calculated discharge	% Error Discharge
9/19/2006 13:21	0.989	1.948	12.021	0.154	0.379	12.249	1.894	0.164	6.557	0.341	10.039	1.863	4.371
10/4/2006 12:30	0.914	0.364	12.360	0.158	0.068	10.811	12.528	0.149	5.468	0.238	250.975	1.076	195.707
11/10/2006 8:36	1.354	16.739	18.956	0.242	1.526	20.137	6.230	0.236	2.545	1.446	5.213	16.567	1.025
12/12/2006 9:25	1.131	5.710	14.719	0.188	0.793	15.146	2.902	0.191	1.757	0.632	20.295	4.738	17.024
1/18/2007 9:00	1.578	41.268	23.616	0.246	2.984	25.658	8.644	0.282	14.430	2.923	2.019	48.060	16.459
3/8/2007 8:25	1.215	9.182	16.315	0.208	1.075	16.965	3.981	0.208	0.201	0.879	18.214	7.798	15.072
5/10/2007 8:05	1.053	3.089	13.237	0.169	0.512	13.527	2.188	0.176	4.106	0.455	11.108	2.882	6.694
6/4/2007 13:55	0.673	0.273	7.363	0.126	0.099	6.661	9.534	0.104	17.022	0.058	41.208	0.128	53.035
8/16/2007 1125	1.034	0.340	12.876	0.164	0.059	13.142	2.068	0.172	4.777	0.419	608.374	2.539	645.874
	11		544.363	2.533									
	19		1391.708	5.684									

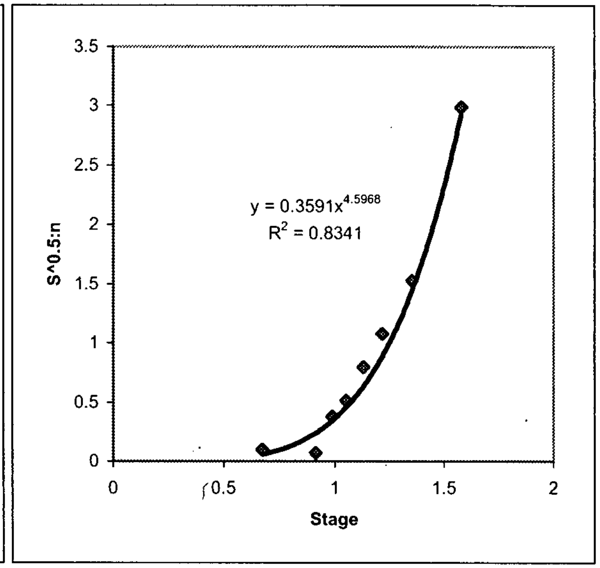
Manning's Eqn: Q=1.49/n x A x S^1/2 x R^2/3

Not used for calibration

Q=1.49*(0.3591*A5^4.5968)*(12.465*D^1.5826)*(0.1657*D^1.1657)^(2/3)





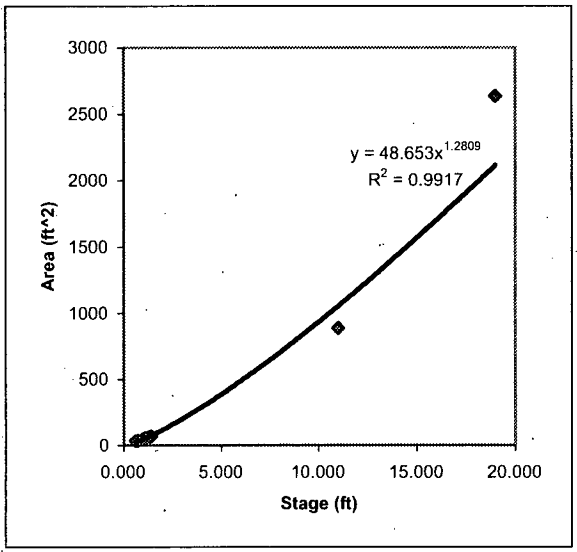


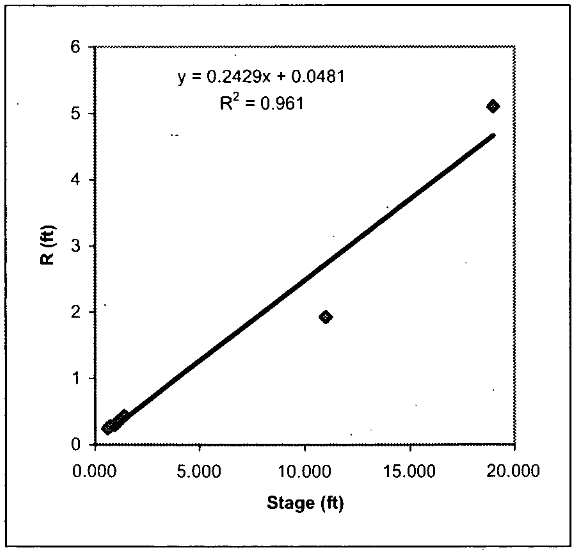
APPENDIX I-3
Stream Gauge Calibration for SGS-BC-03

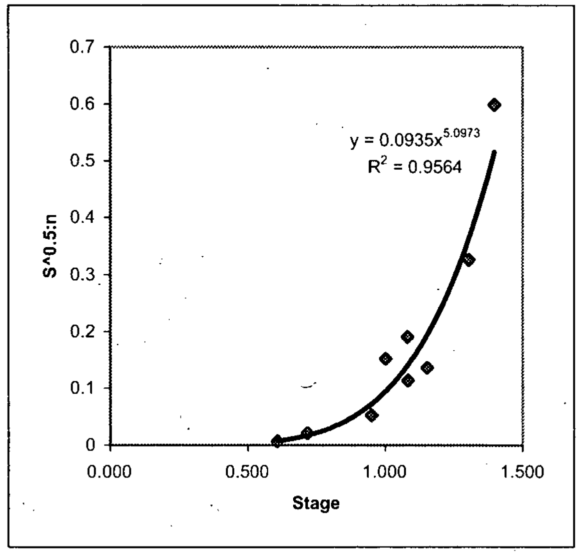
Date and Time	Stage	Discharge (CFS)	A	R	S:n ratio	Calculated A	% Error A	Calculated R	% Error R	Calculated S:n	% Error S:n	Calculated discharge	% Error Discharge
9/19/2006 16:40	1.085	4.326	51.830	0.343	0.114	54.012	4.210	0.312	9.108	0.142	23.933	5.242	21.184
10/3/2006 13:20	0.951	1.625	45.713	0.302	0.053	45.621	0.202	0.279	7.708	0.072	36.639	2.101	29.262
11/10/2006 9:50	1.304	16.512	61.828	0.409	0.325	68.355	10.557	0.365	10.799	0.362	11.210	18.812	13.932
12/12/2006 10:10	1.082	7.169	51.693	0.342	0.190	53.821	4.116	0.311	9.080	0.140	26.593	5.143	28.271
1/18/2007 10:30	1.398	33.980	66.119	0.437	0.599	74.729	13.023	0.388	11.368	0.516	13.826	30.537	10.133
3/8/2007 8:55	1.153	5.668	54.934	0.363	0.136	58.386	6.283	0.328	9.699	0.193	42.084	7.996	41.081
5/10/2007 8:45	1.002	5.066	48.041	0.318	0.152	48.778	1.533	0.291	8.283	0.094	37.840	3.018	40.422
6/4/2007 8:58	0.609	0.121	31.673	0.248	0.006	25.777	18.617	0.196	21.008	0.007	15.272	0.097	19.836
8/16/07 0845	0.717	0.484	36.090	0.283	0.021	31.772	11.965	0.222	21.399	0.017	17.895	0.298	38.439
	11.000		882.186	1.925									
	19.000		2630.889	5.105									

Manning's Eqn: Q=1.49/n x A x S^1/2 x R^2/3

Q=1.49*(48.653*D^1.2809)*(0.2429*D + 0.0481)^(2/3)*(0.0935*D^5.0973)







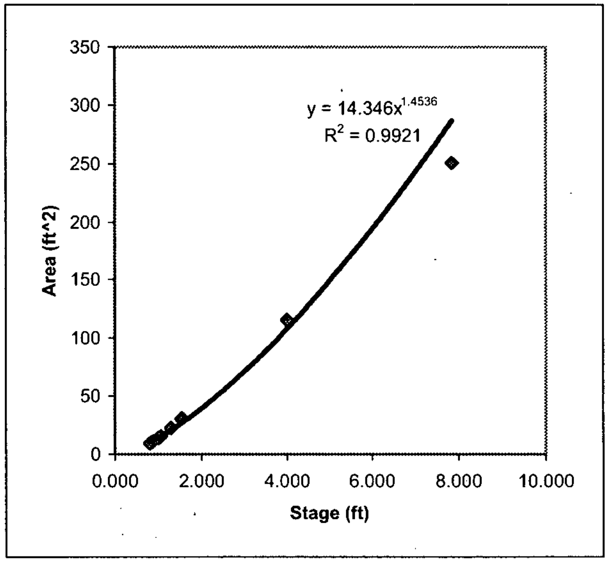
APPENDIX I-4
Stream Gauge Calibration for SGS-MF-01

