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, the Western Upland Area, and the Western Alluvial Area; and a discussion of the distribution of licensed nuclear material detected in groundwater in these areas at the Cimarron Site.

4.1 Historical Overview of Sources of Uranium Impact

The Cimarron facility, a Uranium Plant, was formerly known as the Sequoyah Fuels Cimarron Plant, which was operated by Sequoyah Fuels Corporation, a subsidiary of Kerr-McGee Corporation. The facility was operational from 1966 to 1975.

The Uranium Plant utilized two process collection ponds, two sanitary lagoons, and separate disposal trench areas for handling radioactive and non-radioactive waste during its operational period. In addition, Cimarron Corporation has identified drain lines, waste settling ponds, occasional reported releases of radioactive materials within the Uranium Plant yard, and approved disposal of liquid wastes and sanitary wastes to the Cimarron River via shallow subsurface pipelines.

Sanitary wastes from the Uranium Plant were discharged to two adjacent sanitary lagoons, the East and West Sanitary Lagoons, from 1966 to 1985.

Liquid wastes generated during the processing of enriched uranium were passed through an ion-exchange system for removal of uranium before effluent discharge to the Cimarron River during the period from 1966 to 1971. From 1971 to 1975 (when processing terminated), liquid wastes were discharged via shallow subsurface pipelines to onsite uranium disposal ponds for evaporation. These uranium process collection ponds are referred to as Uranium Ponds #1 and #2.

Pipeline leaks were identified during operations and while decommissioning the site. Many of the drain lines were removed and the soil surveyed and removed, as necessary, starting in 1985. Where leaks had occurred, soil exceeding the license criteria was excavated. These areas were documented in Final Status Survey Reports, which were prepared for different onsite areas as decommissioning activities progressed.

The Sanitary Lagoons and the Uranium Ponds were drained, surveyed, decommissioned, and backfilled between 1975 and 1993. When constructed, the Uranium Ponds were lined with asphalt (Uranium Pond #1) or a clay base with rubber side liners (Uranium Pond #2). These liners were left in place when the ponds were backfilled. The Sanitary Lagoons were unlined. Sludge and soil from the Sanitary Lagoons that exceeded Branch Technical Position (BTP) Option 1 criteria were removed prior to decommissioning and backfilling. The three disposal trench areas (BA #1 Area, BA #2 Area, and BA #3 Area) were surveyed following the removal of licensed material and soil exceeding BTP Option 1 criteria. These trenches were then backfilled with clean soil.

A fourth burial area (i.e., Burial Area #4) was developed south of Uranium Pond #2 for the onsite disposal of BTP Option 2 material.

4.1.1 Disposal Trenches in BA #1 Area

Burial Area #1 operated from 1966 to 1970 as an onsite disposal area for radioactive and some non-radioactive solid waste. In addition, drums containing thorium contaminated material from the Cushing, Oklahoma facility were disposed of in this burial area. Four trenches were used for the disposal of waste. Each of these trenches was approximately 8 to 10 feet in width and up to about 200 feet in length. The trenches were closed and capped with soil in 1970. In 1984, Cimarron staff noticed settling of the soil cap and initiated an investigation that included nine soil borings. Groundwater monitoring wells 1314 through 1317 were installed in 1985.

Monitoring wells installed in 1985 detected uranium immediately downgradient (to the north) of the four trenches in the BA#1 Area. The impacted groundwater was found in the Sandstone B (the water bearing unit beneath the trenches) and was subsequently found to continue northward into the alluvial floodplain. The origin of the groundwater impacts was likely the four trenches, but the timing of the migration of uranium from the trenches into the Sandstone B aquifer is uncertain.

The trenches were excavated to depths of 7 to 8 feet during the period from 1986 to 1988. Approximately 65,000 cubic feet of waste was removed and shipped offsite, and 16,000 cubic feet of impacted soil was removed and stockpiled east of the Uranium Plant building for onsite burial as BTP Option 2 material. Following a survey in 1991, the trenches were excavated an additional four feet in depth and an additional 14,000 cubic feet of impacted soil was removed. The four trenches were released in 1992 for backfilling by the NRC with license amendment #9. The trenches were backfilled with clean soil in 1993 and closed, after having remained opened for the time period from 1988 to 1993.

4.1.2 Disposal Trenches in the BA #2 and #3 Areas

Burial Area #2 was formerly located west to northwest from the Sanitary Lagoons (Figures 2-3, 3-3, 2-8, and 4-13). This unlined burial trench was used in the 1970's for the burial of industrial solid waste (Chase Environmental Group. 1994). Groundwater monitoring wells were installed in these areas in the late 1980's. A 10 meter x 10 meter soil survey conducted in May 1990 with soil samples composited to four feet in depth resulted in 15 samples with greater than 30 pCi/g (the highest being 373 pCi/g). A follow-up 5 meter x 5 meter grid soil survey found 4 areas exceeding 1,000 pCi/g and other areas exceeding 30 pCi/g. Remediation began in this area in 1991. Approximately 20,000 cubic feet of waste, averaging 300 pCi/g, was removed from this burial area and shipped offsite. The final soil survey of the Burial Area #2 was conducted in 1994 and the area was backfilled with clean soil.

Burial Area #3 consisted of several trenches south of Uranium Pond #1. Sandstone A lies below this unlined burial area with the water table being approximately 10 to 15 feet below the former burial trenches. A 10 meter x 10 meter soil survey conducted in 1990 with soil sampled to a depth of six feet resulted in 5 samples with greater than 30 pCi/g. A follow-up 5 meter x 5 meter survey in 1992 resulted in additional samples exceeding 30 pCi/g. Excavation in April 1992 removed waste that included drums of resin and scrap metal. Further investigations in 1993 and 1994 identified other areas of soil and materials requiring removal. Approximately 13,600 cubic feet of waste was removed and shipped off site. Monitoring wells 1352 and 1356 and the 1206 Seep collection pool provided samples from Sandstone A in the vicinity of this burial area.

4.1.3 West Pipeline

The West Pipeline carried treated effluent from the facility to the Cimarron River. This 4-inch-diameter steel pipe was removed in 1985. Effluent to the Cimarron River was monitored to ensure compliance with the discharge permit limit specified in 10 CFR 20 Appendix B. A soil radiological survey in 1994 collected

480 samples at 1-foot intervals to a depth of 4 feet along the pipeline alignment. The average uranium concentration in these samples was 8.7 pCi/g. Only 4 samples exceeded the limit of 30 pCi/g and these were in the range of 37 to 59 pCi/g. Pipeline leaks were discovered during removal in 1985. One such leak was north of the Sanitary Lagoons where the pipeline leaves the upland area and enters the alluvial floodplain of the Cimarron River. Monitor wells installed in 2003 near this former leak include T-62 and T-64. In 2006 Cimarron installed an additional twenty shallow (20) soil borings and two (2) monitoring wells in the drainage way located south of monitoring wells T-62 and T-64. The analytical results associated with these sampling locations are discussed in Section 4.4.4 (Western Alluvial Area). These sampling locations are presented on Figure 4-13.

4.2 General Groundwater Chemistry

Concentrations for both radioactive and non-radioactive constituents in groundwater at the Cimarron Site are available from the August/September 2004 annual sampling event. During this sampling event, constituents considered important for evaluation of uranium fate and transport were measured in selected monitor wells. Table 4-1 summarizes this data by area. The geochemical characteristics of the Garber-Wellington Sandstones and the floodplain alluvium, as well as groundwater within each specific area of interest, are discussed in the following sections.

In addition to radionuclides, concentrations of nitrate and fluoride above background have been found in groundwater at the Cimarron Site. These constituents appear to have been associated with some of the processes and the related aqueous wastes. It has been hypothesized that these compounds may be useful as potential indicators of radionuclide impacts. The presence of these constituents in the BA#1 Area, Western Upland, and Western Alluvial Areas, and their suitability as possible indicators, are discussed in Section 4.3 (Area-specific Geochemical Considerations).

4.2.1 Shallow Sandstone Units

The shallow sandstone water-bearing units at the Cimarron Site include Sandstones A and B. Geochemical data available for Sandstone A is mainly from the western portions of the site. Data for Sandstone B is from the BA #1 Area. Because both Sandstone A in the Western Alluvial Area and Sandstone B in the BA #1 Area are unconfined, their water quality is strongly influenced by infiltrating precipitation.

Groundwater in the shallow water-bearing units is relatively fresh when compared to deeper sandstones or the Cimarron River. The total dissolved solids (TDS) content in Sandstone A in the Western Upland Area ranges from 206 to 1,310 milligrams per liter (mg/L). Geochemical data for Sandstone B in the Western Upland and Alluvial Areas was not collected during the August/September 2004 sampling event. Groundwater samples from the BA #1 Area indicated a TDS content ranging from 254 to 911 mg/L for Sandstone B, with the exception of one sample (TMW-18) that has a TDS value of 2,060 mg/L. The chemistry of groundwater in Sandstone B in the Western Alluvial Area is expected to be similar to that in Sandstone A in the Western Upland or Sandstone B in the BA #1 Area.

To evaluate and compare the chemical pattern of groundwater samples from the different water-bearing units, Stiff diagrams (Stiff, 1951) were constructed for all groundwater samples collected during the August/September 2004 annual sampling event. The comparison of Stiff diagrams allows for rapid identification of differences in chemistry among groundwater samples. Ionic concentrations in milligrams per liter (mg/L) were converted to milliequivalents per liter (meq/L). Sodium plus potassium (Na+K), calcium (Ca), and magnesium (Mg) ions were plotted on the left side of the diagram, with chloride (Cl), bicarbonate plus carbonate (HCO_3+CO_3), and sulfate (SO_4) ions plotted on the right. The lengths of the diagram vertices are proportional to the ionic content. The vertices are connected to form a polygonal pattern. The resulting shape of the pattern bears the "signature" of the chemistry of a groundwater sample while the size corresponds to the relative concentration of ions in a water sample.

Figure 4-1 presents representative Stiff diagrams for the sandstone water-bearing units. Stiff diagrams for all wells sampled during the August-September 2004 sampling event can be found in Appendix A. Both Sandstone A and Sandstone B groundwater have similar water patterns and are characterized as calcium bicarbonate water (bicarbonate concentration significantly greater than sulfate and chloride). The water chemistry is apparently influenced by dissolution of calcite cement in shallow sandstones in the Cimarron Site area.

4.2.2 Deeper Sandstone Unit

The deeper unit (Sandstone C) underlies Sandstone B and is separated by Mudstone B. Sandstone C is confined and is more saline than the overlying units. Data representing the general geochemical parameters of typical Sandstone C groundwater was obtained from the "Cimarron Decommissioning Plan Groundwater Evaluation Report, July 1998." Samples TMW-17 and TMW-23 representing the top of Sandstone C in the BA #1 Area were also collected during the August/September 2004 sampling event.

The TDS concentration in typical Sandstone C water ranges from 2,660 mg/L to 11,000 mg/L based on data reported in previous groundwater sampling events. Wells screened in the shallower portions of Sandstone C are typically lower in TDS concentrations, but still yield brackish water as exhibited in wells 1321, 1323, 1328, and 1332 (TDS concentration range of 2,660–4,090 mg/L). This TDS range, however, represents only the upper portion of Sandstone C, since a deeper Sandstone C well (1339) has previously exhibited a TDS concentration exceeding 11,000 mg/L (the deeper the groundwater within the unit, the higher the TDS content). Samples that represent top of Sandstone C from the BA #1 Area exhibit lower TDS concentrations (830 mg/L and 987 mg/L for TMW-17 and TMW-23, respectively) than typical Sandstone C water.

As is shown in Figure 4-1, Sandstone C groundwater has a distinct water pattern compared to groundwater from the shallow sandstone units both in the shape and the size of its Stiff diagram. In contrast to the bicarbonate type of water associated with the shallow sandstone units, Sandstone C is categorized as a calcium sulfate water (sulfate content significantly greater than bicarbonate and chloride). Its chemistry is apparently influenced by dissolution of gypsum present in deeper sandstone layers.

Compared to typical Sandstone C groundwater in the western portion of the Cimarron Site, the sulfate groundwater in the BA #1 Area has a much lower TDS concentrations due to its shallower depth (40 feet shallower).

4.2.3 Alluvium

Because the three sandstone water-bearing units discharge to the alluvium and mix with groundwater of various sources, there are variations in water quality within the alluvial floodplain.

The TDS content in the alluvium ranges from 391 mg/L to 2,140 mg/L, with the Western Alluvial Area having higher observed TDS concentrations than in the BA #1 Area. Stiff diagrams for representative alluvium well samples are presented in Figure 4-2.

As shown in Figure 4-2, three distinct types of water patterns are present, which represent three distinct types of groundwater. The first type is very similar to that from the shallow sandstone units and is represented by wells 02W29, 02W01, and 02W44 in the BA #1 Area, and T-64 in the Western Alluvial Area. Groundwater in these wells is characterized by relatively low TDS and high bicarbonate ion concentration (HCO_3 > SO_4 > Cl), and is a calcium bicarbonate type water.

The second type of groundwater, which is similar to Sandstone C groundwater, is represented by wells 02W07, 02W23, and 02W36 in the BA #1 Area and wells T-72 and T-74 in the Western Alluvial Area. This groundwater is characterized by its relatively high TDS and sulfate content (SO_4 > HCO_3 > Cl), and is categorized as a calcium/magnesium sulfate water. The presence of this Sandstone C groundwater in the floodplain alluvium provides geochemical evidence that Sandstone C discharges to the alluvium close to the Cimarron River.

The third type of groundwater is represented by 02W10 in the transitional zone of the BA #1 Area. This groundwater is characterized by relatively high magnesium content (Mg > Ca > Na+K) and is categorized as a magnesium bicarbonate water. This type of groundwater is isolated in the southeast quadrant of the BA #1 Area where massive clay and silt deposits are present as discussed in Section 2.3.1 (Detailed Stratigraphic Correlations at Cimarron – BA #1 Area) of this report. This groundwater is in essence a bicarbonate water, as in the Sandstone A and B groundwater, but with elevated Mg content that differentiates it from shallow sandstone groundwater. Given the geological setting, this type of groundwater is likely to be in equilibrium with clay minerals.

No groundwater samples from the alluvium exhibited the chemical characteristics of Cimarron River water. Cimarron River water is categorized as a sodium chloride type water with chloride content significantly higher than sulfate and bicarbonate.

As discussed in Section 4.3, there is a spatial correlation between water type and geological setting within the alluvium.

4.3 Area-specific Geochemical Considerations

4.3.1 BA #1 Area

The spatial distribution of TDS, sulfate, chloride, and bicarbonate alkalinity in Sandstone B and the alluvium within the BA #1 Area are illustrated in Figures 4-3 through Figure 4-6.

Low TDS (less than 500 mg/L) groundwater was observed in the southern portion of the uplands in Sandstone B and several wells in the transitional zone immediately adjacent to the uplands (Figure 4-3). From southeast to northwest, groundwater TDS concentration increases from less than 500 mg/L to more than 1,000 mg/L.

The spatial distribution of sulfate in the BA #1 Area (Figure 4-4) is similar to that of TDS, with groundwater from Sandstone B in the uplands having the lowest sulfate content (less than 10 mg/L). Higher sulfate concentration (greater than 300 mg/L) groundwater is predominantly in the northwest quadrant of the BA #1 Area. The higher observed sulfate concentrations are apparently associated with groundwater from Sandstone C.

The chloride concentration is low (less than 20 mg/L) in most Sandstone B groundwater and the alluvium in the southeastern portion of the BA #1 Area (Figure 4-5). Most of the wells have chloride concentrations less than 80 mg/L. Compared to the chloride content of the Cimarron River, which was reported as 3,600 mg/L in 1986 at the Guthrie Gage, the alluvium has less than 5 percent of the chloride concentration of the river, suggesting that the impact of the river on the alluvium is not significant in the areas where groundwater samples were collected.

The alkalinity in groundwater ranges from 192 mg/L to 677 mg/L in the BA #1 Area. There is no clear trend in the distribution of alkalinity throughout the area and localized high concentrations (greater than 500 mg/L) were observed at multiple locations (Figure 4-6). In general, the alkalinity content in the northeastern half of the area appears to be higher than in the southwestern half. Alkalinity will be an important factor to be considered during the design of any remediation system due to its buffering capacity.

In the BA#1 Area, nitrate and fluoride have been detected only at low concentrations, typically consistent with background. Therefore, there is little to no impact to groundwater from these constituents in this area.

There are three distinct types of groundwater in the BA #1 Area, including calcium bicarbonate water, calcium sulfate water, and magnesium bicarbonate water. Groundwater samples from the uplands are of the calcium bicarbonate type, while the alluvium samples contain all three types of water. Figure 4-7 presents the respective areas of the site where each water type is located. The magnesium-rich groundwater (represented by 02W10) is concentrated in the southeast portion of the alluvium in the transitional zone (area within blue line), the calcium bicarbonate water (Sandstone B groundwater, represented by TMW-2, 02W29, and 02W44) is distributed in the middle and northeast portion of alluvium (area between blue and orange colored lines), and the sulfate water (possibly an indication of water being contributed from Sandstone C represented by 02W24) is isolated in the northwest portion of the alluvium (areas within orange line). These three distinct types of groundwater form three segregated water-quality zones in the alluvium from southeast to northwest.

The spatial distribution of the different groundwater types can be attributed to the geologic environment where each groundwater type is in equilibrium. As discussed in Section 2.2 (Stratigraphy of the Cimarron Site) of this report, the alluvium can be divided into two zones, a clayey transitional zone and a sandy alluvium zone, with the approximate division along the line from monitor wells 02W03 to 02W13. The transitional zone is underlain by Sandstone B or Mudstone B and receives recharge mostly from Sandstone B. Therefore, groundwater in the transitional zone exhibits the geochemical signature of Sandstone B water. The sandy alluvium, in contrast, is underlain by various portions of Mudstone B and Sandstone C and receives recharge from both Sandstones B and C. Consequently, the alluvium has the geochemical signatures of both Sandstone B and Sandstone C water. The magnesium-rich groundwater is almost exclusively associated with clay- or silt-rich sediments.

In Figure 4-7, the Stiff diagrams of the groundwater samples from the high-magnesium and high-sulfate zones are relatively uniform with little changes in shape and sizes. This is because the groundwater within these two zones has seen limited mixing with groundwater from other sources. However, groundwater samples from the calcium bicarbonate zone (area between the blue and the orange zones) show a gradual change in Stiff diagrams from the upland to the sandy alluvium. In the uplands, the Stiff diagram (TMW-2) is small (low TDS) and has roughly equal width and length. As the groundwater moves to the transitional zone, the Stiff diagram (02W29) begins to take on an elongated shape with notable increases in calcium and bicarbonate concentrations. Farther away from the uplands into the sandy alluvium, the Stiff diagram (02W44) is "stretched" even longer (associated with an increase in TDS concentrations). These changes in Stiff diagrams occurred without significant changes in the basic pattern of the Stiff diagrams or the relative concentrations of the major cations and anions. This indicates that the calcium bicarbonate water in the transitional zone and sandy alluvium originates from Sandstone B and is re-equilibrated with the geological materials in the alluvium. Evidence of mixing is apparent along borderlines between two water type zones.

Piper diagrams provide a visual means to compare the chemistry of water samples. Figure 4-8 presents a Piper diagram (Piper, 1944) of groundwater in the BA #1 Area and Cimarron River water (USGS, 1960–1986). Also plotted is Sandstone C groundwater from the western portion of the Cimarron Site for comparison. Major cations (Ca, Mg, and Na+K) are plotted on the left triangle while major anions (HCO_3+CO_3, SO_4, and Cl) are plotted on the right triangle. Data points in the diamond are projected from the two triangles. As shown in the diagram, the river water is a sodium chloride type, with the data points grouped at the Na+K and Cl corners of the triangles. The average chloride to sulfate ratio of the river water is equal to 6. Typical Sandstone B groundwater is grouped at the HCO_3+CO_3 corner, whereas Sandstone C groundwater is at the SO_4 corner. Data points from the sandy alluvium are spread in the middle section between HCO_3+CO_3 and SO_4, indicating possible mixing of Sandstone B and Sandstone C groundwaters.

4.3.2 Western Upland Area

Groundwater geochemical parameters were evaluated during the August/September 2004 groundwater sampling event in the monitor wells in the Western Upland Area.

The Stiff diagrams of representative groundwater samples from the Western Upland Area are illustrated in Figure 4-1. The patterns of Sandstone A and 1206 Seep water are both characterized by low TDS with bicarbonate being the dominant anion. The geochemical signature of this groundwater is very similar to the Sandstone B groundwater in the BA #1 Area, indicating the influence of precipitation.

In the Western Upland Area, fluoride and nitrate have been detected at concentrations above background. The highest concentrations have been detected in the vicinity of the former U Ponds. However, because of remedial actions taken, uranium concentrations are no longer elevated in this area, and therefore they are not included in this report. .

4.3.3 Western Alluvial Area

TDS concentrations are generally high throughout the Western Alluvial Area. Near the escarpment, TDS is in the range of 800 to 1,890 mg/L, but within the area with uranium impacts exceeding 180 pCi/L, TDS is in the range of 700 to 2,140 mg/L. At well T-82, the TDS concentration is 923 mg/L.

The alkalinity concentration ranges from 230 to 438 mg/L, with calcium concentrations ranging from 144 to 406 mg/L and magnesium concentrations ranging from 29 to 84 mg/L. Sulfate concentrations ranged from 54 to 822 mg/L across the Western Alluvial Area.

Nitrate and fluoride are present at concentrations above background in Seeps 1206 and 1208, and in the Western Alluvium. However, their distribution is not coincident with the uranium distribution.

The Stiff diagrams of representative groundwater samples from the Western Alluvial Area are presented in Figure 4-2. There are two distinct types of water pattern in the alluvium.

The first type of groundwater, represented by well T-64, has a Stiff diagram in a fairly symmetrical shape. This groundwater is characterized by relatively low TDS content with bicarbonate content being higher than sulfate and chloride and is categorized as a calcium bicarbonate water. The pattern and TDS range of this groundwater are similar to groundwaters from Sandstone A in the uplands and Sandstone B in the BA #1 Area. Therefore, this groundwater is likely to be from Sandstone A and B with its chemistry influenced by infiltrating rain precipitation.

The second type of groundwater is represented by wells T-72 and T-74. This groundwater is characterized by high TDS content with sulfate concentration greater than bicarbonate and chloride and is categorized as a calcium sulfate water. Chloride concentration can be higher than bicarbonate and sodium higher than magnesium in some samples. The geochemical signature of this groundwater is almost identical to that of Sandstone C groundwater, suggesting some contribution from Sandstone C into the alluvium.

The spatial distribution of water types in the Western Alluvial Area is presented in Figure 4-9. A typical Sandstone C water from well 1332 is also shown for comparison. Of the 20 groundwater samples evaluated in the alluvium, eight exhibit the signature of Sandstone A and B groundwater (bicarbonate water), with the remaining showing the characteristics of Sandstone C groundwater (sulfate water). Generally, bicarbonate water predominates in areas adjacent to the escarpment whereas sulfate water is more abundant in areas away from the uplands.

Comparisons of geochemical characteristics of groundwaters from the Western Upland Area and the Western Alluvial Area are graphically illustrated in Figure 4-10. As can be seen from this Piper Diagram, Sandstone A groundwater clusters at the bicarbonate corner while Sandstone C groundwater clusters at the sulfate corner, with groundwater in the alluvium spreading across the entire spectrum between the two groundwaters. Apparently, groundwater in the alluvium is from Sandstones A, B, and C with various degrees of mixing among them.

4.4 Uranium Impacts to Groundwater

4.4.1 Geochemistry of Uranium

Uranium (U) has 14 isotopes, with the atomic mass of these isotopes ranging from 227 to 240. Naturally occurring uranium typically contains 99.283 percent U^{238}, 0.711 percent U^{235}, and 0.0054 percent U^{234}. Uranium can exist in the U^{3+}, U^{4+}, U^{5+}, and U^{6+} oxidation states, of which the U^{4+} and U^{6+} states are the most common states found in the environment.

The chemical behavior of U^{4+} and U^{6+} is influenced by a variety of reactions including dissolution, precipitation, complexation, and sorption. These reactions are affected by the redox conditions, solution pH, water chemistry, and mineral-water interactions. The U^{4+} species are sparingly soluble in aqueous solutions (less than 30 micrograms per liter [µg/L]) and tend to precipitate out under anoxic (reduced) conditions. U^{6+} species, in contrast, are fairly soluble and are responsible for the mobilization of uranium in oxidized conditions.

In natural groundwater, U^{6+} can be transported in various aqueous species depending on the pH and groundwater composition. In the absence of carbonate, U^{6+} in the form of uranyl ion $(UO_2)^{2+}$ predominates at pH below 5. At pH values between 5 and 9, the U^{6+} hydrolytic species $(UO_2(OH)_2^{o})$ predominates. U^{6+} has a strong tendency to form complexes with carbonate. In solutions where dissolved carbon dioxide is present, the neutral uranyl carbonate species (UO_2CO_3) predominates in the pH range between 5 and 6.5. Anionic uranyl dicarbonate $(UO_2(CO_3)_2^{2-})$ and uranyl tricarbonate $(UO_2(CO_3)_3^{4-})$ species predominate in the pH ranges between 6.5 to 8.5 and above 8.5, respectively.

U^{6+} is readily adsorbed onto an aquifer matrix or single-phase mineral, resulting in a reduction of its mobility in groundwater. Aqueous pH and water chemistry are the two most important factors controlling the adsorption for a given matrix. Groundwater pH affects not only uranium speciation, but also its adsorption onto aquifer materials. Generally a surface is positively charged at lower pH and negatively charged at higher pH. Therefore, lower pH favors the adsorption of anionic species such as uranyl dicarbonate while higher pH facilitates adsorption of cationic species such as uranyl ion. The optimum pH values for uranium adsorption appear to be in the range between 5 and 8.

The composition and concentration of ionic species in the groundwater will affect the speciation of uranium and the adsorption as well. Uranium adsorption in low-TDS water is relatively high and tends to decrease as TDS increases due to competition for adsorption sites from other constituents. Sulfate, for instance, is likely to interfere with the adsorption of uranyl dicarbonate and its removal at pH values above 6 if adsorption or ion exchange is utilized to treat uranium-impacted water.

In an effort to understand the form of uranium that is being transported in groundwater and the propensity of uranium for adsorption under the Cimarron Site's conditions, speciation of uranium in groundwater was calculated using the geochemical model MINTEQA2 (USEPA Version 4.02, 2000). This information is useful in evaluating the fate and transport of uranium at the site and for design of a treatment system where the operating conditions are highly dependent on the speciation of uranium.

