CANADIAN RIVER SALINITY SOURCES, UTE RESERVOIR, NEW MEXICO, TO LAKE MEREDITH, TEXAS: EVAPORITE DISSOLUTION PATTERNS AND RESULTS OF FEBRUARY 1992 WATER QUALITY SURVEY

by

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INTRODUCTION

In February 1992, the Bureau of Economic Geology (BEG) joined representatives of the Canadian River Municipal Water Authority (CRMWA) and Lee Wilson & Associates (LWA) in conducting a survey of water quality along the Canadian River between Ute Reservoir, New Mexico, and Lake Meredith, Texas (fig. 1). This report describes evaporite dissolution patterns in Permian salt-bearing strata in the Ute Reservoir area, discusses conductivity and flow trends observed during the river survey, and concludes with a discussion of chemical analyses of waters sampled from the Canadian River, its tributaries, and adjacent pools and seeps.

EVAPORITE DISSOLUTION PATTERNS IN PERMIAN SALT-BEARING STRATA IN UTE RESERVOIR AREA

Introduction

Dissolution of bedded halite and gypsum from Permian strata has occurred in the Canadian River valley in central Quay County, New Mexico. Approximately 340 ft of halite has been dissolved from the lower San Andres Formation and from the top of the Glorieta Formation to depths of 1,100 ft beneath the Canadian River (fig. 2). An additional 355 ft of halite has been dissolved from the lower San Andres unit 5 and upper San Andres Formation from higher elevations 10 mi south of the Canadian River. Gypsum probably has been dissolved from beds in the Seven Rivers Formation (Artesia Group) in the shallow subsurface of the Canadian River Valley. Release of calcium and sulfate ions probably also occurred in the dissolution zone during hydration of anhydrite to gypsum.

Areas of past and possibly continuing halite dissolution can be identified on regional structural cross sections through parts of eastern New Mexico and the Texas Panhandle (Gustavson and others, 1980; Gustavson and Finley, 1985; Hydro Geo Chem, Inc., 1985; McGookey and others, 1988). More detailed cross sections through the area of Ute Reservoir and Revuelto Creek (figs. 2 and 3; plates 1 and 2) were constructed during the present study to investigate the depths and possible pathways of ground-water circulation. The cross sections identify areas where large amounts of halite are present and may be subject to modern salt dissolution. These areas of preserved halite are potential contributors to the solute load of the Canadian River.

Subsurface data used in this study were extracted from (1) commercial wireline logs and sample logs, and (2) lithologic logs of three cores drilled east of the Ute Dam (U.S. Bureau of Reclamation, 1979, 1984). Criteria for recognition of halite on wireline logs include (1) increasing borehole diameter, as shown on caliper logs, (2) low gamma-ray response, and (3) low density, low porosity, or high sonic velocity. Siliciclastic/halite mixtures that result from interbedding or chaotically admixed mud and halite are recognized by responses intermediate between those of halite and siliciclastic mudstones and siltstones. Criteria that indicate past halite dissolution in the Ute Reservoir area are (1) thinning of halite-bearing units in sections where thicknesses of other lithologies do not change, (2) decreased regional structural dip or dip reversal of strata above areas of thin or missing halite, and (3) variable sonic velocity and cycle-skipping (a process by which some of the first arrivals of a sonic wave pulse are lost, resulting in anomalously long apparent travel times through some intervals, as is typically caused by attenuation of sonic waves in fractured zones; see Schlumberger, 1989, p. 5-2 to 5-3) (figs. 2 and 3; plates 1 and 2).

