Supplemental Characterization of the FMRI Site

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ACRONYMS

AAL - Above Action Level

ALARA - As Low As Reasonably Achievable

BAL - Below Action Level

bgs - below ground surface

CD - Contract Drawing

cm - centimeters

cm/s - centimeters per second

CoC - Chain of Custody

COC - Contaminants of Concern

cpm - Counts per minute

DCGL - Derived Concentration Guideline Level

DP - Decommissioning Plan

dpm - Disintegrations per minute

ET - Evapotranspiration

FSS - Final Status Survey

GIT - Groundwater Interceptor Trench

gpm - gallons per minute

HDPE - High-density Polyethylene

HELP Model - Hydraulic Evaluation of Landfill Performance Model

HF - Hydrogen Fluoride

ICF - ICF Consulting

KPA - Kinetic Phosphorescence Analysis

IDW - Investigation Derived Waste

IEM - Integrated Environmental Management, Inc.

m - meter

MDA - Minimum Detectable Activity

MDC - Minimum Detectable Concentration

mg - milligram

MS/MSD - matrix spike/matrix spike duplicate

NGVD 29 – National Geodetic Vertical Datum of 1929

NOAA - National Oceanographic and Atmospheric Administration

NIST – National Institutes of Standards and Technology

NM – no measurement

NPDES - National Pollutant Discharge Elimination System

OCS - Oklahoma Climatological Survey

OPDES - Oklahoma Pollutant Discharge Elimination System

pCi - picocuries

pCi/g - picocuries per gram

pCi/l - picocuries per liter

pH - presence of hydrogen

PID - Photoionization Detector

ppb - parts per billion

ppm - parts per million

PRSO - Project Radiation Safety Officer

QA/QC - Quality Assurance/Quality Control

RA - Remedial Assessment

SCS - Soil Conservation Service

SER - Safety Evaluation Report

TEDE - Total Effective Dose Equivalent

USDA - U. S. Department of Agriculture

USGS - U. S. Geological Survey

USNRC - U. S. Nuclear Regulatory Commission

WIP - Work In Process materials

WWTP - Waste Water Treatment Plant

1 INTRODUCTION

Before ceasing operations in 1989, the former Fansteel, Inc. (Fansteel) manufacturing facility produced tantalum and columbium (niobium) metals from 1957 (Earth Sciences, 1993) at its site in Muskogee, Oklahoma. The raw materials (ore) used for production contained uranium and thorium as naturally-occurring trace elements. The concentrations of these elements were high enough to require licensing as source material by the Atomic Energy Commission, who issued License No. SMB-911 in 1967 to Fansteel. The following are important dates in the company's regulatory history:

- November, 2001 - Fansteel suspended all operations at the Muskogee site and filed for bankruptcy protection under Chapter 11 reorganization (USBC, 2002).
- July 2003 - Fansteel submitted a revised decommissioning plan, a request for exemption from financial assurance requirements, and a request for authorization to transfer the site license to a subsidiary being formed as part of the bankruptcy reorganization plan.
- November 17, 2003 - The bankruptcy court approved Fansteel's corporate reorganization plan and FMRI, the new subsidiary of the reorganized Fansteel, became the licensee for the Muskogee site.
- December 4, 2003 - The U. S. Nuclear Regulatory Commission (USNRC) approved the revised decommissioning plan, the request for exemption from financial assurance requirements, and the license transfer authorization, subject to the bankruptcy reorganization (USNRC, 2003).

The Muskogee site is currently being decommissioned under the authority of the USNRC pursuant to License No. SMB-911 (issued to FMRI) and the approved Decommissioning Plan, hereinafter referred to as "DP" (Fansteel, 2003). A radiological characterization survey was completed in 1993 (Earth Sciences, 2003), the scope of which included the interior and exterior of site structures, surface soils, subsurface soils, and groundwater, with results described in the DP.

In 2002, as part of a separate action, the USNRC contracted ICF Consulting (ICF) to independently analyze the costs associated with the decommissioning of the Muskogee site (ICF, 2002). ICF reviewed prior characterization data (i.e., including the 1993 characterization survey and the 2003 DP), summarized the data, evaluated their completeness, and provided recommendations on additional data needs that would improve the USNRC's understanding of the radiological and chemical character of the site.

In 2003, the USNRC prepared a Safety Evaluation Report (SER) in support of the decision to approve the DP that was based upon the ICF report (USNRC, 2003b). The SER presented the radiological status of the site as well as a listing of additional information required to support the commitments in the DP. The additional information needs were captured in the following specific condition to License No. SMB-911:

> *31.a: Licensee shall conduct an additional characterization of any additional contaminants at the site, including all soils, buildings and groundwater on the site, using guidance in NUREG-1757 (USNRC, 2006), Vol. 2 . . . Work shall be performed according to the following schedule: a. Submit a site characterization plan not later than February 28, 2011.*

The intent of this license condition is to ensure the additional data needed to support the DP be collected. The USNRC maintains these data are required in order to justify future remediation actions and to support health/safety provisions, fine-tune material volumes, develop final status survey plans, and improve the decommissioning cost estimates.

On February 11, 2011, in compliance with License Provision 31.a, FMRI prepared and submitted a supplemental characterization plan (FMRI, 2011), herein after referred to as the "Plan". The Plan, included herein as Appendix 13.1, was approved for implementation on March 2, 2011 (Shepherd, 2011). The on-site portion of the work began on September 26, 2011 resulting in the data and information captured in this supplemental site characterization report.

Other decommissioning operations have been on-going at the FMRI site (hereinafter referred to as the "Site") since July 18, 2011. Some of these limited the field team's ability to complete all of the tasks specified in the Plan. The following are those items that are yet to be performed:

- Additional characterization of structures, including sewers, waste systems, floor drains, ventilation ducts, and floor joints;

- Additional characterization of surface soil, performance of gamma scan and collection of discrete surface soil (i.e., top 15 centimeters) samples; and

- Additional characterization of subsurface soils near the Chemical A (Chem A) Building, Chemical C (Chem C) Building, Sodium Reduction Building, Thermite Building, R&D building and the Equipment Storage Pad.[1]

The following requirements of the Plan have been completed and are summarized herein:

- Characterization of soil to a depth of one (1) meter;

- Characterization of subsurface soils near Pond No. 2 and Pond No. 3;

- Summary of groundwater monitoring investigations from 1993 to 2010;

- Groundwater water quality and water level information from 1993 to 2010;

- Investigation of hydraulic conductivity and hydrogeologic properties for use in groundwater velocity calculations and future groundwater modeling applications; and

- Groundwater Interceptor Trench System effectiveness.

In addition, Derived Concentration Guideline Levels (DCGLs) were developed for the Site and presented in the DP.[2] Because they are critical to the decommissioning process, additional information relative to their development are required to support the license termination process.

This report contains an overview of the current status of the FMRI site, a brief description of the approach to the supplemental characterization effort, the data that were collected in response to the

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[1] The Equipment Storage Pad and the Chemical Storage Pad are located west of processing building Chem A. It has been previously termed the Ore Storage Pad because ore was stored in this area prior to it being processed in Chem A (i.e., prior to 1989).

[2] DCGLs are the concentrations of residual radioactivity in soil and on building surfaces that represent a radiation dose to the average member of the critical group that is less than 25 millirem per year (mrem/yr).

requirements of the Plan, the DCGL presentation, and FMRI's plan for acquiring the outstanding information. Representatives of FMRI were given an opportunity to review a draft before publication of this report.

2 CURRENT STATUS OF THE SITE

2.1 Physical Setting

The Site is located approximately four kilometers (2.5 miles) east of the center of Muskogee, Oklahoma, with the Arkansas River (Mile 395) on the east, Highway US-62 on the south, and the Muskogee Turnpike on the west. It comprises about 38 hectares (75 acres) in area. A good summary of the general physical setting of the Site, including its physical characteristics and its proximity to people who could be affected by existing contamination or decommissioning activities, can be found in Section 3 of the DP (Fansteel, 2003).

2.2 Nature and Extent of Contaminants

Natural uranium and natural thorium were present in the ores and slags used for tantalum and columbium (i.e., niobium) production in concentrations of about 0.1 percent uranium oxide and 0.25 percent thorium oxide. The raw materials were digested in a hydrofluoric acid (HF) solution but the uranium and thorium were not extracted by the digestion process. As a result, the byproducts of the process, referred to as Work in Process materials or WIP, were disposed of in Pond Nos. 2 and 3. Water from the process and from the French drain constructed around Pond No. 3 was collected and treated, then passed on to Pond Nos. 6, 7, 8, and 9 for solids precipitation prior to discharge through a National Pollutant Discharge Elimination System (NPDES) outfall into the Arkansas River.[3]

Structures and equipment associated with the ore processing operation are the Chem C Building, the Chem A Building, and the R&D Building. In 1993, radiological surveys were performed over the interior and exterior of all Site structures, as well as over open land areas of the Site (Earth Sciences, 1993). These showed the Chem C Building to be with radioactive ore residues. Isolated areas of residual contamination were also identified in the Chem A Building, the R&D Building, and in other structures.

The 1993 land area surveys show surface and subsurface soils to be locally contaminated with low but detectable concentrations of natural uranium and natural thorium (i.e., several 10's of picocuries per gram). The highest concentrations were found in Pond No. 2 and 3 to the east and north respectively of the Chem C building. The average concentrations of uranium in Pond No. 2 and 3 were found to be 360 and 640 picocuries per gram (pCi/g), respectively, with thorium concentrations averaging 360 and 440 pCi/g, respectively (USNRC, 2003b). The 1993 surveys also showed the average concentration of uranium and thorium in Pond No. 5 through Pond No. 9, at the southern end of the Site, to be less than 0.05% by weight. All of the survey data indicate that the constituents of concern are uranium and thorium only, with their radioactive progeny are in general equilibrium. A more detailed description of the extent of residual uranium and thorium contamination at the Site appears in Section 4 of the DP (Fansteel, 2003).

2.3 Decommissioning Actions to Date

FMRI began Phase 1 of the actions outlined in the DP in 2005. Phase 1 included the removal of WIP from Pond No. 3, with transfer of the excavated material to an out-of-state uranium mill for use as alternate feed. All residual WIP was removed from Pond No. 3 in 2006, with the berms and interior reshaped for erosion control.

In 2011, approximately 200 tons of WIP was removed from a drying bed near the southeast corner of Pond No. 3. Approximately 180 two-ton bags of WIP from Pond No. 3 remain staged in the Thermite Building for eventual shipment. Excavation of Pond No. 2 began in September, 2011 and is on-going as of the date of this report.

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[3] In September of 1998, Fansteel constructed an interceptor trench along the east and south sides of the Site. The purpose of the interceptor trench is to capture ground water from the Site, process it through the wastewater treatment facility, then discharge it via the NPDES outfall.

3 APPROACH

Integrated Environmental Management, Inc. (IEM), a Maryland-based radiological services firm, was contracted by FMRI to assist with the implementation of the Plan. Specifically, the following supplemental characterization information is required:

- Radiation surveys of structures, with emphasis on sewer discharge points, waste systems, floor drains, ventilation ducts, piping, floor joints;
- Radiation surveys of systems and equipment for release purposes;
- Surface soil sample collection/analysis at specified locations and depths, gamma scans (i.e., walk-over surveys), exposure rate measurements;
- Subsurface soil collection/analysis at specified locations and radiation screening of soil cores;
- Surface water assessment using data from the ongoing surface water sampling program;
- Sediment sampling; and
- Evaluation of hydrologic data from the Site's extant monitoring well system via compilation, presentation and interpretation of existing groundwater quality and water elevation data.

The remainder of this report addresses these specific information needs. They are presented in the same general order as they appear in the Plan. Those aspects of the Plan that were not completed as part of this initial effort (see Chapter 1, above) are addressed further in Chapter 9, wherein FMRI's commitment to the acquisition of the remaining information is given.

4 FACILITY CHARACTERIZATION

4.1 Structures

Several structures currently exist on site. They currently or at one time in the past housed administration, process, and support activities. No process activities involving ores or WIP have occurred at the Site since completion of the 1993 characterization survey. Historical and periodic surveys of radiation and radioactivity for structures are readily accessible at the FMRI facility. The survey data has been reviewed in detail during USNRC inspections since year 2000. Review of the survey results by FMRI personnel and USNRC inspection has not identified any remarkable condition. Information gaps were identified in the existing radiological characterization of structures (ICF, 2002).

Additional characterization of structures is not necessary to support decommissioning activities (USNRC, 2003b). No radiation surveys of buildings were thus performed as a part of the supplemental characterization. Additional radiation surveys are scheduled after the excavation work is complete in Pond No. 2, anticipated in 2012. The surveys will be completed in the sewers, ventilation ducts, selected process piping and selected floor joints at that time as described in the Plan.

4.2 Systems and Equipment

Several buildings contain equipment that was directly or indirectly involved with processing radioactive material (i.e., WIP). These are comprised of tanks, piping, and associated mixers and pumps. When this supplemental characterization effort began, the equipment had been emptied of bulk material but not cleaned or decontaminated.

Systems and equipment are surveyed for the presence of radioactivity before being released from the Site for unrestricted use. Documentation is generated by the Project Radiation Safety Officer (PRSO) to establish conformance with requirements for release for unrestricted use, including survey results and associated calibration records. No additional radiological characterization of systems and equipment to support decommissioning activities was performed as part of the supplemental characterization.

5 SURFACE WATER AND SEDIMENT CHARACTERIZATION

Historical and periodic sampling of surface waters in accordance with the Oklahoma Pollutant Discharge Elimination System (OPDES) permit is readily accessible at the FMRI facility. The data have been reviewed in detail as part of USNRC inspections since year 2000 and by FMRI, neither of whom identified any remarkable conditions. The FMRI facility has been and continues to be in compliance with the terms of its OPDES Permit as well as the related discharge and monitoring requirements of its USNRC License. Data sufficient to characterize the radiological status of surface water and sediments is provided in Section 4 of the DP (Fansteel, 2003). Remedial action surveys and final status surveys will provide a statistical basis for releasing sediments for unrestricted use, thus no additional data for these environmental media are required at this time.

6 SOIL CHARACTERIZATION

Pursuant to the requirements of the Plan, the project team collected two different types of surface soil samples from designated locations within the FMRI property. These were defined in the Plan as surface soil from 0 to 15 centimeters (cm) below ground surface (bgs) and 0 to 1 meter (m) bgs. As illustrated in Figure 1 of the Plan, distinctly different locations for each of the depths were specified. The 22 shallowest samples were largely confined to a northern tier of the property that had not been used in the operational history of the facility.

The remaining 34 deeper soil samples were designated for locations where either operational activities took place in the past or required additional data collection to improve the understanding of a specific area's characteristics. These one-meter-deep soil samples, hereinafter referred to as "one meter samples", were primarily located in and around Pond No. 3 and other select points in the central and southern portions of the Site.

The supplemental sample collection effort (Program) at FMRI commenced on September 26 and concluded on October 2, 2011. At the outset of the Program, FMRI indicated that a change in sampling activities was desired. The 0 to 15 cm surface soil samples would not be collected during this mobilization event. The one-meter deep sample collection was to proceed without modification, with samples collected in accordance with Plan requirements. Subsurface soil samples (i.e., those soil increments greater than one meter bgs) were also designated for collection during this field event. A further discussion of the "deep" samples is presented in Section 6.3 of this Report.

6.1 Procedures/Methodologies

The purpose of this subsection is to present the procedural activities and methodologies employed during the collection of all soil samples required by the Program. The information herein generally describes the preliminary precautions taken to ensure safe sampling practices at the Site; sample documentation, collection, and shipping protocols observed by the field team; decontamination precaution taken to eliminate possible cross contamination of sampling sites and sample aliquots; waste management activities; and analytical methods used to evaluate each recovered soil sample. Figure 12.1 contains photographs of some of the on-site activities.

6.1.1 Utility Clearance

Prior to conducting invasive sampling operations at the FMRI site, a comprehensive survey of subsurface utilities was undertaken. A local third party utility survey subcontractor (Advanced Electrical Services, Inc.) was retained to conduct the utility assessment and mark known or suspected subsurface hazards. Additionally, the State-chartered "Call Okie" (Oklahoma One-Call System, Inc) was contacted to notify public utilities in the area of the upcoming subsurface investigation.

Utility "mark outs" created by these organizations were subsequently verified by knowledgeable FMRI personnel with significant institutional knowledge of the property and its infrastructure. Several of the proposed soil boring locations were found to be in close proximity to known or suspected buried utilities. In those locations where the potential to encounter subsurface hazards were likely, the field team used manual sample collection techniques to ensure the protection of the utility as well as the safety of personnel. No encounters with buried utilities took place during the course of the Program.

6.1.2 Sample Collection Protocols

Soil media from each one-meter and subsurface core recovered from the boring locations was analyzed for radiological and chemical parameters. Each recovered core was field screened as described in Section 6.1.6, below.

Once the screening of a soil core was complete, the entirety of the one-meter core and a portion of the subsurface core were homogenized and an aliquot sent to an off-site laboratory for radiological and chemical analysis. The radiological parameters of interest were thorium isotopes, radium isotopes (Ra-226 and Ra-228) and total uranium. The chemical parameters included specific target-list metals (antimony, arsenic, cadmium, chromium, lead, niobium, tantalum and thallium), anions (fluoride and nitrate), and ammonia.

Samples of volatile organic compounds (VOCs) and periodic pH sample aliquots were also collected for laboratory analysis. These particular chemical parameters were only collected from subsurface soil cores and not the one-meter cores. The VOC samples were biased, based on the following selection hierarchy, to those segments of the recovered core that either: 1) exhibited elevated field screening VOC levels; 2) were collected at the water table or saturated zone interface or; 3) was collected from the bottom or lowest-level of each core. The VOC samples were collected in a four-ounce jar (with zero head space) for subsequent shipment to the analytical laboratory.

Information regarding the specific types of analyses and laboratory methods used to evaluate all soil samples are presented in Section 6.1.8, below. Quantities of soil collected for these analyses are as follows: 500 milligrams (mg) for radiological analysis (these samples were packaged in plastic bags); one full 4-ounce jar for metals analysis and; one full four-ounce jar for anion and ammonia analyses. No specific pH sample aliquot was collected. Analysis of this physical parameter used extra soils from the metals sample aliquot.

Radiological samples were sent to Outreach Laboratory in Broken Arrow, Oklahoma. Chemical analyses were conducted by ALS Laboratories in Fort Collins, Colorado.

6.1.3 Sample Documentation

Established, industry-standard procedures for documenting the management of soil samples recovered from each sample location were observed during the Program. These recordkeeping methods included the use of Chain-of-Custody (CoC) forms and dedicated project logbooks.

The CoC record serves as a legal record of possession for each sample from its collection in the field to its receipt and analysis by a designated analytical laboratory. As each of the soil samples were collected and placed in labeled sample containers, information regarding the date, time of collection, media matrix – in this instance all samples were soil – and specific analyses required for each sample aliquot was recorded on a pre-printed CoC form. The information recorded on the CoC was compared and confirmed to be identical to the informational label affixed to each individual sample container for quality assurance purposes. The CoC documentation and samples were held together to ensure the custody and integrity of materials collected during the field action. These materials were collectively placed under the care and oversight of the designated sample manager. All samples collected were considered to be under custody if one or more of the following criteria are met: (1) The sample material was in the sampler's possession; (2) The sample was in the sampler manager's view after taking possession; (3) The sample was in the sampler manager's possession and was then locked up to prevent tampering; or (4) The sample was in a designated secure area.

To further differentiate each sample collected from the numerous boring points present on the facility grounds, each sample was assigned a unique sample identifier or "name". The elements of the name included: The project name (FMRI); the general status of the boring, be it a one meter soil (S) or a deeper subsurface soil (D) Program sample; the boring point's numerical designation and; the depth increment (in meters) based on the terminal depth of the specific boring. An example of this sample designation methodology is FMRI-S15-1m or FMRI–D03-4m. This unique sample identification information was recorded on both the CoC and sample label, and served not only to differentiate the samples from one another, but acted as an inventory/accounting tool to ensure no samples were overlooked in the collection and eventual sample shipping process.

Sample documentation information was also recorded in a separate, dedicated project field logbook. The logbook was kept by the field manager and records, among other field observations, the collection dates, times, and boring information for each sample collected. This independent source of sample information is considered a best management practice industry standard as well as a quality assurance/quality control (QA/QC) mechanism for ensuring that discrepancies in sample logging did not occur. Each signed page of the field logbook further ensures the integrity of the information recorded therein and is used, in concert with the CoC data, to develop subsequent reporting deliverable information to the client.

6.1.4 Sample Shipping

Depending on the numbers of individual samples collected and/or "hold time" analytical restrictions that apply to specific analytical methods, more than one shipment of the sample media was required between the field and the designated analytical laboratory. Sample containers that are shipped together as a group were assigned/recorded on a single, signed original CoC that was placed in the secured interior of the shipping container. A duplicate copy of this same CoC was retained for the project files. The container(s) used for sample shipment were commercially available plastic coolers. Shipping was typically arranged through an overnight transport services; for purposes of this project, FedEx® was used to ship all sample materials to the designated chemical analysis laboratory. Radiological samples were hand-delivered due to the proximity of the radiological laboratory in nearby Broken Arrow, Oklahoma.

Upon receipt of the shipments, the laboratory assumed custody of the sample materials and certified their custody of the materials on the enclosed CoC. The laboratory was subsequently instructed to attach a copy of the fully-executed CoC to the completed analytical report delivered to the project team.

6.1.5 Decontamination Procedures

Cross contamination was mitigated by the aggressive performance of radiation surveys throughout the process, as well as performing/documenting equipment release surveys as described in Section 6.1.6.3, below. Potential chemical cross contamination between boring sites was addressed by a multi-step cleaning procedure for all equipment that came in contact with the soil. This typically was restricted to the cutting shoe and sample collection barrel used at each borehole. The internal acetate liner placed in each collection barrel was a one-time use item and, as such, was not subject to decontamination procedures.

