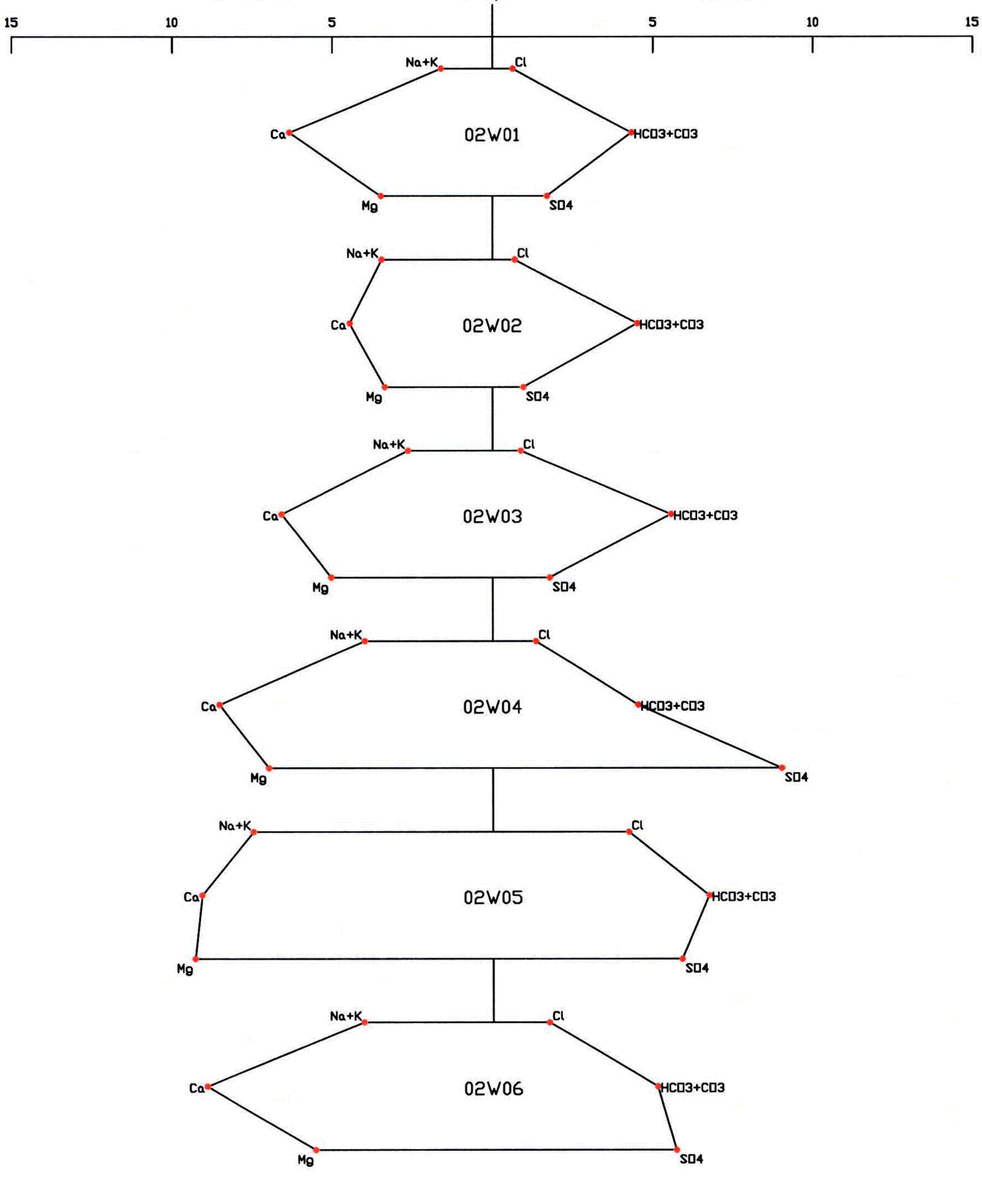
# Appendix A

## Stiff Diagrams for Wells Sampled August/September 2004

# Stiff Diagram

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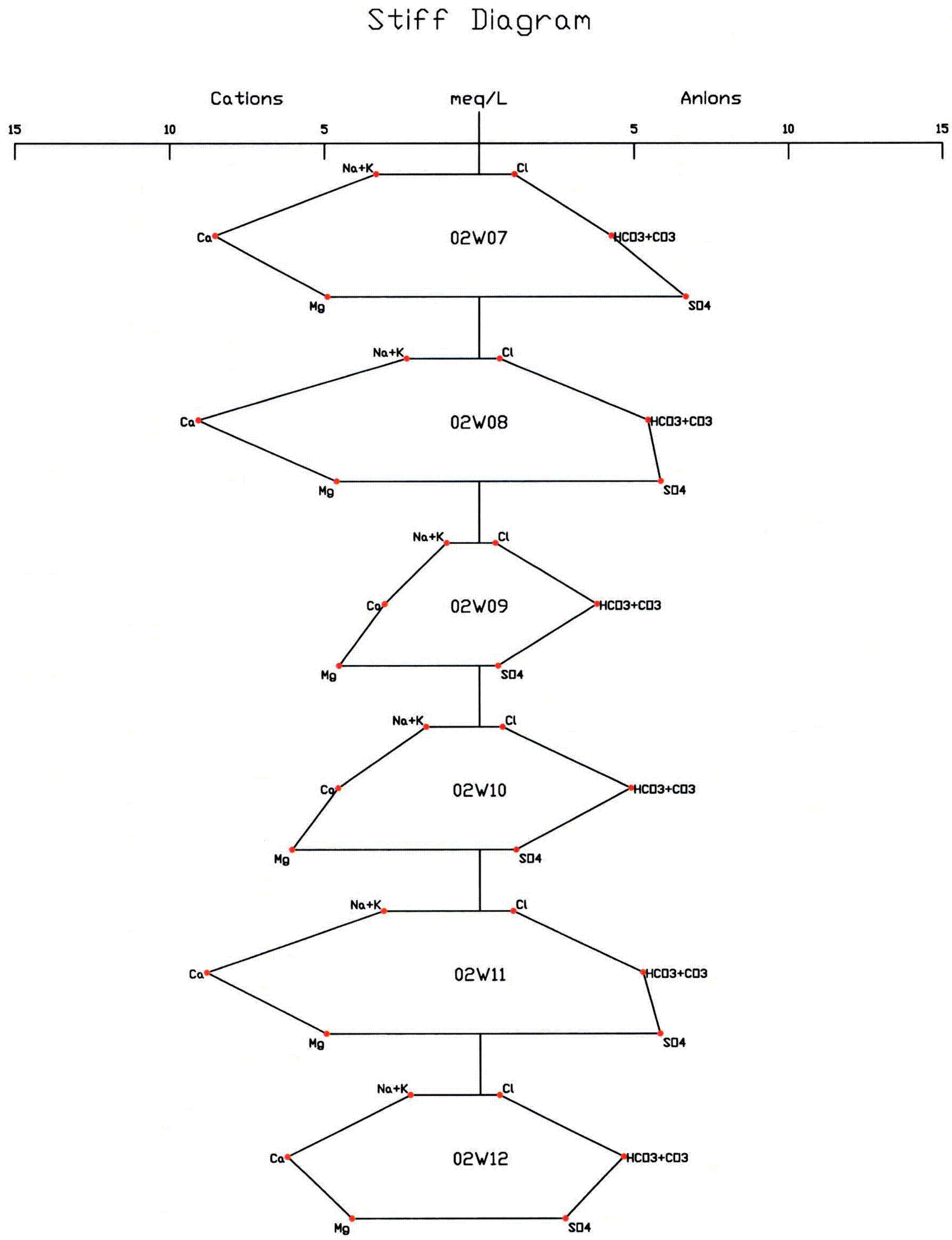
| ENSR INTERNATIONAL Consulting • Engineering • Remediation | DRAWN: JAS | APPENDIX A<br>STIFF DIAGRAMS<br>BA #1 AREA (1 of 12)<br>CIMARRON CORPORATION<br>CRESCENT, OKLAHOMA |
| | CHECKED: DJF | |
| | DATE: 7/22/05 | |
| PROJECT NO.: 04020-044-200 | DRAWING NO.: | |

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| ENSR INTERNATIONAL<br>Consulting • Engineering • Remediation | DRAWN: JAS | APPENDIX A<br>STIFF DIAGRAMS<br>BA #1 AREA (2 of 12)<br>CIMARRON CORPORATION<br>CRESCENT, OKLAHOMA |
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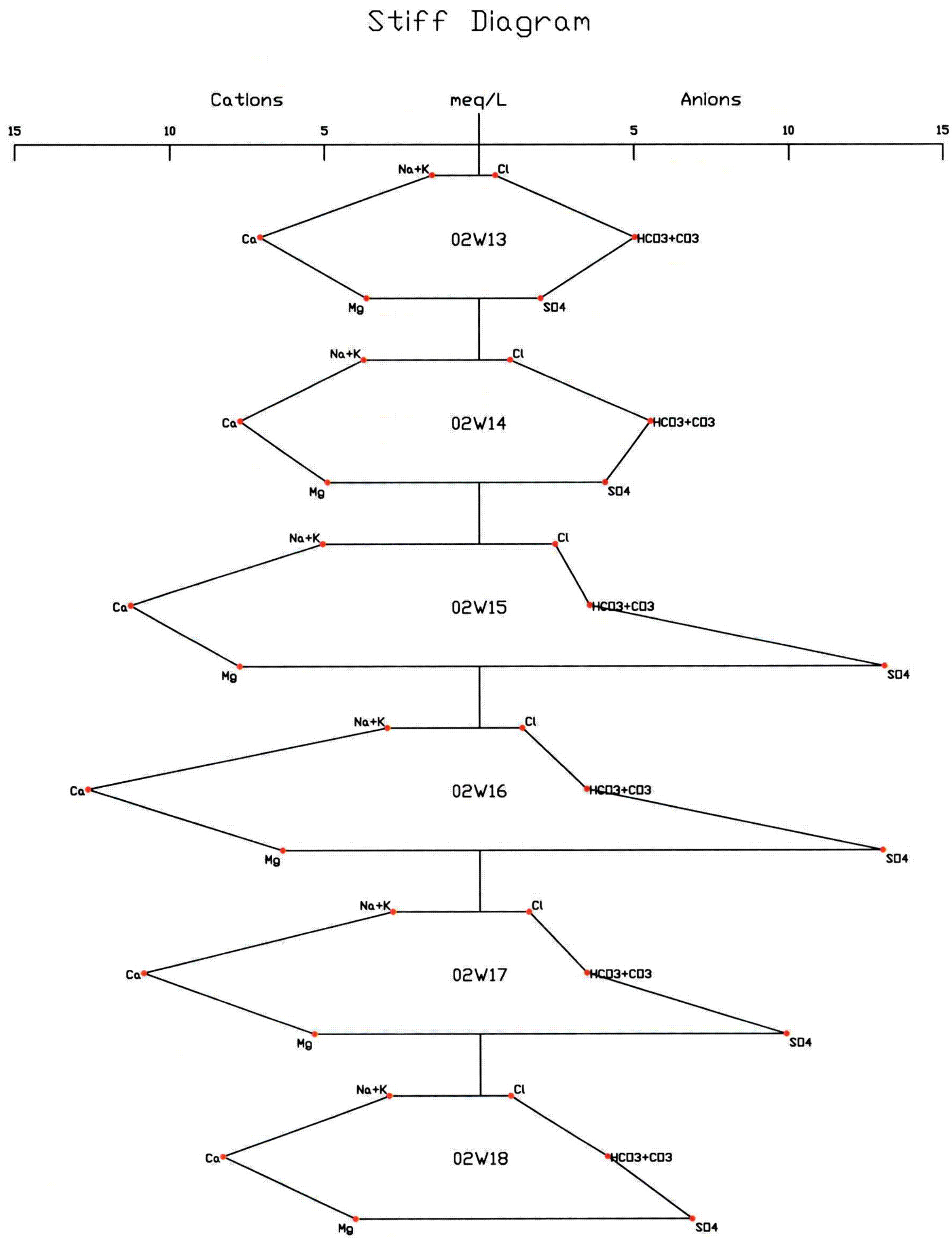


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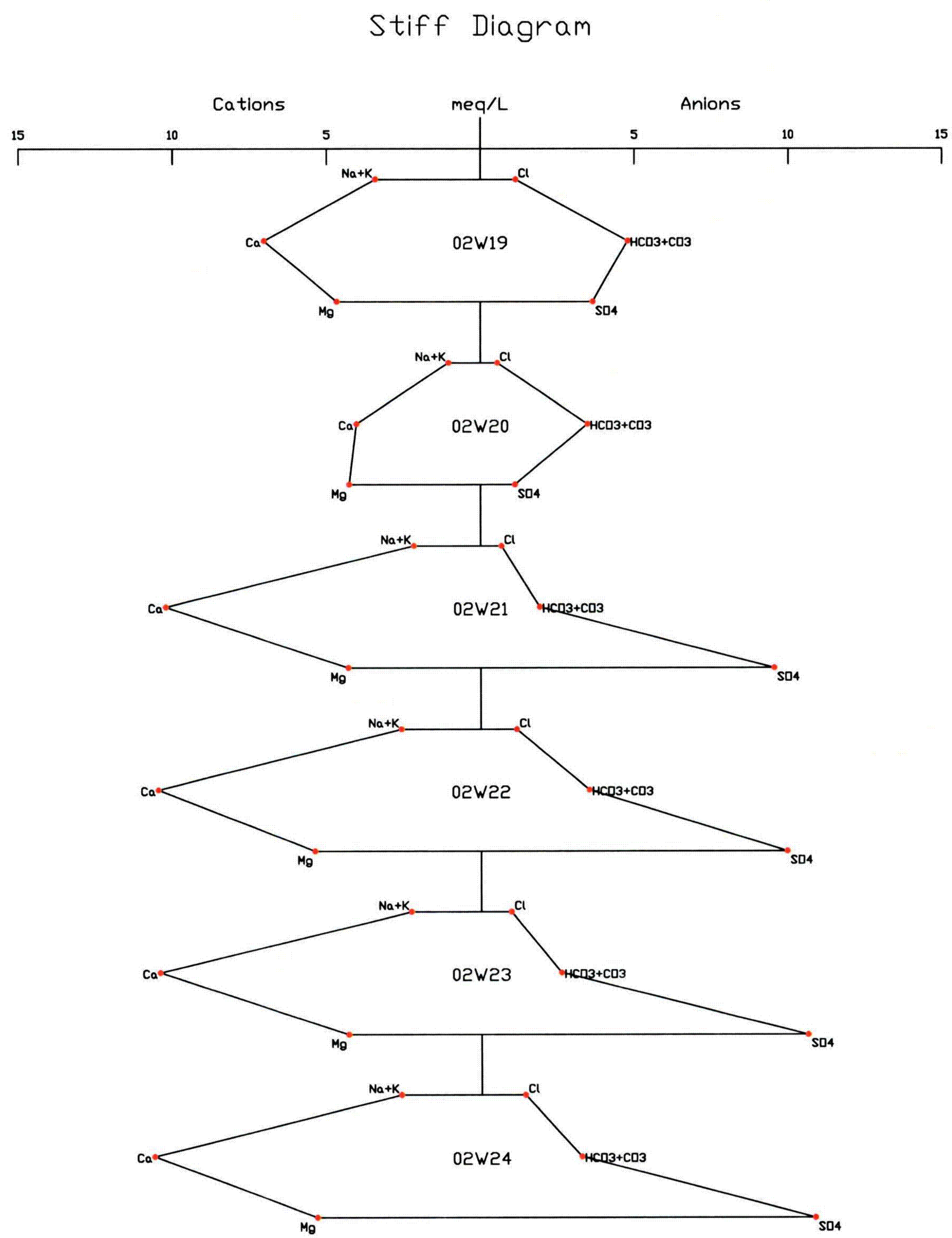
| PROJECT NO.: | 04020-044-200 |
| DRAWN: | JAS |
| CHECKED: | DJF |
| DATE: | 7/22/05 |
| DRAWING NO.: | |

APPENDIX A
STIFF DIAGRAMS
BA #1 AREA (3 of 12)
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

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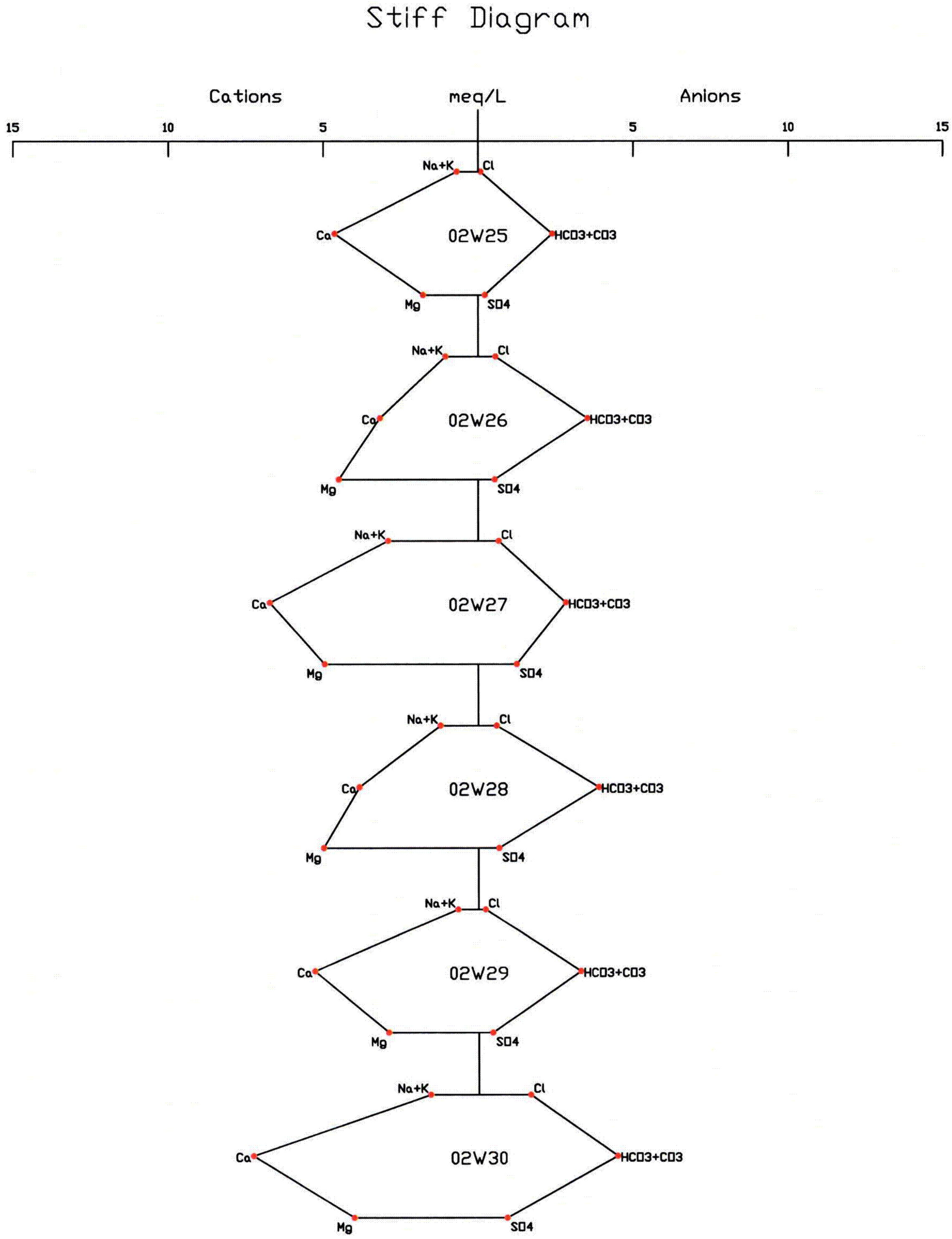
| ENSR INTERNATIONAL Consulting • Engineering • Remediation | DRAWN: JAS | APPENDIX A |
| | CHECKED: DJF | STIFF DIAGRAMS |
| | DATE: 7/22/05 | BA#1 AREA (4 of 12) CIMARRON CORPORATION |
| PROJECT NO.: 04020-044-200 | DRAWING NO.: | CRESCENT, OKLAHOMA |