Stratigraphy

The Canadian River flows west to east between the subsurface structural elements of the Tucumcari Basin and Bravo Dome (see inset on plates) (Foster and others, 1972; Budnik, 1989; Ewing, 1990). Permian units crop out only locally in the Canadian River valley in Oldham County, Texas (Eifler and others, 1983) and dip gently to the south in the subsurface. Permian evaporites have been studied extensively in the Palo Duro Basin of the Texas Panhandle and their log facies identified in stratigraphic cross sections (Handford and others, 1981; Presley, 1981). The base of the Permian section, where it unconformably onlaps Precambrian uplifts, consists of dominantly siliciclastic units including coarse-grained arkoses known as granite wash, the Red Cave Formation, lower Clear Fork Group, and Tubb Formation (plates 1 and 2). Overlying these are cyclic evaporites containing thick halite units interbedded with carbonate, anhydrite and fine-grained siliciclastic mudstones and sandstones, including the upper Clear Fork Group, Glorieta Formation, and San Andres Formation (figs. 2 and 3; plates 1 and 2). Updip siliciclastic-halite units of the Artesia Group (Queen-Grayburg and Seven Rivers Formations) contain thin, regionally traceable anhydrite beds (figs. 2 and 3; plates 1 and 2). The top of the Permian section is characterized by depositional pinch-out of evaporites into siliciclastic rocks in the Salado and Alibates Formations. The uppermost Permian unit is the siliciclastic Dewey Lake Formation. The Permian strata are truncated toward the north by the erosional unconformity beneath the Triassic Dockum Group (plate 1) (Murphy, 1987). Jurassic and Cretaceous units in the northwestern parts of the study area (Eifler and others, 1983) are truncated by an erosional unconformity beneath the Tertiary Ogallala Formation and Quaternary Blackwater Draw Formation (plate 1).

Evaporite Dissolution Patterns

Halite Dissolution

The following variations in halite distribution were determined from logs and constrain areas where halite dissolution has occurred (figs. 2 and 3; plates 1 and 2). There is no evidence of halite in the Red Cave Formation, Lower Clear Fork Group, or Tubb Formation beneath the study area; these strata are characterized by siliciclastic-dominated facies that were probably deposited in an environment proximal to the ancestral Rocky Mountains, away from areas of evaporite precipitation. Halite units are present in the upper Clear Fork Group and are laterally continuous through the study area. Halite units are also present in the Glorieta

Formation, but the uppermost halite beds are missing from beneath the Canadian River valley, presumably because of dissolution.

Thick bedded halite units appear in the San Andres Formation in the Tucumcari Basin, but progressively disappear northward and are completely dissolved from beneath the Canadian River valley (figs. 2 and 3; plates 1 and 2). The thickness of the interval between the top of the San Andres Formation and the base of Lower San Andres unit 5 decreases from 570 ft at the Quay 14 well, 21 mi south of the Canadian River, to 215 ft at the Quay 13 well, 6 mi south of the Canadian River (fig. 2; plate 1). The thickness of the lower part of the San Andres Formation (from the top of San Andres unit 4 to the base of halite in the upper Glorieta Formation) decreases from 540 ft at Quay 13 to 200 ft beneath the Canadian River (fig. 2; plate 1). The thickness decrease of almost 700 ft is interpreted to be entirely the result of halite dissolution. The opposite interpretation (that thinning reflects the original depositional pattern) is contradicted by the observation that individual San Andres carbonate and anhydrite units can be correlated further to the north with only very gradual depositional thinning and pinch-out. The interpretation that dissolution of halite has resulted in subsidence of the overlying strata is suggested by an abrupt decrease in the regional dip of the units above the missing halite and by cycle-skipping on sonic logs (suggesting fracturing). Thick carbonate beds in the lower San Andres Formation and sandstones at the top of the Glorieta Formation have high porosity in areas where halite has been dissolved and may serve as zones of enhanced flow and conduits for transmission of fresh waters into zones of preserved halite. Development of highly porous beds as a result of dissolution of halite cements has been observed in the shallow subsurface San Andres in the eastern Texas Panhandle (Hovorka and Granger, 1988).