MINTEQA2 is an equilibrium geochemical model that computes metal speciation in aqueous solutions. Developed by US EPA, this model is capable of calculating the equilibria among dissolved, adsorbed, solid, and gas phases. MINTEQA2 includes an extensive database of reliable thermodynamic data that allows for solving a broad range of problems encountered in a natural aqueous system. Input data required by the model consist of chemical analyses of total dissolved concentration for the components of interest. Field measured parameters such as pH and Eh can also be input to the model to specify equilibrium conditions, but are not necessary since these values can be calculated by the model.

Analytical data of geochemical parameters (major cations, anions, ferrous and ferric iron, nitrate, fluoride, and silica) and uranium concentrations of selected groundwater samples obtained from September 2004 sampling event were input into the MINTEQA2 model to compute the uranium speciation. The samples selected included 02W01, 02W02, 02W04, 02W19, 02W21, 02W24, 02W31, 02W47, TMW-09, 1315R, 1314, and 1321, which are representatives of different TDS, sulfate, bicarbonate alkalinity, and uranium concentrations of groundwater across the site. Evaluation of these samples provide insight into the effects of the TDS, sulfate, and alkalinity on uranium speciation. Field measured temperature and pH values were used in all model runs. Eh values were not used in the model, as it was assumed that uranium in the site groundwater is in the 6^+ valent state. This assumption is supported by the relatively high uranium concentrations and the presence of ferric iron oxides in the aquifer.

The MINTEQA2 model results indicate that uranyl dicarbonate ($UO_2(CO_3)_2^{2-}$) and uranyl tricarbonate ($UO_2(CO_3)_3^{4-}$) are the predominant uranium species expected in groundwater at the site. The relative abundance of these two species depends on solution pH and bicarbonate alkalinity. Generally, the higher range of pH values and bicarbonate alkalinity concentrations favor the formation of uranyl tricarbonate. For most groundwater at the site; however, the concentration of uranyl dicarbonate is about two times higher than the uranyl tricarbonate species based on geochemical modeling. Other uranium aqueous species including uranyl carbonate and hydrolytic species may also be present, but in minor amounts (less than 2 percent), suggesting that the groundwater at the site has sufficient bicarbonate alkalinity to complex uranium. Sulfate was found to have no effect on the speciation of uranium at the site at the concentrations detected at the Cimarron Site.

The estimated range of historical background concentrations of uranium observed in each of the water-bearing units is as follows:

- Sandstone A: 1.0 to 19.8 pCi/L (based on 7 wells);
- Sandstone B: 0.6 to 3.9 pCi/L (based on 5 wells);
- Sandstone C: 4.6 to 43.6 pCi/L (based on 6 wells); and
- Alluvial floodplain: 5.1 to 35.6 pCi/L (based on 9 wells).

These estimated uranium background concentrations are an update to the previous calculations presented in the document titled "Groundwater Quantity and Quality in Vicinity of Cimarron Corporation's Former Nuclear Fuel Fabrication Facility, Crescent, Oklahoma" 1997, and new well selections provided by Cimarron Corporation hydrogeologists.

4.4.2 BA #1 Area

Monitoring wells installed in 1985 detected uranium immediately downgradient (to the north) of the four trenches in the BA #1 Area. The impacted groundwater was found in Sandstone B (which underlies the trenches) and was subsequently found to continue northward into the alluvial floodplain. The origin of the groundwater impacts was likely the four trenches, but the timing of the migration of uranium from the trenches into Sandstone B is uncertain. The monitoring wells installed in 1985 detected a plume of uranium, with concentrations of total uranium up to 2,500 pCi/L, suggesting that the uranium began migrating in groundwater prior to 1985.

When uranium leached from the former disposal trenches, it was carried into Sandstone B, where it migrated north toward the alluvium driven by the local hydraulic gradient. Groundwater flow velocity in Sandstone B is anticipated to be relatively high because of the steep hydraulic gradient in Sandstone B.

Once the groundwater reached the interface between the sandstone and the alluvial deposits at the buried escarpment, it refracted to the northwest under the influence of a mass of low-permeability clayey material to the northeast of the escarpment. This low permeability material interrupted the northern flow of Sandstone B groundwater and forced it to flow along a southeastern-northwestern trending paleochannel filled with higher permeability sandy material between the sandstone and the clayey materials in the transitional zone. Flow in the sandy paleochannel was uninterrupted until the groundwater encountered a clay-rich barrier in an area between TMW-9 and 02W01 as discussed in Section 2.3.1 (Detailed Stratrigraphic Correlations at Cimarron – BA #1 Area) of this report. This clay-rich barrier affects the migration of uranium both by virtue of its lower permeability and its increased adsorption potential. After the uranium-impacted groundwater migrated through the clay-rich barrier, its flow continued to be slowed by the extremely flat gradient in the sandier alluvial materials, as shown in Figure 3-4.

The spatial distribution of uranium in the BA #1 Area is illustrated in Figure 4-11. As is shown, the uranium concentration varied from background levels to over 4,000 pCi/L based on the August/September 2004 groundwater monitoring data. The uranium plume, defined as uranium concentration exceeding the site-specific groundwater release criteria of 180 pCi/L, has an elongated shape, with the southern portion trending from southeast to northwest and the northern portion from south to north. The orientation and distribution of the plume coincides with the location of the paleochannel, discussed in Section 2.3.1 (Detailed Stratrigraphic Correlations at Cimarron – BA #1 Area) of this report, indicating that the migration of uranium near the escarpment may be influenced by the paleochannel. In areas farther away from the uplands, the movement of uranium is affected by the regional groundwater gradient resulting in its movement toward the Cimarron River channel.

A comparison of the groundwater monitoring data from the August/September 2004 sampling event (Figure 4-11) and the August 2002 (Figure 4-12) event revealed some changes in the uranium distribution between the two data sets. The main differences are:

- The highest observed uranium concentration has decreased from 5,035 pCi/L (TMW-09) during 2002 to 4,387 pCi/L in 2004
- The area containing groundwater above 2,000 pCi/L total uranium appears to have advanced and spread out.
- The plume's leading edge has shifted toward the east relative to its 2002 location and there is little advancement to the north towards the Cimarron River.

Figures 4-11 and 4-12 were developed for comparative purposes, and provide a means for comparing the uranium data from two groundwater sampling events.

Based on data of only two site-wide sampling events, it is difficult to determine whether the spatial variation of the plume is statistically significant. However, there are seven wells (TMW-13, 02W04, 02W07, 02W08, 02W19, 02W43, and 02W62) in the northern portion of the plume that have more than four quarters' data available. For those wells the Mann-Kendall statistics was calculated to evaluate whether the concentration fluctuation was random or directional. The analysis indicated that except for one well (02W19) which showed an upward trend, there is no clear trend associated with the data in other wells, suggesting the concentration variations in those wells were random.

4.4.3 Western Upland Area

The BA #3 Area was excavated, surveyed by Cimarron and the NRC, and backfilled with clean soil prior to 1994. At the Seep 1206 sample collection point, the elevated uranium concentration in a sample collected in 1985 appeared to be spatially related to the BA #3 Area.

Historically, samples designated as being collected from the 1206 Seep were in fact collected from a pool of accumulated surface water near the escarpment. This Seep 1206 sampling location is identified in Figures 2-3, 2-8, 3-3, and 4-13 and represents, a location where water accumulates from a number of seeps along the escarpment.

Since 2003, total uranium concentrations observed in samples from the 1206 Seep collection point appear to be declining. In 2002, uranium values were in the range of 150 to 170 pCi/L. By March 2003, the reported values were around 200 pCi/L. In June 2003, the uranium values sharply declined to approximately 100 pCi/L. In January 2004, the uranium concentration subsequently increased to values around 180 pCi/L. Since that time, the uranium concentrations in samples from the collection pool have been steadily declining and are currently in the range of 100 pCi/L.

Because of the potential for the evapoconcentration of uranium in the surface water collection pools, the concentrations of uranium observed at this location may not be representative of the actual groundwater in this area. This suspicion is supported by the data from wells in the proximity of this area (wells 1354, 1355, 1357, and 1358), which have uranium concentrations below 5 pCi/L. A monitor well located downgradient of 1357 and 1358 may be better suited to evaluate impacts from the BA #3 Area.

Three wells in the BA #3 Area (1351, 1352, and 1356) have also exhibited unexpected fluctuations in uranium concentrations. Observed uranium concentrations in these three wells have fluctuated in the range of 67 pCi/L to 725 pCi/L over the last two years of groundwater monitoring (2003–2005).

Uranium and water quality data from the August/September 2004 groundwater sampling event for the Western Upland Area is presented in Figure 4-14.

4.4.4 Western Alluvial Area

The uranium impacts detected in the Western Alluvial Area above the site-specific groundwater release criteria of 180 pCi/L extend from near the base of the escarpment northward toward the Cimarron River, apparently originating where the western pipeline entered the alluvium north of the former Sanitary Lagoons. Uranium and water quality data from the August/September 2004 groundwater sampling event for the Western Alluvial Area is presented in Figure 4-15.

The observed impacts parallel the trace of the former West Pipeline Corridor that was used to discharge wastewater to the Cimarron River from 1966 to 1970. This pipeline and associated soils exceeding 30 pCi/g were removed in 1985, and the corridor backfilled with clean soil.

Concentrations of uranium detected in the Western Alluvial Area wells are generally in the range of 150 to 250 pCi/L. Concentrations in most wells have not varied to any noticeable degree over the past 2 years of sampling. Wells near the escarpment, mainly wells T-62 and T-64 are the main exceptions. The groundwater impacts in the Western Alluvial Area are not typical of a plume in the sense that a plume has a continuing source and represents a moving and changing zone of dissolved uranium in groundwater; rather, the groundwater impacts in the Western Alluvial Area are the result of downward seepage (i.e., no horizontal flow component) of uranium from a former pipeline that leaked uranium-bearing wastewater during the operational period of the Cimarron facility.

Two groundwater monitoring wells were installed in the Western "transition" area; one in the 1206 drainage (MWWA-09) and the other in the alignment where the former west pipeline was located (MWWA-03). Soil borings were sampled and analyzed for total U during installation of the wells; values ranged between 2.4 to 7.68 + or - ~1.1(pCi/g) for soils from MWWA-03 and MWWA-09. Groundwater samples yielded 268 pCi/L (MWWA-09) and 1110 pCi/L (MWWA-03). It is possible that the pipeline leak has impacted both soil and groundwater near MWWA-03, and seepage from Burial Area #3 has impacted both soil and groundwater near MWWA-09.

4.4.5 Surface Water

The Cimarron River is relatively saline due to contributions in the northwest part of Oklahoma from Permian evaporite beds. The water quality of the Cimarron River is presented in Table 4-2 and was summarized from Adams and Bergman (1994) and data available on the USGS National Water Information System (NWIS) water data website. The TDS concentration of the Cimarron River water decreases from the Waynoka gage southeast to the Guthrie gage, which is located 10 miles east of the Cimarron Site. Similarly, sodium, chloride, and sulfate concentrations also decrease. This is due to the decreasing influence of Permian-age evaporite beds on the river chemistry and the greater influence of runoff from farmed areas and sewage outfalls. In the area of the Cimarron Site, which lies between the Dover and Guthrie gages, the Cimarron River can be expected to have TDS in the range of 8,000 to 12,000 mg/L, chloride between 3,600 and 5,700 mg/L, sulfate between 650 and 780 mg/L, sodium ranging from 1,900 to 3,400 mg/L, and alkalinity (bicarbonate) in the range of 200 mg/L. This water chemistry is very distinct from the groundwater chemistry of the alluvial floodplain. Based on the Secondary Maximum Concentration Limits (MCLs) recommended by the United States Environmental Protection Agency (USEPA) for drinking water, this water is considered non-potable.

Samples collected from the Cimarron River in June 1997 exhibited a mean total uranium concentration of 8.1 pCi/L at the upstream sample location, and 7.3 pCi/L at sample location 1202 downstream of the Cimarron site. (Cimarron Decommissioning Plan Groundwater Evaluation Report for Cimarron Corporation's Former Nuclear Fuel Fabrication Facility, Crescent, Oklahoma, July, 1998).

Table 4-1 August/September 2004 Groundwater Monitoring Data, Cimarron Site, Crescent, Oklahoma

Well ID	Water Bearing Unit	Dissolved Oxygen[1] (mg/L)	Nitrate[2,3] (mg/L)	pH[1] -	Redox Potential[1] (mv)	Uranium[2] (pCi/L)	Calcium[2] (mg/L)	Chloride[2,3] (mg/L)	Magnesium[2] (mg/L)	Sodium[2] (mg/L)	Sulfate[2,3] (mg/L)	Bicarbonte Alkalinity[2,3] (mg/L)	Total Alkalinity[2,3] (mg/L)	Total Dissolved Solids[2] (mg/L)
Burial Area #1														
02W01	Alluvial	1.5	0.3	7.2	271	4150	127	22.3	42.3	36.8	81.4	432	433	535
02W02	Alluvial	1.1	0.1	7.4	14	692.3	89.3	24.7	40.8	78.3	46.3	450	451	719
02W03	Alluvial	5.9	0.1	7.1	64	3779	132	31.2	61.2	60.3	85.6	555	556	1220
02W04	Alluvial	1.5		7.1	224	1789.8	171	47.7	84.9	90.6	433	452	454	1160
02W05	Alluvial	1.0	0.118	7.0	216	2542	182	150	113	170	283	673	677	1360
02W06	Alluvial	1.1	0.2	7.1	218	3462	179	62.1	67.5	91.5	273	512	513	1050
02W07	Alluvial	1.5	4.6	7.2	279	732.4	171	40.1	59.5	75.3	320	426	427	519
02W08	Alluvial	1.6	0.1	7.1	82	120.0	182	23.2	56	52.7	281	545	550	581
02W09	Alluvial	2.0	0.1	7.3	200	1.8	61.3	18.5	55.1	24.2	29	378	379	590
02W10	Alluvial		0.1	7.2		3.2	91.5	26.4	73.7	39.4	56.7	489	492	1330
02W11	Alluvial		0.1	7.1		29.0	177	38.3	60.3	70.5	279	527	534	699
02W12	Alluvial		0.1	7.1		43.7	125	22.3	50.5	50.8	131	463	465	661
02W13	Alluvial		0.1	6.9		30.5	142	18.7	44.3	33.4	95.1	501	502	920
02W14	Alluvial		0.1	7.1		113.7	155	35.3	59.7	84.7	195	553	556	1530
02W15	Alluvial	1.7	0.1	7.2	195	59.8	226	86.8	94.3	115	629	355	359	1440
02W16	Alluvial		0.1	7.1		24.3	254	49	77.5	67.5	626	346	347	1240
02W17	Alluvial	1.4	0.1	7.1	228	39.8	218	56.3	65	63.4	475	346	347	1090
02W18	Alluvial	1.7	0.1	7.1	124	744.7	167	35.2	49.1	66.6	328	410	411	1010
02W19	Alluvial		0.1	7.1		799.3	141	40.3	56.7	77.7	175	479	481	832
02W20	Alluvial	1.9		7.1	48	1.5	80.8	19.3	51.9	23.5	53.7	347	347	475
02W21	Alluvial			7.1		5.6	205	23.8	52.3	49	458	192	192	1030
02W22	Alluvial			7.0		8.6	210	41.4	65.6	58.3	478	352	353	1130
02W23	Alluvial	2.2		6.9	228	7.2	209	34.7	52.4	51.1	510	261	262	1160
02W24	Alluvial	1.5		7.0	120	117.2	213	50.6	65	58.8	520	325	326	1200
02W25	SS B	1.5		7.0	62	13.2	93	2.46	21.6	15.7	10.3	240	240	358
02W26	Alluvial			7.2		2.186	63.7	19.6	54.7	24	25.5	352	353	442
02W27	SS B			7.1		153.5	135	23.2	60.3	66.4	59.7	282	283	629
02W28	Alluvial			7.2		300	77	21	60.8	27.9	31.7	389	390	496

Table 4-1 August/September 2004 Groundwater Monitoring Data, Cimarron Site, Crescent, Oklahoma

Well ID	Water Bearing Unit	Dissolved Oxygen[1] (mg/L)	Nitrate[2,3] (mg/L)	pH[1] -	Redox Potential[1] (mv)	Uranium[2] (pCi/L)	Calcium[2] (mg/L)	Chloride[2,3] (mg/L)	Magnesium[2] (mg/L)	Sodium[2] (mg/L)	Sulfate[2,3] (mg/L)	Bicarbonte Alkalinity[2,3] (mg/L)	Total Alkalinity[2,3] (mg/L)	Total Dissolved Solids[2] (mg/L)
02W29	Alluvial	1.8		7.3	271	1845	106	7.83	35.3	15.1	22	330	331	441
02W30	SS B			6.9		457.4	146	59.2	49.1	35.2	43.2	448	449	656
02W31	Alluvial			7.2		570.5	76.4	18.6	59	26.9	36.3	479	481	499
02W32	Alluvial			7.1		413.3	117	31	63.7	61	124	378	379	707
02W33	Alluvial			6.9		7.5	237	55.3	75.6	67.2	558	266	267	1310
02W34	Alluvial			7.1		4.0	101	24.7	20.1	44.2	45.8	298	299	463
02W35	Alluvial			7.0		167	133	85.7	39.2	75.3	139	298	299	731
02W36	Alluvial	0.9		7.0	91	92.9	190	75.7	61.2	78.2	424	303	305	1140
02W37	Alluvial		0.1	7.0		433	152	122	76.1	163	191	618	622	1120
02W38	Alluvial			7.0		101.9	150	64.5	72.8	130	130	564	566	984
02W39	Alluvial	3.7		7.2	264	1209.7	95.8	9.5	35.4	15.5	19.1	372	374	391
02W40	SS B	1.9		7.2	290	1577	103	7.01	38.2	12	23.3	373	374	437
02W41	SS B	2.4		7.2	250	965.9	87.3	6.17	31.2	12.6	16.3	368	369	389
02W42	SS B	3.6		7.0	238	130.7	108	2.8	27.2	13.7	19	341	342	426
02W43	Alluvial		0.1	7.1		169.9	202	57	69.5	74.5	521	364	366	1240
02W44	Alluvial			7.0		157.8	133	58.3	60.6	81.5	132	586	588	924
02W45	Alluvial	1.3		7.1	61	120.6	214	198	57	139	396	447	449	1330
02W46	Alluvial			7.3		1377.4	109	27.1	66.6	55.9	72.8	543	545	686
02W47	SS B		0.451	6.7		375.8	121	10.3	48	13	29.3	473	474	535
02W50	SS B			7.4		3.5	72.5	16.4	26.9	22	8.47	277	278	369
02W51	SS B	6.9		7.6	274	5.4	57.4	2.2	18.9	11.9	23.3	229	230	254
02W52	SS B			7.4		1.9	60.9	15.6	22.4	19.2	7.75	361	363	322
02W53	SS B			7.1		76.7	130	117	53.3	86.6	184	420	422	911
02W62	Alluvial			7.0		5.5	130	62	29.9	66.4	123	404	406	691
1314	SS B			7.3		1.8	66.4	15.9	22	16.7	6.89	240	241	303
1315R	SS B	1.2	2.47	6.8	273	1793	183	22.5	70.9	30.1	102	628	629	816
1316R	SS B			6.9		151.7	152	11.8	46.7	20.1	30.5	222	222	611
TMW-01	SS B	6.2		6.7	190	1198.8	148	6.99	52.5	14.6	95	443	443	635
TMW-02	SS B	4.5		7.6	219	2.5	53.4	5.23	19.5	18.4	11.5	234	235	254

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Well ID	Water Bearing Unit	Dissolved Oxygen[1] (mg/L)	Nitrate[2,3] (mg/L)	pH[1] -	Redox Potential[1] (mv)	Uranium[2] (pCi/L)	Calcium[2] (mg/L)	Chloride[2,3] (mg/L)	Magnesium[2] (mg/L)	Sodium[2] (mg/L)	Sulfate[2,3] (mg/L)	Bicarbonte Alkalinity[2,3] (mg/L)	Total Alkalinity[2,3] (mg/L)	Total Dissolved Solids[2] (mg/L)
TMW-05	Alluvial	0.9		7.1	84	2.5	95.3	25.7	66.9	35.5	57.4	506	508	607
TMW-06	Alluvial	1.3		7.3	35	2.5	95.3	27.2	61.6	33.9	67.1	522	524	559
TMW-07	Alluvial	1.0		7.2	-9	26.8	93.9	21.6	55.4	40	40.1	490	492	542
TMW-08	SS B	3.7		7.0	262	3066	94.3	18.6	47.1	19.5	21.6	411	412	491
TMW-09	Alluvial			6.9		4387	127	16	39	28.6	76.6	422	424	566
TMW-13	Alluvial			7.2		4096	136	73	89.2	120	181	264	264	1010
TMW-17	SS C			6.9		4.7	161	23.3	45	40.9	301	320	321	830
TMW-18	SS B			7.1		12.4	311	285	113	183	799	251	251	2060
TMW-21	SS B	5.9		7.1	312	116.2	149	8.72	55.5	29.6	30.1	586	588	616
TMW-23	SS C			7.2		7.9	173	101	46.1	115	332	325	326	987
TMW-24	Alluvial	0.7		6.9	22	28.8	186	149	74.1	90.8	252	480	481	1120
TMW-25	SS B			7.2		179.2	67		22.8	16.7				
Minimum	Alluvial	0.7 TMW-24	0.1 02W37	6.9 TMW-24	-9 TMW-07	1.5 02W20	61.3 02W09	7.83 02W29	20.1 02W33	15.1 02W29	19.1 02W39	192 02W21	192 02W21	391 02W39
Maximum	Alluvial	5.9 02W03	4.6 02W07	7.4 02W02	279 02W07	4387 TMW-09	254 02W16	198 02W45	113 02W15	170 02W05	629 02W15	673 02W05	677 02W05	1530 02W14
Minimum	SS B	1.2 1315R		6.7 02W47	62 02W25	1.782 1314	53.4 TMW-02	2.2 02W51	18.9 02W51	11.9 02W51	6.89 1314	222 1316R	222 1316R	254 02W51
Maximum	SS B	6.9 02W51		7.6 02W51	312 TMW-21	3066 TMW-08	311 TMW-18	285 TMW-18	113 TMW-18	183 TMW-18	799 TMW-18	628 1315R	629 1315R	2060 TMW-18
Minimum	SS C			6.9 TMW-17		4.67 TMW-17	161 TMW-17	23.3 TMW-17	45 TMW-17	40.9 TMW-17	301 TMW-17	320 TMW-17	321 TMW-17	830 TMW-17
Maximum	SS C			7.2 TMW-23		7.9 TMW-23	173 TMW-23	101 TMW-23	46.1 TMW-23	115 TMW-23	332 TMW-23	325 TMW-23	326 TMW-23	987 TMW-23
Western Upland Area														
1206	Surface	2.9	3.91	7.3	259	109.0	97.8	6.41	35.8	30.6	31.5	402	407	518
1331	SS A			7.1		82.2								
1332	SS C			7.4		32.2								

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Well ID	Water Bearing Unit	Dissolved Oxygen[1] (mg/L)	Nitrate[2,3] (mg/L)	pH[1] -	Redox Potential[1] (mv)	Uranium[2] (pCi/L)	Calcium[2] (mg/L)	Chloride[2,3] (mg/L)	Magnesium[2] (mg/L)	Sodium[2] (mg/L)	Sulfate[2,3] (mg/L)	Bicarbonte Alkalinity[2,3] (mg/L)	Total Alkalinity[2,3] (mg/L)	Total Dissolved Solids[2] (mg/L)
1334	SS A	5.6		7.2	219	13.3	72.5		38.3	48.3	31.5	324	325	461
1348	SS A	1.3	16.8	7.3	233	136.7	24.7	3.72	9.13	15.3	20.2	277	278	206
1349	SS A	1.9	10.5	7.2	215	43.5	79.5	7.43	27.7	48.1	45.1	309	310	457
1350	SS A	1.1	44.8	7.3	269	35.6	82.8	4.38	28.8	24.4	22.2	261	262	564
1351	SS A	1.8	80.9	7.0	266	67.2	115	3.6	45	20.1	20.1	251	251	704
1352	SS A	1.2		7.0	247	736	137	6.2	31	47.2	24.4	295	297	527
1353	SS A	5.0	14.7	7.1	177		78.6	5.39	23.4	21.9	20.7	256	256	400
1354	SS A	2.0	166.0	7.0	262	3.1	197	6.52	86.7	23	11.1	288	289	1310
1355	SS A		79.6	7.5		2.4	69.3	3.58	23	14.5	12	176	176	720
1356	SS A	3.9	19.3	7.0	244	269.7	109	9.93	35.1	12.9	36.5	324	326	498
1357	SS A	1.4	57.0	7.1	286	2.4	83.6	3.81	30.6	16.5	12.9	245	246	533
1358	SS A	3.4	26.2	7.4	264	1.2	65.9	3.09	22.1	18.8	15.9	203	203	464
1359	SS A	1.1	21.1	7.1	258	26.1	90.6	6.45	30.3	24.8	30.1	288	289	559
1360	SS A	1.1	0.2	7.2	262	86.8	30.8	6.19	11.3	10.8	36.5	357	358	1010
Minimum	SS A	1.1 1350, 1360	0.2 1360	7.0 1356	177 1353	1.2 1358	24.7 1348	3.09 1358	9.13 1348	10.8 1360	11.1 1354	176 1355	176 1355	206 1348
Maximum	SS A	5.6 1334	166.0 1354	7.5 1355	286 1357	736 1352	197 1354	9.93 1356	86.7 1354	48.3 1334	45.1 1349	357 1360	358 1360	1310 1354
Western Alluvial Area														
T-58	Alluvial	3.6		7.1	338	26.4	144	19.2	47.8	35.3	182	229	230	843
T-62	Alluvial	2.7		7.1	335	416.3	167	18.6	69.6	57.5	73.1	405	406	1040
T-63	Alluvial	1.2		6.8	249	54.6	221	29	83.3	69.2	59.2	351	352	1720
T-64	Alluvial	1.9		7.2	327	835.6	119	46.3	50.5	73.1	106	405	406	818

Table 4-1 August/September 2004 Groundwater Monitoring Data, Cimarron Site, Crescent, Oklahoma

Well ID	Water Bearing Unit	Dissolved Oxygen[1] (mg/L)	Nitrate[2,3] (mg/L)	pH[1] -	Redox Potential[1] (mv)	Uranium[2] (pCi/L)	Calcium[2] (mg/L)	Chloride[2,3] (mg/L)	Magnesium[2] (mg/L)	Sodium[2] (mg/L)	Sulfate[2,3] (mg/L)	Bicarbonte Alkalinity[2,3] (mg/L)	Total Alkalinity[2,3] (mg/L)	Total Dissolved Solids[2] (mg/L)
T-65	Alluvial	1.8		7.1	318	178.5	171	18.9	63.4	52.9	94.2	437	438	1030
T-66	Alluvial	1.8		7.1	322	105.2	297	75.8	84.3	121	734	266	267	1890
T-67	Alluvial	1.2	39.0	7.0	263	197.7	193	29	57.1	80.4	205	373	377	988
T-68	Alluvial	1.8		7.1	311	107.0	198	150	58.6	158	426	373	374	1400
T-69	Alluvial	1.3		7.0	315	49.6	235	55	72.3	93.4	543	293	294	1550
T-70R	Alluvial	1.4		7.2	290	200.9	120	29	39.7	51.4	171	341	342	674
T-72	Alluvial	1.8		7.1	288	119.9	259	112	73.6	124	653	298	299	1650
T-73	Alluvial	1.4		7.1	283	11.6	114	54.2	45.5	54.7	83	330	331	629
T-74	Alluvial	2.4		7.2	307	20.6	241	124	65.8	111	609	373	374	1440
T-75	Alluvial	1.1		7.1	263	278.7	248	200	73.8	187	675	314	315	1700
T-76	Alluvial	1.3		7.1	282	206.6	152	25	52.4	57.5	138	389	390	869
T-77	Alluvial	1.0		7.0	267	231.7	293	70.9	83.3	348	104	369	372	749
T-78	Alluvial	1.9		7.1	279	23.76	289	319	72.4	289	822	292	294	2140
T-79	Alluvial	1.1		7.2	298	231.2	125	81.8	38.4	95	197	373	374	828
T-81	Alluvial	2.3		7.1	286	20.21	101	48.5	35	60.3	54.6	372	374	542
T-82	Alluvial	1.4		7.1	261	103.8	145	120	43.7	120	232	388	390	923
Minimum	Alluvial	1.0 T-77	39.0 T-67	6.8 T-63	249 T-63	11.6 T-73	101 T-81	18.6 T-62	35 T-81	35.3 T-58	54.6 T-81	229 T-58	230 T-58	542 T-81
Maximum	Alluvial	3.6 T-58	39.0 T-67	7.2 T-74	338 T-58	835.6 T-64	297 T-66	319 T-78	84.3 T-66	348 T-77	822 T-78	437 T-65	438 T-65	2140 T-78

NOTES: 1 - Data collected in the field and provided by the Cimarron Hydrogeologic Staff.