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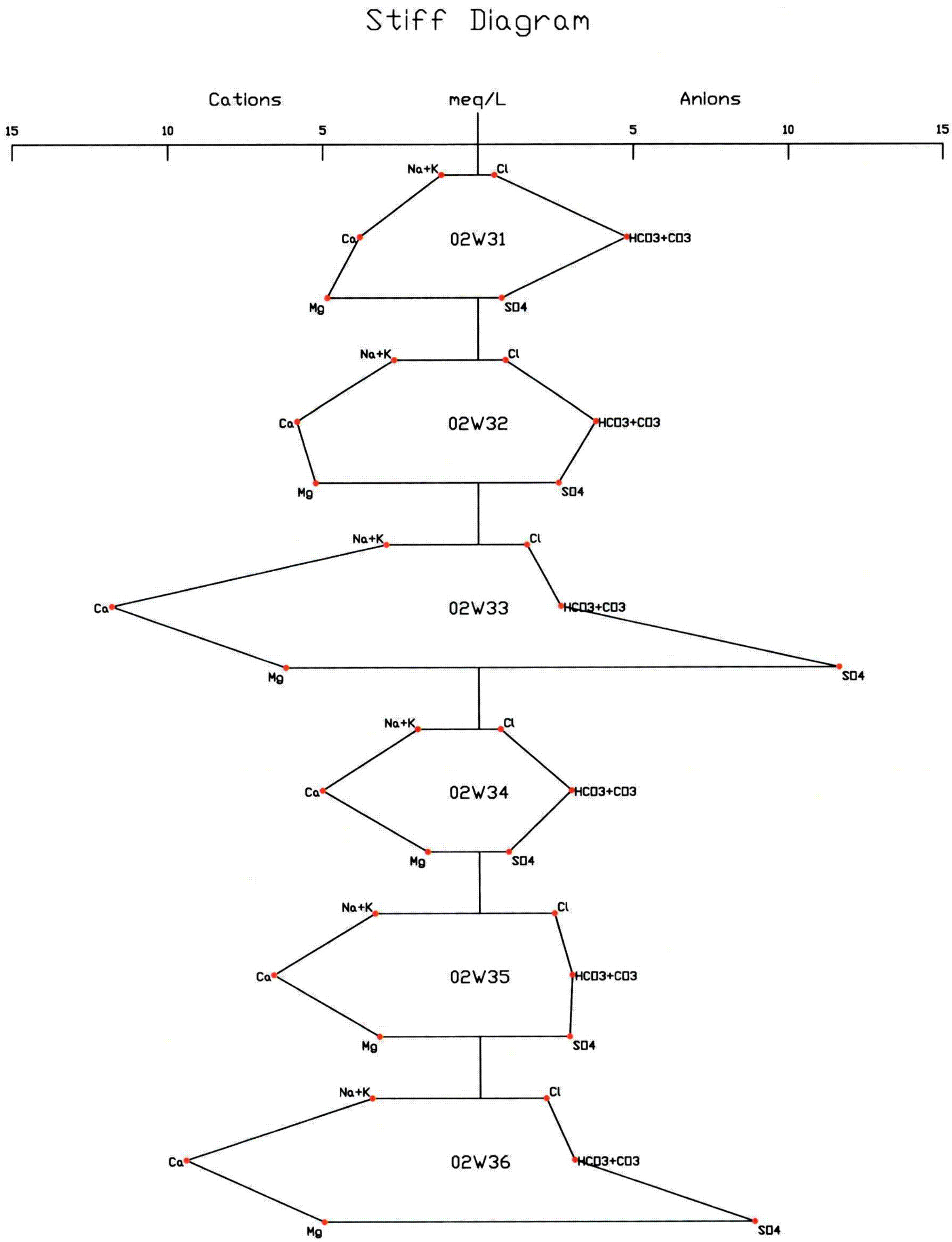
| | CHECKED: DJF | STIFF DIAGRAMS |
| | DATE: 7/22/05 | BA#1 AREA (5 of 12) CIMARRON CORPORATION CRESCENT, OKLAHOMA |
| PROJECT NO.: 04020-044-200 | DRAWING NO.: | |

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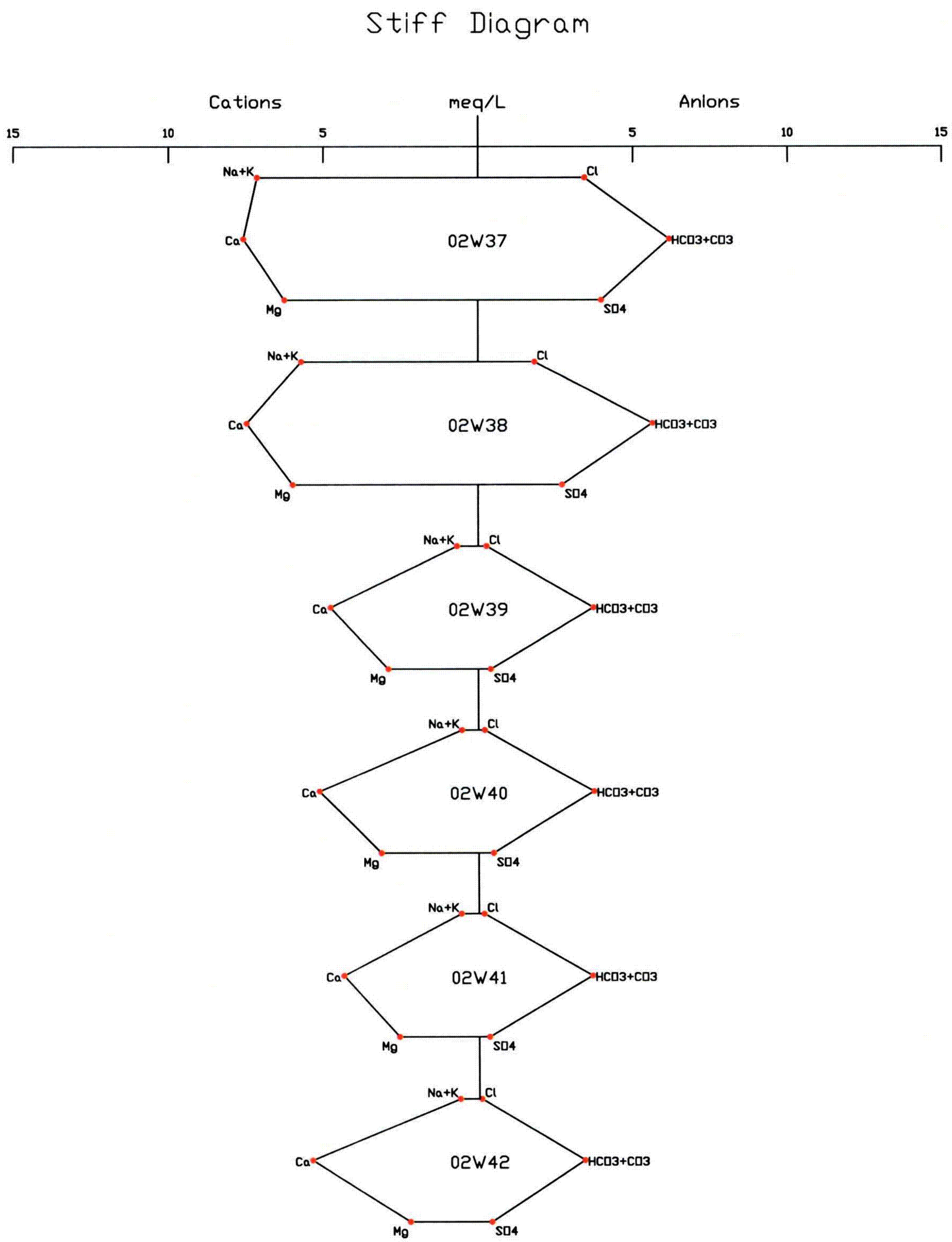


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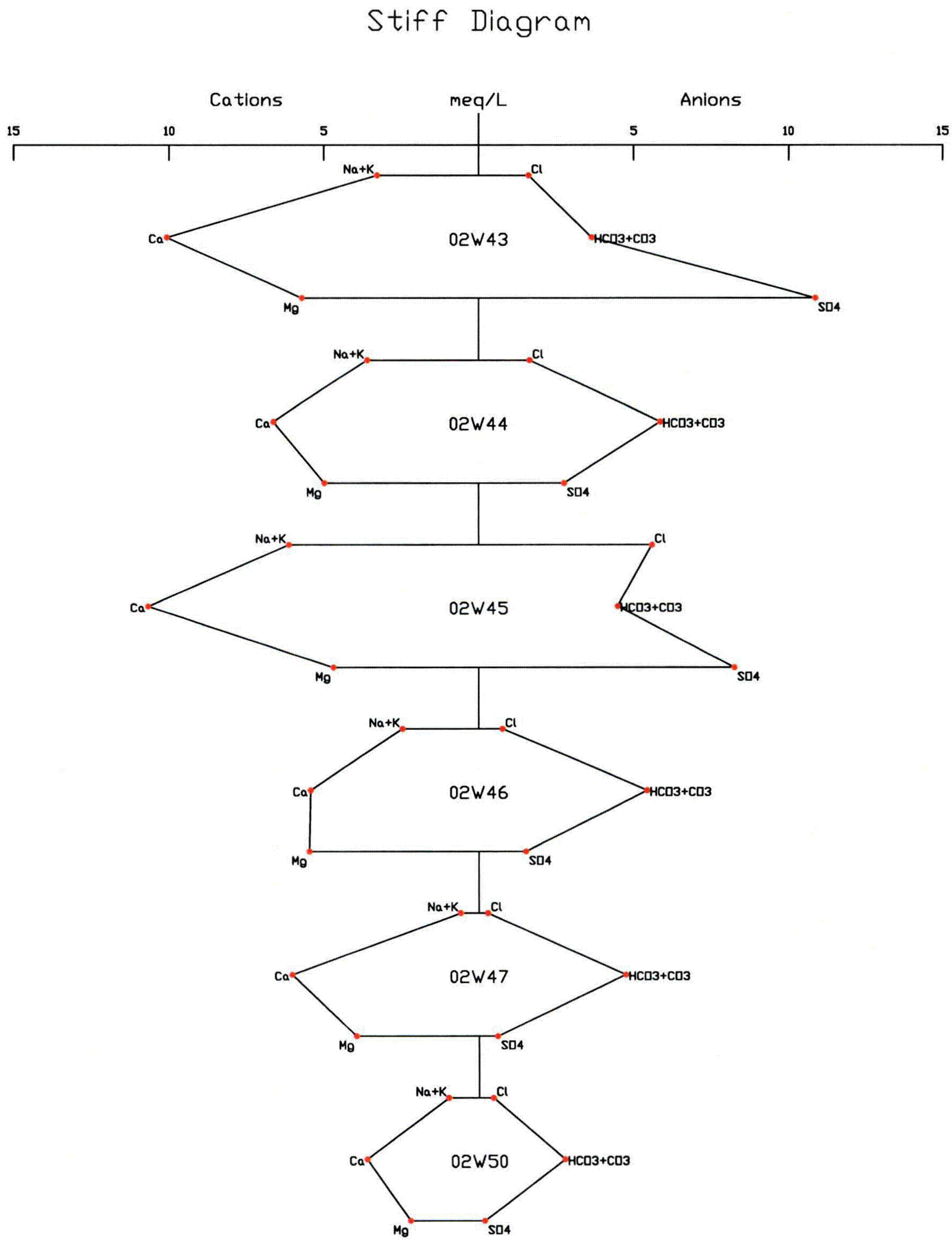
| PROJECT NO.: 04020-044-200 | DRAWNG NO.: | CIMARRON CORPORATION CRESCENT, OKLAHOMA |

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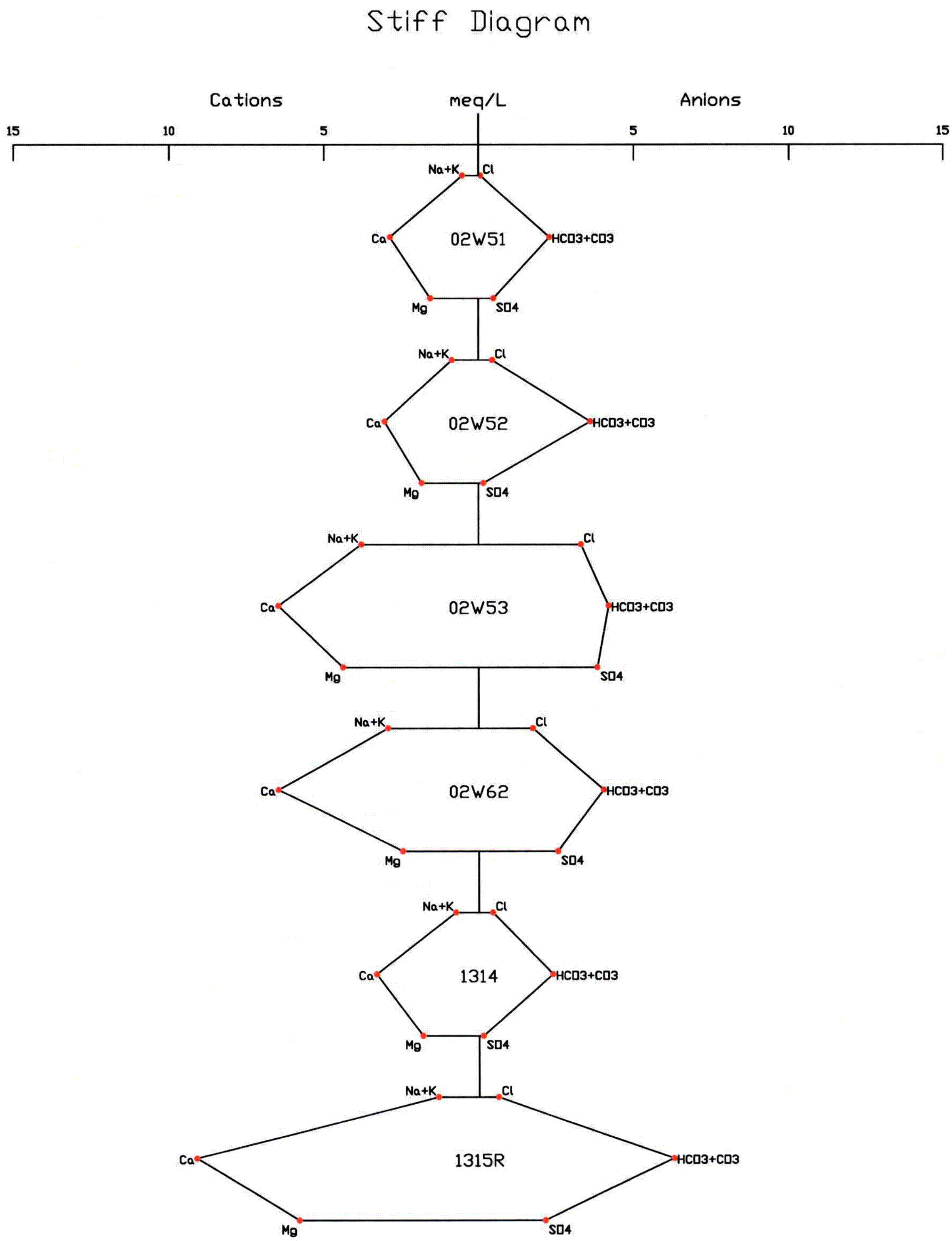
| | DRAWING NO.: | | |

APPENDIX A
STIFF DIAGRAMS
BA#1 AREA (8 of 12)
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

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| DRAWN: | JAS |
| CHECKED: | DJF |
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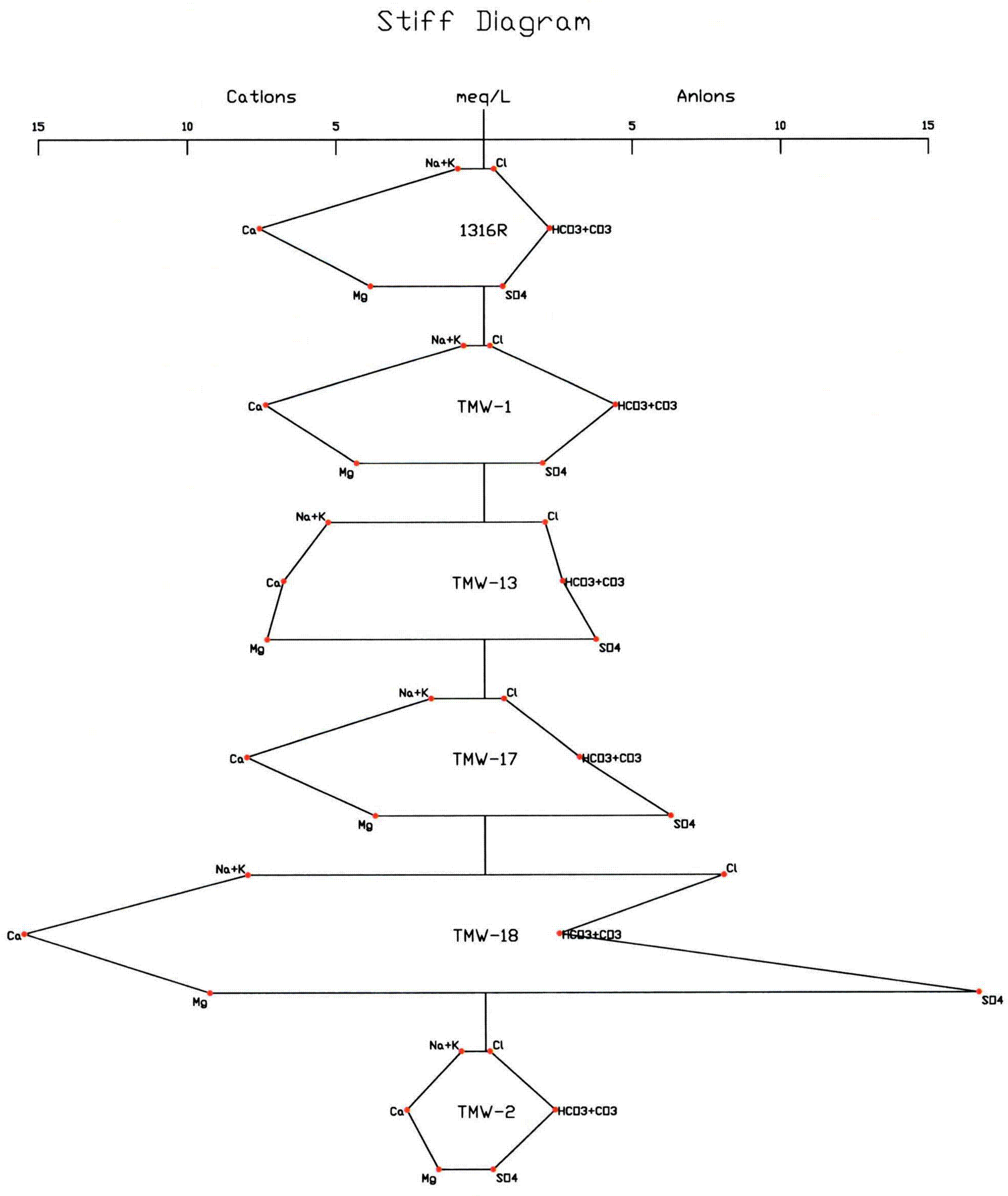
APPENDIX A
STIFF DIAGRAMS
BA#1 AREA (9 of 12)
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