Halite occurs within the Artesia Group in the southern part of the study area in mixed halite-siliciclastic beds and as separate halite interbeds. Halite has been dissolved from the mixed halite-siliciclastic beds in the Queen-Grayburg and Seven Rivers Formations beneath the Canadian River Valley, leaving strata dominated by siliciclastic material. The siliciclastic component thins by 25 percent, from 240 ft at the Quay 13 well to 180 ft over the Bravo

Dome at the Harding 7 well (fig. 2; plate 1). This thinning suggests that the depositional environment changed significantly toward the Bravo Dome, where subsidence rates were slower than in basin areas. Further south, at the Quay 14 well, the thickness and gamma-ray character of the Artesia Group is preserved but the sonic log response indicates that the unit may be highly fractured. This suggests that partial or incipient halite dissolution has occurred in this area. Removal of minor amounts (less than 15 ft) of upper San Andres halite beneath Queen-Grayburg sandstones was recognized in central Quay County 30 mi south of the Canadian River, ahead of the main dissolution front. This intrastratal halite dissolution demonstrates that the presence of highly permeable units within the evaporite section can promote hydrologic circulation and locally enhance the halite dissolution process.

Anhydrite and Gypsum Dissolution

Partial dissolution of anhydrite and the eventual complete dissolution of gypsum both contribute to the solute load of the Canadian River. Calcium sulfate dissolution can occur when anhydrite comes in contact with low-salinity water and is hydrated to gypsum. In the subsurface, this hydration generally proceeds without a major volume increase. However, because the molar volume of gypsum (~75 cm^3) is much greater than that of anhydrite (~46 cm^3), a volume-for-volume replacement of anhydrite by gypsum requires removal of some calcium sulfate.

Units characterized by low gamma-ray response and interpreted as gypsum (or anhydrite) beds can be traced within the Seven Rivers Formation throughout the study area. However, no gypsum beds were noted on the lithologic logs of cores from holes drilled into the upper part of the Artesia Group just downstream from Ute Dam (DH1 and DH2, plate 2). Note that regional correlation during this study indicates that only the upper part of the Artesia Group was penetrated by these holes, contrary to the original interpretations indicated on the logs—see U.S. Bureau of Reclamation (1979, 1984). The absence of gypsum beds in these cores may indicate that gypsum was dissolved in near-surface environments in the Canadian River Valley. Extensive gypsum dissolution has been documented in very shallow subsurface environments in the San Andres Formation in the eastern Texas Panhandle (Hovorka and Granger, 1988).

RESULTS OF FEBRUARY 1992 RIVER CONDUCTIVITY AND FLOW SURVEY

Introduction

The Canadian River water quality survey described here required 9 field days (February 10–18, 1992) and covered a distance of about 150 mi. The survey terminated at Chicken Creek, about 4 mi upstream from Lake Meredith (fig. 1). BEG personnel measured conductivity and water temperature, chloride concentration, and alkalinity, and collected samples of waters from the Canadian River, from flowing tributaries, and from isolated pools in the riverbed and in several nonflowing tributaries (figs. 1, 4, and 5; tables 1 and 2). CRMWA and LWA personnel measured conductivity, water temperature, chloride and sulfate concentrations, and pH, and also measured flows in the river and in flowing tributaries (tables 3 and 4). CRMWA staff returned on February 24 and 25 to collect additional flow and chemistry data at closely spaced intervals along one segment of the river where data from the survey 11 days earlier indicated a substantial increase in flow (between and including survey sites 57 and 67; figs. 1 and 5; table 3).

By prior arrangement, gates at Ute Dam were held closed during the survey, so that no water was directly released from Ute Reservoir; water in the Canadian River during the survey period was contributed entirely by leakage through the dam and its workings, by baseflow and stormflow(?), by inflow from tributaries, and by minor flows from several discrete, small springs.

The survey area was limited to the river, the riverbed and its banks, and tributary mouths. Surveyors did not venture onto adjacent lands to sample wells or attempt to dig to water tables in dry tributary streambeds because express permission had not been granted to enter those areas and because the pace of the survey did not allow time for such activities. Spacing between survey sites varied: (1) average spacing between stops in the first 7 mi below Ute Reservoir was about 0.15 mi (sites 0 through 43, spacing up to 0.4 mi); (2) average spacing along the next 18 mi of the river was about 1 mi (sites 43 through 61, spacing 0.4 to 1.5 mi); and (3) average spacing along the remaining length was about 3 mi (sites 61 through 103, spacing 0.2 to 5.7 mi) (see figs. 1, 4, and 5; tables 1–4).

