Prepared for:
Tronox
Crescent, Oklahoma

Conceptual Site Model (Revision – 01)
Cimarron Site, Crescent, Oklahoma
October 2006

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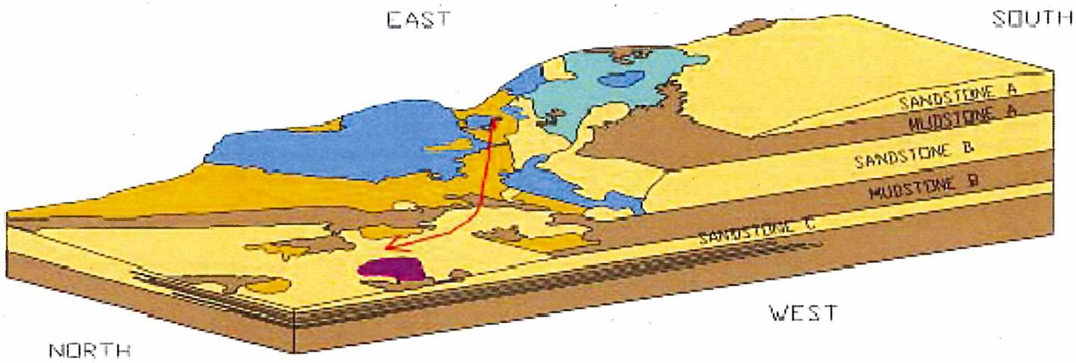

Pictorial Representation of Site Model – Burial Area # 1

Conceptual Site Model, (Revision – 01) Cimarron Site, Crescent, Oklahoma

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List of Abbreviations and Acronyms

AEC	Atomic Energy Commission
amsl	above mean sea level
Bq/L	Becquerels per liter
BTP	Branch Technical Position
cfs	cubic feet per second
cm/s	centimeters per second
CSM	conceptual site model
DEQ	Department of Environmental Quality
EC	effluent concentrations
MCLs	Maximum Concentration Limits
meq/100g	milliequivalents per 100 grams
meq/L	milliequivalents per liter
μg/L	micrograms per liter
mg/L	milligrams per liter
mL/g	milliliters per gram
mrem/yr	millirem per year
mSv/yr	millisieverts per year
mv	millivolts
NRC	Nuclear Regulatory Commission
NWIS	National Water Information System
ORISE	Oak Ridge Institute for Science and Education
pCi/g	picocuries per gram
pCi/L	picocuries per liter
TC-99	Technetium-99
TDS	total dissolved solids
TEDE	Total Effective Dose Equivalent
UF_6	uranium hexafluoride
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey

1.0 Introduction

Cimarron Corporation's site (Cimarron Site) near Crescent, Okalahoma, is a former nuclear fuel manufacturing facility. Since the cessation of operations, the site has been undergoing decommissioning. This decommissioning is being performed by Cimarron Corporation with oversight from the Nuclear Regulatory Commission (NRC) and the Oklahoma Department of Environmental Quality (Oklahoma DEQ). The evaluation presented in this report has been performed to update the understanding of Cimarron Site's geology and hydrogeology based on new data collected since the initial conceptual site model (CSM) was developed. This CSM is focused specifically on areas where impacts remain to be fully remediated: Burial Area #1 (BA #1 Area); the Western Upland Area; and the Western Alluvial Area. Cimarron Corporation completed this evaluation to assist in development of a consensus, among agencies and interested parties, on existing site conditions for use in developing plans for actions to complete remediation of the site.

1.1 Role of Conceptual Site Models

A CSM is defined as a written or pictorial representation of an environmental system, and the biological, physical, and chemical processes that determine the transport of contaminants from sources through environmental media to environmental receptors within the system (ASTM E1689-95(2003) e1).

A CSM is typically used to integrate available site information and to evaluate whether additional information should be collected. The model is used furthermore to facilitate the selection of remedial alternatives and to evaluate the effectiveness of remedial actions. The development of a CSM is normally iterative. Model development should start as early as possible in the site investigation process. In addition, the model should be updated and revised throughout the site investigation process to incorporate additional site data. As part of the ongoing process of updating the CSM as new data becomes available, this current edition of the CSM reflects the addition of data associated with additional field sampling and the development of a groundwater flow model that have occurred since the August 2005 edition (Revision 0) was produced.

1.2 Existing Cimarron Site Characterization Documents/Models

Assessment at the Cimarron Site has been ongoing since the decommissioning process began in 1979. From this period, the following eleven principal characterization documents are integral in the development of the CSM that is being used for the Cimarron Site:

1. Site Investigation Report for the Cimarron Corporation Facility, Logan County, Oklahoma, James L. Grant & Associates, September 1989.

2. Radiological Characterization Report for Cimarron Corporation's Nuclear Fuel Fabrication Facility, Crescent, Oklahoma, Chase Environmental Group, October 1994.

3. Groundwater and Surface Water Assessment for Cimarron Corporation's Former Nuclear Fuel Fabrication Facility, Crescent, Oklahoma, Chase Environmental Group, Inc., December 1996.

4. Cimarron Decommissioning Plan Groundwater Evaluation Report for Cimarron Corporation's Former Nuclear Fuel Fabrication Facility, Crescent, Oklahoma, Cimarron Corporation, July 1998.

5. Environmental Assessment by the Office of Nuclear Material Safety and Safeguards of the Proposed Decommissioning Plan and Other Proposals Related to the Cimarron Corporation Former Fuel Fabrication Facility, Nuclear Regulatory Commission Office of Nuclear Material Safety and Safeguards, July 1999.

6. Burial Area #1 Groundwater Assessment Report for Cimarron Corporation's Former Nuclear Fuel Fabrication Facility, Cimarron Corporation, January 2003.

7. Justification for Utilization of Fully Penetrating Groundwater Monitoring Wells in Shallow Alluvial Aquifer at the Cimarron Facility, Chase Environmental Group, January 2003.

8. Assessment Report for Well 1319 Area for Cimarron Corporation's Former Nuclear Fuel Fabrication Facility, Cimarron Corporation, December 2003.

9. Technetium-99 Groundwater Assessment Report for Cimarron Corporation's Former Nuclear Fuel Fabrication Facility, Crescent, Oklahoma, Chase Environmental Group, Inc., December 2003.

10. Refined Conceptual Site Model, Cimarron Site, Crescent, Oklahoma, ENSR Corporation, August 2005.

11. Ground Water Modeling Report, Cimarron Site, Crescent, Oklahoma, ENSR Corporation, October 2006.

A brief synopsis of each of these eleven reports is presented in the box below.

1. Site Investigation Report for the Cimarron Corporation Facility, Logan County, Oklahoma James L. Grant and Associates September 1989	This report summarizes geological and hydrogeological site investigations conducted at the Cimarron Site and provided the basis for understanding the geological and hydrogeological controls on surface soil, bedrock, and aquifer radiological impacts and the potential movements of impacts. This report provided the first comprehensive CSM and set the stage for determining which areas of the site could have been affected radiologically by former Cimarron facility activities. This report contains the following information: • Characterization of the stratigraphy and lithology of the soils and bedrock at the site; • Characterization of aquifer properties including hydraulic conductivity, groundwater flow directions, and gradient; • Characterization of groundwater quality and determination of the effects that facility operations may have had on groundwater quality; and • Determination of the mobility of radionuclides, particularly uranium, in the subsurface and the ability of subsurface materials to retard migration at the Cimarron Site.

2. Radiological Characterization Report for Cimarron Corporation's Nuclear Fuel Fabrication Facility, Crescent, Oklahoma Chase Environmental Group 1994	This report presents the results of field radiological investigations at the Cimarron Site. It facilitated the subsequent decommissioning of areas potentially affected by previous facility operations. The report also summarizes the site operational history and the decommissioning activities, such as removal of impacted waste and soil up to that date at the Cimarron Site. • This report presents results from a combination of scoping surveys, characterization surveys, remediation control surveys, pre-remediation surveys, post-remediation surveys, final surveys, and confirmatory surveys (Oak Ridge Institute for Science and Education (ORISE) and NRC confirmatory survey results are included for some areas and, in some cases, survey results are included for areas that had already been released by the NRC). • Only uranium and plutonium in chemically separated form were used in the production processes at the Cimarron Site. The concentration of daughter radionuclides was negligible. Radium and thorium detected in groundwater and soil samples were at natural background levels and were, thus, not due to the effects of facility operations.
3. Groundwater and Surface Water Assessment for Cimarron Corporation's Former Nuclear Fuel Fabrication Facility, Crescent, Oklahoma Chase Environmental Group, Inc. December 1996	This report reviews background water quality; assesses historical and then-current groundwater data to determine impacts from past operations; and identifies changes to groundwater quality since issuance of the report prepared by James L. Grant and Associates in 1989. This report also reviews existing surface and groundwater data, including data from a comprehensive sampling event performed in 1996. The conclusions of this report are: • Background, near-surface groundwater quality is hard to very hard, and contains elevated concentrations of dissolved solids, chlorides, sulfates, and nitrates, thus limiting its potential for usage as a potable supply. • The geology of the site limits the groundwater available for withdrawal for beneficial usage to approximately one gallon per minute or less of sustained pumping. • Shallow groundwater, which is found in Sandstones A and B, flows north-northwest until it is discharged to either the ground surface as seeps along low-lying bluffs and cliffs or to the Cimarron River alluvium. • With source removal and further remediation, substantial improvements in localized groundwater quality had been realized as of the date of this report. Groundwater testing indicated that past operations may have affected the groundwater quality adjacent to one or two former waste management units.

	• Only one well location contained groundwater exceeding the uranium effluent concentration (EC) limits presented in 10 CFR 20. Well 1315, located between trenches within the BA #1 Area, showed a total uranium concentration that was twice the EC limit in 1996. However, the 1996 sampling results reflect a substantial reduction in concentration from the 1990 level of 27 times the EC limit. In general, for other wells with slightly elevated uranium, similar downward (improving quality) trends were occurring. Groundwater impacts were contained totally on site. • The deeper wells, located in Sandstone C, have not shown any affect from former facility operations.
4. Cimarron Decommissioning Plan Groundwater Evaluation Report for Cimarron Corporation's Former Nuclear Fuel Fabrication Facility, Crescent, Oklahoma Cimarron Corporation July 1998	The purpose of this report was to provide information regarding groundwater at the Cimarron Site for inclusion in the Cimarron Decommissioning Plan. This report addresses vicinity and site geology/hydrology, presents a summary of closure activities for areas that had groundwater impact, describes background and affected-area groundwater quality, assesses the trending of environmental data for affected areas, and presents a proposal for additional work at the BA #1 Area. The conclusions of this report were as follows: • Effective confining mudstone strata are present between each of the groundwater zones of Sandstones A, B, and C on site. These mudstones influence the lateral flow of groundwater and act to limit the potential downward migration of shallow groundwater between the three sandstone units. • The bluffs overlooking the Cimarron River represent a very large discharge zone that continually drains the upper sandstones. In fact, the upper sandstones were not saturated in those site areas near the bluffs. • The historical and more-recent groundwater and surface water investigations clearly showed that groundwater radionuclide impacts had abated and continued their decreasing trends from the levels reported in 1989 by J.L. Grant and Associates. • Shallow groundwater in Sandstones A and B generally discharges to the incised drainage pathways and the seeps in the low-lying bluffs and cliffs that border the floodplain of the Cimarron River. • Deeper groundwater in both Sandstones B and C discharges to the alluvial deposits that underlie and comprise the Cimarron River bottom and the adjoining floodplain. • Cimarron Corporation would continue to monitor groundwater in the BA #1 Area on a quarterly basis. Even though Cimarron Corporation believed that groundwater concentrations would continue to decrease, it agreed to conduct additional studies for the purpose of understanding the attenuation mechanisms.These studies were to include additional hydrogeologic evaluations of the general area.

	• Cimarron Corporation agreed to retain and control the property areas formerly licensed under NRC Radioactive Material SNM-928 until the proposed groundwater criteria were met. In the unlikely event that the uranium concentrations did not decline sufficiently during the monitoring period, Cimarron Corporation agreed to prepare a corrective action program.
5. Environmental Assessment by the Office of Nuclear Material Safety and Safeguards of the Proposed Decommissioning Plan and Other Proposals Related to the Cimarron Corporation Former Fuel Fabrication Facility Nuclear Regulatory Commission Office of Nuclear Material Safety and Safeguards July 1999	This report assesses the environmental impact of the decommissioning proposed by Cimarron Corporation. It also considers the no-action alternative. This report was prepared and issued pursuant to the National Environmental Policy Act of 1969 (NEPA) and NRC's regulations in 10 CFR 51. NRC staff reviewed both the beneficial and adverse potential impacts of the proposed decommissioning. The staff's conclusions were as follows: • Radiation exposures of persons living or traveling near the site because of onsite operations and waste transportation will be well within the limits contained in 10 CFR 20. • Cimarron Corporation proposed a groundwater standard of 6.7 Becquerels per liter (Bq/L) (180 picocuries per liter [pCi/L]) for total uranium, which it demonstrated to equate to the allowable 0.25 millisieverts per year (mSv/yr) (25 millirems per year (mrem/yr) Total Effective Dose Equivalent (TEDE) to the hypothetical individual drinking the water. NRC staff found the proposed groundwater standard of 6.7 Bq/L (180 pCi/L) for total uranium to be acceptable because the 0.025 mSv/yr (25 mrem/yr) dose associated with that standard, when added to the negligible dose from all other pathways is well below the 0.1 mSv/yr (100 mrem/yr) limit in 10 CFR 20.1301 for individual members of the public. In addition, the likelihood of this groundwater ever being used for domestic or agricultural purposes is low. On the basis of this report, NRC staff concluded that the proposed action would not have any significant effect on the quality of the human environment and did not warrant the preparation of an environmental impact statement.
6. Burial Area #1 Groundwater Assessment Report for Cimarron Corporation's Former Nuclear Fuel Fabrication Facility Cimarron Corporation January 2003	This document details the comprehensive investigation of uranium in groundwater in the BA #1 Area. The conclusions presented in this report were as follows: • None of the soils within the area of groundwater impact exceed the Option 1 criteria for unrestricted release (30 picocuries per gram [pCi/g] above background) in the NRC Branch Technical Position (BTP), "Disposal or Onsite Storage of Thorium and Uranium Wastes from Past Operations." • Uranium concentrations in Sandstone C ranged from 6 to 34 pCi/L for the locations monitored, which is consistent with background levels of Sandstone C.