2 - Analyzed by off-site laboratory (General Engineering Labs, Charleston, SC).

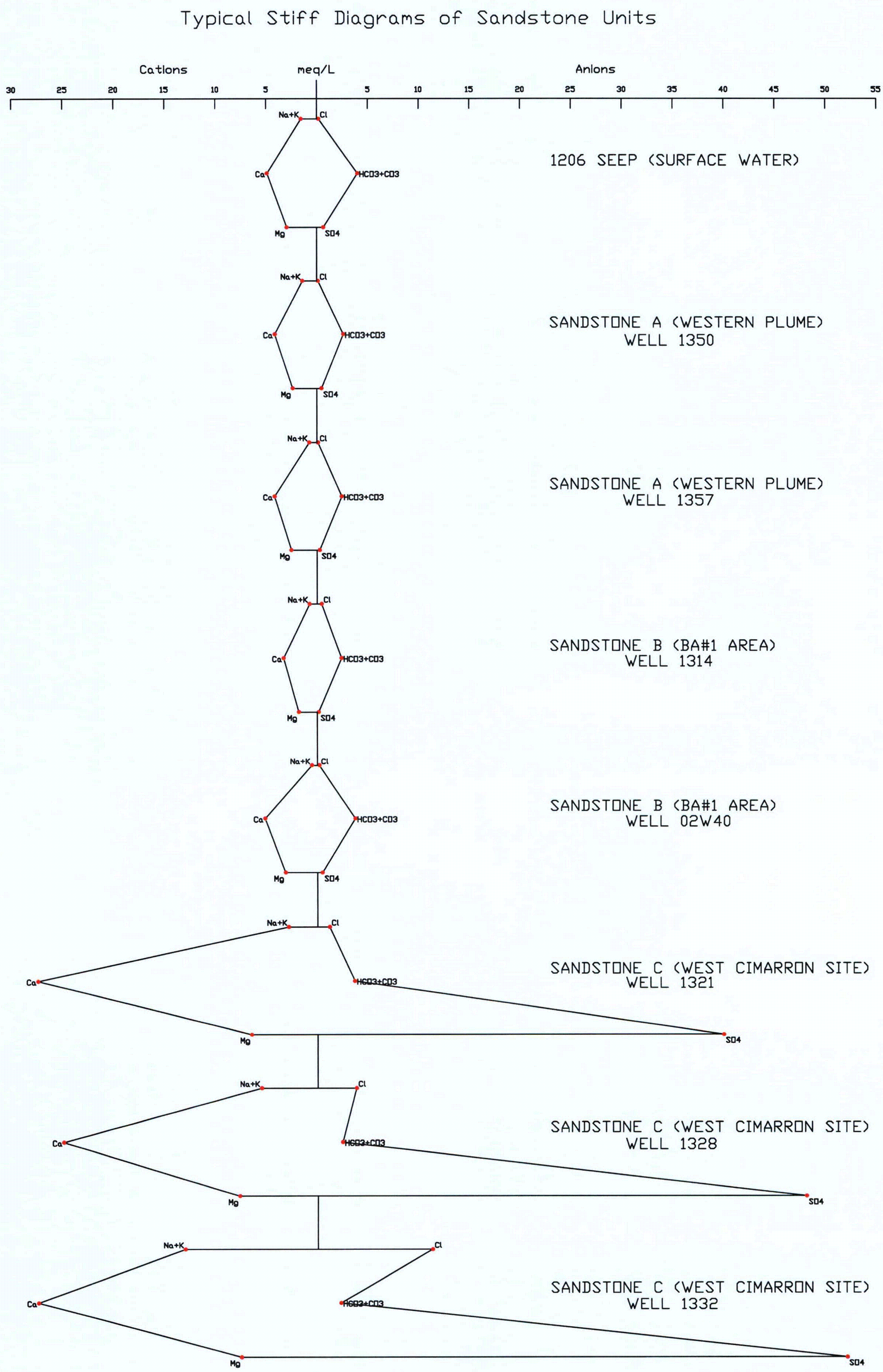
3 - Off-site laboratory data has been QA/QC reviewed and qualified. Qualifier flags have been removed for presentation purposes.

Table 4-2 Cimarron River Water Quality Data, Cimarron Site, Crescent, Oklahoma

SAMPLE LOCATION	DISCHARGE (cfs)	pH	POTASSIUM (mg/L)	SILICA (mg/L)	SPECIFIC CONDUCTANCE (umhos)	CALCIUM (mg/L)	CHLORIDE[2] (mg/L)	MAGNESIUM (mg/L)	SODIUM (mg/L)	SULFATE[2] (mg/L)	TOTAL ALKALINITY (mg/L)	TOTAL DISSOLVED SOLIDS[2] (mg/L)
Waynoka Gage												
(2-86) (Adams et al, 1994)	149	8.2	9.6	10	27,000	290	9,100	100	5,400	940	173	16,600
Ranges (1979-1990) (USGS NWIS Waterdata)	9-17,700	7.5-8.4		10	44,200-51,000	120-450	5,000-21,000	26-160	2,000-12,000	240-1400		5,900-35,900
Dover Gage												
(2-86) (Adams et al, 1994)	304	8.1	7.6	5.1	12,100	240	5,700	89	3,400	780	193	10,600
Ranges (1979-1989) (USGS NWIS Waterdata)		7.5-8.4	6-12		3,270-29,000	76-310	830-9,500	17-100	550-5,800	200-780		1,840-17,300
Guthrie Gage[1]												
(2-86) (Adams et al, 1994)	466	8.4	6.4	6.1	12,000	200	3,600	79	1,900	650	210	7,090

Note (1): Guthrie Gage is located approximately 10 miles east of the Cimarron site.

Note (2): All values for chlorides, sulfates, and TDS reported represent exceedances of the USEPA Secondary Drinking Water Maximum Concentration Limits (MCLs) i.e., 250 mg/L for chlorides/sulfates; 500 mg/L for TDS



SHEET NUMBER: 1

FIGURE NUMBER: 4-1

FIGURE 4-1
STIFF DIAGRAMS FOR SANDSTONE UNITS
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

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

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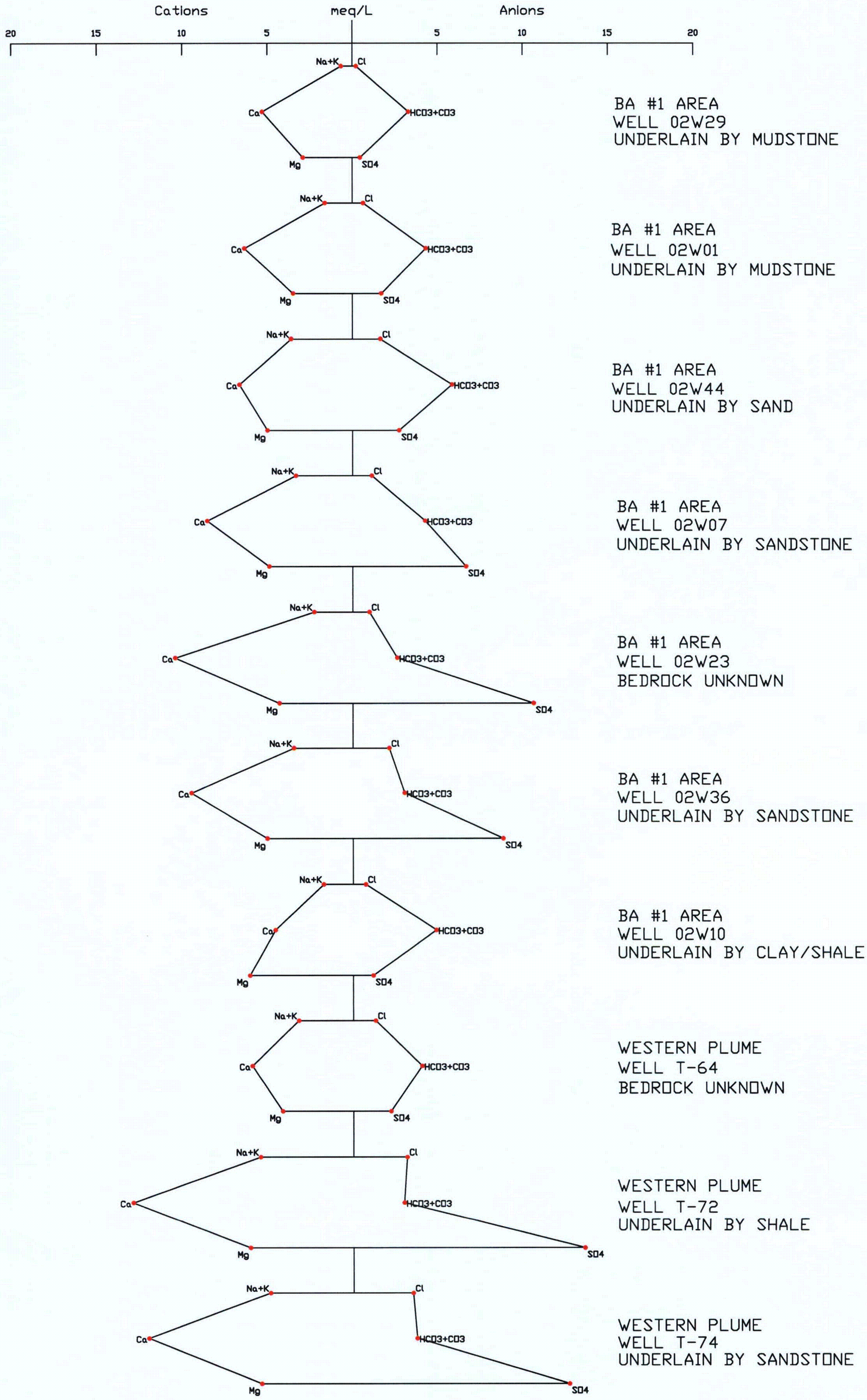
RIVER WATER STIFF DIAGRAM

Typical Stiff Diagrams of Alluvial



SHEET NUMBER:	FIGURE NUMBER:
1	4-2

FIGURE 4-2

STIFF DIAGRAMS FOR ALLUVIUM

CIMARRON CORPORATION

CRESCENT, OKLAHOMA

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1"= 80'	8/10/05	04020-044-200

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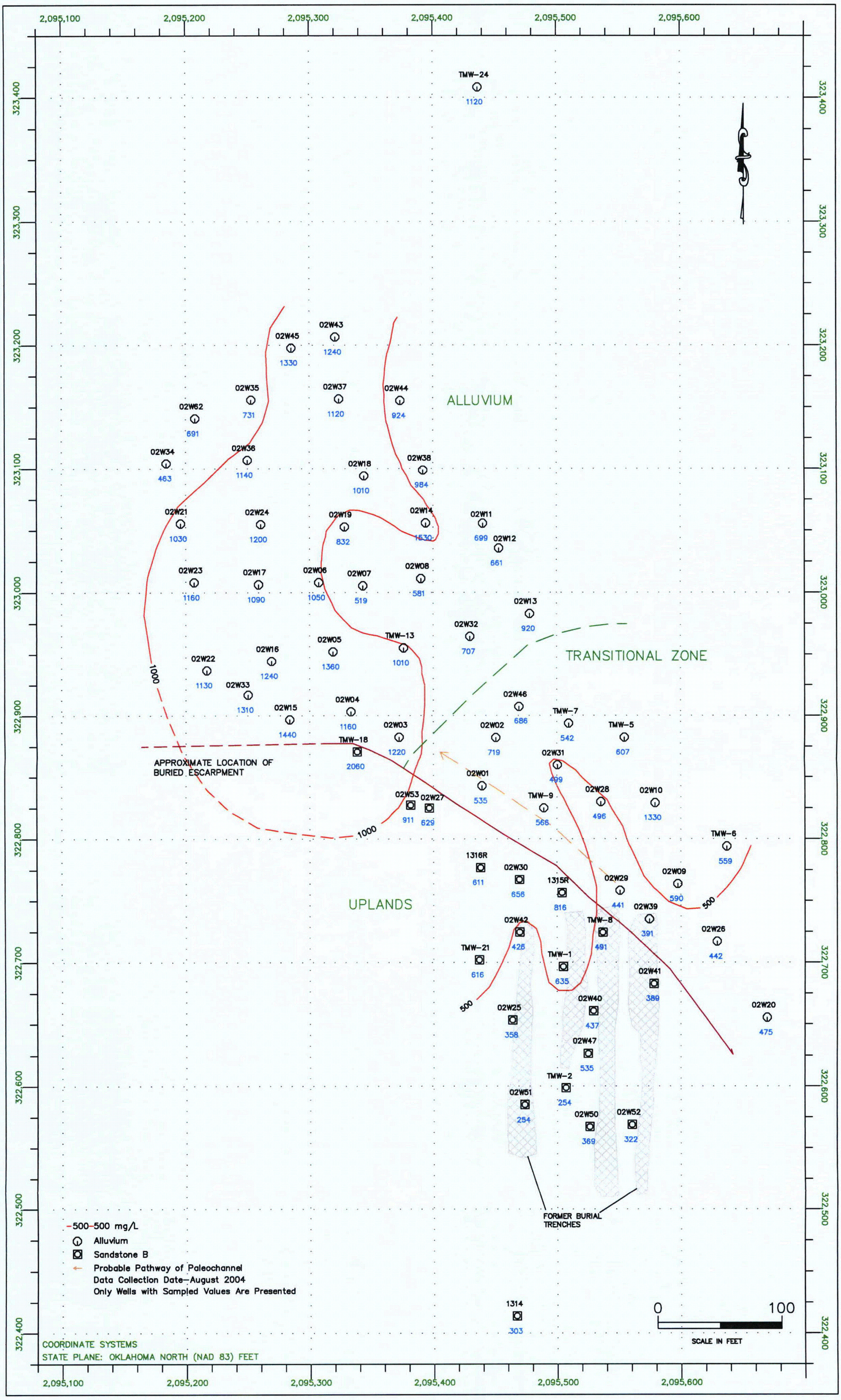

SHEET NUMBER:	FIGURE NUMBER:
1	4-3

FIGURE 4-3
DISTRIBUTION OF TOTAL DISSOLVED SOLIDS IN BA #1 AREA GROUNDWATER
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

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1"= 80'	8/10/05	04020-044-200

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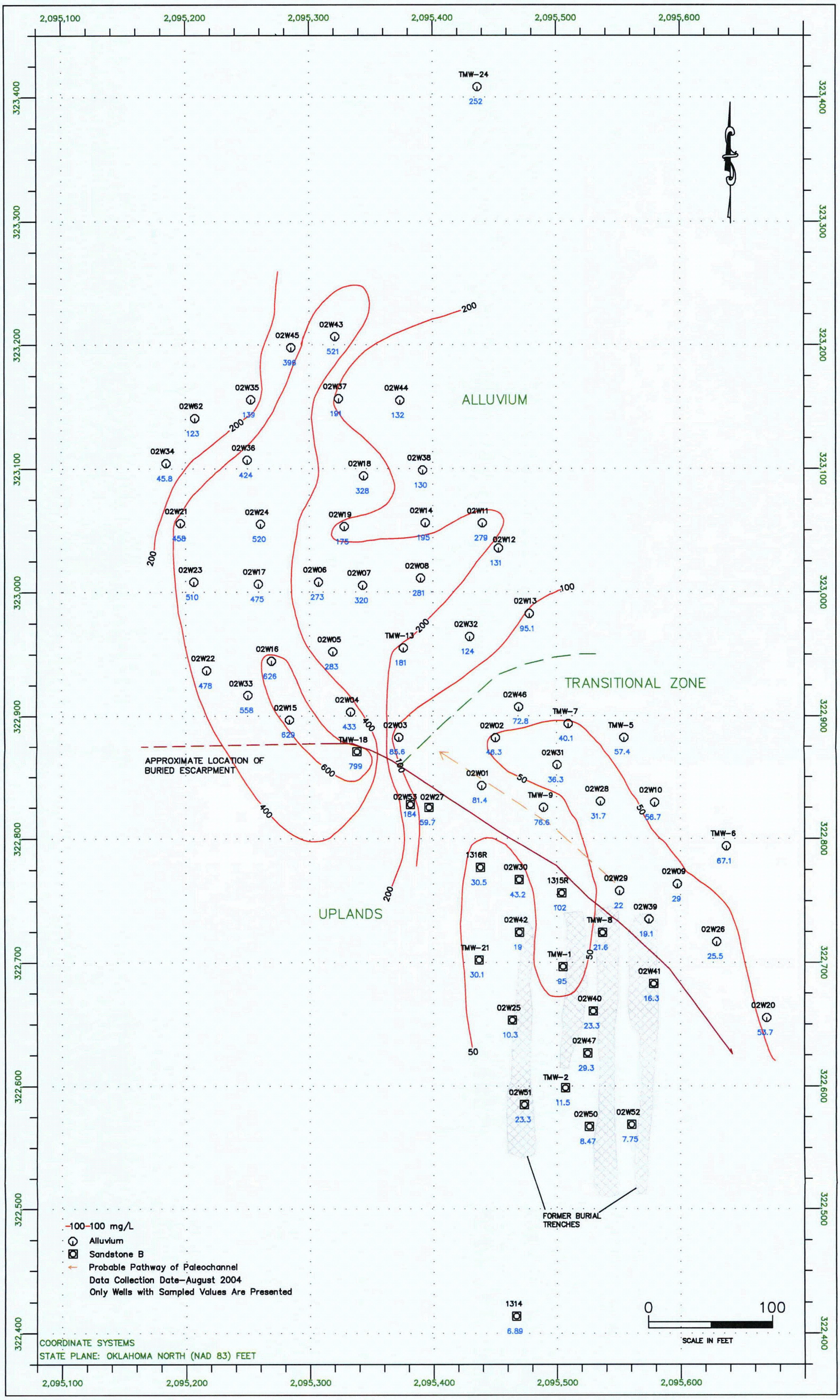

SHEET NUMBER:	FIGURE NUMBER:
1	4-4

FIGURE 4-4
DISTRIBUTION OF SULFATE IONS
IN BA #1 AREA GROUNDWATER
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

SCALE:	DATE:	PROJECT NUMBER:
1"= 80'	8/10/05	04020-044-200

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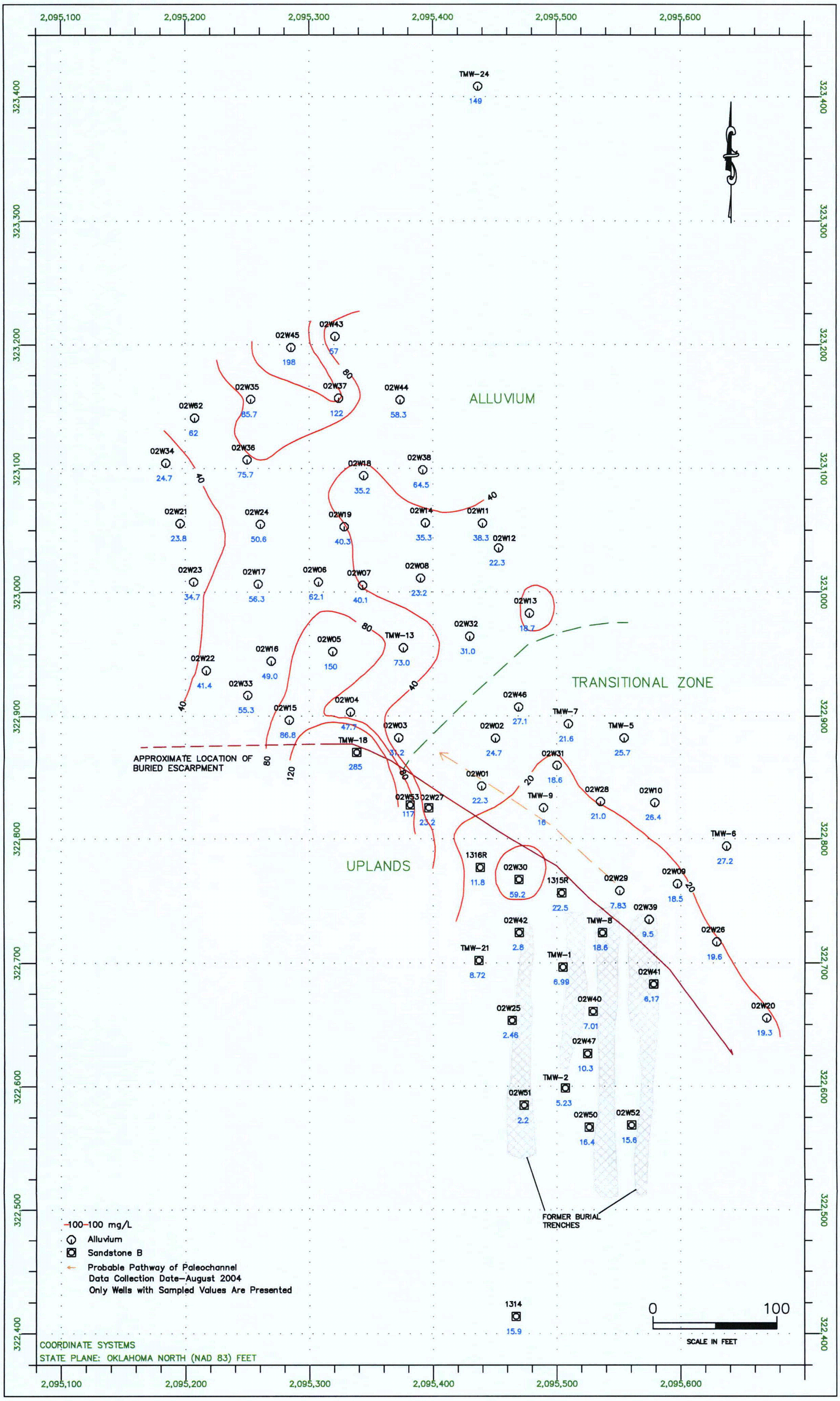

SHEET NUMBER:	FIGURE NUMBER:
1	4–5

FIGURE 4–5
DISTRIBUTION OF CHLORIDE IONS
IN BA #1 AREA GROUNDWATER
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

SCALE:	DATE:	PROJECT NUMBER:
1"= 80'	8/10/05	04020-044-200

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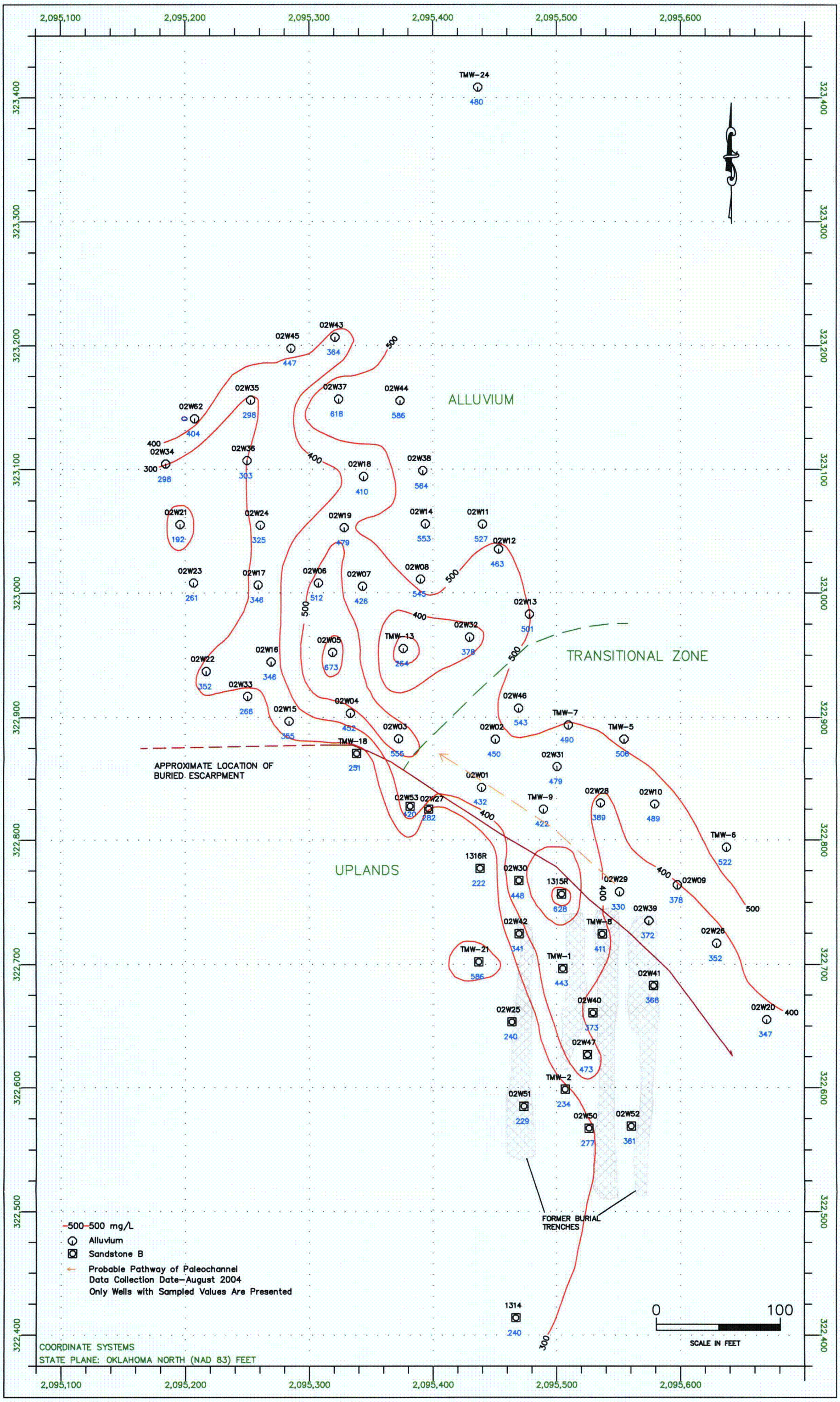

