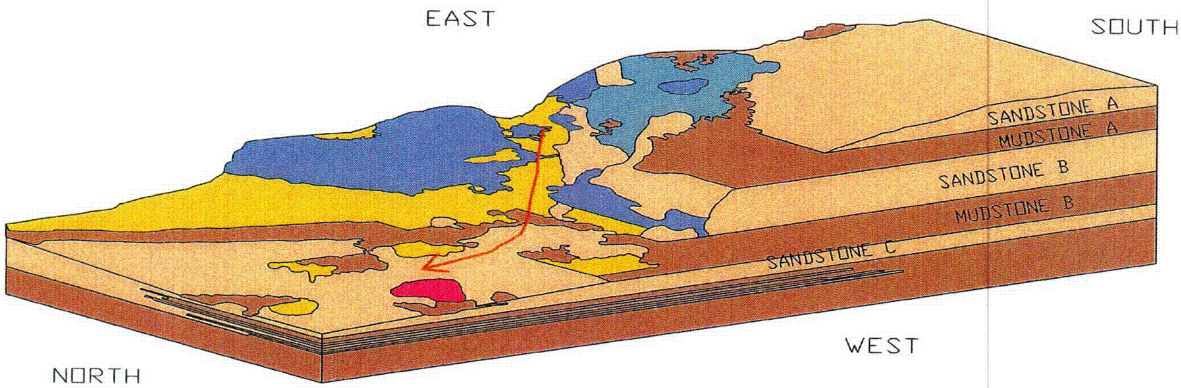
Refined Conceptual Site Model

Cimarron Site – Crescent, Oklahoma

August 2005



Pictorial Representation of Site Model – Burial Area # 1

Prepared for:

Cimarron Corporation
Crescent, Oklahoma

Prepared by:

ENSR INTERNATIONAL
ENSR Corporation
Houston, Texas

ENSR Report No. 04020-044, CSM

C02

TABLE OF CONTENTS

TABLE OF CONTENTS, Continued

TABLE OF CONTENTS, Continued

APPENDICES

LIST OF TABLES

LIST OF FIGURES

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 fuel rod 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 refined and revised throughout the site investigation process to incorporate additional site data.

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 nine principal characterization documents were integral in the development of the prior CSM that has been 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.

A brief synopsis of each of these nine 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.

1.3 Purpose

The purpose of this refined 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 refined 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 refined 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 refined CSM report. The following is a summary of these technical considerations, agreements, and understandings:

- For the purposes of this refined 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 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 refined 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 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 is at least 100 feet thick.

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. 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.

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 geological features that influence the groundwater movement in alluvium.

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 southwest-northeast channel in the transitional zone. Once past the transitional zone, the relatively consistent sands of the alluvium would exert little influence on groundwater flow.

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.

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:

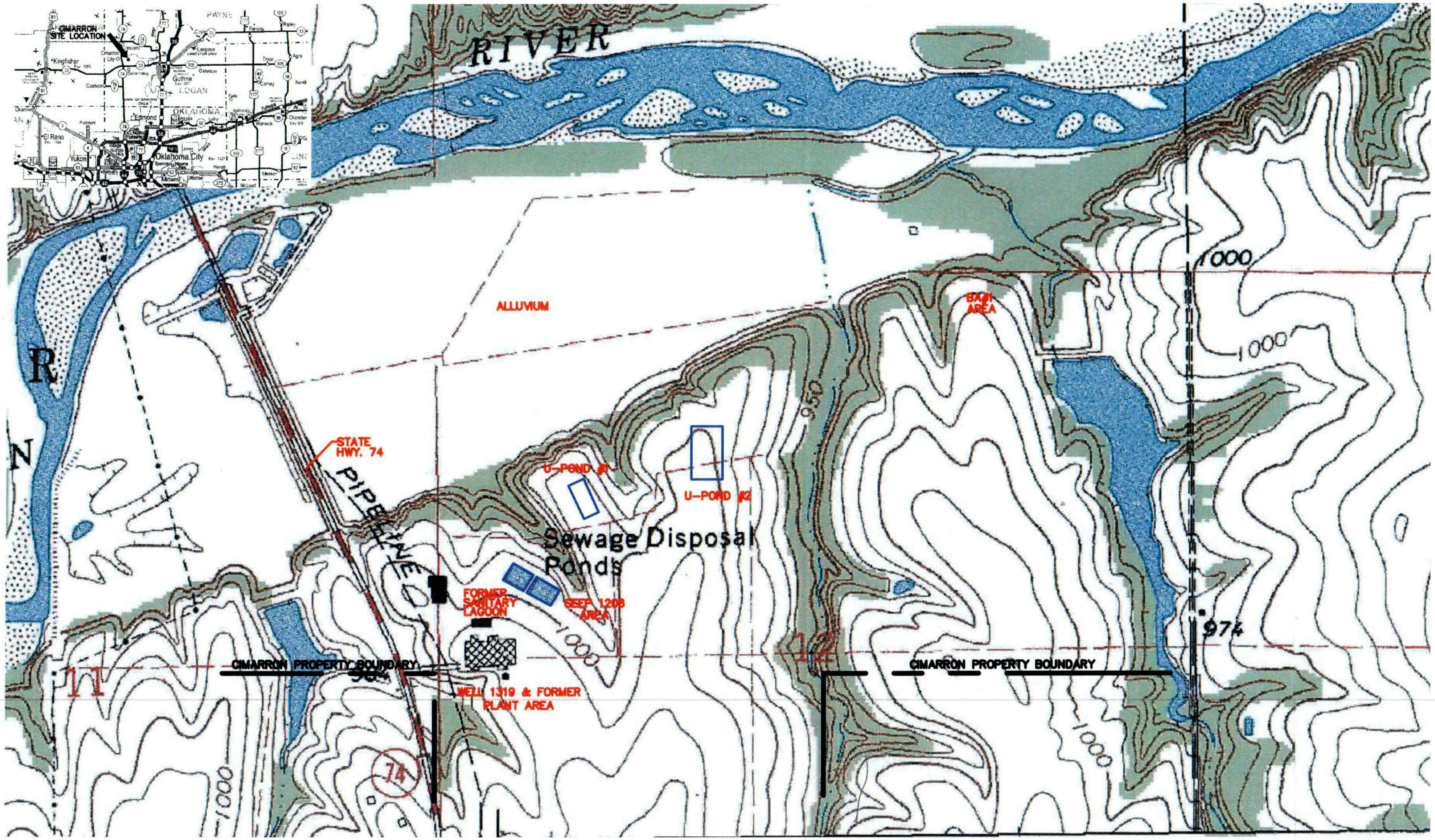
- **BA #1 Area** – The upland is underlain by a sequence of sandstone and mudstone units, namely, from top to bottom, Mudstone A, Sandstone B, Mudstone B, and Sandstone C. The alluvium can be divided into a transitional zone located within the erosional drainage area and an alluvial zone located outside 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.



0 800 1600

SCALE IN FEET

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

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

ENSR INTERNATIONAL
4888 LOOP CENTRAL DR. SUITE 600
HOUSTON, TEXAS 77081
PHONE: (713) 520-9900
FAX: (713) 520-6802
WEB: HTTP://WWW.ENSR.COM

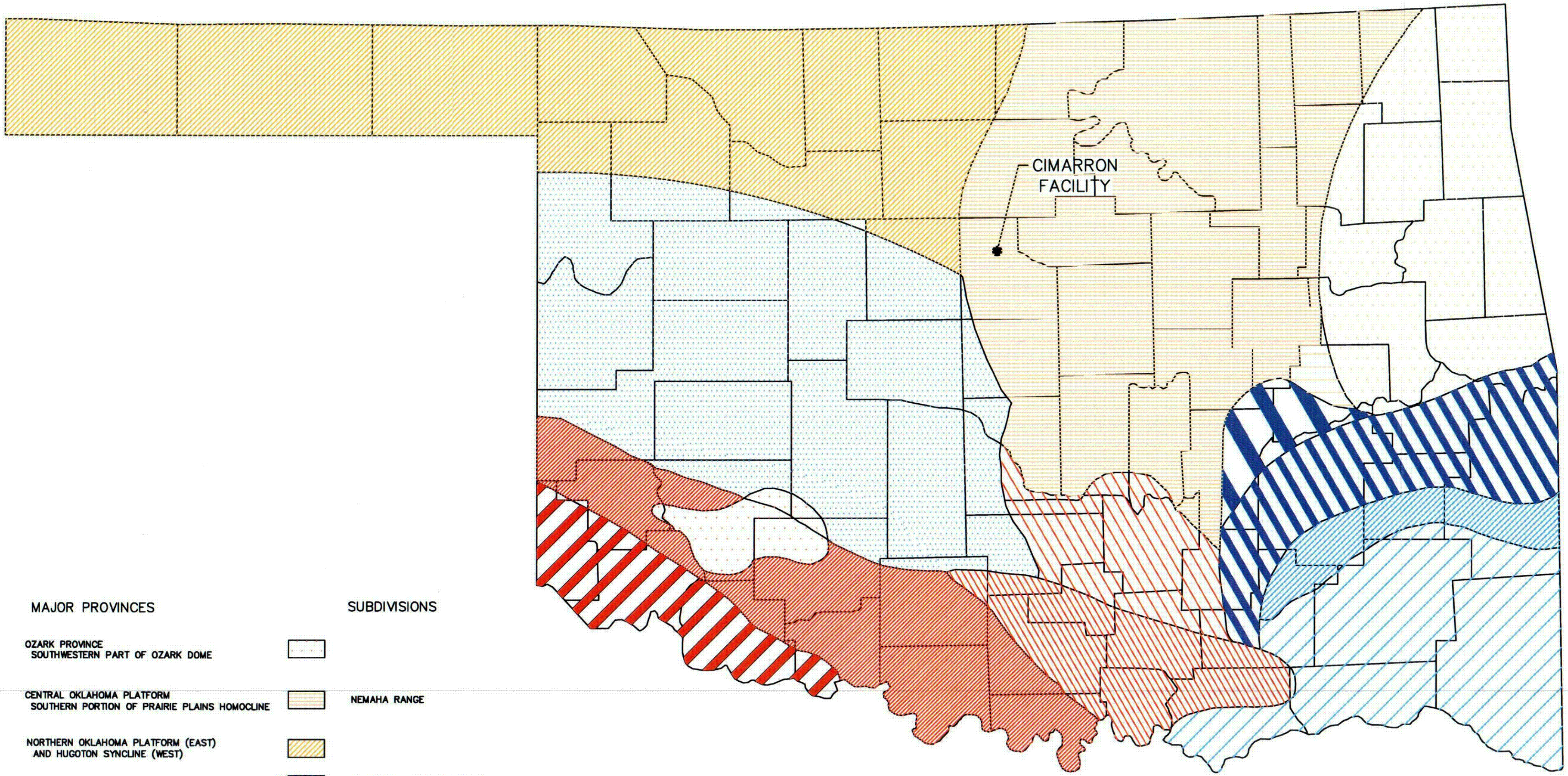
FIGURE 2-1
SITE LOCATION MAP
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

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

FIGURE NUMBER: 2-1

SHEET NUMBER: 1

C03



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

REVISIONS

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

ENSR
INTERNATIONAL
4888 LOOP CENTRAL DR. SUITE 600
HOUSTON, TEXAS 77081
PHONE: (713) 520-9900
FAX: (713) 520-6802
WEB: HTTP://WWW.ENSR.COM