	• A clay/mudstone lithologic unit underlies a significant portion of the area of uranium impact. • The shallow groundwater shows a steep gradient in the bedrock area, and flattens considerably as groundwater discharges into the alluvium. • The geology of the area has been adequately characterized. • Geotechnical properties of subsurface materials have been quantified. • The source of licensed material has been removed. • The disposal trenches extended through the low-permeability materials that covered Sandstone B and the more permeable alluvial material. • The upland area is characterized by Mudstone A overlying Sandstone B, with a buried escarpment covered by alluvial materials. • There is a transitional zone characterized by low-permeability material (clay and clayey silts) with depth in the alluvial channel. • The alluvium typically consists of a layer of fine, well-rounded sands overlain by silts and clays. In a small portion of the area, the sand extends to the surface. • There is a low-permeability layer (clay and/or shale/mudstone) underlying the alluvial sands in most of the area.
7. Justification for Utilization of Fully Penetrating Groundwater Monitoring Wells in Shallow Alluvial Aquifer at the Cimarron Facility Chase Environmental Group January 2003	This technical assessment presents both hydrogeological and future land use information that explains the rationale behind Cimarron Corporation's decision to install monitor wells that are screened across the full saturated thickness of the alluvial aquifer. This paper addresses the nature of the alluvial aquifer and explains why potential future users of groundwater would install wells screened through the entire saturated thickness. This technical assessment presents the conclusion that the shallow alluvium downgradient from the BA #1 Area consists of a vertically undifferentiated and unconfined hydrogeologic unit that is formed by a complex mixture of mostly sand with laterally discontinuous alluvial deposits of clay, silt, and gravel. As a result of the geologic and hydrogeologic characteristics of the shallow alluvial aquifer, the relatively thin and unconfined water-bearing zone of the alluvial deposits cannot practically be separated into an upper and/or lower zone for vertical differentiation of the uranium impact that will require remediation.

8. Assessment Report for Well 1319 Area for Cimarron Corporation's Former Nuclear Fuel Fabrication Facility Cimarron Corporation December 2003	This report summarizes the groundwater evaluation of licensed material in the area of the former Uranium Plant yard near Well 1319. The report presents the following conclusions: • Licensed material in the Well 1319 Area was limited to Sandstones B and C. • Sandstone A was unimpacted because the original Well 1319 was not perforated through the Sandstone A interval. • Groundwater in Sandstones B and C exceeding the limit of 180 pCi/L was restricted to a very small area downgradient of the former well 1319. The report demonstrates that groundwater beneath the Uranium Plant yard had been remediated and the area was ready for release.
9. Technetium-99 Groundwater Assessment Report for Cimarron Corporation's Former Nuclear Fuel Fabrication Facility, Crescent, Oklahoma Chase Environmental Group Inc. December 2003	This report presents the results of the Technetium-99 (Tc-99) groundwater assessment performed for the Cimarron Site. This assessment was performed in response to the NRC's March 12, 2002, letter requesting further evaluation of the presence of Tc-99 in groundwater at the Cimarron Site. The source of the Tc-99 at the facility is due to this radionuclide, which is a fission product, being shipped to the facility as a contaminant present in Atomic Energy Commission (AEC) supplied uranium hexafluoride (UF_6) feed material. This report presents the following results: • Shallow groundwater within Sandstones A and B downgradient from U-Pond #2 has been impacted by prior site operations and shows elevated concentrations of Tc-99. • Seep 1208 was the only sampling location that has yielded Tc-99 concentrations slightly above the license termination guideline value of 3,790 pCi/L. • Since the original source (i.e., U-Ponds #1 and #2) had been removed, concentrations of Tc-99 in groundwater and at the discharge zones will continue to decrease as well as concentrations of Tc-99 in the alluvium. This report demonstrated that elevated levels of Tc-99 were present downgradient from the two former waste management areas of U-Pond #1 and U-Pond #2 within Sandstone A and at the seep outcrops.
10. Refined Conceptual Site Model, Cimarron Site, Crescent , Oklahoma ENSR Corporation August 2005	This report was written to update the understanding of Cimarron Site's geology, hydrogeology, and groundwater geochemistry based on new data collected since the initial conceptual site model (CSM) was developed. This CSM is focused specifically on areas where impacts remain to be fully remediated: Burial Area #1 (BA #1 Area); the Western Upland Area; and the Western Alluvial Area. Cimarron Corporation completed this evaluation to assist in development of a consensus, among agencies and interested parties, on existing site conditions for use in developing plans for actions to complete remediation of the site.

11. Groundwater Modeling Report, Cimarron Site, Crescent , Oklahoma ENSR Corporation October 2006	This report documents the construction and execution of two numerical flow models developed for the BA#1 and Western Alluvium areas in support of groundwater remediation design at the Cimarron site. Details of model setup, calibration, sensitivity analysis, and results are discussed in the report. The models can be used for optimization of well network in pump-and-treat and prediction of oxygen flux in bioremediation.

1.3 Purpose

The purpose of this CSM is to compile and integrate both historical and current information into a comprehensive model of the BA #1 Area and the Western Alluvial Area. The CSM will also be used to facilitate the selection of remedial alternatives and to evaluate the effectiveness of remedial actions in removing licensed material from site groundwater. This CSM is intended to establish a foundation for all parties to share the same understanding of the site characterization, which will enable technical and regulatory personnel to resolve issues concerning the site, and facilitate the decision-making process.

1.4 Technical Considerations

During the course of investigations and assessments of surface water and groundwater at the Cimarron Site since 1990, multiple approaches and methodologies have been discussed and resolved between Cimarron Corporation, NRC, and Oklahoma DEQ. These agreements and understandings have been incorporated into the data acquisition programs at the site. These agreements and understandings, therefore, have a bearing on the information and interpretations outlined in this CSM report. The following is a summary of these technical considerations, agreements, and understandings:

- For the purposes of this CSM report, areas of the Cimarron Site that have continuing groundwater impacts are more extensively considered than areas that have been released and/or areas that are pending release because they currently comply with decommissioning criteria (e.g., Well Area in Subarea K).
- Cimarron Corporation derived a site-specific release criteria limit of 180 pCi/L for uranium in groundwater, which was subsequently approved by the NRC and Oklahoma DEQ.
- NRC stipulated that Tc-99 would have an action limit of 3,790 pCi/L in groundwater at the Cimarron Site.
- Groundwater monitor wells installed in the Cimarron River alluvium are screened across the entire saturated interval.

1.5 Branch Technical Position Options and Groundwater Release Criteria

NRC approved use of the 1981 Branch Technical Position (BTP) as the criteria for decommissioning soils at the Cimarron Site. In their October 5, 1991, letter (SECY 81-576) NRC staff identified five acceptable options for disposal or onsite storage of uranium or thorium. Two of these BTP Options (BTP #1 and BTP #2) have been incorporated into License Condition 27(b) and were utilized at the Cimarron Site during decommissioning activities. These two options are described as follows:

- BTP Option #1 – Allows for the disposal of natural thorium with daughters in secular equilibrium, depleted or enriched uranium, and uranium ores with daughters in secular equilibrium with no restriction on burial method. The concentration limits for natural thorium and depleted or

enriched uranium are set sufficiently low that no member of the public is expected to receive unacceptable radiation under any foreseeable use of the material or property. Material that meets Option 1 limits can be treated as “clean” soil. The BTP Option #1concentration limit for uranium is 30 pCi/g for enriched uranium and 35 pCi/g for depleted uranium.

- BTP Option #2 – Allows for the disposal of natural thorium with daughters in secular equilibrium and depleted or enriched uranium with no daughters present when buried under prescribed conditions with no subsequent land use restrictions and no continuing NRC licensing of the material. Under this option, burial will be permitted only if it can be demonstrated that the buried materials will be stabilized in place and not be transported away from the site. Acceptability of the site for disposal will depend on topographical, geological, hydrogeological, and meteorological characteristics of the site. At a minimum, burial depth will be at least four feet below the surface. The BTP Option #2 concentration range is up to 100 pCi/g for soluble uranium and up to 250 pCi/g for insoluble uranium.

The release criteria for groundwater at the Cimarron Site is 6.7 Bq/L (180 pCi/L) total uranium. Cimarron Corporation will retain control of the property licensed under NRC Radioactive Material License SNM 928 until the groundwater release criteria are met.

1.6 Report Structure

This report is organized as described below.

Section 1.0 Introduction – Presents a discussion of the role of a CSM, a review of past site characterization efforts and understandings, and the reasons for development of this refined CSM.

Section 2.0 Geological Conceptual Site Model – Presents a discussion of the regional geology of the Cimarron Area, the stratigraphy of the Cimarron Project Site, including detailed stratigraphic correlations, and a summary of the Cimarron Project Geological Model.

Section 3.0 Hydrogeological Conceptual Site Model – Presents a discussion of the general hydrogeology of the Cimarron Area, groundwater flow at the Cimarron Site (including delineation of water-bearing units, potentiometric surfaces, flow patterns, surface water interactions, Cimarron River floodplain), and specific area groundwater flow regimes (i.e., BA #1 Area and Western Plume Area).

Section 4.0 Geochemical Conceptual Site Model – This section presents a discussion of the groundwater geochemistry of the primary water-bearing zones; a discussion of the various geochemical patterns observed in groundwater in the BA #1 Area, Western Upland Area, and Western Alluvial Area; and a discussion of the distribution of licensed nuclear material detected in groundwater in these areas.

Section 5.0 Integrated Conceptual Site Model – This section combines the geological, hydrogeological, and geochemical models for the BA #1 Area, Western Upland Area, and Western Alluvial Area and presents an updated and refined CSM based on site data available as of 2004. The goal is to facilitate an understanding, not only of the nature and extent of uranium impact and the environment in which it is present, but of how the uranium is being transported, and expectations regarding its impact on potential receptors.

Section 6.0 Conclusions and Recommendations – This section presents key conclusions from the previous sections and recommendations for finalizing the CSM and for evaluation of remedial alternatives.

Section 7.0 References – Provides bibliographic citations for references used in development of this report.

2.0 Geological Conceptual Site Model

2.1 Regional Geology of the Cimarron Area

2.1.1 Topography

The Cimarron Site lies within the Osage Plains of the Central Lowlands section of the Great Plains physiographic province, just south of the Cimarron River in Sections 11 and 12, T16N, R4W in Logan County, Oklahoma (Figure 2-1). The topography in the Cimarron area consists of low, rolling hills with incised drainages and floodplains along major rivers. Most drainages are ephemeral and receive water from storms or locally from groundwater base flow. The two major drainages in the project area are Cottonwood Creek, which lies about 7 miles south of the site, and the Cimarron River, which borders the site on the north. Elevations in the Cimarron area range from 930 feet above mean sea level (amsl) along the Cimarron River to 1,010 feet amsl at the former plant site. Vegetation in the area consists of native grasses and various stands of trees along and near drainages. The soil (unconsolidated material) thickness in the project area ranges from about one to eight feet. Three unnamed drainages within the site boundaries were dammed to store water for agricultural and industrial use at the former plant site.

2.1.2 Regional Stratigraphy and Structure

The bedrock geology of the Cimarron Area is dominated by Permian-age clastic sedimentary rocks of the Garber-Wellington Formation as shown in Table 2-1.

These units dip to the west at 30 to 40 feet per mile (Carr and Marcher, 1977). The Permian-age Garber Sandstone and underlying Wellington Formation, which comprise the Garber-Wellington Formation, include lenticular channel and sheet-flood sandstones interbedded with shales and mudstones. The combined thickness of the Garber Sandstone and the Wellington Formation is about 1,000 feet. Because the two formations are difficult to distinguish in drill core and in outcrop and have similar water-bearing properties, they are often treated as a single mappable formation and grouped into a single hydrostratigrahic unit, the Garber-Wellington Aquifer (Wood and Burton, 1968).

Structurally, the Cimarron area is part of the Nemaha Uplift of Central Oklahoma (Figure 2-2). The Nemaha Uplift trends northward across Oklahoma and was formed during a period of uplift, faulting, and erosion that occurred between the Mississippian and Pennsylvanian Periods in the Oklahoma area. The Nemaha Uplift consists of north-northwest trending normal faults and anticlinal structures that influenced early Pennsylvanian-age sedimentation in the Oklahoma region (J.L. Grant and Associates, 1989). By middle Pennsylvanian time, the Nemaha Uplift was not active. During the Permian, when the Garber-Wellington Formation was deposited, Central Oklahoma was part of the eastern shelf of a shallow marine sea. The sandstones and shales of the Garber-Wellington Formation were deposited as part of a westward-advancing marine delta fed by numerous streams flowing to the west and northwest. Thus, the sands of the Garber-Wellington Formation are often sinuous, discontinuous, and exhibit the rapid facies changes typical of a deltaic channel and overbank depositional system. Sand accounts for 35 to 75 percent of the Garber-Wellington Formation (Carr and Marcher, 1977).

2.1.3 Cimarron River

The Cimarron River borders the northern side of the Cimarron Site. Floodplain sediments along the south side of the river in Sections 11 and 12 (Figure 2-1) are within the Cimarron Site boundaries. This river drains 4,186 square miles of Central Oklahoma from Freedom to Guthrie, Oklahoma (Adams and

Bergman, 1995). The Cimarron River is a mature river with a well-defined channel and floodplain. The stream bed is generally flat and sandy and the river is bordered by terrace deposits and floodplain gravels and sands (Adams and Bergman, 1995). The river is perennial with a low-water median flow rate of approximately 100 cubic feet per second (cfs) and a high-water median flow rate of 600 cfs (Adams and Bergman, 1995). In the area of the Cimarron Site, the ancestral Cimarron River has carved an escarpment into the Garber-Wellington Formation. Floodplain alluvial sediments currently separate most of the river channel from the escarpment within the site boundaries.

2.2 Stratigraphy of the Cimarron Site

The stratigraphy of the Cimarron Site is dominated by the Garber-Wellington Formation. The Garber Formation is exposed along the escarpment that borders the Cimarron River. The Wellington Formation was found at depth in a deep drill hole, but is not exposed within the project area. A boring completed in 1969 near the plant site penetrated 2,078 feet of the Garber-Wellington Formation (J.L. Grant and Associates, 1989). Identified in this boring was 200 feet of Garber Formation sandstones underlain by 960 feet of Wellington Formation red shales. Beneath the Wellington Formation, the Stratford Formation was found at a depth of 1,160 feet and consisted of red and gray shales with interbedded anhydrite.