The tool cleaning process began with a gross wash procedure in which heavy soil accumulations that might be clinging or smeared on the barrel or shoe were physically removed by heavy wet brushing and scrubbing. Alconox, a concentrated, anionic detergent commonly used to clean environmental sample collection gear, was used as the surfactant cleanser in this cleaning process. After thorough washing and rinsing, a final distilled water rinse was applied to each tooling element.

At any given boring site, only the cutting shoe and sample collection barrel required decontamination. In many instances, cleaning of the same shoe and barrel for each one meter or deeper subsurface drive was not necessary as redundant or "extra" shoes and barrel elements were available to fully address the drive requirements for a single hole. Nevertheless, as one boring was completed and the move to the next sampling site was contemplated, all sample collection tooling used in the prior drive required cleaning before reuse in the next borehole. This decontamination was also applied to all sample barrel connecting rods and the outer tube or casing of the "dual tube" system used during the subsurface sample collection activities. A further discussion of the "dual tube" subsurface soil sample collection technique is presented in Section 6.3 of this report.

6.1.6 Radiological Activities

6.1.6.1 Instrumentation

The radiation detection instruments used for the performance of soil core screening and equipment release are described in the following subsections. Each instrument was calibrated by a licensed commercial calibration service using National Institute of Standards and Technology (NIST) traceable sources and calibration equipment, and subject to daily response checks as required in the work plan. Appendix 13.2 contains the instrument calibration records and daily response check records, including a daily determination of the minimum detectable activity (MDA) of the instrument.

6.1.6.2 Coring Area Surveys

Prior to collecting soil cores, the ambient exposure rate directly above each collection location was measured using a hand-held sodium iodide detector (Ludlum Model 19) with the detector centerline positioned at a distance of approximately six inches from the ground surface. As shown in Appendix 13.3, the survey results ranged from 10 to 42 microR per hour. Two of the coring locations (D04 and D10) were in close proximity to the Pond No. 2 excavation operations and thus exhibited elevated exposure rates consistent with the Pond No. 2 background measurements on that date. One of the locations (S07) was in close proximity to staged supersacks of WIP, thus also exhibiting elevated surface exposure rates.

6.1.6.3 Soil Core Screening

Each of the soil cores collected from both the one meter and subsurface sampling locations were evaluated for lithology. Once released from the restricted zone, the soil-filled acetate tube was taken to a nearby sample logging and collection station. The tube was then cut open and the exposed soil column was field screened using a hand-held GM detector (Ludlum Model 44-9 coupled to a Ludlum Model 12 rate meter) positioned at a distance of approximately 0.5-inch from the core. The scan speed was approximately one 2.5 centimeters per second, with the location of maximum measured count rate noted on collection log. As shown in Appendix 13.4, the screening results (60 to 220 counts per minute) were not distinguishable from background.

Field screening of the exposed soil column was followed by a similar survey using a photoionization detector (PID). The PID was employed to provide real-time indications of the presence of VOCs in the recovered soil cores. Once screened, biased soil sampling or compositing for radiological and chemical testing took place.

One-meter cores were homogenized and an aliquot collected for radionuclide and chemical analysis (see Section 6.1.8, below). For the subsurface cores, the one-meter segment that surrounded the maximum measured screening value was extracted, homogenized and an aliquot submitted for analysis.

6.1.6.4 Equipment and Area Contamination Control

Due to the radiological nature of the investigation at FMRI, a strict protocol for surveying and releasing sample collection tooling, support gear, and sample media was observed throughout the course of the field investigation. At each boring site, a large, reusable plastic tarp was placed atop the specified boring location to designate a "restricted zone" within which all sample collection and field monitoring activities were conducted.

The Geoprobe® was driven onto the plastic and subsequently advanced its sample collection and drive tooling into the ground through a "portal" cut in the underlying plastic. As sample tools were advanced and recovered from each boring, real-time reading instrument surveys of the retracted tooling was conducted by a certified HP technician to ensure residual radiological contamination did not adhere to tooling surfaces that ordinarily come into contact with soils.

As the sample tooling was returned to the surface, connecting rods used to hold the sample collection barrel in place at depth were set aside for the next boring/advance. The sample barrel, which is comprised of a removal cutting shoe and interior acetate collection tube, was broken down to remove the acetate liner (and the soil it contained). Each of these components was surveyed and, if found to be free of radiological contamination, released from the restricted zone for sample recovery. Cutting shoes, sample barrels, and associated tooling were then washed and cleaned prior to re-use (see discussion below). Sampling personnel reported that radiological decontamination of sampling gear (or associated equipment or personnel) was not necessary on any of the numerous borings advanced during this investigation.

All supporting materials and equipment located within the restricted zone, including the Geoprobe® unit itself and any personnel working within the zone, were similarly surveyed for the presence of potential contamination. Once released, these support items and personnel could be removed from the plastic, the bore hole secured (backfilled), and investigation operations moved to the next boring site.

Pursuant to FMRI procedure No. HSDI418, the criteria for release of equipment and personnel from the work areas are 1,000 dpm/100 cm^2 for alpha-emitting activity and 5,000 dpm/100 cm^2 for beta-emitting activity. Appendix 13.5 contains the release survey records for the project.

6.1.7 Investigation Derived Waste Management

During the course of the investigation process, several waste streams were generated in the collection, sampling, and packaging of soil sample aliquots for analysis. The investigation derived wastes (IDW) included: 1) excess soil not used for sampling requirements; 2) tool cleaning waters; 3) disposable materials that came in contact with potentially-contaminated soils and; 4) miscellaneous solid wastes that did not come into contact with sampling operations.

Composited soil not used for sample analyses from each one meter core was collected and stored in 5-gallon plastic buckets rather than being returned to the borehole from which they were generated. These IDW soils were presented to FMRI personnel on a periodic basis for storage with other contaminated media under their control. In a similar fashion, "potentially impacted trash" that might potentially have become contaminated by media contact were bagged and also submitted to FMRI for management and future disposal. Items of this nature included spent acetate liners, gloves, and miscellaneous paper and plastic materials soiled by dirt.

IDW waters associated with decontamination procedures were collected in buckets and discharged to a specific drain located near the Site's wastewater treatment plant (WWTP). These spent waters were subsequently "chased" with a volume of clean water from a nearby hose spigot to ensure the spent decontamination waters were completely flushed to the WWTP.

The final IDW stream created during the Program were miscellaneous solids such as packing materials, cardboard boxes, paper bags, and other support items that largely held supplies used during the investigation, but did not come in contact with sampling activities or soil media. These types of items were bagged and disposed with other releasable facility trash/garbage.

6.1.8 Analytical Requirements

The investigation of FMRI's subsurface soil conditions required the project team to evaluate a specific roster of radiological and chemical parameters considered to be indicative of past industrial activities at the Site. Specific information regarding each of these analytical parameter "classes" is presented below.

6.1.8.1 Radiological Requirements

Soil samples collected from the one meter and subsurface soil cores were transferred to sealable plastic collection containers. Each sample was marked and logged with a unique sample identification, sample depth, the date and time sampled, and the initials of the individual who obtained the sample. The sample containers were placed into coolers and a signed copy of the CoC Record was retained by the field team after the coolers were sealed. The laboratory was instructed to attach a copy of the fully-executed CoC Record to the Certificates of Analysis.

Each sample was prepared by removing rocks and vegetation, drying, grinding, mixing/blending, then analysis. Preparation techniques were carried out in accordance with laboratory-specific procedures and quality control provisions. Each soil sample was analyzed for thorium isotopes, radium isotopes (Ra-226/228) and total uranium (KPA), with the analytical technique and required detection limits as outlined in Table 1 of the Plan. Preliminary results were reviewed and verified for compliance with detection levels before the laboratory reports were finalized.

6.1.8.2 Chemical Requirements

A short list of inorganic compounds and two specific volatile organic compounds comprise the "suite" of analytical parameters cited by the client for consideration under this investigation. Additionally, the physical parameter of pH was also recorded from soils using both real time instruments and laboratory analytical methods. Chemical analysis requirements were not specified in the February 2011 Plan used to conduct this investigation. Instead, the need to evaluate potential chemical contaminants was apparently linked to requirements imposed (or otherwise requested) by the State of Oklahoma and/or the client.

Metals comprise the largest group of potential chemical contaminants specified for this investigation. Sampling for metals was required for both one meter and deep subsurface soil samples. Several of the metals in question (antimony, arsenic, cadmium, chromium, lead, and thallium) are commonly cited contaminants at many industrial and related waste cleanup sites nationwide. In many cases, these metals may have naturally occurring and/or anthropogenic origins at a given site.

In addition to these metallic elements, two rare earth metals directly tied to historical processing/refining activities at the FMRI site were also identified for potential detection in recovered samples. These metals are niobium (historically called columbium) and tantalum. In each case, metals were analyzed via inductively coupled plasma-mass spectrometry (ICP-MS) techniques. Because of the unique nature of niobium and tantalum, EPA Method 6020A rather than the more commonly employed 6010B method, was used by the laboratory to enhance detection results. Each sample was subject to a serial dilution as a standard practice for ICP-MS; further dilutions to bring niobium into the analytical range of the ICP-MS were also required. Analytical results presented elsewhere in this Report for niobium are "flagged" with a "D" qualifier.

The remaining inorganic, non-metallic compounds evaluated from shallow and deep subsurface soils include the anions fluoride (F^-) and nitrate (NO_3^-) and ammonia (NH_3) were evaluated due to their linkage with industrial processing operations that historically occurred in the refining of tantalum and niobium metals. Nitrate and fluoride anions were analyzed via EPA Method 300, while ammonia was analyzed via EPA Method 350.1.

The final group of chemical compounds specifically targeted in subsurface soils were VOCs. The requirement for VOC analysis was driven by the chlorinated solvent trichloroethene (TCE) and the solvent methyl isobutyl ketone (MIBK). MIBK is also identified as 4-methyl-2-pentanone and appears as such in all reporting data received from the analytical laboratory.

TCE and MIBK comprise two of the more than 60 individual VOCs that are included on the target analyte list (TAL) for VOCs via EPA Method 8260B. MIBK is recognized as an agent used in the processing and extraction of metals from ore; niobium and tantalum production was facilitated by the use of this chemical compound and its presence in subsurface media is likely related to past operational activity. Conversely, the solvent TCE was reportedly never used on-site during its operational period, but was nevertheless requested by the State of Oklahoma as an analytical parameter to be investigated during this Program.

Supporting these fixed laboratory analytical methods for volatile compounds, the project team also employed a Photoionization Detector (PID) to provide real-time indications of the presence of VOCs in the recovered soil cores. This instrument is designed as a general volatile chemical detection device and was run along the length of the exposed soil core once the acetate liner was cut away in a effort to selectively/opportunistically collected potential contaminated “hot spots” that might be present in specific sample soil strata.

Although reporting on VOCs other than TCE and MIBK were not specified by the client, the broad range of specific VOCs analyzed is provided for completeness and possible discussion/reporting relevance, as appropriate. A full presentation of all chemical data, including VOC results is provided in Appendix 13.6 of this report.

Another real-time instrument used to characterize soils recovered from varying subsurface depths was a simple pH meter. This dual-pronged soil contact probe yielded general information regarding this physical parameter of the soils relative basic/acidic conditions. Soil sample collected from the select metals subsurface soil sample aliquots were evaluated for pH in fixed laboratory analyses as a quality assurance measure of the real-time instrument’s accuracy.

6.1.9 Quality Assurance/Quality Control Samples
In accordance with the Plan, appropriate QA/QC samples were collected in the field from shallow and deep subsurface soil to assess sampling and analytical precision and accuracy, as well as any interference from the sample matrices. Soil QA/QC samples collected as part of the Site characterization program included: One equipment rinsate sample collected from re-useable sampling equipment (i.e., hand auger); one equipment rinsate sample collected from disposable acetate liners affixed to the re-useable Geoprobe® cutting shoe; eight duplicate samples (three one meter soil and five subsurface soil); and three matrix spike/matrix spike duplicate (MS/MSD) samples. Soil QA/QC samples were submitted for laboratory analysis of select metals, fluoride, nitrate, ammonia, and VOCs. Additionally, one (1) trip blank was submitted as part of the QA/QC samples and was analyzed for VOCs.

6.2 Shallow (One Meter) Soil
6.2.1 Sample Locations
Although the Plan calls for the collection of true surface soil samples (i.e., the top 15 cm of soil) in the far northern portion of the FMRI property, these samples were deferred for the time being. Collection of surface soil samples will reportedly commence upon the completion of the remediation of Pond No. 2 (see Chapter 9, below). Specific information regarding the collection process and data results generated by the one meter sampling operations is presented in detail below. Subsurface (> one meter) soil sampling is described in Section 6.3 of this report.

The project team advanced each of the 34 designated one meter borings, designed as “S” sample identifiers, in those locations specified in Figure 1 of the Plan. A revised copy of this Plan figure, which was modified to provide unique numerical identifiers for each of the designated sampling locations, is presented as Figure 12.2. Additionally, details regarding the physical collection of these samples as well as the analytical results generated from the evaluation of the soils for radiological and chemical contamination are presented below. Soil boring logs detailing soil boring lithology are included as Appendix 13.7.

6.2.2 Sample Collection
As shown in Figure 12.2, most of the one meter soil borings are located in the northern portion of the facility associated with former process areas and Pond No. 3. Smaller subsets of points were also positioned in the former “Borrow Area” situated in the southwestern portion of the property and on the bank of the Arkansas River to the east of the facility. Field personnel reported that most of the sample locations were readily accessible to the track-mounted system Geoprobe® unit and did not clearly conflict with any identified subsurface utility rights-of-way. Those sample sites, however, that presented the most likely potential for utility conflicts were sample points S07 through S13. These points are situated in the central portions of the facility, near buildings Chem “A”, the R&D Building, and the Thermite Building and were located in the general vicinity of subsurface utilities.

Due to the inconclusive results associated with the tracing of some subsurface utilities by a local utility locating subcontractor, soil samples from points S07 through S13 were collected with hand augers rather than the Geoprobe's® hydraulic sample retrieval system. Hand sample collection methods were deemed appropriate to mitigate possible damage to any potential underlying utilities and as an employee safety measure. No contact with any subsurface utilities was encountered during any of these several individual manual sample collection actions.

Another series of one meter soil boring locations that were not accessible to the Geoprobe's® hydraulic-enabled collection system were those points situated near the bank of the adjacent Arkansas River. Due to dense vegetative cover, significant topographic variability, and a perimeter security fence, access to points S16 through S21 via the track mounted probe was nearly impossible. Efforts to collect these one meter samples relied instead on the use of either hand augers or, where difficult soil conditions warranted, the use of a manual slide hammer device designed and sold by Geoprobe Systems, Inc. In either case, the full one meter soil horizon in these remote and difficult to access locations were sampled and the full series of soil sample aliquots recovered for both radiological and chemical analyses.

A final subset of one meter soil boring locations that warrant some discussion here include four locations situated in or around Pond No. 3 that were identified as surface (1 m) sample and deep (>1 m) sample locations. These points (S26, S27, S33, and S34) were designated as "co-located" sample positions. In each of these points, continuous one meter samples were collected from the surface to terminal depths (bedrock and/or advancement refusal) several meters below the surface.

6.2.3 Radiological Results

Ambient exposure rates at the core sample collection locations were unremarkable (see Section 6.1.6.2 , above, and Appendix 13.3), as were the radiological screening results for the individual soil cores (see Section 6.1.6.3 and Appendix 13.4). Appendix 13.8 contains the radioanalytical results for the one meter soil samples, which were all generally within the range of background values. The following is a summary of the data set:

Radionuclide	Average Concentration (pCi/g)	Minimum Concentration (pCi/g)	Maximum Concentration (pCi/g)
Ra-226	2.54 ± 3.23	0.27	10.5
Ra-228	1.68 ± 1.99	-1.28	8.38
Th-228	1.21 ± 2.32	0.11	11.0
Th-230	1.87 ± 3.55	0.08	15.0
Th-232	1.19 ± 2.39	-0.47	10.6
Total U	8.43 ± 10.46 μg/g	1.58 μg/g	45.4 μg/g

The maximum measured total uranium concentration of 45.4 μg/g (15 pCi/g of U-238) was identified at collection location S33 (see Figure 12.2).[4]

6.2.4 Chemical Results

6.2.4.1 Metals

Soil samples collected from the first one-meter interval were submitted for laboratory analysis of select metals. The metals antimony, arsenic, cadmium, chromium, lead, and thallium were detected in each of the 34 one meter soil samples. Similarly, niobium and tantalum which are directly related

[4] The total uranium concentrations can be converted to U-238 concentrations by assuming that isotope comprises 98% of the uranium mass, and by applying a specific activity of 3.3E-07 Curies of U-238 per gram of soil.

to historical site operations, were also detected in each of the one meter soil samples. A brief overview of the findings associated with these last two metals is presented below and a complete presentation of all analytical results for metals in one meter soil is in Appendix 13.6.

Niobium detections across the entire data set ranged from 10 to 470 parts per million (ppm). The lowest concentrations (10 to 20 ppm), by intra-site geographic locale, were detected in samples collected from the Borrow Area (S01 through S06). Niobium was detected in riverbank samples (S16 through S20), east of the facility's perimeter security fence and adjacent Arkansas River, at concentrations ranging from 15 to 75 ppm. Consistently higher niobium concentrations were detected in soils from the process area of the facility (S07 through S15) and Pond No. 3, which contains the balance of the one meter soil samples (S22 through S34). Niobium was detected at concentrations ranging from 17 to 350 ppm in one meter soil samples collected from within the process areas while even higher concentrations (47 to 470 ppm) were detected in samples collected from within and around Pond No. 3.

Tantalum detections, like niobium discussed above, follow the same concentration distribution trends relative to the geography of the Site. The Borrow Area concentrations range from 3.6 to 9.6 ppm while the riverbank concentrations range from 3.2 to 10 ppm. Tantalum was detected in one meter soil samples collected from the process and Pond No. 3 areas at concentrations ranging from 3.5 to 670 ppm and 17 to 1,300 ppm, respectively.

6.2.4.2 Fluoride, Nitrate, and Ammonia
Fluoride, nitrate, and ammonia were detected in each of the 34 one meter soil samples collected. A complete record of fluoride, nitrate, and ammonia analytical results is provided in Appendix 13.6. A brief narrative discussion of the results is found below.

Fluoride was detected in all but one of the one meter soil samples with concentrations ranging from 1.9 to 530 ppm. The lowest concentrations of fluoride (6 to 24 ppm) were detected in the one meter soil samples collected from the Borrow Area (S01 through S06). Slightly higher concentrations of fluoride (1.9 to 180 ppm) were detected in one meter soil samples collected from the central processing area of the facility (S07 through S15). A similar magnitude of fluoride concentrations (8.6 to 190 ppm) were detected in one meter soil samples collected from the riverbank (S16 through S21). Consistently higher concentrations of fluoride (85 to 770 ppm) were detected in one meter soil samples collected from within, and immediately around, Pond No. 3 (S22 through S34).

Nitrate was detected in 11 of the 34 one meter soil samples at concentrations ranging from 2.2 to 9.8 ppm. The highest detected concentration of nitrate (9.8 ppm) was detected at sample location S18, located on the riverbank east of the facility's security fence.

Ammonia was detected in 9 of 34 one meter soil samples collected at the Site. Ammonia concentrations in seven of those samples ranged from 1.2 to 3.2 ppm. Ammonia was detected in two samples (S31 and S34) at concentrations of 30 and 21 ppm, respectively. These particular sample locations are situation on the southern retention berm of Pond No. 3.

6.2.4.3 VOCs
One meter soil samples were not submitted for laboratory analysis of VOCs. As such, there is no data to report regarding these chemical compounds.

6.2.4.4 pH
Neither field measurements nor laboratory analysis of soil pH were conducted on the one meter soil samples obtained during this field investigation.

6.3 Subsurface Soil
Subsurface soil sampling, with the exception of four specific co-located surface/subsurface points, occurred after the one meter samples were acquired. This portion of the Program entailed advancing

direct-push (Geoprobe®) borings at 20 deep soil boring locations. All subsurface soil borings were advanced by a Model 7822DT Geoprobe® unit using a "dual-tube" drive system. This system is comprised of an outer casing that is continuously advanced into the subsurface while the inner tooling "string" is withdrawn with each one meter deep sample recovery drive. Sample media using this system was collected in an approximately one meter long acetate tube that is placed in the sample barrel situated at the head or lead element of the advancing drive string.

6.3.1 Sample Locations

Unlike the one meter samples discussed in Section 6.2, which complied with pre-approved sample points, significant deviations from planned subsurface sample locations specified in the Plan occurred. At the direction of FMRI, alternative subsurface soil sampling locations were sited hydraulically down gradient of Ponds No. 2 and No. 3. A revised copy of the Plan's subsurface boring diagram showing the positions of these new sample points is presented as Figure 12.2.

While the spatial positions of these subsurface points differed, vertical "down hole" sample increments specified by the Plan were observed. These borings, identified as "D" (deep) in the sample nomenclature, were initiated at one meter bgs and sampled at subsequent one meter increments thereafter until bedrock (or advancement refusal) was encountered. At the outset of the investigation, it was generally assumed that bedrock lay approximately 28 feet bgs across the length and breadth of the facility. Under this ideal modeling scenario, each deep boring would involve roughly seven, one meter drives to reach terminal depth.[5]

The lithology of the unconsolidated material at the FMRI facility consists of intermixed layers of clay, silt, sand and gravel. Soil grades from coarse-grained sands near the base of the deposit to silty fine sands and clays near the surface and is consistent with descriptions of alluvial deposits associated with the Arkansas River in Muskogee County, Oklahoma. The saturated zone was observed to correspond with coarse-grained material located at the bedrock interface. Considerable variation in vertical distribution of soil types was observed between boreholes, which is consistent with historical land disturbance that has occurred in the investigation area including construction of the French drain, construction of the retention ponds, and construction of the Groundwater Interceptor Trench (GIT). Additionally, the presence of poorly cemented silt and sandstone material was encountered in the subsurface. Soil boring logs detailing soil boring lithology are included as Appendix 13.7.