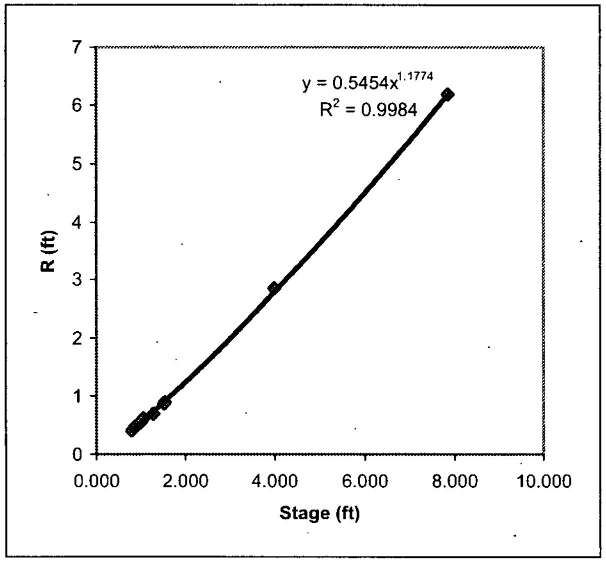
Date and Time	Stage	Discharge (CFS)	A	R	S:n ratio	Calculated A	% Error A	Calculated R	% Error R	Calculated S:n	% Error S:n	Calculated discharge	% Error Discharge
10/5/06 8:55	0.868	0.032	10.931	0.472	0.003	11.678	6.837	0.462	2.181	0.056	1618.092	0.586	1708.778
11/10/06 12:40	1.060	4.433	15.465	0.614	0.266	15.614	0.964	0.584	4.938	0.191	28.418	3.097	30.127
12/12/06 13:00	0.996	1.477	13.929	0.553	0.106	14.263	2.395	0.543	1.917	0.146	38.130	2.062	39.625
1/17/07 16:00	1.287	9.061	22.616	0.691	0.344	20.702	8.461	0.734	6.205	0.349	1.492	8.763	3.290
2/22/07 13:45	1.548	21.043	30.953	0.887	0.494	27.076	12.526	0.912	2.814	0.531	7.555	20.167	4.161
3/8/07 13:50	1.013	1.445	14.337	0.570	0.098	14.618	1.959	0.554	2.791	0.158	60.190	2.316	60.276
4/4/07 15:30	1.532	22.263	30.417	0.872	0.538	26.670	12.319	0.901	3.353	0.520	3.335	19.289	13.358
5/10/07 13:35	0.851	0.487	10.552	0.456	0.052	11.347	7.530	0.451	1.007	0.045	14.845	0.443	9.048
6/4/2007 11:22	0.796	0.030	9.329	0.403	0.004	10.297	10.379	0.417	3.508	0.006	53.523	0.052	73.398
	4.000		115.630	2.854									
	7.850		250.380	6.180									

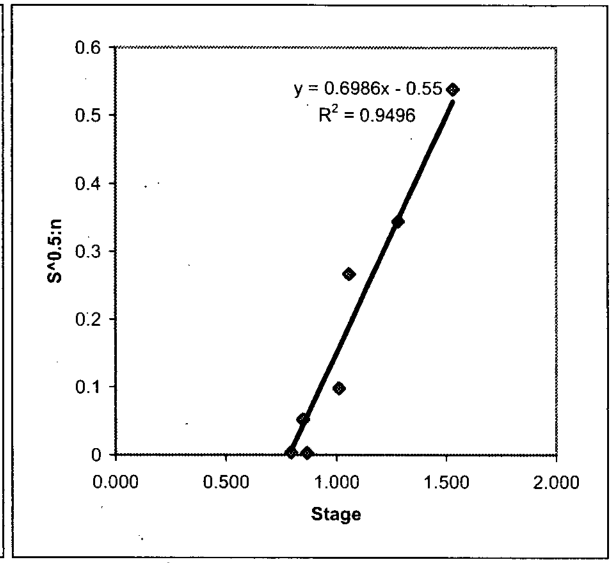
Manning's Eqn: Q=1.49/n x A x S^1/2 x R^2/3

Not used in calibration

Q=1.49*(14.346*D^1.4536)*(0.5454*D^1.1774)^(2/3)*(0.6986*D-0.55)





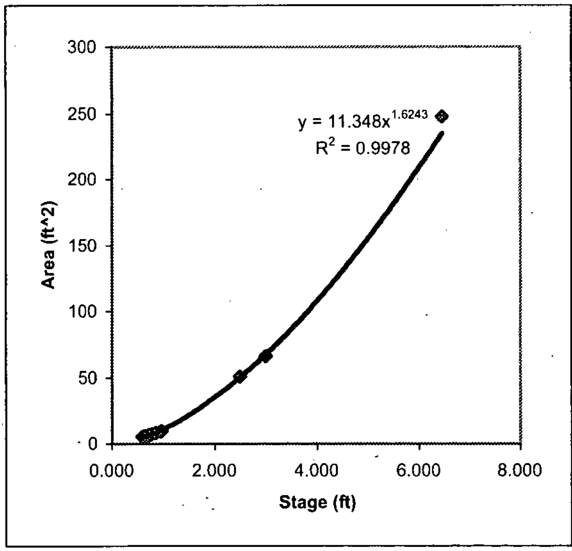


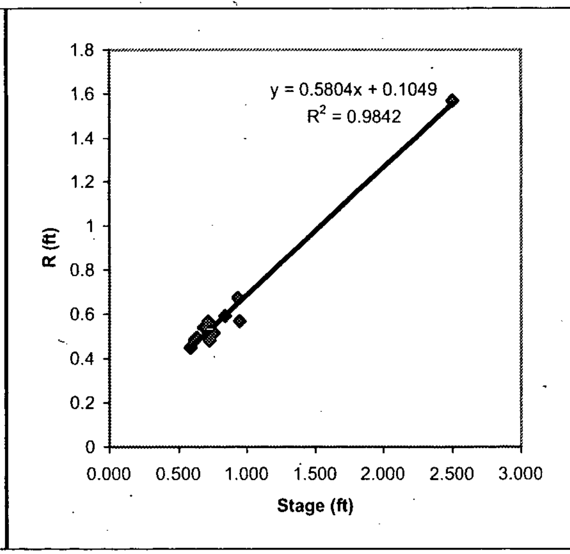
APPENDIX I-5
Stream Gauge Calibration for SGS-MF-02

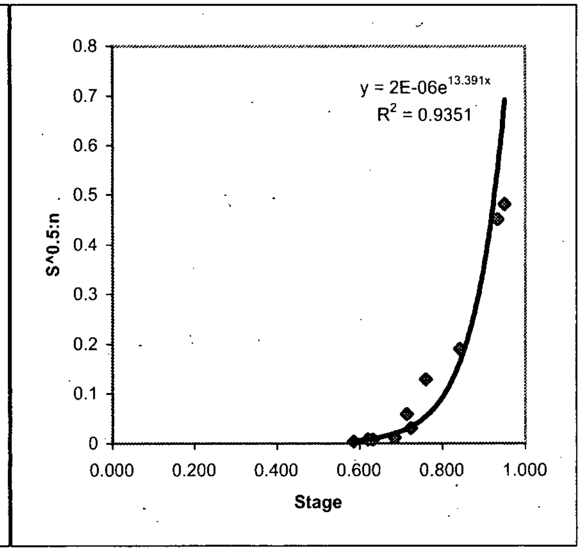
Date and Time	Stage	Discharge (CFS)	A	R	S:n ratio	Calculated A	% Error A	Calculated R	% Error R	Calculated S:n	% Error S:n	Calculated discharge	% Error Discharge
9/20/2006 9:39	0.586	0.019	5.219	0.451	0.004	4.763	8.725	0.445	1.252	0.005	23.740	0.021	12.000
10/5/2006 10:55	0.620	0.042	5.589	0.483	0.008	5.220	6.596	0.465	3.706	0.008	1.615	0.038	10.389
11/10/06 11:55	0.760	0.876	7.100	0.515	0.129	7.266	2.345	0.546	6.017	0.053	59.198	0.380	56.582
12/12/06 11:20	0.715	0.393	6.544	0.565	0.059	6.581	0.564	0.520	7.998	0.029	51.127	0.183	53.508
1/17/07 12:30	0.842	1.631	8.137	0.590	0.191	8.582	5.469	0.594	0.566	0.158	17.503	1.424	12.664
2/22/07 12:30	0.950	4.680	9.519	0.567	0.482	10.441	9.690	0.656	15.791	0.670	38.986	7.868	68.108
3/8/07 10:40	0.724	0.185	6.645	0.482	0.030	6.716	1.070	0.525	8.948	0.032	6.585	0.212	14.060
4/4/07 16:08	0.933	4.807	9.288	0.674	0.452	10.139	9.158	0.646	4.059	0.533	18.029	6.024	25.328
5/10/2007 10:20	0.686	0.075	6.252	0.540	0.012	6.153	1.594	0.503	6.827	0.020	60.324	0.113	50.504
6/4/2007 10:30	0.633	0.040	5.720	0.494	0.008	5.399	5.600	0.472	4.378	0.010	27.182	0.047	16.529
	2.500		50.578	1.569									
	6.460		247.519	3.913									
	3.000		66.343	1.873									
	4.000		106.869	1.884									
	5.000		162.985	2.577									