Within the Cimarron Site boundaries, the Garber Formation consists primarily of sandstone layers separated by relatively continuous siltstone and mudstone layers (J.L. Grant and Associates, 1989). The sandstone units frequently have interbedded, but discontinuous, red-brown shale and mudstone lenses. Lateral facies changes are common in the sandstones and represent shifting channel locations in the Garber delta. J.L. Grant and Associates (1989) divided the Garber sandstones found in the Cimarron Site area into three basic sandstone units separated by two relatively continuous and identifiable mudstone layers. The stratigraphic division of the Garber at the Cimarron Site is summarized below from J.L. Grant and Associates (1989) and described in greater detail in Section 2.3:

- Sandstone A: Uppermost sandstone unit, generally red-brown to tan in color and up to 35 feet in thickness. Bottom of this sandstone unit occurs at an elevation of approximately 950–970 feet amsl (see Figures 2-5, 2-9, 2-10).
- Mudstone A: Red-brown to orange-brown, sometimes tan mudstone and claystone that separates Sandstones A and B. Ranges from 6 to 20 feet thick.
- Sandstone B: Second sandstone unit, similar in color and sedimentary features to Sandstone A. Found at elevations between 925 and 955 feet amsl and is up to 30 feet thick. Found below Mudstone A (see Figures 2-5, 2-9).
- Mudstone B: Mudstone and claystone separating Sandstone B and Sandstone C. Similar in color to Mudstone A and ranges from 6 to 14 feet thick.
- Sandstone C: Lowermost sandstone in the Garber-Wellington Formation. Similar in color and sedimentary features to overlying sandstones. This unit varies in thickness from 10 to 25 feet at the site to at least 100 feet thick regionally.

All three sandstone members of the Garber Formation at the Cimarron Site are basically similar lithologically. They are fine to very fine-grained red-brown to tan sandstones with well-sorted subangular to rounded grains and contain variable amounts of silt (J.L. Grant and Associates, 1989). The silt content ranges from 10 to 50 percent and the sandstones with high silt content are difficult to distinguish from siltstone. The sand grains are mostly quartz with minor amounts of feldspar and occasional magnetite and mica. The intergranular porosity varies with the silt content (J.L. Grant and Associates, 1989). The sandstones are weakly cemented and often friable. Cementing agents are calcite and hematite. Locally,

thin intervals can be found that are well cemented with gypsum and barite. These intervals are often conglomeratic. The sandstones exhibit planar cross-stratification with thin, silty laminae (J.L. Grant and Associates, 1989). Conglomeratic intervals are common in most of the borings and they are observed to contain clasts of mudstone and occasionally sandstone in either a sandstone or mudstone matrix. These conglomeratic zones are up to 2.5 feet thick. Vugs found in these conglomerate zones are lined with calcite, gypsum, and barite (J.L. Grant and Associates, 1989). The sandstones of the Garber Formation were deposited in a fluvial deltaic environment, probably as channel sands.

The mudstone layers that separate the sandstones in the Garber Formation at the Cimarron Site are mostly fine-grained, silty to shaley beds with a red-brown to orange-brown and tan color. The mudstones occasionally exhibit desiccation cracks (J.L. Grant and Associates, 1989). The mudstones are poorly consolidated. The mudstone layers are often encapsulated by thin, bluish-gray laminae that range in thickness from 0.1 to 4.0 inches. These "reduction zones" are common in red beds (J.L Grant and Associates, 1989) and at the site the thickness of these reduction zones is approximately proportional to the thickness of the mudstone layer. These continuous mudstone layers probably represent deltaic overbank deposits formed during flooding of the Garber delta.

A mineralogical analysis of the sandstones and mudstones was conducted by Auburn University using X-ray diffraction, grain-size determinations, and cation exchange capacity measurements (J.L. Grant and Associates, 1989). Quartz and feldspar were found to be the main clastic grains with kaolinite and montmorillonite as the clays in the fine-grained fractions. Illite, smectite, chlorite, hematite, and goethite were also among the minerals detected in the clay fractions according to USGS (Parkhurst et al., 1996). Calcite, iron oxides, and iron hydroxides were identified as the main cementing agents. The clay fraction ranged from 6 to about 20 percent in the sandstones and from about 14 to 50 percent in the mudstones. The mudstones had a cation exchange capacity in the range of 6 to 22 meq/100g. The sandstones had a cation exchange capacity generally below 6 meq/100g. Exchangeable cations were generally calcium and magnesium for both the sandstones and the mudstones. Within the "reduction zones," minerals formed with metals in low oxidation state, including uranium, were identified (Parkhurst et al., 1996).

The Cimarron River floodplain alluvium consists of sand and silt, developed by the erosion of the Garber Formation from the escarpment bordering the river on the south, as well as material transported to the floodplain from upstream within the river system. This alluvium formed gradually over time and contains many buried channels reflective of both transport of the alluvial materials northward toward the river from the escarpment and meandering of the main river channel. Near the present river channel, buried oxbow meanders can be expected. Near the escarpment, buried channels would be expected to be the continuation of present drainages incised into the escarpment sandstones. The alluvium is about 30 to 40 feet thick. Along the present escarpment face, there are local transition zones from the sandstones of the Garber Formation to the coarser alluvial materials. These transition zones can be clay-rich, as is the case with the transitional zone identified with borings in the BA #1 Area.

2.3 Detailed Stratigraphic Correlations at Cimarron

The Cimarron Site has sufficient borings and monitor wells to allow for generalized stratigraphic correlations within specific areas of the site and across the site. Extensive subsurface investigations were performed in the BA #1 Area, Western Upland Area, and Western Alluvial Area (see Figure 2-3). The following sections present a discussion on detailed stratigraphic correlations of these three areas.

2.3.1 BA #1 Area

The BA #1 Area is located in the northeastern corner of the Cimarron Site and includes an upland area and a portion of the floodplain of the Cimarron River (Figure 2-3). Ground surface elevation of the area ranges from 935 feet amsl within the Cimarron River floodplain to 975 feet amsl in the upland area, with a total relief of 40 feet. A buried escarpment separates the upland from the Quaternary alluvial deposits of the Cimarron River floodplain. Four former disposal trenches are situated in the upland near the escarpment. Figure 2-4 shows the location of the geological cross-section presented in Figure 2-5, as well as the location of the former disposal trenches and the monitor wells in the area. Figure 2-5, the geological cross-section of the BA #1 Area, illustrates the lithology and stratigraphy of the area.

The upland is underlain by the Garber Formation. The sandstone units present in the BA #1 Area are mainly Sandstone B and Sandstone C. Sandstone A is eroded from most of the BA #1 Area and was observed to only be approximately 10 feet thick in a borehole (Well 1314) located south of the former disposal trenches. Mudstone A is present in the southern portion of the upland and Sandstone B and Mudstone B appears to be continuous across the upland (Figure 2-5).

The uppermost unit of the Garber Formation exposed in the BA #1 Area is Mudstone A, which is a 10-foot-thick sequence of mudstone and silty mudstone overlying Sandstone B in the southern portion of this area (Figure 2-5).

Sandstone B in the BA #1 Area consists of up to 25 feet of red-to-tan sandstone and silty sandstone. This unit is exposed along the escarpment where it borders the floodplain alluvial sediments.

Mudstone B underlies Sandstone B and separates Sandstone B from Sandstone C. With the exception of areas under the floodplain alluvial sediments, this unit is continuous throughout the BA #1 Area and is considered to be continuous across the entire site.

Sandstone C is the lowermost stratigraphic unit encountered while drilling in the BA #1 Area. It is a sequence of interlayered sandstones and mudstones and underlies the entire site. This unit forms the bedrock beneath the floodplain alluvium (Figure 2-5).

Alluvial sediments in the Cimarron River floodplain consist of sand, silt, and clay. The relative abundance of each material is dependent on the distance relative to the upland, as seen in Figure 2-5. Clay and silt are the dominant lithologic types in areas adjacent to the upland. Farther away from the upland toward the Cimarron River channel, the proportion of sand increases and sand becomes the predominant lithology. Consequently, the alluvium can roughly be divided into two zones: (1) a transitional zone along the buried escarpment; and (2) a sandy alluvial zone forming the bulk of the floodplain sediments. The transitional zone is adjacent to the escarpment and characterized by massive clay and silt deposits while the sandy alluvial zone is farther away from the escarpment and characterized by massive sands. Clay and silt layers are generally thick in the transitional zone and tend to extend vertically to bedrock. In the sandy alluvial zone, however, the clay and silt layers are relatively thin and occur near the ground surface above the sand layer. In addition, the transitional zone mostly overlies Sandstone B or Mudstone B whereas the sandy alluvial zone largely overlies Sandstone C. The approximate division between the two zones appears along the line connecting wells 02W03 and 02W13 where an abrupt change in lithology occurs (Figure 2-4). On this figure, the transitional zone boundary is shown as a solid line on the northeast flank of the upland. The thickness of the alluvium increases from a few feet near the escarpment to 30 feet near the river channel.

The geological model of the BA #1 Area is depicted in a fence diagram (Figure 2-6) constructed using RockWorks 2004 software (RockWare, Inc., 2004). Fences A, B, C, and D show the transitional zone, and Fences E and F the sandy alluvial zone. Note that, in the eastern parts of Fences A and B (transitional zone), there exists a localized body of massive clay and silt. Sand pockets, lenses, and thin layers present between the upland and the clay/silt body may form small preferential pathways and conduits for groundwater entering the alluvium from the former disposal trench area, as indicated by the orange-colored line in Figure 2-6. To the north, these pathways are largely blocked by a clay barrier that lies across the sand channel in the area between TMW-9 and TMW-5 (Fence C). Due to a significant reduction in the thickness of the sand layers, this clay barrier may restrict groundwater flow to the sandy alluvium from the clay-rich transitional sediments. The sand channel ends near Fence D, beyond which there are no significant geological heterogeneities that modify the groundwater movement in alluvium towards the Cimarron River.

In Figure 2-7, Image 2-7A illustrates the surface lithology of the BA #1 Area. A sand channel along the northeastern border of the upland can be observed. If the overburden sand and silt layers in Image 2-7A are electronically "removed," a paleochannel is revealed as shown in Image 2-7B. The presence of the massive clay and silt in the transitional zone is suspected to divert groundwater from flowing directly to the north into the sandy alluvium. Instead, it forces the groundwater entering the alluvium to flow along the southeast-northwest channel in the transitional zone. Once past the transitional zone, the groundwater flow is towards the river with little modification from the relatively consistent sands of the alluvium.

2.3.2 Western Upland Area

As shown in Figure 2-8, the Western Upland Area is located near the 1206 Seep; the BA #3 Area; and monitor wells 1351, 1352, 1354, 1355, 1356, 1357, and 1358. The Western Upland Area includes the drainage channel between the former Sanitary Lagoons and the BA #3 Area. Figures 2-9 and 2-10 present profiles and stratigraphy of the Western Upland Area (i.e., Seep 1206 and the surrounding areas). Locations of the geological cross-section are shown in Figure 2-8. All three sandstone units (Sandstones A, B, and C) and the two mudstone units (Mudstones A and B) are present in this area. The lithologies of sandstone and mudstone are similar to those described for the BA #1 Area.

The geology of the Western Upland Area is dominated by Sandstone A (Figure 2-9). Sandstone A is 20 to 30 feet thick in this area and is underlain by an approximately 20- to 25-foot-thick section of Mudstone A. Around the upgradient monitor well 1350, a shale layer about 20 feet in thickness occupies the upper part of Sandstone A. Near the BA #3 Area, this shale has been replaced by silty sandstone about 10 feet thick. Beneath the shale and silty sandstone layers, Sandstone A is a thick section of mostly sandstone down to the contact with Mudstone A.

In the area of the 1206 Seep, Sandstone A has no shale or silty zones near the top and is about 20 feet thick. The top of Mudstone A is at an elevation of approximately 968 feet amsl (Figure 2-10). Historically, samples designated as being collected from the 1206 Seep were in fact collected from a pool of accumulated surface water near the escarpment. The Seep 1206 sampling location is identified in Figure 2-3, and can be seen in Figure 2-10.

The stratigraphic correlations of the western half of the Cimarron Site are depicted in a fence diagram in Figure 2-11. In this diagram, fences A, B, and C represent the Well 1319 Area, Seep 1206 Area/U-Pond #1 Area, and the U-Pond #2 Area, respectively. This fence diagram was generated utilizing computer geologic modeling software RockWorks 2004 (RockWare, Inc., 2004). Unlike the BA #1 Area, Sandstone A in the western part of the Cimarron Site is ubiquitous across the upland area.

2.3.3 Western Alluvial Area

The Western Alluvial Area is located in the alluvial floodplain to the north of the upland area near the former BA #3 Area, the 1206 Seep Area, and the area of the former Sanitary Lagoons.

Alluvial sediments in the Western Alluvial Area consist predominantly of sand with minor amount of clay and silt. The clay and silt range from 0 to 10 feet thick and occur mostly near the ground surface (Figure 2-9). The alluvium is underlain by Sandstone B near the escarpment and by Mudstone B and Sandstone C closer to the Cimarron River.

Alluvial sediments in the floodplain were deposited on an erosional unconformity over Sandstone B and near the face of the escarpment on Mudstone A. Sand constitutes the bulk of the alluvial sediments in this area.

In addition to the floodplain alluvium, silt and silty sand are also present in a small area located south of wells T-62 and T-64 and is situated in the drainage way of 1206 Seep near the escarpment. These sediments are underlain by Sandstone A or Mudstone A. The thickness of unconsolidated soils varies from 2 ft at higher elevation to about 14 ft at the escarpment. Groundwater in this area is shallow (about 6 ft below ground surface) and appears to be originated from seeps discharged to the drainage way.

2.4 Summary

The regional geology of the Cimarron area and the site-wide stratigraphic correlations for the project area can be combined into a general geological model for the Cimarron Site. The site consists of Permian-age sandstones and mudstones of the Garber-Wellington Formation of central Oklahoma overlain by soil in the upland areas and Quaternary alluvial sediments in the floodplains and valleys of incised streams. The Garber sandstones dip gently to the west and are overlain to the west of the Cimarron Site by the Hennessey Group. The Wellington Formation shales are found beneath the Garber sandstones at a depth of approximately 200 feet below ground surface in the project area.

The Garber Formation at the project site is a fluvial deltaic sedimentary sequence consisting of channel sandstones and overbank mudstones. The channel sandstones are generally fine-grained, exhibit cross-stratification, and locally have conglomeratic zones up to a few feet thick. The sandstones are weakly cemented with calcite, iron oxides, and hydroxides. The silt content of the sandstones is variable and clays within the fine fraction are generally kaolinite or montmorillonite. The mudstones are clay-rich and exhibit desiccation cracks and oxidation typical of overbank deposits. Some of the mudstones are continuous enough at the Cimarron Site to allow for separation of the sandstones into three main units, designated (from top to bottom) as Sandstones A, B, and C. Correlation of these three sandstone units is based primarily on elevation and the presence of a thick mudstone unit at the base of Sandstones A and B that can be correlated between borings. Within each sandstone unit, there are frequent mudstone layers that are discontinuous and not correlative across the project area.