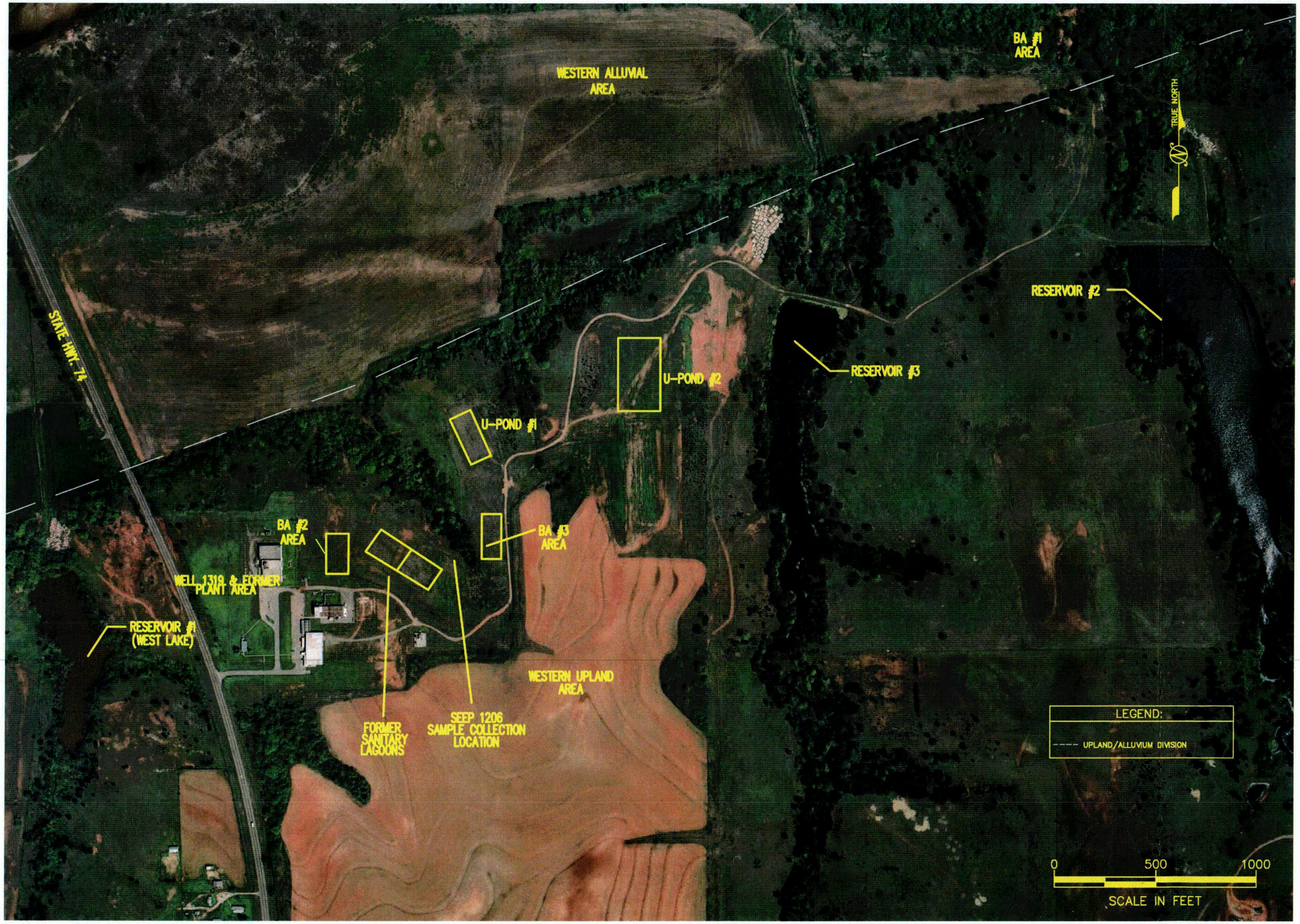
FIGURE 2-2
TECTONIC PROVINCE MAP OF OKLAHOMA
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

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

FIGURE NUMBER: 2-2

SHEET NUMBER: 1

C04



DESIGNED BY:	REVISIONS			
DRAWN BY: HTP	NO.:	DESCRIPTION:	DATE:	BY:
CHECKED BY: DJF	1		4/10/05	
APPROVED BY: DJF	2		6/17/05	

ENSR INTERNATIONAL
4888 LOOP CENTRAL DR. SUITE 600
HOUSTON, TEXAS 77081
PHONE: (713) 520-9900
FAX: (713) 520-6802
WEB: HTTP://WWW.ENSR.COM

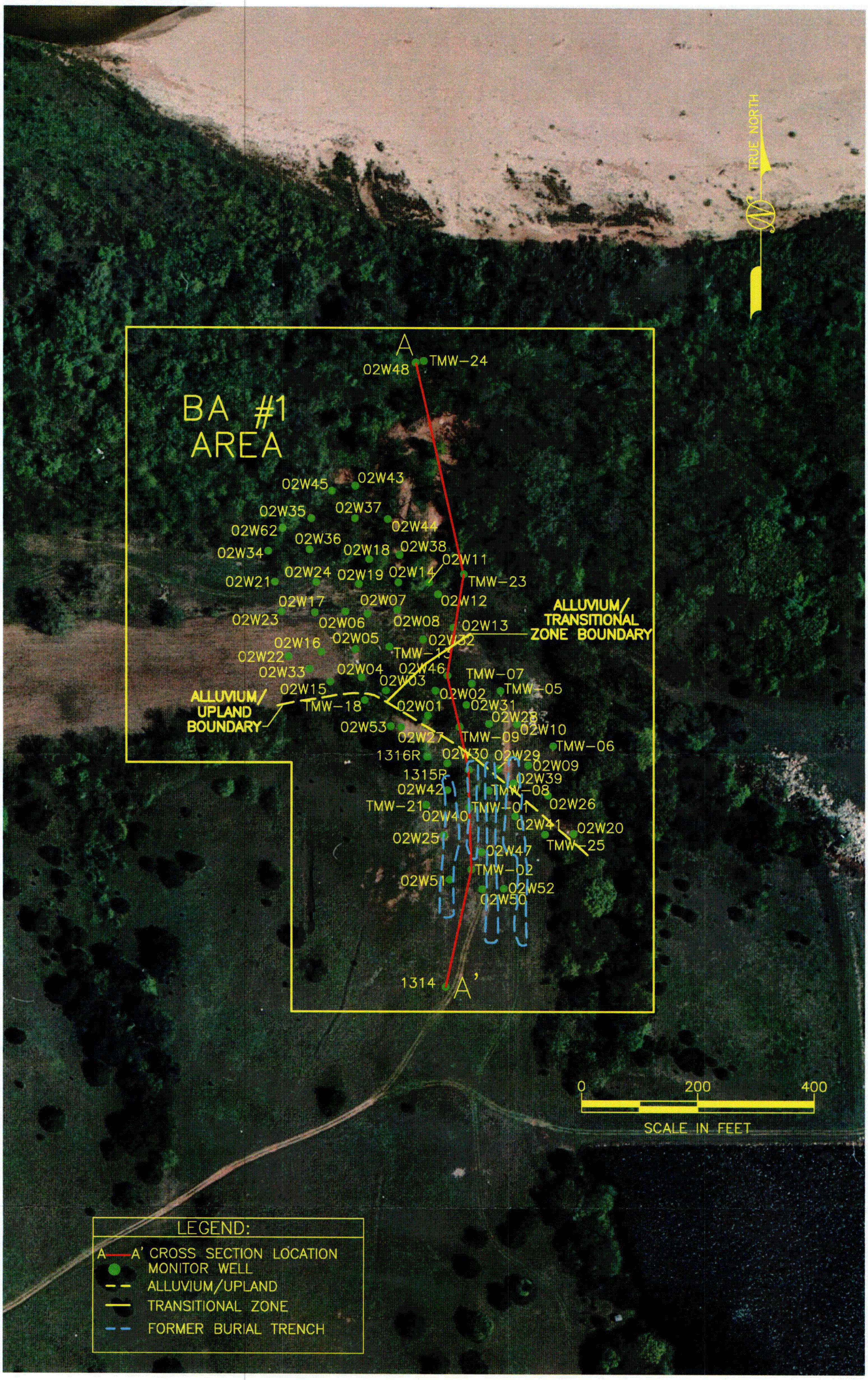
FIGURE 2-3
SITE MAP
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

SCALE:	DATE:	PROJECT NUMBER:
1" = 500'	8/10/05	04020-044-200

FIGURE NUMBER: 2-3

SHEET NUMBER: 1

C05



SHEET NUMBER:	FIGURE NUMBER:
1	2-4

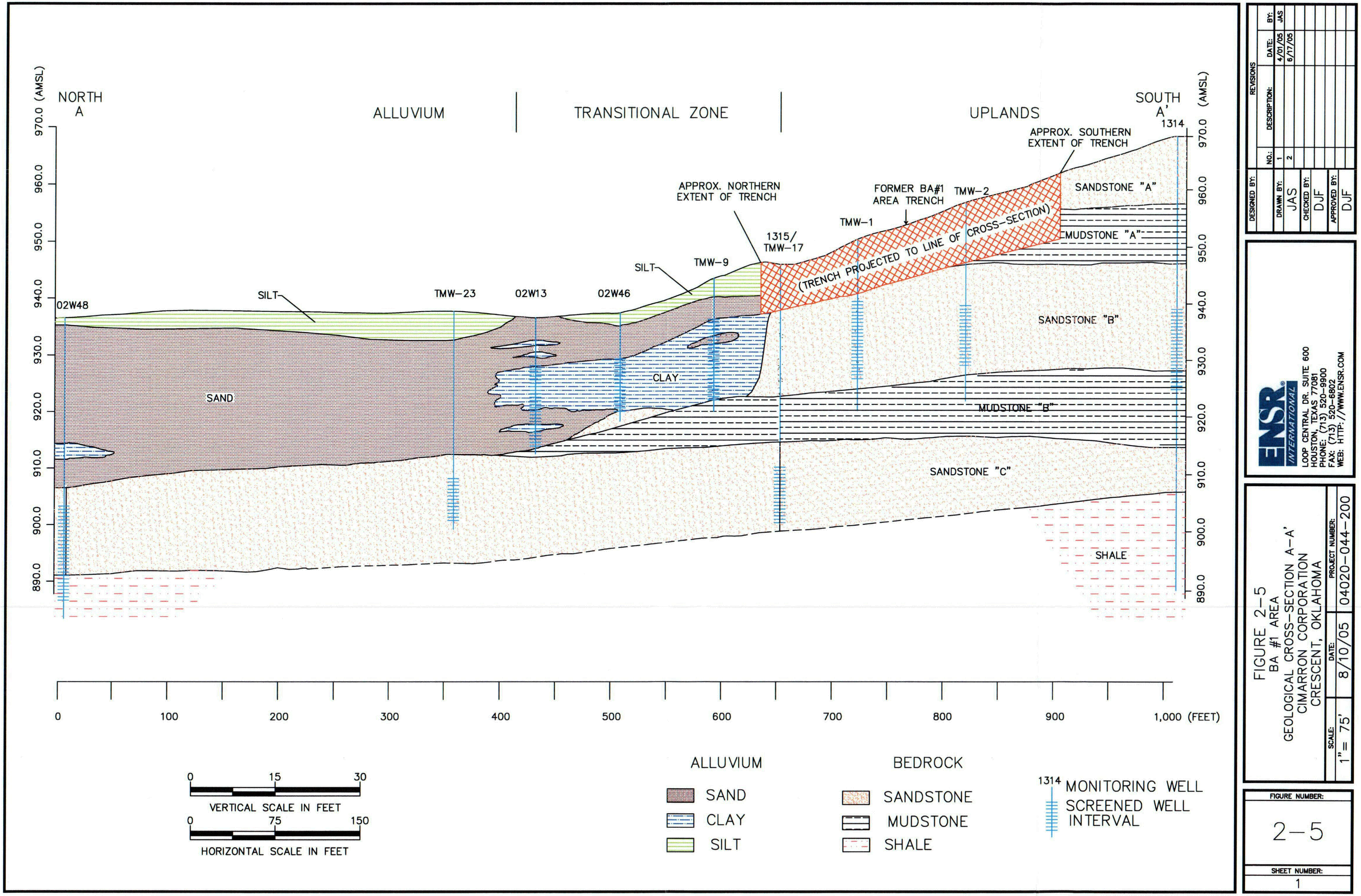
FIGURE 2-4
BA #1 AREA
CROSS SECTION LOCATION MAP
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

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

ENSR INTERNATIONAL
4888 LOOP CENTRAL DR. SUITE 600
HOUSTON, TEXAS 77081
PHONE: (713) 520-9900
FAX: (713) 520-6802
WEB: HTTP://WWW.ENSR.COM

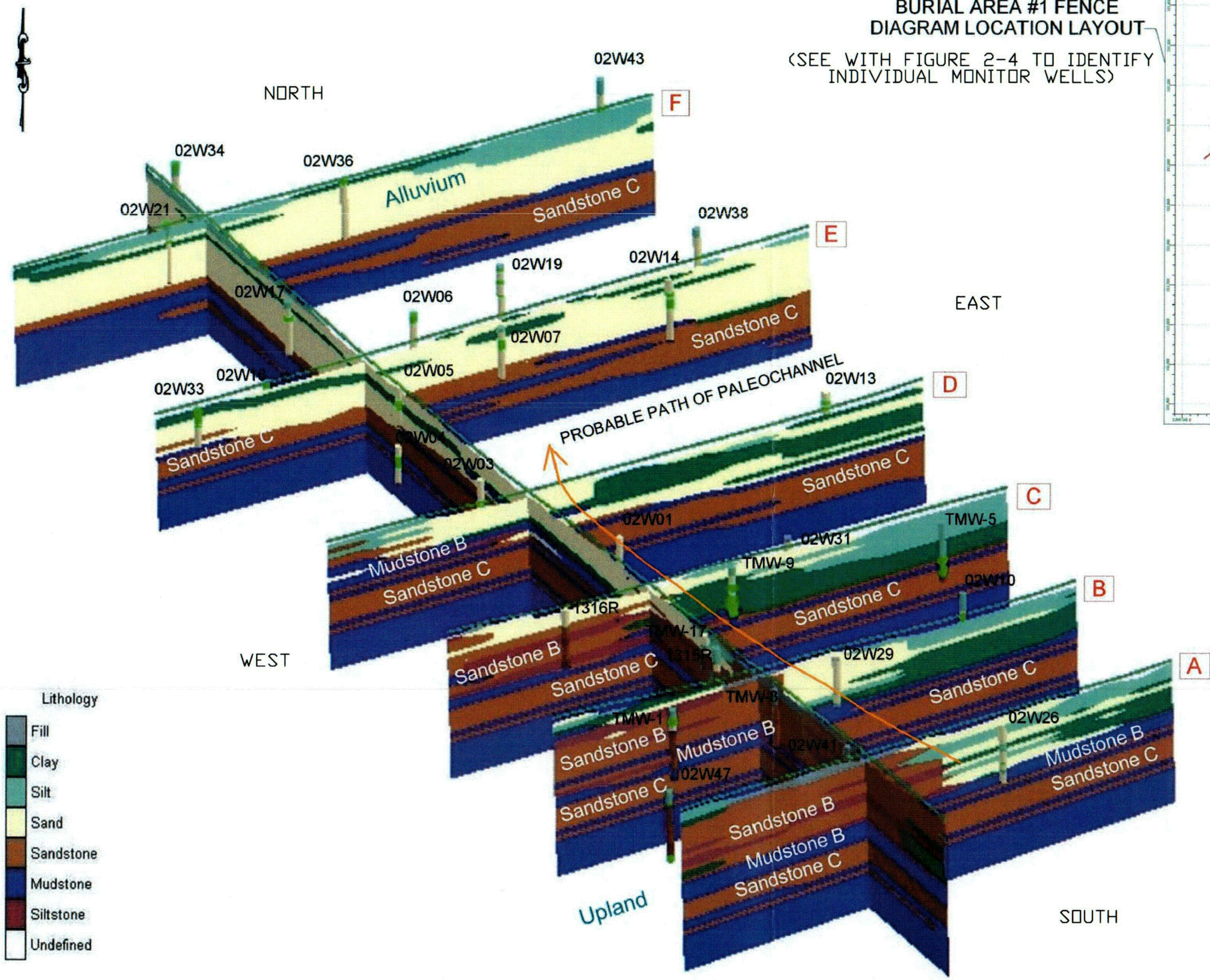
DESIGNED BY:	REVISIONS			
	NO.:	DESCRIPTION:	DATE:	BY:
DRAWN BY:	1		4/01/05	JAS
JAS	2		6/17/05	
CHECKED BY:				
DJF				
APPROVED BY:				
DJF				