Manning's Eqn: Q=1.49/n x A x S^1/2 x R^2/3

Q=1.49*(2E-06*exp(13.391*D))*(11.348*D^1.6243)*(0.5804*D + 0.1049)^(2/3)







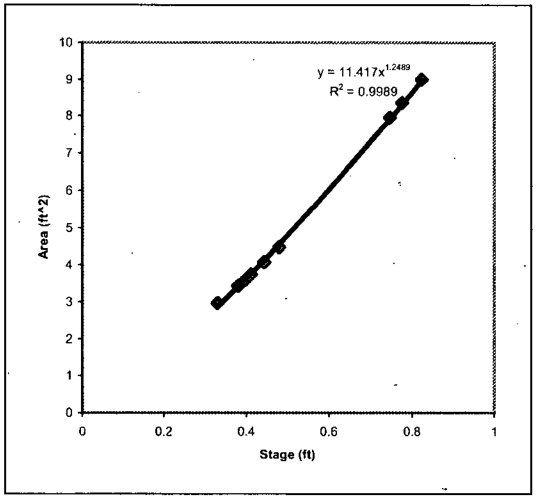
APPENDIX I-6
Stream Gauge Calibration for SGS-MF-03

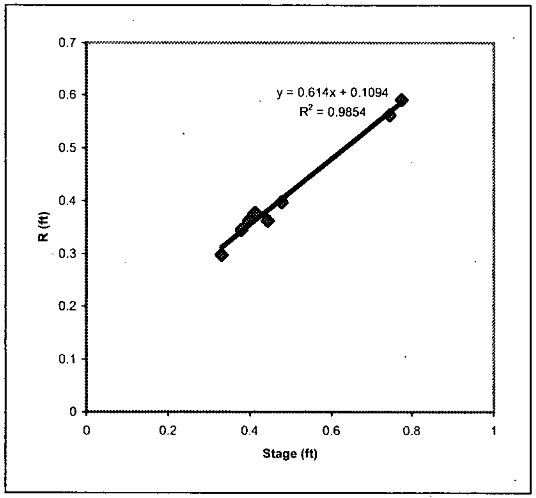
Stage	Stage	Discharge (CFS)	A	R	S:n ratio	Calculated A	% Error A	Calculated R	% Error R	Calculated S:n	% Error S:n	Calculated discharge	% Error Discharge
0.412	0.412	0.103	3.7373	0.376885	0.0354503	1.680637	55.030723	0.362368	3.851824	0.015055	57.53271262	0.019161743	81.39637
0.409	0.409	0.0171	3.70835	0.373966	0.0059622	1.662547	55.167472	0.360526	3.5937822	0.014581	144.5581798	0.01829679	6.99877
0.775	0.775	0.6733	8.3505	0.590162	0.0769123	4.283631	48.702104	0.58525	0.8322559	0.072373	5.902583115	0.323196133	51.9982
0.443	0.443	0.0776	4.0721	0.36209	0.0251756	1.871237	54.047381	0.381402	5.3334984	0.01995	20.75771514	0.029253196	62.30258
0.478	0.478	1.151	4.4641	0.396946	0.3203813	2.094261	53.086592	0.402892	1.4978181	0.025476	92.04816303	0.043365489	96.23236
0.745	0.745	2.70475	7.9485	0.561751	0.335449	4.040388	49.167918	0.56683	0.9041762	0.067636	79.83732514	0.27888122	89.68921
0.38	0.38	0.072625	3.4285	0.345744	0.0288597	1.491	56.511596	0.34272	0.8747109	0.010002	65.34272212	0.010882041	85.01612
0.823	0.823	2.40865	8.9973	0.434729	0.3130853	4.682288	47.958963	0.614722	41.403459	0.079952	74.46328932	0.403265703	83.2576
0.397	0.397	0.024	3.59255	0.362288	0.0088224	1.590827	55.718713	0.353158	2.5200273	0.012686	43.79659141	0.015024165	37.39931
0.331	0.331	0.00015	2.95565	0.29806	7.633E-05	1.215333	58.881018	0.312634	4.8895867	0.002265	2867.105132	0.001889244	1159.496

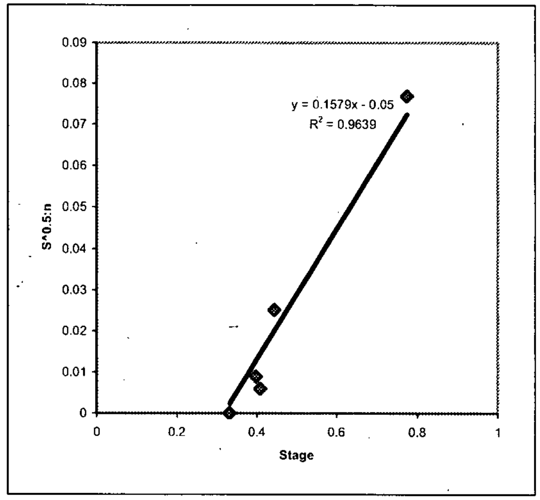
Manning's Eqn: Q=1.49/n x A x S^1/2 x R^2/3

Not used in calibration

Q=1.49*(0.1579D - 0.05)*(11.417D^1.2489)*(0.614D + 0.1094)^(2/3)







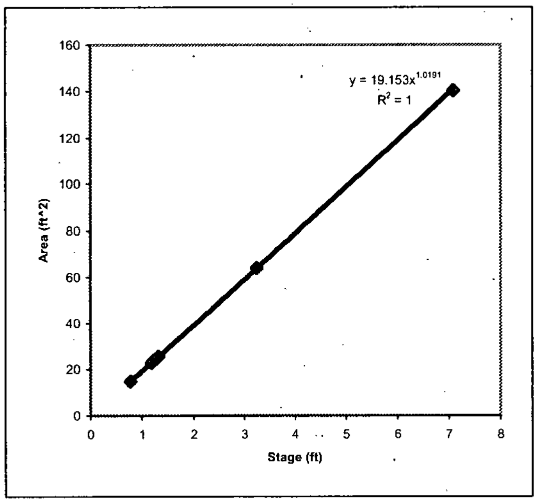
APPENDIX I-7
Stream Gauge Calibration for SGS-MF-04

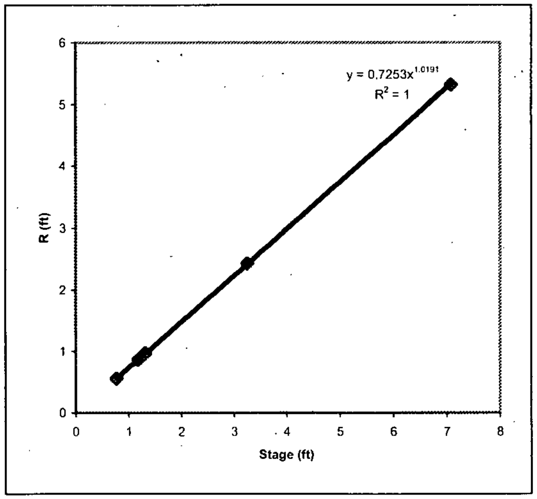
Stage	Stage	Discharge (CFS)	A	R	S:n ratio	Calculated A	% Error A	Calculated R	% Error R	Calculated S:n	% Error S:n	Calculated discharge	% Error Discharge
1.212	1.212	1.77375	23.3298	0.883482	0.0554196	23.29884	0.132699	0.882298	0.1340136	0.149253	169.3138919	4.76635305	168.7162
1.313	1.313	1.72719	25.3397	0.959595	0.0470212	25.27903	0.23943	0.957285	0.2407431	0.193394	311.2916885	7.07540179	309.6481
1.237	1.237	0.46314	23.8273	0.902322	0.0139704	23.7887	0.1619852	0.900848	0.1632994	0.15945	1041.336621	5.27167701	1038.247
1.182	1.182	3.35075	22.7328	0.860874	0.1093142	22.71126	0.0947415	0.860047	0.0960565	0.137622	25.89588743	4.21176054	25.69605
1.317	1.317	6.8065	25.4193	0.96261	0.1843347	25.35751	0.2430677	0.960257	0.2443808	0.195308	5.952814769	7.18242355	5.523008
0.772	0.772	0.523875	14.5738	0.551899	0.035856	14.71322	0.9566182	0.557171	0.9552893	0.034663	3.328464713	0.51453367	1.783121
1.283	1.283	8.15912	24.7427	0.936987	0.2311289	24.69054	0.2108083	0.935	0.2121218	0.179453	22.35791299	6.31261377	22.63119
7.09	7.09		140.302	5.31313									
3.25	3.25		63.886	2.419314									