The Cimarron Site is located on part of an upland or topographic high between Cottonwood Creek and the Cimarron River. The project site is dissected by shallow, incised drainages that drain northward toward the Cimarron River. Groundwater base flow and surface water runoff during storms have been ponded in two reservoirs (Reservoirs #2 and #3) on the project site. The Cimarron River is a mature river that has incised the Garber Formation, forming escarpments that expose the upper part of the Garber sandstones. Within the Cimarron Site, the Cimarron River has developed a floodplain of unconsolidated sands, silts, and clays that separate the Garber sandstones exposed in an escarpment from the main river channel. Surface drainages within the project site flow toward the Cimarron River.

Geological features of each specific area of the Cimarron Site, from east to west, are highlighted as follows:

- BA #1 Area – The upland is underlain by a sequence of sandstone and mudstone units, namely, from top to bottom, Mudstone A, Sandstone B, Mudstone B, and Sandstone C. The alluvium can be divided into a transitional zone located within the erosional drainage area and an alluvial zone located outside the escarpment line. The transitional zone consists predominantly of clay and silt and overlies Sandstone B or Mudstone B. A paleochannel appears to exist in the transitional zone, which may control the flow of groundwater in the vicinity of the upland in this area. The alluvium consists of mainly sand and overlies Sandstone C and, to a lesser extent, Mudstone B.
- Western Upland Area – The upland area that includes the BA #3 Area, the 1206 Seep Area, and the former Sanitary Lagoons is composed primarily of Sandstone A. Sandstone B is exposed near the base of the drainage between the former Sanitary Lagoons and the BA #3 Area at the mouth of the drainage where it opens into the alluvial floodplain of the Cimarron River. In the vicinity of BA #3 Area and also the former Sanitary Lagoons, the upper part of Sandstone A is composed mostly of siltstone and shale, rather than sandstone. A surface drainage extending through the area is incised into Sandstone A and Mudstone A. The remaining members of the Garber-Wellington Formation are present at depth in the area
- Western Alluvial Area – Alluvial sediments in this area consist of predominantly sand with minor amount of clay and silt. Sandstone B and Mudstone B exist beneath the alluvial sediments near the escarpment and Sandstone C underlies the alluvial sediments farther out in the floodplain.

Table 2-1 Geologic Units Exposed in Southern Logan and Northern Oklahoma Counties, Oklahoma

System and Series	Unit	Maximum Thickness (ft)	Lithology
			Quaternary
Holocene	Alluvium	50	Sand, silt, clay, and thin layers of gravel.
Pleistocene	Terrace deposits	50	Lenticular beds of sand, silt, clay and gravel.
			Permian
Hennessey Group	Bison Formation	95	Mostly reddish-brown shale.
	Salt Plains Formation	200	Reddish-brown blocky shale and orange-brown siltstone.
	Kingman Siltstone	30	Orange-brown to greenish-gray even-bedded siltstone, and some fine-grained sandstone and reddish-brown shale.
	Fairmount Shale	30	Reddish-brown blocky shale; grades into Garber Sandstone at base.
	Garber-Wellington Formation	1,000	Mostly reddish-brown to tan fine-grained alluvial sandstones with interbedded red-brown shales and mudstones and local chert and mudstone conglomerates. Formation consists of fluvial/deltaic sands and overbank clays preserved as mudstone layers. Deltaic sands consist of both channel sands and sheet-flood sands.

Prepared for:
Tronox
Crescent, Oklahoma

Conceptual Site Model (Revision – 01) Cimarron Site, Crescent, Oklahoma October 2006

ENSR Corporation
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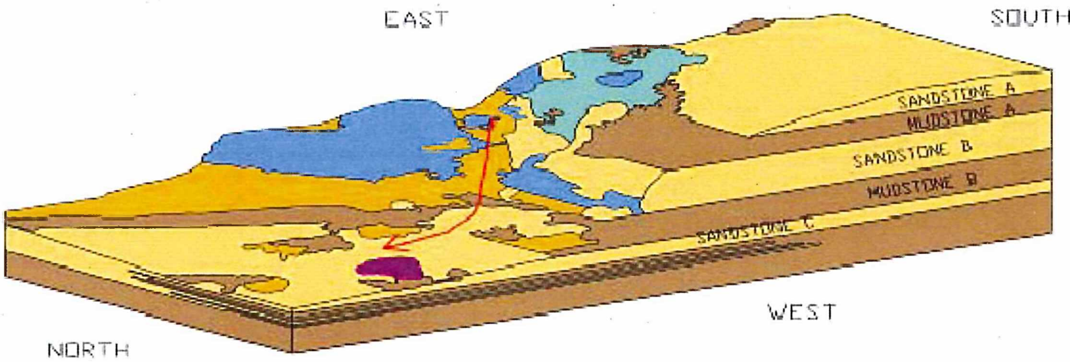

Pictorial Representation of Site Model – Burial Area # 1

Conceptual Site Model, (Revision – 01) Cimarron Site, Crescent, Oklahoma

Prepared By: D. Joseph Ferguson

Reviewed By: Michael K. Meenan, PE

ENSR Corporation
October 2006
Document No.: 04020-044

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List of Abbreviations and Acronyms

AEC	Atomic Energy Commission
amsl	above mean sea level
Bq/L	Becquerels per liter
BTP	Branch Technical Position
cfs	cubic feet per second
cm/s	centimeters per second
CSM	conceptual site model
DEQ	Department of Environmental Quality
EC	effluent concentrations
MCLs	Maximum Concentration Limits
meq/100g	milliequivalents per 100 grams
meq/L	milliequivalents per liter
µg/L	micrograms per liter
mg/L	milligrams per liter
mL/g	milliliters per gram
mrem/yr	millirem per year
mSv/yr	millisieverts per year
mv	millivolts
NRC	Nuclear Regulatory Commission
NWIS	National Water Information System
ORISE	Oak Ridge Institute for Science and Education
pCi/g	picocuries per gram
pCi/L	picocuries per liter
TC-99	Technetium-99
TDS	total dissolved solids
TEDE	Total Effective Dose Equivalent
UF_6	uranium hexafluoride
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey

1.0 Introduction

Cimarron Corporation's site (Cimarron Site) near Crescent, Okalahoma, is a former nuclear fuel manufacturing facility. Since the cessation of operations, the site has been undergoing decommissioning. This decommissioning is being performed by Cimarron Corporation with oversight from the Nuclear Regulatory Commission (NRC) and the Oklahoma Department of Environmental Quality (Oklahoma DEQ). The evaluation presented in this report has been performed to update the understanding of Cimarron Site's geology and hydrogeology based on new data collected since the initial conceptual site model (CSM) was developed. This CSM is focused specifically on areas where impacts remain to be fully remediated: Burial Area #1 (BA #1 Area); the Western Upland Area; and the Western Alluvial Area. Cimarron Corporation completed this evaluation to assist in development of a consensus, among agencies and interested parties, on existing site conditions for use in developing plans for actions to complete remediation of the site.

1.1 Role of Conceptual Site Models

A CSM is defined as a written or pictorial representation of an environmental system, and the biological, physical, and chemical processes that determine the transport of contaminants from sources through environmental media to environmental receptors within the system (ASTM E1689-95(2003) e1).

A CSM is typically used to integrate available site information and to evaluate whether additional information should be collected. The model is used furthermore to facilitate the selection of remedial alternatives and to evaluate the effectiveness of remedial actions. The development of a CSM is normally iterative. Model development should start as early as possible in the site investigation process. In addition, the model should be updated and revised throughout the site investigation process to incorporate additional site data. As part of the ongoing process of updating the CSM as new data becomes available, this current edition of the CSM reflects the addition of data associated with additional field sampling and the development of a groundwater flow model that have occurred since the August 2005 edition (Revision 0) was produced.

1.2 Existing Cimarron Site Characterization Documents/Models

Assessment at the Cimarron Site has been ongoing since the decommissioning process began in 1979. From this period, the following eleven principal characterization documents are integral in the development of the CSM that is being used for the Cimarron Site:

1. Site Investigation Report for the Cimarron Corporation Facility, Logan County, Oklahoma, James L. Grant & Associates, September 1989.

2. Radiological Characterization Report for Cimarron Corporation's Nuclear Fuel Fabrication Facility, Crescent, Oklahoma, Chase Environmental Group, October 1994.

3. Groundwater and Surface Water Assessment for Cimarron Corporation's Former Nuclear Fuel Fabrication Facility, Crescent, Oklahoma, Chase Environmental Group, Inc., December 1996.

4. Cimarron Decommissioning Plan Groundwater Evaluation Report for Cimarron Corporation's Former Nuclear Fuel Fabrication Facility, Crescent, Oklahoma, Cimarron Corporation, July 1998.

5. Environmental Assessment by the Office of Nuclear Material Safety and Safeguards of the Proposed Decommissioning Plan and Other Proposals Related to the Cimarron Corporation Former Fuel Fabrication Facility, Nuclear Regulatory Commission Office of Nuclear Material Safety and Safeguards, July 1999.

6. Burial Area #1 Groundwater Assessment Report for Cimarron Corporation's Former Nuclear Fuel Fabrication Facility, Cimarron Corporation, January 2003.

7. Justification for Utilization of Fully Penetrating Groundwater Monitoring Wells in Shallow Alluvial Aquifer at the Cimarron Facility, Chase Environmental Group, January 2003.

8. Assessment Report for Well 1319 Area for Cimarron Corporation's Former Nuclear Fuel Fabrication Facility, Cimarron Corporation, December 2003.

9. Technetium-99 Groundwater Assessment Report for Cimarron Corporation's Former Nuclear Fuel Fabrication Facility, Crescent, Oklahoma, Chase Environmental Group, Inc., December 2003.

10. Refined Conceptual Site Model, Cimarron Site, Crescent, Oklahoma, ENSR Corporation, August 2005.

11. Ground Water Modeling Report, Cimarron Site, Crescent, Oklahoma, ENSR Corporation, October 2006.

A brief synopsis of each of these eleven reports is presented in the box below.

1. Site Investigation Report for the Cimarron Corporation Facility, Logan County, Oklahoma James L. Grant and Associates September 1989	This report summarizes geological and hydrogeological site investigations conducted at the Cimarron Site and provided the basis for understanding the geological and hydrogeological controls on surface soil, bedrock, and aquifer radiological impacts and the potential movements of impacts. This report provided the first comprehensive CSM and set the stage for determining which areas of the site could have been affected radiologically by former Cimarron facility activities. This report contains the following information: • Characterization of the stratigraphy and lithology of the soils and bedrock at the site; • Characterization of aquifer properties including hydraulic conductivity, groundwater flow directions, and gradient; • Characterization of groundwater quality and determination of the effects that facility operations may have had on groundwater quality; and • Determination of the mobility of radionuclides, particularly uranium, in the subsurface and the ability of subsurface materials to retard migration at the Cimarron Site.

2. Radiological Characterization Report for Cimarron Corporation's Nuclear Fuel Fabrication Facility, Crescent, Oklahoma Chase Environmental Group 1994	This report presents the results of field radiological investigations at the Cimarron Site. It facilitated the subsequent decommissioning of areas potentially affected by previous facility operations. The report also summarizes the site operational history and the decommissioning activities, such as removal of impacted waste and soil up to that date at the Cimarron Site. • This report presents results from a combination of scoping surveys, characterization surveys, remediation control surveys, pre-remediation surveys, post-remediation surveys, final surveys, and confirmatory surveys (Oak Ridge Institute for Science and Education (ORISE) and NRC confirmatory survey results are included for some areas and, in some cases, survey results are included for areas that had already been released by the NRC). • Only uranium and plutonium in chemically separated form were used in the production processes at the Cimarron Site. The concentration of daughter radionuclides was negligible. Radium and thorium detected in groundwater and soil samples were at natural background levels and were, thus, not due to the effects of facility operations.
3. Groundwater and Surface Water Assessment for Cimarron Corporation's Former Nuclear Fuel Fabrication Facility, Crescent, Oklahoma Chase Environmental Group, Inc. December 1996	This report reviews background water quality; assesses historical and then-current groundwater data to determine impacts from past operations; and identifies changes to groundwater quality since issuance of the report prepared by James L. Grant and Associates in 1989. This report also reviews existing surface and groundwater data, including data from a comprehensive sampling event performed in 1996. The conclusions of this report are: • Background, near-surface groundwater quality is hard to very hard, and contains elevated concentrations of dissolved solids, chlorides, sulfates, and nitrates, thus limiting its potential for usage as a potable supply. • The geology of the site limits the groundwater available for withdrawal for beneficial usage to approximately one gallon per minute or less of sustained pumping. • Shallow groundwater, which is found in Sandstones A and B, flows north-northwest until it is discharged to either the ground surface as seeps along low-lying bluffs and cliffs or to the Cimarron River alluvium. • With source removal and further remediation, substantial improvements in localized groundwater quality had been realized as of the date of this report. Groundwater testing indicated that past operations may have affected the groundwater quality adjacent to one or two former waste management units.

	• Only one well location contained groundwater exceeding the uranium effluent concentration (EC) limits presented in 10 CFR 20. Well 1315, located between trenches within the BA #1 Area, showed a total uranium concentration that was twice the EC limit in 1996. However, the 1996 sampling results reflect a substantial reduction in concentration from the 1990 level of 27 times the EC limit. In general, for other wells with slightly elevated uranium, similar downward (improving quality) trends were occurring. Groundwater impacts were contained totally on site. • The deeper wells, located in Sandstone C, have not shown any affect from former facility operations.
4. Cimarron Decommissioning Plan Groundwater Evaluation Report for Cimarron Corporation's Former Nuclear Fuel Fabrication Facility, Crescent, Oklahoma Cimarron Corporation July 1998	The purpose of this report was to provide information regarding groundwater at the Cimarron Site for inclusion in the Cimarron Decommissioning Plan. This report addresses vicinity and site geology/hydrology, presents a summary of closure activities for areas that had groundwater impact, describes background and affected-area groundwater quality, assesses the trending of environmental data for affected areas, and presents a proposal for additional work at the BA #1 Area. The conclusions of this report were as follows: • Effective confining mudstone strata are present between each of the groundwater zones of Sandstones A, B, and C on site. These mudstones influence the lateral flow of groundwater and act to limit the potential downward migration of shallow groundwater between the three sandstone units. • The bluffs overlooking the Cimarron River represent a very large discharge zone that continually drains the upper sandstones. In fact, the upper sandstones were not saturated in those site areas near the bluffs. • The historical and more-recent groundwater and surface water investigations clearly showed that groundwater radionuclide impacts had abated and continued their decreasing trends from the levels reported in 1989 by J.L. Grant and Associates. • Shallow groundwater in Sandstones A and B generally discharges to the incised drainage pathways and the seeps in the low-lying bluffs and cliffs that border the floodplain of the Cimarron River. • Deeper groundwater in both Sandstones B and C discharges to the alluvial deposits that underlie and comprise the Cimarron River bottom and the adjoining floodplain. • Cimarron Corporation would continue to monitor groundwater in the BA #1 Area on a quarterly basis. Even though Cimarron Corporation believed that groundwater concentrations would continue to decrease, it agreed to conduct additional studies for the purpose of understanding the attenuation mechanisms.These studies were to include additional hydrogeologic evaluations of the general area.