6.3.2 Sample Collection

As shown in Figure 12.2, most of the deep soil borings are located in the eastern half of the former Pond No. 3 basin and its perimeter berms. Based on observations from the soil borings advanced on the perimeter of Pond No. 3 (primarily pH measurements), the locations of the subsequent borings were biased towards areas suspected to have been impacted by site operations. Several additional soil boring locations were selected hydraulically down gradient of former Pond No. 2. All deep soil boring locations were located hydraulically up gradient of the GIT. All sample locations were readily accessible to the track-mounted Geoprobe® unit and did not conflict with known or suspected subsurface utilities. As mentioned above, four of the deep soil borings corresponded spatially with surface sample locations. These co-located points are illustrated in Figure 12.2 by split coloration (green/orange) circles; the corresponding deep and surface boring designators are D01/S26, D02/S27, D03/S33, and D10/S34.

Deep soil boring encountered frequent "refusal" well-above the anticipated depth of shale bedrock. Most of these refusal events encountered what was described as "cemented silt and sand" formations that arrested the advancement of the hydraulically-advanced tooling string. This condition was reported by the client to likely be the result of a chemical reaction between native alluvial deposits

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[5] It is important to note that the one-meter bgs increment was not considered a "D" boring increment for purposes of this investigation.

and hydrofluoric and sulfuric acids stored in Ponds 2 and 3. Based on the distribution of this material in the subsurface, the materials formerly stored in Ponds 2 and 3, and the physical inspection of representative samples obtained during the 2011 supplemental characterization campaign, the material encountered is suspected to be fluorogypsum.

Fluorogypsum is a solid material consisting primarily of fine particles of calcium sulfate and is a mineral processing waste, specifically from the digestion of ore using hydrofluoric acid. There are likely other chemical compounds in fluorogypsum that were present in the ore or were otherwise used in mineral processing. Fluorogypsum is typically transported to, and deposited in, waste retention ponds as slurries. The slurry subsequently dries and hardens (EPA, 1990). It is suspected that fluorogypsum slurry was deposited in Ponds 2 and 3 and may have been released to the subsurface during the failure of the Pond No. 3 liner in 1989 (Kirkpatrick & Lockhart, 1993). In the subsurface, the fluorogypsum slurry may have mixed to some extent with natural alluvial materials before drying, resulting in a fluorogypsum with sand and silt components.

Refusal attributed to fluorogypsum occurred in 15 of the 20 deep soil borings at depths ranging from 0.5 to 2.5 meters bgs. Refusal due to the anticipated shale bedrock was encountered in the remaining 5 deep soil borings. A refusal summary map depicting the locations and depths at which fluorogypsum and shale bedrock were encountered is included as Figure 12.3.

Fluorogypsum may be a continuing source of groundwater contamination at the FMRI site. Further investigation into the extent fluorogypsum in the subsurface in the vicinity of Pond No. 2 and 3 and the chemical characteristics and resulting leachate concentrations of the fluorogypsum at the Site is thus warranted.

6.3.3 Radiological Results

Ambient exposure rates at the core sample collection locations were unremarkable (see Section 6.1.6.2 , above, and Appendix 13.3), as were the radiological screening results for the individual soil cores (see Section 6.1.6.3 and Appendix 13.4). Appendix 13.8 contains the radioanalytical results for the subsurface soil samples, which were all generally within the range of background values. The following is a summary of the data set:

Radionuclide	Average Concentration (pCi/g)	Minimum Concentration (pCi/g)	Maximum Concentration (pCi/g)
Ra-226	1.35 ± 3.77	-0.04	30.5
Ra-228	1.04 ± 0.98	-0.50	5.73
Th-228	1.57 ± 4.47	-0.34	36.9
Th-230	1.89 ± 5.02	-0.11	40.4
Th-232	1.49 ± 4.08	-0.21	33.3
Total U	9.61 ± 20.62 μg/g	1.52 μg/g	165.0 μg/g

The maximum measured total uranium concentration of 165 μg/g (54.5 pCi/g of U-238) was at a depth of two meters at collection location D16 (see Figure 12.2).[6] The maximum measured Th-232 concentration of 33.3 pCi/g was at a depth of 2.5 meters at collection location D01. The maximum measured Ra-226 concentration of 30.5 pCi/g was at the same depth and collection location as the elevated Th-232 result.

[6] The total uranium concentrations can be converted to U-238 concentrations by assuming that isotope comprises 98% of the uranium mass, and by applying a specific activity of 3.3E-07 Curies of U-238 per gram of soil.

6.3.4 Chemical Results
6.3.4.1 Metals
Subsurface soil samples collected at one meter intervals from the deep soil borings were submitted for laboratory analysis of select metals. The metals antimony, arsenic, cadmium, chromium, lead, and thallium were detected in each of the 69 subsurface soil sampling intervals. Similarly, niobium and tantalum which are directly related to historical site operations, were also detected in all subsurface soil samples. A brief overview of the findings associated with niobium and tantalum is presented below and a complete presentation of all analytical results for metals in subsurface soils is in Appendix 13.6.

Niobium and tantalum concentrations detected across the entire data set ranged from 4.3 to 1,700 ppm and 1 to 1,300 ppm, respectively. All of the data points are situated in or around the eastern half of Pond No. 3 (or points immediately east and north of the Pond) and no obvious or definitive trends related to the horizontal distribution of contaminants are noted. The data do show, however, significant correlation between concentrations and specific depth (vertical) increments. Niobium and tantalum concentrations were largely co-located; corresponding increases or decreases in niobium and tantalum concentrations were observed between boreholes or depth increments. Similarly, the highest concentrations for both metals were detected in the same subsurface soil samples. This is particularly the case with points D03, D04, and D13 which are located south and southeast of Pond No. 3, outside of its earthen berm.

6.3.4.2 Fluoride, Nitrate, and Ammonia
Fluoride, nitrate, and ammonia were detected at varying depth increments in subsurface soil samples collected from the 20 deep soil borings. A complete record of these analytical results is provided in Appendix 13.6.

Fluoride was detected in all of the subsurface soil samples collected from the deep soil borings at concentrations ranging from 2.3 to 6,300 ppm. No distinct spatial patterns related to the horizontal distribution of fluoride were evident; however, a trend in the vertical distribution of fluoride was observed. The highest concentrations of fluoride were detected in samples collected from deeper intervals, particularly at depths of five meters bgs or greater. Several of the highest fluoride concentrations were detected in samples collected from soil borings located on or around the eastern retention berm of Pond No. 3.

Nitrate was detected in eight of the 69 subsurface soil samples at concentrations ranging from 2.5 to 28 ppm. The highest detected concentration of nitrate (28 ppm) was detected in subsurface soil sample D15-3m. Discounting the highest result, detected concentrations of nitrate ranged from 2.5 to 13 ppm. Like fluoride described above, nitrate was primarily detected in subsurface soil samples collected from soil borings located on or around the eastern retention berm of Pond No. 3.

Ammonia was detected in 50 of 69 subsurface soil samples at concentrations ranging from 1.8 to 720 ppm. No distinct trends in the spatial distribution of ammonia in subsurface soil were observed.

6.3.4.3 VOCs
Of the analytes included on the target analyte list for VOCs, only five VOCs were detected in one or more of the 69 subsurface soil sample collected. These compounds were: 4-methyl-2-pentanone (MIBK), acetone, carbon disulfide, methylene chloride, and toluene. Trichloroethene (TCE) which was identified by the State of Oklahoma as a potential contaminant of concern was not detected in any of the subsurface soil samples collected during this investigation. Appendix 13.6 provides a complete summary record of all VOC data obtained from the subsurface soil samples and summarizes analytical results of the detected VOCs. A brief discussion of MIBK analytical results is presented below.

MIBK or 4-methyl-2-pentanone was detected in 17 of the 20 deep soil borings at one depth or another within their individual soil columns. Among the detections, concentrations ranged from 8 to 3,300 ppb. In many instances, detections of MIBK occurred in the final depth increment of each boring. According to the soil boring logs (Appendix 13.7), soils at these depths corresponded to the water table or the top of the saturated zone. The specific gravity of MIBK (0.802 grams per milliliter [g/ml]) suggests that this solvent compound would accumulate at or near the water table.

Conversely, a small number of MIBK detections (ranging in concentration from 150 to 230 ppb) were in soil samples collected from subsurface intervals that were dry at the terminal depth of the boring (D18 through D20). These soil borings are located in close proximity to the GIT and are the furthest eastward borings advanced by the field team. Termination of these borings was attributed to the presumed presence of fluorogypsum and not to the shale formation said to be representative of true bedrock. Whether the presence of MIBK in dry soils is indicative of a smear zone caused by the drawdown of the water table due to the operation of the GIT cannot be determined with the data currently available.

6.3.4.4 pH

Measurements of pH were taken from specific moist or saturated subsurface soil increments within individual 1-meter cores where evidence of groundwater was most visually profound. These measurements were conducted using a real time, analog soil moisture and pH instrument that was calibrated by the instrument manufacturer. Measurements recovered from these instrument readings were recorded in the boring logs for each deep boring location, as applicable. In those instances were a reading could not be taken due to dry soil conditions, a no measurement (NM) notation was made in the log. Soil boring logs are included as Appendix 13.7.

Instrument measurements ranged from neutral to near neutral conditions (pH 7) to more acidic conditions (pH of 2). The lowest pH measurement of 2 was recorded in soil boring D16 at a depth of 2.5 m. In an effort to determine the accuracy of the real-time pH measurements, a select number of subsurface soil samples were submitted for laboratory analysis of soil pH. These laboratory analyses were performed from excess soil present in the metals soil sample aliquots. These chemical sample aliquots were collected from the homogenization of entire, individual 1-meter soil cores. As a result, the field soil pH data and the homogenized 1-meter soil aliquot laboratory pH data from a given core do not directly correlate.

A comparison of the laboratory data against the real-time readings suggests that the field instrument readings show that the field instrument readings collected from specific points within the soil column were consistently more acidic. In most instances, the instrument readings appeared to be a point or, in a limited number of cases, two points lower (more acidic) than the corresponding laboratory result. As a result, the pH measurements collected in the field should only be used as a general measure of the relative acidity of the subject soils, not as a precise indicator of their pH values. A table presenting all of the above mentioned pH data is summarized in Appendix 13.6.

7 GROUNDWATER CHARACTERIZATION

From September 28 through October 3, 2011, the project team conducted a file review at the FMRI facility in Muskogee, Oklahoma. All available historical files with environmental relevance were reviewed with the objective of obtaining sufficient documentation to address data gaps identified by ICF and the USNRC and to complete the evaluations of groundwater and site hydrology required by the Plan (FMRI, 2011). Both electronic and paper copies of available documentation were reviewed and were reproduced or otherwise retained by the project team for inclusion in this report. Additionally, the project team reviewed files available through the USNRC document accession website, United States Geologic Survey (USGS) online resources, USGS information requests, United States Department of Agriculture (USDA) Natural Resource Conservation Service, the National Oceanographic and Atmospheric Administration (NOAA) Climate Center, and other online resources. Any remaining data gaps identified after the completion of the file review were resolved through telephone interviews and e-mail correspondence with FMRI personnel and additional document requests. The project team has obtained and reviewed sufficient documentation, analytical data, hydrologic data, and geologic data to meet the requirements of the Plan.

File review limitations included the availability of data and records associated with historical groundwater quality data and historical groundwater extraction pumping rates. The project team has only included available historical groundwater quality analytical data in its presentation and evaluation included herein. In the cases of gaps groundwater extraction pumping rates, the project team has made reasonable assumptions to determine cumulative pumping volumes and states those assumptions where relevant.

7.1 Groundwater Potentiometric Surface Maps

Available groundwater elevation data were compiled for all wells and sumps from 1993 through 2010. All groundwater elevation data were normalized to the vertical elevations determined during the 2009 survey of the FMRI site to allow for comparison of groundwater elevations between all years of the study period. For each year during that period, the most complete contemporaneous gauging event was selected for the generation of a potentiometric surface map. The maps were evaluated to determine groundwater flow directions and gradients (Section 7.6) and to determine the influence of the GIT on groundwater levels (Section 7.4.5). Groundwater potentiometric surface maps from 1993 to 2010 are included as Appendix 13.9.

7.2 Bedrock Elevation Contour Map

As part of the supplemental characterization, the project team completed a review and compilation of bedrock elevation data and generated a hypsographic map depicting bedrock surface elevation contours for the McCurtain Shale underlying the FMRI site (Figure 12.4). Bedrock elevation data were compiled from soil boring logs associated with monitoring well installation events in 1991 and 1993. Horizontal and vertical survey data from a site survey completed in June 2009 was used to normalize bedrock elevation data. The normalization of bedrock elevation data allows for a direct comparison to water table, ground surface, and river level elevations.

Bedrock elevation data from monitoring well MW-72S and the four sumps associated with the GIT were not included in the generation of the hypsographic map. Monitoring well MW-72S is located in close proximity to the French drain sump. The bedrock surface in this area is suspected to have been intentionally altered to create a hypsographic low to increase the efficiency of the French drain system. The sumps associated with the GIT are set more than one foot into the bedrock and, according to GIT construction records (Section 7.4.1), the bedrock surface in the vicinity of the GIT was intentionally altered (i.e., lowered by excavation) to enhance the flow of water captured by the trench toward the sumps. The bedrock surface elevation data associated with monitoring well MW-72S and the GIT sumps created depressions in the bedrock surface contour that are not representative of the actual hypsographic surface. Conversely, the alterations in the natural bedrock surface associated with the French drain and the GIT are not reflected on the hypsographic map.

7.3 Historical Groundwater Quality

Historical analytical data for various groundwater quality parameters were collected from existing consultant reports and laboratory data tables available in FMRI's administrative files. These data include records from 25 monitoring wells – including wells that have been abandoned over time as well as extant wells that have been sampled as recently as 2010 – and the four sumps associated with the GIT. In most instances, the information from the monitoring wells reflects data collected from February 1993 to September 2010. The data collection time line for the sumps reflects their initial sampling (after construction) in May 1999 to September 2010.

While the quantity of data amassed is indeed impressive, unfortunately it is not uniform in either its data acquisition time frames or the parameters (e.g., radiological or chemical) being evaluated. As such, detailed year-to-year comparisons of specific parameters or consideration of contaminants from well-to-well or sump-to-sump cannot be fully evaluated over the time lines provided. This condition is best illustrated in a review of the numerous data quality tables that are presented in Appendix 13.10. A quick review of this tabular information shows that a uniform "suite" of contaminants of concern (COC) were not consistently evaluated during each sampling event. Nevertheless, general information regarding trends among parameters or between wells/sumps can be inferred (to varying degrees) to provide some understanding of potential hazards or concerns the radiological and/or chemical parameters pose to the environment.

In an effort to graphically portray possible rises and/or falls in contaminant levels within a given well or sump, time series plots were also developed to visually depict the data. These plots are presented in Appendix 13.11. Due to the data inconsistency issue noted previously, each well or sump plot does not present data with the same parameters. Where three or more sets of data (per parameter) were available for review, they are portrayed in the following plots: Total uranium (i.e., the sum of Uranium-234, -235, and -238 isotopes); thorium (i.e., Thorium-232); radium (i.e., Radium-226 and -228), metals (i.e., antimony, arsenic, cadmium, chromium, lead, niobium, thallium, and tantalum), and VOCs (i.e., MIBK and TCE, exclusively). In most instances, these plots are configured as typical time versus concentration presentations. Readers should note that a second concentration axis is sometimes employed in these graphical presentations if significant concentration departures are present among the individual parameters displayed on the same plot.

A final presentation vehicle used to document the historical groundwater data is a mapping product that is provided in Appendix 13.12 of this Report. This spatial presentation of the data uses informational "tags" associated with each well or sump to convey the analytical data tied to each of these sampling locations. Four separate facility base maps are used to portray the appropriate topical COC data, with radiological data including uranium isotopes U-234, -235, -238 and total uranium, Thorium-232, and Radium-226 and -228, and with chemical data including metals and VOCs. The four resulting topical COC "tag maps" are further subdivided into the following three distinct chronological time periods: 1) February 1993 to August 1998 (pre-GIT construction); 2) May 1999 to April 2002 (GIT installation to termination of intermittent pumping of sumps) and; 3) June 2002 to September 2010 (GIT persistent pumping of sumps). Given the numbers of topical COC considerations and the chronology of the presentation, a total of 12 individual tag maps are found in Appendix 13.12.

7.4 Groundwater Interceptor Trench (GIT) Effectiveness

7.4.1 Overview of the GIT

Construction of the GIT was initiated in July of 1998 by Fansteel's environmental consultant, Earth Sciences Consultant's Inc., and the consultant's construction subcontractor, Cook Construction. site preparation included: Clearing and grubbing of the approximately 3,100 foot-long, roughly "L-shaped" trench alignment (right-of-way); installing protective erosion controls; developing temporary access roads and; establishing stockpile areas for exhumed trench soils found to be either radiologically contaminated (i.e., above action level or AAL) or non-radiologically contaminated (i.e., below action level or BAL).

Contaminated AAL soil (i.e., those soils with uranium and thorium concentrations in excess of 10 pCi/g above background) were trucked to a central repository within the facility, placed on a high-density polyethylene (HDPE) membrane liner, and covered with lighter-weight plastic sheeting for protection from the weather. In all, 6,775 tons of AAL soils were recovered from four distinct areas along the trench right-of-way prior to developing the GIT (Earth Sciences, 1999). Non-contaminated BAL soils (i.e., those containing less than 10 pCi/g of uranium and thorium) were also stockpiled on-site for later re-use as general trench backfill and for related construction activities. BAL soil comprised the majority of the soil and bedrock material exhumed (and reused) at the Muskogee site.

The design of the collection system was developed by Fansteel's consultant and was presented in a series of "Contract Drawings" (CD) and performance specifications that were subsequently used by the construction subcontractor to build the GIT. In general, the CD plans called for a 3-foot wide trench along the length of the established GIT right-of-way. With regard to depth, the design called for the trench to be extended downward until bedrock was encountered. In concert with the excavation itself, a gravity fed pipe and sump system was specified to be installed within the trench in close proximity to the bedrock stratum. The placement of this collection system deep within the trench was designed to preferentially collect migrating groundwater flowing eastward, southward, and northeastward from the central portions of the facility. A further description of the trench and collection system is provided in the several paragraphs below. Presentations of relevant CD plans illustrating the trench alignment, cross sectional views, and collection system details are provided for reference purposes in Appendix 13.13.

Excavation and construction of the actual trench structure began in late September 1998 and was completed in February 1999. Construction of the GIT began at the northern end of its alignment and closely paralleled the facility's security (and property) fence line. Over most of its length, the trench was situated in close proximity to the bluff that lies along the western edge of the Site and forms the western bank of the adjacent Arkansas River. The selected trench alignment required some accommodations of existing utility, drainage, and security infrastructure, which was either re-routed or replaced upon project completion. This construction activity also resulted in the outright destruction of a small number of existing monitoring wells that had previously been developed to support investigations of groundwater conditions beneath the Site. These particular monitoring wells (MW-58S, 59S, 60S, 61S, 66S, and 73S) were decommissioned in accordance with the contractor's specification and, as such, became unavailable for future monitoring purposes by the end of 1998 or early 1999.

While the width and length of the GIT was readily specified and established, the depth to native black shale bedrock (McCurtain Shale) varied considerably due to surface and subsurface topographic and hypsographic conditions, respectively. Trenching depths (post-bedrock preparation) ranged anywhere from 3 feet to 31 feet below ground surface (bgs) along the length of the GIT right-of-way. More typically, depth to bedrock had an average range of 15 to 20 feet bgs over long stretches of the trench's route. Furthermore, as suggested above, some preparation of the bedrock was necessary to provide the appropriate slope conditions necessary to create, what in geologic terms might be described as miniature "basin and range" groundwater collection areas within the GIT. In all, four such "basins" were created by the project.

The groundwater collection system installed within the trench relies on gravitation forces to capture and preferentially direct the flow of groundwater entering the GIT. The principal elements of this gravitational collection system are a perforated pipe and collection sump system that rests in the bedrock (in the case of the sumps) or near the bedrock /soil interface (in the case of the piping). The natural and/or artificially cut and sloped aspects of the bedrock, as shown in the cross sectional views of the trench provided in CD-4 and CD-5 of Appendix 13.13, provides the basic structure of the "basins" mentioned above and provide the "fall" or angled slope for the piping necessary to channel collected groundwater to the four individual sumps.

Situated at the lowest point within each of these four basins is a 36-inch precast concrete cylinder that serves as the collection vessel for each basin's sump. Each of these sumps was further recessed into the bedrock (up to a depth of four feet) to further enhance the overall drainage fall of the collection system. Once each of the four collection vessels were set, additional precast pipe segments of the same diameter were set atop the bottom collection vessel to create a vertical access portal (manway) that extends to the surface. Each of the manways provides access for any necessary maintenance requirements that may be required for the individual sump pumps and supporting plumbing systems. These sumps, in turn, are connected to an on-site WWTP where the contaminated groundwater is treated and managed prior to discharge from a state-permitted outfall to the adjacent Arkansas River.

Serving each of the sumps is a single, perforated 6-inch HDPE pipe that enters each sump from either side of the precast concrete collection vessel (due to design requirements, only one pipe enters Sump No. 1, which is located at the northern terminus of the GIT). These perforated plastic pipes are set approximately 6 inches above the bedrock and are surrounded by a sand bed to facilitate preferential drainage towards the pipe. The sand bed, in turn, is backfilled (topped) with aggregate (stone) to an elevation two feet above the established "high water table" exhibited by the local aquifer. Together, the stone and sand bedding plains present preferential flow characteristics throughout the saturated thickness of the aquifer. Additionally, a low permeability HDPE membrane placed beneath the pipe (in contact with the bedrock) and lapped up the down gradient wall of the trench to the top of the aggregate bed also serves to retain laterally-flowing groundwater and enhance the system's overall collection capabilities. Details regarding the construction of the piping and sump infrastructure are portrayed in the several structural cross sections presented in CD-6 of Appendix 13.13.

As the piping slopes upward - parallel to the bedrock surface and away from each of the collection sumps, they eventually reach their respective, localized drainage divides or "ranges". At these points, the piping is routed vertically upward until they reach the soil's surface. Each of these piping outcrops are designed to serve as "clean outs" for their respective subsurface pipe runs should the need for maintenance and/or cleaning be required. Locking caps place over singular or paired clean outs (depending on the specific design requirements) prevents unauthorized access to this element of the collection system. A typical view of these clean out ports is provided in CD-7 of Appendix 13.13.