C06



NORTH
A
ALLUVIUM
TRANSITIONAL ZONE
UPLANDS
SOUTH
A'
970.0 (AMSL)
960.0
950.0
940.0
930.0
920.0
910.0
900.0
890.0
APPROX. SOUTHERN EXTENT OF TRENCH
APPROX. NORTHERN EXTENT OF TRENCH
FORMER BA#1 AREA TRENCH
(TRENCH PROJECTED TO LINE OF CROSS-SECTION)
1314
TMW-2
TMW-1
1315/ TMW-17
TMW-9
02W46
02W13
TMW-23
02W48
SILT
SAND
CLAY
SANDSTONE "A"
MUDSTONE "A"
SANDSTONE "B"
MUDSTONE "B"
SANDSTONE "C"
SHALE
0
100
200
300
400
500
600
700
800
900
1,000 (FEET)
0 15 30
VERTICAL SCALE IN FEET
0 75 150
HORIZONTAL SCALE IN FEET
ALLUVIUM
SAND
CLAY
SILT
BEDROCK
SANDSTONE
MUDSTONE
SHALE
1314 MONITORING WELL
SCREENED WELL INTERVAL
REVISIONS
NO.: DESCRIPTION: DATE: BY:
1 4/01/05 JAS
2 6/17/05
DESIGNED BY:
DRAWN BY: JAS
CHECKED BY: DJF
APPROVED BY: DJF
ENSR INTERNATIONAL
LOOP CENTRAL DR. SUITE 600
HOUSTON, TEXAS 77081
PHONE: (713) 520-9900
FAX: (713) 520-6802
WEB: HTTP://WWW.ENSR.COM
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

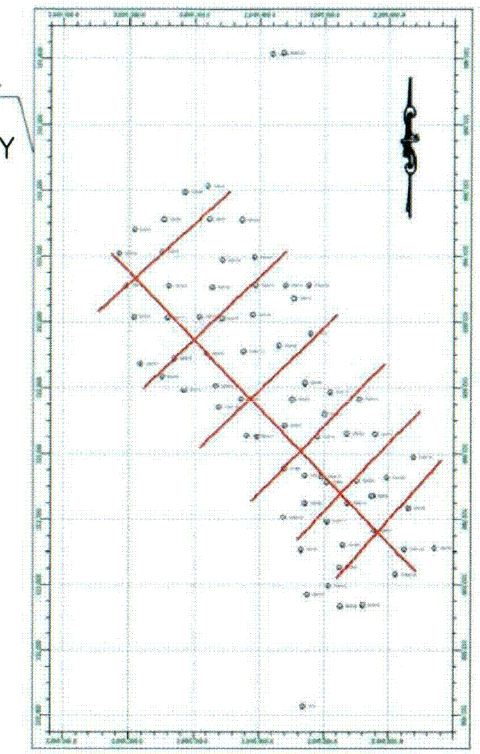
C07



VIEW LOOKING NORTHWARD

BURIAL AREA #1 FENCE DIAGRAM LOCATION LAYOUT

(SEE WITH FIGURE 2-4 TO IDENTIFY INDIVIDUAL MONITOR WELLS)



REFERENCE: ROCKWORKS 2004

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

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

ENSR INTERNATIONAL
4888 LOOP CENTRAL DR. SUITE 600
HOUSTON, TEXAS 77081
PHONE: (713) 520-9900
FAX: (713) 520-6802
WEB: HTTP://WWW.ENSR.COM

FIGURE 2-6
BA #1 AREA FENCE DIAGRAM
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

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

FIGURE NUMBER: 2-6

SHEET NUMBER: 1

C08

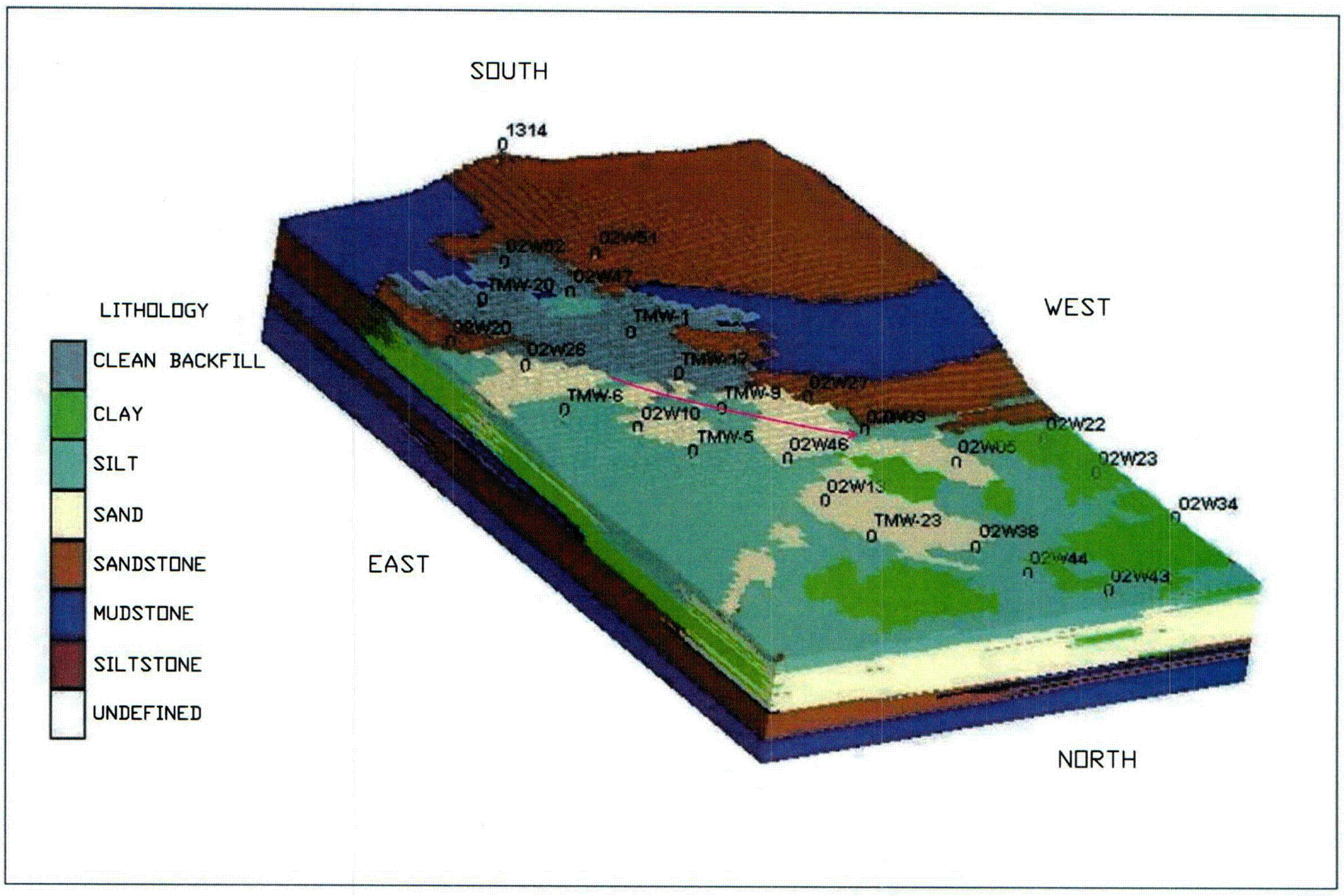


IMAGE 2-7A. Lithologic model of BA #1 Area before overburden sand was 'removed'. View from northeast.

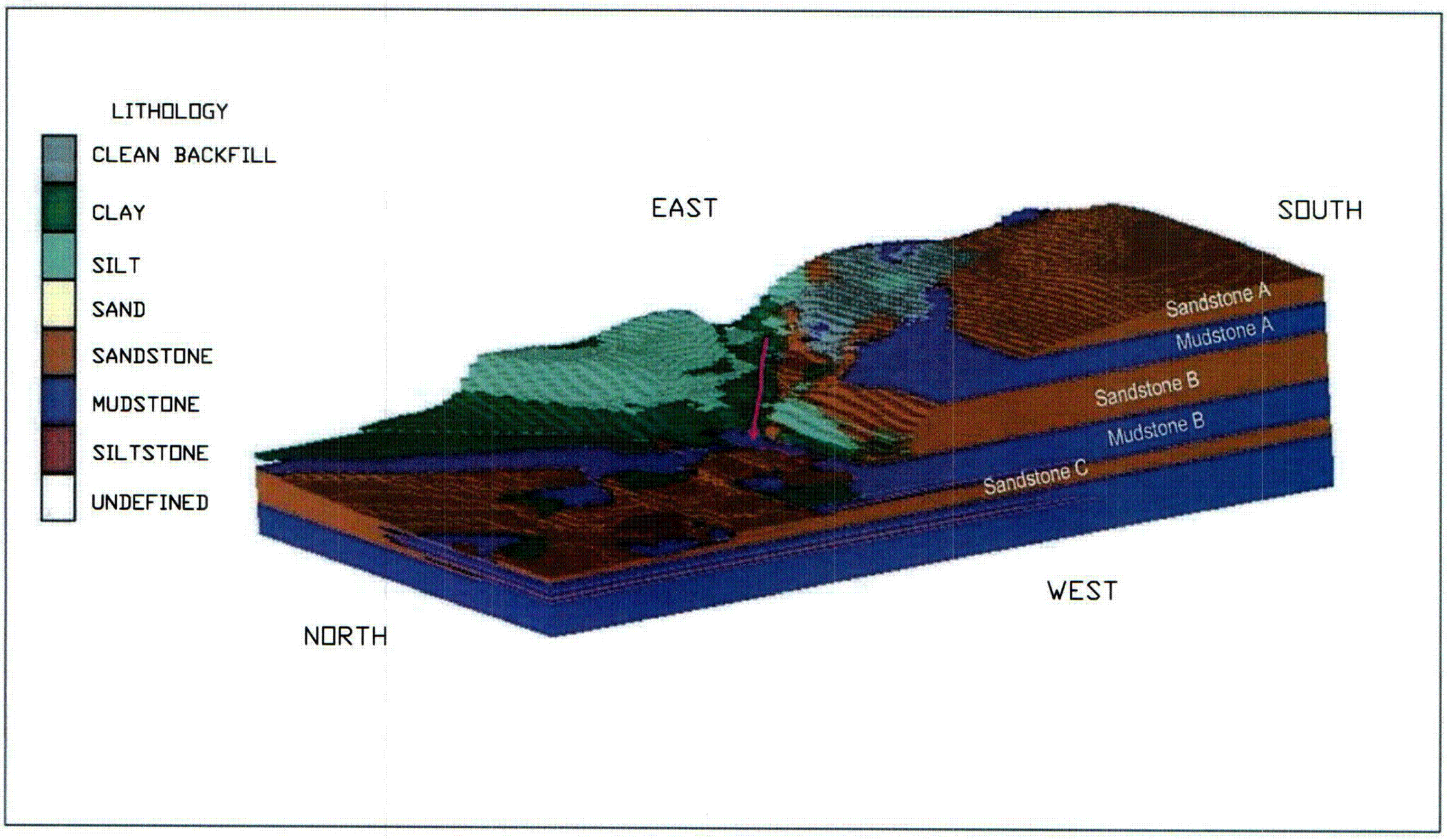


IMAGE 2-7B. Lithologic model of BA #1 Area after overburden sand was 'removed', revealing a paleochannel depicted as a valley in the figure. The curve with arrow head indicates probable path of the channel. View from northwest.