	• Cimarron Corporation agreed to retain and control the property areas formerly licensed under NRC Radioactive Material SNM-928 until the proposed groundwater criteria were met. In the unlikely event that the uranium concentrations did not decline sufficiently during the monitoring period, Cimarron Corporation agreed to prepare a corrective action program.
5. Environmental Assessment by the Office of Nuclear Material Safety and Safeguards of the Proposed Decommissioning Plan and Other Proposals Related to the Cimarron Corporation Former Fuel Fabrication Facility Nuclear Regulatory Commission Office of Nuclear Material Safety and Safeguards July 1999	This report assesses the environmental impact of the decommissioning proposed by Cimarron Corporation. It also considers the no-action alternative. This report was prepared and issued pursuant to the National Environmental Policy Act of 1969 (NEPA) and NRC's regulations in 10 CFR 51. NRC staff reviewed both the beneficial and adverse potential impacts of the proposed decommissioning. The staff's conclusions were as follows: • Radiation exposures of persons living or traveling near the site because of onsite operations and waste transportation will be well within the limits contained in 10 CFR 20. • Cimarron Corporation proposed a groundwater standard of 6.7 Becquerels per liter (Bq/L) (180 picocuries per liter [pCi/L]) for total uranium, which it demonstrated to equate to the allowable 0.25 millisieverts per year (mSv/yr) (25 millirems per year (mrem/yr) Total Effective Dose Equivalent (TEDE) to the hypothetical individual drinking the water. NRC staff found the proposed groundwater standard of 6.7 Bq/L (180 pCi/L) for total uranium to be acceptable because the 0.025 mSv/yr (25 mrem/yr) dose associated with that standard, when added to the negligible dose from all other pathways is well below the 0.1 mSv/yr (100 mrem/yr) limit in 10 CFR 20.1301 for individual members of the public. In addition, the likelihood of this groundwater ever being used for domestic or agricultural purposes is low. On the basis of this report, NRC staff concluded that the proposed action would not have any significant effect on the quality of the human environment and did not warrant the preparation of an environmental impact statement.
6. Burial Area #1 Groundwater Assessment Report for Cimarron Corporation's Former Nuclear Fuel Fabrication Facility Cimarron Corporation January 2003	This document details the comprehensive investigation of uranium in groundwater in the BA #1 Area. The conclusions presented in this report were as follows: • None of the soils within the area of groundwater impact exceed the Option 1 criteria for unrestricted release (30 picocuries per gram [pCi/g] above background) in the NRC Branch Technical Position (BTP), "Disposal or Onsite Storage of Thorium and Uranium Wastes from Past Operations." • Uranium concentrations in Sandstone C ranged from 6 to 34 pCi/L for the locations monitored, which is consistent with background levels of Sandstone C.

	• A clay/mudstone lithologic unit underlies a significant portion of the area of uranium impact. • The shallow groundwater shows a steep gradient in the bedrock area, and flattens considerably as groundwater discharges into the alluvium. • The geology of the area has been adequately characterized. • Geotechnical properties of subsurface materials have been quantified. • The source of licensed material has been removed. • The disposal trenches extended through the low-permeability materials that covered Sandstone B and the more permeable alluvial material. • The upland area is characterized by Mudstone A overlying Sandstone B, with a buried escarpment covered by alluvial materials. • There is a transitional zone characterized by low-permeability material (clay and clayey silts) with depth in the alluvial channel. • The alluvium typically consists of a layer of fine, well-rounded sands overlain by silts and clays. In a small portion of the area, the sand extends to the surface. • There is a low-permeability layer (clay and/or shale/mudstone) underlying the alluvial sands in most of the area.
7. Justification for Utilization of Fully Penetrating Groundwater Monitoring Wells in Shallow Alluvial Aquifer at the Cimarron Facility Chase Environmental Group January 2003	This technical assessment presents both hydrogeological and future land use information that explains the rationale behind Cimarron Corporation's decision to install monitor wells that are screened across the full saturated thickness of the alluvial aquifer. This paper addresses the nature of the alluvial aquifer and explains why potential future users of groundwater would install wells screened through the entire saturated thickness. This technical assessment presents the conclusion that the shallow alluvium downgradient from the BA #1 Area consists of a vertically undifferentiated and unconfined hydrogeologic unit that is formed by a complex mixture of mostly sand with laterally discontinuous alluvial deposits of clay, silt, and gravel. As a result of the geologic and hydrogeologic characteristics of the shallow alluvial aquifer, the relatively thin and unconfined water-bearing zone of the alluvial deposits cannot practically be separated into an upper and/or lower zone for vertical differentiation of the uranium impact that will require remediation.

8. Assessment Report for Well 1319 Area for Cimarron Corporation's Former Nuclear Fuel Fabrication Facility Cimarron Corporation December 2003	This report summarizes the groundwater evaluation of licensed material in the area of the former Uranium Plant yard near Well 1319. The report presents the following conclusions: • Licensed material in the Well 1319 Area was limited to Sandstones B and C. • Sandstone A was unimpacted because the original Well 1319 was not perforated through the Sandstone A interval. • Groundwater in Sandstones B and C exceeding the limit of 180 pCi/L was restricted to a very small area downgradient of the former well 1319. The report demonstrates that groundwater beneath the Uranium Plant yard had been remediated and the area was ready for release.
9. Technetium-99 Groundwater Assessment Report for Cimarron Corporation's Former Nuclear Fuel Fabrication Facility, Crescent, Oklahoma Chase Environmental Group Inc. December 2003	This report presents the results of the Technetium-99 (Tc-99) groundwater assessment performed for the Cimarron Site. This assessment was performed in response to the NRC's March 12, 2002, letter requesting further evaluation of the presence of Tc-99 in groundwater at the Cimarron Site. The source of the Tc-99 at the facility is due to this radionuclide, which is a fission product, being shipped to the facility as a contaminant present in Atomic Energy Commission (AEC) supplied uranium hexafluoride (UF_6) feed material. This report presents the following results: • Shallow groundwater within Sandstones A and B downgradient from U-Pond #2 has been impacted by prior site operations and shows elevated concentrations of Tc-99. • Seep 1208 was the only sampling location that has yielded Tc-99 concentrations slightly above the license termination guideline value of 3,790 pCi/L. • Since the original source (i.e., U-Ponds #1 and #2) had been removed, concentrations of Tc-99 in groundwater and at the discharge zones will continue to decrease as well as concentrations of Tc-99 in the alluvium. This report demonstrated that elevated levels of Tc-99 were present downgradient from the two former waste management areas of U-Pond #1 and U-Pond #2 within Sandstone A and at the seep outcrops.
10. Refined Conceptual Site Model, Cimarron Site, Crescent , Oklahoma ENSR Corporation August 2005	This report was written to update the understanding of Cimarron Site's geology, hydrogeology, and groundwater geochemistry based on new data collected since the initial conceptual site model (CSM) was developed. This CSM is focused specifically on areas where impacts remain to be fully remediated: Burial Area #1 (BA #1 Area); the Western Upland Area; and the Western Alluvial Area. Cimarron Corporation completed this evaluation to assist in development of a consensus, among agencies and interested parties, on existing site conditions for use in developing plans for actions to complete remediation of the site.

11. Groundwater Modeling Report, Cimarron Site, Crescent , Oklahoma ENSR Corporation October 2006	This report documents the construction and execution of two numerical flow models developed for the BA#1 and Western Alluvium areas in support of groundwater remediation design at the Cimarron site. Details of model setup, calibration, sensitivity analysis, and results are discussed in the report. The models can be used for optimization of well network in pump-and-treat and prediction of oxygen flux in bioremediation.

1.3 Purpose

The purpose of this CSM is to compile and integrate both historical and current information into a comprehensive model of the BA #1 Area and the Western Alluvial Area. The CSM will also be used to facilitate the selection of remedial alternatives and to evaluate the effectiveness of remedial actions in removing licensed material from site groundwater. This CSM is intended to establish a foundation for all parties to share the same understanding of the site characterization, which will enable technical and regulatory personnel to resolve issues concerning the site, and facilitate the decision-making process.

1.4 Technical Considerations

During the course of investigations and assessments of surface water and groundwater at the Cimarron Site since 1990, multiple approaches and methodologies have been discussed and resolved between Cimarron Corporation, NRC, and Oklahoma DEQ. These agreements and understandings have been incorporated into the data acquisition programs at the site. These agreements and understandings, therefore, have a bearing on the information and interpretations outlined in this CSM report. The following is a summary of these technical considerations, agreements, and understandings:

- For the purposes of this CSM report, areas of the Cimarron Site that have continuing groundwater impacts are more extensively considered than areas that have been released and/or areas that are pending release because they currently comply with decommissioning criteria (e.g., Well Area in Subarea K).
- Cimarron Corporation derived a site-specific release criteria limit of 180 pCi/L for uranium in groundwater, which was subsequently approved by the NRC and Oklahoma DEQ.
- NRC stipulated that Tc-99 would have an action limit of 3,790 pCi/L in groundwater at the Cimarron Site.
- Groundwater monitor wells installed in the Cimarron River alluvium are screened across the entire saturated interval.

1.5 Branch Technical Position Options and Groundwater Release Criteria

NRC approved use of the 1981 Branch Technical Position (BTP) as the criteria for decommissioning soils at the Cimarron Site. In their October 5, 1991, letter (SECY 81-576) NRC staff identified five acceptable options for disposal or onsite storage of uranium or thorium. Two of these BTP Options (BTP #1 and BTP #2) have been incorporated into License Condition 27(b) and were utilized at the Cimarron Site during decommissioning activities. These two options are described as follows:

- BTP Option #1 – Allows for the disposal of natural thorium with daughters in secular equilibrium, depleted or enriched uranium, and uranium ores with daughters in secular equilibrium with no restriction on burial method. The concentration limits for natural thorium and depleted or

enriched uranium are set sufficiently low that no member of the public is expected to receive unacceptable radiation under any foreseeable use of the material or property. Material that meets Option 1 limits can be treated as "clean" soil. The BTP Option #1concentration limit for uranium is 30 pCi/g for enriched uranium and 35 pCi/g for depleted uranium.

- BTP Option #2 – Allows for the disposal of natural thorium with daughters in secular equilibrium and depleted or enriched uranium with no daughters present when buried under prescribed conditions with no subsequent land use restrictions and no continuing NRC licensing of the material. Under this option, burial will be permitted only if it can be demonstrated that the buried materials will be stabilized in place and not be transported away from the site. Acceptability of the site for disposal will depend on topographical, geological, hydrogeological, and meteorological characteristics of the site. At a minimum, burial depth will be at least four feet below the surface. The BTP Option #2 concentration range is up to 100 pCi/g for soluble uranium and up to 250 pCi/g for insoluble uranium.

The release criteria for groundwater at the Cimarron Site is 6.7 Bq/L (180 pCi/L) total uranium. Cimarron Corporation will retain control of the property licensed under NRC Radioactive Material License SNM 928 until the groundwater release criteria are met.

1.6 Report Structure

This report is organized as described below.

Section 1.0 Introduction – Presents a discussion of the role of a CSM, a review of past site characterization efforts and understandings, and the reasons for development of this refined CSM.

Section 2.0 Geological Conceptual Site Model – Presents a discussion of the regional geology of the Cimarron Area, the stratigraphy of the Cimarron Project Site, including detailed stratigraphic correlations, and a summary of the Cimarron Project Geological Model.

Section 3.0 Hydrogeological Conceptual Site Model – Presents a discussion of the general hydrogeology of the Cimarron Area, groundwater flow at the Cimarron Site (including delineation of water-bearing units, potentiometric surfaces, flow patterns, surface water interactions, Cimarron River floodplain), and specific area groundwater flow regimes (i.e., BA #1 Area and Western Plume Area).

Section 4.0 Geochemical Conceptual Site Model – This section presents a discussion of the groundwater geochemistry of the primary water-bearing zones; a discussion of the various geochemical patterns observed in groundwater in the BA #1 Area, Western Upland Area, and Western Alluvial Area; and a discussion of the distribution of licensed nuclear material detected in groundwater in these areas.

Section 5.0 Integrated Conceptual Site Model – This section combines the geological, hydrogeological, and geochemical models for the BA #1 Area, Western Upland Area, and Western Alluvial Area and presents an updated and refined CSM based on site data available as of 2004. The goal is to facilitate an understanding, not only of the nature and extent of uranium impact and the environment in which it is present, but of how the uranium is being transported, and expectations regarding its impact on potential receptors.

Section 6.0 Conclusions and Recommendations – This section presents key conclusions from the previous sections and recommendations for finalizing the CSM and for evaluation of remedial alternatives.

Section 7.0 References – Provides bibliographic citations for references used in development of this report.

2.0 Geological Conceptual Site Model

2.1 Regional Geology of the Cimarron Area

2.1.1 Topography

The Cimarron Site lies within the Osage Plains of the Central Lowlands section of the Great Plains physiographic province, just south of the Cimarron River in Sections 11 and 12, T16N, R4W in Logan County, Oklahoma (Figure 2-1). The topography in the Cimarron area consists of low, rolling hills with incised drainages and floodplains along major rivers. Most drainages are ephemeral and receive water from storms or locally from groundwater base flow. The two major drainages in the project area are Cottonwood Creek, which lies about 7 miles south of the site, and the Cimarron River, which borders the site on the north. Elevations in the Cimarron area range from 930 feet above mean sea level (amsl) along the Cimarron River to 1,010 feet amsl at the former plant site. Vegetation in the area consists of native grasses and various stands of trees along and near drainages. The soil (unconsolidated material) thickness in the project area ranges from about one to eight feet. Three unnamed drainages within the site boundaries were dammed to store water for agricultural and industrial use at the former plant site.

2.1.2 Regional Stratigraphy and Structure

The bedrock geology of the Cimarron Area is dominated by Permian-age clastic sedimentary rocks of the Garber-Wellington Formation as shown in Table 2-1.