SHEET NUMBER:	FIGURE NUMBER:
1	4–6

FIGURE 4–6
DISTRIBUTION OF BICARBONATE ALKALINITY IN BA #1 AREA GROUNDWATER
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

SCALE:	DATE:	PROJECT NUMBER:
1"= 80'	8/10/05	04020-044-200

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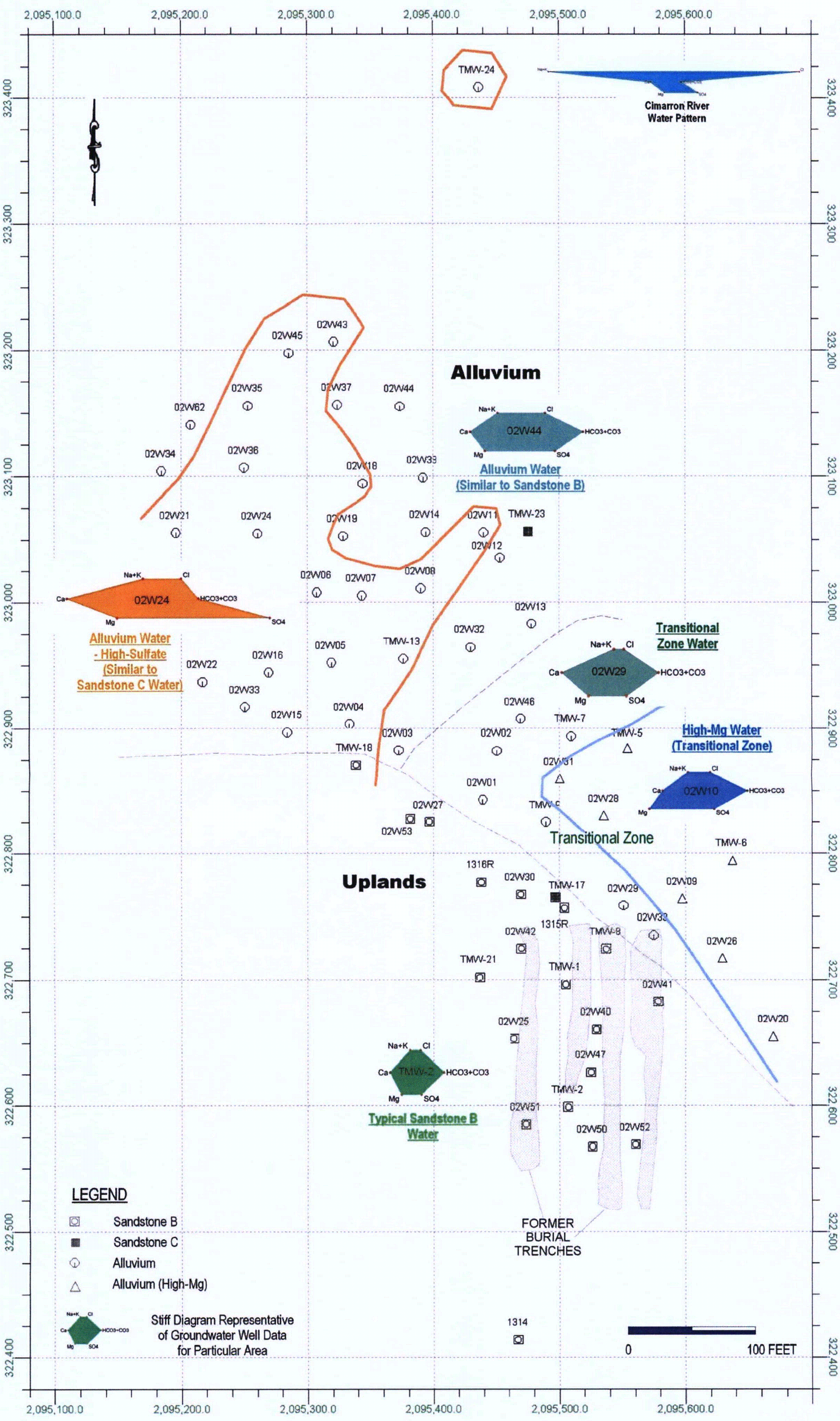

SHEET NUMBER:	FIGURE NUMBER:
1	4-7

FIGURE 4-7
DISTRIBUTION OF WATER TYPES
IN BA #1 AREA
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

SCALE:	DATE:	PROJECT NUMBER:
1"= 80'	8/10/05	04020-044-200

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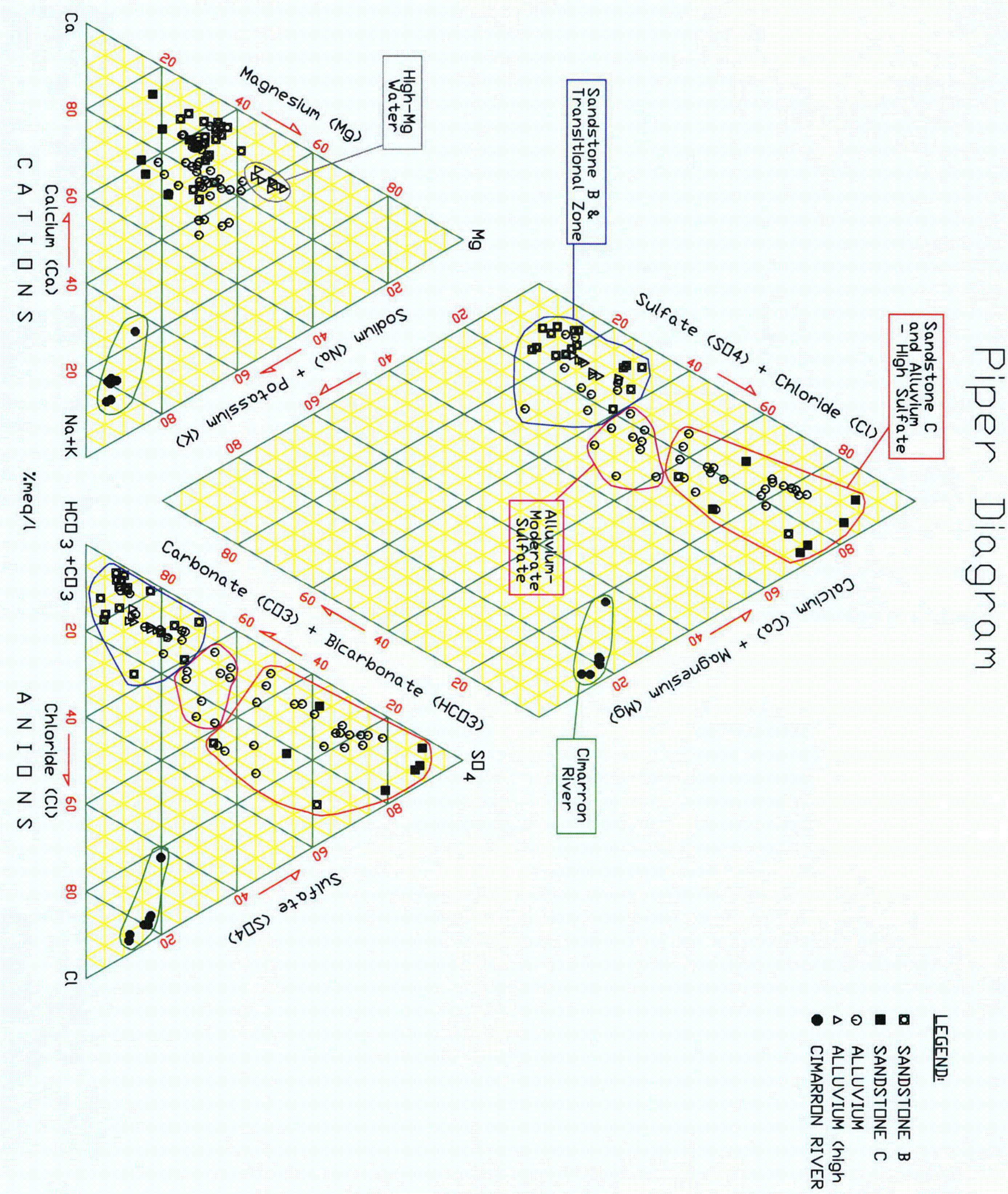

FIGURE 4-8
PIPER DIAGRAM FOR BA #1 AREA
WATER SAMPLES
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

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

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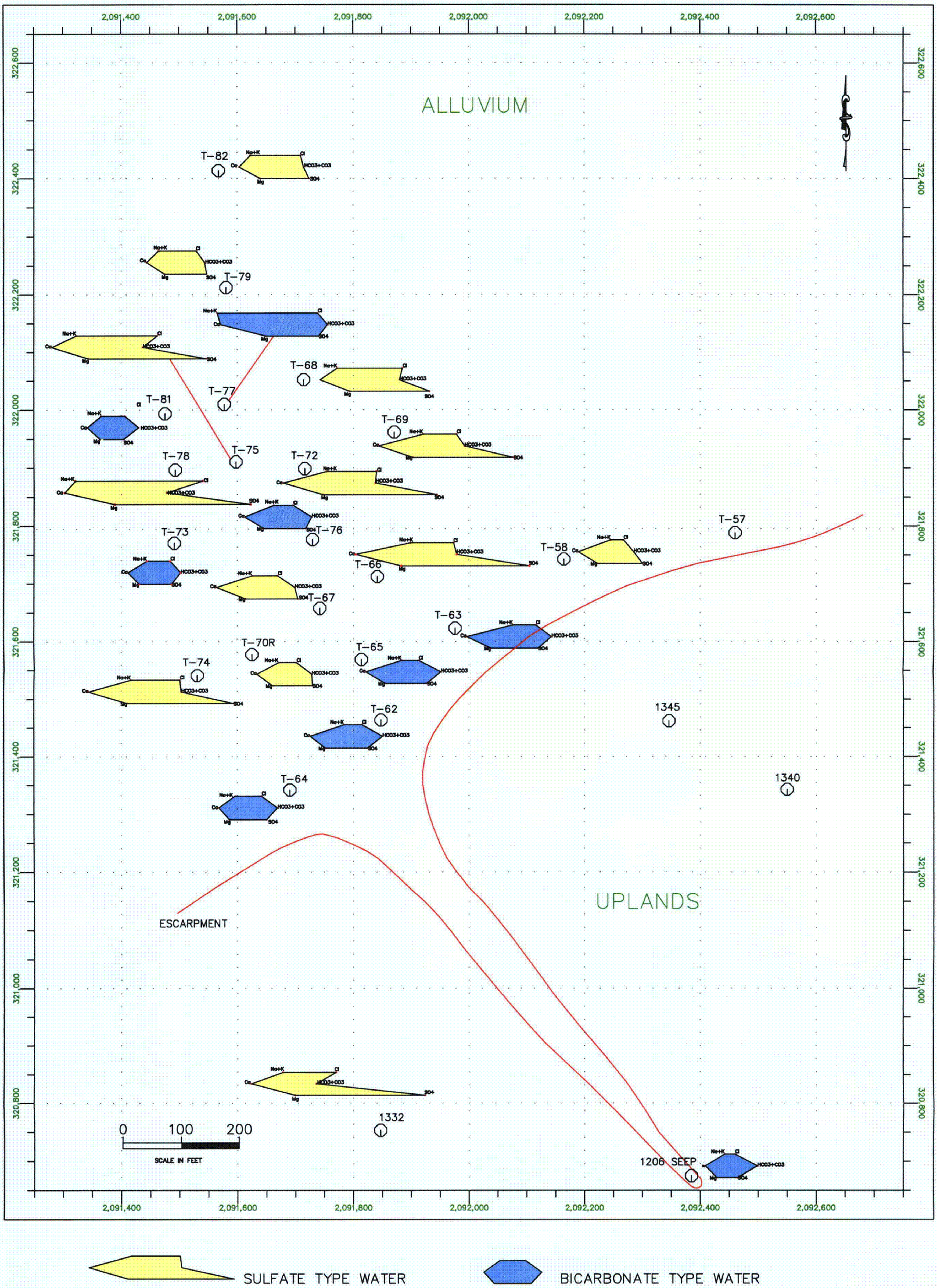
FIGURE NUMBER: 4-8
SHEET NUMBER: 1



SHEET NUMBER:	FIGURE NUMBER:
1	4-9

FIGURE 4-9
WATER TYPE DISTRIBUTION
IN WEST ALLUVIAL AREA
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

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

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1		6/17/05	

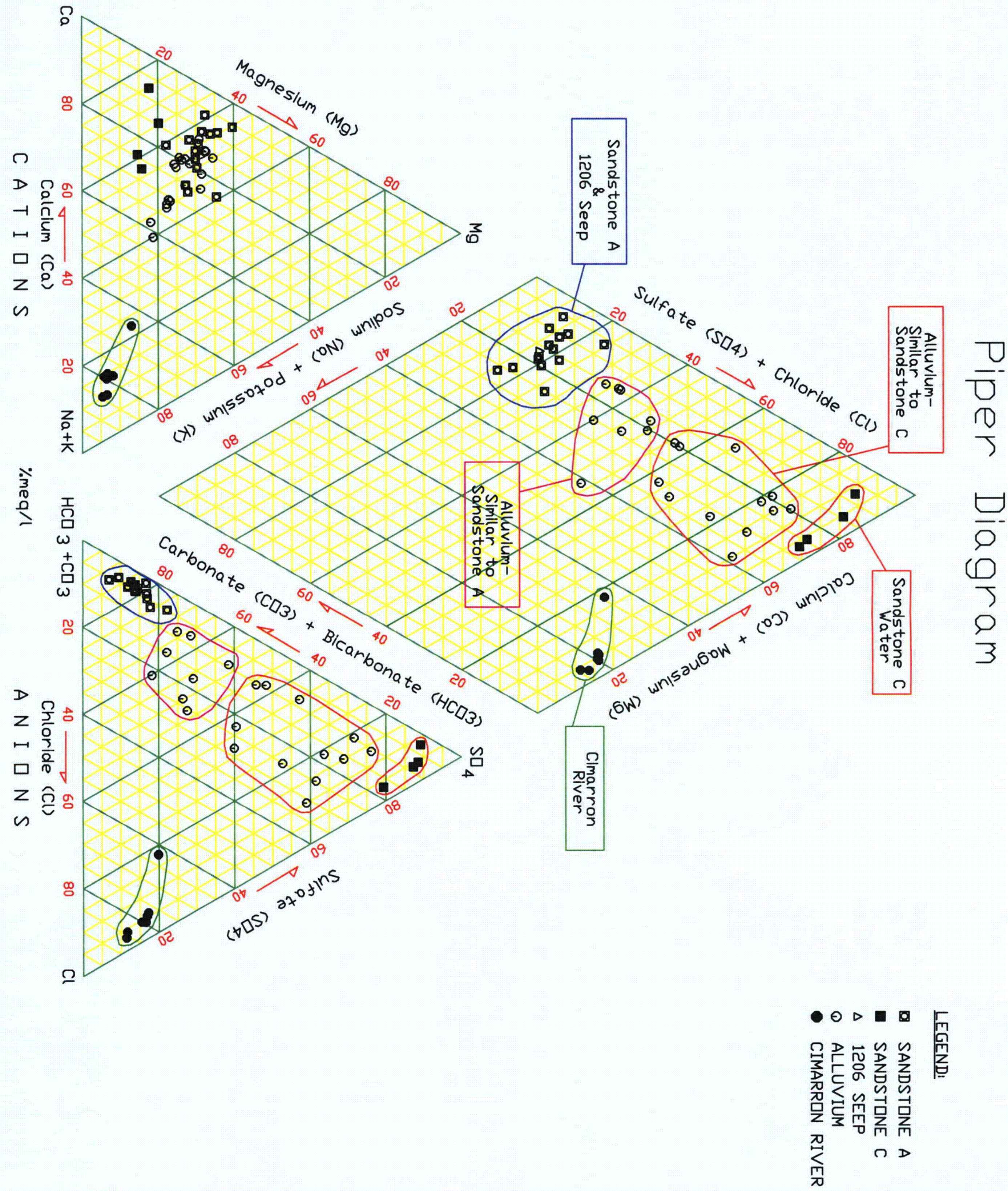

FIGURE NUMBER:	SHEET NUMBER:
4-10	1

FIGURE 4-10
PIPER DIAGRAM FOR GROUNDWATER SAMPLES FROM WESTERN PORTION OF SITE
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

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

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CHECKED BY: DJF				
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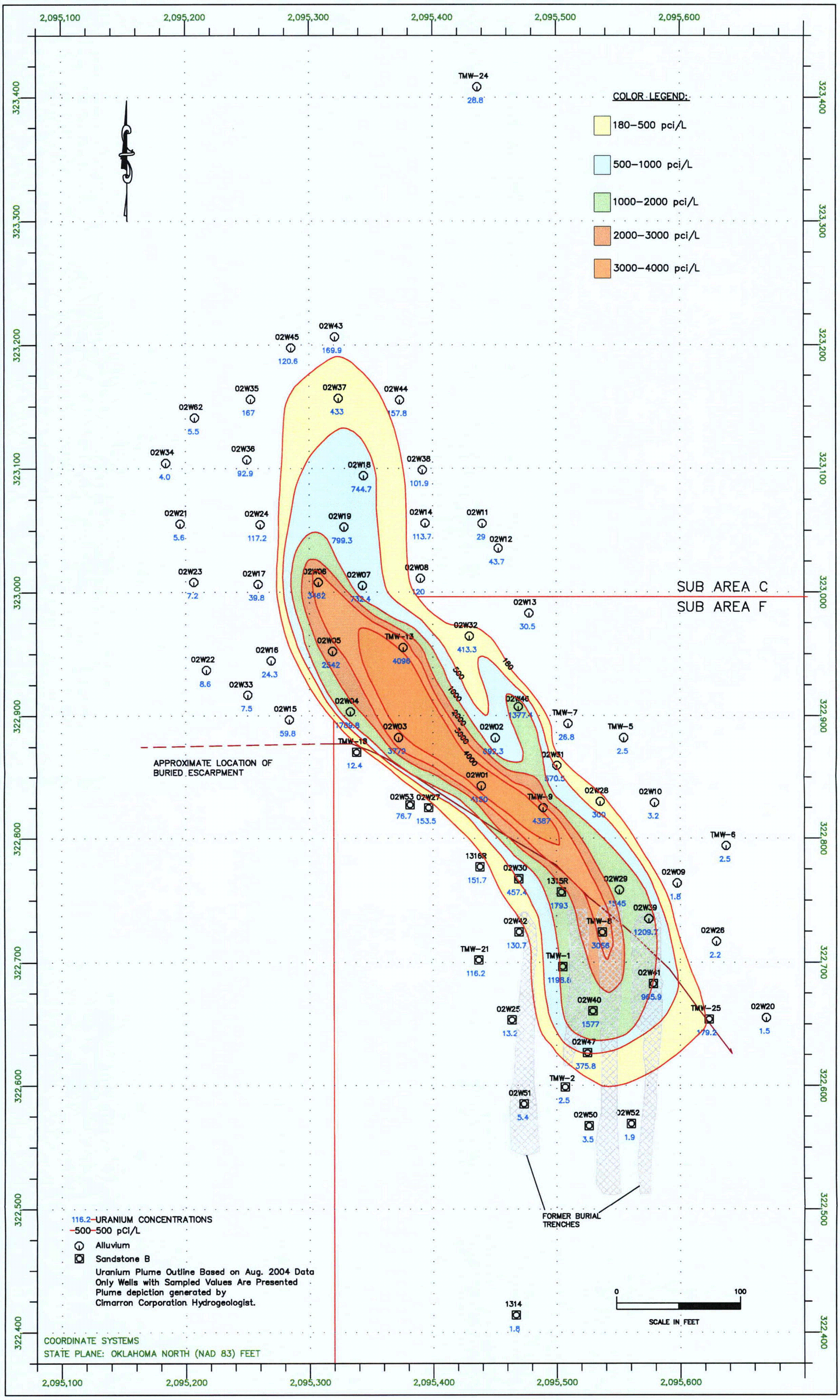

SHEET NUMBER:	FIGURE NUMBER:
1	4–11

FIGURE 4–11
URANIUM DISTRIBUTION IN BA #1 AREA
AS OF AUGUST 2004
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

SCALE:	DATE:	PROJECT NUMBER:
1"= 80'	8/10/05	04020-044-200

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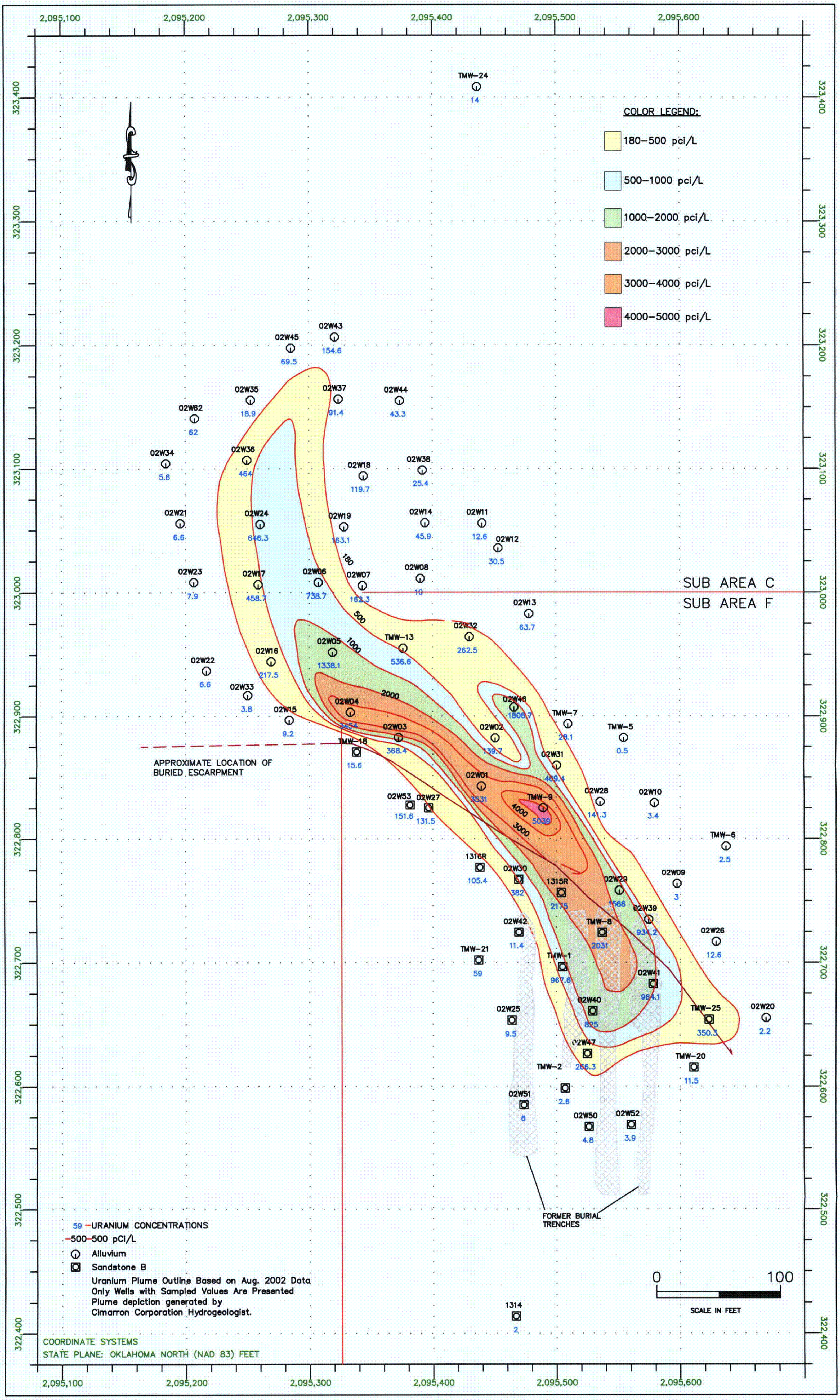