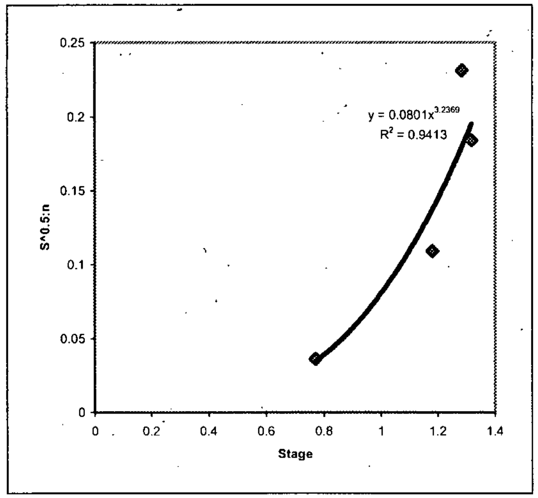
Manning's Eqn: Q=1.49/n x A x S^1/2 x R^2/3

Not used in calibration

Q=1.49*(0.0801*D^3.2369)*(19.153*D^1.0191)*(0.7253*D^1.0191)^(2/3)







APPENDIX I-8

Date	Average Temp (F)	Low Temp (F)	High Temp (F)	Precipitation (in)
10/1/2006	59.04348	46	76	0.01
10/2/2006	64.26087	49	80	0
10/3/2006	70.13043	60	82	0
10/4/2006	73.3913	64	86	0
10/5/2006	55.82609	47	67	0.01
10/6/2006	49.56522	39	64	0
10/7/2006	51.21739	39	67	0
10/8/2006	57.73913	42	75	0
10/9/2006	62.30435	49	78	0
10/10/2006	62.91304	52	75	0
10/11/2006	59.91304	45	67	0.13
10/12/2006	39.82609	31	49	0
10/13/2006	41.78261	31	53	0
10/14/2006	42.04348	29	55	0
10/15/2006	42.91304	26	56	0
10/16/2006	49.36364	48	52	1.41
10/17/2006	60.17391	52	69	1.13
10/18/2006	58	53	67	0
10/19/2006	50.16667	43	59	0.4
10/20/2006	41.61905	35	51	0.01
10/21/2006	46.125	32	60	0
10/22/2006	44.54167	37	52	0
10/23/2006	36.16667	34	39	0
10/24/2006	37.65217	27	46	0
10/25/2006	38.58333	23	52	0
10/26/2006	43.83333	42	48	0.52
10/27/2006	49.75	44	52	1.51
10/28/2006	45.95652	41	53	0.03
10/29/2006	49.08333	39	62	0
10/30/2006	57.16667	37	72	0
10/31/2006	53.75	44	62	0.3
11/1/2006	39.45833	32	43	0.1
11/2/2006	32.08333	22	44	0
11/3/2006	29	17	43	0
11/4/2006	38.17391	24	50	0
11/5/2006	46	41	56	0.01
11/6/2006	50.20833	42	59	0.08
11/7/2006	50.83333	49	52	0.51
11/8/2006	50.45833	42	56	0
11/9/2006	55.20833	46	71	0
11/10/2006	60.83333	44	74	0
11/11/2006	46.56522	40	67	0.25
11/12/2006	37.125	31	42	0
11/13/2006	38.41667	33	47	0
11/14/2006	39.45833	28	50	0
11/15/2006	43.33333	42	47	0.68
11/16/2006	46.5	38	53	0.44
11/17/2006	38.54167	31	44	0
11/18/2006	40.73913	32	47	0.01
11/19/2006	37.29167	33	42	0
11/20/2006	34.08333	26	42	0.04
11/21/2006	33.86957	23	48	0
11/22/2006	36.08333	21	54	0
11/23/2006	39.66667	24	60	0
11/24/2006	44.375	28	65	0
11/25/2006	50.79167	32	66	0
11/26/2006	54.04167	40	64	0
11/27/2006	52.625	41	63	0
11/28/2006	54.95833	46	64	0
11/30/2006	58.13043	50	65	1.68
12/1/2006	37.625	27	58	0.79
12/2/2006	29.875	24	41	0
12/3/2006	24.83333	18	28	0
12/4/2006	21.29167	11	29	0
12/5/2006	29	20	37	0

Date	Average Temp (F)	Low Temp (F)	High Temp (F)	Precipitation (in)
12/6/2006	38.54167	31	46	0
12/7/2006	22.04167	13	31	0
12/8/2006	16.25	7	26	0
12/9/2006	29.625	18	41	0
12/10/2006	40	32	48	0
12/11/2006	44.75	37	58	0
12/12/2006	50.125	47	53	0.46
12/13/2006	49.04167	37	58	0
12/14/2006	50.70833	43	59	0
12/15/2006	46.56522	31	56	0
12/16/2006	46.54167	31	61	0
12/17/2006	58.375	54	64	0
12/18/2006	48.70833	39	57	0.01
12/19/2006	35.58333	28	44	0
12/20/2006	38.70833	26	53	0.02
12/21/2006	48.70833	43	53	0.93
12/22/2006	50.16667	39	55	0.28
12/23/2006	38.25	33	43	0
12/24/2006	37.33333	29	46	0
12/25/2006	37.625	36	39	0.76
12/26/2006	34.5	31	36	0.09
12/27/2006	34.5	27	43	0
12/28/2006	39.75	30	52	0
12/29/2006	40.83333	30	57	0
12/30/2006	43.58333	32	54	0
12/31/2006	51.79167	47	59	1.04
1/1/2007	37.41667	34	46	0.02
1/2/2007	33.75	26	46	0
1/3/2007	39.95833	28	53	0
1/4/2007	48.29167	42	56	0.33
1/5/2007	58.95833	53	62	0.55
1/6/2007	45.25	32	52	0.26
1/7/2007	37.45833	31	41	0.44
1/8/2007	36.04167	30	40	0.04
1/9/2007	34.5	28	40	0.01
1/10/2007	29.16667	20	38	0
1/11/2007	39.41667	29	48	0.04
1/12/2007	51.56522	48	54	0.33
1/13/2007	51.70833	45	55	0.81
1/14/2007	50	45	57	1.03
1/15/2007	45.20833	32	57	1.23
1/16/2007	26.125	20	31	0
1/17/2007	24.33333	15	33	0
1/18/2007	34.70833	26	42	0
1/19/2007	31.20833	28	36	0.01
1/20/2007	28.20833	19	35	0
1/21/2007	31.16667	26	34	0.28
1/22/2007	32.16667	29	35	0.15
1/23/2007	29.875	27	34	0
1/24/2007	29.20833	24	35	0.06
1/25/2007	25.58333	18	30	0
1/26/2007	30	13	44	0
1/27/2007	38.125	29	44	0
1/28/2007	16.58333	11	27	0
1/29/2007	19.54167	9	29	0
1/30/2007	19.75	10	28	0
1/31/2007	18.75	9	25	0
2/1/2007	25.16667	21	27	0
2/2/2007	21.54167	7	29	0.03
2/3/2007	14.375	2	27	0
2/4/2007	11.20833	2	19	0
2/5/2007	5.083333	-3	14	0
2/6/2007	9.583333	-3	17	0
2/7/2007	13.08333	5	19	0.15
2/8/2007	12.54167	2	22	0.03