SHEET NUMBER:	FIGURE NUMBER:
1	2-7

FIGURE 2-7
BA #1 AREA PALEOCHANNEL
IN TRANSITIONAL ZONE
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

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

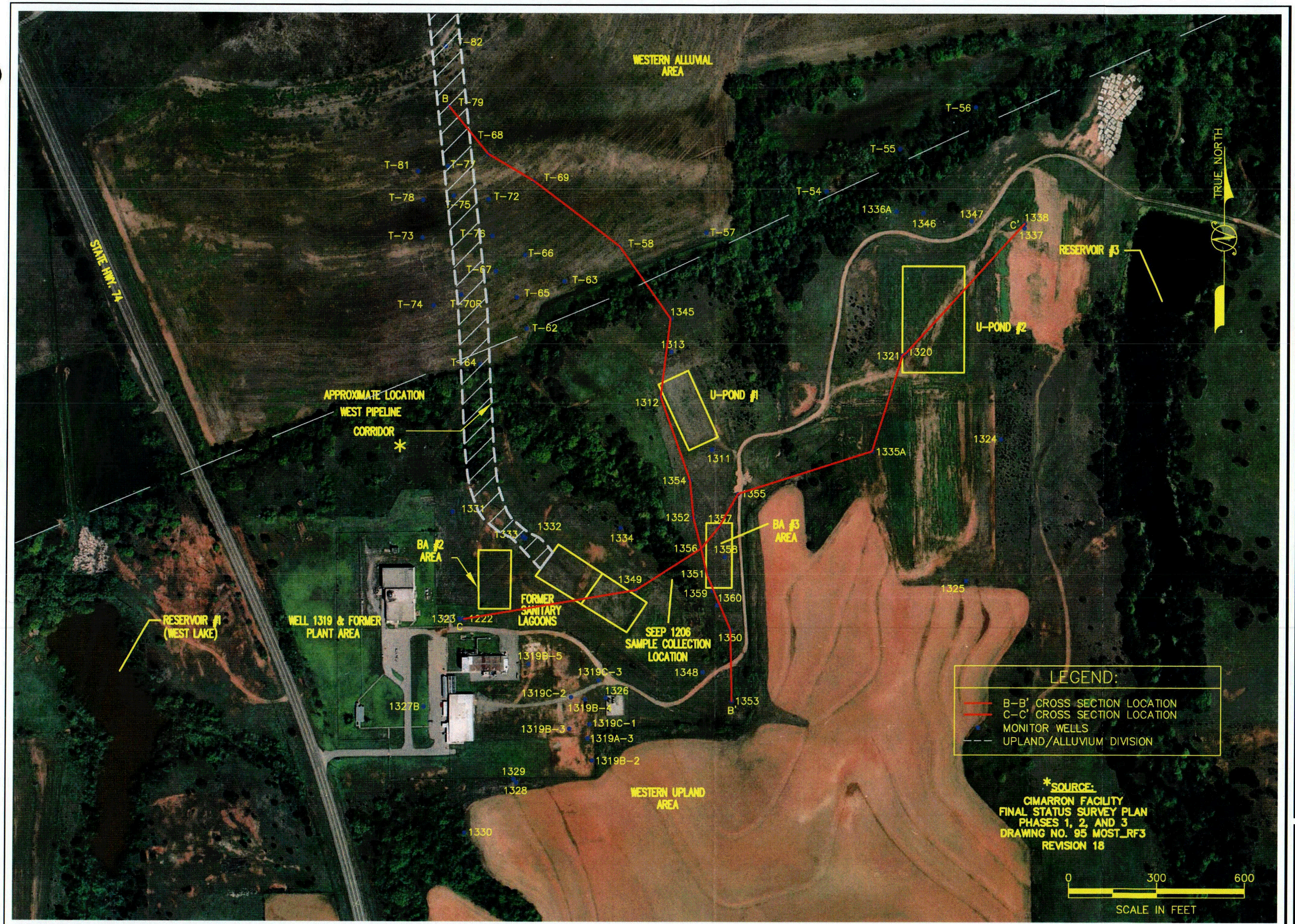
ENSR INTERNATIONAL
4888 LOOP CENTRAL DR. SUITE 600
HOUSTON, TEXAS 77081
PHONE: (713) 520-9900
FAX: (713) 520-6802
WEB: HTTP://WWW.ENSR.COM

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

REVISIONS

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

C09



DESIGNED BY:	REVISIONS			
DRAWN BY: HTP	NO.:	DESCRIPTION:	DATE:	BY:
CHECKED BY: DJF	1		4/10/05	
APPROVED BY: DJF	2		6/17/05	

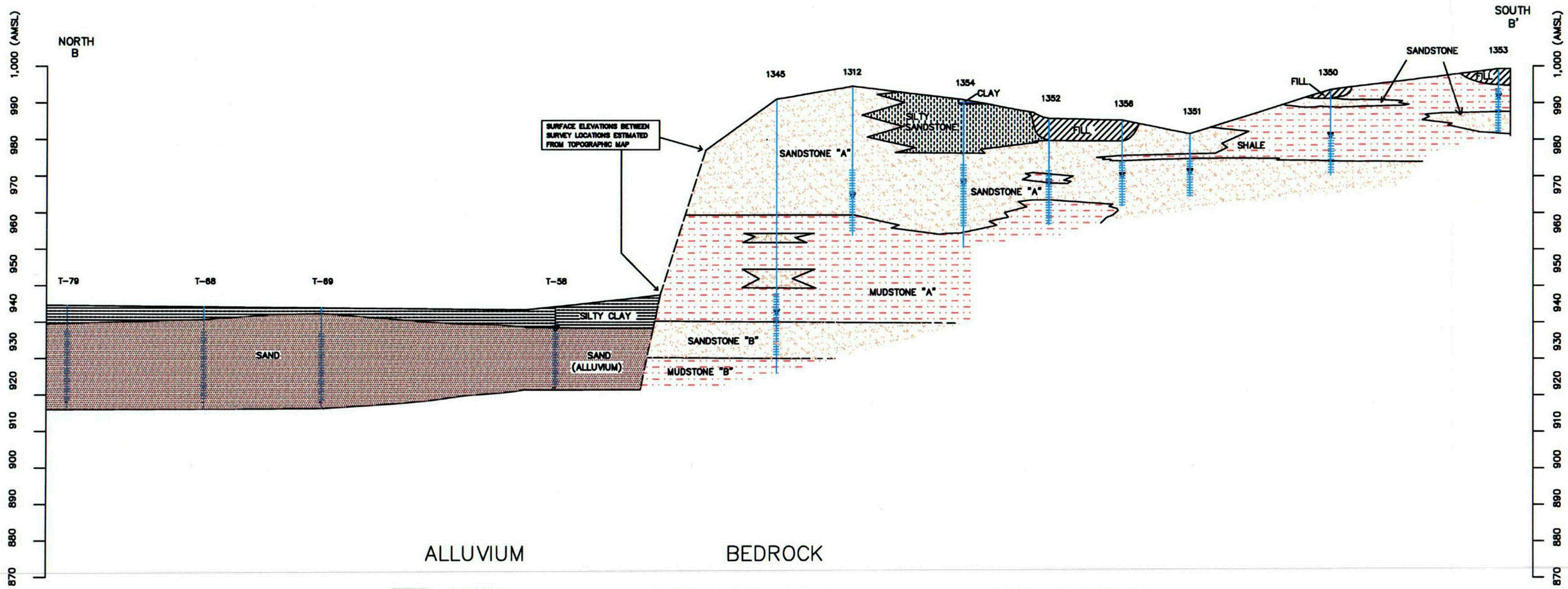
ENSR INTERNATIONAL
4888 LOOP CENTRAL DR. SUITE 600
HOUSTON, TEXAS 77081
PHONE: (713) 520-9900
FAX: (713) 520-6802
WEB: HTTP://WWW.ENSR.COM

FIGURE 2-8
CROSS-SECTION LOCATIONS
FOR WESTERN PORTION OF SITE
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

SCALE:	DATE:	PROJECT NUMBER:
1" = 300'	8/10/05	04020-044-200

FIGURE NUMBER: 2-8

SHEET NUMBER: 1



ALLUVIUM	BEDROCK	
SAND	SANDSTONE	1351 MONITORING WELL
CLAY	MUDSTONE	SCREENED WELL INTERVAL
SILTY CLAY	SILTY SANDSTONE	
	FILL	

0 35 70
VERTICAL SCALE IN FEET

0 200 400
HORIZONTAL SCALE IN FEET

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

REVISIONS

ENSR INTERNATIONAL
4888 LOOP CENTRAL DR. SUITE 600
HOUSTON, TEXAS 77081
PHONE: (713) 520-9900
FAX: (713) 520-6802
WEB: HTTP://WWW.ENSR.COM

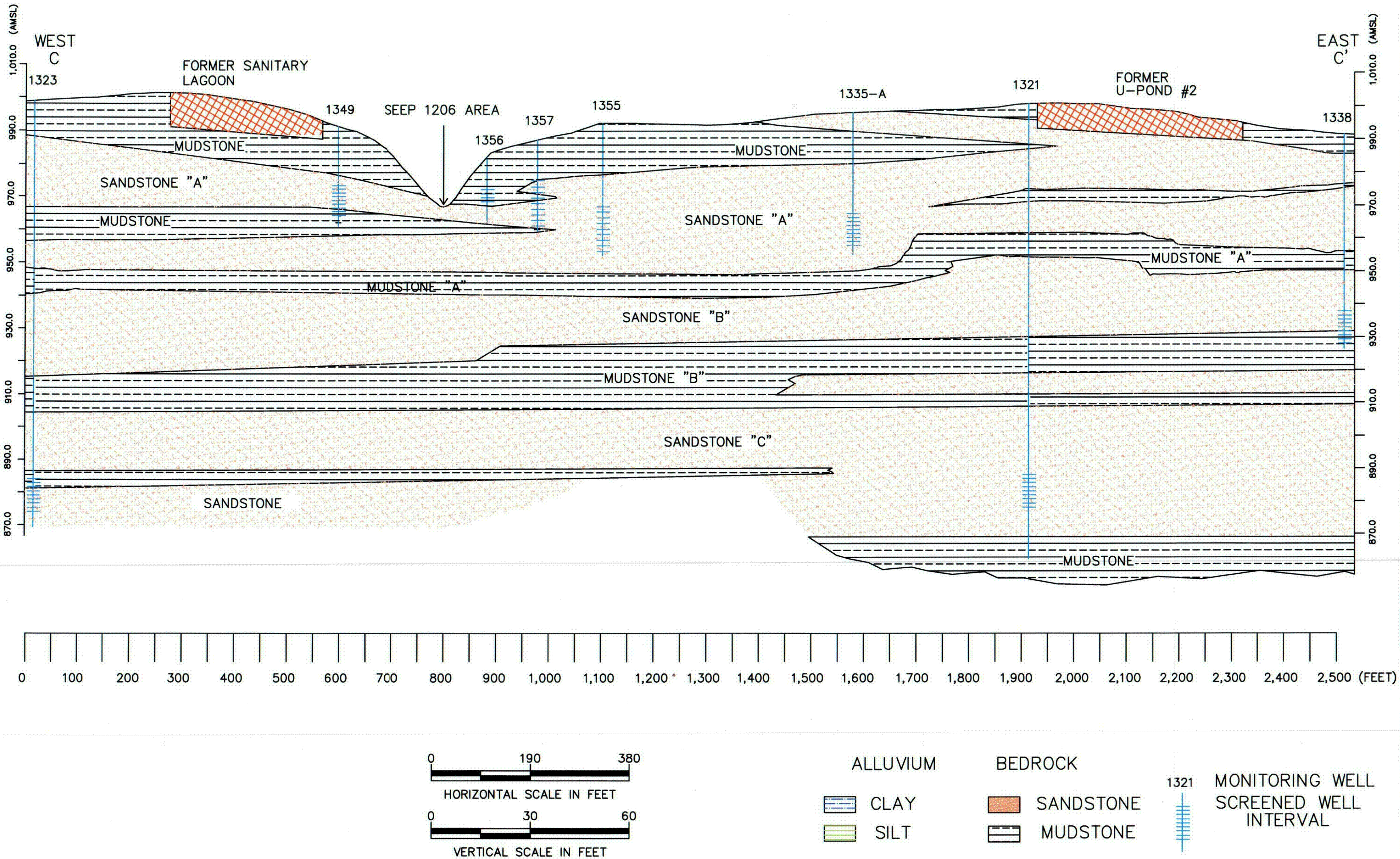
FIGURE 2-9
GEOLOGICAL CROSS SECTION B-B'
WESTERN UPLAND AND ALLUVIAL AREAS
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

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

FIGURE NUMBER: 2-9

SHEET NUMBER: 1

C11



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

DESIGNED BY:

DRAWN BY: JAS

CHECKED BY: DJF

APPROVED BY: DJF

ENSR INTERNATIONAL

4888 LOOP CENTRAL DR. SUITE 600
HOUSTON, TEXAS 77081
PHONE: (713) 520-9900
FAX: (713) 520-6802
WEB: HTTP://WWW.ENSR.COM

FIGURE 2-10
GEOLOGICAL CROSS SECTION C-C'
SANITARY LAGOON TO U-POND #2 AREA
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

SCALE: 1" = 190'

DATE: 8/10/05

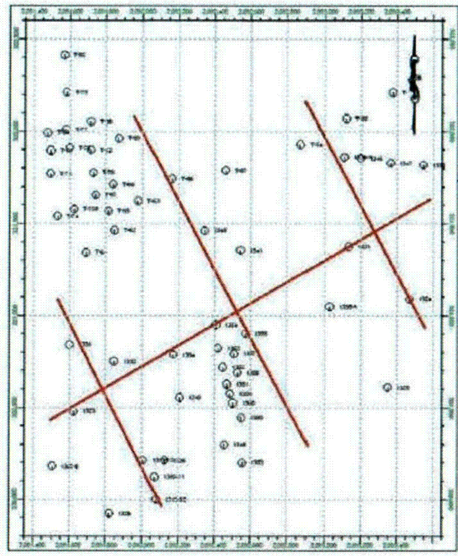
PROJECT NUMBER: 04020-044-200

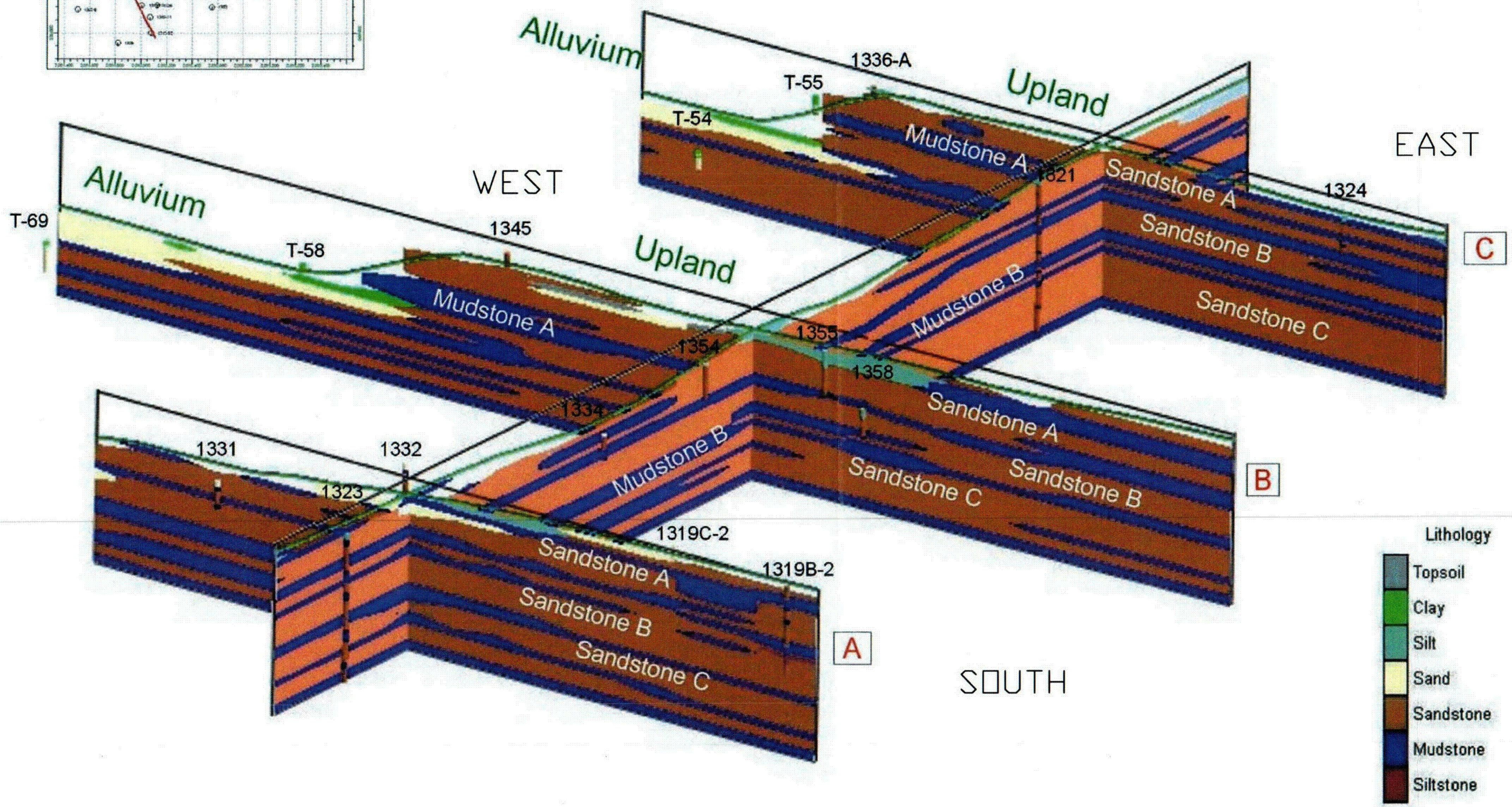
FIGURE NUMBER: 2-10

SHEET NUMBER: 1

C12

WESTERN UPLAND AND ALLUVIUM AREA FENCE DIAGRAM LOCATION LAYOUT (SEE WITH FIGURE 2-8 TO IDENTIFY INDIVIDUAL MONITOR WELLS)





VIEW LOOKING NORTH-NORTHEASTWARD

REFERENCE: ROCKWORKS 2004

DWG. No.

REVISIONS			
NO.	DESCRIPTION	DATE	BY
1		4/01/05	JAS
2		4/05/05	JAS
3		6/17/05	

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

ENSR INTERNATIONAL
4888 LOOP CENTRAL DR. SUITE 600
HOUSTON, TEXAS 77081
PHONE: (713) 520-9900
FAX: (713) 520-6802
WEB: HTTP://WWW.ENSR.COM

FIGURE 2-11
WESTERN UPLAND AND ALLUVIAL AREA FENCE DIAGRAM
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

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

FIGURE NUMBER: 2-11

SHEET NUMBER: 1

C13

3.0 HYDROGEOLOGICAL CONCEPTUAL SITE MODEL

3.1 General Hydrogeology of the Cimarron Area

The following sections describe the climate in the region, the general features of the Cimarron River floodplain, surface water features, and groundwater in the area of the Cimarron Site.

3.1.1 Climate

Adams and Bergman (1995) summarized the precipitation for the Cimarron River from Freedom to Guthrie, Oklahoma. Their study showed that precipitation ranges from an average of 24 inches per year near Freedom, Oklahoma, in the northwest part of the Cimarron River floodplain in Oklahoma, to 32–42 inches per year at Guthrie, Oklahoma. Wet years between 1950 and 1991 were in 1973–1975, 1985–1987, and 1990–1991. The wettest months are May through September, while the winter months are generally the dry months. The period from 1973 to 1975 was 23 inches above normal total for the three-year period (Carr and Marcher, 1977).

Precipitation data collected by the National Oceanic and Atmospheric Administration (NOAA) for Guthrie County, Oklahoma, from 1971 to 2000 indicates that the annual average precipitation is 36.05 inches. The minimum monthly average precipitation is 1.33 inches (January) and the maximum monthly average is 5.48 inches (May).

3.1.2 Cimarron River Floodplain

The Cimarron River and its floodplain, consisting of terrace deposits and alluvial floodplain gravels and sands, is the major hydrologic feature at the Cimarron Site. The Cimarron River heads in Union County, New Mexico. It flows through areas of Colorado, Kansas, and Oklahoma and terminates at the Keystone Reservoir on the Arkansas River. Land along the course of the river is used mainly for farming, ranching, and residential development.

The alluvial gravel and sand deposits are up to 50 feet thick and average about 20 feet thick (Adams and Bergman, 1995). Both are reddish brown in color. Dune deposits (loess) can be found along the north side of the river up to 70 feet high and are the result of strong southerly winds blowing the unconsolidated terrace material. The geology of the Cimarron River floodplain is shown in Figure 3-1. The location of key stream gages is presented in Figure 3-2.

3.1.2.1 River Flow

The Cimarron River is a gaining river over its entire course from Freedom to Guthrie, Oklahoma. In the vicinity of the Cimarron Site and Guthrie, the flow is perennial. Base flow from the alluvial and terrace aquifers and from the Permian sandstone units that border the river is highest in the winter months due to the higher water tables in these aquifers, which result from decreased evapotranspiration. Base flow is lowest from late summer through early winter because water tables are at their low point during that time. Because the Cimarron River is fed mainly by base flow from groundwater aquifers, flow in the Cimarron River parallels this seasonal fluctuation in groundwater levels.

River flow has not been directly measured at the site because there are no stream gages within the Cimarron Site boundary. From 1990 to 2003, the Guthrie gage, located approximately 10 miles east of the site, recorded from 591 to 3,271 cfs average annual flow rates (United States Geological Survey [USGS] water data website).

3.1.2.2 Alluvial and Terrace Groundwater

Groundwater from alluvial and terrace deposits discharges to the Cimarron River throughout most of the river's course through Oklahoma. Estimates for hydraulic parameters from water well tests gave a median hydraulic conductivity of 221 feet/day (0.078 centimeters per second [cm/s]) for the floodplain alluvium and a median of 98 feet/day (0.035 cm/s) for the terrace deposits. Recharge to the alluvial gravels and the terrace deposits along the Cimarron River was estimated at 8 percent of precipitation based on base flow calculations and the assumption of steady-state equilibrium in the gravels and terrace sands (Adams and Bergman, 1995). Water-level fluctuations in water wells with 10 years or more of records averaged about 3 feet on a seasonal basis.

3.1.3 Surface Water Features in the Cimarron Area

Surface water features at the Cimarron Site are shown in Figure 3-3. Besides the Cimarron River, the next major surface water feature is Cottonwood Creek, which is located about seven miles south of the site and flows northeast through Guthrie. Cottonwood Creek, like the Cimarron River, is a gaining stream and drains southern Logan and northern Oklahoma counties. On the north side of the Cimarron River, across from the Cimarron Site, springs can be found at Indian Springs and small lakes are present at Crescent Springs. On the south side of the Cimarron River near the site, Gar Creek on the east and Cox Creek on the west are named drainages that receive most of their flow from groundwater base flow. Most drainages within and near the Cimarron Site are ephemeral in nature and flow only in response to heavy rainfall or groundwater base flow. Within the Cimarron Site, three unnamed drainages have been dammed to form small reservoirs, numbered 1 through 3 as shown in Figure 3-3. Reservoir #1 maintains a surface water elevation of approximately 959.3 feet amsl, Reservoir #2 an elevation of approximately 966.3 feet amsl, and Reservoir #3 an elevation of approximately 959.7 feet amsl (J.L. Grant and Associates, 1989). This placed Reservoirs #1 and #3 below the 1989 groundwater table in the shallow sandstone unit, and Reservoir #2 above the shallow sandstone unit groundwater table. Thus, Reservoir 2 is suspected of acting as a recharge source for groundwater in the eastern part of the site, southeast of the BA #1 Area, while Reservoirs #1 and #3 are groundwater drains that evaporate groundwater at approximately the rate of groundwater influx, on an average annual basis. The pond evaporation rate in this part of central Oklahoma is approximately 60 inches per year.

3.1.4 Groundwater in the Cimarron Area

Groundwater in the Permian-age Garber Formation is found in the Garber Sandstones and the underlying Wellington Formation. Shallow groundwater, defined by Carr and Marcher (1977) as groundwater at depths of 200 feet or less, is generally fresh and mostly unconfined. Groundwater deeper than 200 feet can be artesian to semi-artesian. The base of fresh groundwater at the Cimarron Site is at approximately 950 feet amsl and the thickness of the fresh water zones has been estimated at 150 feet (Carr and Marcher, 1977). Data from the Cimarron Site shows that groundwater in Sandstone C, which is generally more saline than groundwater in Sandstones A and B, is usually at an elevation around 900 to 920 feet amsl. Thus, at the Cimarron Site, the bottom of fresh water is somewhat lower than estimated by Carr and Marcher (1977) for this part of the Garber Formation and, conversely, the thickness of the fresh water zone is somewhat greater. Following Carr and Marcher (1977), the groundwater in Sandstone C at the Cimarron Site, therefore, represents the top of the saline groundwater zone in the Garber Formation.

Recharge to shallow groundwater in the Permian-age Garber Formation near the Cimarron Site has been estimated at 190 acre-feet per square mile, or about 10 percent of annual precipitation (Carr and Marcher, 1977). A regional groundwater high is located south of the Cimarron Site between the Cimarron River and Cottonwood Creek (Carr and Marcher, 1977). The maximum groundwater elevation on this high is around 1,050 feet amsl. Groundwater flows north toward the Cimarron River from this location. Groundwater also flows southward from the high to Cottonwood Creek. The regional northward gradient from the groundwater high to the Cimarron River in the shallow sandstone unit is approximately 0.0021 foot/foot. The gradient to the south to Cottonwood Creek is 0.0067 foot/foot. This groundwater high and the Cimarron Site are within a major recharge area for the Garber Formation.