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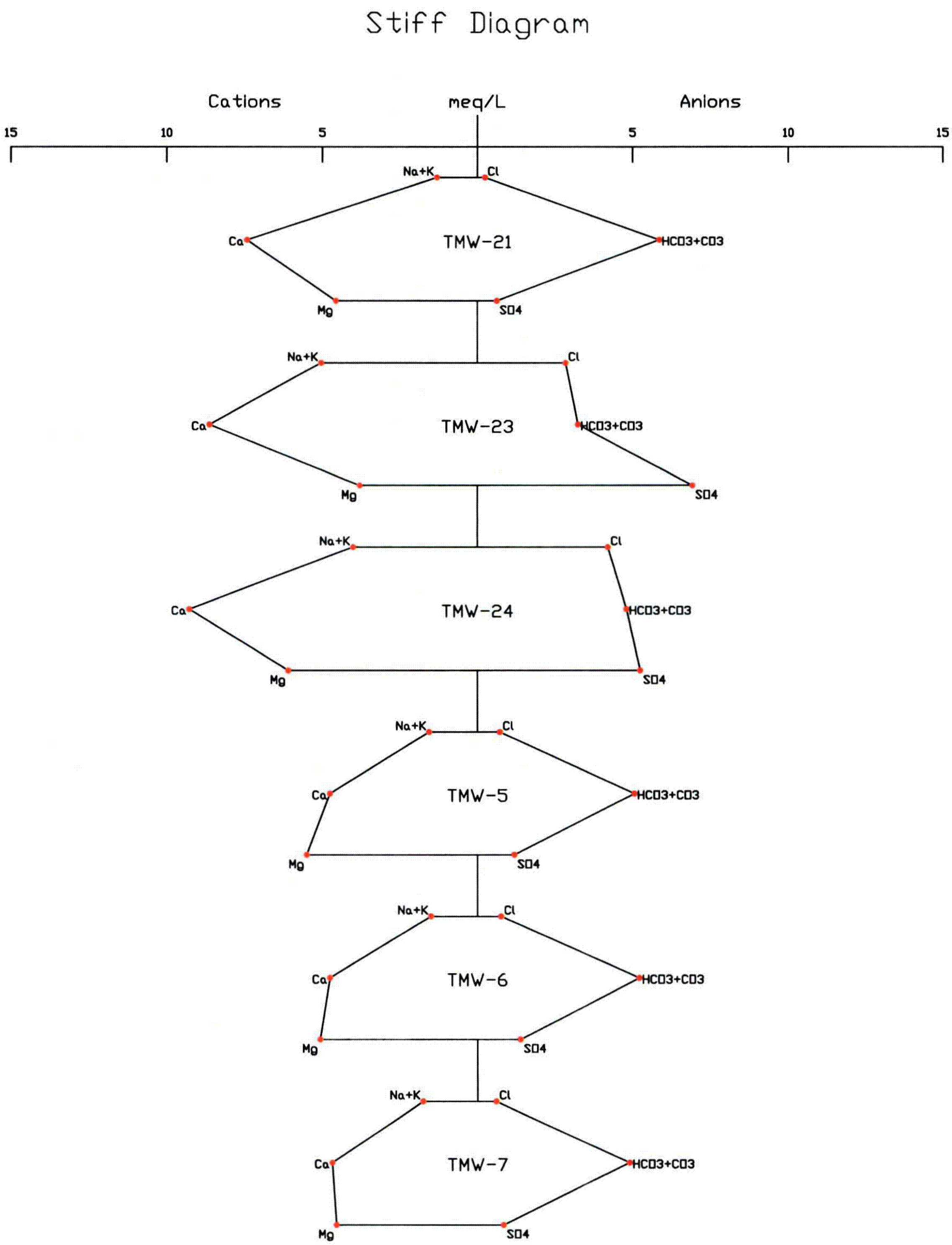
| ENSR INTERNATIONAL Consulting • Engineering • Remediation | DRAWN: JAS | APPENDIX A |
| | CHECKED: DJF | STIFF DIAGRAMS |
| | DATE: 7/22/05 | BA#1 AREA (10 of 12) |
| PROJECT NO.: 04020-044-200 | DRAWING NO.: | CIMARRON CORPORATION CRESCENT, OKLAHOMA |

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|---|---|---|
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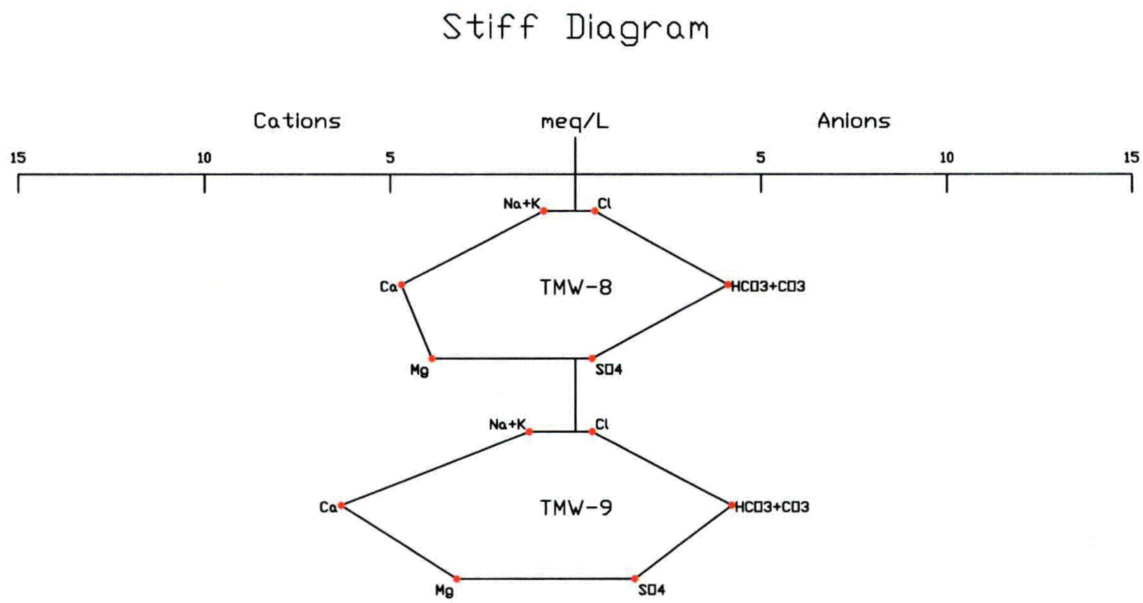
| PROJECT NO.: 04020-044-200 | DRAWING NO.: | |

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| ENSR INTERNATIONAL<br>Consulting • Engineering • Remediation | DRAWN: JAS<br>CHECKED: DJF<br>DATE: 7/22/05 | APPENDIX A<br>STIFF DIAGRAMS<br>BA#1 AREA (12 of 12)<br>CIMARRON CORPORATION<br>CRESCENT, OKLAHOMA |
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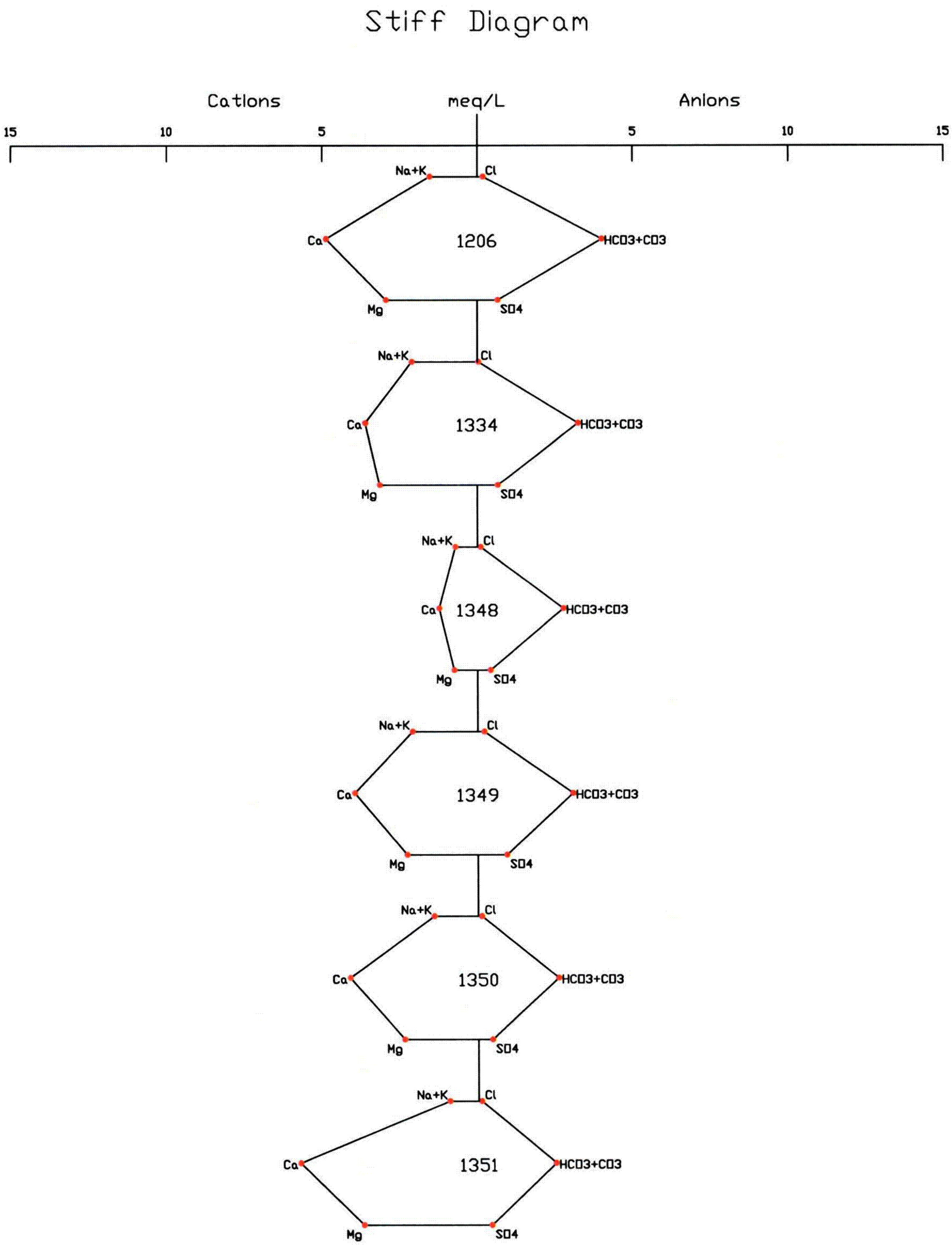


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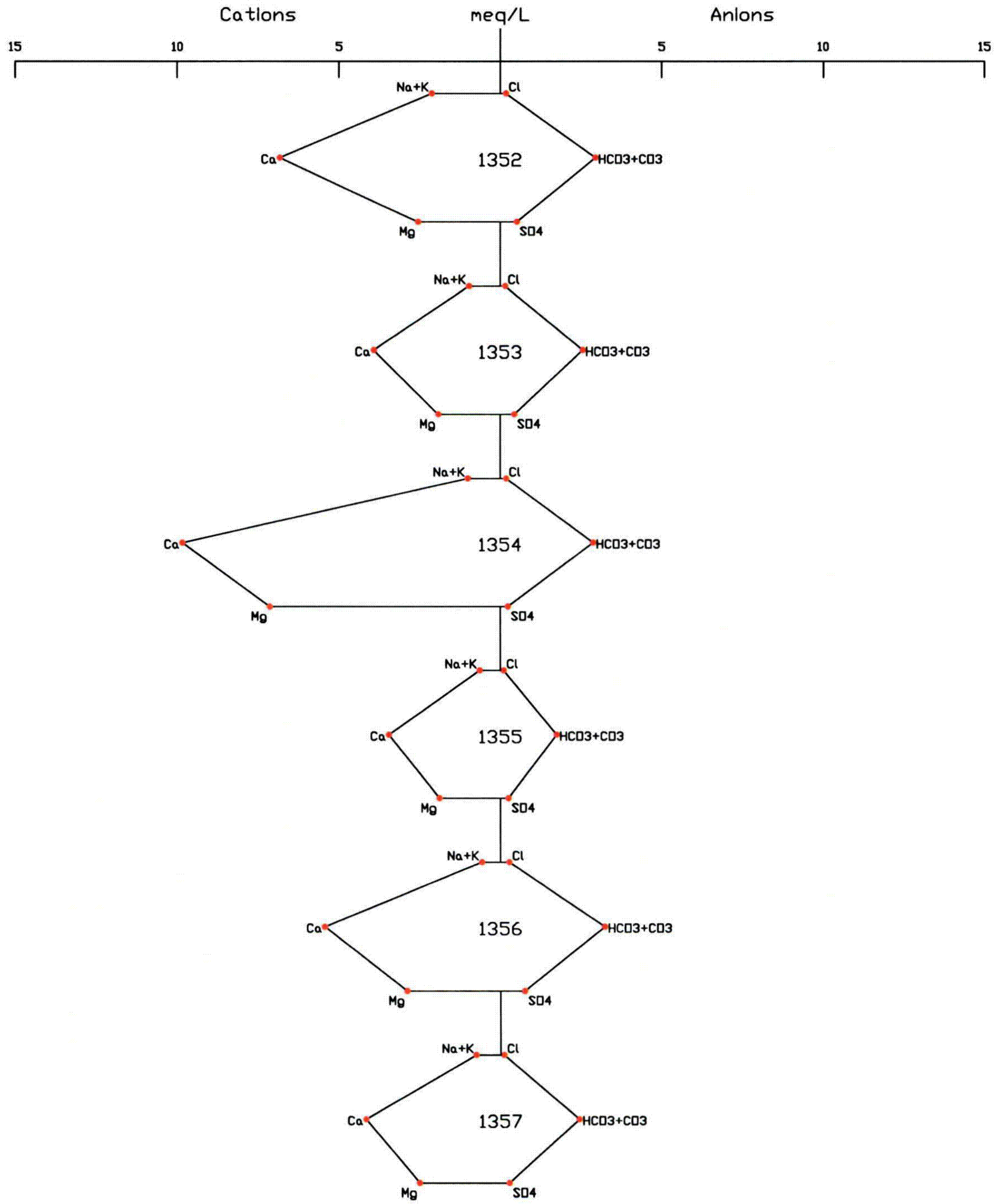
| | CHECKED: DJF | STIFF DIAGRAMS |
| | DATE: 7/22/05 | WESTERN UPLAND AREA (1 of 4) CIMARRON CORPORATION |
| PROJECT NO.: 04020-044-200 | DRAWING NO.: | CRESCENT, OKLAHOMA |

# Stiff Diagram

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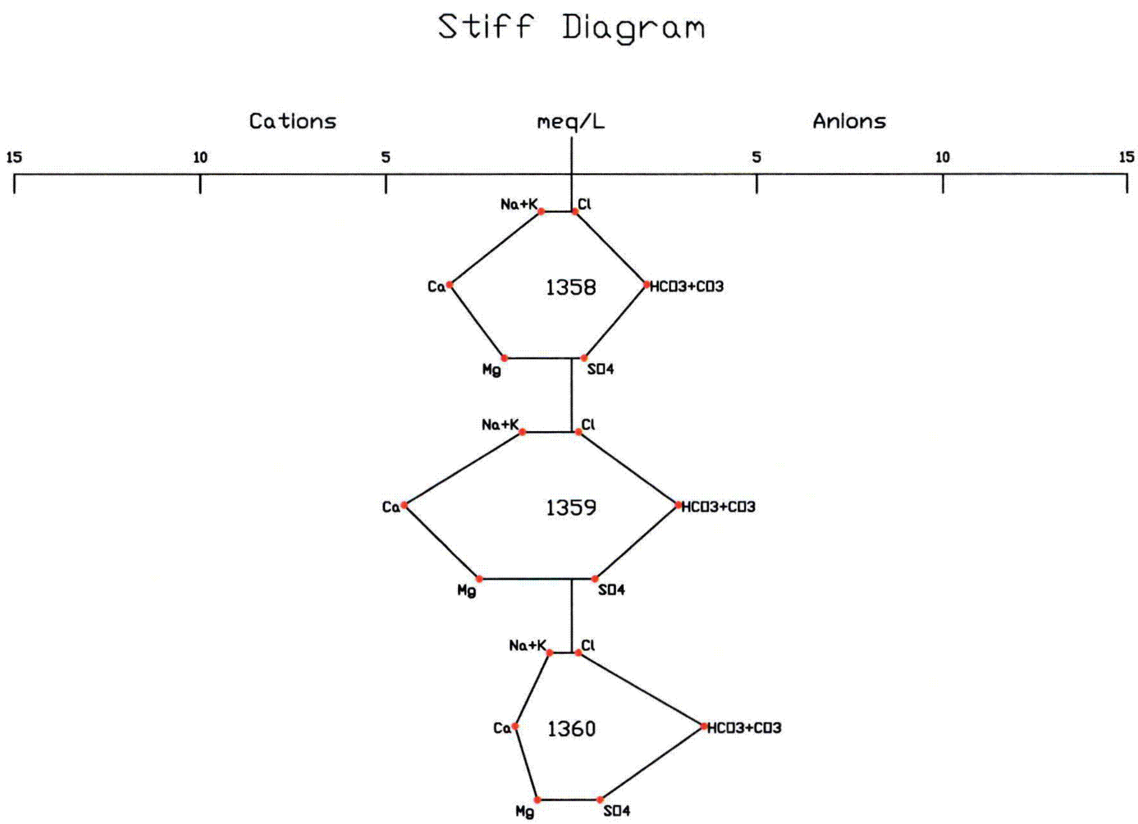
|---|---|---|
| PROJECT NO.: 04020-044-200 | DRAWN: JAS | APPENDIX A |
| | CHECKED: DJF | STIFF DIAGRAMS |
| | DATE: 7/22/05 | WESTERN UPLAND AREA (2 of 4) |
| | DRAWING NO.: | CIMARRON CORPORATION, CRESCENT, OKLAHOMA |

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|---|---|---|
| ENSR INTERNATIONAL Consulting • Engineering • Remediation | DRAWN: JAS | APPENDIX A<br>STIFF DIAGRAMS<br>WESTERN UPLAND AREA (3 of 4)<br>CIMARRON CORPORATION<br>CRESCENT, OKLAHOMA |
| | CHECKED: DJF | |
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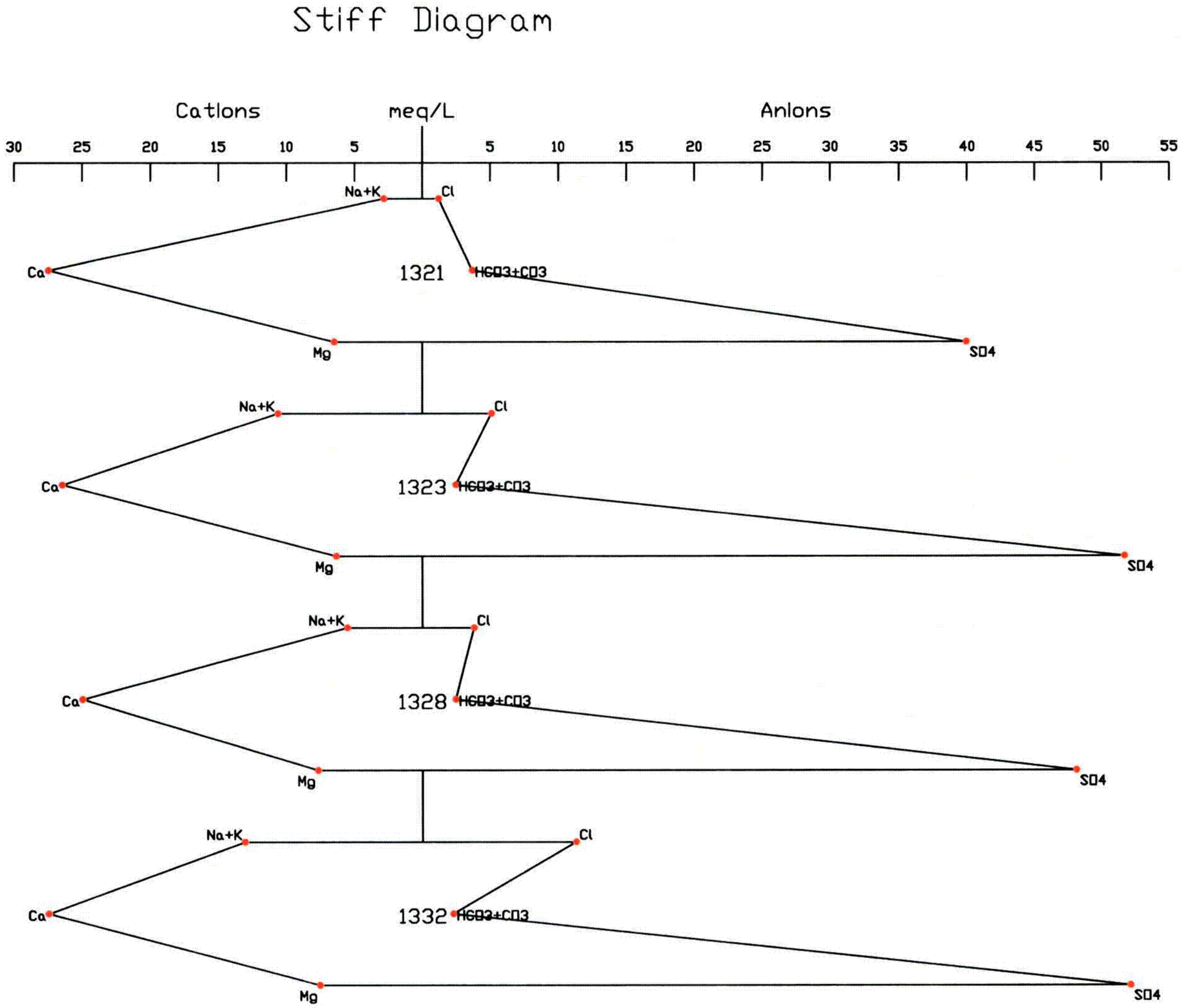
| PROJECT NO.: 04020-044-200 | DRAWING NO.: | |