These units dip to the west at 30 to 40 feet per mile (Carr and Marcher, 1977). The Permian-age Garber Sandstone and underlying Wellington Formation, which comprise the Garber-Wellington Formation, include lenticular channel and sheet-flood sandstones interbedded with shales and mudstones. The combined thickness of the Garber Sandstone and the Wellington Formation is about 1,000 feet. Because the two formations are difficult to distinguish in drill core and in outcrop and have similar water-bearing properties, they are often treated as a single mappable formation and grouped into a single hydrostratigrahic unit, the Garber-Wellington Aquifer (Wood and Burton, 1968).

Structurally, the Cimarron area is part of the Nemaha Uplift of Central Oklahoma (Figure 2-2). The Nemaha Uplift trends northward across Oklahoma and was formed during a period of uplift, faulting, and erosion that occurred between the Mississippian and Pennsylvanian Periods in the Oklahoma area. The Nemaha Uplift consists of north-northwest trending normal faults and anticlinal structures that influenced early Pennsylvanian-age sedimentation in the Oklahoma region (J.L. Grant and Associates, 1989). By middle Pennsylvanian time, the Nemaha Uplift was not active. During the Permian, when the Garber-Wellington Formation was deposited, Central Oklahoma was part of the eastern shelf of a shallow marine sea. The sandstones and shales of the Garber-Wellington Formation were deposited as part of a westward-advancing marine delta fed by numerous streams flowing to the west and northwest. Thus, the sands of the Garber-Wellington Formation are often sinuous, discontinuous, and exhibit the rapid facies changes typical of a deltaic channel and overbank depositional system. Sand accounts for 35 to 75 percent of the Garber-Wellington Formation (Carr and Marcher, 1977).

2.1.3 Cimarron River

The Cimarron River borders the northern side of the Cimarron Site. Floodplain sediments along the south side of the river in Sections 11 and 12 (Figure 2-1) are within the Cimarron Site boundaries. This river drains 4,186 square miles of Central Oklahoma from Freedom to Guthrie, Oklahoma (Adams and

Bergman, 1995). The Cimarron River is a mature river with a well-defined channel and floodplain. The stream bed is generally flat and sandy and the river is bordered by terrace deposits and floodplain gravels and sands (Adams and Bergman, 1995). The river is perennial with a low-water median flow rate of approximately 100 cubic feet per second (cfs) and a high-water median flow rate of 600 cfs (Adams and Bergman, 1995). In the area of the Cimarron Site, the ancestral Cimarron River has carved an escarpment into the Garber-Wellington Formation. Floodplain alluvial sediments currently separate most of the river channel from the escarpment within the site boundaries.

2.2 Stratigraphy of the Cimarron Site

The stratigraphy of the Cimarron Site is dominated by the Garber-Wellington Formation. The Garber Formation is exposed along the escarpment that borders the Cimarron River. The Wellington Formation was found at depth in a deep drill hole, but is not exposed within the project area. A boring completed in 1969 near the plant site penetrated 2,078 feet of the Garber-Wellington Formation (J.L. Grant and Associates, 1989). Identified in this boring was 200 feet of Garber Formation sandstones underlain by 960 feet of Wellington Formation red shales. Beneath the Wellington Formation, the Stratford Formation was found at a depth of 1,160 feet and consisted of red and gray shales with interbedded anhydrite.

Within the Cimarron Site boundaries, the Garber Formation consists primarily of sandstone layers separated by relatively continuous siltstone and mudstone layers (J.L. Grant and Associates, 1989). The sandstone units frequently have interbedded, but discontinuous, red-brown shale and mudstone lenses. Lateral facies changes are common in the sandstones and represent shifting channel locations in the Garber delta. J.L. Grant and Associates (1989) divided the Garber sandstones found in the Cimarron Site area into three basic sandstone units separated by two relatively continuous and identifiable mudstone layers. The stratigraphic division of the Garber at the Cimarron Site is summarized below from J.L. Grant and Associates (1989) and described in greater detail in Section 2.3:

- Sandstone A: Uppermost sandstone unit, generally red-brown to tan in color and up to 35 feet in thickness. Bottom of this sandstone unit occurs at an elevation of approximately 950–970 feet amsl (see Figures 2-5, 2-9, 2-10).
- Mudstone A: Red-brown to orange-brown, sometimes tan mudstone and claystone that separates Sandstones A and B. Ranges from 6 to 20 feet thick.
- Sandstone B: Second sandstone unit, similar in color and sedimentary features to Sandstone A. Found at elevations between 925 and 955 feet amsl and is up to 30 feet thick. Found below Mudstone A (see Figures 2-5, 2-9).
- Mudstone B: Mudstone and claystone separating Sandstone B and Sandstone C. Similar in color to Mudstone A and ranges from 6 to 14 feet thick.
- Sandstone C: Lowermost sandstone in the Garber-Wellington Formation. Similar in color and sedimentary features to overlying sandstones. This unit varies in thickness from 10 to 25 feet at the site to at least 100 feet thick regionally.

All three sandstone members of the Garber Formation at the Cimarron Site are basically similar lithologically. They are fine to very fine-grained red-brown to tan sandstones with well-sorted subangular to rounded grains and contain variable amounts of silt (J.L. Grant and Associates, 1989). The silt content ranges from 10 to 50 percent and the sandstones with high silt content are difficult to distinguish from siltstone. The sand grains are mostly quartz with minor amounts of feldspar and occasional magnetite and mica. The intergranular porosity varies with the silt content (J.L. Grant and Associates, 1989). The sandstones are weakly cemented and often friable. Cementing agents are calcite and hematite. Locally,

thin intervals can be found that are well cemented with gypsum and barite. These intervals are often conglomeratic. The sandstones exhibit planar cross-stratification with thin, silty laminae (J.L. Grant and Associates, 1989). Conglomeratic intervals are common in most of the borings and they are observed to contain clasts of mudstone and occasionally sandstone in either a sandstone or mudstone matrix. These conglomeratic zones are up to 2.5 feet thick. Vugs found in these conglomerate zones are lined with calcite, gypsum, and barite (J.L. Grant and Associates, 1989). The sandstones of the Garber Formation were deposited in a fluvial deltaic environment, probably as channel sands.

The mudstone layers that separate the sandstones in the Garber Formation at the Cimarron Site are mostly fine-grained, silty to shaley beds with a red-brown to orange-brown and tan color. The mudstones occasionally exhibit desiccation cracks (J.L. Grant and Associates, 1989). The mudstones are poorly consolidated. The mudstone layers are often encapsulated by thin, bluish-gray laminae that range in thickness from 0.1 to 4.0 inches. These “reduction zones” are common in red beds (J.L Grant and Associates, 1989) and at the site the thickness of these reduction zones is approximately proportional to the thickness of the mudstone layer. These continuous mudstone layers probably represent deltaic overbank deposits formed during flooding of the Garber delta.

A mineralogical analysis of the sandstones and mudstones was conducted by Auburn University using X-ray diffraction, grain-size determinations, and cation exchange capacity measurements (J.L. Grant and Associates, 1989). Quartz and feldspar were found to be the main clastic grains with kaolinite and montmorillonite as the clays in the fine-grained fractions. Illite, smectite, chlorite, hematite, and goethite were also among the minerals detected in the clay fractions according to USGS (Parkhurst et al., 1996). Calcite, iron oxides, and iron hydroxides were identified as the main cementing agents. The clay fraction ranged from 6 to about 20 percent in the sandstones and from about 14 to 50 percent in the mudstones. The mudstones had a cation exchange capacity in the range of 6 to 22 meq/100g. The sandstones had a cation exchange capacity generally below 6 meq/100g. Exchangeable cations were generally calcium and magnesium for both the sandstones and the mudstones. Within the “reduction zones,” minerals formed with metals in low oxidation state, including uranium, were identified (Parkhurst et al., 1996).

The Cimarron River floodplain alluvium consists of sand and silt, developed by the erosion of the Garber Formation from the escarpment bordering the river on the south, as well as material transported to the floodplain from upstream within the river system. This alluvium formed gradually over time and contains many buried channels reflective of both transport of the alluvial materials northward toward the river from the escarpment and meandering of the main river channel. Near the present river channel, buried oxbow meanders can be expected. Near the escarpment, buried channels would be expected to be the continuation of present drainages incised into the escarpment sandstones. The alluvium is about 30 to 40 feet thick. Along the present escarpment face, there are local transition zones from the sandstones of the Garber Formation to the coarser alluvial materials. These transition zones can be clay-rich, as is the case with the transitional zone identified with borings in the BA #1 Area.

2.3 Detailed Stratigraphic Correlations at Cimarron

The Cimarron Site has sufficient borings and monitor wells to allow for generalized stratigraphic correlations within specific areas of the site and across the site. Extensive subsurface investigations were performed in the BA #1 Area, Western Upland Area, and Western Alluvial Area (see Figure 2-3). The following sections present a discussion on detailed stratigraphic correlations of these three areas.

2.3.1 BA #1 Area

The BA #1 Area is located in the northeastern corner of the Cimarron Site and includes an upland area and a portion of the floodplain of the Cimarron River (Figure 2-3). Ground surface elevation of the area ranges from 935 feet amsl within the Cimarron River floodplain to 975 feet amsl in the upland area, with a total relief of 40 feet. A buried escarpment separates the upland from the Quaternary alluvial deposits of the Cimarron River floodplain. Four former disposal trenches are situated in the upland near the escarpment. Figure 2-4 shows the location of the geological cross-section presented in Figure 2-5, as well as the location of the former disposal trenches and the monitor wells in the area. Figure 2-5, the geological cross-section of the BA #1 Area, illustrates the lithology and stratigraphy of the area.

The upland is underlain by the Garber Formation. The sandstone units present in the BA #1 Area are mainly Sandstone B and Sandstone C. Sandstone A is eroded from most of the BA #1 Area and was observed to only be approximately 10 feet thick in a borehole (Well 1314) located south of the former disposal trenches. Mudstone A is present in the southern portion of the upland and Sandstone B and Mudstone B appears to be continuous across the upland (Figure 2-5).

The uppermost unit of the Garber Formation exposed in the BA #1 Area is Mudstone A, which is a 10-foot-thick sequence of mudstone and silty mudstone overlying Sandstone B in the southern portion of this area (Figure 2-5).

Sandstone B in the BA #1 Area consists of up to 25 feet of red-to-tan sandstone and silty sandstone. This unit is exposed along the escarpment where it borders the floodplain alluvial sediments.

Mudstone B underlies Sandstone B and separates Sandstone B from Sandstone C. With the exception of areas under the floodplain alluvial sediments, this unit is continuous throughout the BA #1 Area and is considered to be continuous across the entire site.

Sandstone C is the lowermost stratigraphic unit encountered while drilling in the BA #1 Area. It is a sequence of interlayered sandstones and mudstones and underlies the entire site. This unit forms the bedrock beneath the floodplain alluvium (Figure 2-5).

Alluvial sediments in the Cimarron River floodplain consist of sand, silt, and clay. The relative abundance of each material is dependent on the distance relative to the upland, as seen in Figure 2-5. Clay and silt are the dominant lithologic types in areas adjacent to the upland. Farther away from the upland toward the Cimarron River channel, the proportion of sand increases and sand becomes the predominant lithology. Consequently, the alluvium can roughly be divided into two zones: (1) a transitional zone along the buried escarpment; and (2) a sandy alluvial zone forming the bulk of the floodplain sediments. The transitional zone is adjacent to the escarpment and characterized by massive clay and silt deposits while the sandy alluvial zone is farther away from the escarpment and characterized by massive sands. Clay and silt layers are generally thick in the transitional zone and tend to extend vertically to bedrock. In the sandy alluvial zone, however, the clay and silt layers are relatively thin and occur near the ground surface above the sand layer. In addition, the transitional zone mostly overlies Sandstone B or Mudstone B whereas the sandy alluvial zone largely overlies Sandstone C. The approximate division between the two zones appears along the line connecting wells 02W03 and 02W13 where an abrupt change in lithology occurs (Figure 2-4). On this figure, the transitional zone boundary is shown as a solid line on the northeast flank of the upland. The thickness of the alluvium increases from a few feet near the escarpment to 30 feet near the river channel.

The geological model of the BA #1 Area is depicted in a fence diagram (Figure 2-6) constructed using RockWorks 2004 software (RockWare, Inc., 2004). Fences A, B, C, and D show the transitional zone, and Fences E and F the sandy alluvial zone. Note that, in the eastern parts of Fences A and B (transitional zone), there exists a localized body of massive clay and silt. Sand pockets, lenses, and thin layers present between the upland and the clay/silt body may form small preferential pathways and conduits for groundwater entering the alluvium from the former disposal trench area, as indicated by the orange-colored line in Figure 2-6. To the north, these pathways are largely blocked by a clay barrier that lies across the sand channel in the area between TMW-9 and TMW-5 (Fence C). Due to a significant reduction in the thickness of the sand layers, this clay barrier may restrict groundwater flow to the sandy alluvium from the clay-rich transitional sediments. The sand channel ends near Fence D, beyond which there are no significant geological heterogeneities that modify the groundwater movement in alluvium towards the Cimarron River.

In Figure 2-7, Image 2-7A illustrates the surface lithology of the BA #1 Area. A sand channel along the northeastern border of the upland can be observed. If the overburden sand and silt layers in Image 2-7A are electronically "removed," a paleochannel is revealed as shown in Image 2-7B. The presence of the massive clay and silt in the transitional zone is suspected to divert groundwater from flowing directly to the north into the sandy alluvium. Instead, it forces the groundwater entering the alluvium to flow along the southeast-northwest channel in the transitional zone. Once past the transitional zone, the groundwater flow is towards the river with little modification from the relatively consistent sands of the alluvium.

2.3.2 Western Upland Area

As shown in Figure 2-8, the Western Upland Area is located near the 1206 Seep; the BA #3 Area; and monitor wells 1351, 1352, 1354, 1355, 1356, 1357, and 1358. The Western Upland Area includes the drainage channel between the former Sanitary Lagoons and the BA #3 Area. Figures 2-9 and 2-10 present profiles and stratigraphy of the Western Upland Area (i.e., Seep 1206 and the surrounding areas). Locations of the geological cross-section are shown in Figure 2-8. All three sandstone units (Sandstones A, B, and C) and the two mudstone units (Mudstones A and B) are present in this area. The lithologies of sandstone and mudstone are similar to those described for the BA #1 Area.

The geology of the Western Upland Area is dominated by Sandstone A (Figure 2-9). Sandstone A is 20 to 30 feet thick in this area and is underlain by an approximately 20- to 25-foot-thick section of Mudstone A. Around the upgradient monitor well 1350, a shale layer about 20 feet in thickness occupies the upper part of Sandstone A. Near the BA #3 Area, this shale has been replaced by silty sandstone about 10 feet thick. Beneath the shale and silty sandstone layers, Sandstone A is a thick section of mostly sandstone down to the contact with Mudstone A.