Based on the available Construction Certification Report issued by Fansteel's consultant, all BAL soils stockpiled for purposes of back filling the trench and restoring surface conditions along the GIT right-of-way were appropriately applied, graded, and compacted in accordance project performance specifications. A total of 2,242 additional tons of topsoil were also trucked to the Site to complete restoration (e.g., surface top dressing and re-vegetation) of the Site. Project completion reportedly occurred by the Spring of 1999.

7.4.2 Relationship to Bedrock, Saturated Alluvium, and the Arkansas River

The GIT was designed to prevent potentially contaminated groundwater within the saturated zone of the unconsolidated alluvium on the Site from migrating off site and ultimately entering the Arkansas River. As part of the supplemental characterization, data were compiled to illustrate the relationship between the GIT, shale bedrock, the saturated zone of the unconsolidated alluvial material, and the Arkansas River. A cross-section illustrating the conceptual relationship between each of the aforementioned elements was developed based on available data and is included as Figure 12.5.

The cross section corresponds to the area between monitoring well MW-69S and the Arkansas River from west to east. This area was selected for the generation of the cross section because the west to east line intersects MW-69S up gradient of the GIT, the GIT in close proximity to SUMP 1, monitoring well MW-75S down gradient of the GIT, and ultimately the Arkansas River. The cross-section location is depicted on Figure 12.6.

Bedrock elevation within the GIT and monitoring wells are available from as-built construction diagrams and soil boring logs. According to a bedrock geology map for East-Central, Oklahoma, the Arkansas River in the vicinity of the Site is underlain by McAlester Formation (Marcher, 1969). It is assumed that the McCurtain Shale member of the McAlester formation observed underlying the FMRI site extends under the Arkansas River. No data is available related to the elevation of the McCurtain shale at the riverbank east of monitoring well MW-75S or underlying the river.

The saturated zone of the unconsolidated alluvium is determined based on water levels within the groundwater monitoring wells, the GIT and relative bedrock elevation. For the purposes of the cross-section, groundwater elevation data from the monitoring wells and GIT was selected from a gauging event conducted on March 1, 2010. This date was selected because it occurred during a period of sustained pumping from the GIT and is representative of the relationship between water levels in monitoring wells and the GIT in equilibrium under pumping conditions.

River level elevations were obtained via information request from the USGS Stream Gauge No. 07194500 for the Arkansas River near Muskogee, Oklahoma. The location of USGS Stream Gauge No. 07194500 is depicted on Figure 12.7. River level elevations were provided from July 25, 2003 through November 21, 2011 and a river level hydrograph for that time period is included as Figure 12.8. River levels are reported in a vertical datum (NGVD 29) consistent with the vertical datum used for the survey conducted at the FMRI site in 2009, allowing for a direct comparison of river levels with on-site groundwater and bedrock elevations.

7.4.3 Monitoring Well and GIT Sump Hydrographs

The extensive collection of groundwater data obtained from FMRI's administrative files was compiled and presented in a graphical format to illustrate elevation trends over several years. The data captures groundwater elevations within the four sumps situated in the GIT as well as the numerous monitoring wells that pre-date the construction of the GIT. As shown in the series of hydrographs presented in Appendix 13.14, sump data derived from the initial activation of the GIT in 1999 to September 2010 (most current available data) is presented in a time v. elevation graphical format. In a similar fashion, monitoring well data dating to 1993 illustrates the variation of water levels in these sentinel systems.

Other features presented in the illustrations identify bedrock/soil interface as it is expressed in each boring or sump as well as historical construction and operational data regarding the GIT. The inclusion of GIT construction and operational information provides important insights into the observed variations of groundwater levels in most wells and sumps, especially as improved operational performance was realized beginning in May of 2002.

Saturated thickness is depicted in hydrographs as the area between the bedrock surface elevation and the water table elevation is the saturated thickness of the unconsolidated alluvium underlying the FMRI site. Based on the similarities between the hydrographs and time series plot of saturated thickness over time, time-series plots of saturated thickness were not completed as part of this work element. A summary of saturated thickness including minimum, maximum, average from 1993 to 2010, average from 1993 to May 2002, and average from May 2002 to 2010 is included in Appendix 13.14.

7.4.4 Pumping Rates and Effects on Water Levels

There are three primary sources of groundwater withdrawal at the facility: the GIT, the French drain around Pond No. 3, and the sump in the southeast corner of Pond No. 3. Pumping rates of the four (4) sumps associated with the GIT were reviewed for the time period from the installation in 1999 to 2010. Pumping rates from the French drain system surrounding Pond No. 3 were also reviewed for the same time period. Pumping rates from the Pond No. 3 sump were also reviewed.

7.4.4.1 Groundwater Interceptor Trench (GIT)
During the early years (1999 to 2002) of the GIT operation, groundwater from the trench was pumped to evaporation tanks. There were four evaporation tanks at the facility. The tank' heating elements were fueled by natural gas and were rated for the evaporation of 2.5 gallons per minute (gpm). The evaporation tanks had limited storage capacity, were constantly taken out of service for maintenance, and were frequently non-functional. During this period, the rate at which extracted water evaporated was the limiting factor for pumping rates. The limitation on pumping rates prevented the GIT system from performing up to its potential. Other limitations during the early years of operation included blockages in sump pump lines and pump failures.

As an alternative to managing extracted groundwater with the evaporation tanks, the facility's NPDES permit was modified to allow extracted groundwater to be treated in the existing on-site WWTP. Additionally, larger diameter sump pumps and lines were installed in the GIT to alleviate problems associated with clogged lines and pumps. The WWTP had the capacity to treat large volumes of groundwater as it was extracted from the GIT, allowing for higher pumping rates to be sustained over time.

Pumping from the GIT began in August of 1999. From August 1999 to mid-October 1999, select sumps pumped at rates ranging from 4 to 10 gpm. Due to various problems associated with the start-up of the system, pumping during this time frame was inconsistent and not all sumps were operating at the same time. Sumps 3 and 4 were primarily pumping during this period (FMRI, 2011a).

From mid-October 1999 to May of 2002, the pumping rates were limited by the capacity of the evaporation tanks and their ability to effectively evaporate extracted groundwater. Prolonged periods of no pumping intermixed with periods of low pumping rates occurred during this time frame. Some notable periods of no pumping include mid-October 1999 to January 2000, October 2000 to April 2001, and December 2001 to May 2002.

Periodic pumping and low pumping rates during this 1999 to 2002 period resulted in minimal impact to water levels within the trench sumps and established groundwater monitoring wells. Variations in water levels observed during that period were generally attributable to isolated pumping events; documented drawdown in wells and sumps were seen to quickly recover. Sustained drawdown of water levels in wells or sumps was not observed during this period.

In May of 2002, the NPDES permit for the existing WWTP was modified to allow for the treatment and subsequent discharge of groundwater extracted from the GIT. Pumping from the GIT resumed on May 8, 2002 and pumping rates were initially very high (up to 28 gpm). The initial high pumping rates effectively dewatered the GIT. Water levels within sumps 1, 2, 3, and 4 were initially lowered (from average water levels before May 2002) by 4.77, 6.91, 6.81, and 5.67 feet, respectively. Water levels within sumps 1, 2, and 3 were lowered to below bedrock surface while the water level in sump 4 remained slightly above bedrock.

During the same time frame, water levels within monitoring wells were also observed to be lower. The drawdown in monitoring wells was not as great as the drawdown observed in the GIT sumps and generally decreased with distance from the GIT. Figure 12.9 presents the locations of monitoring wells relative to the GIT.

The greatest drawdown was observed in monitoring wells MW-57S (3.67 feet) and MW-62S (3.90) which are located 43 and 75 feet from the GIT, respectively. Monitoring wells MW-57S and MW-71S were dry after the initial May 2002 drawdown. Monitoring wells in the vicinity of Pond No. 3 seem to be less influenced by GIT pumping because the French drain sump has been pumping in that area since 1979. This drain and sump collection system had already depressed the water table in this localized area. Water levels in monitoring wells MW-51S, MW-52S, MW-53S, MW-54S, MW-68S, and MW-69S did not appear to be influenced by pumping. A summary of initial drawdown in sumps and monitoring wells in response to the high sump pumping rates in May 2002 is included as Table 11.1.

After initial high pumping rates in May 2002, pumping rates were gradually reduced to an approximate range of 4 to 8 gpm and were sustained from May 2002 to the present. During this time period, the sumps operated on cycles consisting of 20 minutes on and 20 minutes off.

For purposes of estimating pumping rates over the life of the GIT, average pumping rates (approximately one-half of the observed pumping rate) were used by the project team for calculating the total volume of groundwater removed from the system. Pumping rates were typically measured once a week; however, there are several periods during which pumping rates were measured less frequently. In order to estimate the total volume pumped for those periods, it is assumed that the pumping rates are consistent with those observed before and after the period without measured pumping rates.

Sustained drawdown observed in monitoring wells and sumps during the period from May 2002 to 2010, recovered only slightly from the initial drawdown observed. Water levels within sumps 1, 2, 3, and 4 were maintained at levels 3.18, 5.74, 5.44, and 4.86 feet lower, respectively, than average water levels before sustained pumping (May 2002). The drawdown observed in sumps under sustained pumping conditions was less than the initial drawdown observed. Within monitoring wells, sustained drawdown was generally greater than the initial drawdown. This was particularly evident in monitoring wells MW-57S and MW-72S, which are located in close proximity to the GIT. A summary of sustained drawdown in sumps and monitoring wells in response to the high sump pumping rates in May 2002 is included as Table 11.1.

From 1999 to 2010, the estimated volume of groundwater extracted from the GIT is estimated at 59 million gallons. Of that total volume, approximately 57.3 million gallons were extracted from the GIT from May 2002 to 2010. An annual summary of sump pumping volumes is included as Table 11.2.

7.4.4.2 French Drain

A French Drain System encircling Pond No. 3 was installed during the construction of Pond No. 3 in 1979. The purpose of this system was to intercept groundwater in the vicinity of the Pond to relieve hydrostatic pressure on the liner placed in this basin. The Pond itself was designed and constructed as a retention structure for residues produced during ore processing. A single synthetic liner was intended to retain waste fluids and protect underlying groundwater resources.

Materials stored in Pond No. 3 included digested ores, slags, and fluids comprised of hydrofluoric and sulfuric acids, the solvent MIBK, various metals, and low-level radiological contaminants. During the construction of Pond No. 3, groundwater was observed in the alluvial material overlying the natural shale bedrock which prompted the construction of the French Drain System (Kirkpatrick & Lockhart, 1993).

The French drain sump was installed in the topographically lowest area, outside of the northeast corner of Pond No. 3. Initially, the sump discharged to the ground surface in a small drainage swale east of the retention pond which eventually flowed to the Arkansas River. Sometime after Pond No. 3 was placed into service, the pH of the discharge waters decreased (became more acidic), suggesting the liner of the pond had been compromised. The discharge of groundwater from the system to the ground surface was stopped and subsequently redirected either directly to Pond No. 3 or the WWTP. In 1989, contaminants associated directly with Pond No. 3 were detected in the sump discharge, providing the clearest evidence yet that the Pond's liner had failed. Efforts to contain the released fluids consisted of the construction of two temporary retention dikes hydraulically down gradient of pond. Liquid accumulating in the temporary retention dikes were subsequently pumped to the WWTP. Despite these efforts, it was estimated that 90,000 gallons of fluid contained in Pond No. 3 was released to the Arkansas River (Kirkpatrick & Lockhart, 1993).

Although the French Drain System is suspected to have partially collapsed at the time of the Pond No. 3 liner failure (Kirkpatrick & Lockhart, 1993), the French drain sump has continued to actively collect and pump groundwater. Pumping rates for the Pond No. 3 sump are available from 2002 to the present. Average pumping rates from 2002 to the present were used to estimate pumping volumes from 1993 to 2002. According to FMRI personnel, the French drain sump was taken out of service for a period of time during the start-up of the GIT. Based on water levels in monitoring well MW-72S, which is located in close proximity to the French drain sump, the sump appeared to be out of service from January of 1999 until April 30, 2002.

Based on the project team's calculations, approximately 20.2 million gallons of groundwater was pumped from the Pond No. 3 French Drain System from 1993 to August 1999 and 25.4 million gallons of groundwater was pumped from the System's sump from August 1999 to August 2010.

7.4.4.3 Pond No. 3 Sump

During the excavation of Pond No. 3, a sump (not to be confused with the Pond No. 3 French drain sump) was installed in the southeast corner of the pond. This sump was designed to dewater accumulated precipitation as this basin was remediated. Water pumped from the Pond No. 3 sump was discharged directly to the WWTP (FMRI, 2011a). Pumping records for the Pond No. 3 sump were maintained during March and May of 2007; however, no other sump pumping records were maintained. Reportedly, the sump is used only when surface water accumulates within Pond No. 3 and does not pump from the saturated zone of the alluvium (FMRI, 2011a). The total volume of water pumped from the Pond No. 3 sump could not be determined from available data.

7.4.5 Evaluation of Groundwater Potentiometric Surface Maps

Groundwater potentiometric surface maps for each year from 1993 to 2010 (Appendix 13.9) were evaluated relative to the GIT installation and operation (sump locations and pumping rates) and the operation of the Pond No. 3 French drain system. Additionally, the influence of the GIT and French Drain Systems on the potentiometric surface contours over the entire site were evaluated for each year of the study period.

- December 1993 - As detailed in Appendix 13.9, groundwater flow across the Site is in a northeastern, eastern and southeastern direction. Flow to the northeast appears to be heavily influenced by the Pond No. 3 French drain sump. Flow in the eastern direction is related to a localized groundwater high, which stretches across the Site under Pond No. 8 and may be related to liquid loss from this Pond or subsurface flow from the east. The southeastern flow regime appears to exist naturally, although it is clearly being fed from the elevated groundwater levels under Pond No. 8.

- June 1994 - The flow regime depicted in June of 1994 is very similar to that presented in December 1993. Groundwater continues to flow across the Site is in a northeastern, eastern and southeastern direction. Flow to the northeast appears to be heavily influenced by the Pond No. 3 French drain sump, while flow in the eastern direction is related to a localized groundwater high, which stretches across the Site under Pond No. 8. The southeastern flow regime continues to exhibit influence from the elevated groundwater levels under Pond No. 8. It is also worth noting that groundwater levels have increased within the wells south of MW-70S by between 0.5 to 1.0 feet when compared to a year earlier. This is likely the result of increased precipitation.

- September 1994 - The flow regime is similar to that presented in June 1994. There is a continued groundwater high under Pond No. 8 which continues to drive flow to the north- and south-east and groundwater extraction occurring at the Pond No. 3 French drain sump is creating a depression in the groundwater table in the vicinity of the sump.

- April 1995 - While the overall flow patterns observed in previous contours continue to be present, there is a significant difference noted in the northeast area of the Site in the vicinity of the Pond No. 3 French drain sump. It appears that the rate of pumping has decreased as the groundwater level within MW-72S has increased by about 1 foot.
- June 1995 - Similar to April 1995, the overall flow patterns remain the same although the relative groundwater levels have increased across the Site. Clearly precipitation effects are contributing to this rise, as is the apparent reduced pumping rate at the Pond No. 3 French drain sump.

- April 1996 - Groundwater continues to display the northeastern, eastern and southeastern flow components although the overall flow gradients to the north and southeast appear to be decreasing. This is highlighted by the increased distance between the contour lines in these areas. This may be due to a number of factors including increased precipitation, the continued reduced extraction rate in the Pond No. 3 French drain sump, as well as a reduced contribution from Pond No. 8 into the subsurface flow regime.

- April 1997 - The April 1997 groundwater potentiometric surface map is characterized by an increased pumping rate at the Pond No. 3 French drain sump and the associated tightening of the groundwater flow contours in the northeast of the Site. The groundwater elevation under Pond No. 8 has increased significantly over that depicted in April 1996. There is clearly more groundwater in the system as indicated by the groundwater elevations in the southeast and likely reflects a response to a significant amount of precipitation.

- April 1998 - The groundwater flow regime retains the Site based flow structure (northeast, east and southeast) although the groundwater table elevations are very high. The effects of pumping the Pond No. 3 French drain sump are less pronounced than observed in April 1997 with nearby groundwater levels being up to one foot higher than the previous year. It appears that these elevated groundwater levels are driven by precipitation, although the localized high water table under Pond No. 8 and the continued pumping at the Pond No. 3 French drain sump cannot be ignored.

- May 1999 - The May 1999 groundwater contour is the first contour which exhibits an influence from the then newly constructed GIT. The change from the April 1998 regime (highlighted in the April 1998 potentiometric surface map) is significant with a disappearance of the elevated groundwater level under Pond No. 8, as well as the associated well-defined northeast and southeast flow components. Interestingly, these components still exist, although in a more radial flow pattern which to a great extent appears controlled by the GIT. Pumping at the Pond No. 3 French drain sump continues although the effect on the groundwater flow to the northeast does not appear to be as dramatic as in previous years. This may be a result of a reduced pumping rate.

- May 2000 - The May 2000 contour exhibits a similar structure to that depicted in May 1999. There are, however, two key differences. The first is the relative flattening of the water table across the central and southeast sections of the Site which reflects a more gradual flow gradient towards the GIT and the second is a much more pronounced flow structure related to the groundwater extraction taking place via the Pond No. 3 French drain sump. The observed gradual flow gradient in the direction of the GIT may be a result of a gravity driven drainage situation due to the intermittent pumping of the trench sumps.

- May 2001 - The May 2001 groundwater potentiometric surface map represents a further evolution in the Site based groundwater flow regime. The flow gradient across the central part of the Site continues to flatten, while the southeast flow component appears to have remained similar to the previous years'. The continued flattening of the groundwater flow gradient is likely due to the continued intermittent pumping on the sumps associated with the trench. The most significant change on this contour is the absence of a pumping induced flow structure around the Pond No. 3 French drain sump. It appears that little to no groundwater extraction was occurring from this sump during May 2001.

- April 2002 - Inspection of the groundwater contour reveals a flow regime that appears to be under stress. The stress in this case is provided by the increased pumping of the groundwater interception trench sumps that took place in 2002. There is a notable steepening of the flow gradient across the Site, especially in the directions of sumps 1, 2 and 3. It's difficult to determine the effect of sump 4 given the lack of localized data. It is worth noting that the Pond No. 3 French drain sump was not being pumped during this period.

- April 2003 – June 2009 - The time period from April 2003 to June 2009 is characterized by a reduced data set which clearly impacted the overall detail of the associated groundwater contours with respect to the western and southern parts of the Site. However, the salient features of the Site-based flow system as it relates to the effects of the GIT and Pond No. 3 French drain sump pumping did, to a great extent, remain visible. To this end, a defined flow structure is again present in the vicinity of the Pond No. 3 French drain sump and this dominates the flow to the northeast. This feature is visible in all of the groundwater potentiometric surface maps within the stated time frame. Also present in each contour are the eastern and southeastern flow components which appear driven by the GIT and the pumping of sumps 2 and 3. It is also worth noting that from the historic pumping data compiled as part of this study, sump 4 remained very active in terms of groundwater extraction over this period.

- June 2010 - June 2010 marked the return to the gauging of all available groundwater monitoring wells. The associated contour continues to highlight the flow patterns observed in earlier years with groundwater extraction via the GIT and the pumping of sumps 1 through 4, along with the pumping at the Pond No. 3 French drain sump driving the flow. This pattern is characterized by a steep flow gradient towards the Pond No. 3 French drain sump (northeast), as well as flow to the GIT with influence exhibited due to the pumping of sumps 2 and 3, east and southeast, respectively.

7.4.6 Water Quality in the GIT

Water quality monitoring was routinely conducted on the GIT sumps from the installation of the system in 1999 through 2010. Groundwater quality data from those monitoring events were compiled in analytical data summary tables and graphically represented as time series plots first presented in Section 7.3 of this report as Appendix 13.10 and Appendix 13.11, respectively. The time series plots are somewhat limited by the availability of data as analysis of all contaminants of were not performed during each monitoring event or between sumps during a single monitoring event.

Based on the time series plots of water quality within the GIT, trends in contaminant concentrations over time for some COCs were identified. The identification of trends in contaminant concentrations was limited by the availability of data for some COCs. Identified trends are discussed in the proceeding subsections.

7.4.6.1 Radionuclides
Specific radionuclides that were routinely evaluated in GIT sumps include Thorium-228, Thorium-230, Thorium-232, Uranium-234, Uranium-235, and Uranium-238. Radium-226 and Radium-228 were not analyzed in any of the sump samples during the study period and were not included in the time series plots of water quality. Total uranium activity and Thorium-232 activity are presented in time series plots for the study period, showing generally decreasing trends in sumps 1, 2, 3, and 4 over time. Higher total uranium activities are observed in sump 1 and 2.

7.4.6.2 Total Metals
Total metals included in routine monitoring of arsenic, cadmium, chromium, and lead. Antimony, niobium, tantalum, and thallium were not included in routine monitoring and are not included on time series plots for the GIT sumps. With the exception of arsenic, elevated concentrations of metals were not detected in sumps. Arsenic was detected at peak concentrations of 12.6 mg/L in sump 3 in August 1999. No other elevated concentrations of arsenic were detected; however, decreasing concentrations in arsenic concentrations in all sumps was observed during the study period.

7.4.6.3 VOCs
The VOCs MIBK and TCE were the only VOCs considered as part of the groundwater quality evaluation of the GIT. TCE was only included in analysis in sump 3 on two occasions and was not detected in either instance. TCE was never analyzed in sump 1, sump 2, or sump 4. MIBK was included in routine monitoring of sump 1 and 3 water quality; however, was not routinely included in monitoring of sump 3 and sump 4 water quality. Maximum concentrations in sump 1 were observed from 1999 to 2000. After that period, MIBK concentrations in sump 1 have exhibited a generally decreasing trend and were last detected in sump 1 in March of 2009. MIBK concentrations detected in sump 2 are highly variable and do not exhibit an identifiable trend over time, suggesting that there is a continuing source of MIBK contamination located up gradient of the GIT in the area of sump 2.