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| DATE: | 7/22/05 |
| DRAWING NO.: | |

PROJECT NO.: 04020-044-200

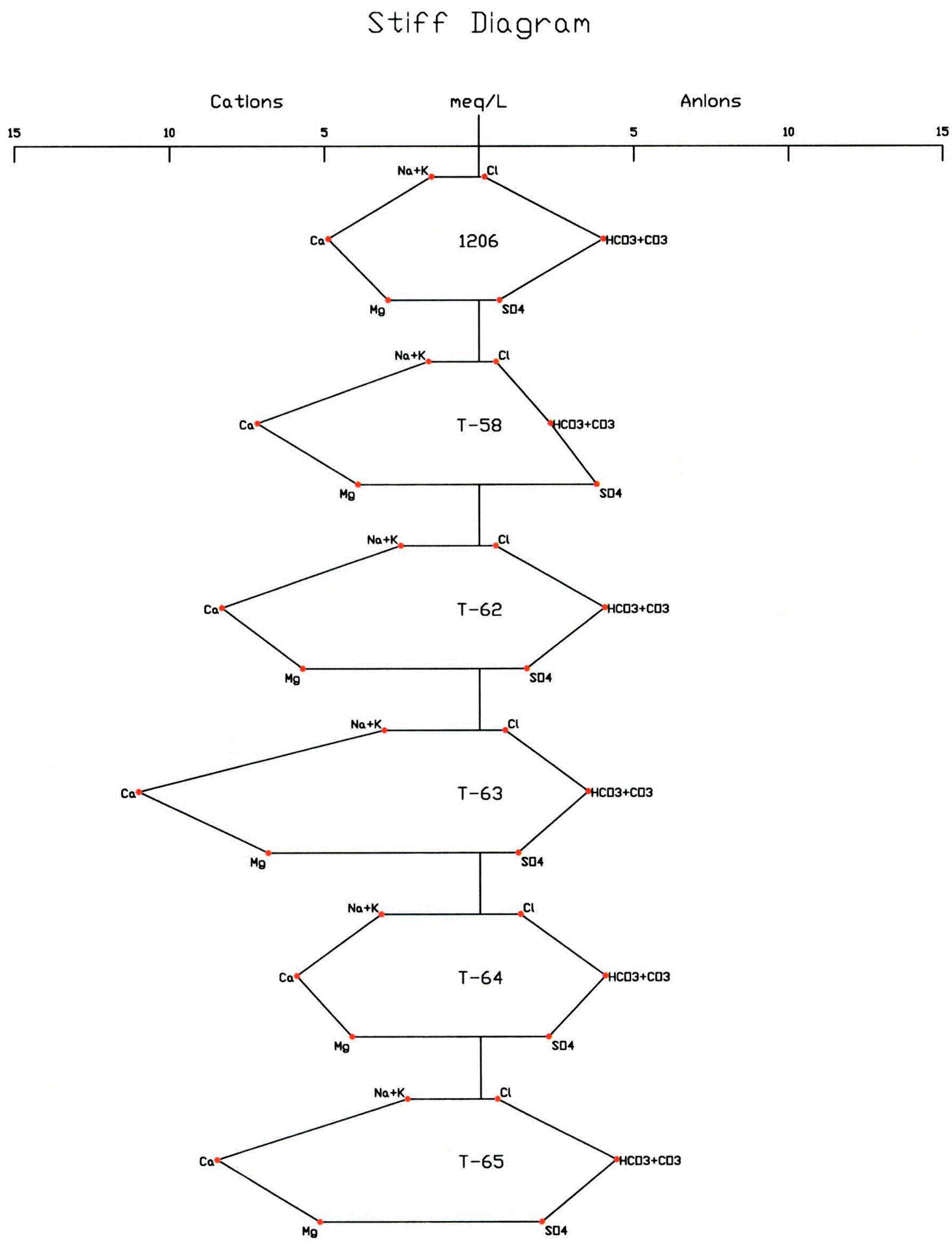
APPENDIX A

STIFF DIAGRAMS

WESTERN UPLAND AREA (4 of 4)

CIMARRON CORPORATION

CRESCENT, OKLAHOMA

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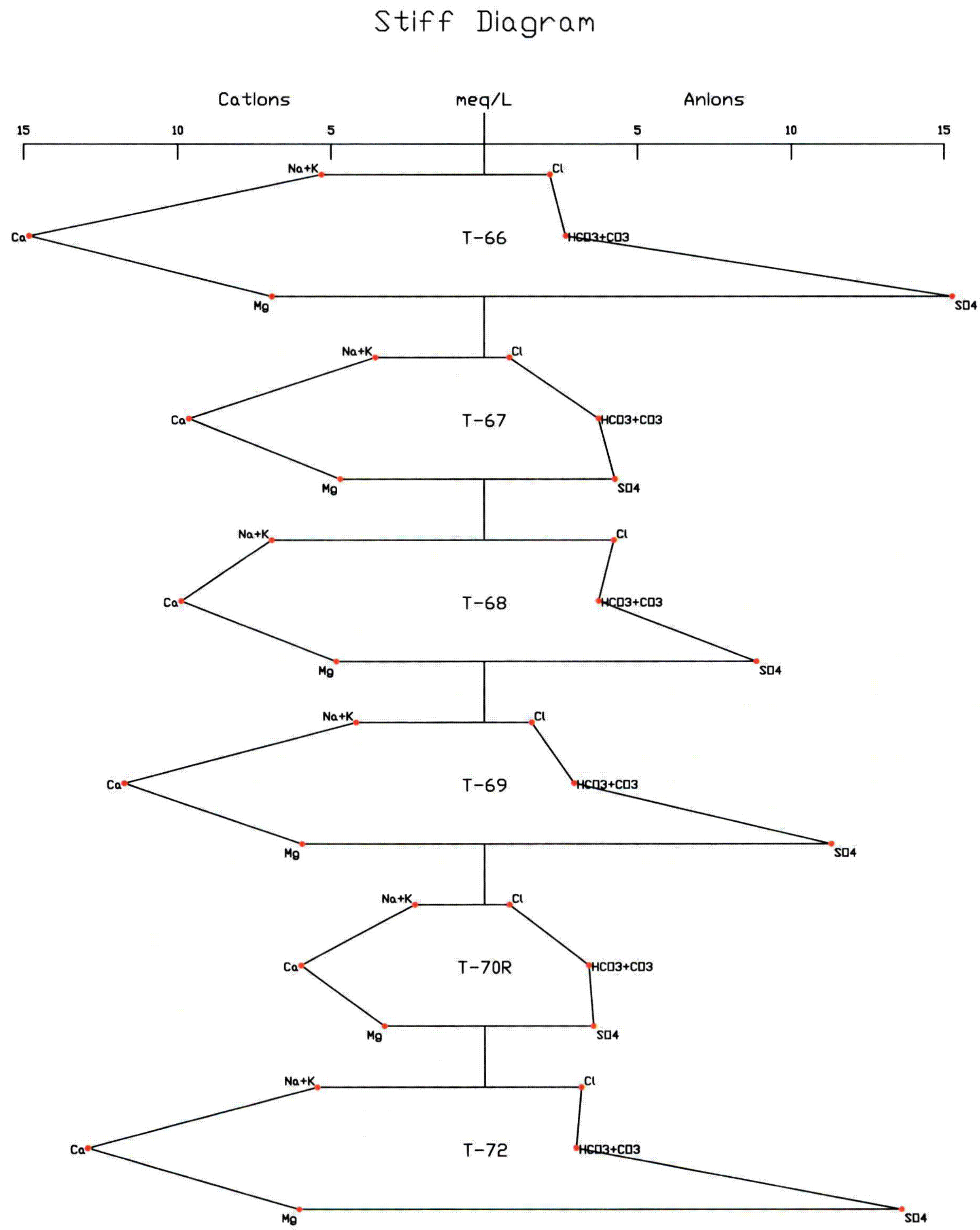
|---|---|---|
| ENSR INTERNATIONAL<br>Consulting • Engineering • Remediation | DRAWN: JAS | APPENDIX A<br>STIFF DIAGRAMS<br>WESTERN ALLUVIUM AREA (1 of 4)<br>CIMARRON CORPORATION<br>CRESCENT, OKLAHOMA |
| | CHECKED: DJF | |
| | DATE: 7/22/05 | |
| PROJECT NO.: 04020-044-200 | DRAWING NO.: | |

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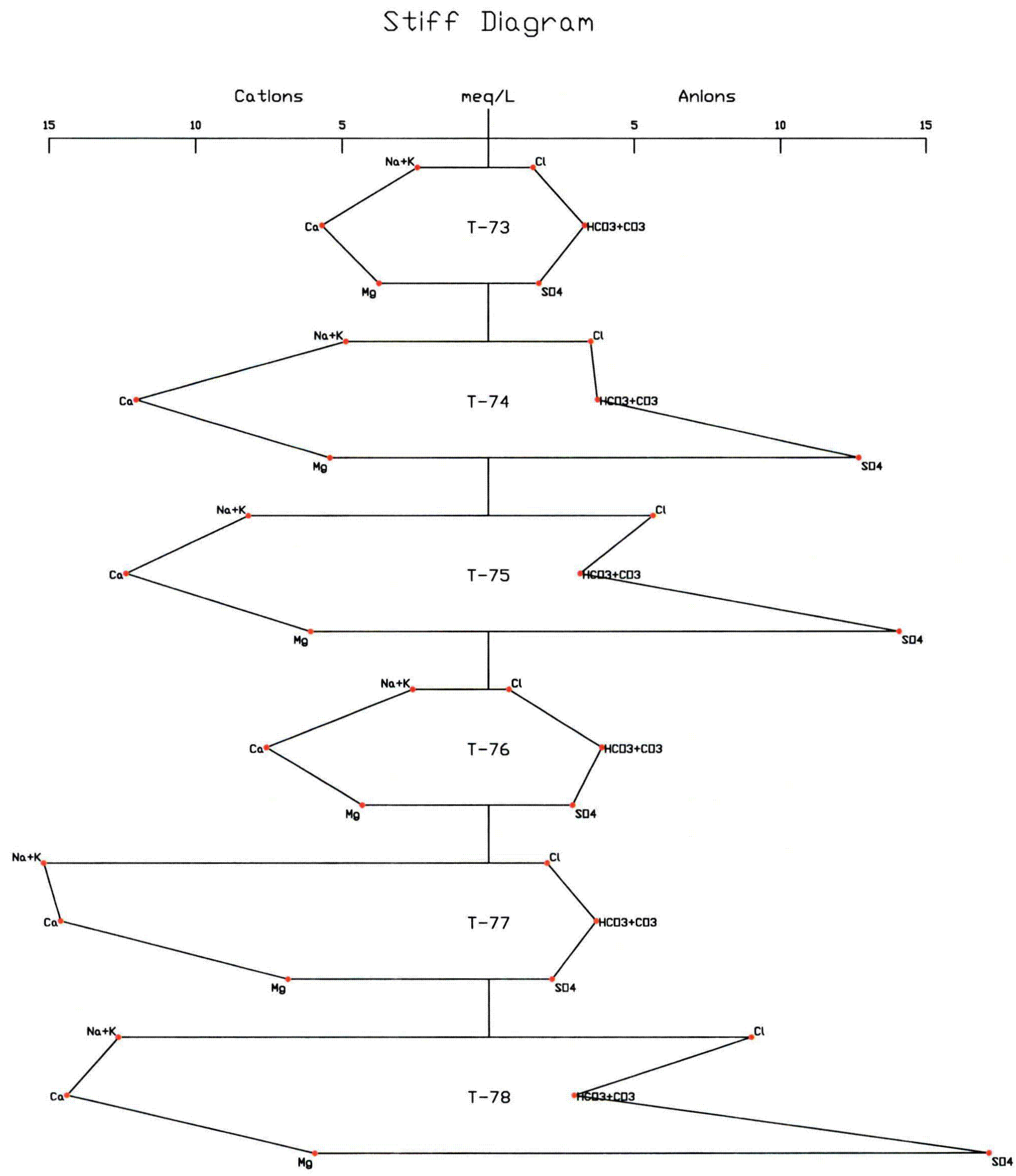
| ENSR INTERNATIONAL Consulting • Engineering • Remediation | DRAWN: JAS<br>CHECKED: DJF<br>DATE: 7/22/05 | APPENDIX A<br>STIFF DIAGRAMS<br>WESTERN ALLUVIUM AREA (2 of 4)<br>CIMARRON CORPORATION<br>CRESCENT, OKLAHOMA |
| PROJECT NO.: 04020-044-200 | DRAWING NO.: | |

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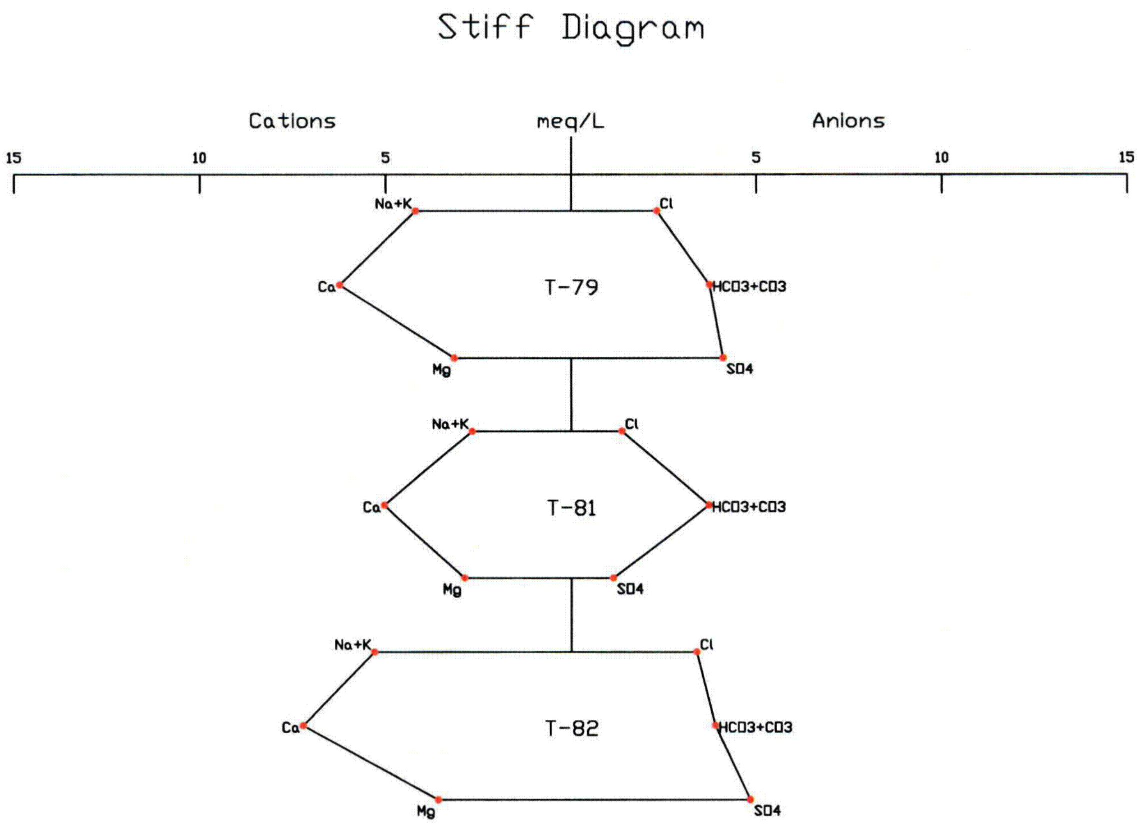
| PROJECT NO.: 04020-044-200 | DRAWN: JAS | CHECKED: DJF | DATE: 7/22/05 |
| | DRAWING NO.: | | |

APPENDIX A
STIFF DIAGRAMS
WESTERN ALLUVIUM AREA (3 of 4)
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

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| ENSR INTERNATIONAL<br>Consulting • Engineering • Remediation | DRAWN: | JAS | APPENDIX A<br>STIFF DIAGRAMS<br>WESTERN ALLUVIUM AREA (4 of 4)<br>CIMARRON CORPORATION<br>CRESCENT, OKLAHOMA |
| | CHECKED: | DJF | |
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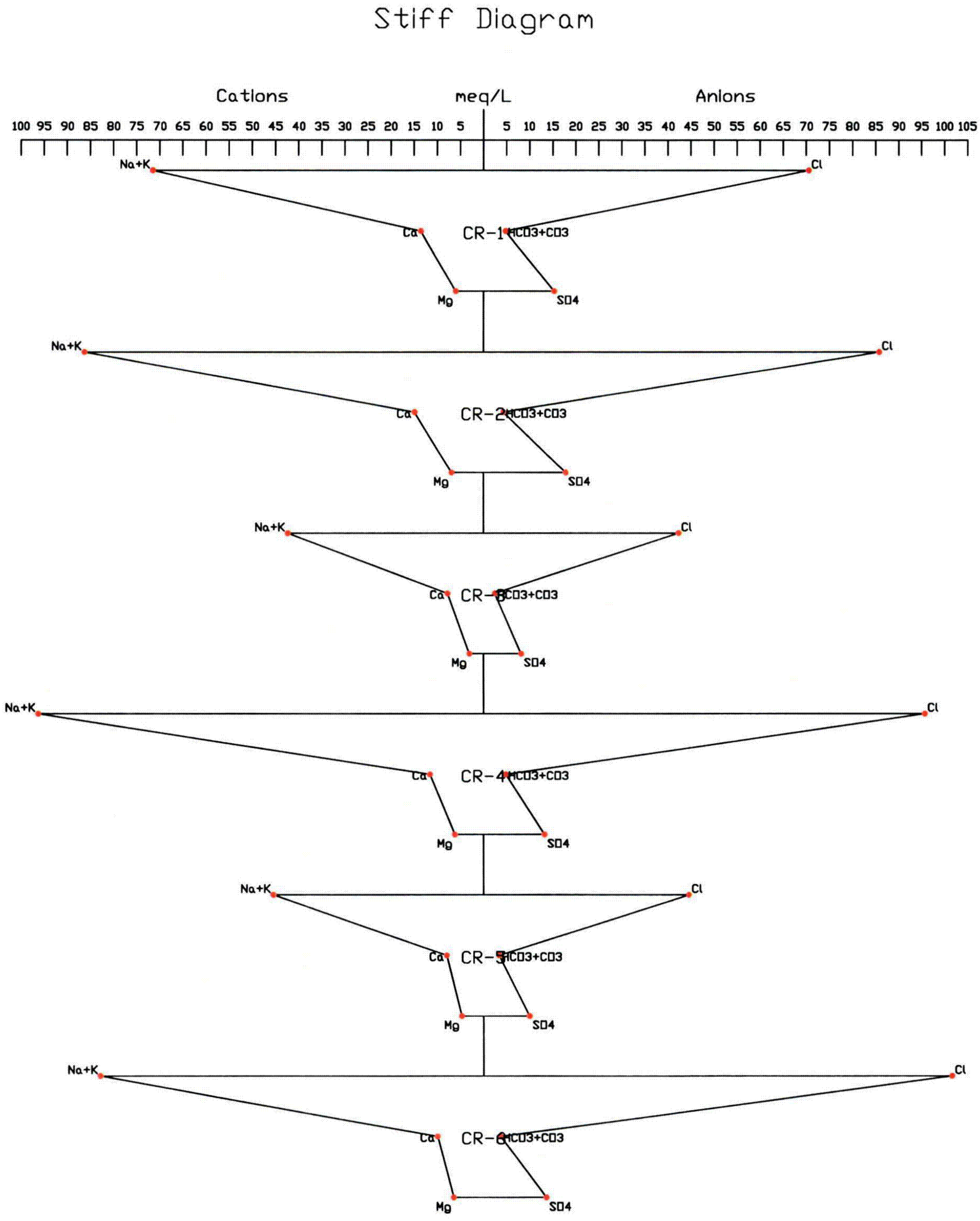
| PROJECT NO.: 04020-044-200 | DRAWING NO.: | | |