In the area of the 1206 Seep, Sandstone A has no shale or silty zones near the top and is about 20 feet thick. The top of Mudstone A is at an elevation of approximately 968 feet amsl (Figure 2-10). Historically, samples designated as being collected from the 1206 Seep were in fact collected from a pool of accumulated surface water near the escarpment. The Seep 1206 sampling location is identified in Figure 2-3, and can be seen in Figure 2-10.

The stratigraphic correlations of the western half of the Cimarron Site are depicted in a fence diagram in Figure 2-11. In this diagram, fences A, B, and C represent the Well 1319 Area, Seep 1206 Area/U-Pond #1 Area, and the U-Pond #2 Area, respectively. This fence diagram was generated utilizing computer geologic modeling software RockWorks 2004 (RockWare, Inc., 2004). Unlike the BA #1 Area, Sandstone A in the western part of the Cimarron Site is ubiquitous across the upland area.

2.3.3 Western Alluvial Area

The Western Alluvial Area is located in the alluvial floodplain to the north of the upland area near the former BA #3 Area, the 1206 Seep Area, and the area of the former Sanitary Lagoons.

Alluvial sediments in the Western Alluvial Area consist predominantly of sand with minor amount of clay and silt. The clay and silt range from 0 to 10 feet thick and occur mostly near the ground surface (Figure 2-9). The alluvium is underlain by Sandstone B near the escarpment and by Mudstone B and Sandstone C closer to the Cimarron River.

Alluvial sediments in the floodplain were deposited on an erosional unconformity over Sandstone B and near the face of the escarpment on Mudstone A. Sand constitutes the bulk of the alluvial sediments in this area.

In addition to the floodplain alluvium, silt and silty sand are also present in a small area located south of wells T-62 and T-64 and is situated in the drainage way of 1206 Seep near the escarpment. These sediments are underlain by Sandstone A or Mudstone A. The thickness of unconsolidated soils varies from 2 ft at higher elevation to about 14 ft at the escarpment. Groundwater in this area is shallow (about 6 ft below ground surface) and appears to be originated from seeps discharged to the drainage way.

2.4 Summary

The regional geology of the Cimarron area and the site-wide stratigraphic correlations for the project area can be combined into a general geological model for the Cimarron Site. The site consists of Permian-age sandstones and mudstones of the Garber-Wellington Formation of central Oklahoma overlain by soil in the upland areas and Quaternary alluvial sediments in the floodplains and valleys of incised streams. The Garber sandstones dip gently to the west and are overlain to the west of the Cimarron Site by the Hennessey Group. The Wellington Formation shales are found beneath the Garber sandstones at a depth of approximately 200 feet below ground surface in the project area.

The Garber Formation at the project site is a fluvial deltaic sedimentary sequence consisting of channel sandstones and overbank mudstones. The channel sandstones are generally fine-grained, exhibit cross-stratification, and locally have conglomeratic zones up to a few feet thick. The sandstones are weakly cemented with calcite, iron oxides, and hydroxides. The silt content of the sandstones is variable and clays within the fine fraction are generally kaolinite or montmorillonite. The mudstones are clay-rich and exhibit desiccation cracks and oxidation typical of overbank deposits. Some of the mudstones are continuous enough at the Cimarron Site to allow for separation of the sandstones into three main units, designated (from top to bottom) as Sandstones A, B, and C. Correlation of these three sandstone units is based primarily on elevation and the presence of a thick mudstone unit at the base of Sandstones A and B that can be correlated between borings. Within each sandstone unit, there are frequent mudstone layers that are discontinuous and not correlative across the project area.

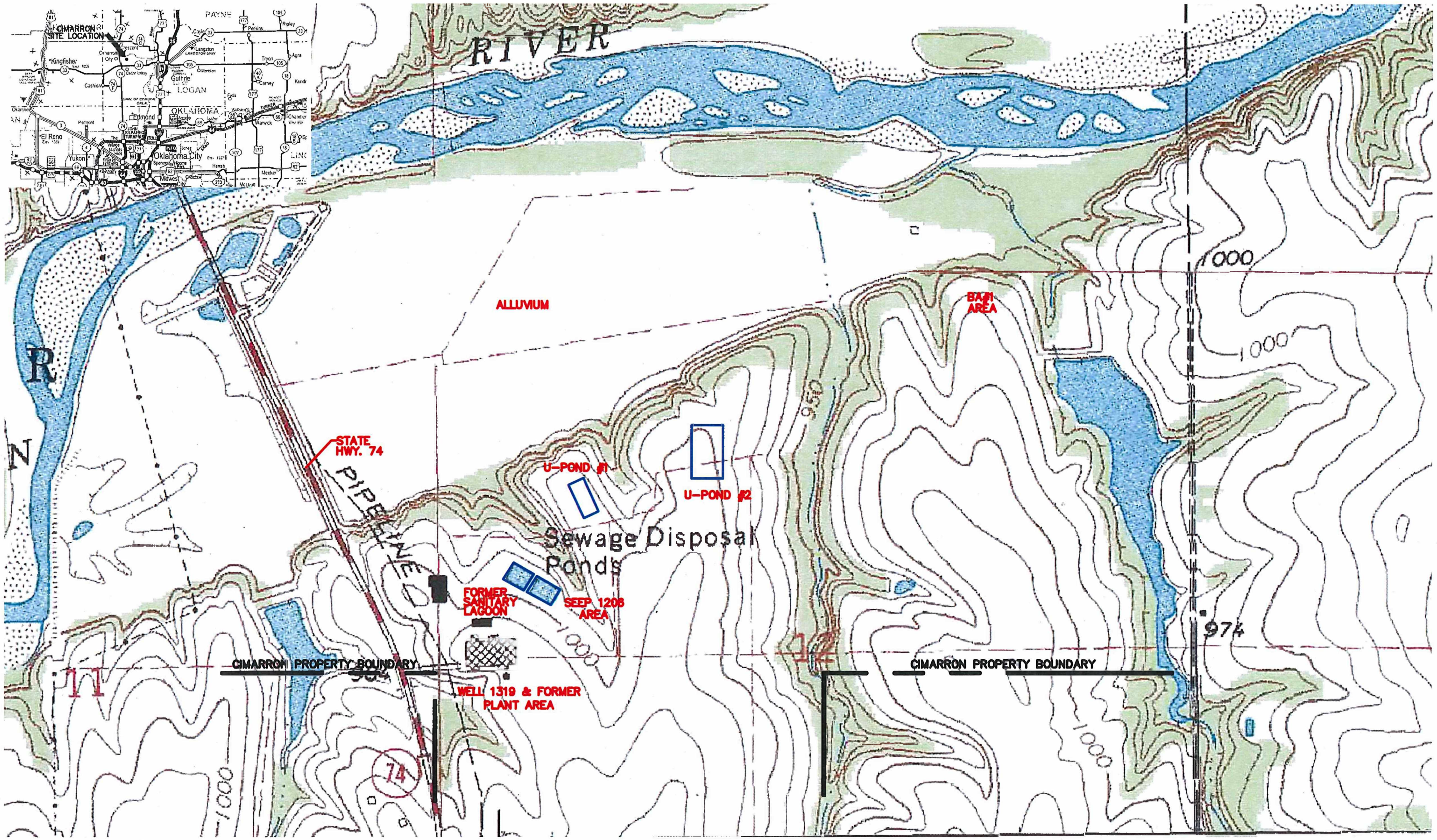
The Cimarron Site is located on part of an upland or topographic high between Cottonwood Creek and the Cimarron River. The project site is dissected by shallow, incised drainages that drain northward toward the Cimarron River. Groundwater base flow and surface water runoff during storms have been ponded in two reservoirs (Reservoirs #2 and #3) on the project site. The Cimarron River is a mature river that has incised the Garber Formation, forming escarpments that expose the upper part of the Garber sandstones. Within the Cimarron Site, the Cimarron River has developed a floodplain of unconsolidated sands, silts, and clays that separate the Garber sandstones exposed in an escarpment from the main river channel. Surface drainages within the project site flow toward the Cimarron River.

Geological features of each specific area of the Cimarron Site, from east to west, are highlighted as follows:

- BA #1 Area – The upland is underlain by a sequence of sandstone and mudstone units, namely, from top to bottom, Mudstone A, Sandstone B, Mudstone B, and Sandstone C. The alluvium can be divided into a transitional zone located within the erosional drainage area and an alluvial zone located outside the escarpment line. The transitional zone consists predominantly of clay and silt and overlies Sandstone B or Mudstone B. A paleochannel appears to exist in the transitional zone, which may control the flow of groundwater in the vicinity of the upland in this area. The alluvium consists of mainly sand and overlies Sandstone C and, to a lesser extent, Mudstone B.
- Western Upland Area – The upland area that includes the BA #3 Area, the 1206 Seep Area, and the former Sanitary Lagoons is composed primarily of Sandstone A. Sandstone B is exposed near the base of the drainage between the former Sanitary Lagoons and the BA #3 Area at the mouth of the drainage where it opens into the alluvial floodplain of the Cimarron River. In the vicinity of BA #3 Area and also the former Sanitary Lagoons, the upper part of Sandstone A is composed mostly of siltstone and shale, rather than sandstone. A surface drainage extending through the area is incised into Sandstone A and Mudstone A. The remaining members of the Garber-Wellington Formation are present at depth in the area
- Western Alluvial Area – Alluvial sediments in this area consist of predominantly sand with minor amount of clay and silt. Sandstone B and Mudstone B exist beneath the alluvial sediments near the escarpment and Sandstone C underlies the alluvial sediments farther out in the floodplain.

Table 2-1 Geologic Units Exposed in Southern Logan and Northern Oklahoma Counties, Oklahoma

System and Series	Unit	Maximum Thickness (ft)	Lithology
Quaternary			
Holocene	Alluvium	50	Sand, silt, clay, and thin layers of gravel.
Pleistocene	Terrace deposits	50	Lenticular beds of sand, silt, clay and gravel.
Permian			
Hennessey Group	Bison Formation	95	Mostly reddish-brown shale.
	Salt Plains Formation	200	Reddish-brown blocky shale and orange-brown siltstone.
	Kingman Siltstone	30	Orange-brown to greenish-gray even-bedded siltstone, and some fine-grained sandstone and reddish-brown shale.
	Fairmount Shale	30	Reddish-brown blocky shale; grades into Garber Sandstone at base.
	Garber-Wellington Formation	1,000	Mostly reddish-brown to tan fine-grained alluvial sandstones with interbedded red-brown shales and mudstones and local chert and mudstone conglomerates. Formation consists of fluvial/deltaic sands and overbank clays preserved as mudstone layers. Deltaic sands consist of both channel sands and sheet-flood sands.



REFERENCE: UNITED STATES GEOLOGICAL SURVEY
CRESCENT QUADRANGLE, OKLAHOMA–LOGAN CO.
7.5 MINUTE SERIES (TOPOGRAPHIC), 1970 (PHOTOINSPECTED 1981).

REVISIONS			
NO.:	DESCRIPTION:	DATE:	BY:
1	DESCRIPTION:	4/01/05	JAS
2		6/17/05	

DESIGNED BY:
DRAWN BY: JAS
CHECKED BY: DJF
APPROVED BY: DJF

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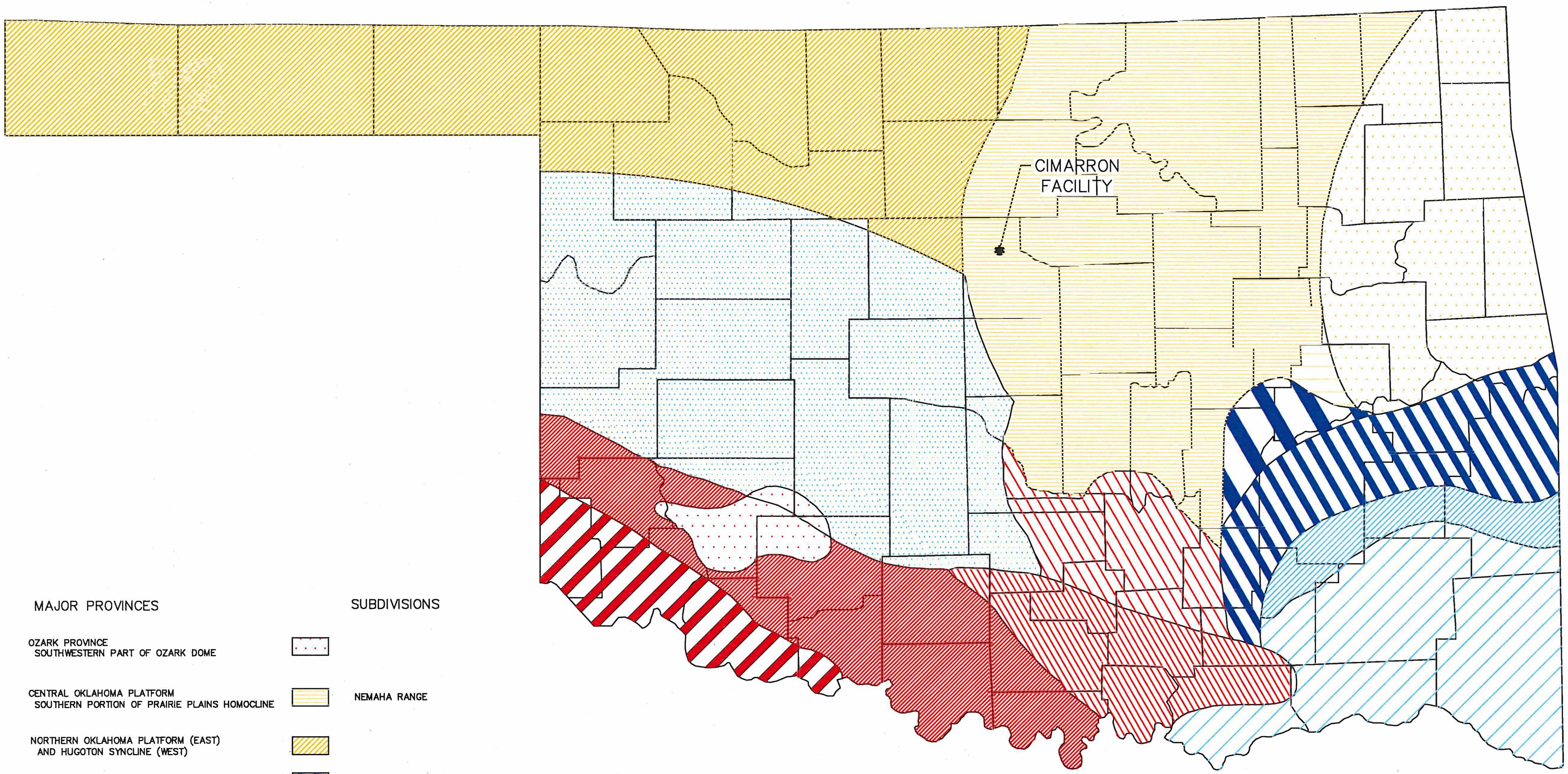
FIGURE 2–1
SITE LOCATION MAP
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