Conductivity and water temperature were measured using a Yellow Springs Instrument model 33 S-C-T conductivity meter. The instrument incorporates an electronic temperature correction so that conductivity readings are expressed as equivalent conductivity at 77° F.

Salinity was measured in the field using Quantab chloride titrator strips (for $Cl^- < 6{,}000$ ppm) (see table 6). The indicator strips proved to be fairly accurate, giving only slightly higher readings than laboratory measurements (fig. 6). Salinity can also be judged indirectly from conductivity measurements, although it is a less reliable technique. The line of best fit on a plot of laboratory-determined chloride values versus field conductivity data has an intercept on the conductivity axis of 1,494 micromhos/cm (fig. 7), indicating that conductivity readings of less than that value would theoretically result in negative chloride concentrations. This anomaly is caused by the fact that at low total-dissolved-solids concentrations (TDS), ions other than chloride are major contributors to conductivity. As TDS increases, the proportion of conductance due to chloride ions increases more rapidly than that due to other ions, so that high values of conductivity can be considered to closely reflect chloride concentrations.

Conductivity and Flow Survey

The highest conductivities recorded during the survey were of waters along the first 7 mi of the Canadian River below Ute Reservoir. "Baseline" conductivity of river water increased steadily along the first 6 mi below Ute Reservoir, from <1,000 to >10,000 micromhos/cm (fig. 4; table 1). River flow also increased along this segment of the river, from ~2.3 cfs just downstream from the dam (site 8—all apparent surface flows and most canyon wall seeps have joined the river above this point) to almost 6 cfs (just upstream from the confluence with Revuelto Creek) (table 3). There were no flowing tributaries along this segment of the river at the time of the survey, indicating that the added volume must have entered directly by discharge from the riverbed aquifer.

The trend of increasing conductivity and flow in the first 6 mi downstream from Ute Reservoir indicates that water in the riverbed alluvium aquifer is of high conductivity. Indeed, measured conductivities along the first 1.5 mi were highest in slow-moving pool stretches where turbulence is at a minimum, suggesting that "peak" values (fig. 4; table 1) represent waters which had entered the river nearby but not yet thoroughly mixed with the river water; these "peak" values probably reflect the conductivity of the water contained in the riverbed aquifer. The conclusion that riverbed aquifer water is of high conductivity is further corroborated by the occurrence of high-conductivity waters in isolated pools in the riverbed between 3.5 (site 26) and 6.5 mi (site 42) (figs. 1 and 4; table 2); the isolated pools are thought to represent "windows" into the riverbed aquifer; their chemistries may have been altered by dilution or by evaporation. It is notable that the measured conductivity within many of the pools (including pool sections of the river and isolated pools in the riverbed) varied greatly with placement of the conductivity probe; measured conductivity was generally lowest when the probe was suspended within the upper part of the water column and highest when the probe was positioned on or within the sediment on the bottom (tables 1 and 2).

"Baseline" conductivity of the Canadian River decreased substantially (from 10,000 to 5000 micromhos/cm) (fig. 4; table 1) just downstream from its confluence with Revuelto Creek (approx. mile 6.25, site 40), due to the diluting effect of the added flow from the creek, which itself carried water of low conductivity (<2,000 micromhos/cm). The overall trend of increasing river conductivity, however, continues to approximately mile 9.5 (site 46) (figs. 1 and 4).

Conductivity in the Canadian River remained fairly constant between 10 and 20 mi downstream from Ute Reservoir (sites 46 through 56; figs. 1 and 5; tables 1 and 3), whereas measured flow actually decreased slightly. These observations suggest that there was no inflow to the river in this stretch and therefore no increase in salinity.