SHEET NUMBER:	FIGURE NUMBER:
1	4–12

FIGURE 4–12
URANIUM DISTRIBUTION IN BA #1 AREA
AS OF AUGUST 2002
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

SCALE:	DATE:	PROJECT NUMBER:
1"= 80'	8/10/05	04020-044-200

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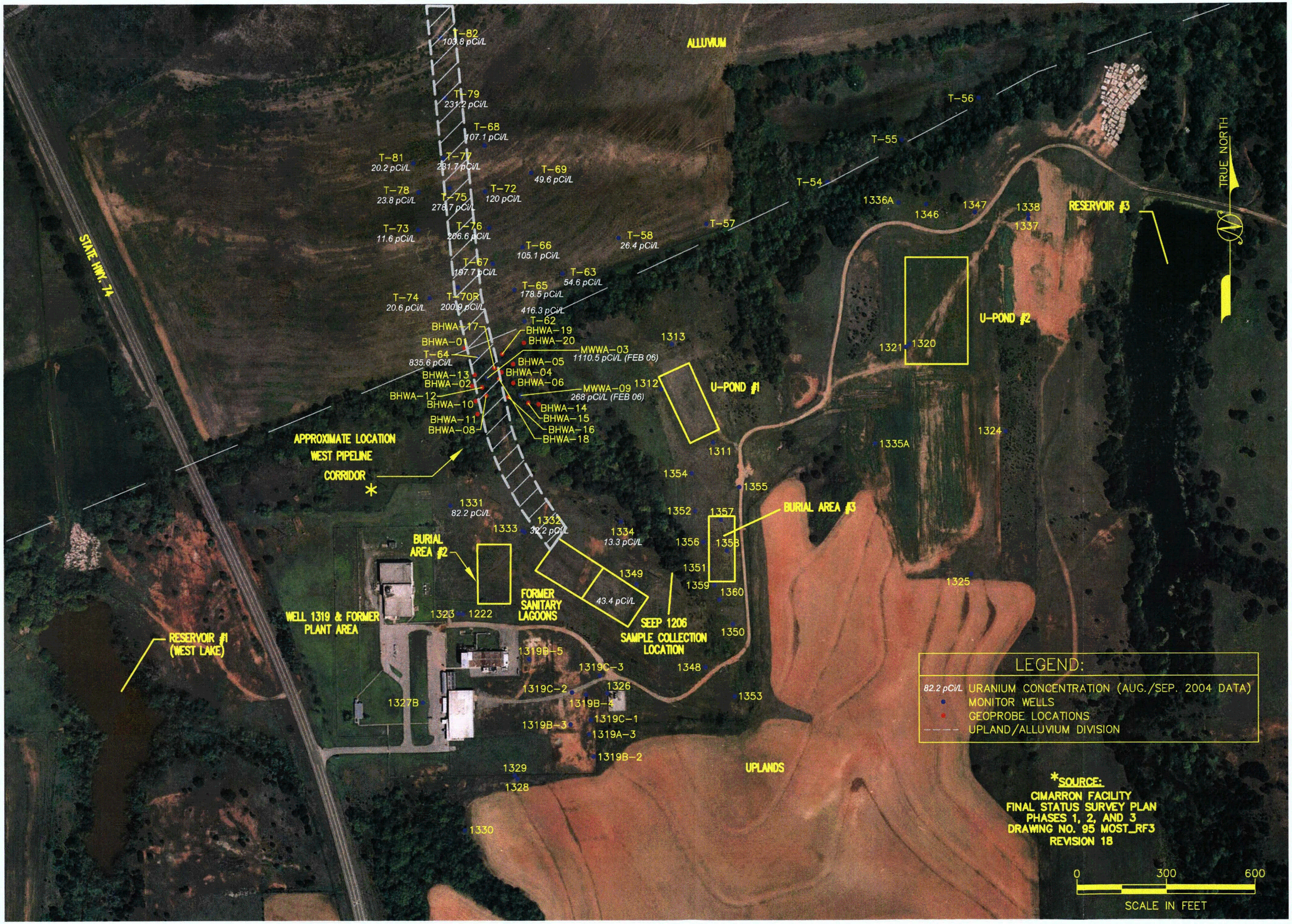

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	NO.:	DESCRIPTION:	DATE:	BY:
DRAWN BY: HTP	1		4/10/05	JAS
	2		6/17/05	JAS
CHECKED BY: DJF	3		9/27/06	JAS
APPROVED BY: DJF				

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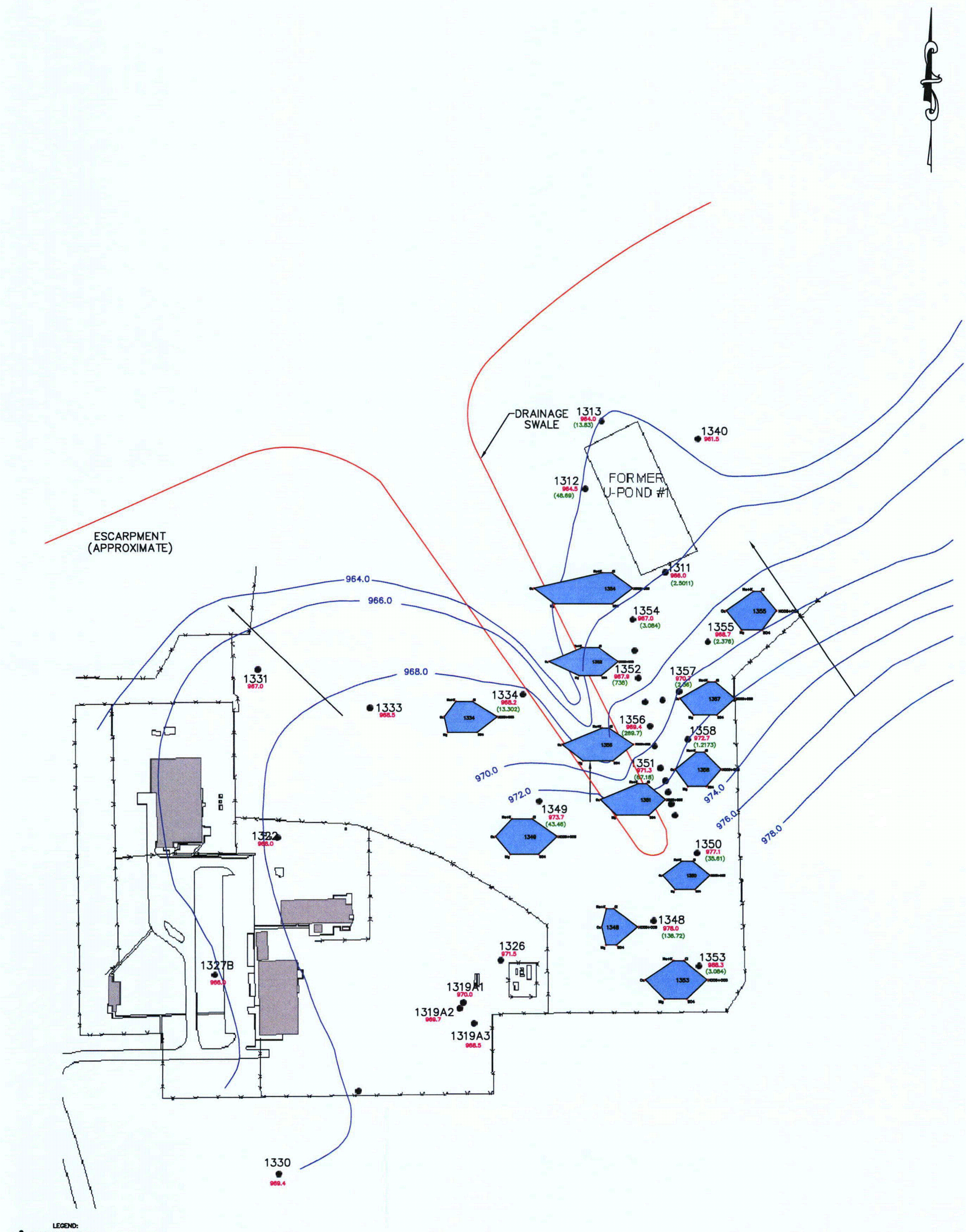
FIGURE 4-13
URANIUM DISTRIBUTION MAP
FOR WESTERN PORTION OF SITE
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

SCALE:	DATE:	PROJECT NUMBER:
1" = 300'	9/27/06	04020-044-325

FIGURE NUMBER: 4-13

SHEET NUMBER: 1



LEGEND:
- MONITORING WELL
- GROUNDWATER CONTOUR
- DIRECTION OF GROUNDWATER FLOW
- (136.72) URANIUM CONCENTRATIONS (pCi/L)
- 947.5 WATER LEVEL ELEVATION (FEET-AMSL)

WATER LEVEL DATA
AS OF AUGUST/SEPTEMBER 2004

BICARBONATE TYPE WATER

NOT TO SCALE

SHEET NUMBER:	FIGURE NUMBER:
1	4-14

FIGURE 4-14
WATER TYPE AND URANIUM (U)
IMPACT DISTRIBUTION IN
WESTERN UPLAND AREA
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

SCALE:	DATE:	PROJECT NUMBER:
N.T.S.	8/10/05	04020-044-325

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	NO.:	DESCRIPTION:	DATE:	BY:
DRAWN BY:	1.		10/19/06	JAS
JAS				
CHECKED BY:				
DJF				
APPROVED BY:				
DJF				

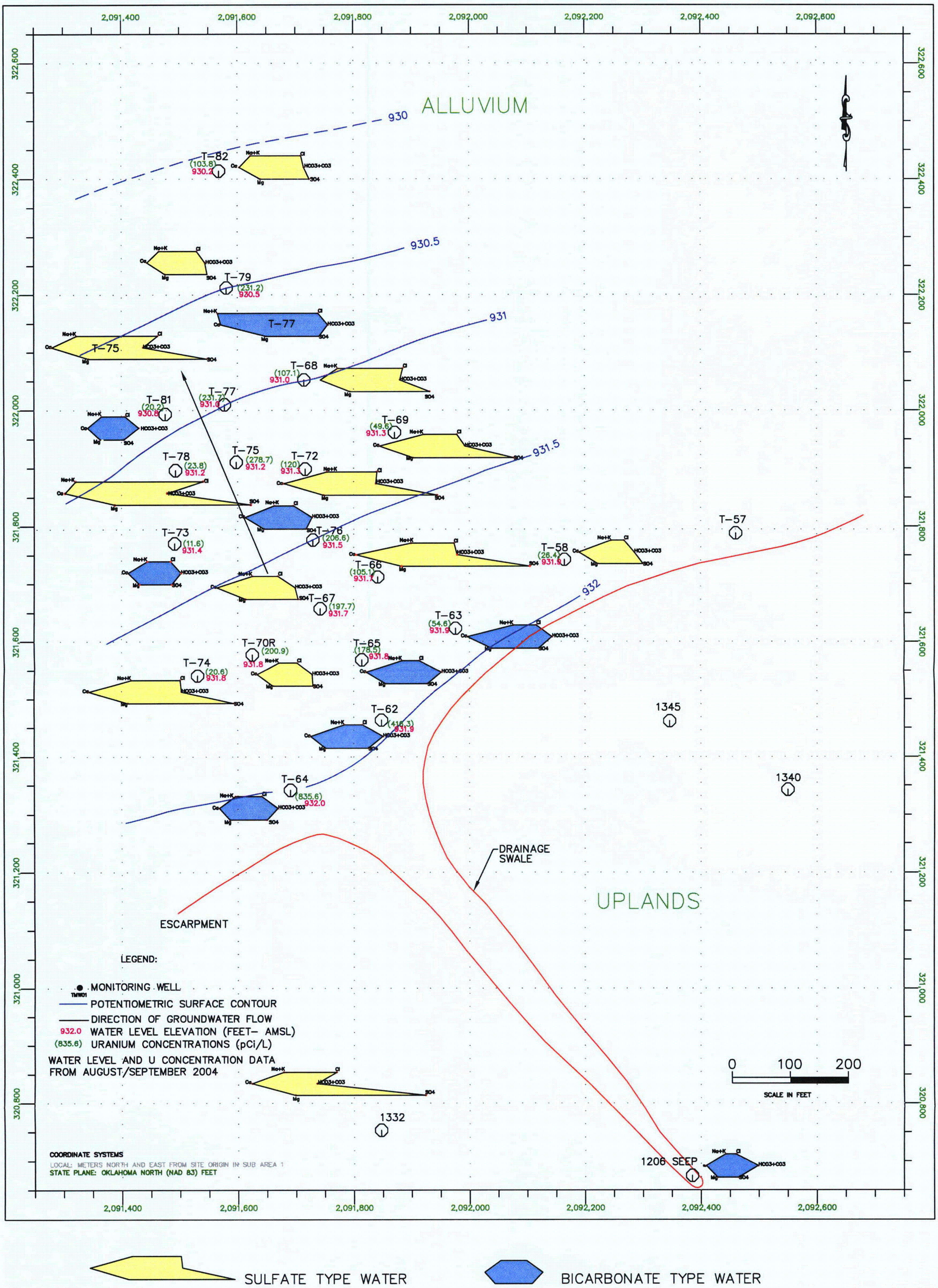

FIGURE 4-15
WATER TYPE AND URANIUM (U) IMPACT DISTRIBUTION IN WESTERN ALLUVIAL AREA
CIMARRON CORPORATION
CRESCENT, OKLAHOMA

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

FIGURE NUMBER: 4-15

SHEET NUMBER: 1

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5.0 Integrated Conceptual 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 CSM based on site data available as of 2006. 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.

5.1 BA #1 Area

The upland in the BA #1 Area is underlain by a sequence of sandstone and mudstone units, namely, from top to bottom: Sandstone A, Mudstone A, Sandstone B, Mudstone B, and Sandstone C (Figure 2 5). The alluvium can be divided into a clayey transitional zone and a sandy alluvial zone. The transitional zone consists predominantly of clay and silt and overlies Sandstone B or Mudstone B (Figure 2-5). A paleochannel appears to exist in the transitional zone parallel to the northeast border of the upland, which may control the flow of groundwater in the vicinity of the upland (Figure 2-7). The alluvium consists of mainly sand and overlies Sandstone C and, to a lesser extent, Mudstone B (Figure 2-5).

Groundwater from the former disposal trenches in the BA #1 Area flows into Sandstone B, across a buried escarpment that separates Sandstone B and the Cimarron River Floodplain Alluvium, and then into and through the floodplain alluvium to the Cimarron River (Figure 2-5).

Three geochemically distinct types of groundwater are present in the BA #1 Area: a calcium bicarbonate water from Sandstone B; a calcium sulfate water from Sandstone C; and a magnesium bicarbonate water in the transitional zone (Figure 4-7). Both Sandstone B groundwater and Sandstone C groundwater are present in the sandy alluvium. The influence of Sandstone C groundwater discharging into the alluvium increases closer to the Cimarron River (Figure 4-7).

Nitrate and fluoride are detected in groundwater in this area at levels that are consistent with background.

5.1.1 Nature and Extent

The only licensed material detected in the BA #1 Area at levels above the site-specific release criteria is total uranium. The spatial distribution of uranium concentrations detected in the vicinity of the BA #1 Area is illustrated in Figure 4-11. The uranium concentration varied from background concentrations to over 4,000 pCi/L based on the August/September 2004 data. The uranium-impacted groundwater, which has uranium concentrations exceeding the established site-specific groundwater release criteria of 180 pCi/L, has an elongated shape with the southern portion trending from southeast to northwest and the northern portion trending from south to north. The orientation and distribution of the impacted groundwater coincides with the location of a paleochannel discussed in Section 2.0 (Geological Conceptual Site Model), indicating that the migration of uranium near the escarpment may be controlled by the paleochannel. The numerical groundwater flow model (ENSR, 2006) replicates this groundwater flow direction based solely on the geologic conditions input to the model.

Uranium in all three types of groundwater found in the BA #1 Area is believed to be in the U^{6+} oxidation state, with the anionic forms uranyl carbonates as the predominant species. Of all the uranium aqueous species present in groundwater, the divalent uranyl dicarbonate ($UO_2(CO_3)_2^{2-}$) is by far the most abundant species at the concentration and pH ranges encountered at the site.

5.1.2 Fate and Transport

The primary mechanisms controlling transport for the U in groundwater in the BA#1 Area are advection (with the groundwater flow) and dispersion (spreading during transport). The numerical groundwater flow model (ENSR 2006), demonstrates that the directions of groundwater are to the northeast in Sandstone B, to the northwest in the transition area, and to the north in the alluvium, which is exactly the path taken by the U plume away from the burial trenches.

Flow in Sandstone B within the eastern BA #1 Area is mostly northeastward and is driven by a relatively steep hydraulic gradient (0.10 foot/foot) at the interface between Sandstone B and the floodplain alluvium. Once the groundwater enters the BA #1 Area transitional zone, the flow is refracted to a more northwest direction due to the presence of low-permeability clay northeast of the escarpment. These low-permeability sediments interrupt the northeasterly flow of Sandstone B groundwater and force it to flow along a southeastern-northwestern trending paleochannel containing relatively high-permeability sandy materials layered between the sandstone and the clayey material. The hydraulic gradient in the sand channel decreases to around 0.008 foot/foot due in part to the much higher overall hydraulic conductivity in the paleochannel compared to Sandstone B (10^{-3} cm/s versus 10^{-5} to 10^{-4} cm/s in Sandstone B) and the presence of a clay-rich barrier downgradient of the sandy paleochannel near TMW-9 and 02W01. In the sandy alluvium, the flow direction is northwards towards the Cimarron River, the groundwater discharge point. Calculated average linear groundwater velocities range from approximately 0.03 to 5 ft/day for the different geologic units.

As described in Section 3 above, the hydraulic gradients and flow directions do not change significantly over time. Therefore, rates and directions of contaminant transport are also unlikely to change significantly. It is possible that river flooding, surface water flow in the drainageways, and other short-term phenomenon could affect migration. However, these phenomena are by their nature of short duration. The migration of the U plume over the long term is controlled by the average hydraulic gradient and the nature of the geologic materials.

The principal factors controlling reactions of uranium during transport in groundwater at the BA #1 Area are pH, redox potential (Eh), ionic composition, and the physical characteristics of the subsurface materials as discussed in Section 4.4.

Uranium that was present in the waste materials buried in the former trenches in the BA #1 Area was leached out by infiltrating precipitation that percolated through the vadose zone into Sandstone B. Uranium was most likely transported in the forms of uranyl dicarbonate and tricarbonate species given the oxidative conditions of groundwater (most groundwater samples in this area have oxidation-reduction potential greater than 100 mv), the near-neutral groundwater pH, and the results of speciation modeling.

Uranyl dicarbonate is an anionic species and tends to be adsorbed onto positively charged surfaces. The potential surface for uranium adsorption at the site is likely to be iron hydroxides or oxides. Reddish colored clay, silt, and sand are widespread in the alluvium at the Cimarron Site, indicating the presence of iron hydroxides or oxides. At pH values encountered at the site (around 7), the surfaces of these minerals are positively charged, thus providing a favorable media for the adsorption of uranium. Adsorption onto subsurface materials results in a retardation of uranium migration, which appears to have occurred in the transitional zone.

Adsorption of uranium onto subsurface materials has previously been studied at the BA #1 Area. Hazen (2002), contracted by Cimarron Corporation, conducted experimental studies to assess the distribution of uranium between groundwater and site soils using a batch test. That study yielded a uranium soil-water distribution coefficient (Kd) value of 3 milliliters per gram (mL/g). In another study also conducted by Hazen on behalf of Cimarron Corporation and supervised by ENSR in 2006, dynamic column elution tests were performed using three types of aquifer materials and two types of groundwater from the site, The three types of materials represent three size fractions of alluvial soils including sand, silt, and clay. The two waters were representatives of sandstone B and C waters. This study yielded Kd values of 0.5, 2.0, and 3.4 for sand, silt, and clay, respectively, indicating a clear size dependence. These results confirm that adsorption of uranium onto subsurface materials is occurring at the site and may influence the distribution of uranium in the subsurface.

Competition for adsorption sites from other anions may affect the adsorption of uranium onto soil particles. As discussed in Section 4.4, adsorption in low TDS and sulfate water is relatively high, and tends to decrease in high TDS and sulfate water due to increased competition for adsorption sites. The dynamic column elution tests discussed above also confirm that high TDS and sulfate water resulted in reduction of uranium Kd values. Therefore, in the transitional zone where the TDS and sulfate contents are low, conditions are more favorable for uranium adsorption. Uranium adsorption in the sandy alluvium is expected to be low or even negligible due to the presence of high TDS and sulfate water from Sandstone C. As a result, uranium in the sandy alluvium is thought to be more mobile than in the transitional zone. However, the actual rates of migration are also dependent on the relative velocities in the different geologic materials.

5.1.3 Impact to Receptors

The impacted media in the BA #1 Area is the shallow groundwater. As a result, it poses little threat to human or environmental receptors. Access restriction to the site precludes any exposure to the general public. The primary receptor is the Cimarron River. A risk assessment (Roberts Schornick & Associates, 1998) showed there were no unacceptable risks associated with the U, nitrate, or fluoride in groundwater at the site under current and likely future use.

An estimate of the time for the uranium to reach the river, plus an estimate of the maximum concentration of uranium in groundwater that will reach the river, was submitted by Cimarron Corporation as an attachment to a March 31, 2004, letter to David Cates of the Oklahoma DEQ. The conclusions of the analytical modeling performed at that time indicated the leading edge of the uranium-impacted groundwater is not expected to reach the Cimarron River for over 1,000 years of migration, and even then the concentration of uranium in groundwater will be less than 2 pCi/L when it reaches the river.

5.2 Western Upland Area

The Western Upland Area, which includes the former Uranium Pond #1, the 1206 Seep Area, and the former Sanitary Lagoons, is underlain primarily by Sandstone A, as shown in Figure 2-9. Sandstone B is exposed near the base of the drainage between the former Sanitary Lagoons and the former Uranium Pond #1 at the mouth of the drainage where it opens into the alluvial floodplain of the Cimarron River. In the vicinity of the BA #3 Area and the former Sanitary Lagoons, the upper part of Sandstone A is composed mostly of siltstone and shale, rather than sandstone (Figure 2-4).

Groundwater in the Western Upland Area is found in Sandstones A, B, and C. Groundwater flow in Sandstone A follows topography over most of the Cimarron Site. In the Western Upland Area, the drainage between the BA #3 Area and the former Sanitary Lagoons acts as a local drain for groundwater in Sandstone A (Figure 2-10). Groundwater flows toward this drainage from the vicinity of the BA #3 Area, as this drainage is incised into Sandstone A and Mudstone A. The thick vegetation and groundwater seeps, such as those at the Western Upland Area, attest to groundwater discharge to this drainage (thus becoming surface water) from Sandstone A. Although vertical downward gradients are likely in Mudstone A, the relatively higher permeability of the sandstone units results in preferred horizontal flow in the water bearing units compared to vertical flow across units. The hydrogeology of the Western Upland Area is discussed in Section 3.0 (Hydrogeological Conceptual Site Model) of this report.

5.2.1 Nature and Extent

Elevated uranium concentrations in groundwater appear to be spatially related to the BA #3 Area. This disposal trench was excavated, surveyed by the NRC, and backfilled with clean soil prior to 1994. Thus, any remaining sources of uranium in Sandstone A may be secondary sources generated by precipitation of uranium in Sandstone A during the operational phase of the BA #3 Area, or sources related to material left in the trench at the BA #3 Area. Other constituents detected in the groundwater are reasonably typical for the Cimarron Site.

5.2.2 Fate and Transport

Uranium has been detected in the Western Upland Area in only a limited number of monitor wells screened in Sandstone A near the BA #3 Area. This suggests diffusion and slow migration of uranium away from local "hot spots" related to the BA #3 Area.

The uranium transport mechanism in the Western Upland Area is uncertain. Based on observations in other areas, the primary mechanisms are expected to be advective transport and hydrodynamic dispersion. Because there is no well-defined groundwater plume in the Western Upland Area, formally evaluating the "fate and transport" of uranium in this area is not necessarily useful.

5.2.3 Impact to Receptors

There is no present impact to environmental, biological, or human receptors in the Western Upland Area due to the localized nature of the elevated uranium concentrations detected in groundwater. A risk assessment has demonstrated that there is no unacceptable risk associated with exposure to the uranium, nitrate or fluoride in the seeps (Roberts Schornick & Associates, 1998).

5.3 Western Alluvial Area

Alluvial sediments of the Cimarron River floodplain in the Western Alluvial Area consist predominantly of sand with minor amounts of clay and silt (Figure 2-9). The alluvial floodplain consists of groundwater in the alluvial floodplain sands that flow toward the Cimarron River under a very low hydraulic gradient. The hydraulic gradient is influenced by the stage of the Cimarron River and can on rare occasion temporarily reverse during periods of flooding by the river. Recharge to the alluvial floodplain comes from Sandstone A through seepage along the escarpment face, from Sandstones B and, and from precipitation.

There are two distinct types of groundwater in the alluvium: a calcium bicarbonate water; and a calcium sulfate water. Additional information on the various types of water encountered at the Western Alluvial Area is presented in Section 4.3.3 (Area-specific Geochemical Considerations – Western Alluvial Area) of this report.

5.3.1 Nature and Extent

Impact in the Western Alluvial Area consists mainly of uranium in groundwater. Data from the August/September 2004 annual sampling event for the Western Alluvial Area is presented in Table 4-1. The spatial distribution of uranium in groundwater in the Western Alluvial Area is shown in Figure 4-13.

The uranium concentration varied from background concentrations to over 800 pCi/L based on the August/September 2004 data. The uranium-impacted groundwater, which has uranium concentrations exceeding the established site-specific groundwater release criteria of 180 pCi/L, has an elongated shape extending for the escarpment northwards approximately 900 ft towards the Cimarron River.

The impacts apparently originate near the mouth of the upland drainage that separates the former Sanitary Lagoons and the BA #3 Area. The uranium impacts parallel the trace of the former West Pipeline Corridor that was used to discharge wastewater to the Cimarron River from 1966 to 1970. The pipeline was removed in 1985, at which time the soil areas exceeding 30 pCi/g were excavated and backfilled with clean soil.

Nitrate and fluoride are also elevated relative to background in the Western Alluvium Area.

5.3.2 Fate and Transport

The primary transport mechanisms within the Western Alluvial Area are probably advection and hydrodymanic dispersion. However, the current distribution of uranium in this area is not entirely due to transport, but also to leaks from the former pipeline. The sources for the uranium in this area include leaks from the pipeline, and also transport of uranium into the alluvium from the mouth of the drainage way. Recent installation of two wells in this area shows the presence of uranium in groundwater, and uranium is present upgradient in water at Seep 1206.

The groundwater flow and chemical transport directions in the alluvial materials are to the north towards the Cimarron River. Calculated average linear groundwater velocities range from approximately 0.9 to 1.5 ft/day.

As described in Section 3 above, the hydraulic gradients and flow directions do not change significantly over time. Therefore, rates and directions of contaminant transport are also unlikely to change significantly. It is possible that river flooding, surface water flow in the drainageways, and other short-term phenomenon could affect migration. However, these phenomena are by their nature of short duration. The migration of the U plume over the long term is controlled by the average hydraulic gradient and the nature of the geologic materials.

The relatively low clay content of the alluvial materials and the uniform geochemistry of non-licensed materials suggest that mass removal processes, such as adsorption, are not significantly affecting transport of the uranium.

5.3.3 Impact to receptors

In the Western Alluvial Area, the uranium impact is farther from the Cimarron River, and uranium concentrations are lower than at the BA #1 Area. As in the BA#1 Area, the primary receptor is the Cimarron River. A risk assessment (Roberts Schornick & Associates, 1998) showed there were no unacceptable risks associated with the U, nitrate, or fluoride in groundwater at the site under current and likely future use.

6.0 Conclusions and Recommendations

6.1 Purpose and Objective

Cimarron Corporation has investigated the geology, hydrogeology, and geochemistry related to licensed material in groundwater at the Cimarron Site. The purpose of this CSM is to provide an overview of the geology and hydrogeology of the Cimarron Site, and to compile and integrate historical and recent site information into a focused comprehensive model of the BA #1 Area, the Western Upland Area, and the Western Alluvial Area.