APPENDIX I-8

Date	Average Temp (F)	Low Temp (F)	High Temp (F)	Precipitation (in)
2/9/2007	11.79167	5	22	0
2/10/2007	12.375	1	22	0
2/11/2007	19.75	-2	31	0.03
2/12/2007	30.66667	24	37	0.05
2/13/2007	22.61538	0	32	0.8
2/14/2007	13.26667	7	17	0
2/15/2007	10.875	0	19	0.05
2/16/2007	9.7	2	22	0.18
2/18/2007	16.08333	8	26	0.28
2/19/2007	31.75	4	48	0.02
2/20/2007	44.91667	38	51	0.65
2/21/2007	37.25	31	48	0.01
2/22/2007	37.16667	29	46	0.01
2/23/2007	29.95833	22	40	0
2/24/2007	29.95455	23	36	0.99
2/25/2007	42	35	53	0.09
2/26/2007	34.83333	26	43	0
2/27/2007	30.5	20	43	0
2/28/2007	35.70833	26	47	0
3/1/2007	48.82609	40	54	0.6
3/2/2007	42.54545	35	51	0
3/3/2007	29.5	24	33	0
3/4/2007	25.54545	20	32	0
3/5/2007	34.90476	26	49	0
3/6/2007	27	18	36	0
3/7/2007	34.7619	27	45	0
3/8/2007	34.58333	20	51	0
3/9/2007	49.17391	30	68	0
3/10/2007	52.95833	39	59	0.16
3/11/2007	42.79167	31	58	0
3/12/2007	51	29	66	0
3/13/2007	66.125	54	77	0
3/14/2007	63.13043	57	73	0.26
3/15/2007	41.75	36	61	0.29
3/16/2007	33.83333	29	41	0
3/17/2007	31.41667	25	40	0
3/18/2007	33	18	44	0
3/19/2007	45.41667	33	55	0.34
3/20/2007	51	39	60	0.01
3/21/2007	61.125	46	75	0
3/22/2007	62.91667	57	66	0.42
3/23/2007	63.16667	60	72	0.12
3/24/2007	65.79167	57	77	0.01
3/25/2007	68.20833	56	81	0
3/26/2007	68.625	56	78	0
3/27/2007	67.54167	57	80	0
3/28/2007	61.54167	57	66	0.84
3/29/2007	59.45833	49	70	0
3/30/2007	63.25	50	75	0
3/31/2007	66.75	60	75	0.22
4/1/2007	66.04167	58	74	0.15
4/2/2007	64.25	49	77	0
4/3/2007	64.54167	56	80	0.66
4/4/2007	37.95833	30	58	0
4/5/2007	32.20833	29	38	0
4/6/2007	29.58333	23	38	0
4/7/2007	27.66667	23	31	0
4/8/2007	32.69565	27	37	0
4/9/2007	36.78261	25	49	0
4/10/2007	43.625	24	56	0
4/11/2007	48.41667	40	59	0.92
4/12/2007	40.16667	37	50	0
4/13/2007	44.70833	37	54	0
4/14/2007	40.25	34	44	0.75
4/15/2007	41.91667	34	52	0
4/16/2007	47.875	37	58	0
4/17/2007	52.83333	31	71	0
4/18/2007	54.29167	48	66	0
4/19/2007	46.95833	41	55	0.12
4/20/2007	53.29167	35	70	0
4/21/2007	59.875	40	76	0
4/22/2007	64.95833	43	80	0
4/23/2007	69.25	63	78	0.35
4/24/2007	67.54167	54	80	0
4/25/2007	68.75	62	75	0.08
4/26/2007	62.5	59	67	0.69
4/27/2007	52.54167	48	57	0.02
4/28/2007	61.25	49	73	0
4/29/2007	63.58333	43	79	0
4/30/2007	72.04167	60	87	0
5/1/2007	72.75	55	84	0
5/2/2007	67.29167	59	76	0.1
5/3/2007	59	52	65	0.12
5/4/2007	62.5	56	70	0.11
5/5/2007	66	61	77	0.01
5/6/2007	60.08333	51	70	0
5/7/2007	63.41667	49	78	0.02
5/8/2007	68.08333	49	85	0
5/9/2007	67.95833	57	82	0.27
5/10/2007	69.78261	56	85	0
5/11/2007	69.41667	56	83	0
5/12/2007	71.91667	58	85	0
5/13/2007	58.25	45	71	0
5/14/2007	62.29167	40	81	0
5/15/2007	72.29167	56	84	0.39
5/16/2007	57.875	44	63	0.17
5/17/2007	51.08333	42	60	0
5/18/2007	52.25	39	66	0
5/19/2007	56.875	37	73	0
5/20/2007	63.41667	44	79	0
5/21/2007	65.6087	47	82	0
5/22/2007	68.54167	49	85	0
5/23/2007	71.375	54	86	0
5/24/2007	70.875	57	85	0
5/25/2007	71.25	58	85	0
5/26/2007	66.875	0	84	0
5/27/2007	68.75	57	85	0.35
5/28/2007	71.25	62	85	0
5/29/2007	74.91667	63	88	0
5/30/2007	73.95833	60	88	0
5/31/2007	71.54167	59	84	0
6/1/2007	74.08333	63	87	0
6/2/2007	70.45833	61	87	0.05
6/3/2007	69.16667	62	80	0.11
6/4/2007	64	57	74	0.32
6/5/2007	63.45833	52	73	0.01
6/6/2007	65.79167	47	79	0
6/7/2007	78	65	88	0
6/8/2007	75.125	60	81	0.42
6/9/2007	67.625	55	80	0
6/10/2007	65.66667	51	79	0
6/11/2007	72.33333	59	84	0
6/12/2007	69.75	54	83	0
6/13/2007	73.20833	56	88	0
6/14/2007	74.45833	60	88	0
6/15/2007	70.66667	56	84	0
6/16/2007	72.95833	53	91	0
6/17/2007	76.95833	61	92	0
6/18/2007	76.33333	62	88	0
6/19/2007	73.41667	62	79	0

APPENDIX I-8

Date	Average Temp (F)	Low Temp (F)	High Temp (F)	Precipitation (in)
6/20/2007	69	53	83	0
6/21/2007	71.08333	49	88	0
6/22/2007	65.54167	60	73	0.95
6/23/2007	67.75	60	77	0.02
6/24/2007	69.58333	63	81	0.04
6/25/2007	72.70833	66	83	0.46
6/26/2007	76.875	64	90	0.31
6/27/2007	76.25	66	87	0.02
6/28/2007	73.20833	67	88	0.71
6/29/2007	71.45833	67	77	0.01
6/30/2007	70.875	64	80	0
7/1/2007	69.25	57	80	0
7/2/2007	65	53	77	0
7/3/2007	69.29167	51	86	0
7/4/2007	72.58333	60	83	0.08
7/5/2007	73.04167	68	85	0.03
7/6/2007	74.52174	59	89	0
7/7/2007	74.75	60	88	0
7/8/2007	76.15	58	89	0
7/9/2007	76.04167	62	90	0
7/10/2007	75.33333	66	85	0
7/11/2007	73.58333	57	81	0.04
7/12/2007	66.70833	51	81	0
7/13/2007	67.66667	55	81	0.37
7/14/2007	71.58333	53	85	0
7/15/2007	75.25	65	85	0
7/16/2007	73.5	58	88	0
7/17/2007	69.56667	61	87	0.81
7/18/2007	74.33333	65	87	0.23
7/19/2007	74.54167	69	85	1.55
7/20/2007	66.54167	55	77	0
7/21/2007	64.45833	51	77	0
7/22/2007	66.16667	52	81	0
7/23/2007	67.875	55	81	0
7/24/2007	68.04167	56	83	0
7/25/2007	70.66667	55	84	0
7/26/2007	71.66667	63	80	0.01
7/27/2007	72.58333	67	82	1.52
7/28/2007	71.58333	67	81	0
7/29/2007	74.375	66	86	0
7/30/2007	74.625	64	87	0
7/31/2007	74.875	61	89	0
8/1/2007	75.375	58	90	0
8/2/2007	77.58333	63	92	0
8/3/2007	77.91667	65	92	0
8/4/2007	77.16667	66	91	0.22
8/5/2007	79.58333	70	91	0.03
8/6/2007	81.54167	74	93	0
8/7/2007	82.54167	71	95	0
8/8/2007	81.20833	71	97	2.25
8/9/2007	82	68	95	0.01
8/10/2007	78.66667	68	89	0
8/11/2007	75.5	62	89	0
8/12/2007	77.54167	63	94	0
8/13/2007	75.91667	60	90	0
8/14/2007	69.20833	52	84	0
8/15/2007	78.33333	63	94	0
8/16/2007	77.29167	69	94	0.83
8/17/2007	74.16667	64	86	0.01
8/18/2007	68.33333	56	81	0
8/19/2007	75.70833	63	90	0
8/20/2007	78.79167	71	90	0
8/21/2007	76.29167	70	86	0
8/22/2007	81.5	71	95	0
8/23/2007	81.41667	69	95	0
8/24/2007	80.875	68	95	0
8/25/2007	75.66667	66	87	0
8/26/2007	72.625	62	86	0
8/27/2007	73.41667	59	91	0
8/28/2007	75.91667	58	94	0
8/29/2007	76.33333	65	94	0.27
8/30/2007	72	65	78	0
8/31/2007	68.65217	58	82	0
9/1/2007	68.45833	54	84	0
9/2/2007	71.16667	57	89	0
9/3/2007	72.875	55	92	0
9/4/2007	73.26087	55	94	0
9/5/2007	74.33333	58	96	0
9/6/2007	74.5	62	87	0
9/7/2007	78.20833	71	86	0.03
9/8/2007	75.04167	71	87	0.2
9/9/2007	74.91667	66	85	0.05
9/10/2007	73.29167	62	87	0
9/11/2007	67.29167	54	76	0.08
9/12/2007	59.95833	44	78	0
9/13/2007	63.875	46	84	0
9/14/2007	67.5	54	85	0
9/15/2007	53.16667	40	67	0
9/16/2007	55.95833	39	73	0
9/17/2007	61.95833	42	82	0
9/18/2007	67.625	49	88	0
9/19/2007	68.875	53	88	0
9/20/2007	70.20833	53	89	0
9/21/2007	70.875	52	90	0
9/22/2007	74.625	60	92	0
9/23/2007	73.875	58	92	0
9/24/2007	77.41667	62	93	0
9/25/2007	73	65	86	0.1
9/26/2007	68.70833	66	74	0.69
9/27/2007	64.54167	54	73	1.22
9/28/2007	61.3913	47	78	0
9/29/2007	60.45833	45	79	0
9/30/2007	65.41667	45	83	0