7.4.7 Comparison of Pumping Rates to Precipitation
As part of the supplemental characterization, precipitation was compared to water levels in site wells and sumps as well as pumping rates within sumps in an effort to determine the lag time between precipitation events and changes in the saturated thickness, estimated infiltration of precipitation, and the percent of precipitation captured by the GIT. Insufficient data was available to support a determination in lag time between precipitation events and water levels in sumps and monitoring wells. The estimated infiltration was calculated based on site specific conditions discussed in detail in Section 7.4.7.2, below. Insufficient data are available to quantitatively evaluate percent capture; however, a conceptual evaluation was conducted and is presented in Section 7.4.7.3, below.

7.4.7.1 Precipitation Based Lag Time
In accordance with the Plan, a site-based relationship for the lag time between precipitation events and the observed pumping rates at the GIT must be established. Following an in-depth review of available data, it has become apparent that insufficient information exists to establish this relationship. While the pumping data for the various sumps does exist, it is based on the actual pre-programmed operation of the pumps (i.e., on a timer) and not on the volume of groundwater flowing into the GIT. As such, the precipitation induced change in the subsurface flow regime will have to be established via the related water table level change (and corresponding saturated thickness) in the monitoring wells. However, in order to achieve this, the well gauging data must have been performed on a frequency high enough to track these precipitation induced changes and the currently available data set does not provide this level of detail.

7.4.7.2 Estimated Infiltration

The evaluation of estimated infiltration of precipitation is based on a classical water balance equation based on the principle of conservation of mass. The water balance equation accounts for all of the water entering and exiting the system and is summarized below:

Inputs (precipitation + groundwater inflow) = Outputs (groundwater outflow + evapotranspiration + runoff)

Each variable in the water balance equation is accounted for by direct measurement (from nearby weather stations, see Section 7.8) or can be calculated from other measured variables or site specific hydrologic properties. For the purposes of estimating infiltration, we can assume that the volume of groundwater outflow minus the groundwater inflow is approximately equal to the infiltration. A simplified water balance equation solved for infiltration is as follows:

Infiltration = Precipitation – Evapotranspiration – Runoff

Precipitation was determined from compiled weather data (Appendix 13.15). Precipitation is multiplied by the total area of the Site to determine the total volume of precipitation over the study period. Runoff from impervious surfaces in this area is assumed to be captured by the on-site storm water retention system and directed to the WWTP. It is assumed that impervious surfaces within the Site area do not contribute to infiltration and these land areas were not considered in the calculation of total precipitation across the Site.

Evapotranspiration (ET) was calculated using the Hydraulic Evaluation or Landfill Performance (HELP) model. The HELP Modeling Software program is widely used by industry and regulatory agencies to predict and analyze water balance in standard and alternative capping systems by estimating the effectiveness of landfill caps by modeling water movement across, into, through, and out of landfills (Schroeder et al., 1994). For the purposes of this study, the HELP model was modified to evaluate evapotranspiration for surface soils and climate data specific to the FMRI site. HELP model estimations of ET at FMRI are summarized in Appendix 13.16.

Runoff was calculated using the Soil Conservation Service (SCS) runoff curve number method presented in SCS Technical Release 55: Urban Hydrology for Small Watersheds (USDA, 1985). Runoff curve numbers were determined for each of the unique surface soil types and overlying vegetation identified at the FMRI site (USDA, 2011). As previously mentioned, runoff from impervious surfaces at FMRI are captured by a storm water retention system and do not contribute to runoff or infiltration. As a result, the land area of the impervious surfaces is not considered in the evaluation of runoff. The remaining land area was divided by soil type and vegetative cover and each area was assigned a runoff curve number. A weighted average (by land area) of assigned runoff curve numbers was calculated to be 75. The calculated runoff curve number represents the FMRI site, exclusive of impervious surfaces.

Runoff produced for rain events of less than 1.2 inches is considered negligible and was excluded from the runoff estimate (USDA, 1986). During the study period (January 1, 1993 and October 31, 2011), there was a total of 786 inches of precipitation including a total of 159 precipitation events with greater than 1.2 inches of precipitation. The total runoff for an area with a runoff curve number of 75 receiving this amount of precipitation is estimated at 13.43 inches. The HELP model used to estimate ET also provides an estimation of runoff. The HELP model estimation of runoff and runoff curve number estimations of runoff on an annual basis are included as Appendix 13.16.

Based on the simplified water balance equation and the calculated volumes of precipitation, ET, and runoff, the estimated infiltration for each year of the study period (1993 to 2010) was calculated. Estimated infiltration in volume and inches (over the study area) for each year of the study is presented in Table 11.3.

7.4.7.3 Percent Capture

Similar to the evaluation of lag time, insufficient data is available to complete a quantitative evaluation of the capture efficiency of the GIT. Conceptually, the GIT captures 100% of groundwater flowing into it if it is operating in accordance with its design. There is no evidence that the GIT is not performing in accordance with its initial design and appears to be capturing all groundwater that flows into the trench, including groundwater that is attributed to the infiltration of precipitation at the Site. Additional water level and groundwater quality data, particularly hydraulically down gradient of the GIT, is necessary for a quantitative evaluation of the percentage of groundwater captured by the system.

7.5 Slug Testing

The slug test is an aquifer test that allows for the measurement of saturated hydraulic conductivity within an aquifer with a single well. The method consists of quickly lowering or raising the water level from equilibrium within a well and subsequently measuring the rate of rise or fall, respectively (Bouwer, 1989).

Among the varied field investigation activities undertaken as part of the Remediation Assessment (RA) in March of 1993, fifteen (15) slug tests were conducted on shallow groundwater monitoring wells at the Site. Data collected during those slug tests was obtained from Appendix C of the RA (Volume II) and each complete data set was reanalyzed with the Bouwer-Rice method for partially penetrating wells. A total of thirteen (13) slug tests in Appendix C of the RA contained complete data sets and were reanalyzed. Data for two (2) slug tests were not included in the RA and were not re-evaluated. All slug testing conducted as part of the 1993 RA consisted of rising head tests only. Falling head tests were not conducted on any wells. The results of the original (1993) slug test analysis and the re-analysis (2011) are summarized in Table 11.4. A complete presentation of the 1993 and 2011 slug test data and analyses are included as Appendix 13.17.

The values presented in the 1993 RA ranged from 1.24E-03 to 3.93E-02 centimeters per second (cm/s) with a geometric mean of 3.78E-03 cm/s. The recalculated hydraulic conductivity values range from 1.04E-04 to 2.33E-02 cm/s with a geometric mean of 1.60E-03 cm/s. The MW-59S slug test was not analyzed for hydraulic conductivity during the 1993 RA. As a result, it was not considered in the hydraulic conductivity range or the calculation of the geometric mean for the 1993 data set. The re-analysis of the MW-59S slug test data identified it as the minimum hydraulic conductivity (1.04E-04 cm/s). The MW-59S slug test result was included in the 2011 calculation of the geometric mean, resulting in the geometric mean of the 2011 re-analysis hydraulic conductivity to be biased lower than the geometric mean calculated from the 1993 hydraulic conductivity data set.

Hydraulic conductivity values within these ranges correspond to silty sands and fine sands (Freeze and Cherry, 1979). Generally, the lithology of overburden material at the FMRI site consists of sand, silt, and clay. A general feature of the alluvium of the Arkansas River is the gradation in grain size from gravel or coarse-grained sand near the base of the alluvial deposits to silt and clay near the surface (Kirkpatrick & Lockhart, 1993) (Tanaka et. al., 1966). The reported heterogeneity of the alluvium is consistent with the lithology observed at FMRI during the 1993 RA and the 2011 soil boring program conducted by the project team. The results of the 1993 slug tests are consistent with published hydraulic conductivity values for the Arkansas River alluvium in Muskogee County (Tanaka et. al., 1966).

In general, the hydraulic conductivity values presented in the RA report were greater than those calculated during the 2011 evaluation of the slug test data. The slug tests were analyzed in 1993 and 2011 using aquifer testing software with the Bouwer-Rice method for unconfined aquifers with partially penetrating wells (Bouwer and Rice, 1976). The aquifer tests were analyzed using AQTESOLV Version 1.10 software and Waterloo Hydrogeologic Aquitest Version 2.5 software in 1993 and 2003, respectively. From the water level over time data measured during the slug test, the aquifer testing software graphs the change in hydraulic head (h/h0) on a logarithmic y-axis versus time. Based on the slope of the best fit line (determined by the user), the aquifer testing software calculates the hydraulic conductivity (Bouwer and Rice, 1976). The difference between the 1993 and 2011 slug test analyses is the determination of the best fit line.

When the change in hydraulic head versus time is graphed on a semi-logarithmic scale, it typically forms two straight line segments. The first line corresponds to flow into the well through the high permeability sand or gravel pack surrounding the monitoring well. The second straight line corresponds to flow into the well from the aquifer (Bouwer, 1989). During the 1993 evaluation of the slug test data, the best fit line was fit to the first line. As a result, the hydraulic conductivity values calculated during the 1993 RA correspond to the permeability of the sand pack surrounding the well and are not considered representative of the permeability of the saturated alluvium at the Site. During the 2011 re-evaluation of the slug tests, the best fit line was fit to the second line. The resulting hydraulic conductivity values were less than those calculated during the 1993 RA for all wells and are considered more representative of the permeability of the saturated alluvium at the Site. An example (MW-56S) of the difference between the best fit lines of the 1993 and 2011 slug test evaluations is presented in Figure 12.10.

Slug testing was completed on three (3) wells in October of 2011 to verify the results of aquifer tests (slug and pumping tests) conducted in 1993. The new tests (rising head and falling head) were performed on monitoring wells MW-53S, MW-63S, and MW-68S. Slug tests were conducted using a pressure transducer and a 3-foot by 3.75 inch PVC slug. The transducer is a combined data logger and pressure transducer that records water levels at one-second intervals based upon pressure changes. At each well, the initial depth to water was measured using a water level indicator. The transducer, attached to a 1/8-inch steel cable, was placed approximately one foot from the bottom of the well, and was left in the well for the duration of slug testing activities.

Both rising and falling head slug tests were performed on each well. After the transducer was placed in the well and the original water level was restored, slug testing began. The slug was lowered into the well until the top of the slug was below the static water level depth. Water levels were manually monitored to determine when the static water level was regained. Once static water levels were regained, the slug was removed from the well. After static water level was restored, the transducer was removed from the well and data were downloaded and verified in the field.

Slug test data from the transducer were plotted as a logarithmic curve to identify the beginning and end of each test (rising and falling). Each test was then isolated and analyzed with the Bouwer-Rice method for partially penetrating wells. The resulting hydraulic conductivity values ranged from 1.78E-04 cm/s in MW-68S to 6.75E-04 cm/s in MW-53S. The geometric mean of the 2011 slug tests (both rising and falling head) is 3.72E-04 cm/s. Slug test analyses are included as Appendix 13.17, with results summarized in Table 11.4.

The hydraulic conductivity values determined from the new slug testing conducted in 2011 are slightly lower than the hydraulic conductivity values re-calculated from the 1993 slug tests but remain within the range of hydraulic conductivities for silty sand (Freeze and Cherry, 1979). The observed difference in calculated hydraulic conductivity values between the new 2011 slug testing and the original slug testing re-calculation may be attributed to the fluctuation of the water table. At the time the October 2011 slug tests were conducted, water levels within MW-63S and MW-68S were 3.50 and 1.86 feet lower, respectively, than water levels in the same wells in 1993. As a result, the slug test results correspond to a slightly different lithology within the heterogeneous alluvium. The variation in hydraulic conductivity as a function of depth is consistent with published hydraulic conductivity values for the alluvium of the Arkansas River in Muskogee County (Tanaka et. al., 1966).

7.6 Hydrogeologic Properties

The FMRI facility is located within the floodplain of the Arkansas River in Muskogee, Oklahoma. General geologic information for the area indicates a stratigraphy characterized by alluvial deposits underlain by Pennsylvanian age bedrock, specifically the McCurtain Shale. Alluvial deposits consist of clay, silt, sand, and gravel in proportions that vary locally. A general feature of the alluvium is the gradation in grain size from gravel or coarse-grained sand near the base of the deposit to silt and clay near the surface. Hydrogeologic investigations conducted previously at the Site, along with easily ascertainable published hydrological reports for the Arkansas River alluvial deposits were reviewed as part of this study, with relevant hydrogeological properties being extracted and compiled. The compilation of the hydrogeologic data is intended to serve as a basis for future groundwater velocity calculations, as well as fate and transport modeling. Compiled Hydrogeologic Data are summarized in Table 11.5.

7.6.1 Hydraulic Conductivity

Aquifer tests, including slug tests and a pumping test, were conducted at the Site as part of the 1993 RA. A total of fifteen (15) slug tests were conducted on shallow groundwater monitoring wells with screened intervals within the alluvial deposits and four (4) slug tests were conducted on deep groundwater monitoring wells with screened intervals within the McCurtain Shale. Data collected during the slug tests on shallow wells were reevaluated in September 2011 to confirm the results of the previous slug test analyses. Three (3) additional slug tests were conducted in September of 2011 to assess the accuracy of the previously conducted slug tests. 1993 aquifer test results (for alluvium and bedrock), slug test re-analysis results (alluvium only), and 2011 slug test results are presented in Table 11.4 and discussed in greater detail in Section 7.5, above.

Hydraulic conductivity of the Arkansas River flood plain alluvium determined through laboratory testing ranged from 2.36E-02 to 4.72E-06 cm/sec. Hydraulic conductivity for the intervals that correspond to the saturated zone of the alluvium (e.g., immediately above bedrock) range from 1.27E-02 to 3.30E-04 cm/sec (Tanaka et. al., 1966). Published hydraulic conductivity values for the Arkansas River flood plain alluvium are consistent with the results of the slug tests conducted at the facility which were seen to range from 2.33E-02 to 1.04E-04 cm/s.

7.6.2 Vertical Permeability

A geotechnical study was completed in 1978 to support the construction of Pond No. 3. This geotechnical investigation calculated permeability for several specific intervals within three boreholes and two composite samples by laboratory falling head tests. The falling head tests were conducted on one-foot intervals corresponding to alluvium above the water table (Hemphill Corporation, 1978). The results of this study are not considered valid for use as a hydraulic conductivity because lab studies of alluvial material from intervals above the water table do not represent the actual permeability of the saturated zone of the alluvial deposits. The estimated permeability (1.9E-07 to 2.6E-08 cm/sec) is not consistent with published values for the observed lithology (clayey silt, sandy silt, and silty clay) and appear to underestimate the permeability by two (or more) orders of magnitude (Freeze and Cherry, 1979) (Hemphill Corporation, 1978). For example, the reported permeability values for unsaturated alluvium (1.9E-07 to 2.6E-08 cm/sec) in the 1978 Hemphill study are the same order of magnitude as the laboratory determined permeability of engineered clay landfill covers (1E-08 cm/sec) and are considered an overestimate (Purdy and Peters, 2004). The permeability data are presented in Table 11.5 as permeability of the unsaturated alluvium. However, the data is not considered reliable and has limited usability (if any) in future groundwater or fate and transport modeling applications.

7.6.3 Transmissivity

Transmissivity (T) is a measurement of the horizontal flow of groundwater in the saturated zone and is a function of hydraulic conductivity (K) times the saturated thickness (b) ($T = Kb$). In an unconfined aquifer situation, the saturated thickness is represented by the height of the water table above the top of the underlying aquitard that bounds the aquifer (Freeze and Cherry, 1979). The application of this relationship to slug test results must be done with great care given the fact that any result would be representative of only the area in the direct vicinity of the piezometer used for the test and could not be applied across the aquifer system in question.

Under the 1993 RA, transmissivity values were determined from slug tests and a single pumping test. For the slug tests, it appears that the modeler utilized the Papadopoulos method to process the data to achieve these results which, based on the application of groundwater theory, is an incorrect approach. This method is applicable for slug test results from confined aquifers only. As such, these results, along with any calculations that were undertaken with them are, at best, unreliable.

The pumping test interpretation from the 1993 study also raises questions. Within the text of the report, it is stated that the pumping test was conducted at a rate of 0.1 gpm for over 6,000 minutes and drawdown was not observed in any of the observation wells. Within the appendices, drawdown versus time plots are presented for some of the monitoring wells (OW-1 and OW-2). Review of the plotted data indicates that the plots only represent about 400 minutes of pumping and inspection of the plotted data clearly indicates that the ground water elevation was both rising and falling during this time. Given the apparent discrepancies with the reporting and data treatment, it has been concluded that the results associated with this test are also unreliable.

7.6.4 Storativity and Specific Yield

Specific yield is the volume of water that an unconfined aquifer releases from storage per unit surface area of aquifer per unit decline in the water table (Freeze and Cherry, 1979). In coarse porous media, specific yield is approximately equal to porosity. Based on information presented in Freeze and Cherry (1979) the usual range for specific yield is 0.01 to 0.30.

In a confined aquifer, this metric is called storativity and is also a function of the compressibility of water and aquifer material. Storativity is directly proportional to aquifer thickness, while specific yield is not a function of aquifer thickness (Hemond, 2000). Based on information presented in Freeze and Cherry (1979) the usual range for storativity in confined aquifers is from 0.005 to 0.00005.

Storativity and specific yield were included in the slug test and pumping analyses conducted as part of the 1993 RA although they were not formally reported in the RA. However, as discussed above, the methodology applied to interpret the slug test data were inappropriate for an unconfined aquifer system and consequently, any storativity/specific yield results reported would be invalid. In addition, it is worth noting that according to Freeze and Cherry (1979), storativity results from slug tests (even when the solution is appropriately applied) are very unreliable due to the similarity in the slopes of the type curves of the Papadopoulos solution.

The storativity/specific yield results presented in the 1993 RA based on the pumping test results are also considered unreliable due to the discrepancies detailed in the previous section.

7.6.5 Saturated Thickness

Groundwater within the McCurtain Shale does not appear to be hydraulically connected to the groundwater system located within the overlying soils. As such, it was not considered during the 1993 RA or 2011 Site Characterization activities. The saturated thickness within the alluvium is the distance between the McCurtain Shale and the water table. As a result, the saturated thickness of the alluvium is variable, depending on local bedrock elevation and water table elevation. Based on 1993 water table elevations, the saturated thickness within the alluvium ranged from 1.5 feet (MW-56S) to 17.5 feet (MW-54S). Bedrock elevations were included on the hydrographs prepared for all site wells with all available groundwater elevation data as part of 2011 Site Characterization activities. The hydrographs present saturated thickness (the difference between the water table and bedrock elevations) over time and are included as Appendix 13.14.

The saturated thickness at the Site was influenced by the installation and operation of the GIT in 1999-2000. Saturated thicknesses observed in monitoring wells in close proximity to the GIT were reduced and, in some wells, the wells became dry. The influence of the trench on saturated thicknesses within the alluvium is discussed in detail in Section 7.4.2 and 7.4.3.

7.6.6 Porosity

Porosity was not evaluated at the Site during the 1993 RA, 2011 Site Characterization, or any other investigation historically conducted at the facility. Porosity is typically estimated for use in groundwater velocity and modeling applications. Porosity of the Arkansas River floodplain alluvium determined through laboratory testing ranges from 29.9 to 50.6%. Porosity for the intervals that correspond to the saturated zone of the alluvium (e.g., immediately above bedrock) range from 29.9 to 33.8% (Tanaka et. al., 1966). Primary and secondary porosity data were not available for the McCurtain Shale. Available porosity data is summarized in Table 11.5.

7.6.7 Hydraulic Gradient

A single groundwater potentiometric surface map was generated for the saturated alluvium and a second was generated for groundwater within the McCurtain Shale during the 1993 RA. Groundwater flow directions and hydraulic gradients were determined from these potentiometric surface contour maps.

7.6.7.1 McCurtain Shale

Based on the potentiometric surface contour map for groundwater within the McCurtain Shale, the RA identified bi-directional groundwater flow with a component flowing to the east and component flowing to the west-northwest. Calculated hydraulic gradients for the east and west-northwest components of groundwater flow within the McCurtain Shale were 0.00565 and 0.017 respectively.

Groundwater levels within the McCurtain Shale used to generate the bedrock groundwater potentiometric surface contour map were not measured during a single contemporaneous gauging event. Water levels were measured in former monitoring well MW-151D on April 21, 1993 and water levels were measured in former monitoring wells MW-161D, MW-171D, and MW174D on April 29, 1993. According to compiled precipitation data (Section 7.8), the area received approximately 1.53 inches of precipitation between gauging events. During this time period, precipitation may have percolated to the subsurface resulting in changes in water levels within the saturated alluvium and the McCurtain Shale. As a result, the water level measured in MW-151D should not be considered in conjunction with the water levels measured in the other deep monitoring wells. When MW-151D is not considered, there is insufficient data to identify the west-northwest component of groundwater flow within the McCurtain Shale. The remaining three (3) deep monitoring wells are all located on the eastern edge of the Site, in close proximity to the Arkansas River. Considering groundwater elevations within these three former wells, groundwater within the McCurtain shale flows east-northeast at a hydraulic gradient of 0.059.

Groundwater elevation data from the former deep monitoring wells was available for several other gauging events conducted in 1994 and 1995. Groundwater potentiometric surface contour maps were not generated for these data sets; however, the review of the data indicated that bi-directional flow within the McCurtain Shale was consistently observed during that time period. The hydraulic gradient over that time period in the east-northeast direction ranged from 0.042 to 0.059 with an average of 0.051. The average hydraulic gradient may not be representative of the hydraulic gradient within the McCurtain Shale in Muskogee County and is possibly influenced by the close proximity of former monitoring wells MW-161D, MW-171D, and MW174D to the Arkansas River.

Only one former monitoring well (MW-151D) is located west of the groundwater flow direction divide. As a result, the hydraulic gradient for the west-northwest component of groundwater flow within the McCurtain Shale cannot be reliably determined. The hydraulic gradient for the west-northwest component of groundwater flow within the McCurtain Shale presented in the 1993 RA (0.017) is not considered reliable.