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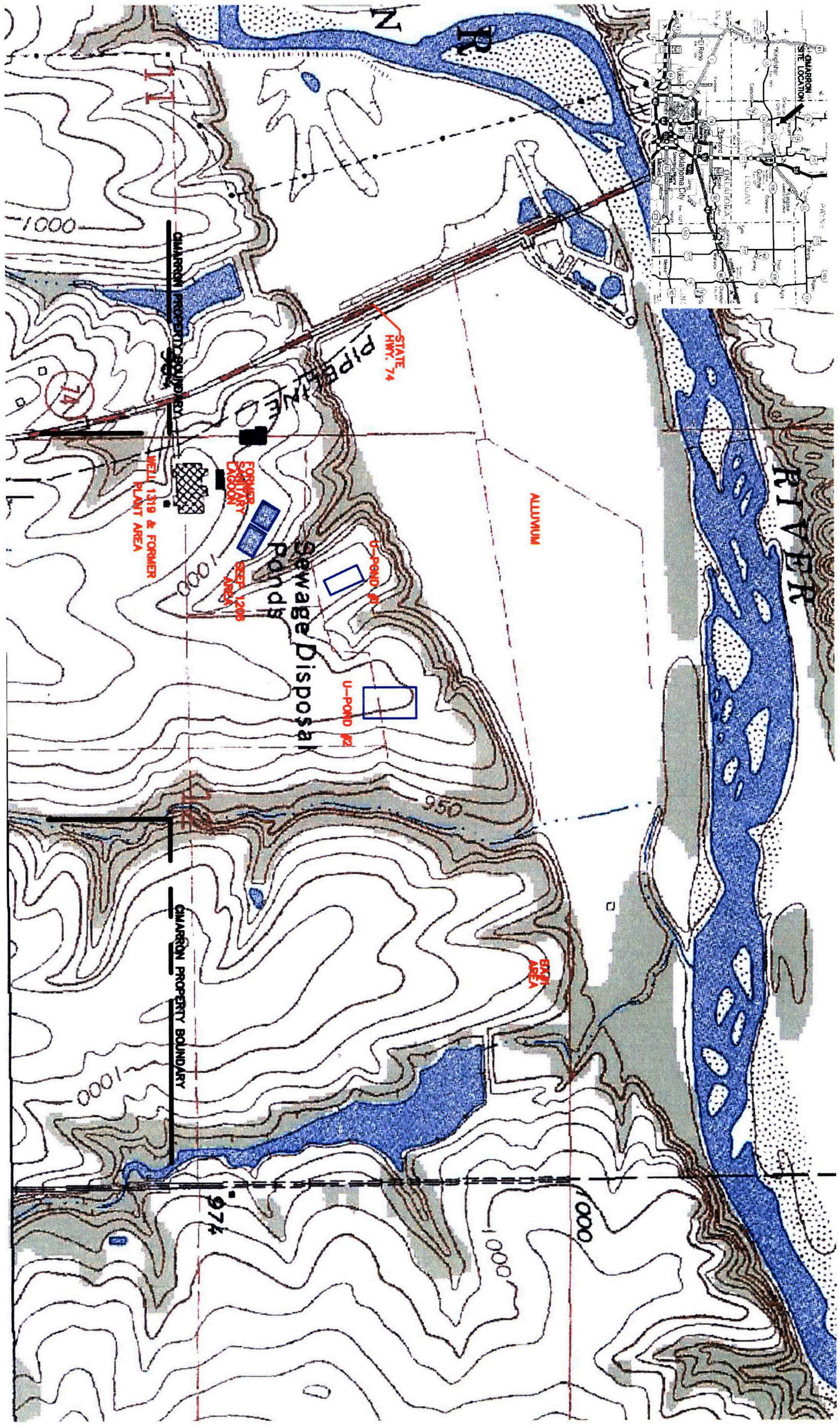
| PROJECT NO.: 04020-044-200 | DRAWING NO.: | |

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




0 800 1600
SCALE IN FEET

| FIGURE NUMBER: | SHEET NUMBER: |
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| 2-1 | 1 |

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

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

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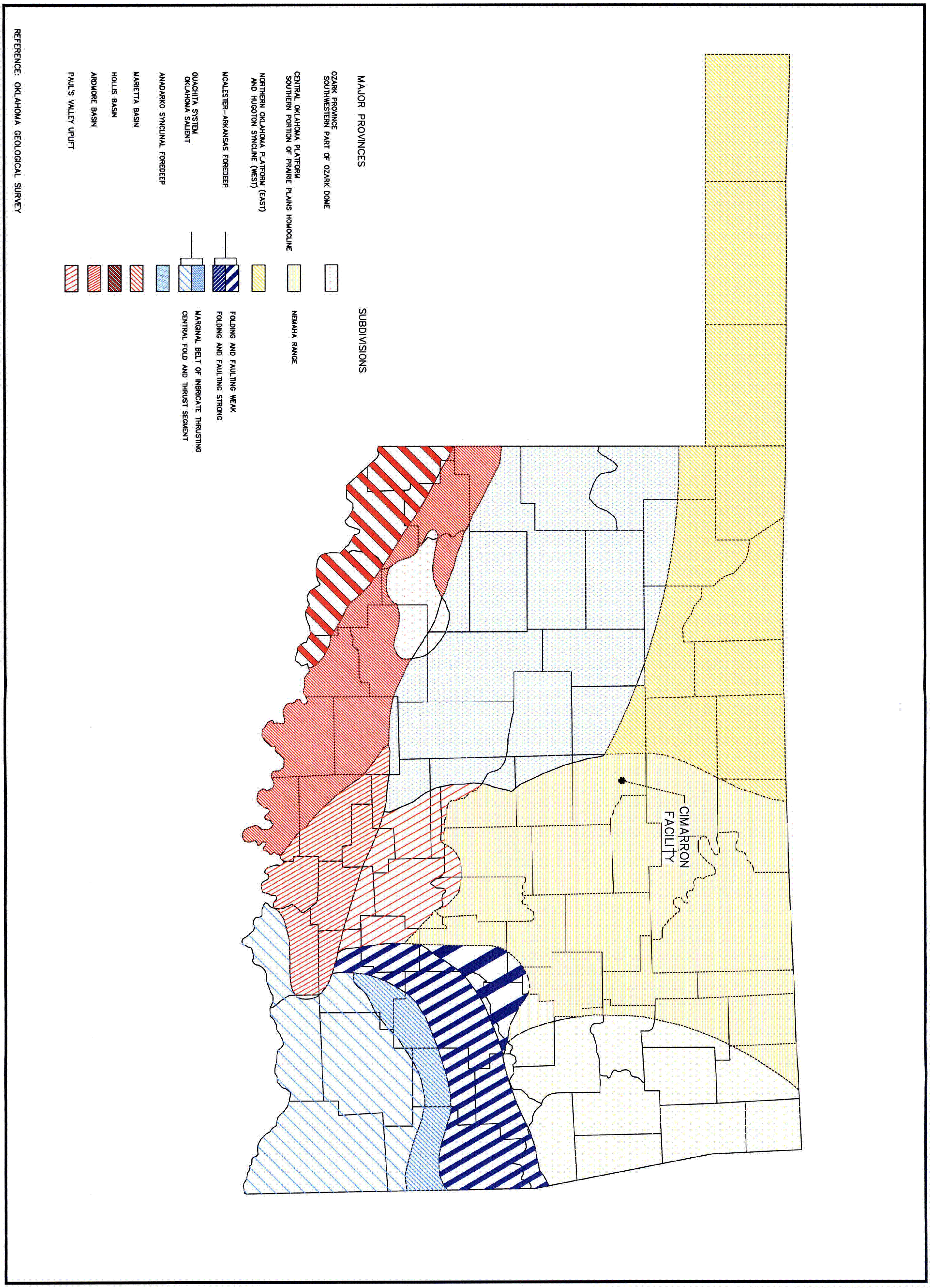
| DRAWN BY: | 1 | DESCRIPTION: | 4/01/05 | JAS |
| JAS | 2 | | 8/17/05 | |
| CHECKED BY: | | | | |
| DJF | | | | |
| APPROVED BY: | | | | |
| DJF | | | | |




| SHEET NUMBER: | FIGURE NUMBER: |
|---|---|
| 1 | 2-2 |

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

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

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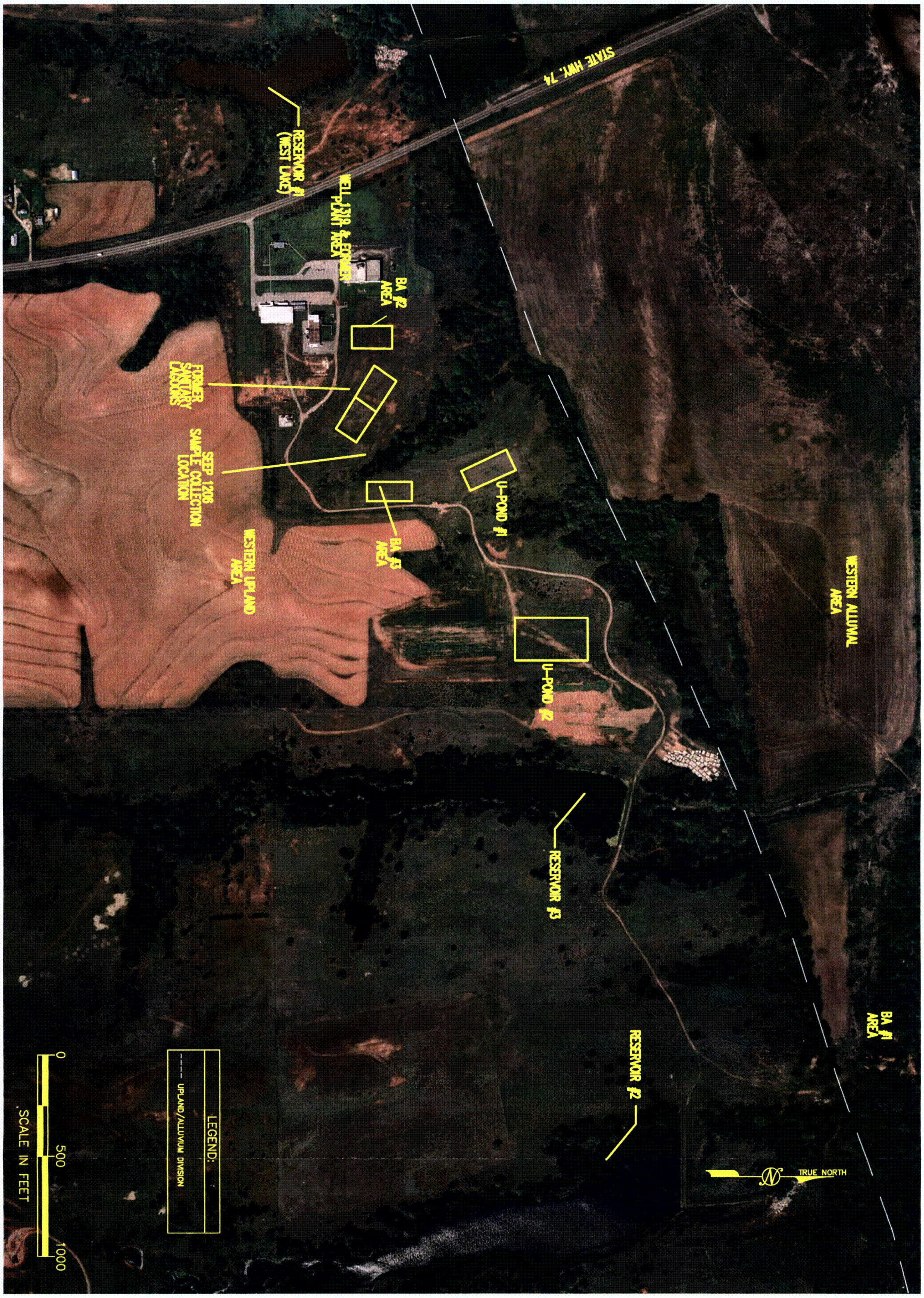
| DESIGNED BY: | NO.: | DESCRIPTION: | DATE: | BY: |
|---|---|---|---|---|
| DRAWN BY: JAS | 1 | | 4/01/05 | JAS |
| CHECKED BY: DJF | 2 | | 6/17/05 | |
| APPROVED BY: DJF | | | | |




| SHEET NUMBER: | FIGURE NUMBER: |
|---|---|
| 1 | 2-3 |

FIGURE 2-3
SITE MAP
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

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

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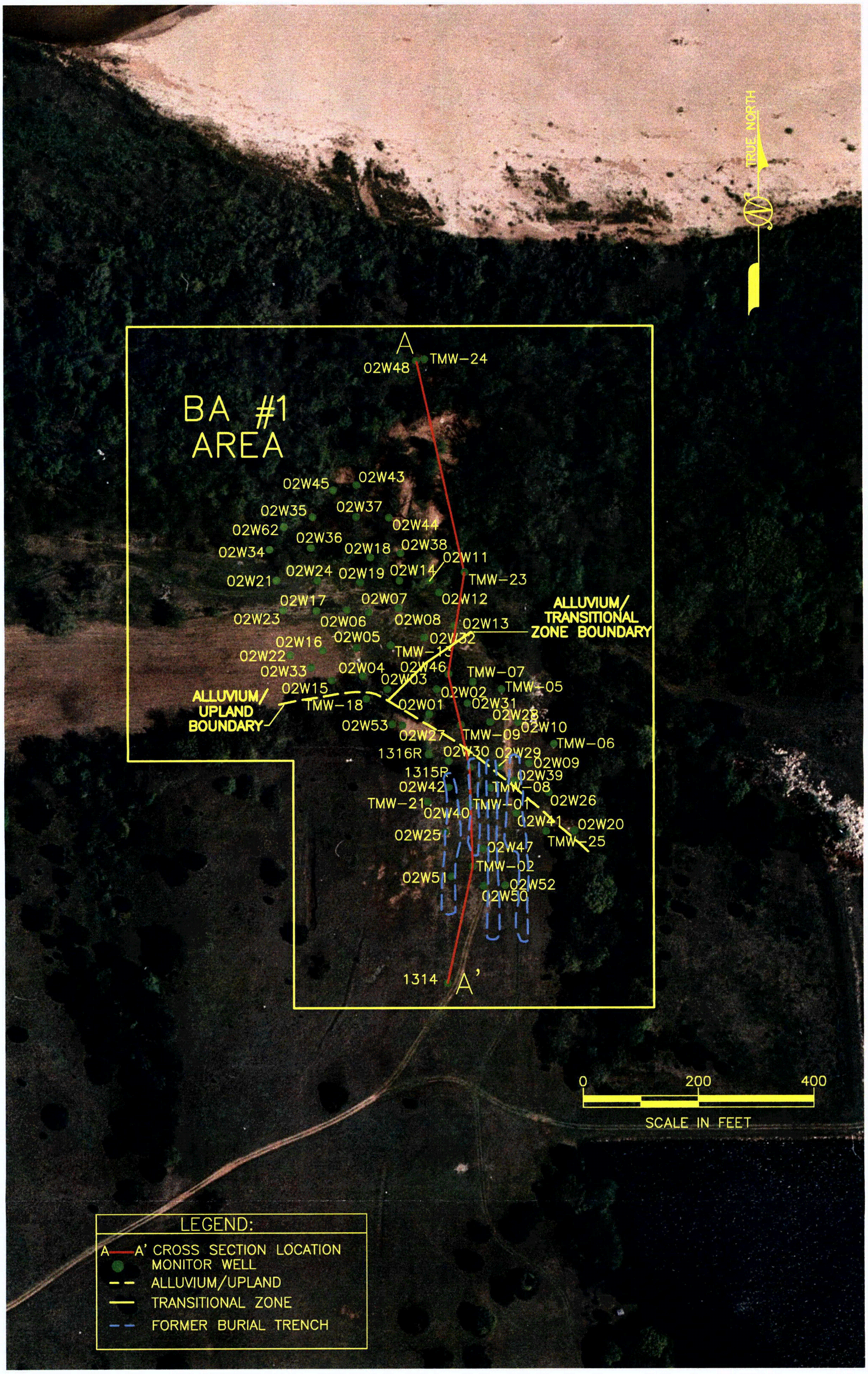
| DESIGNED BY: | |
|---|---|
| DRAWN BY: | HTP |
| CHECKED BY: | DJF |
| APPROVED BY: | DJF |