SCALE:	DATE:	PROJECT NUMBER:
1" = 800'	8/10/05	04020-044-200

FIGURE NUMBER: 2–1

SHEET NUMBER: 1



MAJOR PROVINCES | SUBDIVISIONS

MAJOR PROVINCES	SUBDIVISIONS
OZARK PROVINCE SOUTHWESTERN PART OF OZARK DOME	
CENTRAL OKLAHOMA PLATFORM SOUTHERN PORTION OF PRAIRIE PLAINS HOMOCLINE	NEMAHA RANGE
NORTHERN OKLAHOMA PLATFORM (EAST) AND HUGOTON SYNCLINE (WEST)	
MCALESTER–ARKANSAS FOREDEEP	FOLDING AND FAULTING WEAK
	FOLDING AND FAULTING STRONG
OUACHITA SYSTEM OKLAHOMA SALIENT	MARGINAL BELT OF INBRICATE THRUSTING
	CENTRAL FOLD AND THRUST SEGMENT
ANADARKO SYNCLINAL FOREDEEP	
MARIETTA BASIN	
HOLLIS BASIN	
ARDMORE BASIN	
PAUL'S VALLEY UPLIFT	

REFERENCE: OKLAHOMA GEOLOGICAL SURVEY

DESIGNED BY:	REVISIONS			
	NO:	DESCRIPTION:	DATE:	BY:
DRAWN BY: JAS	1		4/01/05	JAS
CHECKED BY: DJF	2		6/17/05	
APPROVED BY: DJF				

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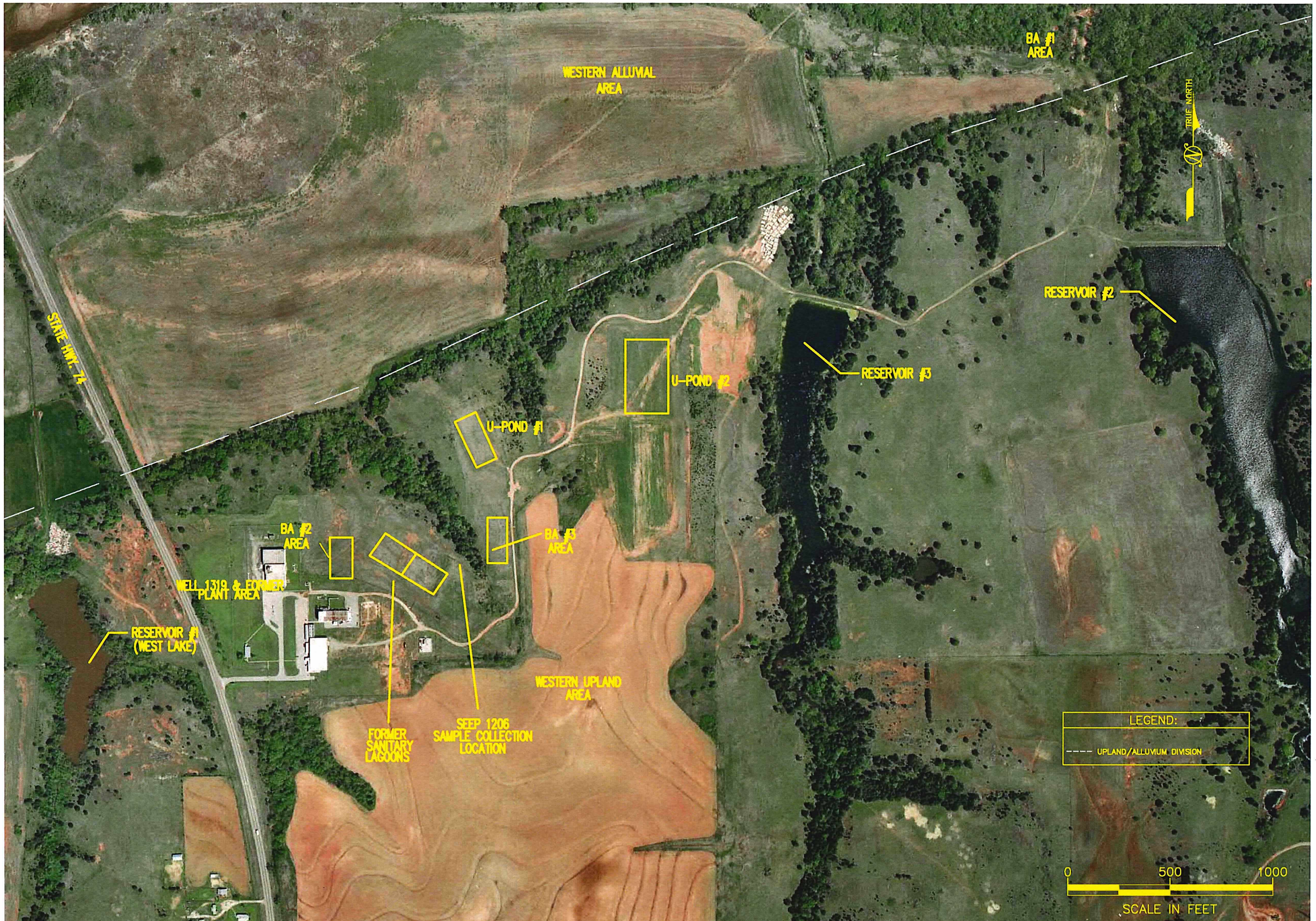
FIGURE 2–2
TECTONIC PROVINCE MAP OF OKLAHOMA
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

SCALE:	DATE: 8/10/05	PROJECT NUMBER: 04020–044–200

FIGURE NUMBER: 2–2

SHEET NUMBER: 1



REVISIONS			
NO.:	DESCRIPTION:	DATE:	BY:
1		4/10/05	
2		6/17/05	

DESIGNED BY:

DRAWN BY: HTP

CHECKED BY: DJF

APPROVED BY: DJF

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FIGURE 2-3
SITE MAP
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

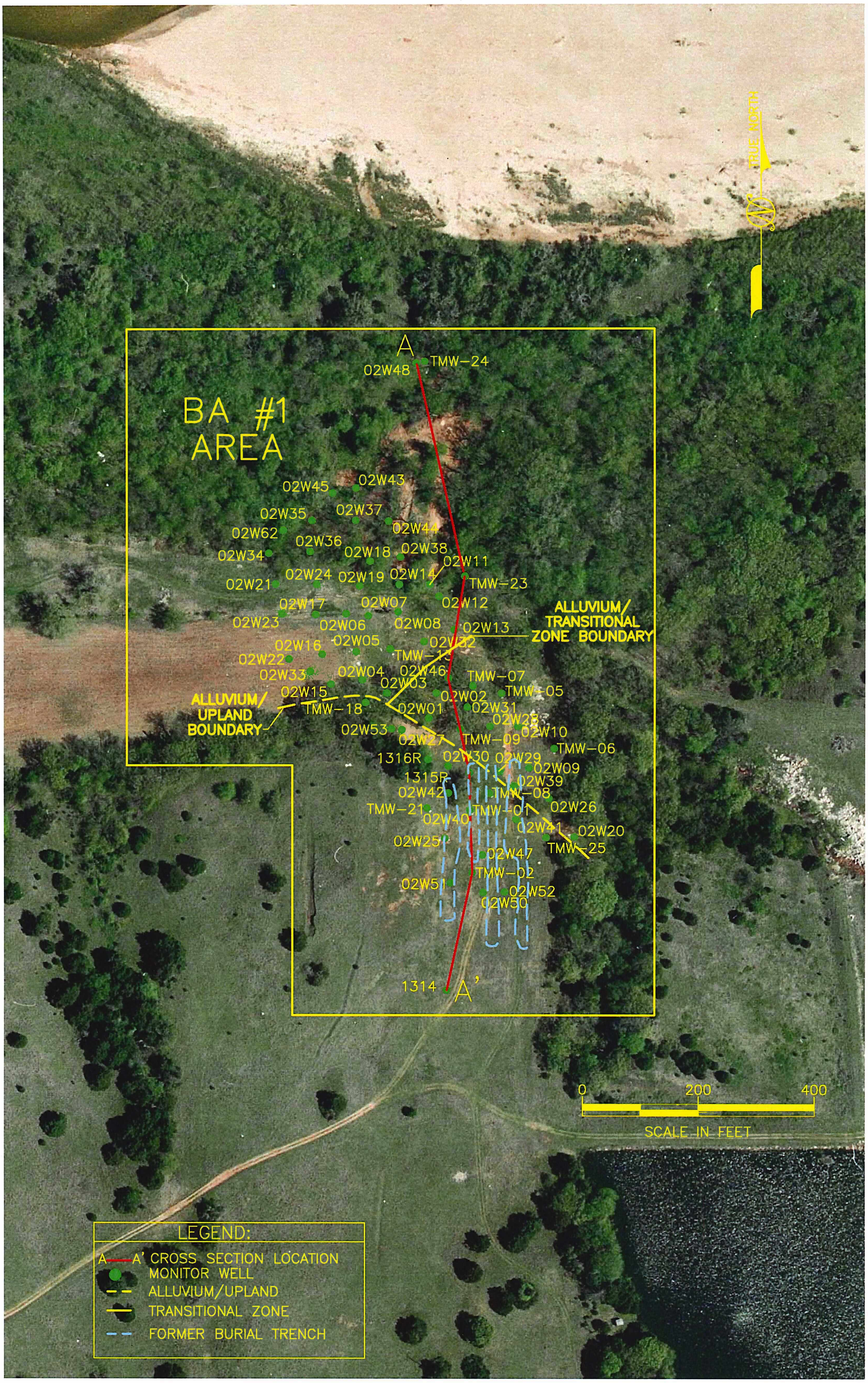
SCALE: 1" = 500'

DATE: 8/10/05

PROJECT NUMBER: 04020-044-200

FIGURE NUMBER: 2-3

SHEET NUMBER: 1



SHEET NUMBER:	FIGURE NUMBER:
1	2-4

FIGURE 2-4
BA #1 AREA
CROSS SECTION LOCATION MAP
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

SCALE:	DATE:	PROJECT NUMBER:
1"= 200'	8/10/05	04020-044-200

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JAS	2		6/17/05	
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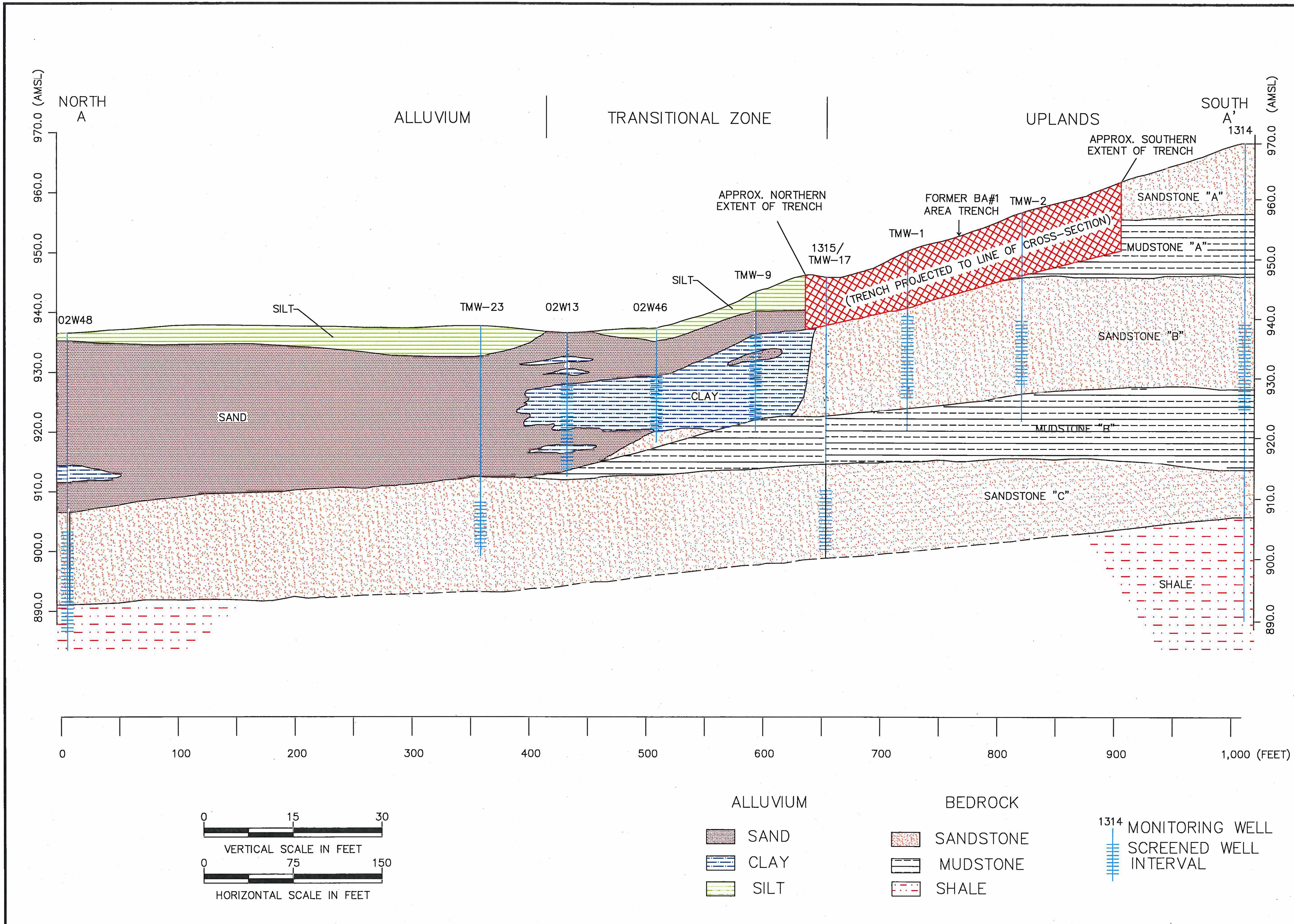
DJF				
APPROVED BY:				
DJF				



NO.:	DESCRIPTION:	DATE:	BY:
1		4/01/05	JAS
2		6/17/05	

REVISIONS

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FIGURE 2-5
BA #1 AREA
GEOLOGICAL CROSS-SECTION A-A'
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

SCALE: 1" = 75'
DATE: 8/10/05
PROJECT NUMBER: 04020-044-200

FIGURE NUMBER: 2-5

SHEET NUMBER: 1