Appendix I-9
Thornthwaite Calculation
Averaged Monthly Rainfall, Evapotranspiration, and Recharge
DU Impact Area, Jefferson Proving Ground, Indiana

STATION	YEAR	JAN (in)	FEB (in)	MAR (in)	APR (in)	MAY (in)	JUN (in)	JUL (in)	AUG (in)	SEP (in)	OCT (in)	NOV (in)	DEC (in)
MADISON	1976	4.16	3.31	2.33	0.88	2.93	6.03	3.15	3.42	2.74	4.38	0.94	0.5
MADISON	1977	2.23	1.67	5.2	3.7	2.25	3.84	3.92	7.82	2.27	3.14	5.36	6.46
MADISON	1978	3.89	0.22	3.36	3.45	5.24	4.94	7.93	6.3	0.93	3.33	3.54	6.44
MADISON	1979	3.63	4.6	2.15	5.68	4.51	4.59	7.42	5.86	7.93	2.45	7.35	2.93
MADISON	1980	2.44	1.37	4.87	2.21	5.34	4.39	3.47	3.73	1.91	3.42	2.39	1.29
MADISON	1981	0.52	3.31	1.78	3.9	5.49	2.47	3.8	2.12	1.84	2.76	1.92	3.81
MADISON	1982	8.21	1.88	4.62	2.5	4.93	5.76	4.91	4.22	2.8	1.67	5.2	4.84
MADISON	1983	1.77	1.01	2	7.08	9.29	4.78	0.94	1.4	0.69	12.3	5.48	3.63
MADISON	1984	0.81	2.21	4.78	5.45	5.62	1.14	6.13	3.03	3.14	3.69	5.81	5.28
MADISON	1985	1.89	2.84	5.72	1.71	3.88	4.59	4.42	6.35	0.98	4.34	7.39	1.89
MADISON	1986	1.63	2.88	3.15	2.36	5.05	2.78	4.7	1.73	3.72	4.52	3.85	2.33
MADISON	1987	0.87	2.24	4.63	2.23	1.31	3.98	6.66	2.95	1.47	0.83	1.95	4.12
MADISON	1988	2.73	3.8	2.74	4.31	3.09	0.34	4.91	4.3	3.69	3.64	7.14	1.07
MADISON	1989	4.73	6.87	6.57	5.33	5.19	4.39	5.68	6.11	2.9	3.44	2.01	2.4
MADISON	1990	3.08	7.82	3.78	5.29	8.39	5.18	2.14	4.85	4.12	5.89	2.46	7.93
MADISON	1991	1.84	3.05	6.53	4.45	3.41	3.8	1.95	5.43	2.05	1.96	1.63	4.79
MADISON	1992	2.14	0.64	4.61	3.39	2.42	5.34	7.08	6.72	3.34	1.53	4.71	1.42
MADISON	1993	3.82	3.16	2.8	4.34	3.35	4.81	4.23	7.36	2.76	2.16	5.82	4.41
MADISON	1994	2.58	2.59	3.15	8.22	3.14	4.5	5.63	4.27	1.59	2.48	4.04	3.68
MADISON	1995	3.81	1.54	1.82	4.17	11.63	3.01	4.54	4.97	1.74	4.21	1.69	5.23
MADISON	1996	4.53	1.91	4.78	ND	9.51	5.09	5.93	2.06	7.25	1.66	4.78	3.3
MADISON	1997	4.06	2.15	7.8	3.04	9.29	9	1.57	2.43	0.88	1.25	3.39	1.78
MADISON	1998	2.61	2.8	3.56	7.53	5.3	7.09	3.22	1.67	0.24	2.3	1.18	4.15
MADISON	1999	5.35	3.3	4.05	2.82	2.07	5.1	1.35	1.16	1.04	3.3	1.56	5.21
MADISON	2000	6.05	6.54	3.38	3.84	2.88	4.76	6.01	6.01	4.95	1.9	2.6	5.33
MADISON	2001	1.16	2.18	1.04	1.04	5.01	3.12	5.15	2.9	4.32	6.64	4.48	5.65
MADISON	2002	2.54	1.43	4.29	7.07	7.9	3.95	3.75	1.76	8.22	3.75	3.18	4.4
MADISON	2003	3.1	4.19	1.79	4.2	7.5	3.47	9.36	6.63	6.75	2.48	4.41	2.62
MADISON	2004	5.51	1.18	2.96	5.24	7.1	1.28	5.33	3.5	0.69	7.7	7.09	4.16
MADISON	2005	7.19	1.77	4.07	3.06	2.74	1.88	2.11	7.44	3.16	1.68	5.13	2.69
MADISON	2006	4.78	1.3	6.64	5.7	4.02	4.39	4.63	8.9	6.4	4.97	3.32	4.4
MADISON	2007	5.47	3.7	2.93	5.36	2.87	4.02	5.4	2	1.99	7.61	ND	ND
Average Monthly Rainfall		3.41	2.80	3.87	4.18	5.08	4.18	4.61	4.36	3.08	3.67	3.93	3.81
Average MonthlyPotential Et		0.1	0.17	0.9	2.12	3.73	5.24	6.14	5.55	3.83	2.05	0.82	0.19
Average Monthly Realized Et		0.1	0.17	0.9	2.12	3.73	4.18	4.61	4.36	3.08	2.05	0.82	0.19
Average Monthly Recharge		3.3103125	2.625625	2.97125	2.0590323	1.3528125	0	0	0	0	1.618125	3.1090323	3.6209677

46.97	Average Year Rainfall Total
30.84	Average Year Potential Et
26.31	Average Year Realized Et
20.67	Average Year Recharge

Climate Data from http://www1.ncdc.noaa.gov/pub/orders/016229826525675021208094717.html
Averaged Monthly Et from Appendix I-10
ND=No data available
=greatest mean monthly rainfall
=lowest mean monthly rainfall