River flow increased dramatically (nearly doubling, from ~12 cfs to more than 21 cfs) between about 20 and 40 mi downstream from Ute Reservoir (sites 57 through 67) (figs. 1 and 5; table 3). An important observation is that while the river flow did increase dramatically, conductivity remained fairly constant, implying that the incoming waters must have been approximately as saline as the river waters (if the incoming waters had not been saline, then their dilution effect should have caused river conductivity to fall). A small proportion of the increase in river flow was due to inflow from two tributaries that were flowing at the time of the survey (unnamed tributary, near mile 24, site 60; and Rana Arroyo, near mile 33, site 64). The major part of the flow increase, however, must have been contributed by discharge from the riverbed aquifer. CRMWA staff returned on February 24 and 25 to collect additional flow and chemistry data at closely spaced intervals along this segment of the river (between and including sites 57 to 67). The data from that second survey indicated that most of the increase occurred along the first half of the river segment (fig. 5; table 2); those data also showed that overall flow volume had decreased since the first survey 11 days earlier. The decrease in flow was in part due to decreased contributions from some tributaries, but also apparently due to a decrease of discharge from the riverbed alluvium along that river segment (fig. 5) (between sites 57 and 67). This pattern suggests that the contributions from the riverbed alluvium were not strictly baseflow but must have also included some stormflow.

The beginning of the segment along which river flow increased dramatically (between sites 57 and 67) is also the approximate location of an "outlying" occurrence of high-conductivity waters (up to 15,500 micromhos/cm) in isolated pools in the riverbed and in pools in an unnamed, flowing tributary on the south side of the river near mile 24 (site 60) (figs. 1 and 5; table 2).

Between about 40 and 48 mi downstream from Ute Reservoir, conductivity declined, while river flow increased. This seems to be a normal relationship indicating dilution of through-flowing river water, with little or no absolute increase in salinity.

River conductivity increased modestly between 48 and 57 mi (sites 68 through 72), while river flow remained the same, or decreased slightly. This corresponds to the broad, widely meandering portion of the Canadian River in the vicinity of Nara Visa Arroyo and Horse Creek. Brune (1981) reports that Salinas Plaza, an early-inhabited area with a "salt lake," was located on the north side of the river in the approximate vicinity of Nara Visa Arroyo.

River conductivity declined slightly between 57 and 85 mi (sites 72 through 80), while river flow increased somewhat. Again, this suggests a normal relationship indicating dilution of through-flowing river water, with little or no absolute increase in salinity.

Beyond 85 miles and to the end of the survey, river conductivity varied slightly, though "baseline" conductivity remained approximately the same (~3,000 micromhos/cm).

Notable features along this stretch included:

- one isolated, saline pool in the riverbed just upstream from Punta de Agua (with an apparent corresponding increase in river conductivity);
- substantial inflow from Punta de Agua (causing a slight drop in river conductivity?), followed by a slight loss of flow between there and the following flow station;
- modest conductivities (≤2,350 micromhos) in pools in Alamosa Creek and Sierrita de la Cruz;
- very high conductivities (≤13,000 micromhos) in Lahey Creek and in a seep immediately upstream from the creek. Although conductivities at these locations were high, flow was quite low, so that there was little net effect on river conductivity. Nevertheless, these high conductivities suggest that this is another potential salinity source area; and
- modest conductivities (up to 2,300 micromhos) in pools in Tecovas Creek, Horse Creek, West Amarillo Creek, and East Amarillo Creek.

Geologic Controls on Hydrology

In the Ute Reservoir area, saline water forced from areas of high head in Permian strata rises through fine-grained rocks in the upper part of the Permian section and lower part of the Triassic section, probably along fractures, then enters more permeable sandstone units; from there the saline water presumably drains into riverbed sediments, and then finally discharges into the Canadian River. The beginning of the segment of the Canadian River where river flow begins to increase dramatically (site 57, near mile 21) is approximately the point of the last occurrence of high-conductivity waters (≤15,500 micromhos/cm) (fig. 5; table 2), with the exception of the Lahey Creek area about 100 mi further downstream, in Texas. This is also approximately where the river canyon cuts through the resistant sandstones of the Trujillo Formation (middle member of Late Triassic Dockum Group) and exposes fine-grained sandstones and mudstones of the underlying Tecovas Formation (lower member of Dockum Group) (fig. 5). This contact may actually have been crossed by the channel some distance upstream (0.5 mi, or more), because the bedrock floor of the canyon may be ≥50 ft below the surface of the riverbed alluvium.