This suggests that vertical groundwater flow in the area of recharge between Cottonwood Creek and the Cimarron River is downward. At the Cimarron River and at Cottonwood Creek, regional groundwater flow in the fresh water zone of the Garber Formation is vertically upward to allow for discharge at these surface water features, which act as groundwater drains in this part of central Oklahoma (Carr and Marcher, 1977). The nature of vertical groundwater flow in the saline water zone of the Garber Formation at the Cimarron River and at Cottonwood Creek is uncertain.

3.2 Groundwater Flow at the Cimarron Site

General groundwater flow at the Cimarron Site is northward from the groundwater high south of the Cimarron Site toward the Cimarron River. Within the Cimarron Site, groundwater flow varies locally depending on depth within the Garber Formation.

3.2.1 Delineation of Water-bearing Units

Geologically, the Garber Formation Sandstones at the Cimarron Site have been divided into Sandstones A, B, and C, as discussed in Section 2.2 (Stratigraphy of the Cimarron Site) of this report. The Garber and Wellington Formations have been grouped into the Garber-Wellington Formation by Carr and Marcher (1977). At the Cimarron Site, the Garber-Wellington Formation can be further divided into water-bearing units because the mudstone layers that separate the three main sandstone units of the Garber Formation at the site act as semi-confining units. In the upper 200 feet at the Cimarron Site, there are thus four main water-bearing units as follows:

1. Sandstone A;
2. Sandstone B;
3. Sandstone C; and
4. Cimarron River Alluvium.

Each of these four water-bearing units at the Cimarron Site has its own specific flow patterns and hydraulic properties. For Sandstone A, slug tests completed by J.L. Grant and Associates (1989) gave a geometric mean hydraulic conductivity of 1.03×10^{-3} cm/s with a range from 2.41×10^{-4} cm/s to 5.7×10^{-3} cm/s. The geometric mean for transmissivity was 33.4 square feet/day (ft^2/d) with a range from 10.3 ft^2/d to 108 ft^2/d. For the Sandstone C, the geometric mean hydraulic conductivity was 1.27×10^{-4} cm/s with a range from 1.39×10^{-5} cm/s to 7.06×10^{-4} cm/s. The geometric mean transmissivity was 7.96 ft^2/d with a range from 0.67 ft^2/d to 50 ft^2/d.

Aquifer tests in the BA #1 Area (Cimarron Corporation, January 2003) included slug tests on many of the monitor wells and a pumping test using well 02W56 with observation wells at distances from 16 to 107 feet from the pumping well. For Sandstone B, hydraulic conductivity estimates ranged from 5.5×10^{-4} cm/s to 2.39×10^{-5} cm/s. For Sandstone C, one aquifer test yielded a value of 2.85×10^{-5} cm/s for the hydraulic conductivity estimate. For the alluvial sediments of the Cimarron River Floodplain, hydraulic conductivity estimates varied from values in the 10^{-2} cm/s to 10^{-3} cm/s range for the coarser sediments (sandy alluvium) to values in the range of 10^{-4} to 10^{-5} cm/s for sediments high in clays and silts (transitional zone). Because the alluvial sediments have higher clay and silt content near the escarpment where Sandstone B is exposed, the slug tests in the alluvial sediments gave lower hydraulic conductivities nearer the escarpment.

3.2.2 Potentiometric Surfaces

Groundwater flow in each of the four water-bearing units at the Cimarron Site is slightly different, although all four units have a general flow pattern from south to north toward the Cimarron River. Figure 3-4 presents a potentiometric surface map of Sandstone B and the alluvium for the BA #1 Area based on groundwater-level measurements during the August/September 2004 annual sampling of monitor wells at the Cimarron Site. Figures 3-5 and 3-6 present potentiometric surface maps, respectively, of the Western Upland and Alluvial Areas based on groundwater level measurements collected during the August/September 2004 annual sampling of monitor wells at the Cimarron Site.

3.2.3 General Groundwater Flow Patterns

In those areas where Sandstone A is the uppermost water-bearing unit, flow in Sandstone A is controlled by local topography. Groundwater in Sandstone A flows from the topographically higher areas to adjacent drainages and reflects local recharge from precipitation events. Flow in Sandstones B and C is more regionally controlled. Generally, flow in Sandstones B and C is north to northwest toward the Cimarron River. In the vicinity of the BA #1 Area local groundwater flow in Sandstone B is more to the north and east, because Sandstone B is the uppermost water-bearing unit and flow within it is influenced by local topography. Flow in the alluvial floodplain of the Cimarron River is difficult to discern because of the relatively flat hydraulic gradient. Flow in the alluvium is toward the Cimarron River because the river is a gaining stream throughout its reach from Freedom to Guthrie. Flood events coupled with seasonal variations in water levels in the floodplain make it difficult to establish a definite long-term regional hydraulic gradient for the floodplain.

3.2.4 Stream/Aquifer Interactions

The drainages within the Cimarron Site receive flow from precipitation events and from groundwater base flow. Most of the drainages penetrate only Sandstone A and thus act as local drains for shallow groundwater during precipitation events. Sandstone B is penetrated by a drainage near the BA #1 Area. Sandstone C is not penetrated by the drainages and thus has no local interaction with stream flow. The alluvium of the Cimarron River floodplain drains to the river, except during floods events.

3.2.5 Cimarron River Floodplain

Floodplain sediments receive water from five main sources in the site's vicinity: 1) precipitation, 2) upward flow from Sandstone B or Sandstone C when either lies beneath the alluvium; 3) discharges from Sandstone A and Sandstone B at the escarpment; 4) surface water runoff from drainages; and 5) periodic flooding of the Cimarron River. Long-term water supply to the floodplain alluvium comes from upward flow in Sandstone B due to convergence of regional groundwater flow at the Cimarron River (Carr and Marcher, 1977). Vertically upward flow in Sandstone C at or near the Cimarron River beneath the floodplain alluvial sediments is uncertain because of the density of the more-saline water in Sandstone C. However, in areas where Sandstone C directly underlies the alluvium, groundwater in Sandstone C may flow into the floodplain alluvium as evidenced by site geochemical data (see Sections 4.3 and 4.4 of this report). Precipitation recharges the alluvial floodplain at a rate of about 8 percent of annual precipitation (Adams and Bergman, 1995). Periodic flooding by the Cimarron River temporarily affects bank storage in the alluvium adjacent to the river channel.

3.3 Groundwater Flow Regimes at the Cimarron Site

Because groundwater flow varies locally across the Cimarron Site, a discussion of groundwater flow for specific areas of interest is presented in this section.

3.3.1 BA #1 Area

Groundwater in the vicinity of the BA #1 Area (Figure 3-3) originates as precipitation that infiltrates into the shallow groundwater unit recharge zones in the area of the former disposal trenches and flows into Sandstone B. This groundwater then flows across a buried escarpment that acts as an interface for the Sandstone B water-bearing unit and the Cimarron River floodplain alluvium, and finally into and through the floodplain alluvium to the Cimarron River. Flow in Sandstone B is mostly northward in the area that is west of the transitional zone and northeastward along the interface with the transitional zone. Flow is driven by a relatively steep hydraulic gradient (0.10 foot/foot) at the interface between Sandstone B and the floodplain alluvium.

Once groundwater enters the floodplain alluvium, the hydraulic gradient decreases to around 0.023 foot/foot and flow is refracted to a more northwesterly direction. The decrease in hydraulic gradient is due in part to the much higher overall hydraulic conductivity in the floodplain alluvium compared to Sandstone B (10^{-2} to 10^{-3} cm/s versus 10^{-5} to 10^{-4} cm/s in Sandstone B). The refraction to the northwest may also be due to a paleochannel in the floodplain alluvial sediments. The direction of this paleochannel is to the northwest near the buried escarpment and then is redirected to the north as it extends farther out into the floodplain. This paleochannel is discussed in Section 2.3.1 (Detailed Stratrigraphic Correlations at Cimarron – BA #1 Area) of this report and shown in Figure 2-7. Once groundwater passes through the transitional zone, it enters an area where the hydraulic gradient is essentially flat. In the sandy alluvium, there are no geological boundaries to govern the flow of groundwater. The flow direction in this area is controlled by two flow components: the northwesterly flow from the paleochannel in the transitional zone; and the northerly flow from Sandstones B and C, both of which discharge to the alluvium in the western portion of the BA #1 Area.

3.3.2 Western Upland Area

In the Western Upland Area, the drainage between the former Uranium Pond #1 and the former Sanitary Lagoons acts as a local drain for groundwater in Sandstone A. Groundwater flows toward this drainage from both the east and west, including the BA #3 Area and the former Sanitary Lagoons. The thick vegetation and groundwater seeps, such as those at the Western Alluvial Area, attest to groundwater base flow entering this drainage (thus becoming surface water) from Sandstone A.

Groundwater gradients steepen along the cliff faces of the drainage. Along the cliff face bordering the Cimarron River floodplain alluvium just north of the former Uranium Pond #1, groundwater flows north to northwest toward the floodplain in Sandstone A and discharges in a myriad of small seeps that are difficult to locate. Groundwater gradients in Sandstone A near the former Uranium Pond #1 are approximately 0.01 foot/foot toward the drainages to the northeast and northwest (September 2003 data) and about 0.02 foot/foot toward the north. Groundwater levels in Sandstone A range from around 985 feet amsl at the south end of the 1206 Area near Well 1353 to around 970 feet amsl near the escarpment (Well 1312). Groundwater in Sandstone A surfaces and flows into the drainage to the west of BA#3 from small seeps that commingle at the 1206 Seep sampling location, which is at an elevation of approximately 971 feet amsl and is situated about three feet above a clay zone in Sandstone A.

Groundwater in Sandstones B and C flows northwest toward the Cimarron River beneath the Western Upland Area. The top of Sandstone B is exposed in the lower part of the escarpment north of the BA #3 Area. In Sandstone B, the groundwater gradient is toward the north-northwest at about 0.023 foot/foot. In Sandstone C, the gradient is also toward the north at about 0.013 foot/foot (J.L. Grant and Associates, 1989). Groundwater flow in Sandstones B and C is below the base of the escarpment in the Western Upland Area, thus Sandstones B and C do not form seeps in the escarpment. These two water-bearing units are not intercepted by the drainages in the area of the BA #3 Area.

3.3.3 Western Alluvial Area

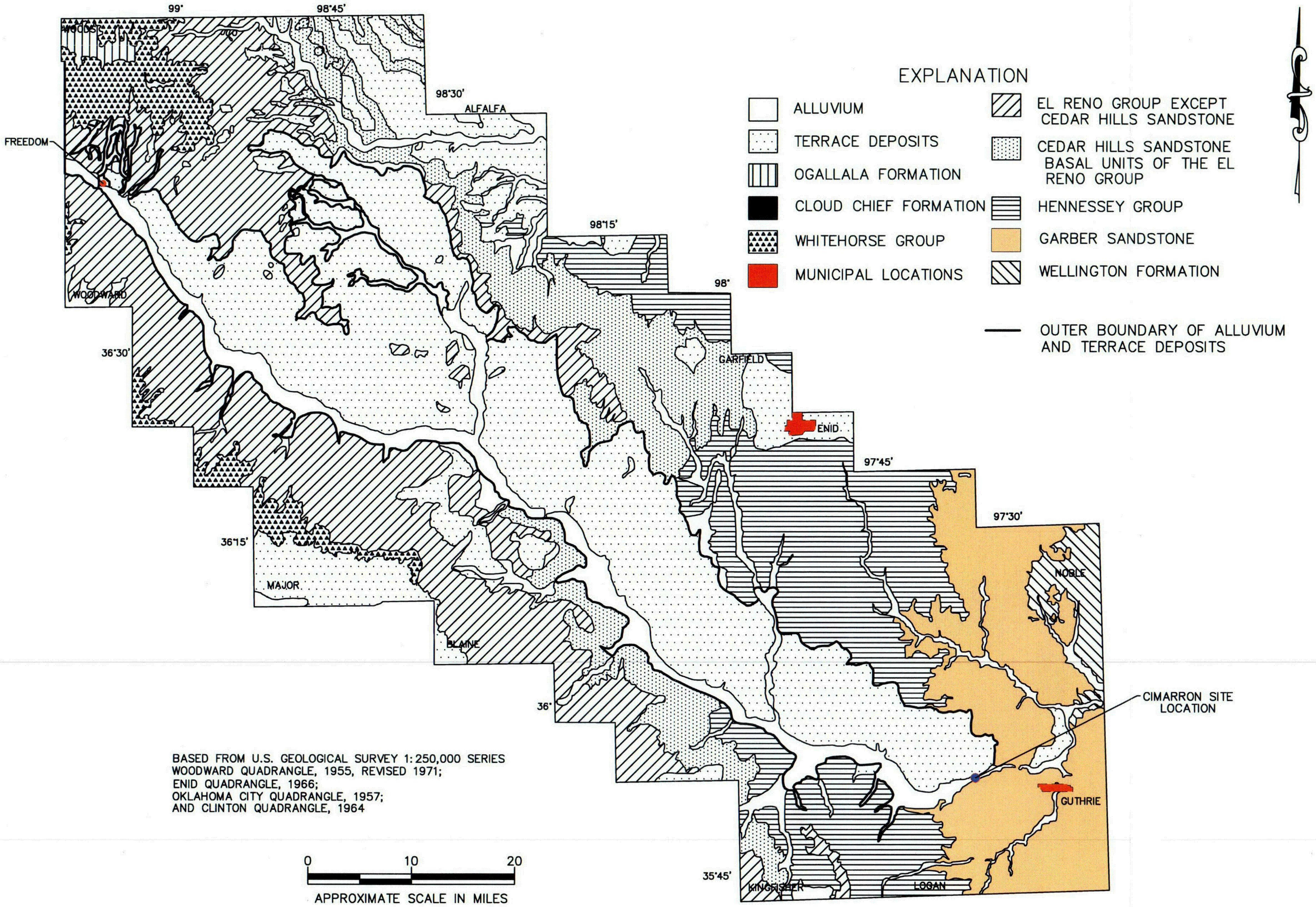
Groundwater flow in the Western Alluvial Area (Figure 3-3) is found in the alluvial floodplain of the Cimarron River. Groundwater flow in the Western Alluvial Area is generally northward toward the Cimarron River. Characterization of groundwater flow in the floodplain alluvium is difficult to discern due to the low hydraulic gradient coupled with seasonal fluctuations in water levels and periodic flooding.