REVISIONS

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




| 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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| DRAWN BY: | 1 | | 4/01/05 | JAS |
| JAS | 2 | | 6/17/05 | |
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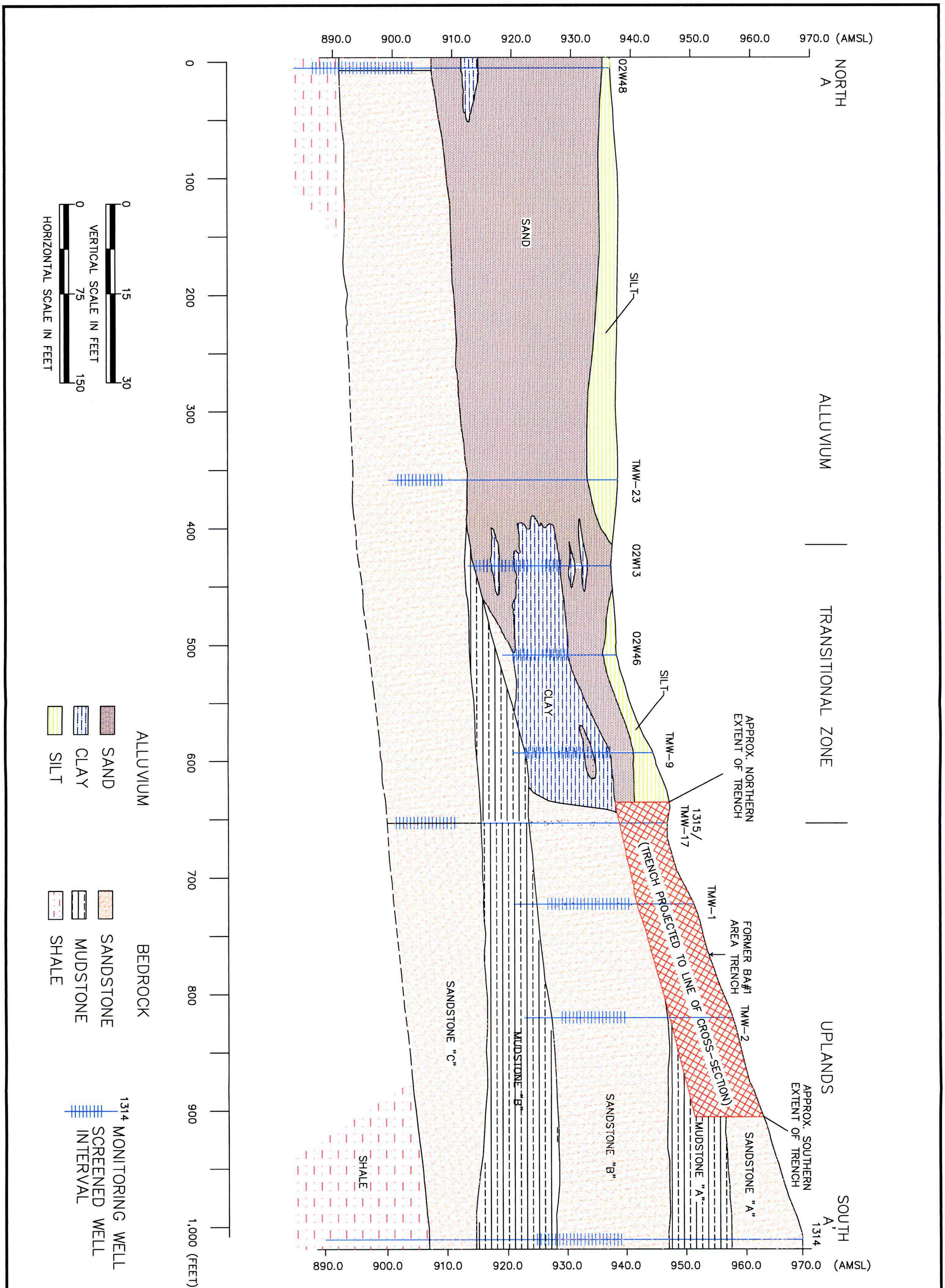
| DJF | | | | |
| APPROVED BY: | | | | |
| DJF | | | | |




| SHEET NUMBER: | FIGURE NUMBER: |
|---|---|
| 1 | 2–5 |

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

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

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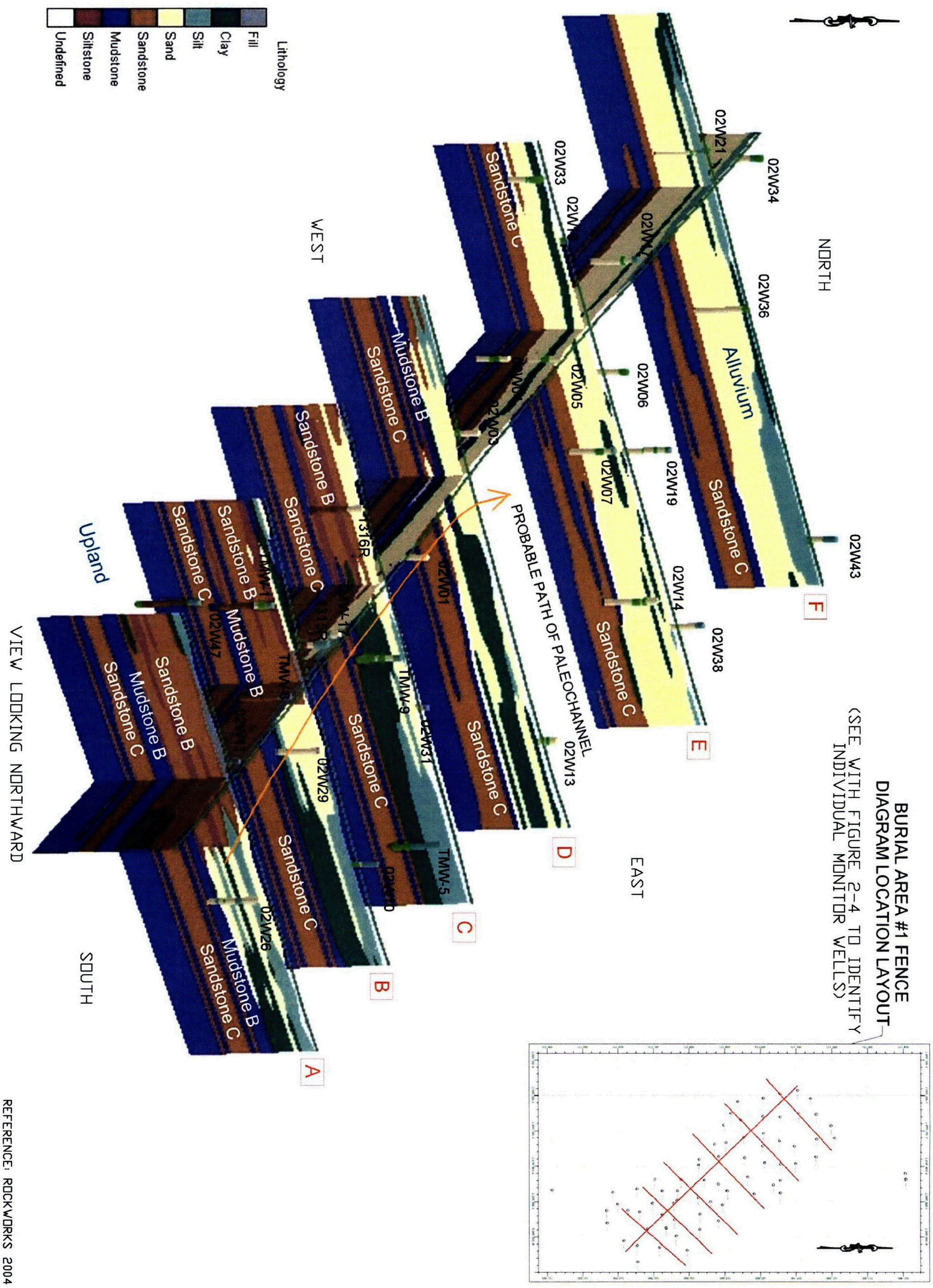
| JAS | 2 | | 6/17/05 | |
| CHECKED BY: | | | | |
| DJF | | | | |
| APPROVED BY: | | | | |
| DJF | | | | |

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| | NO. | DESCRIPTION | DATE |
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| | 2 | | 6/17/05 |
| CHECKED BY: DJF | | | |
| APPROVED BY: DJF | | | |

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

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

FIGURE NUMBER: 2-6
SHEET NUMBER: 1

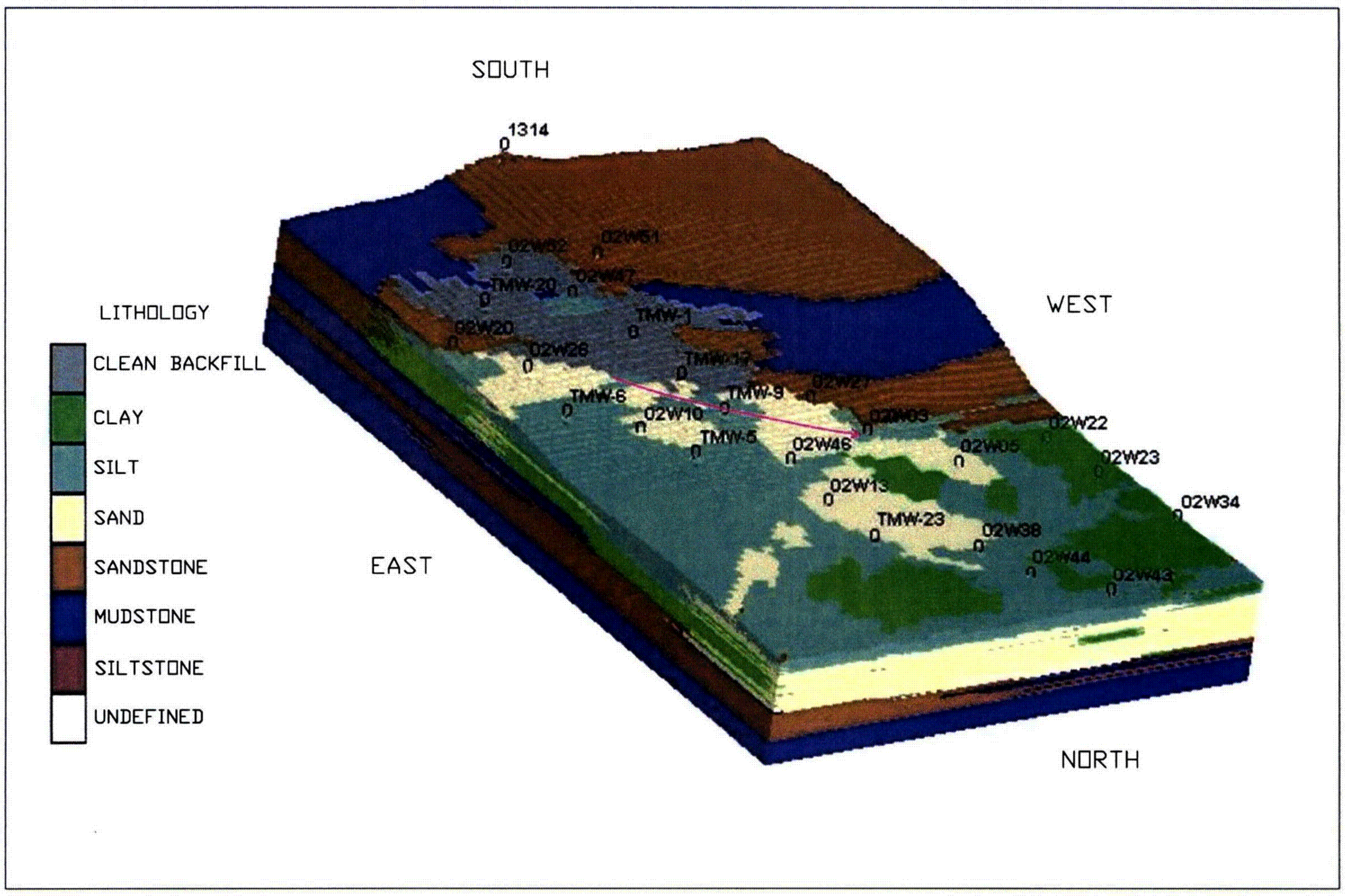


IMAGE 2-7A. Lithologic model of BA #1 Area before overburden sand was 'removed'. View from northeast.

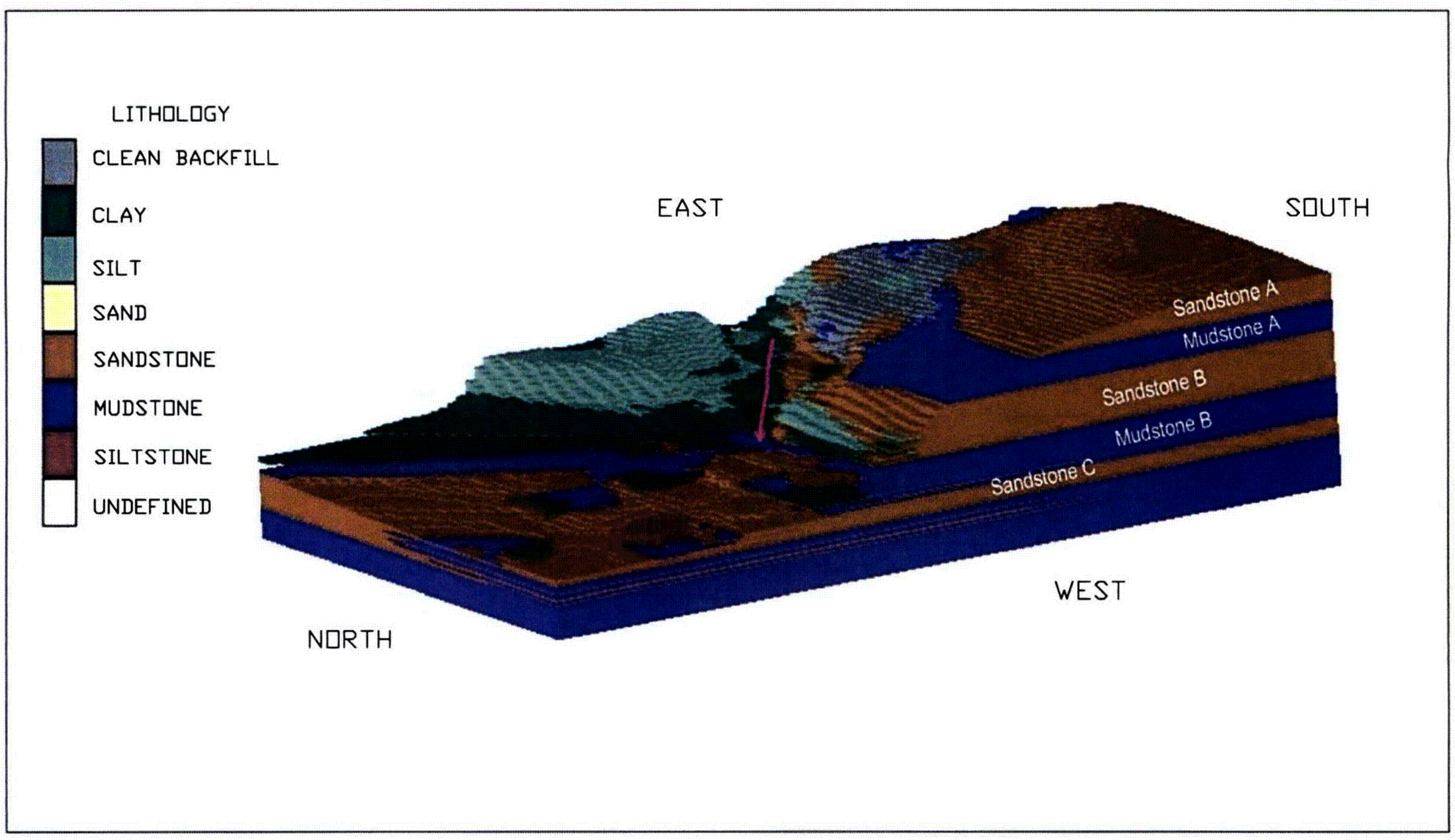


IMAGE 2-7B. Lithologic model of BA #1 Area after overburden sand was 'removed', revealing a paleochannel depicted as a valley in the figure. The curve with arrow head indicates probable path of the channel. View from northwest.

SHEET NUMBER: 1

FIGURE NUMBER: 2-7

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

| SCALE: | DATE: | PROJECT NUMBER: |
|---|---|---|
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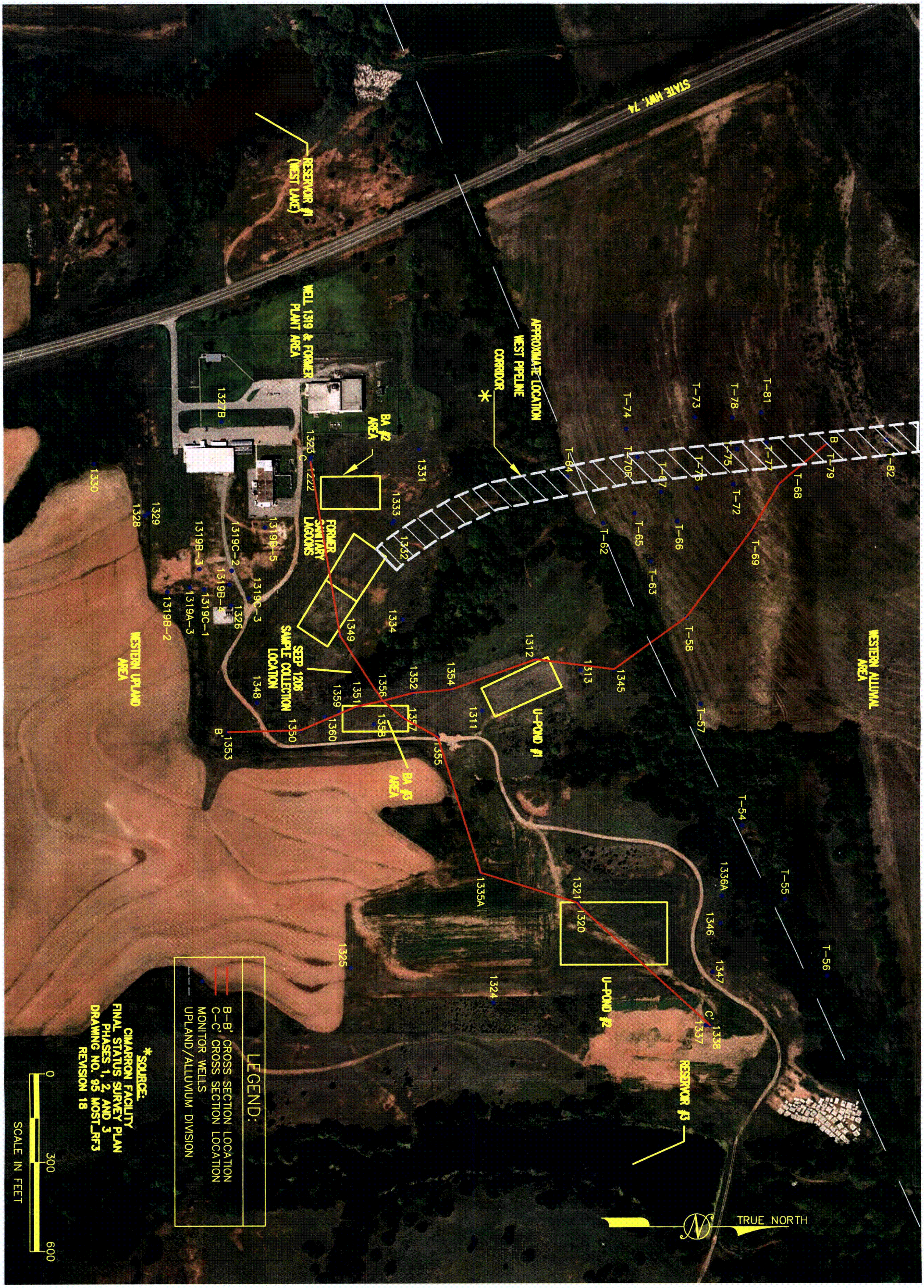
| 2 | | 6/17/05 | |

DWG. NO. 040200008




| | |
|---|---|
| FIGURE NUMBER: | 2-8 |
| SHEET NUMBER: | 1 |

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 |

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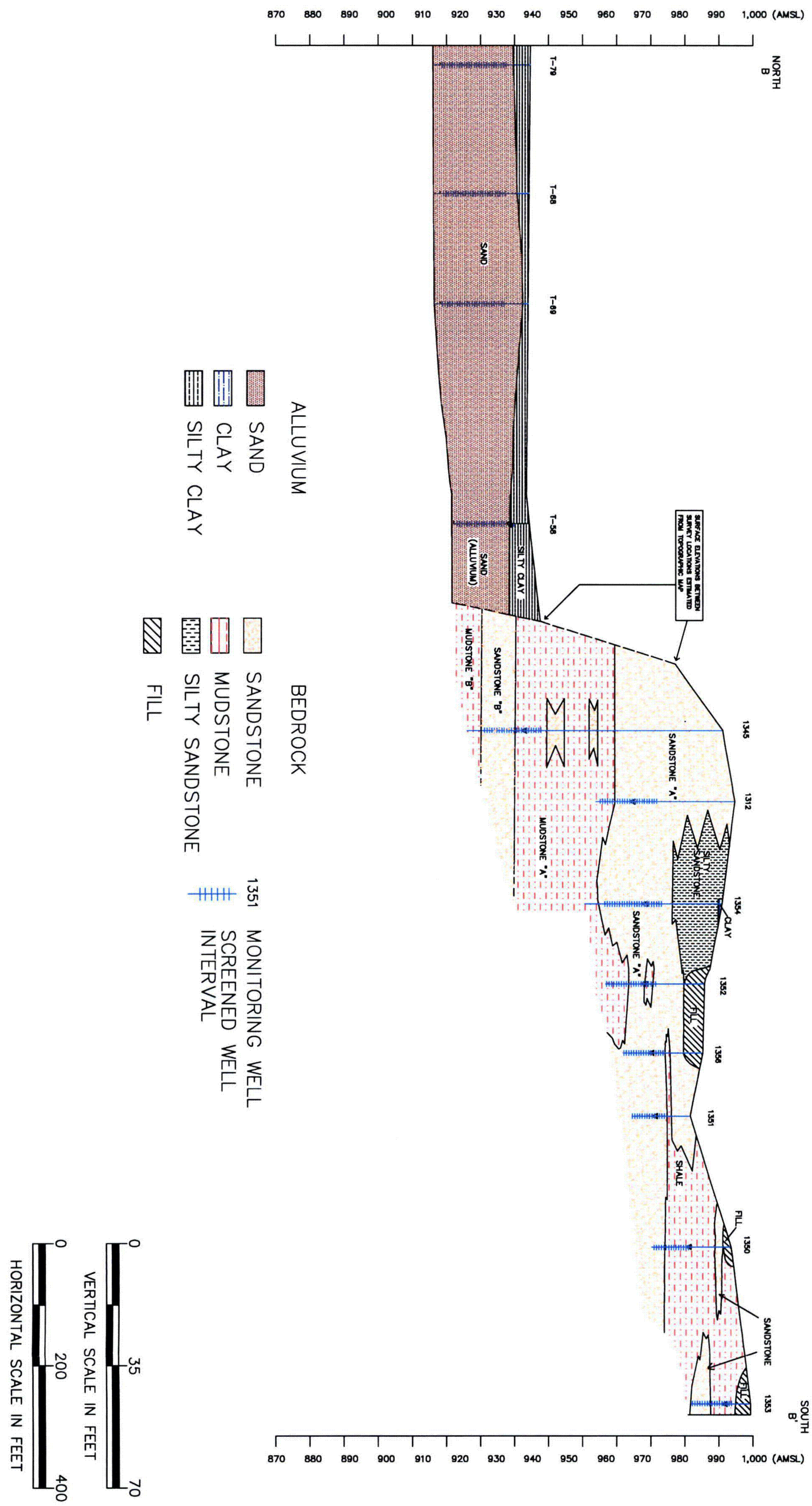


| SHEET NUMBER: | FIGURE NUMBER: |
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| 1 | 2-9 |