Appendix I-10

Average Monthly Evapotranspiration

DU Impact Area, Jefferson Proving Ground, Indiana

STATION	YEAR	JAN °C	i	Etp	Et	FEB °C	i	Etp	Et	MAR °C	i	Etp	Et	APR °C	i	Etp	Et	MAY °C	i	Etp	Et	JUN °C	i	Etp	Et
MADISON	1976	-0.2	0	0.0	0.0	7.1	1.70	2.05	1.72	11.8	3.64	4.26	4.39	14.5	4.94	5.70	6.33	17.4	6.52	7.43	9.14	23.7	10.30	11.51	14.27
MADISON	1977	-8.1	0	0.0	0.0	1.3	0.13	0.19	0.16	10.3	2.95	3.56	3.66	15.7	5.55	6.45	7.16	ND	ND	ND	ND	23.0	9.87	11.09	13.75
MADISON	1978	-5.0	0	0.0	0.0	-4.4	0	0.00	0.00	5.0	1.00	1.18	1.22	13.9	4.63	5.26	5.84	17.2	6.39	7.21	8.87	23.2	9.97	11.12	13.79
MADISON	1979	-4.0	0	0.0	0.0	-2.4	0	0.00	0.00	9.5	2.62	3.13	3.22	12.3	3.87	4.54	5.04	17.4	6.49	7.41	9.12	22.7	9.65	10.83	13.43
MADISON	1980	1.3	0.13	0.16	0.13	-1.2	0	0.00	0.00	4.7	0.90	1.05	1.08	11.9	3.69	4.19	4.65	18.8	7.31	8.19	10.07	22.2	9.33	10.41	12.90
MADISON	1981	-1.4	0	0.0	0.0	3.2	0.50	0.59	0.50	6.9	1.62	1.86	1.92	16.3	5.90	6.64	7.37	16.6	6.03	6.77	8.33	23.8	10.41	11.57	14.35
MADISON	1982	-2.4	0	0.0	0.0	1.8	0.21	0.24	0.20	8.8	2.35	2.62	2.70	11.0	3.26	3.63	4.03	21.1	8.68	9.63	11.84	21.7	9.02	10.01	12.41
MADISON	1983	2.0	0.25	0.26	0.22	5.0	1.00	1.05	0.88	9.0	2.41	2.59	2.67	11.7	3.56	3.85	4.27	16.7	6.09	6.65	8.18	23.1	9.90	10.92	13.55
MADISON	1984	-2.3	0	0.0	0.0	4.3	0.79	1.00	0.84	3.7	0.63	0.80	0.83	11.6	3.51	4.14	4.60	16.2	5.84	6.72	8.26	24.0	10.52	11.75	14.57
MADISON	1985	-3.7	0	0.0	0.0	-0.8	0	0.00	0.00	9.4	2.57	2.93	3.02	15.7	5.58	6.27	6.96	18.5	7.12	7.97	9.80	21.2	8.74	9.75	12.09
MADISON	1986	0.7	0.05	0.06	0.05	2.7	0.40	0.46	0.38	8.4	2.17	2.44	2.51	13.7	4.55	5.07	5.63	19.4	7.64	8.49	10.44	23.4	10.15	11.27	13.97
MADISON	1987	0.8	0.06	0.06	0.05	4.5	0.85	0.92	0.77	8.4	2.17	2.36	2.43	12.8	4.09	4.47	4.97	21.3	8.81	9.73	11.97	24.2	10.63	11.76	14.58
MADISON	1988	-0.9	0	0.0	0.0	1.3	0.14	0.18	0.15	7.3	1.78	2.13	2.20	12.7	4.03	4.68	5.20	18.7	7.21	8.18	10.06	22.9	9.83	11.00	13.64
MADISON	1989	4.4	0.84	1.17	0.99	0.6	0.04	0.08	0.06	8.0	2.02	2.62	2.70	12.1	3.77	4.63	5.13	15.6	5.52	6.55	8.06	21.8	9.09	10.35	12.83
MADISON	1990	4.4	0.84	1.06	0.90	5.3	1.10	1.38	1.16	9.0	2.41	2.90	2.99	11.5	3.49	4.12	4.57	16.4	5.93	6.82	8.39	21.8	9.09	10.23	12.69
MADISON	1991	0.2	0.01	0.01	0.01	3.0	0.46	0.51	0.43	8.1	2.04	2.26	2.33	14.1	4.71	5.21	5.79	21.2	8.74	9.69	11.91	23.9	10.44	11.57	14.35
MADISON	1992	1.4	0.16	0.28	0.23	4.7	0.90	1.33	1.11	6.9	1.62	2.23	2.30	12.6	4.01	5.02	5.57	16.2	5.84	7.03	8.64	20.3	8.20	9.51	11.79
MADISON	1993	2.2	0.29	0.43	0.36	-0.6	0	0.00	0.00	5.3	1.08	1.46	1.50	11.2	3.34	4.10	4.56	17.6	6.58	7.67	9.43	21.9	9.16	10.40	12.90
MADISON	1994	-3.8	0	0.0	0.0	1.3	0.14	0.21	0.18	6.0	1.31	1.71	1.76	13.4	4.41	5.26	5.84	15.5	5.46	6.41	7.89	23.7	10.30	11.57	14.34
MADISON	1995	0.6	0.04	0.07	0.06	0.4	0.03	0.05	0.04	7.7	1.92	2.43	2.50	12.5	3.95	4.75	5.27	17.3	6.42	7.46	9.18	22.6	9.62	10.85	13.46
MADISON	1996	-1.1	0	0.0	0.0	1.4	0.16	0.33	0.28	3.6	0.61	1.06	1.09	ND	ND	ND	ND	18.1	6.86	8.30	10.20	22.2	9.33	10.79	13.38
MADISON	1997	-2.4	0	0.0	0.0	1.6	0.18	0.34	0.28	7.5	1.84	2.56	2.63	9.9	2.80	3.71	4.12	14.4	4.91	6.08	7.48	20.5	8.30	9.65	11.97
MADISON	1998	4.3	0.79	0.88	0.75	5.4	1.12	1.24	1.04	7.1	1.70	1.88	1.94	12.0	3.72	4.12	4.58	19.8	7.87	8.72	10.73	22.3	9.44	10.47	12.98
MADISON	1999	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	13.6	4.46	5.52	6.13	ND	ND	ND	ND	23.6	10.23	11.57	14.35
MADISON	2000	0.2	0.01	0.01	0.01	5.6	1.17	1.46	1.23	9.1	2.46	2.95	3.04	12.0	3.72	4.37	4.85	19.3	7.57	8.60	10.58	22.3	9.40	10.57	13.11
MADISON	2001	-0.2	0	0.0	0.0	3.4	0.56	0.69	0.58	5.1	1.02	1.23	1.27	14.7	5.02	5.75	6.39	18.7	7.21	8.15	10.03	21.7	9.06	10.15	12.59
MADISON	2002	3.2	0.52	0.63	0.53	3.4	0.56	0.68	0.57	6.2	1.39	1.64	1.69	13.7	4.52	5.16	5.73	15.9	5.69	6.46	7.94	23.3	10.05	11.20	13.89
MADISON	2003	-2.7	0	0.0	0.0	-1.8	0	0.00	0.00	7.7	1.92	2.47	2.55	13.3	4.33	5.22	5.80	17.4	6.52	7.61	9.36	20.2	8.10	9.29	11.53
MADISON	2004	-1.9	0	0.0	0.0	1.2	0.11	0.16	0.13	8.2	2.11	2.57	2.65	12.3	3.85	4.54	5.04	19.9	7.93	9.01	11.08	22.3	9.40	10.58	13.12
MADISON	2005	1.7	0.20	0.25	0.21	3.6	0.60	0.73	0.61	4.8	0.93	1.12	1.15	13.3	4.33	4.95	5.49	15.6	5.52	6.26	7.70	23.4	10.15	11.32	14.04
MADISON	2006	4.3	0.79	1.28	1.09	2.0	0.25	0.48	0.40	6.3	1.43	2.13	2.19	14.7	5.02	6.30	7.00	15.8	5.61	6.93	8.52	20.9	8.54	9.96	12.35
MADISON	2007	2.6	0.37	0.45	0.39	-3.8	0	0.00	0.00	9.1	2.44	2.85	2.93	8.3	2.15	2.52	2.80	19.6	7.73	8.70	10.71	22.6	9.62	10.75	13.33
Average Monthly Et (in)					0.1				0.17				0.90				2.12				3.73				5.24

Climate Data from http://www1.ncdc.noaa.gov/pub/orders/016229826525675021208094717.html

$Etp=1.6(10T/I)^a$

Etp=uncorrected evapotranspiration

T=mean monthly temperature (°C)

I=sum of the monthly heat index (i)

$a=6.7E\text{-}07(I)^3-7.7E\text{-}05(I)^2+1.8E\text{-}02(I)+0.49$

Et=Etp x mean possible duration of sunlight factor from Table V, Thornthwaite, 1948, p93

ND=No data available

Appendix I-10
Average Monthly Evapotranspiration
DU Impact Area, Jefferson Proving Ground, Indiana