3.4 Summary

In summary, the Cimarron Site is underlain by the Garber-Wellington Aquifer of Central Oklahoma. At the site, the Garber Formation can be divided into three separate water-bearing zones that parallel the geological division of the formation into Sandstones A, B, and C. The uppermost water-bearing zone in the Garber Formation is generally unconfined, although it can be locally semi-confined by mudstone and shale units. The two lower units in Sandstones B and C are confined to semi-confined, depending on the thickness and continuity of the overlying mudstone unit.

Groundwater flow in Sandstone A is local in nature and flows from topographic highs, which also act as recharge areas, to topographic low areas such as the drainages. Sandstone A discharges through groundwater seeps in the escarpment that borders the Cimarron River floodplain. Groundwater flow in Sandstone B is regionally controlled. Sandstone B forms seeps near the base of the escarpment at the eastern end of the Cimarron Site, but lies mostly below the base of the escarpment toward the western side of the site. Groundwater flow in Sandstone C is also regionally controlled. The Sandstone C unit is part of the saline water zone of the Garber-Wellington Formation. Sandstone C is not exposed at the escarpment and lies entirely below the base of the drainages. Sandstone B discharges groundwater to the alluvial floodplain. In the BA #1 Area, Sandstone C may have vertically upward flow at discrete locations where it underlies the floodplain alluvium.

The Cimarron Site is within a recharge area for the upper fresh water zone of the Garber-Wellington Formation. Thus vertical groundwater flow is generally downward, except at major discharge areas such as the Cimarron River. The Cimarron River is a gaining river and thus receives groundwater from its floodplain alluvium.



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

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

ENSR INTERNATIONAL
4888 LOOP CENTRAL DR. SUITE 600
HOUSTON, TEXAS 77081
PHONE: (713) 520-9900
FAX: (713) 520-6802
WEB: HTTP://WWW.ENSR.COM

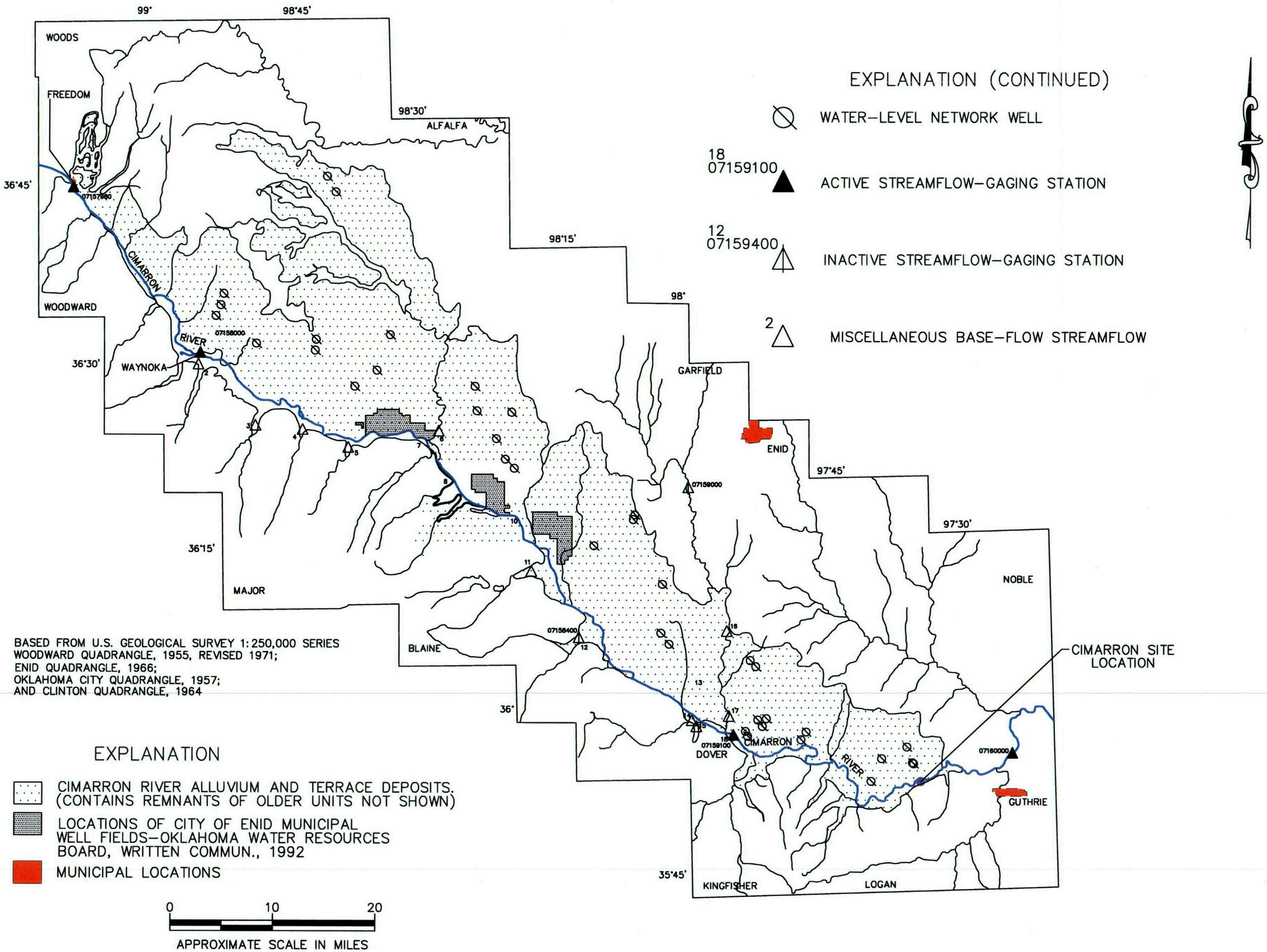
FIGURE 3-1
GEOLOGY ALONG THE CIMARRON RIVER FROM FREEDOM TO GUTHRIE, OKLAHOMA
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

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

FIGURE NUMBER: 3-1

SHEET NUMBER: 1

C14



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

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

ENSR INTERNATIONAL
4888 LOOP CENTRAL DR. SUITE 600
HOUSTON, TEXAS 77081
PHONE: (713) 520-9900
FAX: (713) 520-6802
WEB: HTTP://WWW.ENSR.COM

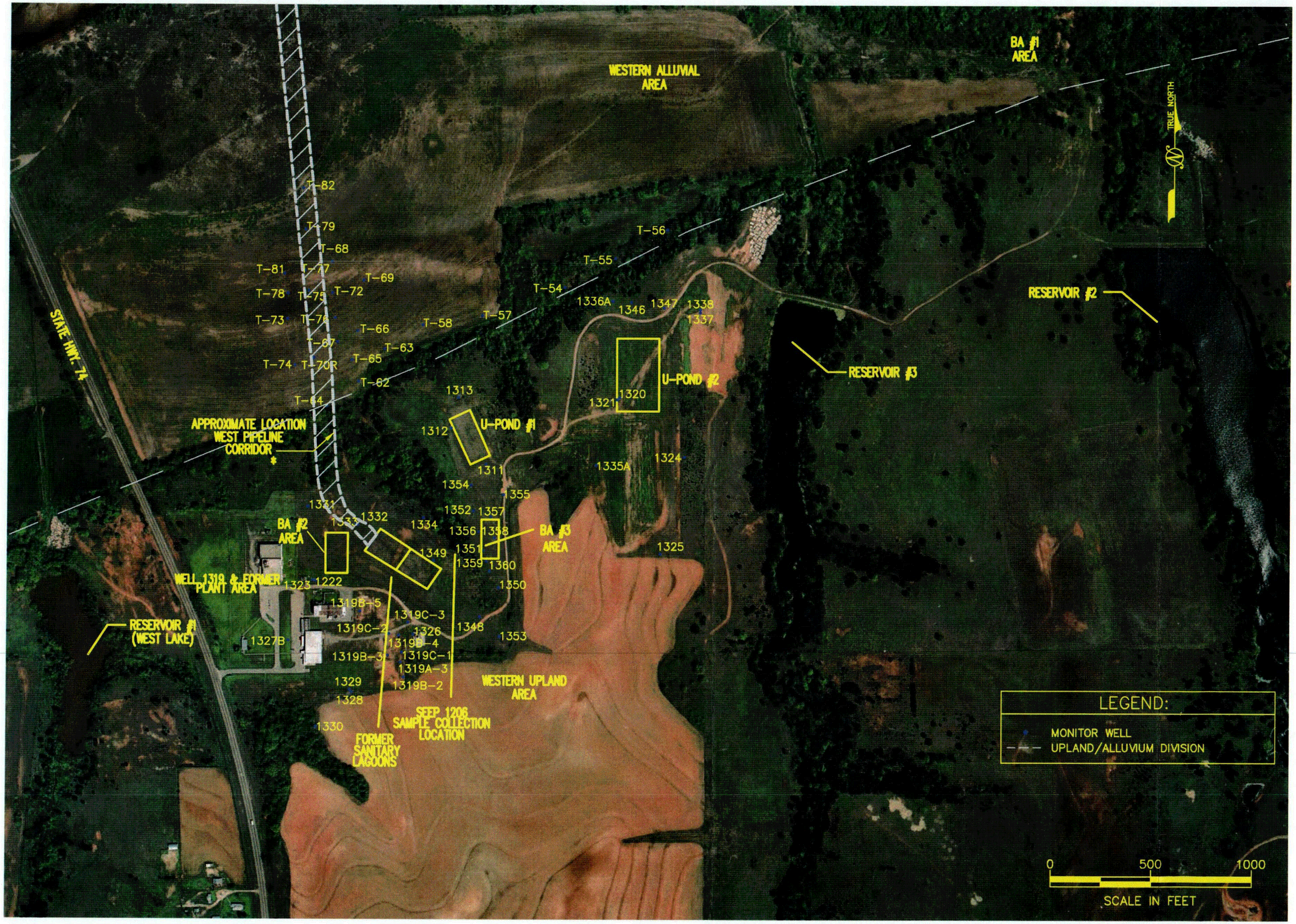
FIGURE 3-2
LOCATION OF NETWORK WELLS, BASE-FLOW STREAM-MEASURING SITES ALONG THE CIMARRON RIVER FROM FREEDOM TO GUTHRIE, OKLAHOMA
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

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

FIGURE NUMBER: 3-2

SHEET NUMBER: 1

C15



DESIGNED BY:	REVISIONS			
DRAWN BY: HTP	NO.:	DESCRIPTION:	DATE:	BY:
CHECKED BY: DJF	1		4/10/05	
APPROVED BY: DJF	2		6/17/05	