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 |


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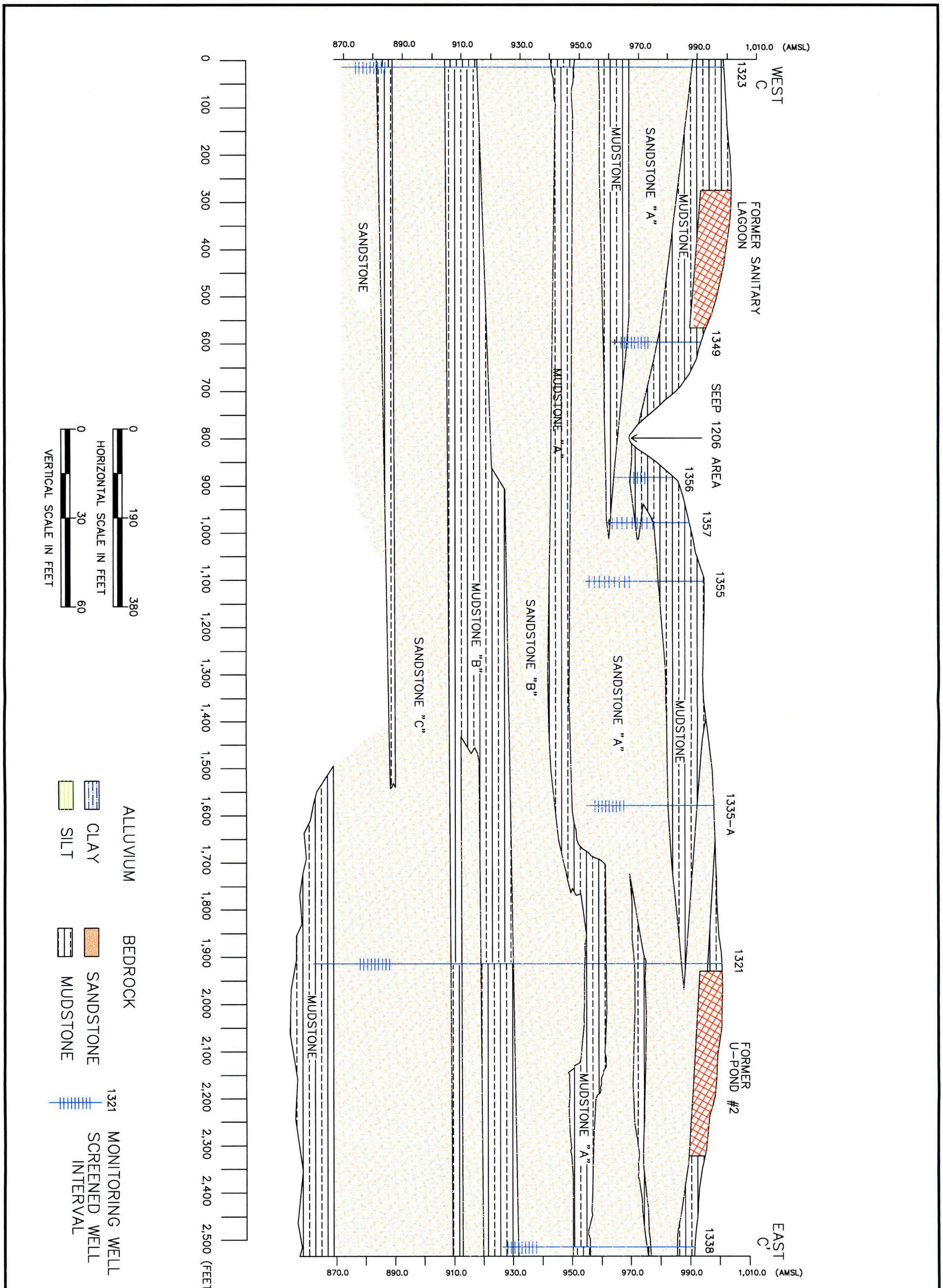


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| 1 | 2-10 |

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

| SCALE: | DATE: | PROJECT NUMBER: |
|---|---|---|
| 1"= 190' | 8/10/05 | 04020-044-200 |

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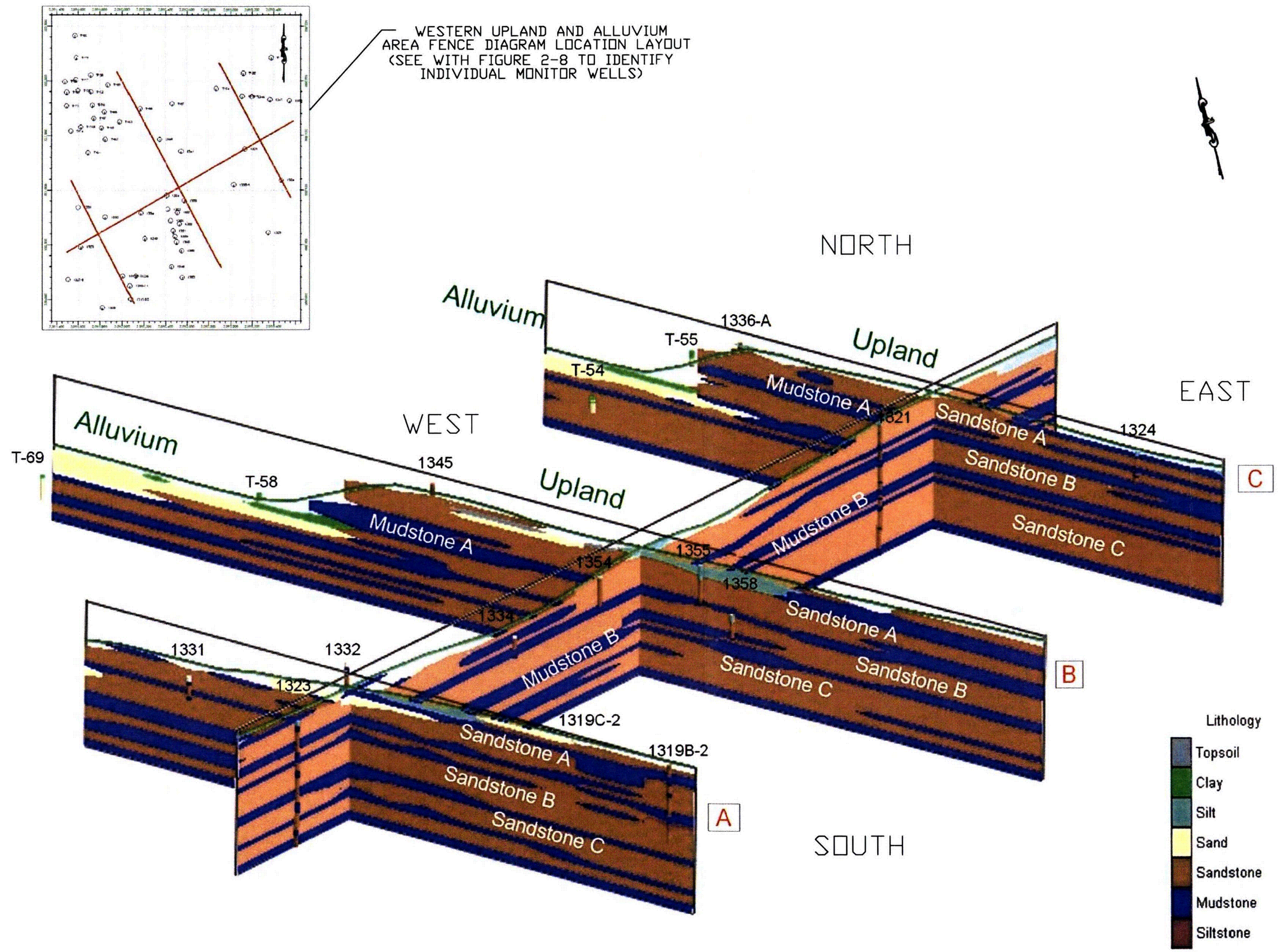


VIEW LOOKING NORTH-NORTHEASTWARD

REFERENCE: ROCKWORKS 2004

DWG. No.

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| CHECKED BY: DJF | 3 | | 6/17/05 | |
| APPROVED BY: DJF | | | | |


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

| SCALE: | DATE: | PROJECT NUMBER: |
|---|---|---|
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FIGURE NUMBER: 2-11

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# 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 regional 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). Adams and Bergman (1955) reported a low-water median flow rate of approximately 100 cubic feet per second (cfs) and a high-water median flow rate of 600 cfs.

Flood statistics for the Cimarron River have been compiled by the USGS (Tortorelli and McCabe, 2001). Peak flows range from a 2-yr flood with a discharge of 26,700 cfs to a 500-yr flood with a discharge of 237,000 cfs. Floods most typically occur in this area in May-June or October, largely as a function of heavy rainfall in upstream portions of the watershed. The most recent significant flood was 20 years ago in 1986. The extent of flooding for the 100-yr flood includes the entire alluvial valley, but not the upland areas of the site.

#### 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 Other 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 from groundwater base flow when groundwater levels are relatively high.

Within the Cimarron Site, three unnamed drainages have been dammed to form small reservoirs, numbered 1 through 3 as shown in Figure 3-3. The maximum water levels in the reservoirs are controlled by spillways. When water levels in the reservoirs exceed the elevation of the spillways, which typically occurs following heavy rainfall, water flows over the top of the spillways into the drainage ways below. 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 Regional 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). Adams and Bergman (1995) estimate a similar recharge of 8 percent of annual precipitation. 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 uplands at 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

The general groundwater flow direction 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 directions vary locally depending on depth within the Garber Formation.

The conceptual model of the groundwater system at the Cimarron site is based on information collected over many years, as noted in Section 1.4. In addition, to support evaluation of remedial alternatives, a numerical groundwater flow model was recently constructed (ENSR, 2006). The model has also served as a tool in refining the groundwater conceptual model. The model geometry, inputs, calibration process and simulated hydraulic heads are discussed in detail in the Groundwater Flow Modeling Report, Cimarron Site (ENSR, 2006). As appropriate, information from the numerical modeling has been incorporated in the conceptual model discussion below.

### 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 $1.03 \times 10^{-3}$ cm/s with a range from $2.41 \times 10^{-4}$ cm/s to $5.7 \times 10^{-3}$ 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 $7.85 \times 10^{-5}$ cm/s.

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 $9.97 \times 10^{-4}$ cm/s to $2.39 \times 10^{-5}$ cm/s. 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.

A comprehensive summary of site-specific hydraulic conductivity values is provided in the Groundwater Flow Modeling Report. In addition, the numerical modeling included calibration of hydraulic conductivity. The calibrated values for the various geologic materials are presented in the Report.

Depths to groundwater vary across the site, depending on the geologic unit and time of measurement. The following discussion is based on four rounds of water levels collected over various seasons between 2003 and 2005 (Sept 2003, Dec 2003, Aug-Sept 2004, and May 2005).

In general, the highest water levels are found in the spring, with the lowest in the fall. This pattern is typical in temperate areas where plant evapotranspiration intercepts much of the recharge to groundwater during the growing season, with a resulting lowering of groundwater levels.

In the Western Upland area, depths to groundwater range from approximately 20 to 50 feet in Sandstone A, fluctuating up to about 2 feet across the four monitoring events. The depth to water in Sandstone B in the Western Upland Area is approximately 30 feet greater than Sandstone A. The relative groundwater levels suggest there may be some perching of water in Sandstone A, especially to the north, near the escarpment. That is, there may be some portions of Sandstone B that are unsaturated.

In the Western Alluvium Area, the depth to groundwater ranges from approximately 20 to 35 feet, fluctuating approximately 2 feet over time. In the BA#1 Area, depths to groundwater in Sandstone B range from approximately 20 to 35 feet, with fluctuations over time of up to 7 ft. In the alluvium, depths to water range from approximately 20 to 30 feet, with fluctuations of 2 to 3 feet.

In general, changes in water levels are more similar across wells in the alluvium, consistent with its higher permeability and greater storage capacity. This suggests that hydraulic gradients in the alluvium are very consistent, not changing significantly in direction or magnitude over time. In contrast, water level fluctuations are more variable across wells in the bedrock units, although still relatively small, typically on the order of a few feet.

### 3.2.2 Potentiometric Surfaces

The direction of 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 Sandstone A in the Western Upland Area and the Alluvial Area based on groundwater level measurements collected during the August/September 2004 annual sampling of monitor wells at the Cimarron Site. As noted in Section 3.2.2, groundwater levels may change seasonally, however, the piezometric surface maps do not change significantly over time.

### 3.2.3 General Groundwater Flow Patterns

In those areas where Sandstone A is the uppermost water-bearing unit, the hydraulic gradient in Sandstone A mimics local topography. Groundwater in Sandstone A flows from the topographically higher areas to adjacent drainages and reflects local recharge from precipitation events. That is, the hydraulic gradients in Sandstone A are northwards towards the escarpment, with components of flow to the east and/or west towards the drainages in their vicinity. This same pattern is observed in water levels from Sandstone B where it is the uppermost water-bearing unit in the BA#1 area.

Flow in deeper Sandstones B and C is more regionally controlled. Generally, flow in Sandstones B and C is north to northwest toward the Cimarron River. Flow in the alluvium is northward toward the Cimarron River because the river is a gaining stream throughout its reach from Freedom to Guthrie.

Locally, groundwater flow is expected to be affected by local geologic conditions. The occurrence of the paleochannel in the transition zone in the BA#1 area may provide a preferential pathway for groundwater flow in the otherwise lower permeability of the silts and clays. The presence of the mudstones between the sandstone units will affect flow between the units. Similarly, interbedded layers of silts and clays in the sandy alluvial materials can be expected to have some influence on groundwater flow.

In addition to the horizontal groundwater flow, vertical components of the hydraulic gradient are present depending on the groundwater recharge-discharge relations. In the uplands and generally to the south, the vertical component of the gradient is expected to be downward, as this is an area of groundwater recharge, as described in Section 3.1.4. In the alluvium and near the Cimarron River, vertical gradients are expected to be upward, reflecting groundwater discharge to the River.

### 3.2.4 Groundwater/Surface Water Interactions

The drainages within the Cimarron Site receive flow from precipitation events and from groundwater base flow when groundwater levels are relatively high. Most of the drainages penetrate only the uppermost sandstone (Sandstone A in the Western Alluvial area, Sandstone B in the BA#1 area) and thus act as local drains for shallow groundwater during precipitation events. Sandstone C has no local interaction with stream flow, except regionally with the Cimarron River. The alluvium of the Cimarron River floodplain drains to the river, except during flood events when the long-term, stable gradient is disrupted and groundwater flow may be at least partially from the river towards the south.

The other surface water bodies present at the site are the three reservoirs (see Figure 2-3). As described in Section 3.1.3, based on the maintained water levels in the reservoirs, shallow groundwater is expected to discharge to Reservoirs #1 and #3, and Reservoir 2 is suspected of acting as a recharge source for groundwater.

### 3.2.5 Cimarron River Floodplain

Floodplain sediments can receive water from five possible sources in the site's vicinity: 1) precipitation, 2) upward flow from Sandstone B and/or Sandstone C when either lies beneath the alluvium; 3) discharges from Sandstone A and/or 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 and/or Sandstone C due to convergence of regional groundwater flow at the Cimarron River (Carr and Marcher, 1977). In areas where Sandstone C directly underlies the alluvium, groundwater in Sandstone C flows upward into the floodplain alluvium as evidenced by site geochemical data (see Sections 4.3 and 4.4 of this report). Vertically upward flow from deeper units at or near the Cimarron River beneath the floodplain alluvial sediments is uncertain because of the density of the more-saline water in these units. 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, with reference to the local groundwater contour maps presented in Figures 3-4, 3-5, and 3-6.

### 3.3.1 BA #1 Area

Groundwater in the vicinity of the BA #1 Area (Figure 3-4) 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. Groundwater also enters this area from upgradient. 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. There is also flow in the BA#1 Area towards the drainage to the east. As shown in Figure 3-4, flow in Sandstone B in the area that is west of the transitional zone is mostly northward, and to the south it is eastward towards the drainage. Between these two areas, the gradient is to the northeast along the interface with the transitional zone. Flow is driven by a relatively steep hydraulic gradient (0.10 foot/foot) in Sandstone B.

Based on their relative elevations, it seems likely that groundwater discharges from Sandstone B into the southern portion of the drainage. However, to the north, the groundwater elevation is well below the stream bed. Therefore, when water is flowing in the northern portion of the drainage, such as following precipitation events, groundwater may be locally recharged. The elevation of Reservoir #2 is well above the groundwater in the BA#1 Area. Whatever hydrologic effect the reservoir has on groundwater is reflected in the measured groundwater levels. It is unlikely that fluctuations in the level of the reservoir would affect groundwater flow.

Once groundwater enters the transition zone of 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. When constructing the numerical groundwater flow model (ENSR, 2006), groundwater flow in the transition zone was to the northwest based solely on the site-specific geologic information.

Once groundwater passes through the transitional zone, it enters the sandy alluvial material where the hydraulic gradient is very flat (0.0007 foot/foot). The decrease in gradient is caused by the higher permeability of the sandy alluvium. Groundwater flow in the alluvium is northward, with discharge ultimately to the Cimarron River. Also in the alluvium, there is expected to be upward flow from the underlying bedrock as groundwater in the bedrock is discharging to the River.

There is no evidence of perched groundwater in this area. However, the presence of the mudstones is likely to restrict vertical movement of groundwater in preference to horizontal flow in the sandstones. The presence of the mudstones indicates that vertical hydraulic conductivities across units are significantly smaller than horizontal conductivities within water-bearing units. Gradients within these lower permeability units are expected to be predominantly vertical. However, due to the low permeabilities of the mudstones, flow will be predominantly horizontal in the water-bearing units, with a minor component of flow vertically across units.

Based on measured hydraulic gradients and estimated hydraulic conductivities, groundwater velocities in the various units can be estimated. Average linear groundwater velocities were calculated using the hydraulic properties presented above and assuming porosity for the sandstone of 5%, 20% for the transition zone, and 33% for the alluvium. The calculated velocities are 0.6 ft/day for Sandstone B, 0.03 ft/day for the transition zone, and 0.3 ft/day for the alluvium. Velocities generated by the groundwater model are approximately 5 ft/day for the sandstone, 3 ft/day for the transition zone, and 4 ft/day for the alluvium.

### 3.3.2 Western Upland Area

As in the BA#1 Area, groundwater in the Western Upland Area (Figure 3-5) also originates as precipitation that infiltrates into the shallow groundwater unit recharge zones and flows into Sandstone A.

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 escarpment 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 drainage to the northwest (September 2003 data) and about 0.02 foot/foot toward the north.

To the west of the drainage, groundwater flows northeastward towards the drainage near it, and more northerly to the alluvial floodplain at greater distances. At the western edge of the Upland Area, groundwater flow is to the west, most likely towards Reservoir #1, which is located to the west and maintained at an elevation below the groundwater level.