STATION	YEAR	JUL °C	i	Etp	Et	AUG °C	i	Etp	Et	SEP °C	i	Etp	Et	OCT °C	i	Etp	Et	NOV °C	i	Etp	Et	DEC °C	i	Etp	Et	sum i (I)	a'
MADISON	1976	24.5	10.85	12.10	15.24	23.0	9.87	11.05	13.04	19.3	7.60	8.61	8.96	11.6	3.51	4.12	3.95	4.4	0.82	1.03	0.86	0.33	0.02	0.03	0.02	59.76	1.434
MADISON	1977	26.6	12.24	13.58	17.11	24.7	10.99	12.28	14.49	22.6	9.62	10.82	11.26	13.3	4.35	5.14	4.93	9.4	2.57	3.13	2.63	0.78	0.06	0.09	0.08	58.33	1.411
MADISON	1978	25.1	11.22	12.47	15.71	24.4	10.77	11.98	14.14	22.8	9.72	10.85	11.28	13.1	4.22	4.81	4.62	10.1	2.85	3.28	2.76	4.00	0.72	0.85	0.70	61.50	1.462
MADISON	1979	23.8	10.37	11.59	14.61	24.1	10.59	11.83	13.96	20.2	8.13	9.20	9.57	14.2	4.80	5.56	5.34	8.1	2.04	2.47	2.07	4.61	0.89	1.11	0.91	59.45	1.429
MADISON	1980	26.9	12.51	13.86	17.47	26.7	12.32	13.65	16.11	22.2	9.37	10.44	10.86	13.1	4.22	4.78	4.59	7.3	1.78	2.05	1.72	3.00	0.46	0.55	0.45	62.02	1.470
MADISON	1981	25.8	11.71	12.99	16.37	23.9	10.48	11.65	13.75	20.0	8.00	8.94	9.30	14.5	4.94	5.57	5.35	9.1	2.46	2.81	2.36	1.11	0.10	0.13	0.10	62.15	1.472
MADISON	1982	25.8	11.71	12.98	16.35	23.2	10.01	11.10	13.10	20.0	8.00	8.88	9.24	15.6	5.52	6.13	5.89	9.8	2.73	3.05	2.56	8.11	2.07	2.30	1.89	63.55	1.495
MADISON	1983	27.2	12.70	14.09	17.75	27.7	13.06	14.49	17.09	21.9	9.19	10.13	10.53	15.7	5.55	6.05	5.80	8.0	2.02	2.16	1.82	-2.06	0	0.00	0.00	65.74	1.531
MADISON	1984	23.4	10.12	11.33	14.27	24.6	10.88	12.14	14.33	19.4	7.67	8.70	9.05	17.0	6.27	7.18	6.90	6.7	1.54	1.89	1.59	6.83	1.60	1.96	1.60	59.37	1.427
MADISON	1985	24.1	10.59	11.77	14.83	23.5	10.19	11.33	13.37	20.3	8.20	9.16	9.52	16.5	5.99	6.73	6.46	11.0	3.26	3.70	3.11	-1.56	0	0.00	0.00	62.25	1.474
MADISON	1986	26.0	11.86	13.15	16.57	22.8	9.76	10.83	12.78	22.3	9.44	10.48	10.90	14.9	5.17	5.76	5.53	7.1	1.68	1.88	1.58	2.72	0.40	0.46	0.37	63.27	1.490
MADISON	1987	25.7	11.67	12.92	16.28	24.9	11.11	12.29	14.51	21.1	8.68	9.58	9.96	10.8	3.19	3.48	3.34	9.9	2.80	3.06	2.57	4.28	0.79	0.85	0.70	64.85	1.516
MADISON	1988	26.1	11.90	13.21	16.64	25.7	11.63	12.93	15.25	20.3	8.17	9.21	9.58	10.2	2.90	3.41	3.28	7.9	2.00	2.39	2.01	2.83	0.43	0.54	0.45	60.01	1.438
MADISON	1989	24.5	10.85	12.16	15.32	23.2	10.01	11.30	13.33	19.4	7.64	8.82	9.18	13.4	4.41	5.34	5.12	7.1	1.70	2.23	1.87	-5.11	0	0.00	0.00	55.88	1.372
MADISON	1990	23.7	10.30	11.52	14.52	23.3	10.05	11.25	13.28	20.5	8.30	9.39	9.76	13.6	4.49	5.24	5.03	9.6	2.67	3.19	2.68	3.50	0.59	0.76	0.62	59.25	1.426
MADISON	1991	25.5	11.52	12.76	16.08	24.2	10.66	11.82	13.94	20.4	8.23	9.12	9.48	15.1	5.23	5.78	5.55	5.9	1.30	1.43	1.20	3.89	0.69	0.76	0.62	64.04	1.503
MADISON	1992	24.0	10.52	11.87	14.95	21.3	8.81	10.14	11.96	18.9	7.34	8.61	8.96	12.7	4.03	5.04	4.84	7.9	1.98	2.68	2.25	2.22	0.30	0.49	0.40	53.71	1.338
MADISON	1993	26.2	12.01	13.35	16.82	24.6	10.92	12.23	14.43	18.7	7.25	8.38	8.72	12.4	3.93	4.77	4.58	7.2	1.72	2.22	1.87	1.67	0.19	0.30	0.24	56.46	1.381
MADISON	1994	23.8	10.41	11.68	14.72	22.1	9.26	10.49	12.37	18.8	7.31	8.41	8.75	14.1	4.74	5.63	5.40	10.3	2.95	3.62	3.04	4.78	0.93	1.24	1.02	57.22	1.393
MADISON	1995	24.8	11.07	12.37	15.59	26.5	12.20	13.54	15.98	18.5	7.12	8.21	8.53	12.7	4.06	4.87	4.67	4.4	0.84	1.12	0.94	0.00	0.00	0.00	0.00	57.27	1.394
MADISON	1996	22.9	9.83	11.27	14.20	23.3	10.05	11.48	13.55	19.2	7.54	8.99	9.35	13.8	4.60	5.90	5.66	3.6	0.61	1.06	0.89	2.17	0.29	0.55	0.45	49.88	1.279
MADISON	1997	24.7	10.96	12.33	15.53	22.8	9.76	11.13	13.14	19.6	7.77	9.11	9.47	13.7	4.52	5.65	5.42	5.6	1.19	1.74	1.46	2.50	0.35	0.60	0.49	52.58	1.321
MADISON	1998	24.1	10.59	11.74	14.79	24.4	10.81	11.98	14.14	22.8	9.72	10.78	11.21	14.8	5.11	5.67	5.44	8.5	2.22	2.46	2.07	4.06	0.73	0.81	0.67	63.81	1.499
MADISON	1999	26.7	12.36	13.70	17.26	24.0	10.52	11.87	14.00	19.8	7.90	9.19	9.56	13.9	4.66	5.74	5.51	10.5	3.04	3.92	3.30	3.33	0.54	0.85	0.69	53.71	1.338
MADISON	2000	23.8	10.41	11.64	14.66	23.4	10.15	11.37	13.41	19.2	7.54	8.56	8.91	15.4	5.43	6.27	6.02	6.3	1.43	1.76	1.48	-3.83	0	0.00	0.00	59.28	1.426
MADISON	2001	24.2	10.66	11.88	14.97	24.7	10.96	12.20	14.40	19.1	7.44	8.40	8.74	13.7	4.55	5.23	5.02	10.6	3.09	3.60	3.03	4.83	0.95	1.16	0.95	60.52	1.446
MADISON	2002	25.7	11.63	12.92	16.27	25.1	11.25	12.51	14.76	22.6	9.62	10.74	11.17	13.3	4.33	4.95	4.75	6.1	1.35	1.60	1.34	2.11	0.27	0.34	0.28	61.18	1.456
MADISON	2003	23.8	10.41	11.70	14.74	24.1	10.59	11.89	14.03	18.6	7.15	8.29	8.62	13.3	4.35	5.25	5.04	9.5	2.62	3.29	2.77	2.28	0.31	0.46	0.38	56.29	1.379
MADISON	2004	23.4	10.15	11.38	14.33	21.9	9.19	10.36	12.22	20.6	8.37	9.47	9.85	14.6	4.97	5.78	5.55	9.7	2.71	3.26	2.74	1.17	0.11	0.16	0.13	58.92	1.420
MADISON	2005	25.4	11.44	12.71	16.02	25.8	11.71	13.00	15.34	22.1	9.30	10.40	10.81	14.4	4.88	5.56	5.34	8.2	2.09	2.44	2.05	-0.28	0	0.00	0.00	61.15	1.456
MADISON	2006	ND	ND	ND	ND	25.1	11.25	12.64	14.92	18.2	6.93	8.31	8.65	11.9	3.67	4.80	4.61	7.6	1.86	2.67	2.24	4.56	0.87	1.39	1.14	50.87	1.295
MADISON	2007	22.9	9.79	10.94	13.78	26.8	12.39	13.74	16.21	23.1	9.90	11.06	11.50	17.4	6.52	7.37	7.08	ND	ND	ND	ND	ND	ND	ND	ND	60.91	1.452
Average Monthly Et (in					6.14				5.55				3.83				2.05				0.82				0.19		

Climate Data from http:/Climate Data from http://www1.ncdc.noaa.gov/pub/orders/016229826525675021208094717.html

$Etp=1.6(10T/I)^a$ $Etp=1.6(10T/I)^a$

Etp=uncorrected evapotrEtp=uncorrected evapotranspiration

T=mean monthly tempeıT=mean monthly temperature (^{0}C)

I=sum of the monthly heI=sum of the monthly heat index (i)

$a=6.7E-07(I)^3-7.7E-05(I$ $a=6.7E-07(I)^3-7.7E-05(I)^2+1.8E-02(I)+0.49$

Et=Etp x mean possible ‹Et=Etp x mean possible duration of sunlight factor from Table V, Thornthwaite, 1948, p93

ND=No data available ND=No data available

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APPENDIX J

PART AND RORA BASE-FLOW MODEL INPUT/OUTPUT

(Provided on CD only)

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