Caution should be exercised when considering the hydraulic gradient within the McCurtain Shale because groundwater flow in bedrock is governed by secondary porosity (fractures) and there is no guarantee in connectivity between fractures or boreholes. Differing elevations within boreholes screened in bedrock formations are not necessarily representative of a flow gradient.

7.6.7.2 Unconsolidated Saturated Alluvium

Based on the potentiometric surface contour map for the saturated alluvium at the Site presented in the 1993 RA, groundwater flow within the unconsolidated zone was identified to be in three directions, southeast, southwest, and northeast. Calculated hydraulic gradients for the northeast, southeast, and southwest components of groundwater flow within the unconsolidated zone were 0.0076, 0.003 and 0.0064, respectively.

Groundwater potentiometric surface contour maps for the unconsolidated saturated alluvium were generated for every year from 1993 to 2010 and are included as Appendix 13.9. Groundwater flow was observed in two flow directions, northeast and southeast, in each of the potentiometric surface maps. A southwest component of groundwater flow was not identified in any of the potentiometric surface maps.

Based on the groundwater potentiometric surface maps from 1993 to 1998 (prior to the installation of the GIT) the average hydraulic gradient for the northeast and southeast component of groundwater flow was 0.0081 and 0.0037, respectively. During a period from 1999 to 2002, the French drain sump was not operating and the GIT was not fully functional. The groundwater potentiometric surface maps during this period are most representative of natural groundwater flow and indicate groundwater flow to the northeast and southwest at average gradients of 0.0063 to 0.0029, respectively. From 2002 through 2009, the GIT and the French drain sump were fully operational. Groundwater potentiometric surface maps for this period represent groundwater flow conditions under the influence of these pumping systems. Groundwater flow was identified to the northeast and southeast at average gradients of 0.013 and 0.0026, respectively.

Average hydraulic gradients reported in the 1993 RA and average hydraulic gradients calculated for the three time periods corresponding to before the installation of the GIT, during the installation of the GIT, and during the operation of the GIT are included in Table 11.5.

7.7 Data Gaps

Based on the findings of the ICF report, three data gaps were identified in groundwater characterization at the FMRI site:

- The Chem C Building is considered a likely source of groundwater contamination. However, it has not been fully characterized. The installation and sampling of a groundwater monitoring well that is hydraulically down-gradient of the Chem C Building is recommended, with samples analyzed for gross beta, gross alpha, isotopic thorium, isotopic uranium and isotopic radium.

- The groundwater flow direction has not been fully established throughout the Site. Additional groundwater elevation data should be compiled and analyzed to firmly establish groundwater flow patterns.

- Elevated concentrations of gross alpha activity and uranium have been detected in monitoring well MW-56S, located in the borrow pit area. Site activities affecting groundwater in the borrow pit area are unknown. The installation of two additional groundwater monitoring wells (one up gradient and one down gradient of MW-56S) in the borrow pit area is recommended, with samples analyzed for gross beta, gross alpha, isotopic thorium, isotopic uranium and isotopic radium.

As part of this supplemental characterization effort, the project team reviewed all available data for the FMRI site. The data reviewed included all facets of groundwater flow, groundwater extraction, and groundwater quality. This data is evaluated and presented in the preceding sections. Based on the review and evaluation of that data, the project team has come to the following conclusions and has made recommendations for each of the three data gaps identified in the ICF report.

7.7.1 Chemical C Building Characterization

The project team agrees that Chem C is a possible source of groundwater contamination and agrees that the installation of a groundwater monitoring well hydraulically down gradient of the building would be useful for monitoring groundwater quality up gradient of the GIT. The project team also agrees that any groundwater contamination potentially originating from Chem C is being captured by the GIT.

The project team believes the installation of the additional monitoring well would provide data that can help determine if Chem C is in fact a source of groundwater contamination as well as help differentiate the contribution of Chem C to groundwater contamination from other potential sources in the area (Ponds No. 2 and 3). Furthermore, the installation of a second monitoring well inside of the Chem C would provide soil and groundwater quality data at the suspected source of contamination. This information is critical to the design of a remedial strategy for addressing the contamination source in Chem C.

7.7.2 Groundwater Flow Direction Analysis

The project team has reviewed and compiled all available groundwater elevation data from 1993 to 2010 and has generated groundwater potentiometric surface maps for each year of the study period. Groundwater flow direction and gradients are discussed in detail in Sections 7.1 and 7.6. The project team did not identify a southwest component of groundwater flow or radial groundwater flow originating in the center of the Site in any of the potentiometric surface maps. The project team has concluded that the two primary components of groundwater flow are southeast and northeast (being fed by an easterly flow). The team also concluded that the groundwater elevation contour map presented in the 1993 RA does not accurately represent groundwater flow.

7.7.3 Characterization of the Borrow Area

The project team agrees that there is not currently sufficient information available on site activities associated with the Borrow Area to positively identify the source of elevated gross alpha and isotopic uranium observed in monitoring well MW-56S. Based on the re-evaluation of groundwater flow direction on the southern portion of the Site, the groundwater contamination in this area may not be captured by the existing GIT system. The project team concurs that the installation of additional monitoring wells in this area is ultimately necessary to delineate the extent of groundwater contamination in this area. However, a more thorough review of the potential sources of contamination should be conducted before recommending the numbers and locations of additional groundwater monitoring wells in this area. The source review may include, but is not limited to, a review of site operations in and around the Borrow Area, interviews with FMRI personnel familiar with the operational history of the Borrow Area, and regular sampling of monitoring wells and observation wells for gross alpha and individual isotopes.

7.8 Climate Data

Climate data for Muskogee County and the surrounding region was compiled for 1993 through 2010. Climate data is an important component of a water balance evaluations and can be used in future groundwater modeling applications. For ease of use, compiled climate data from 1993 through 2010 is included as Appendix 13.15.

Daily climate records data from 1994 through 2011 were obtained from Oklahoma Mesonet. Mesonet is a service run by the Oklahoma Climatological Survey (OCS) that collects and verifies weather data from 120 weather stations throughout the state of Oklahoma. The weather parameters that were collected include:

- Ambient Temperature
- Precipitation
- Dew Point

- Relative Humidity
- Solar Radiation
- Atmospheric pressure in inches of mercury
- Average wind speed at 2 meters height

The bulk of the climate data were downloaded from the Haskell weather station which had the most complete data record of available weather stations in the vicinity of FMRI. The Haskell weather station is situated approximately 19 miles east of the FMRI site within Muskogee County. Alternatives sources of weather data from other relatively close stations (i.e., the Porter, Cookson and Tahlequah weather stations) were used to fill data gaps in the Haskell weather station climate record. A map showing the relative location of these weather stations in proximity to the FMRI site is shown in Figure 12.11 and weather station locations are summarized in Table 11.6.

Daily weather data prior to 1994 were downloaded from the National Oceanic and Atmospheric Administration (NOAA) National Data Center. NOAA climate data were compiled from weather stations at Tulsa Airport. This data were also used to fill gaps in records of ambient temperature and dew point from 1994 through 1997 in data available through the Oklahoma Mesonet. Daily solar radiation data for 1993 was not available. Daily solar radiation for this period was derived by averaging daily solar radiation data from 1994 through 2010.

As previously mentioned, compiled climate data from 1993 through 2010 are included as Appendix 13.15. Daily data were compiled for the entirety of the study period from a variety of weather stations. Within Appendix 13.15, daily weather data are color coded to denote its’ source. A legend for the color coding of the daily data is presented below.

- Black - Haskell Weather Station
- Red - Porter Weather Station
- Blue - Cookson Weather Station
- Orange - Tahlequah Weather Station
- Green - Tulsa International Airport
- Pink - data extrapolated from average values

In addition to daily climate data, monthly and annual summations of climate data are presented in Appendix 13.15.

8 DERIVED CONCENTRATION GUIDELINE LEVELS

FMRI plans to ultimately release the entirety of the Muskogee, Oklahoma property for unrestricted use (Fansteel, 2003). Therefore, dose modeling must be performed to demonstrate compliance with the following (USNRC, 1997):

> *"A site will be considered acceptable for unrestricted use if the residual radioactivity that is distinguishable from background radiation results in a total effective dose equivalent (TEDE) to an average member of the critical group that does not exceed 25 millirem (0.25 mSv) per year, including that from groundwater sources of drinking water, and the residual radioactivity has been reduced to levels that are As Low As Reasonably Achievable (ALARA). Determination of the levels which are ALARA must take into account consideration of any detriments, such as deaths from transportation accidents, expected to potentially result from decontamination and waste disposal."*

Residual radioactivity levels that are distinguishable from background remaining at the Site at the time of license termination cannot result in a total effective dose equivalent (TEDE) to an average member of the critical group (i.e., hypothetical industrial worker) that exceeds 25 millirem per year (mrem/yr). Residual radioactivity must also be reduced to levels that are ALARA.

Dose modeling was performed to assess the TEDE to an average member of the critical group from residual radioactivity at the FMRI site. Based on the current and expected future industrial land use of the FMRI site, an industrial use scenario was applied to develop site-specific DCGL's for the residual radioactivity present in soil and on building surfaces at the time of Final Status Survey (FSS) and the FMRI site release (Fansteel, 2003 and USNRC, 2003b).

DCGLs were developed for eleven (11) radionuclides identified in the DP, with the values applicable to the supplemental characterization shown in Table 11.7. Each DCGL value for soil represents the activity equivalent of a dose of 25 mrem/yr to a member of the critical group (i.e., hypothetical industrial workers). During decommissioning and the performance of final status surveys, the sum of fractions rule will be used to account for the fact that multiple radionuclides are present.

9 CONCLUSIONS AND FOLLOW-UP ACTION

In compliance with Provision 31.a of License No. SMB-911, a supplemental site characterization plan was submitted to and approved by the USNRC (FMRI, 2011 and Shepherd, 2011). The on-site portion of the work began on September 26, 2011 resulting in the data and information captured in this report. In general, the findings are as follows:

- Residual radioactivity in concentrations that are slightly above the applicable DCGLs (see Table 11.7) was identified in occasional one-meter and in subsurface soil cores;

- Chemical data collected from the one-meter and subsurface (> one meter) soil cores revealed the full range of metal analytes subject to investigation in each sample recovered, regardless of depth. Niobium and tantalum were most highly concentrated in the vicinity of Pond No. 3. Fluoride, nitrate, and ammonia were also detected in most soils, with higher concentrations observed in the immediate vicinity of Pond No. 3.

- VOCs were only evaluated in the subsurface soil increments below one meter. MIBK and TCE, the primary COCs, were observed disproportionately. MIBK was noted in 17 of the 20 deep soil borings, and were primarily observed in the terminal core increment of each boring corresponding to the water table. Conversely, TCE was not detected in any of the deep soil borings.

- Groundwater elevation data indicate general groundwater flow to the east across the Site with northeast and southeast components of flow emanating from the center of the Site. The general groundwater flow direction correlates with the observed slope of the bedrock surface underlying the Site and is toward the Arkansas River. However, the minor components of groundwater flow do not directly correlate with the slope of the bedrock surface. The southwestern component of groundwater flow reported in the 1993 RA was not observed in any of the groundwater potentiometric surface maps prepared for each year of the study period.

- Historical groundwater quality data for select COCs were tabulated. However, a uniform "suite" of COCs was not consistently evaluated in all of the monitoring wells during each sampling event. As a result, the usability of the data for site characterization purposes is limited.

- The GIT, based on pumping data collected since its construction in 1999, reveals a mixed performance record during its operation. From 1999 to April 2002, groundwater extraction rates were inconsistent and were limited by inefficient treatment infrastructure. This condition was corrected in May 2002, resulting in sustained pumping rates and performance consistent with system design. Sustained reduction in water levels in the GIT and in nearby groundwater monitoring wells was observed. As of August 2010, the system has recovered and treated approximately 59 million gallons of groundwater.

- Conceptually, the GIT is capturing all of the groundwater that enters the trench, and is effective at preventing the off-site migration of water-born contaminants. Water quality data are not available east of the GIT, thus capture effectiveness could not be confirmed.

- Hydrogeologic properties for the Site were reviewed and tabulated for reference and inclusion in future groundwater velocity calculations or groundwater modeling applications. Reported hydraulic conductivity values were re-evaluated and additional aquifer testing was conducted. The updated hydraulic conductivity values were slightly lower than previously reported.

- Climate data were compiled and tabulated for inclusion in future water balance evaluations and infiltration modeling. Modeling estimated that 17% of the precipitation falling on the Site results in infiltration.

Decommissioning operations that have been on-going at the FMRI site since July 18, 2011 impeded the field team's ability to complete all of the tasks specified in the Plan. The following is a listing of those items that are yet to be performed:

- Characterization of structures, including sewers, waste systems, floor drains, ventilation ducts, and floor joints;

- Characterization of surface soil, performance of gamma scan and collection of discrete surface soil (i.e., top 15 centimeters) samples; and

- Characterization of subsurface soils near Buildings Chem A and Chem C, Sodium Reduction Building, Thermite Building, R&D building and the Equipment Storage Pad.[7]

- Radiological dose assessment and dose modeling to demonstrate the Site in its entirety may be released for unrestricted use.

These tasks will be completed once the Pond No. 2 excavation work is complete, with an anticipate start date of early 2012. The findings of the follow-on investigation will be captured in a separate report or an addendum to this report.

There are also gaps in the information needed to characterize groundwater impacts at the Site. These were identified by ICF (ICR, 2002) and confirmed by the project team as outlined in Section 7.7, above. To fill the gaps, the following additional actions were recommended:

- Install a groundwater monitoring well near and down-gradient of the Chem C building, a known source of groundwater contamination

- A second monitoring well should be installed within the Chem C building to assess groundwater quality at the suspected source;

- Compile additional groundwater elevation data to establish groundwater flow direction throughout the Site; and

- Additional characterization of the borrow area is warranted, although additional groundwater quality data from monitoring wells located in and around the borrow area (i.e., one up-gradient and one down-gradient of MW-56S) should be collected and evaluated before determining the number and location of additional wells.

These recommendations will be addressed as part of the Phase IV Work Plan, with provisions incorporated to ensure the groundwater remediation phase of the project is sufficiently comprehensive and effective.

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[7] The Equipment Storage Pad and the Chemical Storage Pad are located west of processing building Chem A. It has been previously termed the Ore Storage Pad because ore was stored in this area prior to it being processed in Chem A (i.e., prior to 1989).

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11 TABLES

Table 11.1 - Sumps and Monitoring Well Drawdown Summary

Well/Sump	Distance from GIT (ft)	Initial Groundwater Elevation	Initial Drawdown		Sustained Drawdown	
		Average 1993 to April 2002	Minimum in May 2002	Initial Drawdown	Average May 2002 to 2010	Sustained Drawdown
Sump 1	0	507.85	503.08	4.77	504.67	3.18
Sump 2	0	509.4	502.49	6.91	503.66	5.74
Sump 3	0	509.32	502.51	6.81	503.88	5.44
Sump 4	0	508.06	502.39	5.67	503.2	4.86
MW-51S	1,760	515.23	NM	NA	515.27	-0.04
MW-52S	1,100	513.41	NM	NA	513.16	0.25
MW-53S	1,160	514.5	NM	NA	513.86	0.64
MW-54S	1,100	514.31	NM	NA	513.47	0.84
MW-55S	703	511.66	507.6	4.06	509.48	2.18
MW-57S	43	511.44	507.77 (DRY)	3.67 (DRY)	507.75	3.69
MW-62S	75	511.98	508.44	3.54	508.08	3.9
MW-63S	540	511.83	509.96	1.87	509.72	2.11
MW-64S	350	511.08	509.7	1.38	509.05	2.03
MW-65S	240	511.47	508.9	2.57	509.04	2.43
MW-67S	45	510.8	508.93	1.87	508.8	2.00
MW-68S	800	511.77	512.3	-0.53	511.69	0.08
MW-69S	140	508.43	508.39	0.04	507.78	0.65
MW-70S	375	510.95	510.26	0.69	509	1.95
MW-71S	166	508.97	506.49 (DRY)	2.48 (DRY)	508.13	0.84
MW-72S*	140	507.04	508.94	1.4	504.4	2.64
MW-74S	26	508.62	505.94	2.68	507.42	1.2
MW-75S**	42	507.33	506.25	1.08	506.45	0.88
NM - Depth to water not measured in May 2002						
NA - Not Applicable						
* Initial drawdown in MW-72S was calculated from April 2002 water levels due to the influence of the French Drain Sump on historical water levels						
** MW-75S is located down gradient of the GIT. Observed drawdown is related to the elimination of recharge from groundwater flow.						

Table 11.2 - Annual Summary of Sump Pumping Volumes (Gallons)

Year	Sump 1	Sump 2	Sump 3	Sump 4	Annual Total
1999*	138,240	20,160	226,080	308,160	**692,640**
2000	133,920	28,800	255,600	69,120	**487,440**
2001	0	0	79,200	28,800	**108,000**
2002	820,613	1,792,800	2,431,642	1,838,794	**6,883,848**
2003	341,136	1,450,512	1,570,896	1,729,296	**5,091,840**
2004	586,656	1,831,536	2,210,688	1,488,240	**6,117,120**
2005	558,288	1,824,768	2,544,336	1,770,048	**6,697,440**
2006	297,072	926,064	1,690,848	1,155,456	**4,069,440**
2007	1,910,592	463,824	3,376,656	2,359,728	**8,110,800**
2008	2,126,434	1,799,597	3,311,712	1,947,672	**9,185,414**
2009	1,259,856	1,573,488	2,095,646	1,977,768	**6,906,758**
2010**	479,232	1,359,360	1,565,280	1,313,712	**4,717,584**
Sump Total	**8,652,038**	**13,070,909**	**21,358,584**	**15,986,794**	**59,068,325**
*Pumping began on August 18, 1999					
**2010 pumping data only available through August 25, 2010					

Table 11.3 - Infiltration Summary Table

Year	Total Precipitation (Inches)	Runoff - Modified HELP Model (inches)	Evapotranspiration - Modified HELP Model (inches)	Calculated Infiltration - Modified HELP Model (inches)	Calculated Infiltration - Modified HELP Model (%)
1993	38.96	0.22	37.32	1.41	4%
1994	47.56	0.21	39.76	7.58	16%
1995	44.07	0.37	35.89	7.81	18%
1996	35.52	0.82	31.09	3.61	10%
1997	44.36	0.26	35.03	9.07	20%
1998	45.73	2.20	31.87	11.66	26%
1999	49.73	0.90	37.38	11.45	23%
2000	45.92	1.09	36.08	8.75	19%
2001	43.52	1.22	29.52	12.78	29%
2002	38.06	0.48	34.47	3.11	8%
2003	33.70	0.49	32.32	0.90	3%
2004	46.88	0.78	34.72	11.38	24%
2005	30.41	0.12	28.94	1.36	4%
2006	35.47	0.05	25.17	10.26	29%
2007	47.98	0.66	38.70	8.62	18%
2008	52.78	2.45	39.87	10.46	20%
2009	44.84	0.74	34.45	9.65	22%
2010	33.37	0.05	33.93	-0.61	-2%
Total:	758.86	13.09	616.51	129.26	17.03%

Table 11.4 - Slug Test Summary

Well	1993 Slug Test Analysis (cm/s)	2011 Slug Test Analysis (cm/s)
MW-55S	1.42E-03	8.18E-04
MW-56S	5.15E-03	9.30E-04
MW-57S	6.65E-03	4.35E-03
MW-58S	1.91E-03	1.61E-03
MW-59S**	NA	1.04E-04
MW-60S	2.70E-03	1.94E-03
MW-63S*	3.45E-03	1.37E-03
MW-65S	2.60E-02	2.09E-02
MW-66S	1.24E-03	5.13E-04
MW-68S*	1.55E-03	7.67E-04
MW-70S	2.94E-03	2.03E-03
MW-72S	1.68E-03	7.77E-04
MW-75S	3.93E-02	2.33E-02
Minimum	1.24E-03	1.04E-04
Maximum	3.93E-02	2.33E-02
Geometric Mean	3.78E-03	1.60E-03

NA — Not Analyzed
* slug test was conducted in 2011 for verification of previous results
** MW-59S slug test was not analyzed for hydraulic conductivity in 1993

Monitoring Well	MW-53S Summary		MW-63S Summary		MW-68S Summary	
Test	**Rising Head**	**Falling Head**	**Rising Head**	**Falling Head**	**Rising Head**	**Falling Head**
Hydraulic Conductivity (cm/s)	5.69E-04	6.75E-04	4.06E-04	4.57E-04	1.78E-04	2.08E-04

Table 11.5 - Hydrogeologic Properties Summary

Hydraulic Conductivity (K) in cm/s	**Minimum**	**Maximum**	**Geometric Mean**
Saturated Alluvium - 1993 RA Slug Test	1.24E-03	3.93E-02	3.78E-03
Saturated Alluvium - 1993 RA Slug Test Re-analysis	1.04E-04	2.33E-02	1.60E-03
Saturated Alluvium - 2011 Slug Test	1.78E-04	6.75E-04	3.72E-04
Saturated Alluvium - Published Data (Tanaka et. al., 1966)	3.30E-04	1.27E-02	4.04E-03
McCurtain Shale - 1993 RA Slug Test	3.82E-06	1.08E-03	2.80E-05
Vertical Permeability in cm/s	**Minimum**	**Maximum**	**Geometric Mean**
Unsaturated Alluvium - 1978 Pond No. 3 Geotechnical Report	2.60E-08	1.90E-07	6.92E-08
Unsaturated Alluvium - Published Data (Tanaka et. al., 1966)	4.72E-06	2.36E-02	3.33E-04
Saturated Thickness in feet	**Minimum**	**Maximum**	
Saturated Alluvium - 1993 RA	1.5	17.5	
Porosity in %	**Minimum**	**Maximum**	
Saturated Alluvium - Published Data (Tanaka et. al., 1966)	29.9	33.8	
Unsaturated Alluvium - Published Data (Tanaka et. al., 1966)	32.2	50.6	
Hydraulic Gradient	**Calculated Gradient**	**Direction**	
Saturated Alluvium - 1993 RA	0.0076	NE	
Saturated Alluvium - 1993 RA	0.0030	SE	
Saturated Alluvium - 1993 RA	0.0064	SW	
Saturated Alluvium - 2011 Analysis - Average 1993 to 1998	0.0081	NE	
Saturated Alluvium - 2011 Analysis - Average 1993 to 1998	0.0037	SE	
Saturated Alluvium - 2011 Analysis - Average 1999 to 2002	0.0063	NE	
Saturated Alluvium - 2011 Analysis - Average 1999 to 2002	0.0029	SE	
Saturated Alluvium - 2011 Analysis - Average 2003 to 2010	0.013	NE	
Saturated Alluvium - 2011 Analysis - Average 2003 to 2010	0.0026	SE	
McCurtain Shale - 1993 RA	0.017	WNW	
McCurtain Shale - 1993 RA	0.0057	E	
McCurtain Shale - 2011 Re-analysis - Average 1993 to 1995	0.051	E	