ENSR INTERNATIONAL

4888 LOOP CENTRAL DR. SUITE 600
HOUSTON, TEXAS 77081
PHONE: (713) 520-9900
FAX: (713) 520-6802
WEB: HTTP://WWW.ENSR.COM

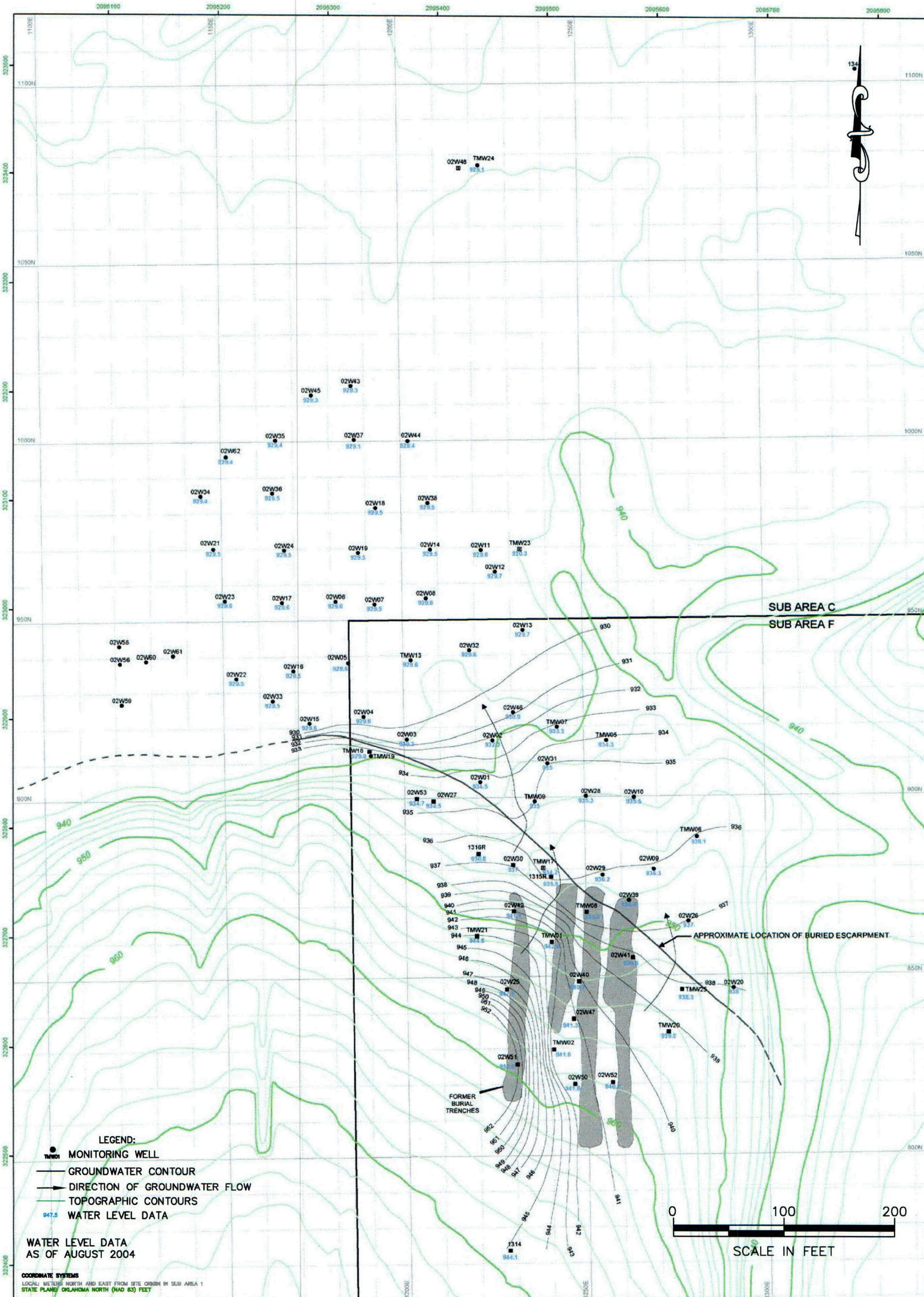
FIGURE 3-3
WELL LOCATIONS AND
UPLAND/ALLUVIUM DIVISION MAP
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

SCALE:	DATE:	PROJECT NUMBER:
1" = 500'	8/10/05	04020-044-200

FIGURE NUMBER: 3-3

SHEET NUMBER: 1

C16



SHEET NUMBER:	FIGURE NUMBER:
1	3–4

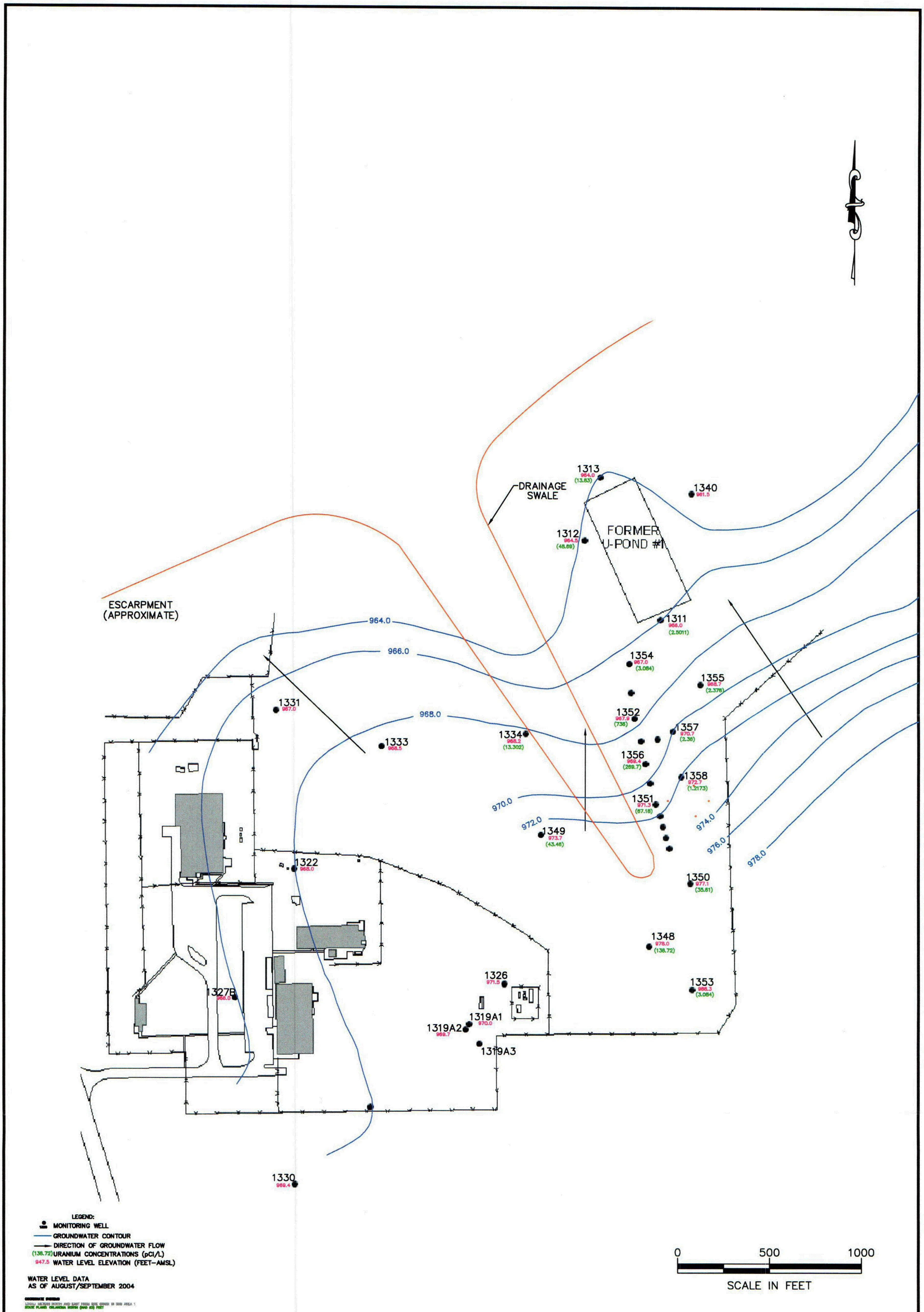
FIGURE 3–4
BA #1 AREA
POTETIOMETRIC SURFACE MAP
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

SCALE:	DATE:	PROJECT NUMBER:
1"=100'	8/10/05	04020-044-200

ENSR INTERNATIONAL
4888 LOOP CENTRAL DR. SUITE 600
HOUSTON, TEXAS 77081
PHONE: (713) 520-9900
FAX: (713) 520-6802
WEB: HTTP://WWW.ENSR.COM

DESIGNED BY:	REVISIONS			
	NO.:	DESCRIPTION:	DATE:	BY:
DRAWN BY:	1		4/10/05	
JAS	2		6/17/05	
CHECKED BY:				
DJF				
APPROVED BY:				
DJF				

C17



SHEET NUMBER: 1

FIGURE NUMBER: 3–5

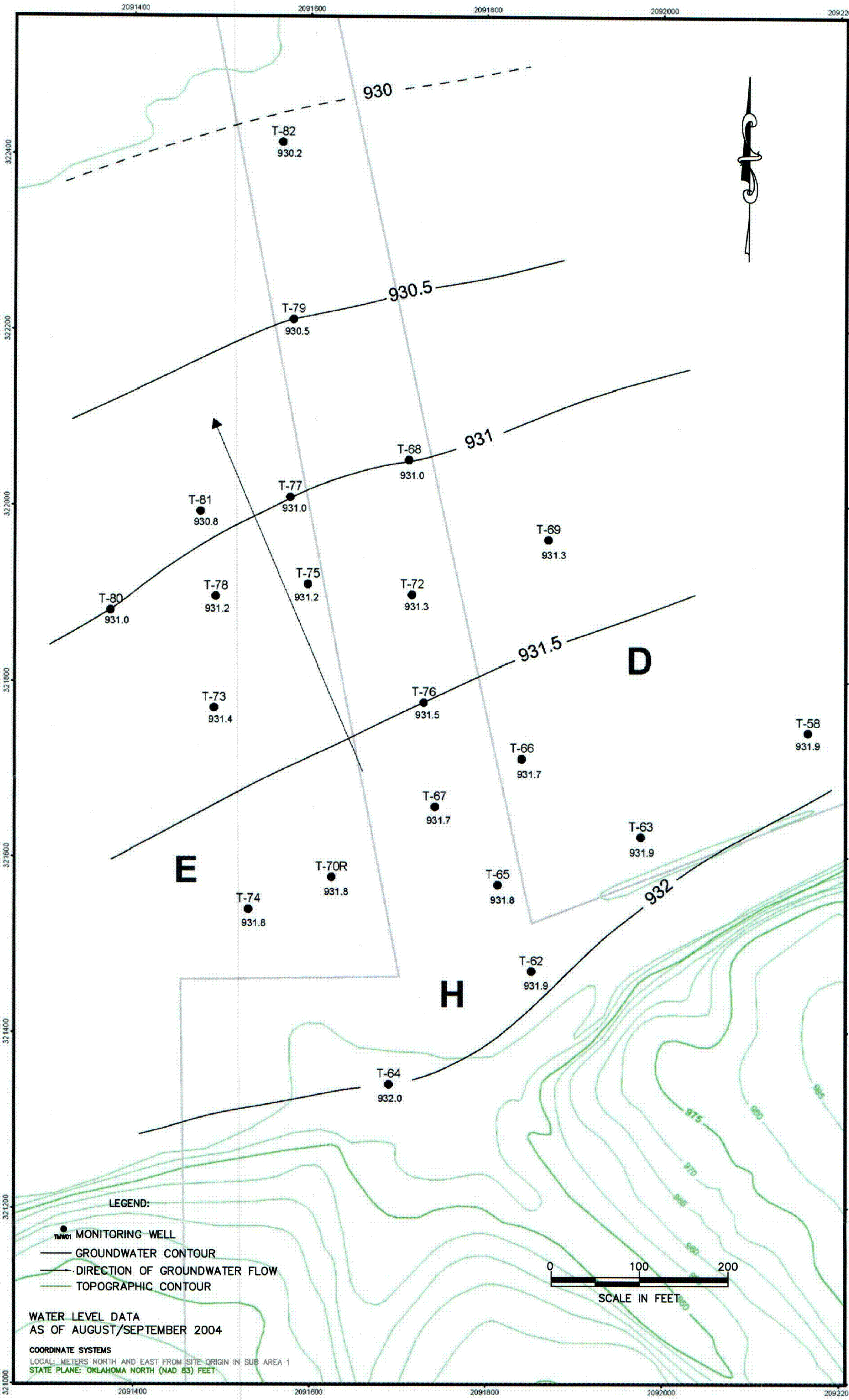
FIGURE 3–5
WESTERN UPLAND AREA
POTENTIOMETRIC SURFACE MAP
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

SCALE:	DATE:	PROJECT NUMBER:
1"= 500'	8/10/05	04020-044-200

ENSR INTERNATIONAL
4888 LOOP CENTRAL DR. SUITE 600
HOUSTON, TEXAS 77081
PHONE: (713) 520-9900
FAX: (713) 520-6802
WEB: HTTP://WWW.ENSR.COM

DESIGNED BY:	REVISIONS			
	NO.:	DESCRIPTION:	DATE:	BY:
DRAWN BY:	1			
JAS				
CHECKED BY:				
DJF				
APPROVED BY:				
DJF				

C18



SHEET NUMBER: 1

FIGURE NUMBER: 3-6

FIGURE 3-6
WESTERN ALLUVIAL AREA
POTENTIOMETRIC SURFACE MAP
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

SCALE:	DATE:	PROJECT NUMBER:
1"=100'	8/10/05	04020-044-200

ENSR INTERNATIONAL
4888 LOOP CENTRAL DR. SUITE 600
HOUSTON, TEXAS 77081
PHONE: (713) 520-9900
FAX: (713) 520-6802
WEB: HTTP://WWW.ENSR.COM

DESIGNED BY:

DRAWN BY: JAS

CHECKED BY: DJF

APPROVED BY: DJF

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

C19