The objectives of this CSM are twofold:

- To provide a defensible integrated conceptual model understood by Cimarron, NRC, and Oklahoma DEQ personnel; and
- To provide a basis upon which groundwater remediation activities can be designed and justified.

This section summarizes the information presented in Section 5.0 (Integrated Conceptual Model) as a conclusion for each of the three areas of concern, and presents recommendations for moving forward.

6.2 BA #1 Area

6.2.1 Conclusion

Assessment of the BA #1 Area is complete. Licensed material exists in shallow groundwater, migrating from former disposal trenches into Sandstone B, and then into the Cimarron River alluvium. Groundwater monitoring results indicate that the maximum concentration of licensed material is decreasing slowly over time. The maximum concentration observed in the 2004 sampling events was less than 4,500 pCi/L. Monitoring results also show that impacted groundwater migrates through a permeable paleochannel in the alluvium, is slowed by a "barrier" of low-permeability clay, and then progresses into a zone with higher permeability but a relatively flat potentiometric surface. Continued migration appears to be relatively slow.

6.2.2 Recommendation

Cimarron Corporation intends to remediate groundwater exceeding 180 pCi/L in this area. Cimarron Corporation will submit a detailed remedial design to both NRC and Oklahoma DEQ. The design will include a post-decommissioning monitoring program to demonstrate compliance with groundwater decommissioning criteria.

6.3 Western Upland Area

6.3.1 Conclusion

Assessment of the Western Upland Area is complete. Licensed material has been observed at concentrations typically less than 500 pCi/L in a few monitor wells in Sandstone A. These monitor wells are located near the BA #3 Area, which was decommissioned prior to 1992. Other nearby wells yield total uranium concentrations below 30 pCi/L (the MCL for uranium).

Impacted groundwater migrates from Sandstone A in the Western Upland Area into the nearby drainage way, where it combines with other seepage from both sides of this drainage. The impacted shallow groundwater in the Western Upland Area poses no threat to human or environmental receptors.

6.3.2 Recommendation

Cimarron Corporation intends to remediate groundwater exceeding 180 pCi/L in this area. Cimarron Corporation will submit a detailed remedial design to both NRC and Oklahoma DEQ. The design will include a post-decommissioning monitoring program to demonstrate compliance with groundwater decommissioning criteria.

6.4 Western Alluvial Area

6.4.1 Conclusion

Assessment of the Western Upland Area is complete. Licensed material has been observed at low concentrations (typically, less than 300 pCi/L) in alluvial materials immediately beneath the trace of a former pipeline. The pipeline was excavated in 1985; "source" material exceeding 30 pCi/g total uranium was removed by 1995. Because of the flat hydraulic gradient in this area, impacted groundwater appears to be moving very slowly.

6.4.2 Recommendation

Cimarron Corporation intends to remediate groundwater exceeding 180 pCi/L in the Western Alluvial Area. Cimarron Corporation will submit a detailed remedial design to both NRC and Oklahoma DEQ. The design will include a post-decommissioning monitoring program to demonstrate compliance with groundwater decommissioning criteria.

7.0 References

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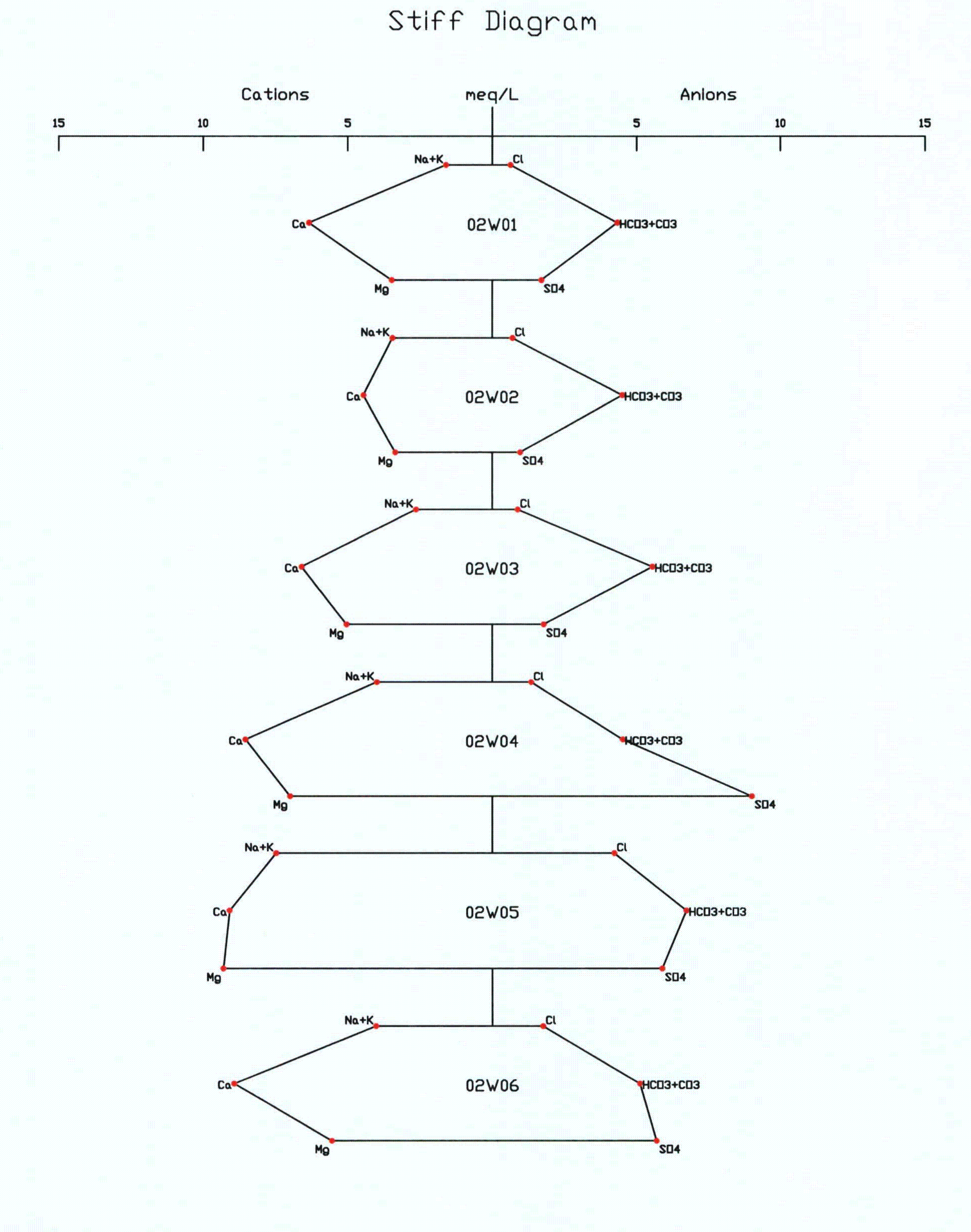
Appendix A

Stiff Diagrams for Wells Sampled August/September 2004



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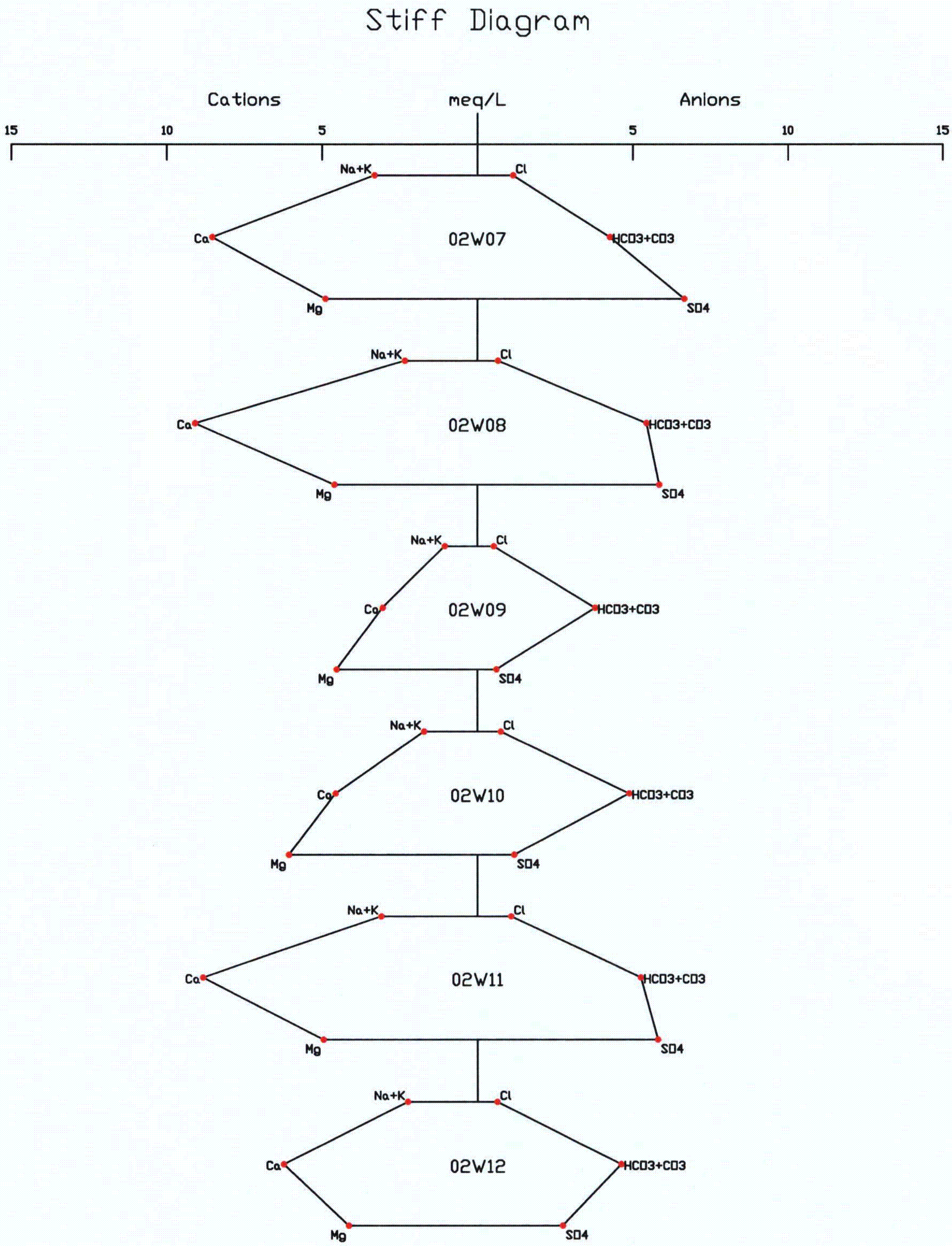

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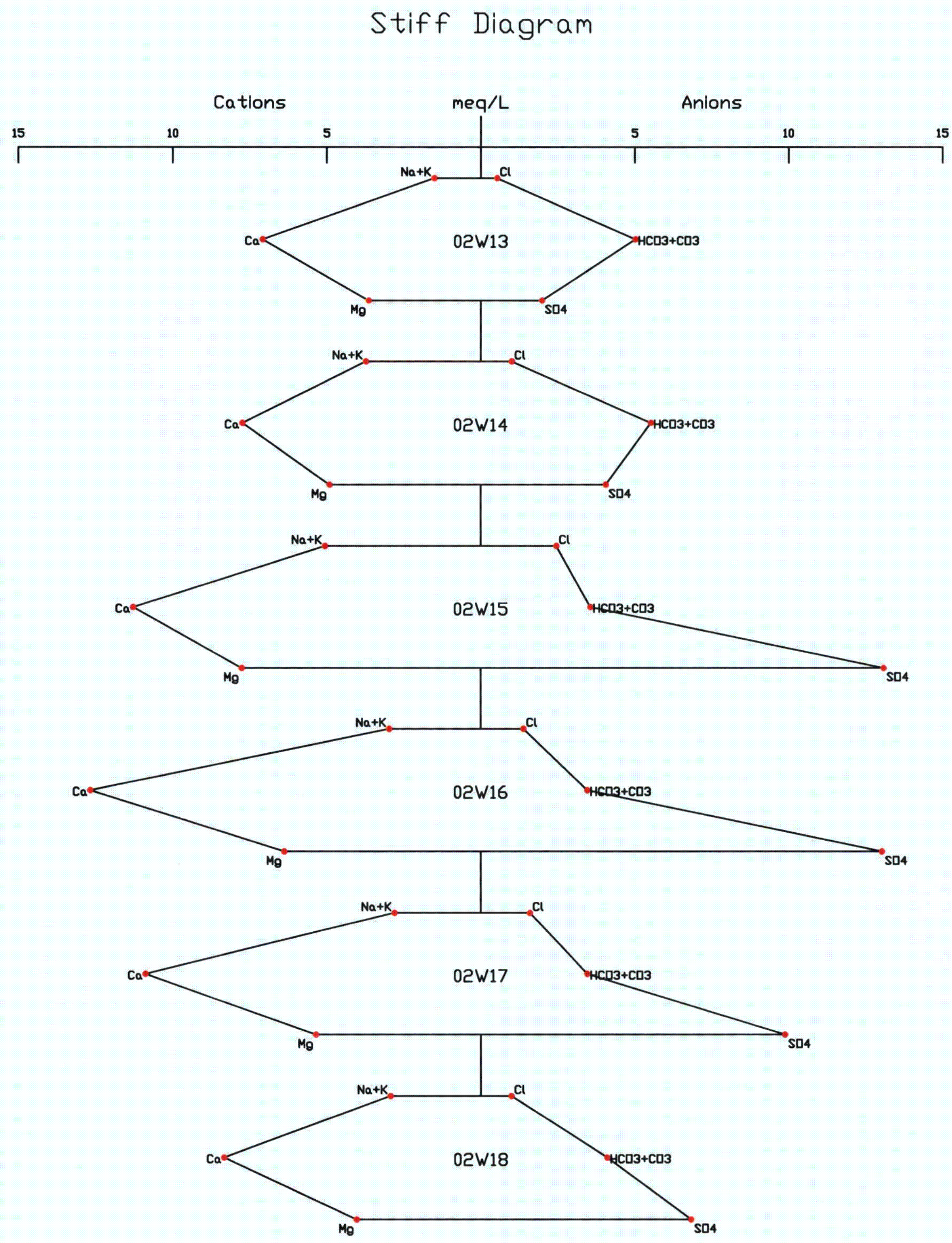

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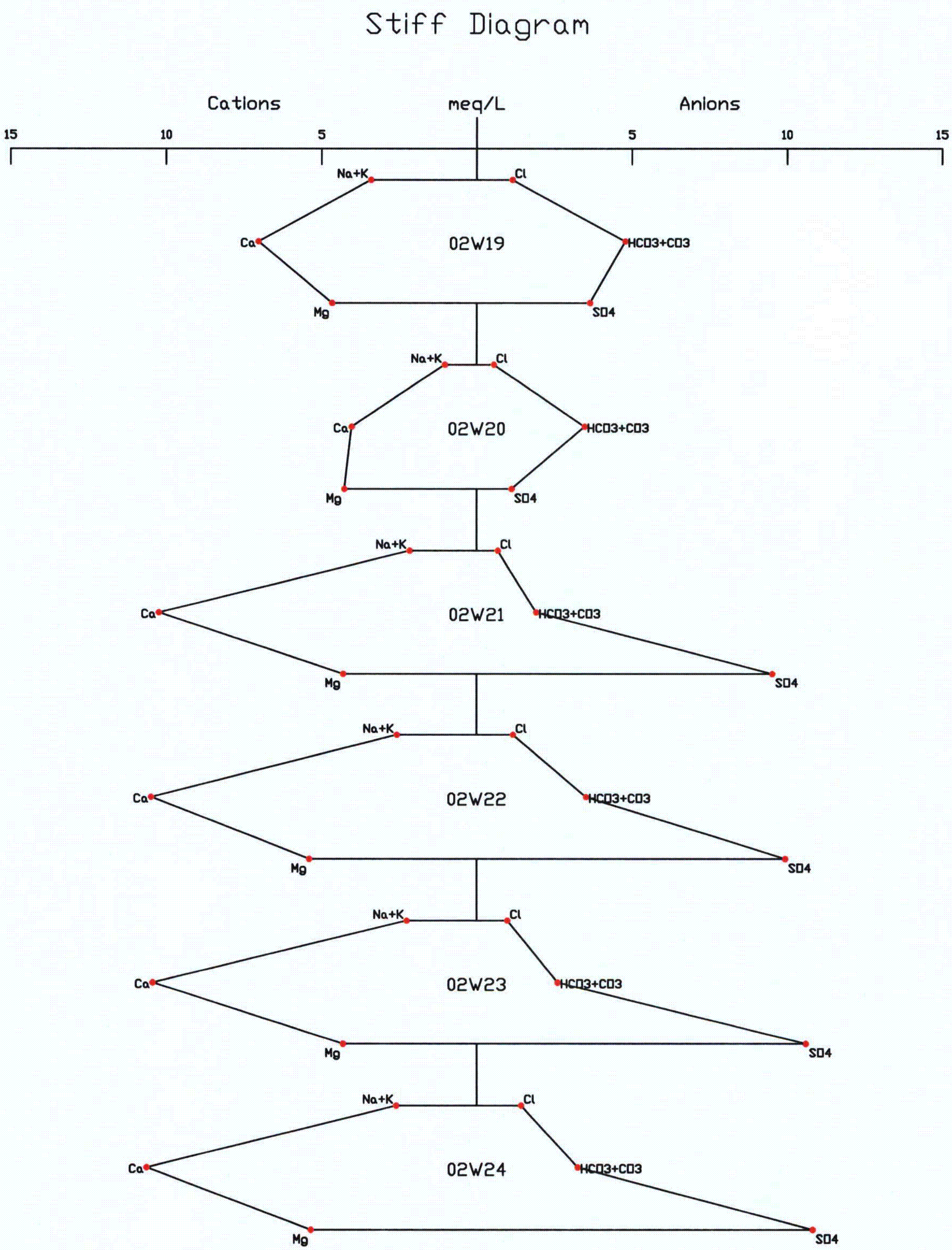

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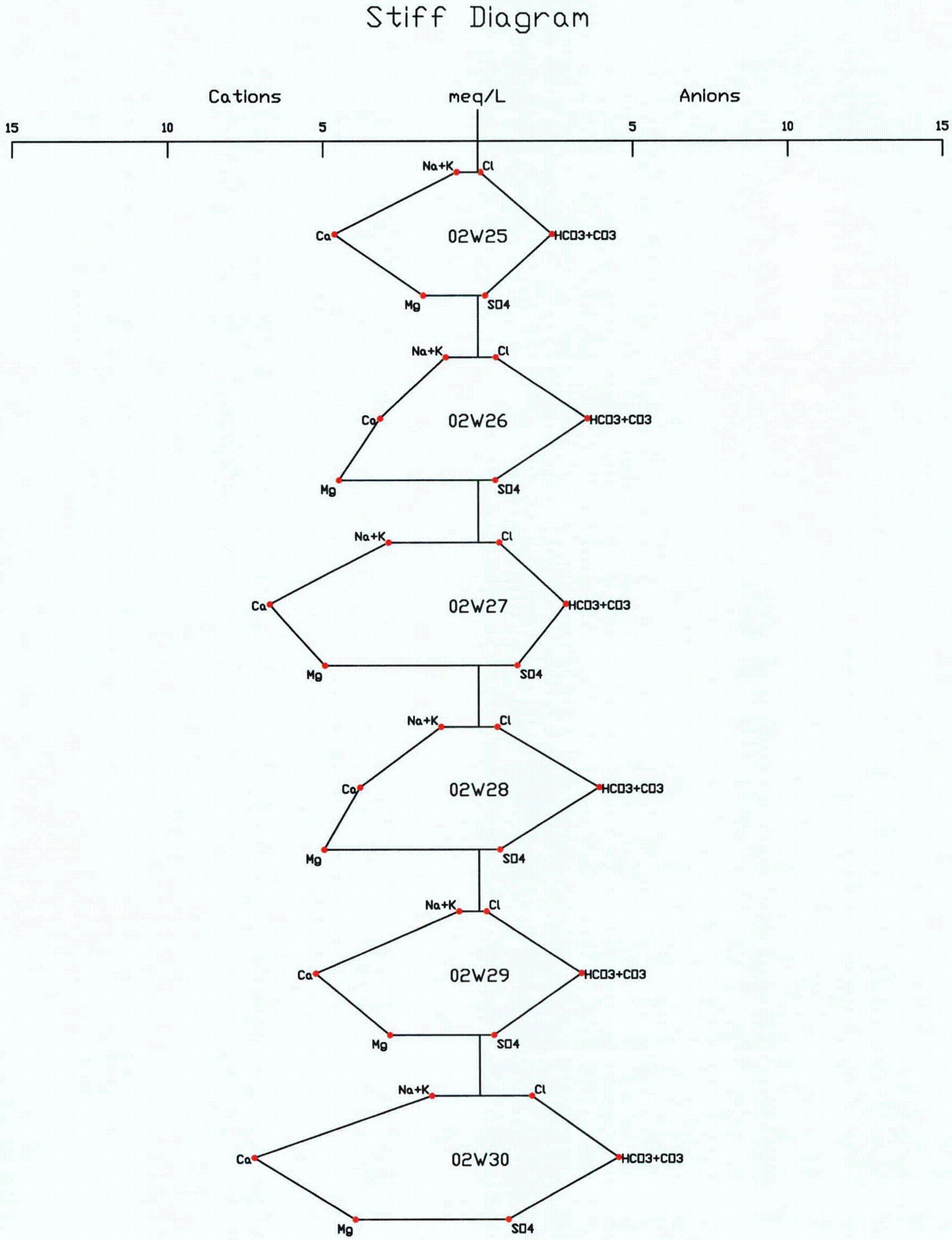

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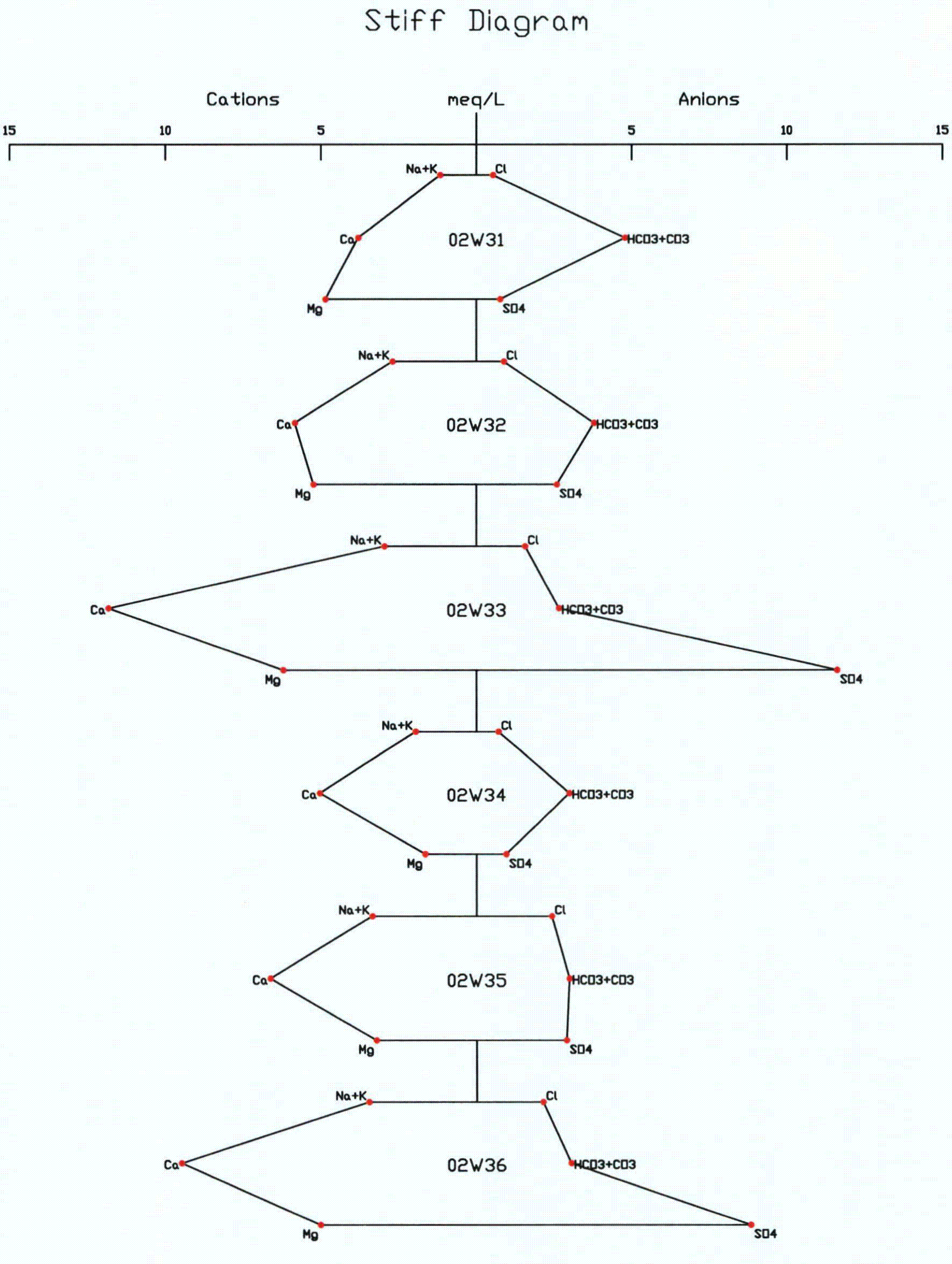