Table 11.6 - Weather Station Location Summary

Station Name	City	County	OK North State Plane Coordinates		Elevation	Distance from FMRI
			Easting (Feet)	Northing (Feet)	Meters	Miles
Haskell	Haskell	Muskogee	2,668,602	280,785	183	18.94
Porter	Clarksville	Wagoner	2,691,834	309,659	193	14.75
Cookson	Marble City	Cherokee	2,904,184	262,721	299	26.43
Tahlequah	Tahlequah	Cherokee	2,859,991	367,787	290	22.52
Tulsa Airport	Tulsa	Tulsa	2,592,967	443,629	192	43.77

Table 11.7 - Derived Concentration Guideline Levels (DCGLs) for Soil

Radionuclide and Entire Chain in Equilibrium	Industrial Worker DCGL (pCi/g)	Mass Equivalent (µg/g Total U)
Uranium 238 and decay chain	14.1	42.7**
Uranium 235 and decay chain	37	--
Thorium 232 and decay chain	10	--

**Assumes U-238 is 98% of the total uranium mass and a specific activity of U-238 of 3.3E-07 Ci/g.

12 FIGURES

Figure 12.1 - Selected Photographs of On-site Activities

SELECTED PHOTOGRAPHS OF ON-SITE ACTIVITIES

Figure 1 - Pond 3, looking to the north west

Figure 2 - Measuring ambient gamma exposure rate at subsurface soil sample collection location

Figure 3 - Collecting subsurface sample using Geoprobe

Figure 4 - Collecting subsurface sample using Geoprobe

Figure 5 - Removing soil sample from sample sleeve

Figure 6 - Handling Geoprobe tube and sleeve

Figure 7 - Collecting soil sample from sample sleeve

Figure 8 - Soil core from collection location D08

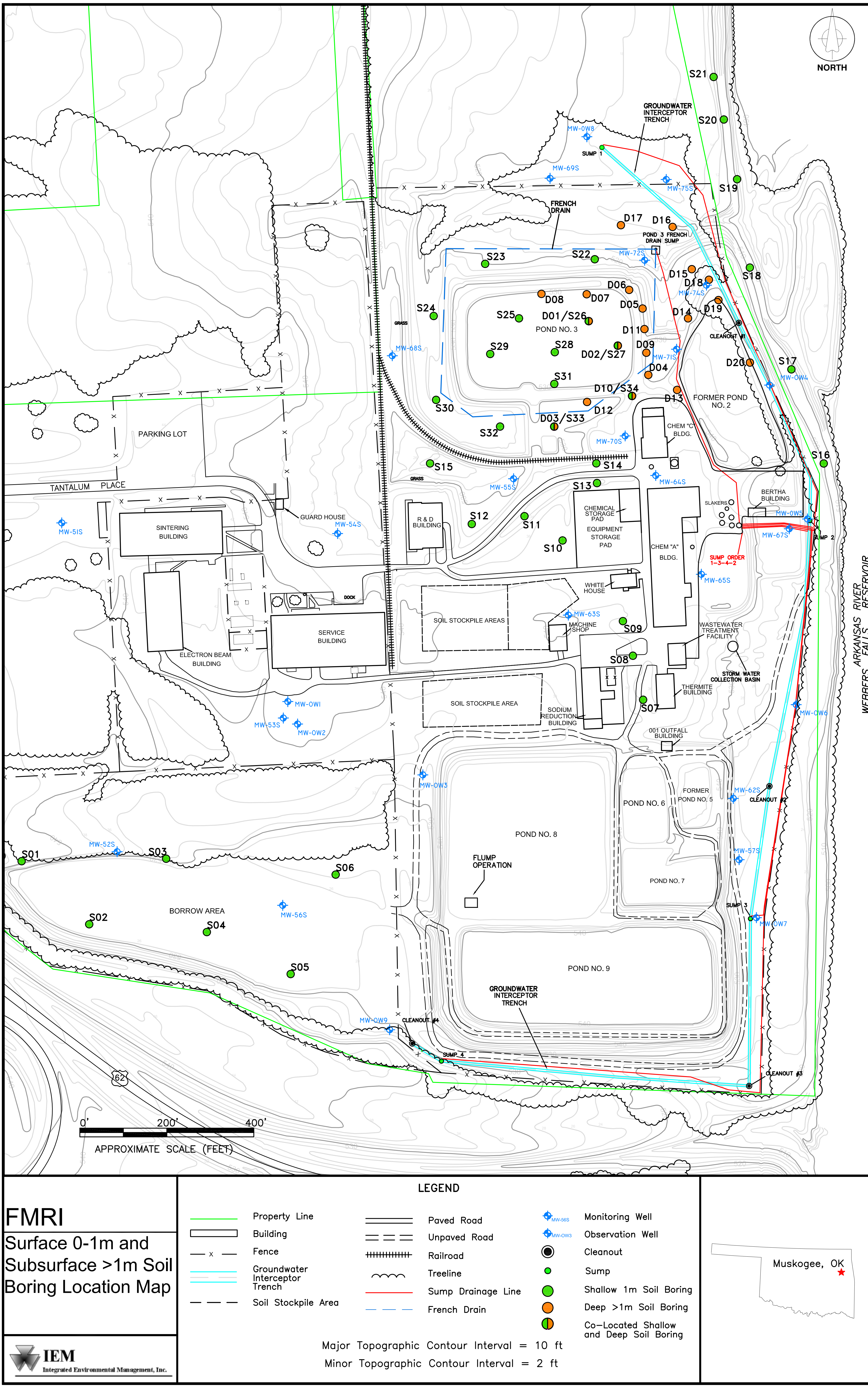
Figure 9 - Radiological screening of soil core

Figure 10 - One-meter deep sample collection using hammer drill

Figure 11 - Release survey on sampling equipment

Figure 12 - Measuring height of water column in MW 74

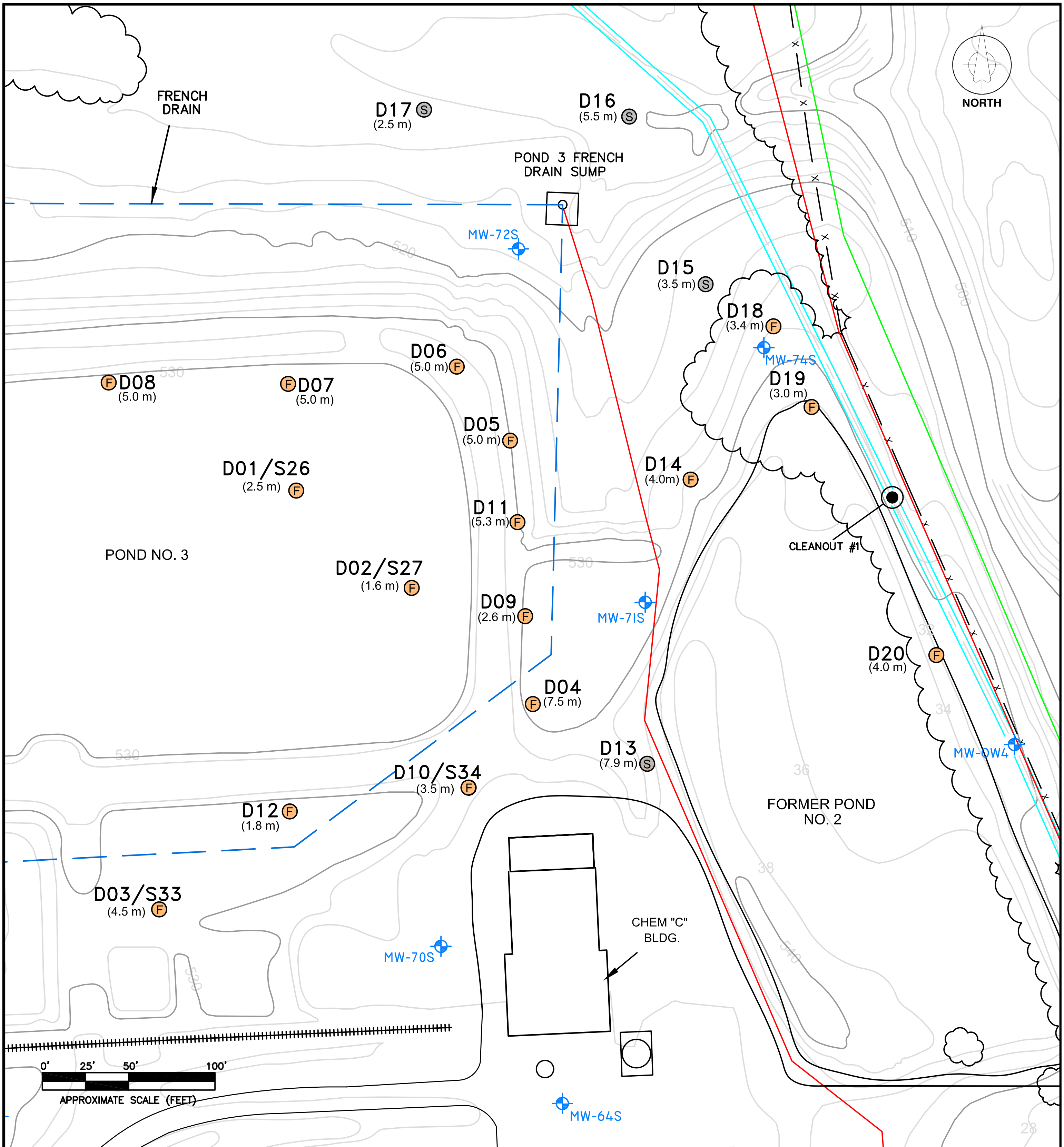
Figure 12.2 - Shallow and Subsurface Soil Boring Location Map



FMRI

Surface 0-1m and Subsurface >1m Soil Boring Location Map

Figure 12.3 - Subsurface Soil Boring Refusal Summary Map



FMRI

Subsurface Soil Boring Refusal Summary Map

IEM Integrated Environmental Management, Inc.

LEGEND

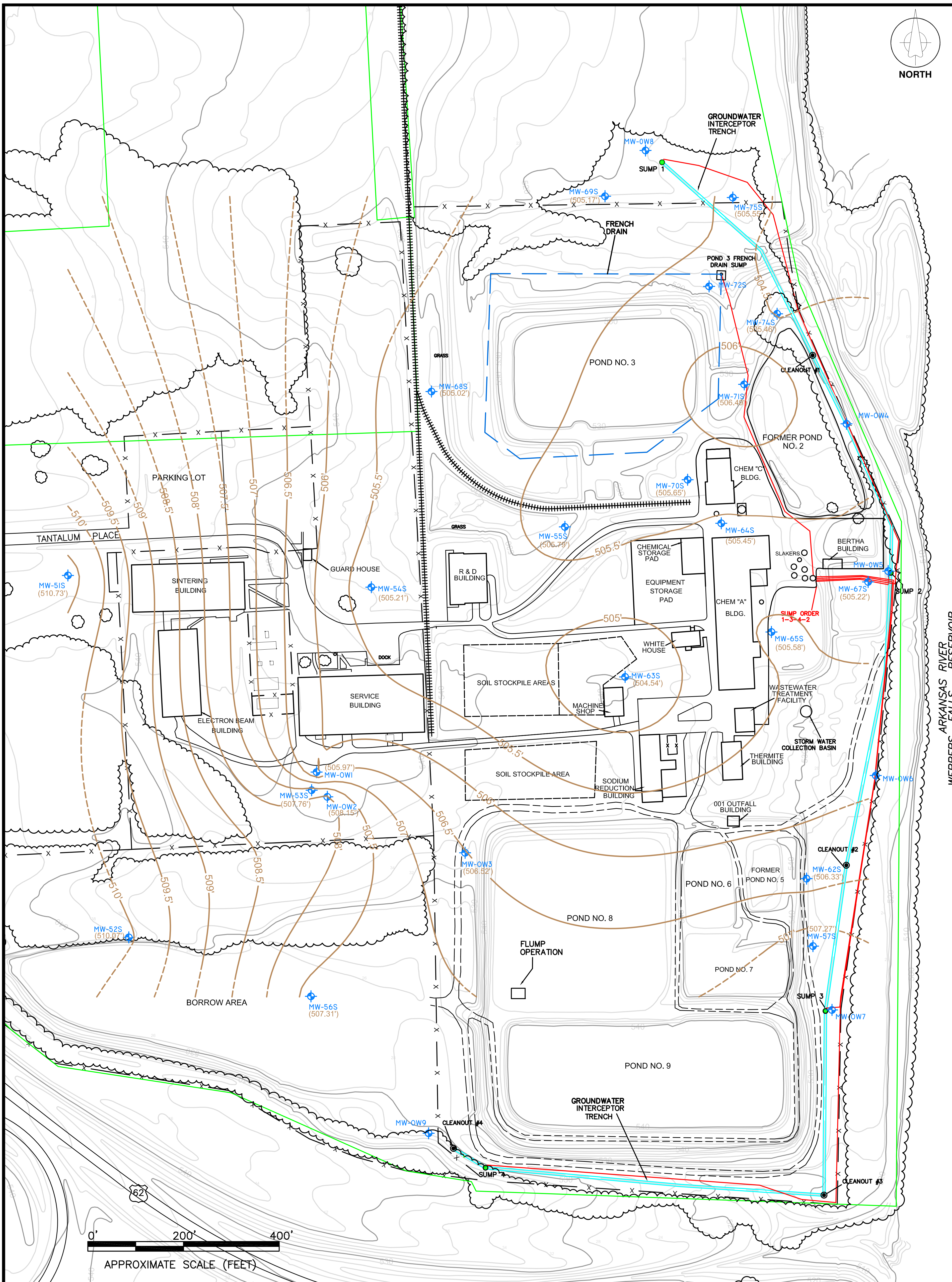
Property Line	Paved Road
Building	Railroad
Fence	Treeline
Groundwater Interceptor Trench	Monitoring Well (MW-56S)
Sump Drainage Line	Cleanout
French Drain	Refusal in Fluorogypsum (F)
	Refusal in Shale (S)

Major Topographic Contour Interval = 10 ft

Minor Topographic Contour Interval = 2 ft

Muskogee, OK

Figure 12.4 - Hypsographic Map



FMRI Hypsographic Map

IEM Integrated Environmental Management, Inc.

LEGEND

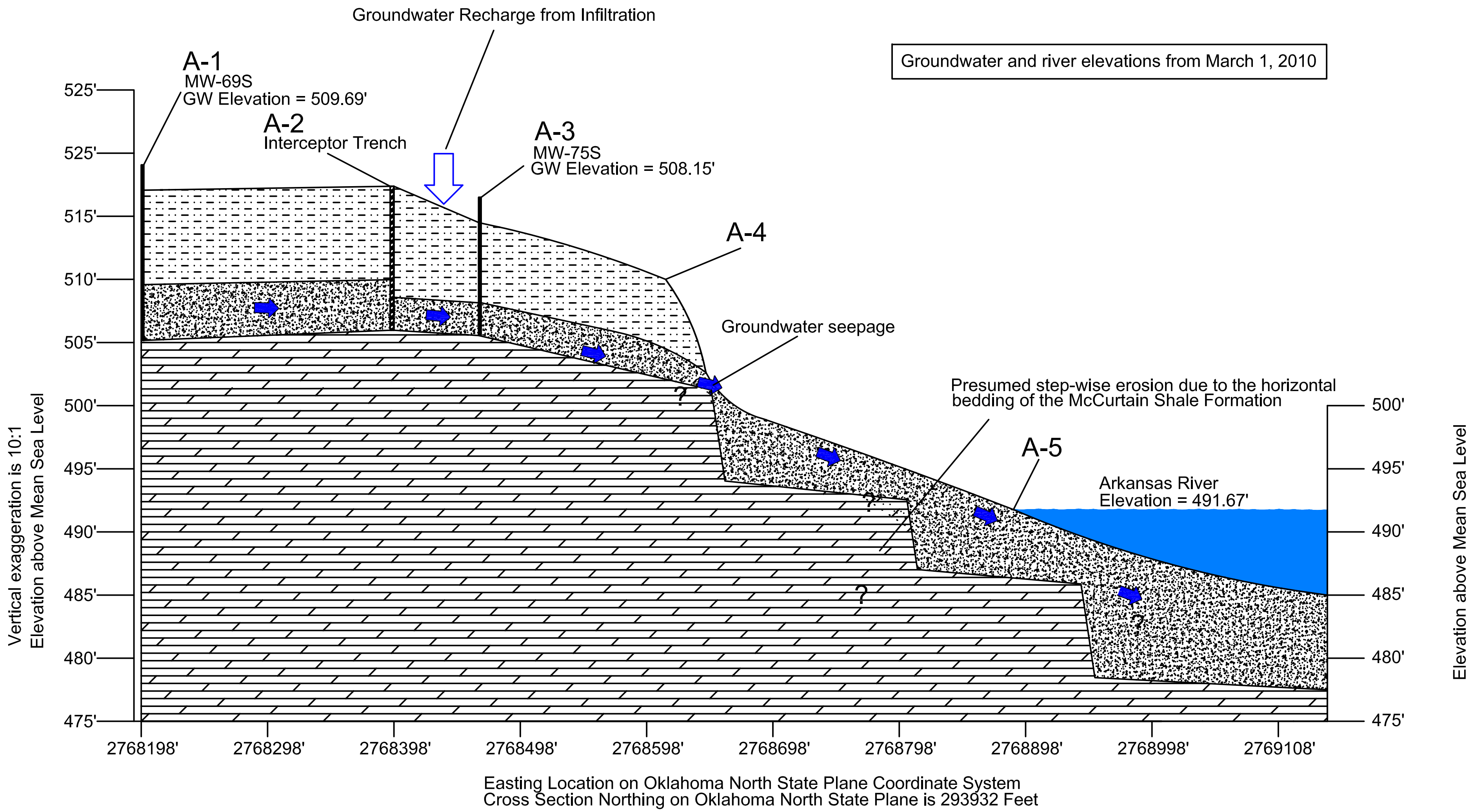
- Property Line
- Building
- Fence
- Groundwater Interceptor Trench
- Soil Stockpile Area
- Paved Road
- Unpaved Road
- Railroad
- Treeline
- Sump Drainage Line
- French Drain
- MW-56S Monitoring Well
- MW-OW3 Observation Well
- Cleanout
- Sump
- 500' Bedrock Elevation Contour
- (505.65') Bedrock Elevation

Major Topographic Contour Interval = 10 ft

Minor Topographic Contour Interval = 2 ft

Muskogee, OK

Figure 12.5 - Site Cross Section



Site Cross Section

IEM
Integrated Environmental Management, Inc.

LEGEND

- Unsaturated Alluvium
- Saturated Alluvium
- McCurtain Shale
- Ground Water Flow Direction

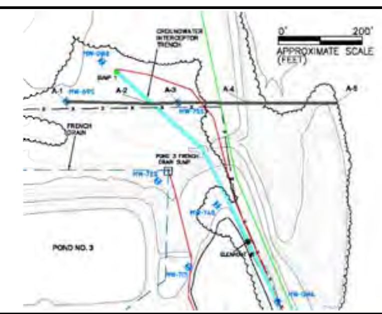
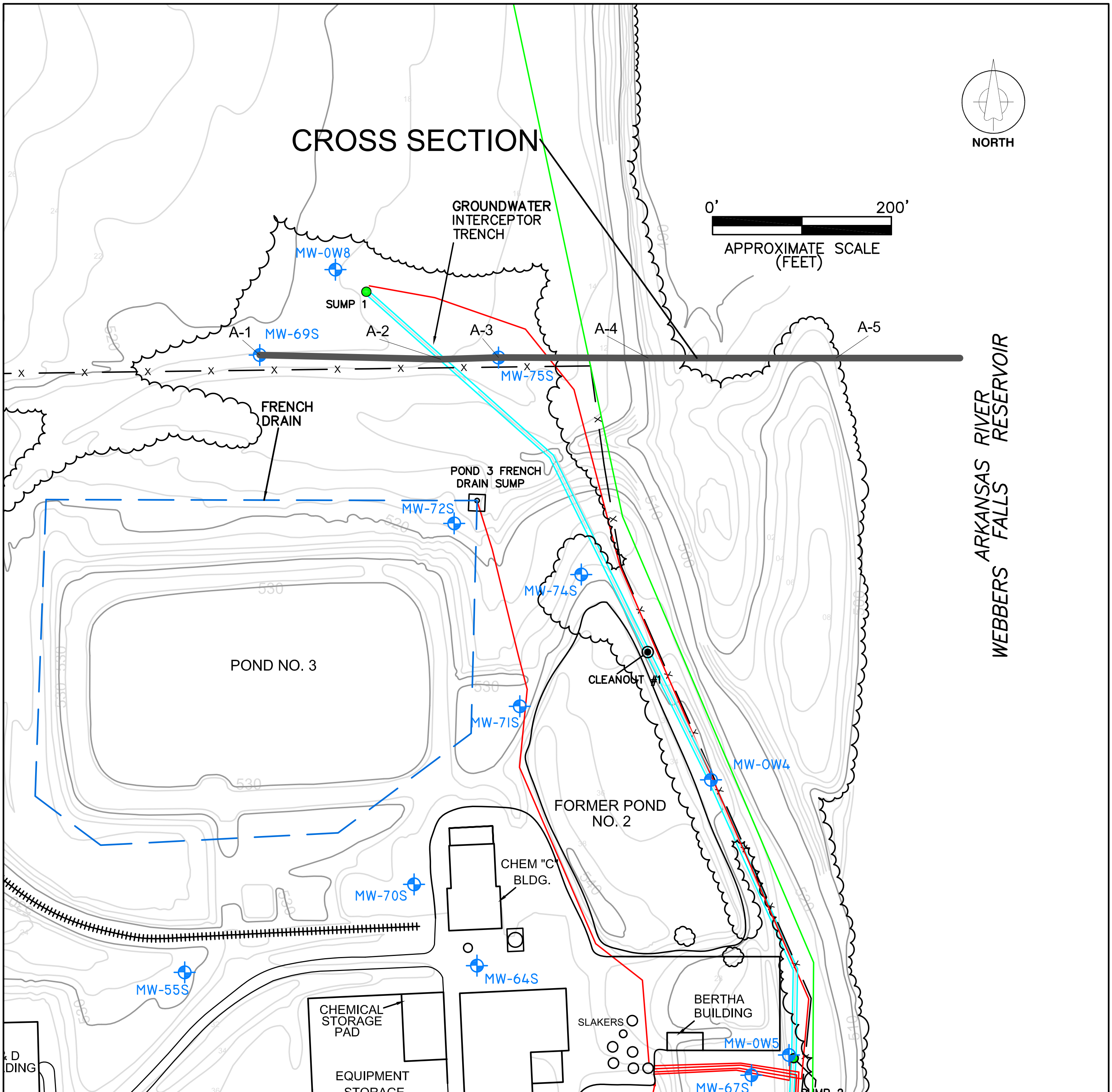


Figure 12.6 - Cross Section Location Map



Cross Section
Location Map

IEM
Integrated Environmental Management, Inc.