Groundwater levels in Sandstone A range from around 978 feet amsl at the south end of the 1206 Area near Well 1353 to around 964 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 with surface water 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 is present about 30 feet below the groundwater in Sandstone A. The deeper groundwater 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 discharge to seeps in the escarpment. These two water-bearing units are not intercepted by the drainages in the area of the BA #3 Area.

The relative groundwater levels suggest there may be some perching of water in Sandstone A, especially to north, near the escarpment. That is, there may be some portions of Sandstone B that are unsaturated. However, the presence of the mudstones between the water-bearing units is likely to restrict vertical movement of groundwater in preference to horizontal flow. Vertical hydraulic conductivities across units are expected to be significantly smaller than horizontal conductivities within water-bearing units. Gradients within these lower permeability units are expected to be predominantly vertical. Due to the low permeabilities of the mudstones, flow will be predominantly horizontal in the water-bearing units, with a minor component of flow vertically across units. This is demonstrated by the appearance of the seeps, representing horizontal flow within Sandstone A. Seepage from Sandstone A into the drainage way does not infiltrate into Sandstone B, but commingles with surface water, flows along Mudstone A, and is discharged into the transition zone from which it discharges in to the alluvium.

Based on measured hydraulic gradients and estimated hydraulic conductivities, groundwater velocities can be estimated. Average linear groundwater velocities were calculated using the hydraulic properties presented above and assuming porosity for the sandstone of 5%. The calculated groundwater velocity is 1.2 ft/day for Sandstone A.

### 3.3.3 Western Alluvial Area

The water table in the Western Alluvial Area (Figure 3-6) is found in the alluvial floodplain of the Cimarron River. Groundwater flow in the Western Alluvial Area is generally northward toward the Cimarron River, as shown in the groundwater contour map in Figure 3-6. The hydraulic gradient is approximately 0.002 foot/foot. This is significantly lower than in the adjacent uplands, due to the increased permeability of the alluvial materials.

As in the BA#1 area, there is expected to be upward flow from the underlying bedrock into the alluvial material as groundwater in the bedrock is discharging to the Cimarron River.

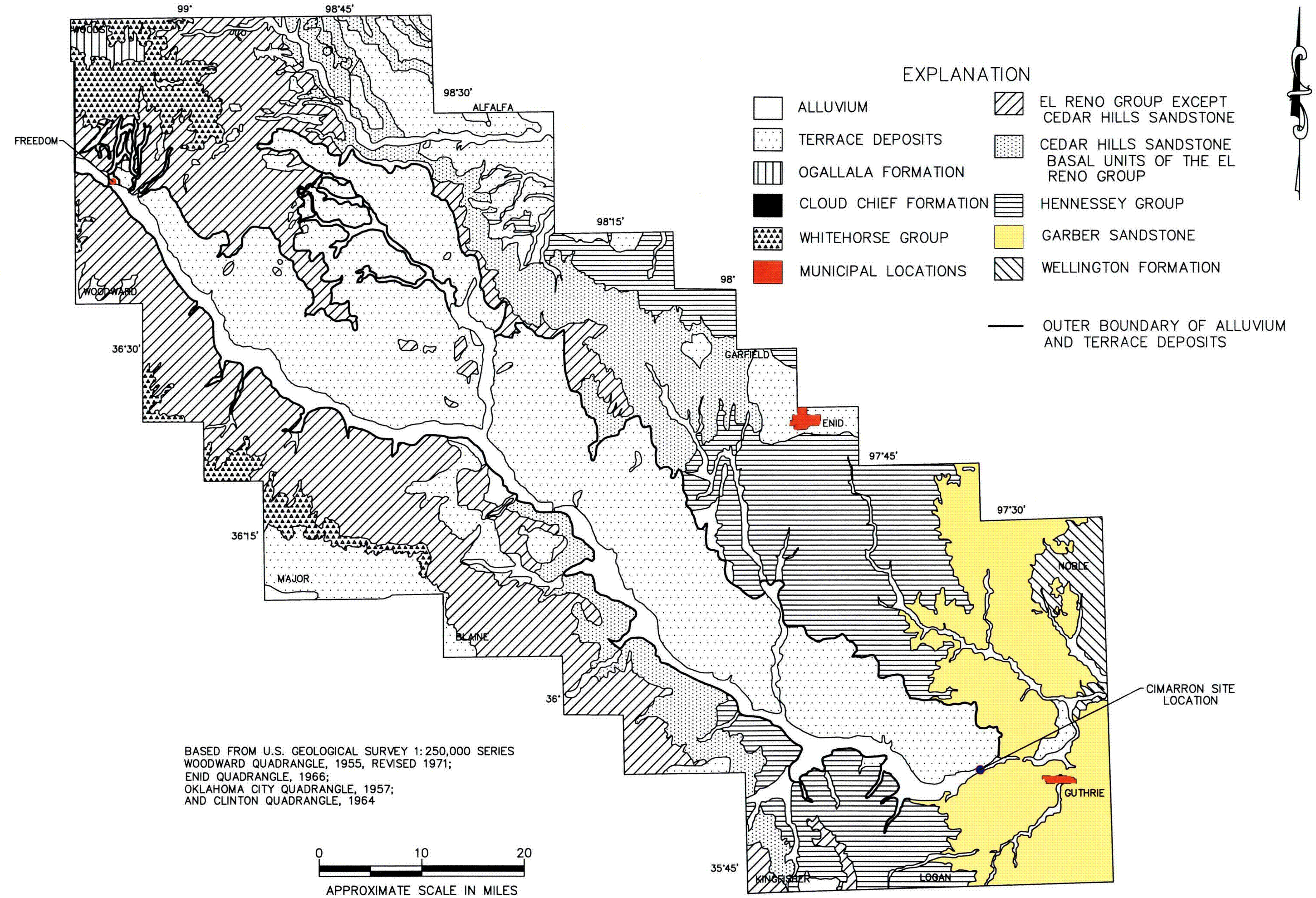
Average linear groundwater velocities were calculated using the hydraulic properties presented above and assuming porosity for the alluvium of 33%. The calculated groundwater velocity is 0.9 ft/day for the alluvium in the Western Alluvial Area. The velocity generated by the groundwater flow model (ENSR, 2006) is approximately 1.5 ft/day.

## 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 uppermost water-bearing unit is local in nature and flows from topographic highs, which also act as recharge areas, to topographic low areas such as the drainages. In the Western Upland Area, groundwater in Sandstone A discharges through groundwater seeps into the escarpment that borders the Cimarron River floodplain. In the BA#1 Area, groundwater in Sandstone B flows eastward to the drainage, and northward to the alluvial sediments and the transition zone. In the deeper bedrock units groundwater flow is regionally controlled, with flow predominantly to the north towards the Cimarron River, with a component of upward flow as it ultimately discharges to the River.

The Cimarron Site is within a recharge area for the upper fresh water zone of the Garber-Wellington Formation. Thus vertical hydraulic gradients are generally downward, except at major discharge areas such as the Cimarron River. However, the low permeabilities of the mudstone units results in flow predominantly horizontal in the water-bearing units, with a minor component of flow vertically across units. The Cimarron River is a gaining river and thus receives groundwater from its floodplain alluvium.

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| | NO.: | DESCRIPTION: | DATE: | BY: |
| DRAWN BY: JAS | 1 | | 4/10/05 | |
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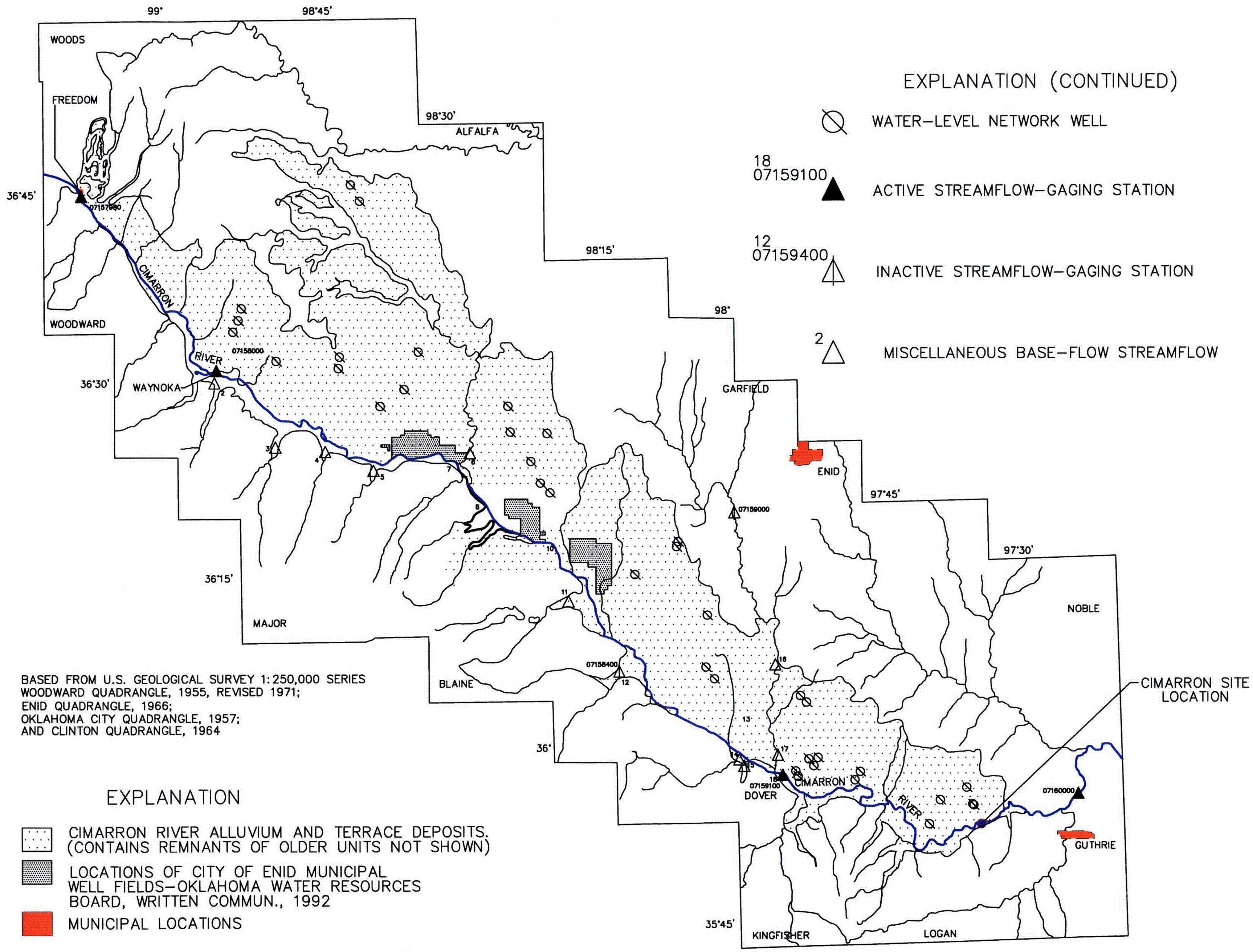
FIGURE 3-1
GEOLOGY ALONG THE CIMARRON RIVER FROM FREEDOM TO GUTHRIE, OKLAHOMA
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

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

FIGURE NUMBER: 3-1

SHEET NUMBER: 1




## EXPLANATION (CONTINUED)

- WATER-LEVEL NETWORK WELL
- 18 07159100 — ACTIVE STREAMFLOW-GAGING STATION
- 12 07159400 — INACTIVE STREAMFLOW-GAGING STATION
- 2 — MISCELLANEOUS BASE-FLOW STREAMFLOW

BASED FROM U.S. GEOLOGICAL SURVEY 1:250,000 SERIES
WOODWARD QUADRANGLE, 1955, REVISED 1971;
ENID QUADRANGLE, 1966;
OKLAHOMA CITY QUADRANGLE, 1957;
AND CLINTON QUADRANGLE, 1964

## EXPLANATION

- CIMARRON RIVER ALLUVIUM AND TERRACE DEPOSITS. (CONTAINS REMNANTS OF OLDER UNITS NOT SHOWN)
- LOCATIONS OF CITY OF ENID MUNICIPAL WELL FIELDS—OKLAHOMA WATER RESOURCES BOARD, WRITTEN COMMUN., 1992
- MUNICIPAL LOCATIONS

0 10 20
APPROXIMATE SCALE IN MILES

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

FIGURE NUMBER: 3–2

SHEET NUMBER: 1

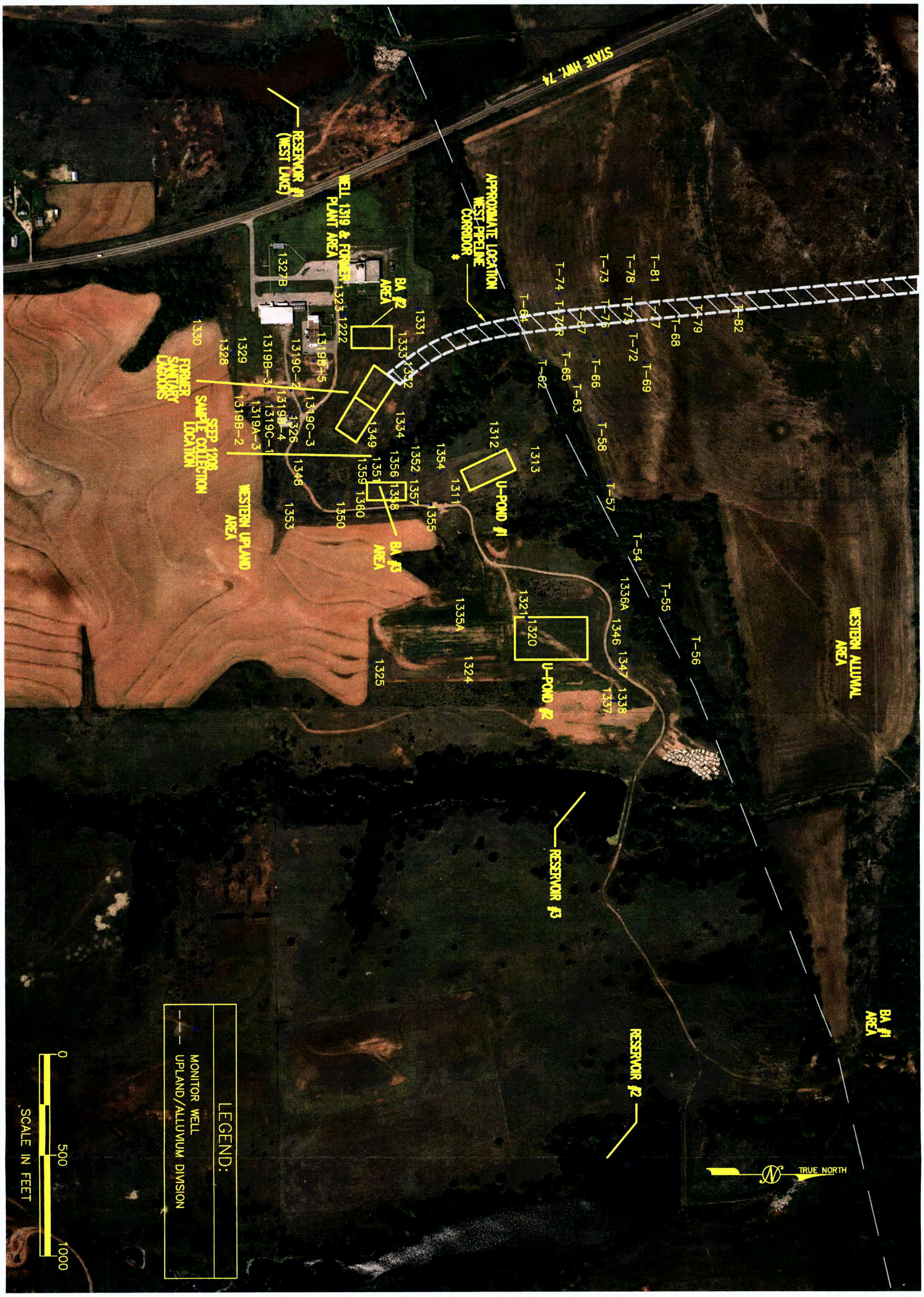


FIGURE 3-3
WELL LOCATIONS AND
UPLAND/ALLUVIUM DIVISION MAP
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

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


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FIGURE NUMBER: 3-3

SHEET NUMBER: 1

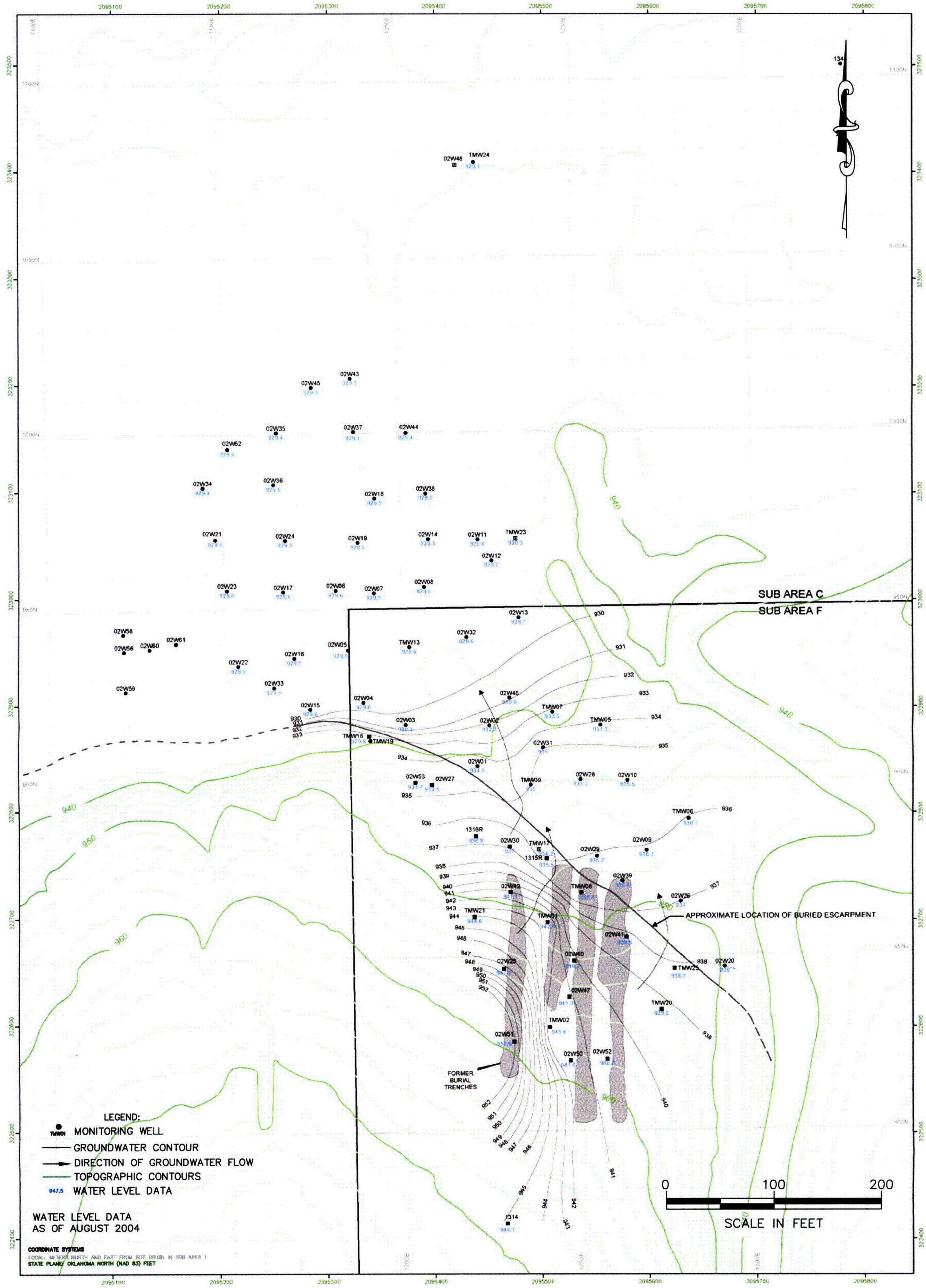


FIGURE 3–4
BA #1 AREA
POTETIOMETRIC SURFACE MAP
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

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

FIGURE NUMBER: 3–4

SHEET NUMBER: 1

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