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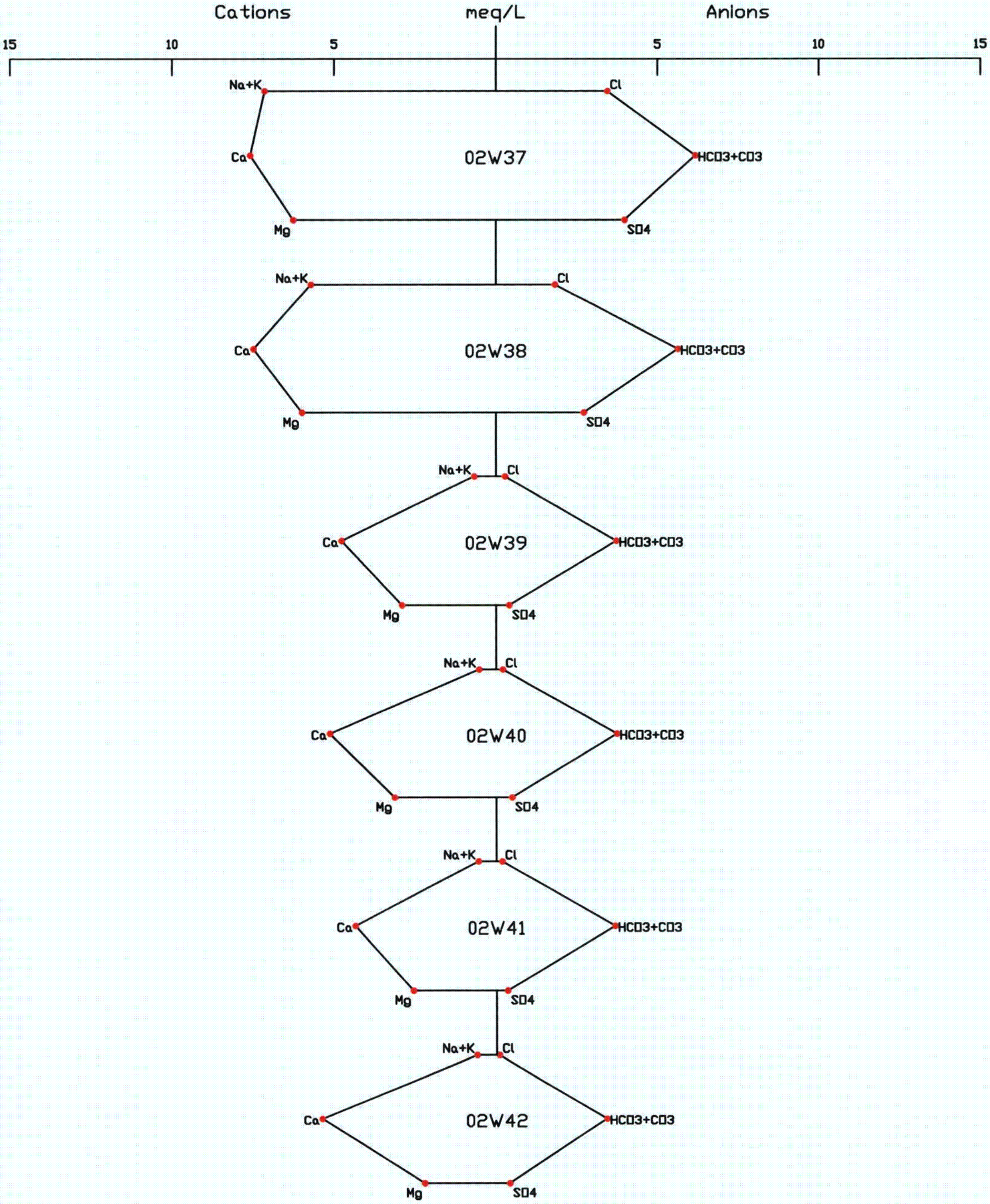
Stiff Diagram



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APPENDIX A
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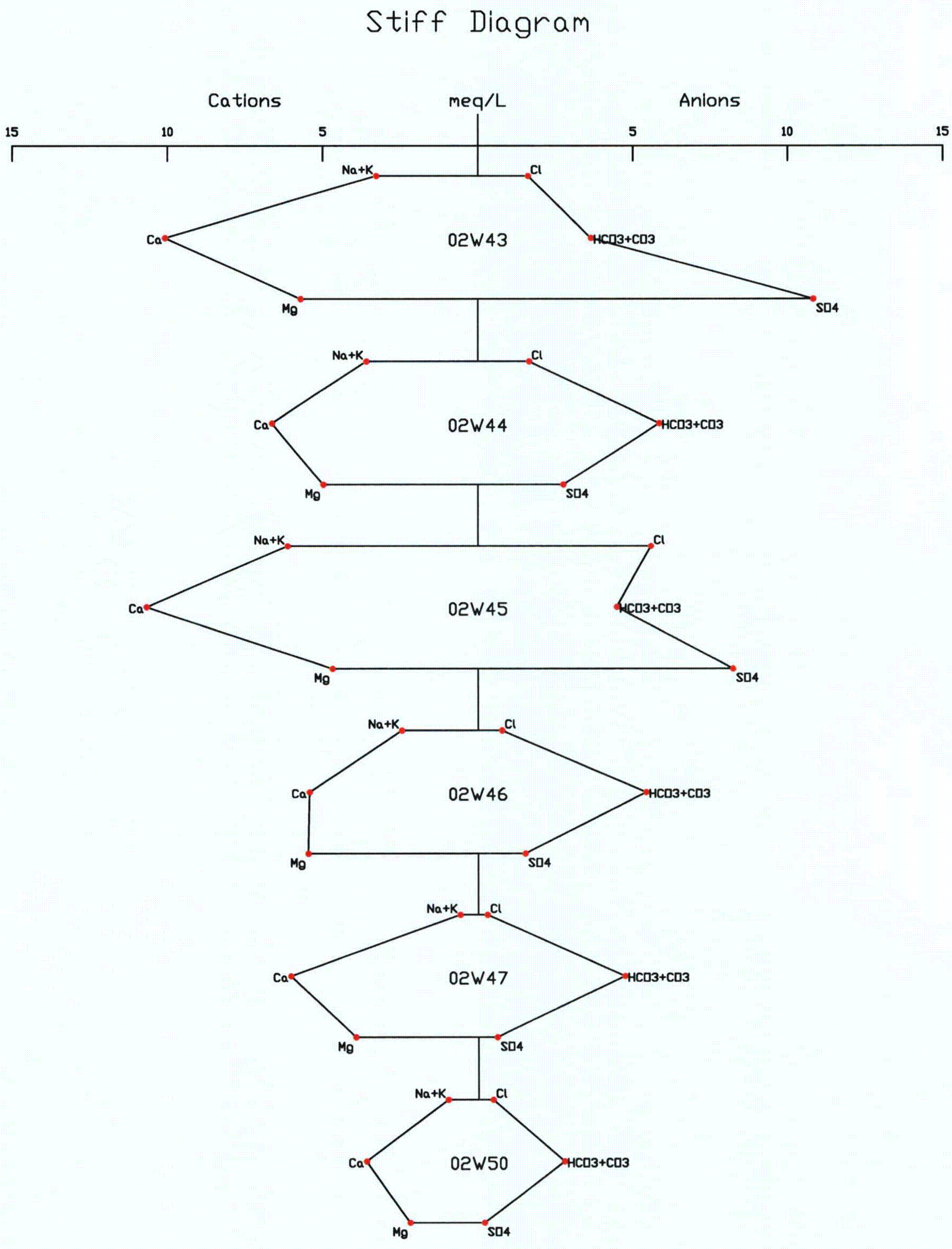
BA#1 AREA (7 of 12)
CIMARRON CORPORATION
CRESCENT, OKLAHOMA



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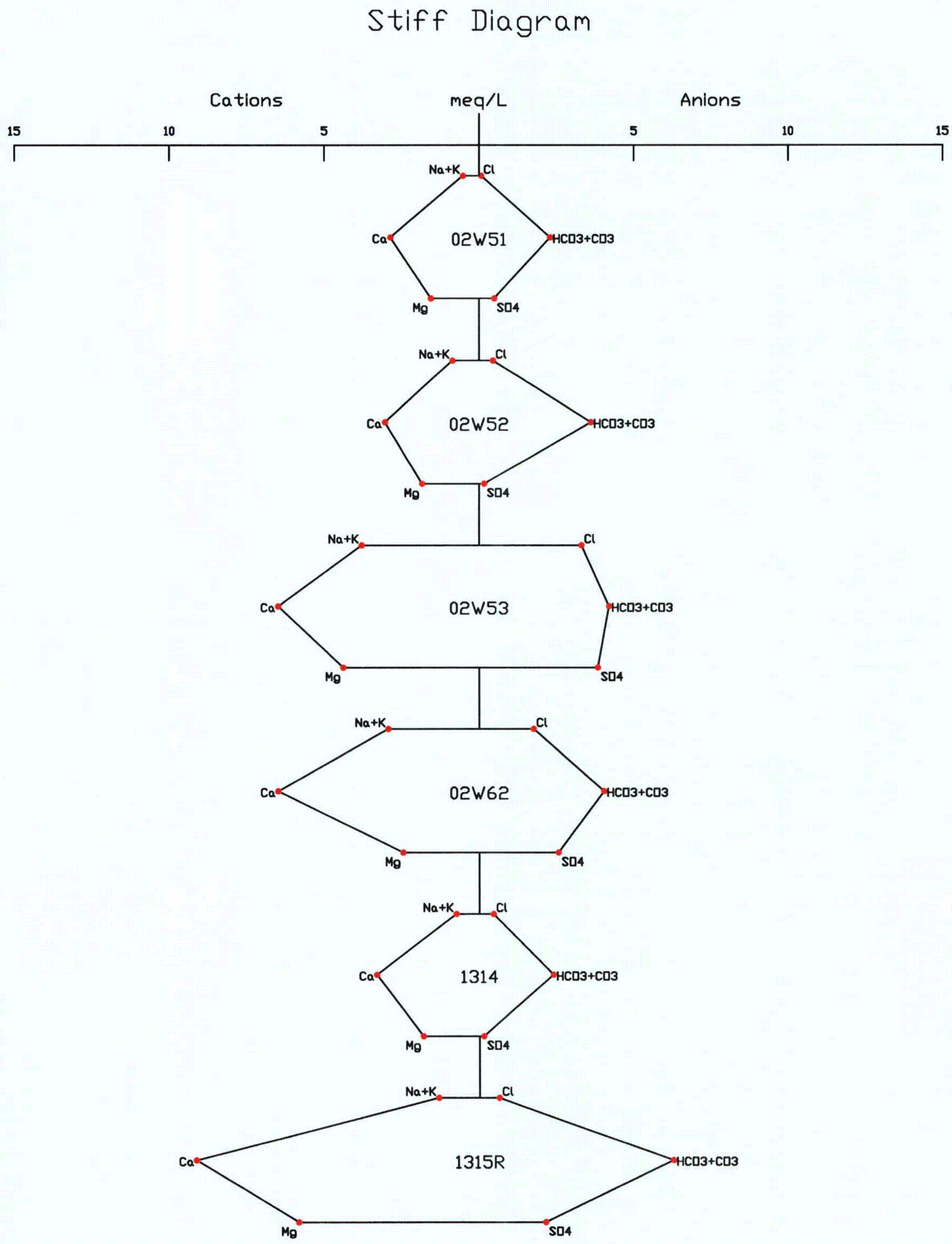
BA#1 AREA (8 of 12)
CIMARRON CORPORATION
CRESCENT, OKLAHOMA



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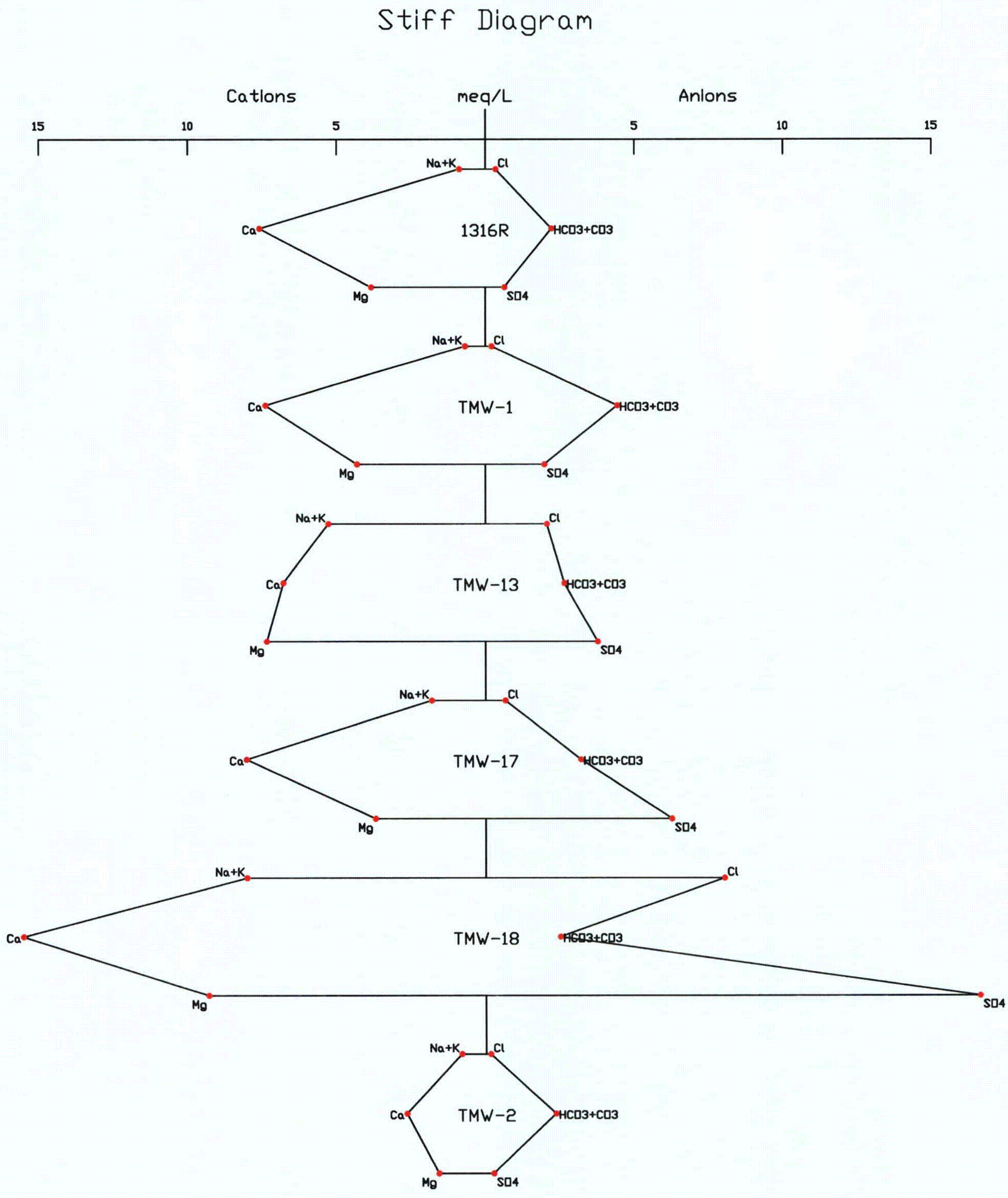

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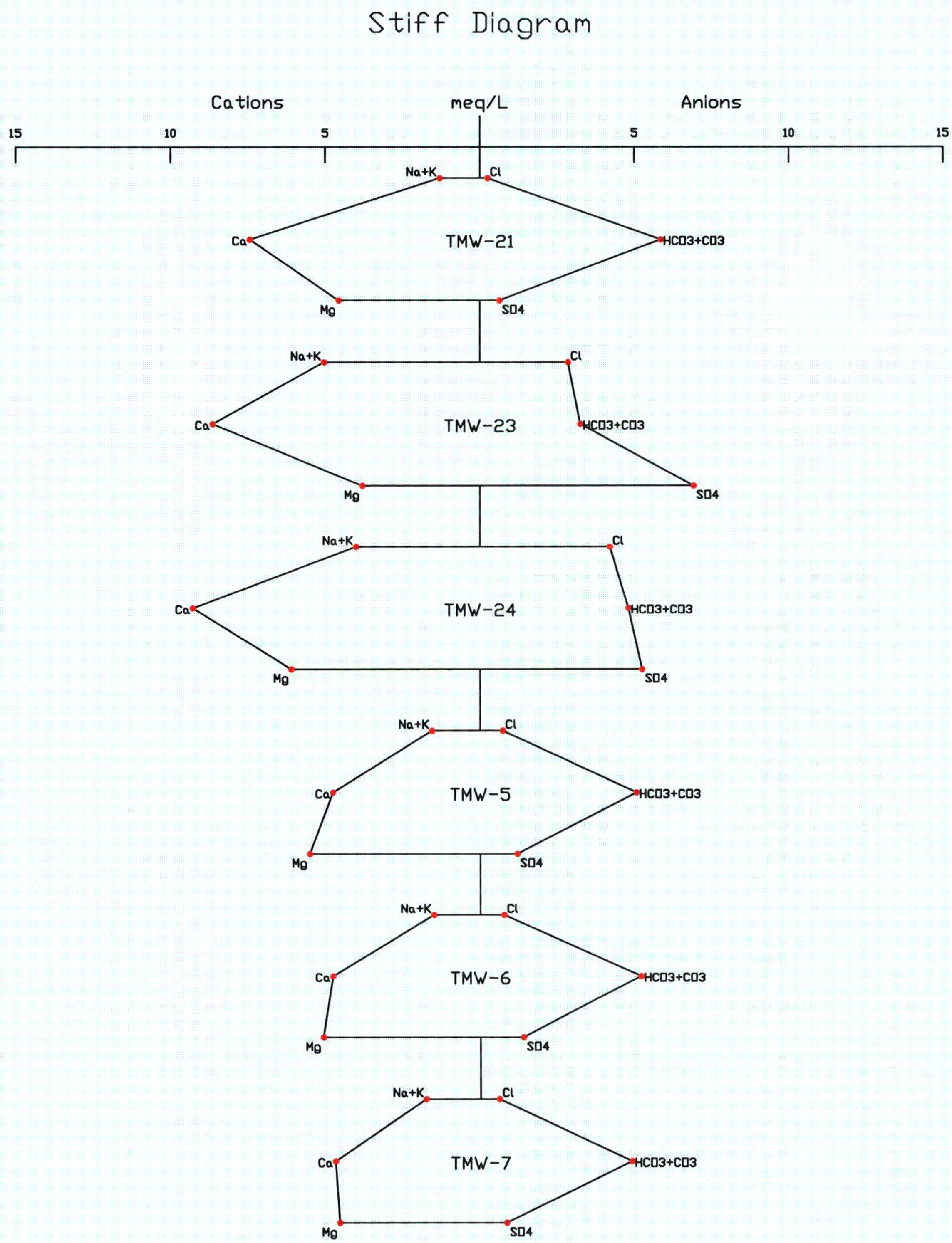

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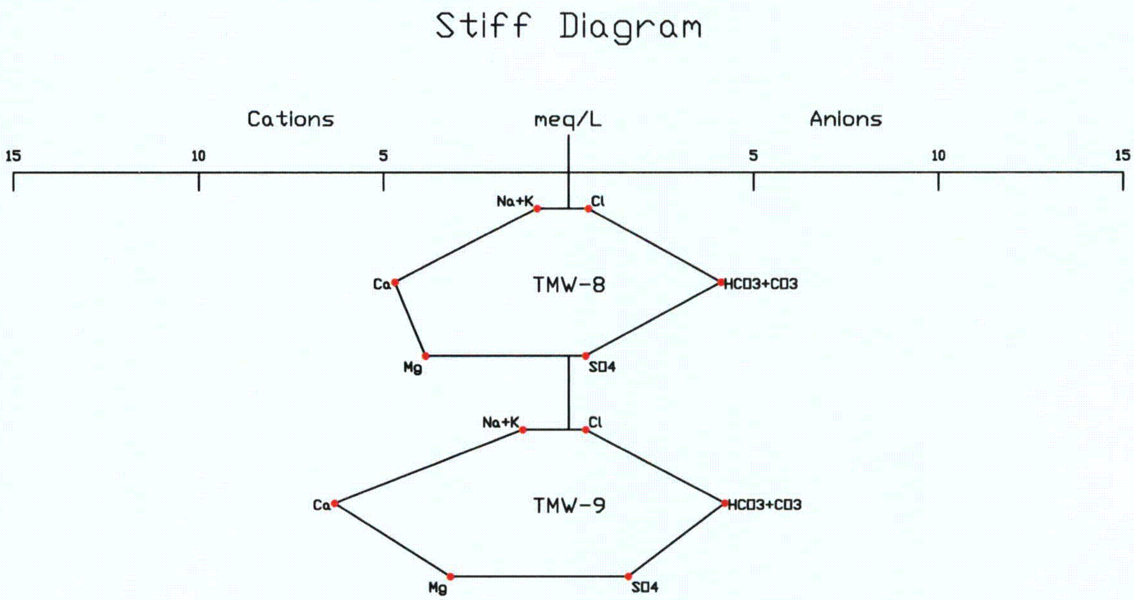

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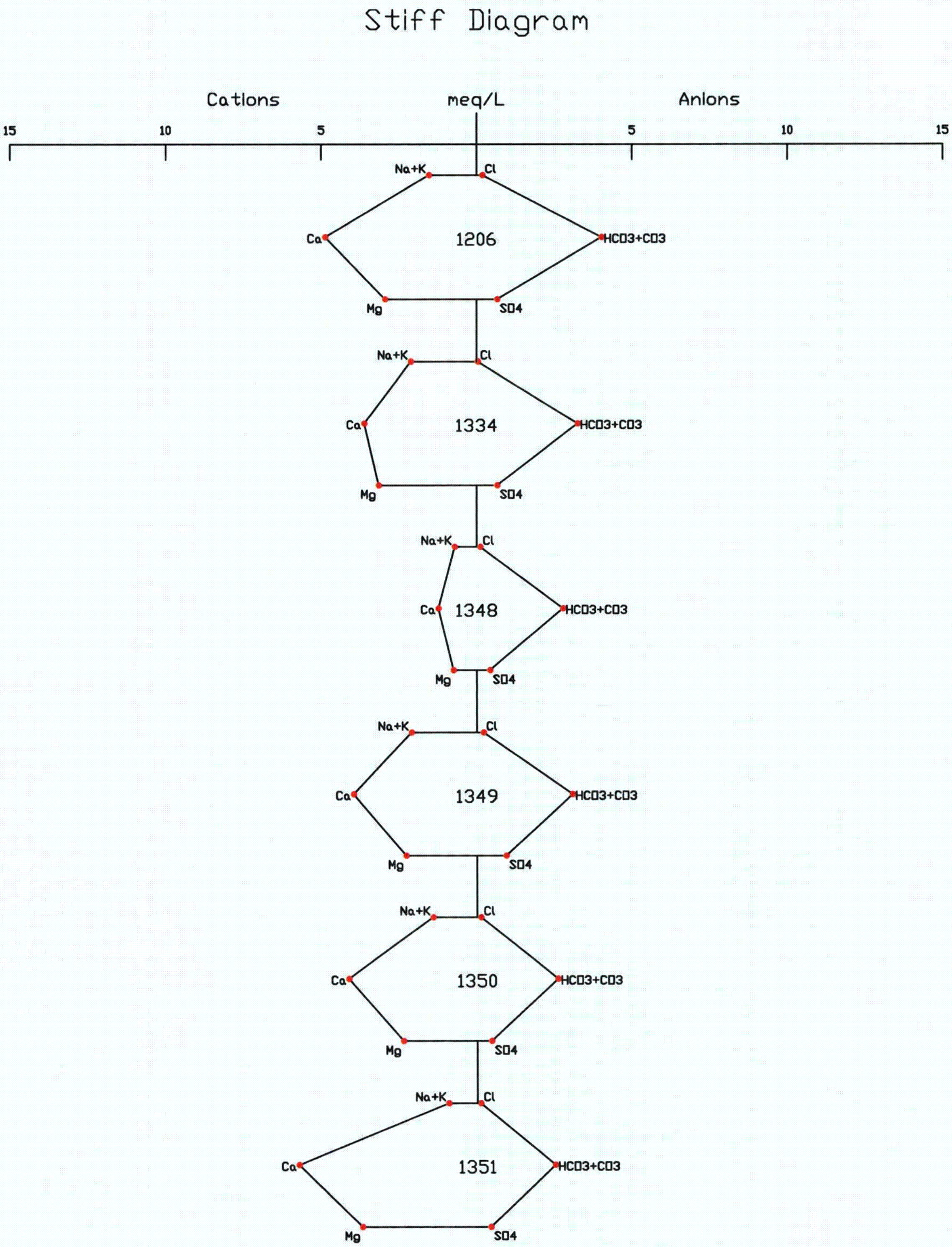

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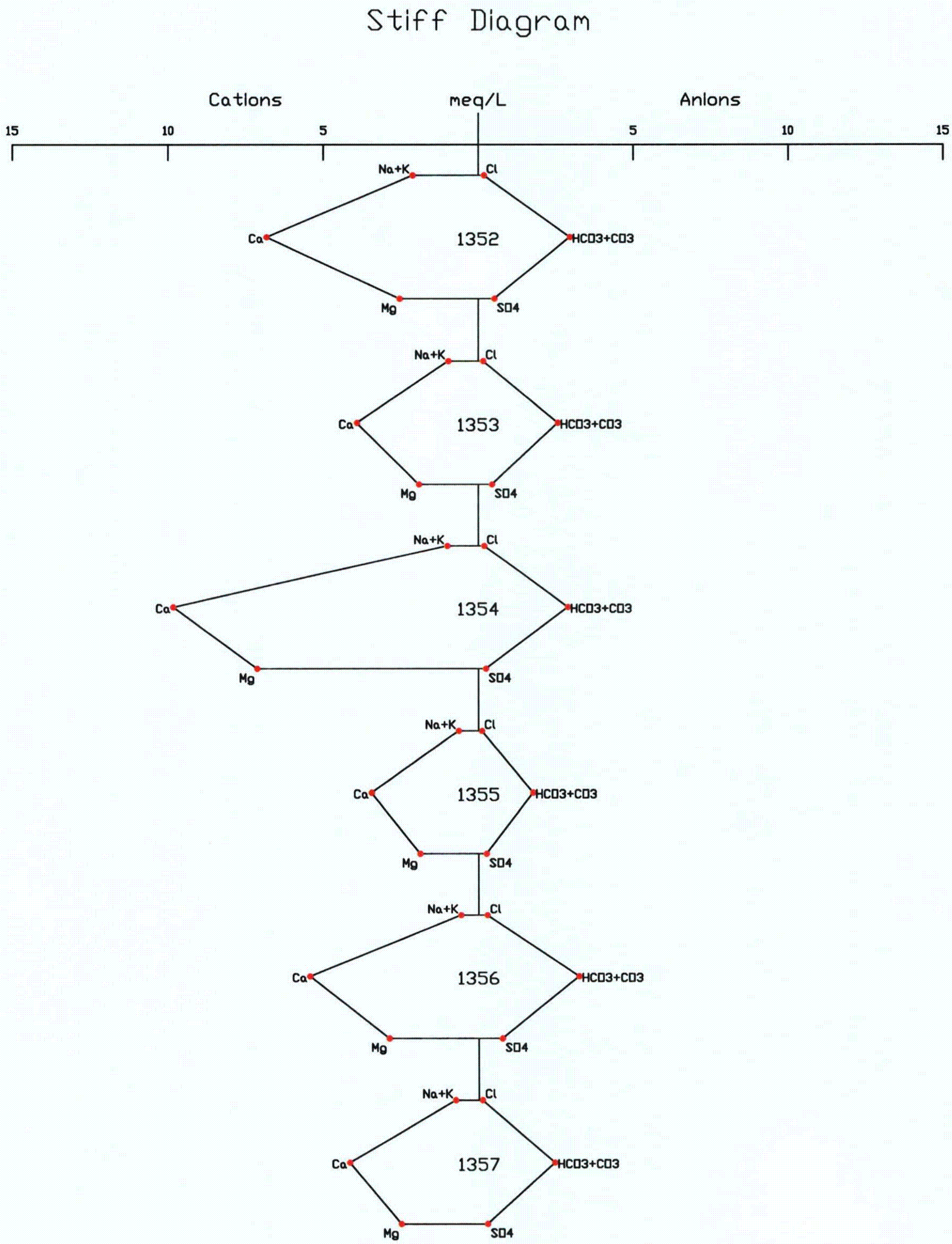