LEGEND

	Property Line		Paved Road
	Building		Unpaved Road
	Fence		Railroad
	Groundwater Interceptor Trench		Treeline
	Cleanout		Monitoring Well
	Sump		Observation Well
	Soil Stockpile Area		Sump Drainage Line
A-5	Cross–Section		French Drain

Major Topographic Contour Interval = 10 ft
Minor Topographic Contour Interval = 2 ft

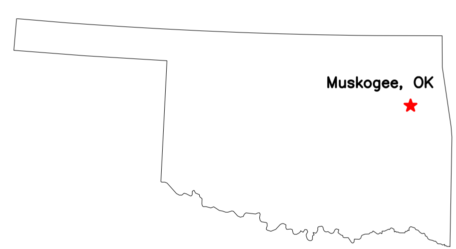
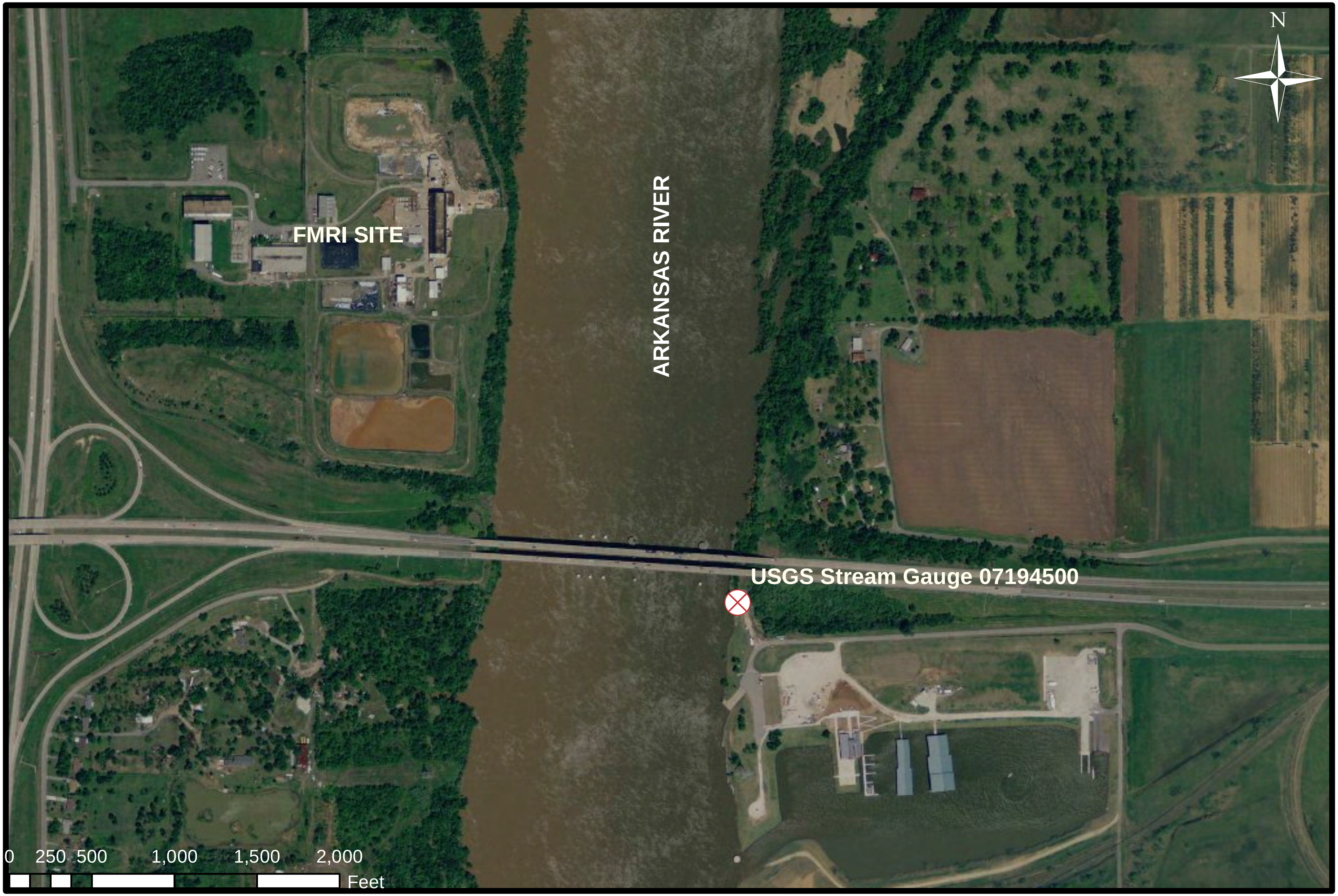


Figure 12.7 - Location of Arkansas River Stream Gauge 07194500



Location of Arkansas River Stream Gauge 07194500

IEM
Integrated Environmental Management, Inc.

Figure 12.8 - Arkansas River Level Elevation Near Muskogee

Arkansas River Level Elevation near Muskogee, Oklahoma

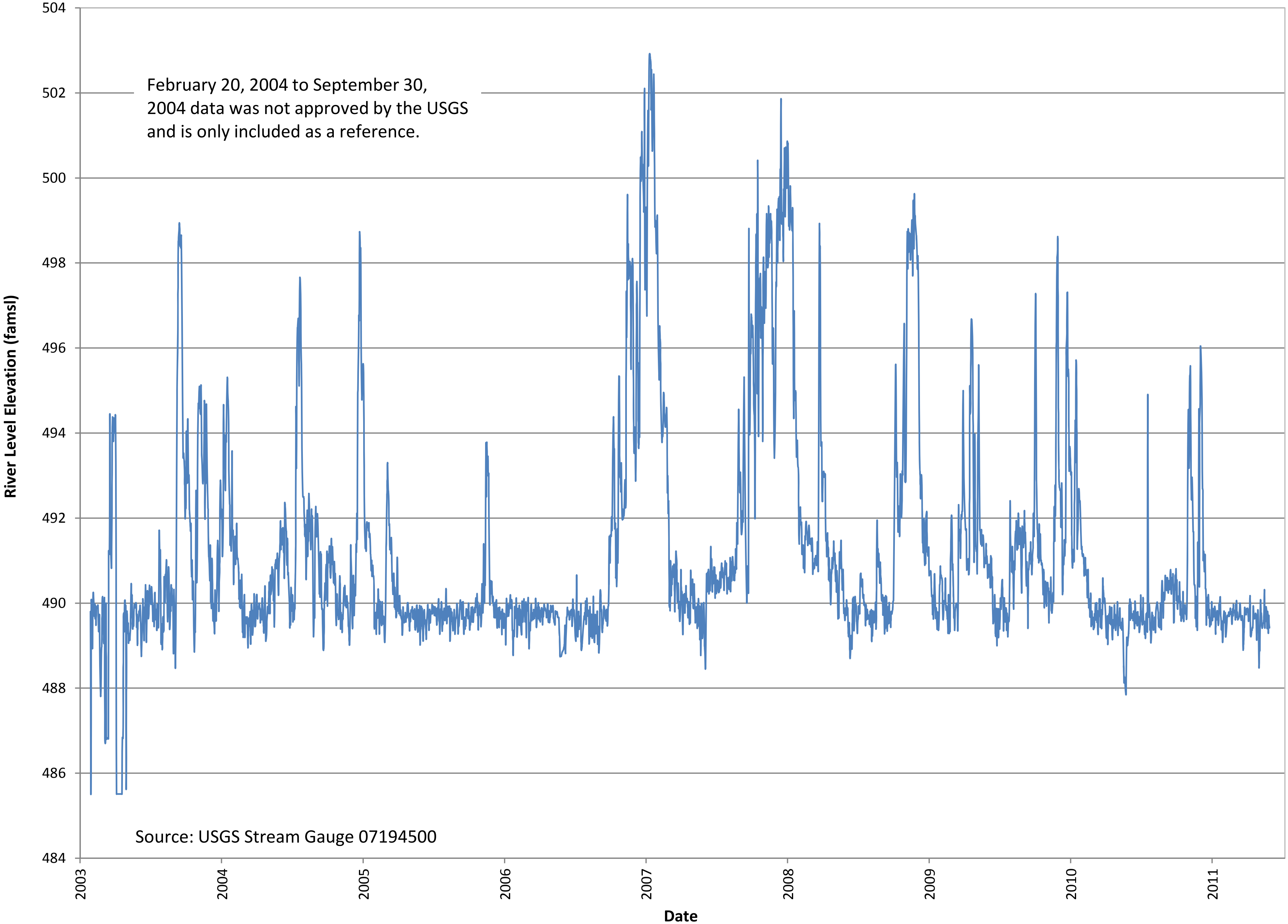
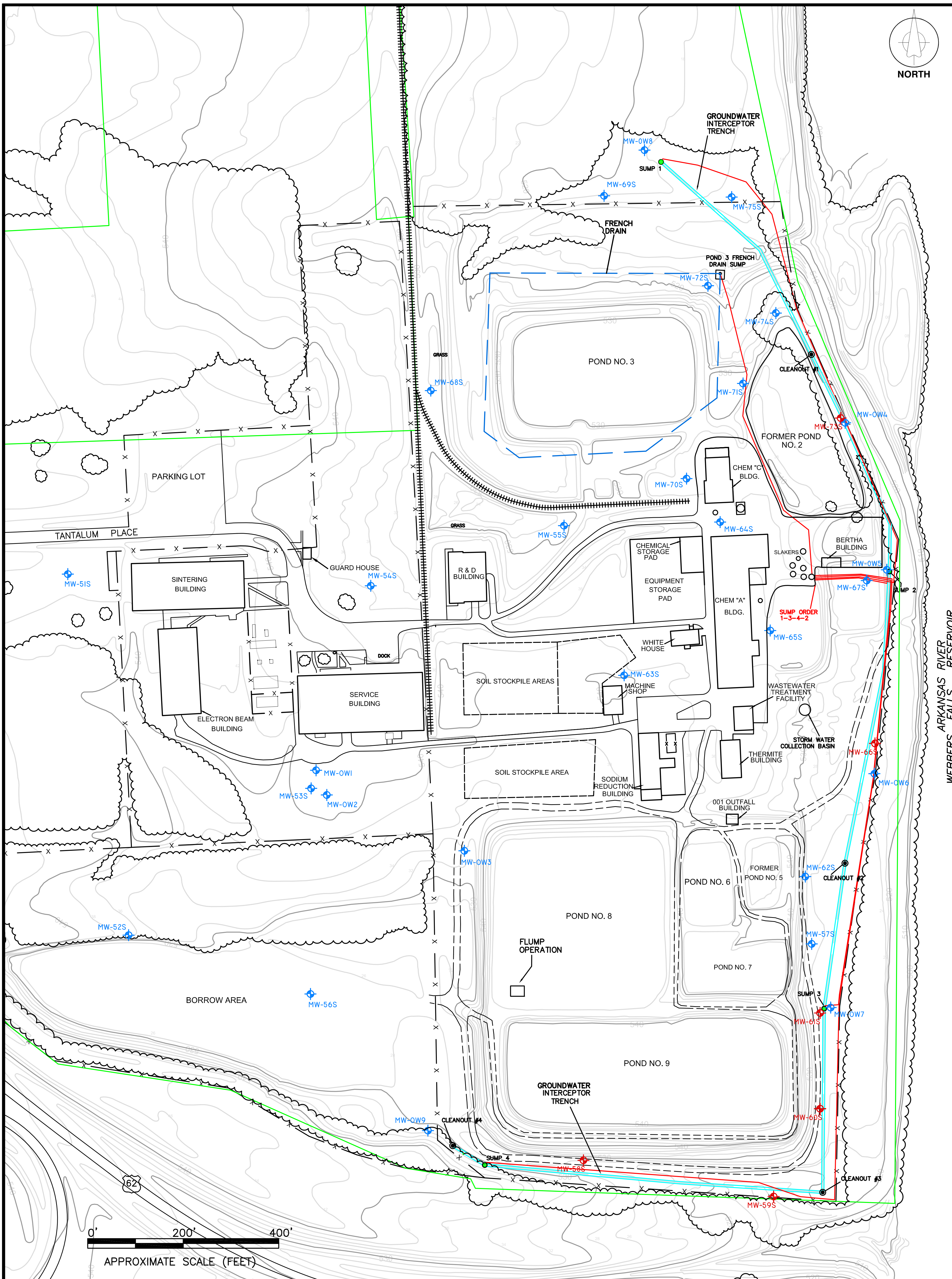


Figure 12.9 - FMRI Monitoring Well Location Map



FMRI Monitoring Well Location Map

LEGEND

	Property Line		Paved Road
	Building		Unpaved Road
	Fence		Railroad
	Groundwater Interceptor Trench		Treeline
		MW-56S	Monitoring Well
	Cleanout	MW-OW3	Observation Well
	Sump	MW-59S	Destroyed Monitoring Well
	French Drain		Sump Drainage Line
	Soil Stockpile Area		

Major Topographic Contour Interval = 10 ft
Minor Topographic Contour Interval = 2 ft

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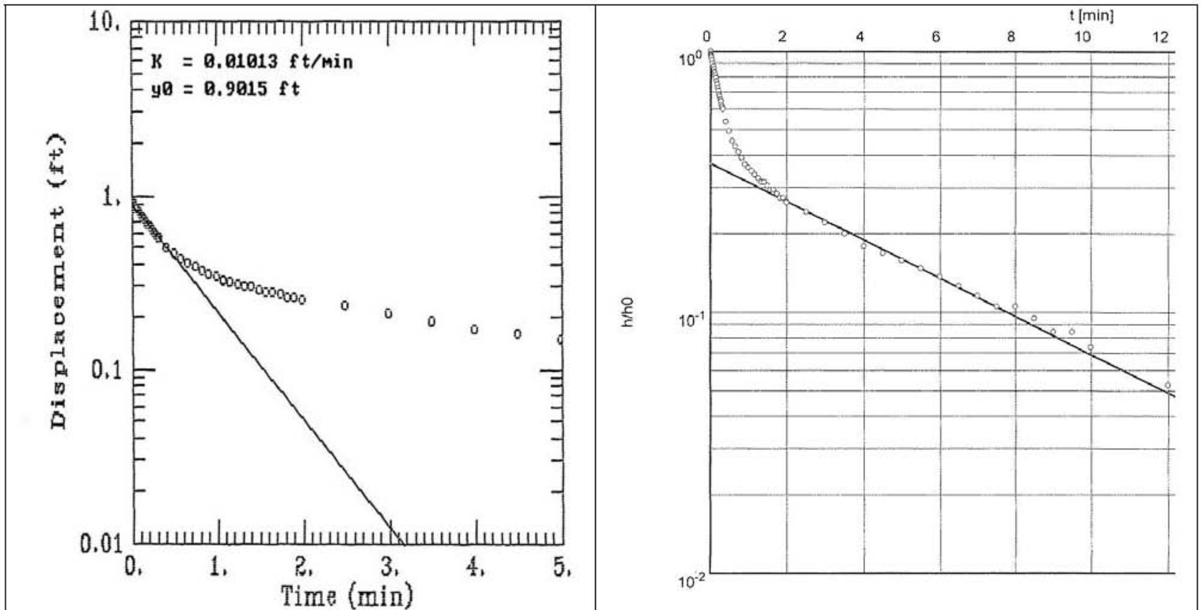
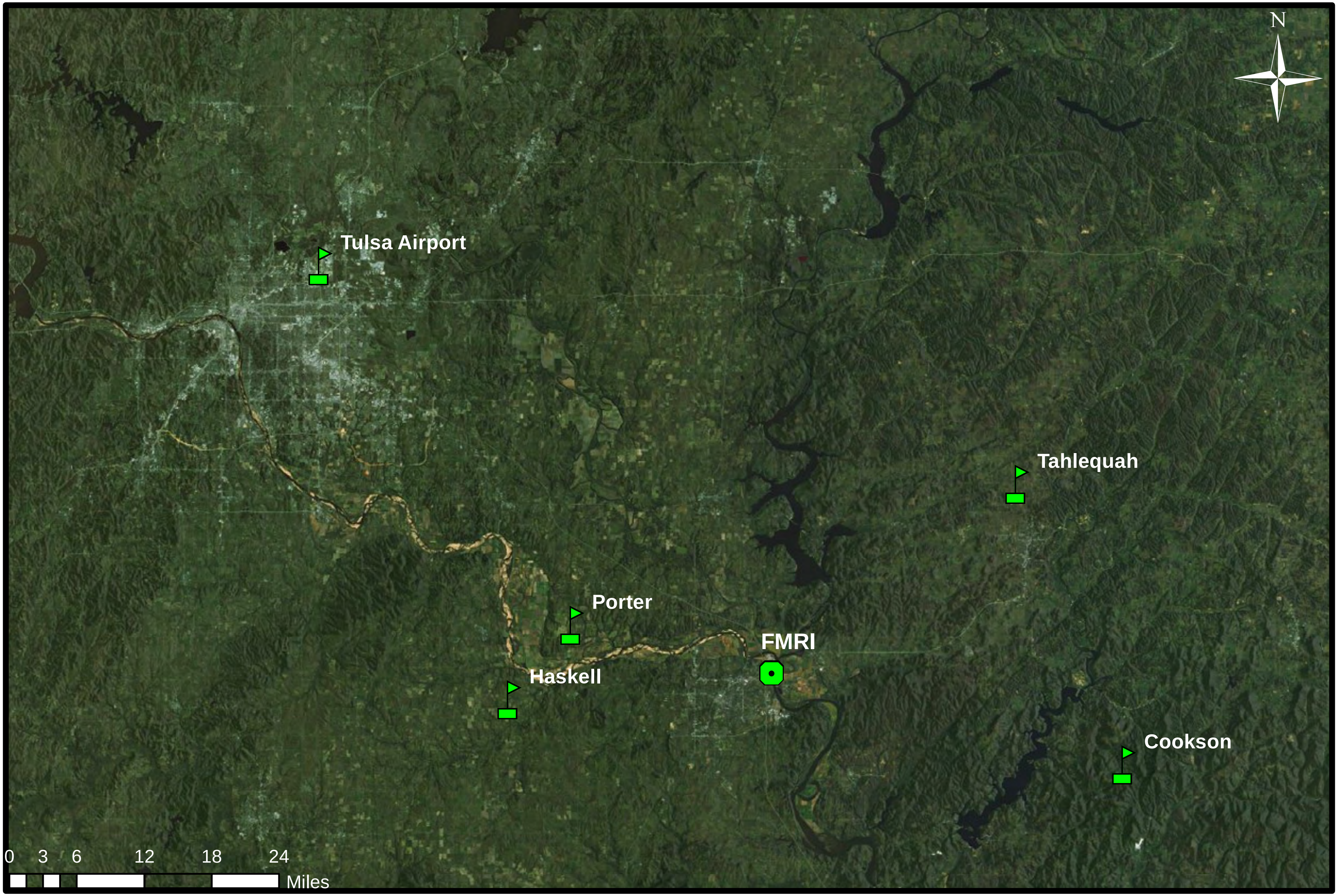
Figure 12.10 - Comparison of 1993 and 2011 Slug Test Analysis of MW-56S



Calculated Hydraulic Conductivity = 5.15×10^{-3} cm/s	Calculated Hydraulic Conductivity = 9.30×10^{-4} cm/s

Figure 12.11 - Locations of Weather Stations Used for Climate Data Compilations



Location of Weather Stations used for Climate Data Compilation

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13 APPENDICES

Appendix 13.1 - 2011 Supplemental Characterization Plan
Appendix 13.2 - Instrument Records
Appendix 13.3 - Sample Location Ambient Exposure Rates
Appendix 13.4 - Sample Collection Logs
Appendix 13.5 - Release Survey Records
Appendix 13.6 - Certificates of Analysis (Chemical)
Appendix 13.7 - Soil Boring Logs
Appendix 13.8 - Certificates of Analysis (Radiological)
Appendix 13.9 - Potentiometric Surface Maps
Appendix 13.10 - Historical Groundwater Quality Data
Appendix 13.11 - Historical Water Quality Plots
Appendix 13.12 - Radiological Tag Maps
Appendix 13.13 - Trench Construction Contract Drawings
Appendix 13.14 - Saturated Thickness Summary and Hydrographs
Appendix 13.15 - Climate Data (1993 to 2011)
Appendix 13.16 - HELP Model Output
Appendix 13.17 - Slug Test Analysis

(If this is a hard-copy report, the appendices are on the CD that is affixed below. If this is an electronic copy, they are in an associated zip file.)

This report was prepared under the direction of
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