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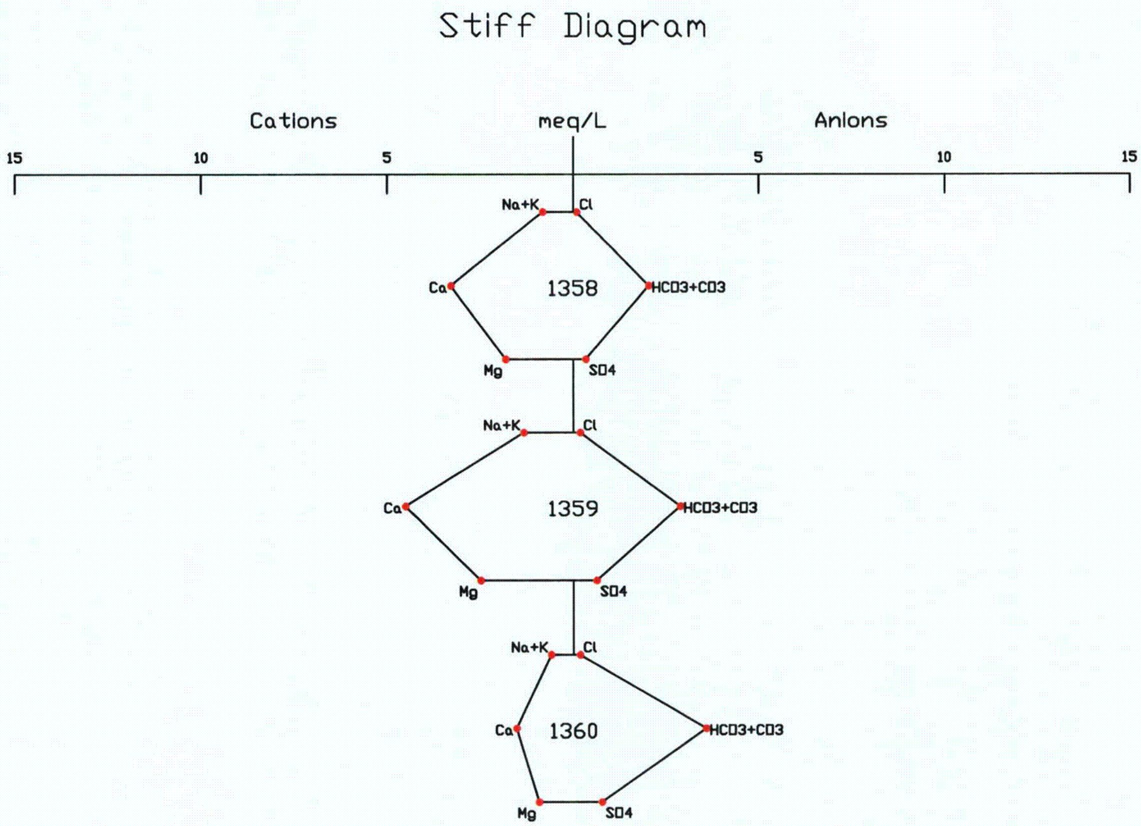
APPENDIX A
STIFF DIAGRAMS
WESTERN UPLAND AREA (2 of 4)
CIMARRON CORPORATION
CRESCENT, OKLAHOMA



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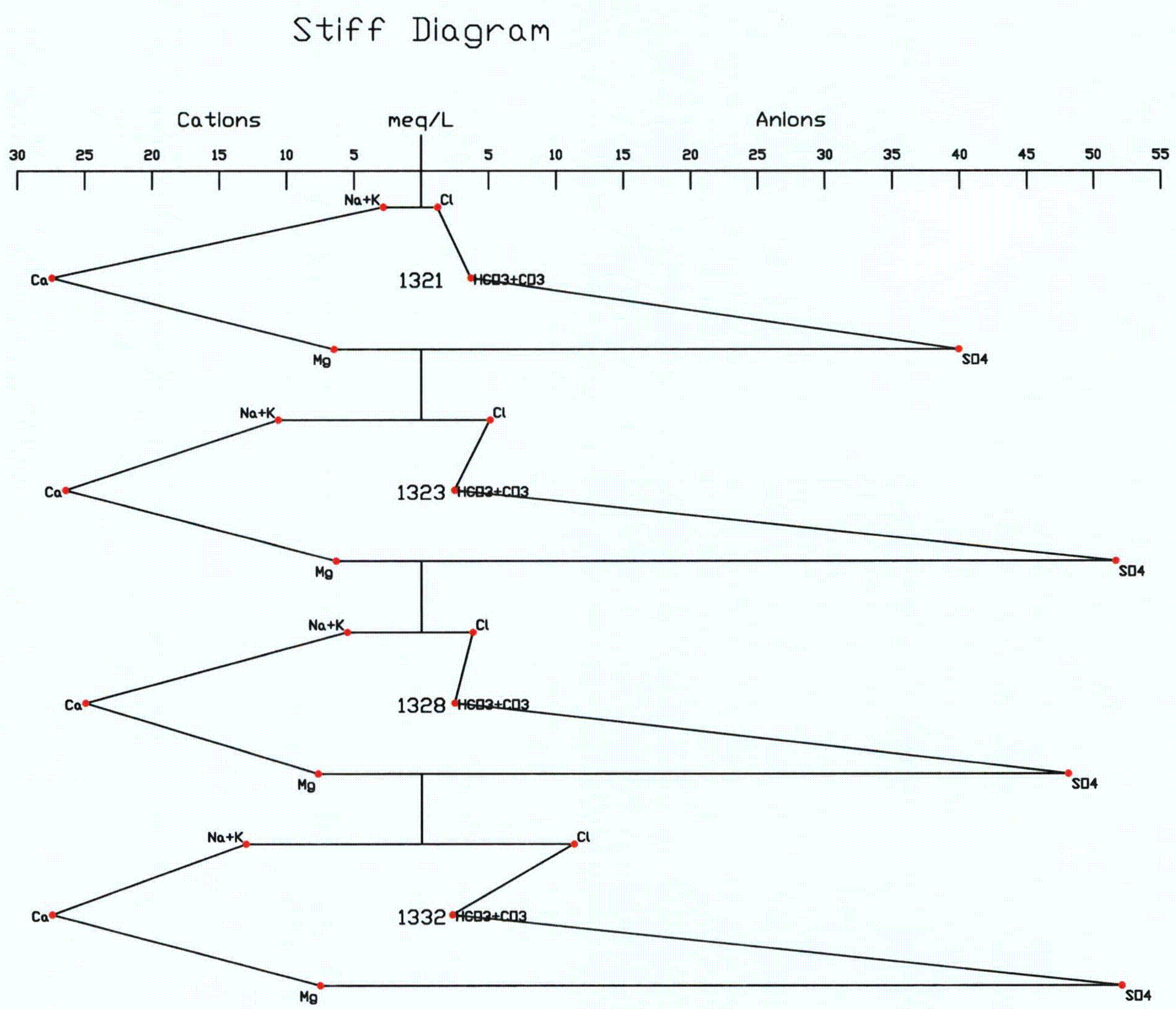

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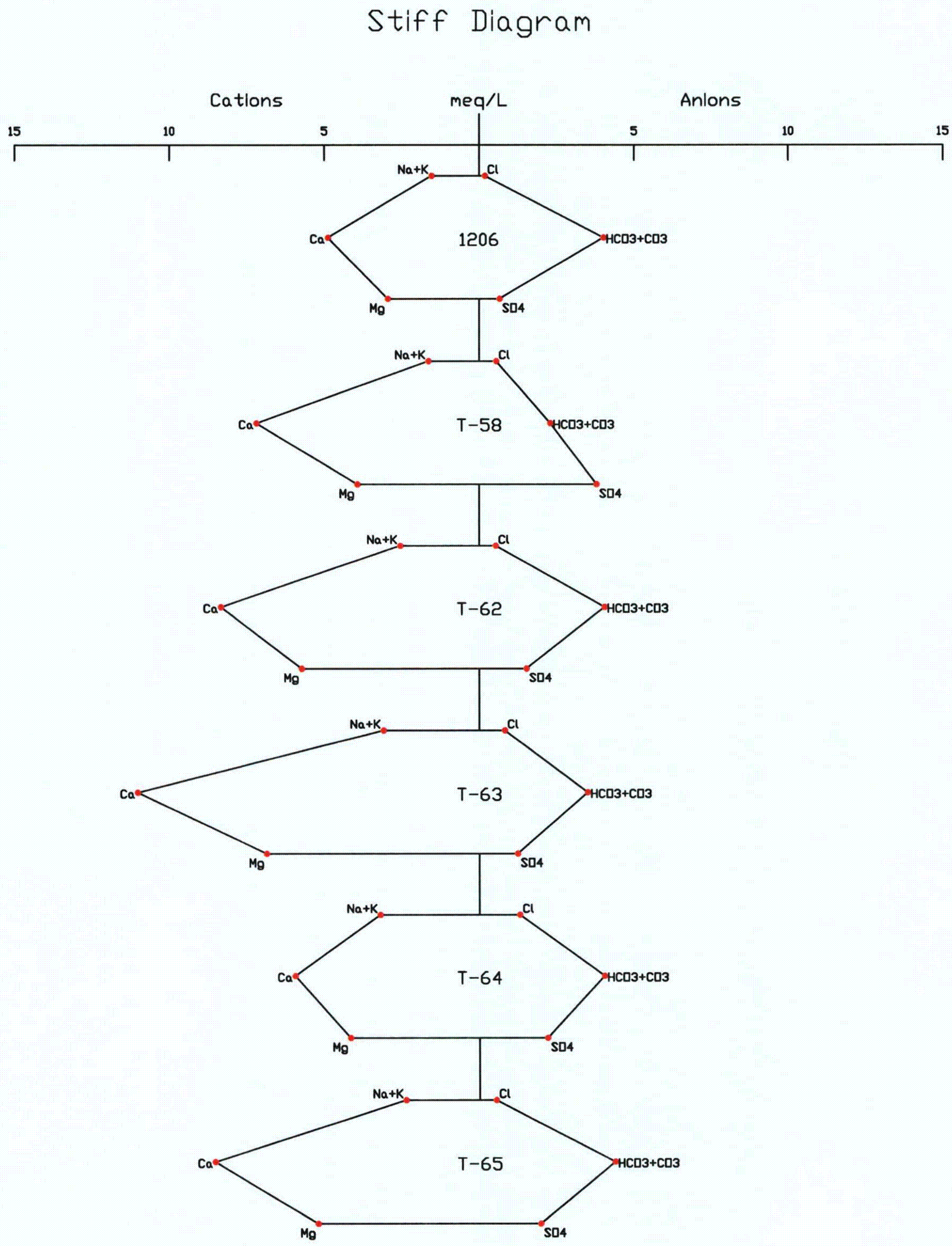

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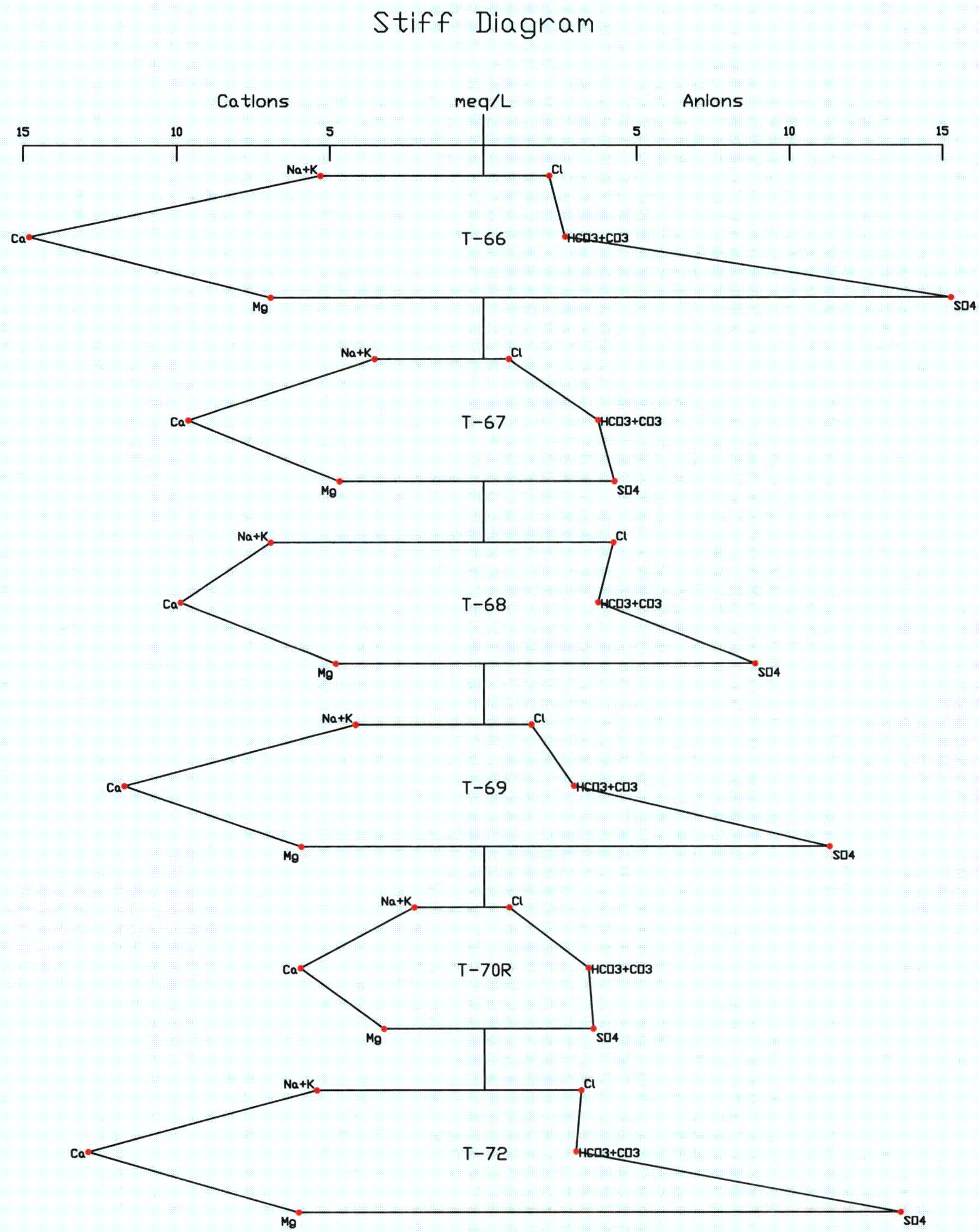
APPENDIX A
STIFF DIAGRAMS
WESTERN ALLUVIUM AREA (1 of 4)
CIMARRON CORPORATION
CRESCENT, OKLAHOMA



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	DATE: 7/22/05	
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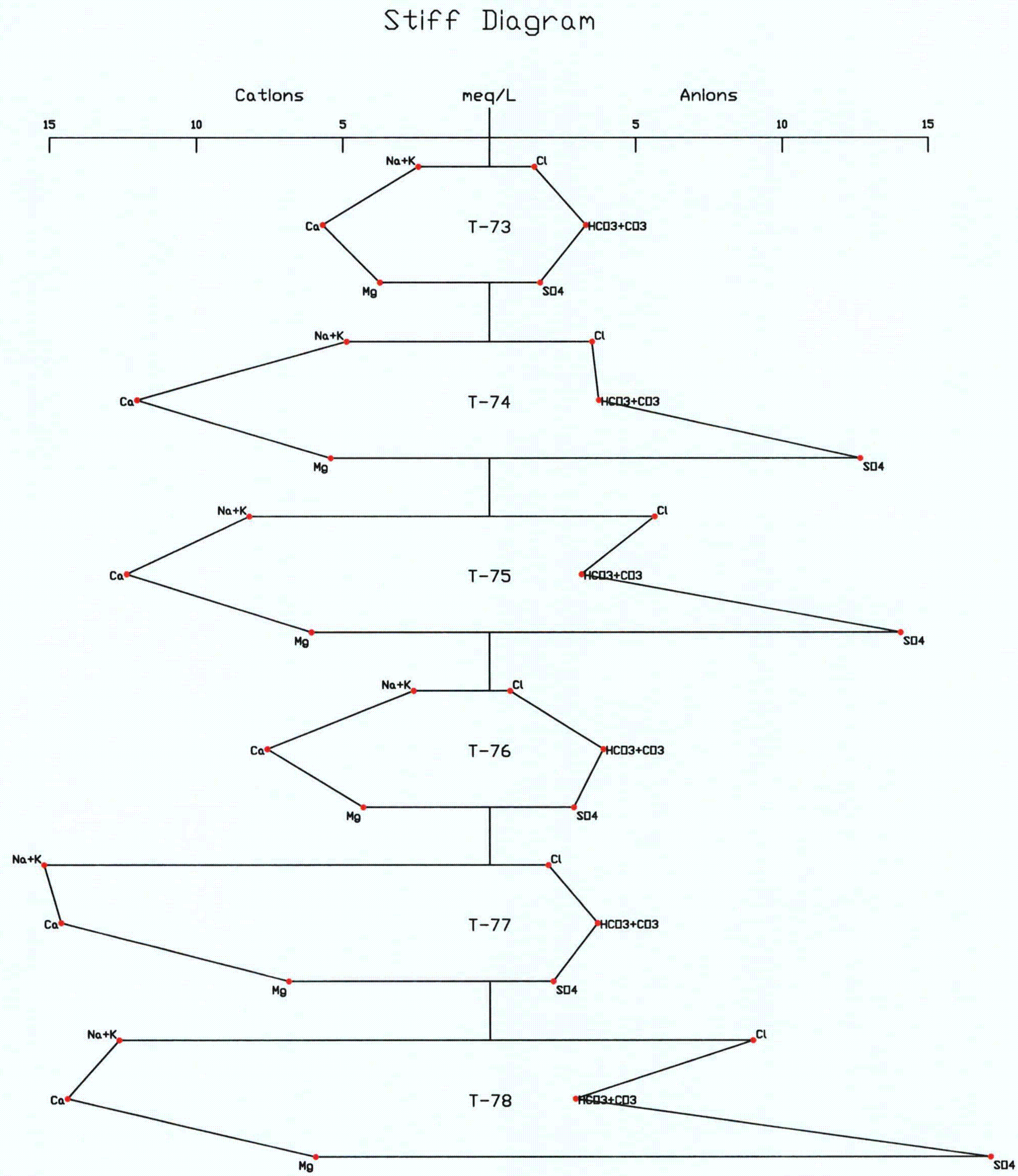
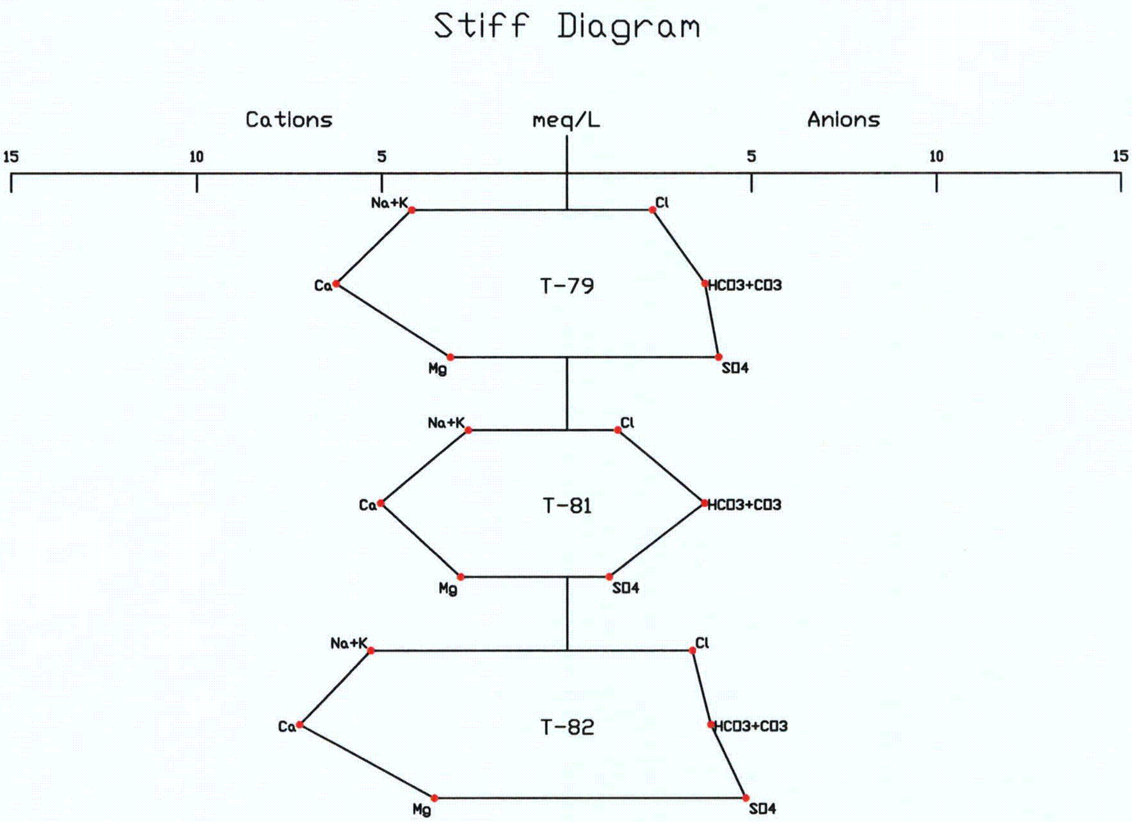
APPENDIX A
STIFF DIAGRAMS
WESTERN ALLUVIUM AREA (2 of 4)
CIMARRON CORPORATION
CRESCENT, OKLAHOMA



ENSR INTERNATIONAL Consulting • Engineering • Remediation	DRAWN: JAS	APPENDIX A
	CHECKED: DJF	STIFF DIAGRAMS
	DATE: 7/22/05	WESTERN ALLUVIUM AREA (3 of 4) CIMARRON CORPORATION
PROJECT NO.: 04020-044-200	DRAWING NO.:	CRESCENT, OKLAHOMA



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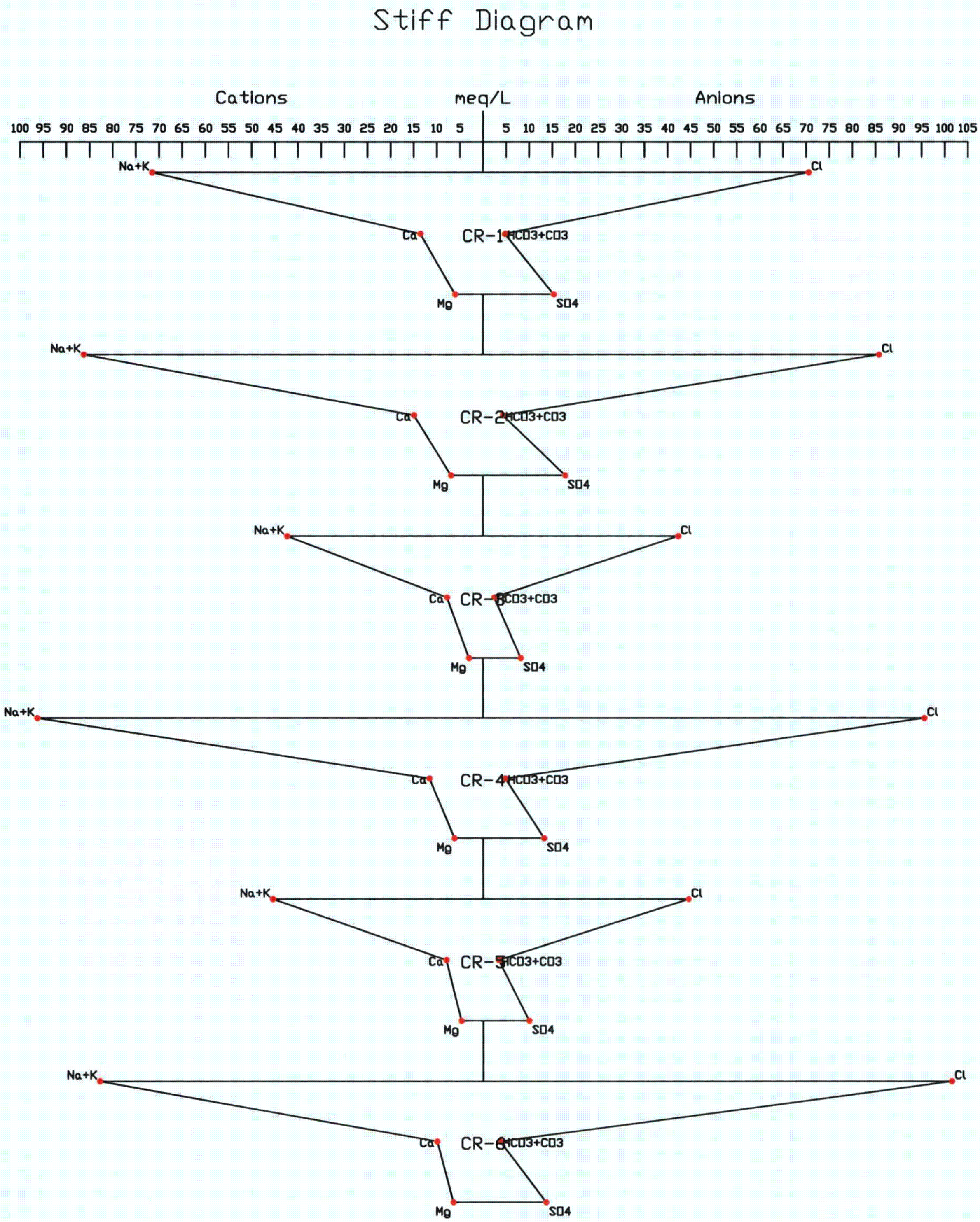
PROJECT NO.: 04020-044-200	DRAWN: JAS	APPENDIX A
	CHECKED: DJF	STIFF DIAGRAMS
	DATE: 7/22/05	WESTERN ALLUVIUM AREA (4 of 4)
	DRAWING NO.:	CIMARRON CORPORATION CRESCENT, OKLAHOMA



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

APPENDIX A
STIFF DIAGRAMS
CIMARRON RIVER (1 of 1)
CIMARRON CORPORATION
CRESCENT, OKLAHOMA