The only notable source of high-conductivity waters along the Texas portion of the river survey is in the vicinity of Lahey Creek (~13,000 micromhos/cm, site 96, near mile 128). This area is at the upstream end of a segment of the river canyon that exposes Permian bedrock.

Preliminary calculations by CRMWA, based on February 1992 chloride concentration and flow data, support the conclusion that most of the salt loading of the Canadian River (expressed in terms of chloride load) occurs within the first 40 mi (table 5), reaching a "plateau" at about 45,000 tons-chloride/yr. Beyond that point (site 67, near the Texas-New Mexico state line), the chloride load trend remains approximately constant to about 96 mi downstream from Ute Reservoir (site 86), and then declines to about 80 percent of the maximum value.

WATER CHEMISTRY

During the salinity survey, 28 water samples were collected from pools alongside the Canadian River, from tributaries, from seeps, and from the main channel of the river itself. The sampling was deliberately biased toward collection of waters with high conductivity, as determined by field measurements. Of the 28 samples, 20 were analyzed for major chemical constituents (Ca, Mg, Na, K, HCO_3 [field determination], SO_4, and Cl) and for Br (table 6).

Water quality of analyzed samples ranges from fresh (Cl < 250 mg/L) to highly saline (Cl > 10,000 mg/L); most of the higher salinity waters were collected from areas in New Mexico (fig. 8). Similar ratios among major cations and anions in the different samples suggest that the waters are related; this pattern is reflected in bivariate plots by more or less linear trends of the data points (figs. 9 and 10). These trends suggest mixing between two different water types, with mixing products falling between the end members. One end member of this mixing trend is fresh water derived from meteoric precipitation. The chemistry of this fresh water changes as it infiltrates the ground, where it interacts with soil and aquifer material before being discharged to the Canadian River. The other end member is highly saline water derived from dissolution of halite (mineral composition NaCl), as indicated by molar sodium-to-chloride ratios (Na/Cl) of approximately 1 in virtually all the analyzed samples, and by Br/Cl weight ratios of smaller than 0.001 in all but the freshest water samples (fig. 11). Ratios of Na/Cl and Br/Cl have been used successfully for identification of halite-dissolution brines in other parts of Texas and in Kansas (e.g., Whittemore and Pollock, 1979; Richter and Kreitler, 1986).

Halite dissolution occurs within evaporite-bearing Permian strata and produces a water chemistry different from that in overlying Triassic aquifer units (fig. 12a and 12b). Revuelto Creek, the only large tributary along the 10-mi stretch downstream from Ute Reservoir (where saline inflows are significant), appears to be influenced by discharge from both Permian and Triassic units (fig. 12c). At times, Revuelto Creek carries water of low salinity with Na/Cl ratios that follow a trend typical of Triassic well waters in the area (figs. 12b and 12c). At other times, the creek carries water of much higher salinities with Na/Cl ratios that approach 1, which is typical of halite-dissolution waters encountered within Permian units in the area (figs. 12a and 12c), suggesting mixing between waters from Triassic and Permian water-bearing units.

The most saline water sample obtained along the Texas portion of the Canadian River (from site 96a, table 6) contains relatively high concentrations of Ca, Mg, and SO_4, relative to other samples with similar Na and Cl concentrations (figs. 9 and 10). This sample and others collected along the Texas portion of the Canadian River show trends in bivariate plots of Ca versus Cl and of SO_4 versus Cl that are distinctly different from those for samples collected along the New Mexico portion (figs. 13a and 13b). This difference is not the result of different $CaSO_4$ concentrations, as indicated by the overlap of data points for the two areas in a Ca-versus-SO_4 plot (fig. 13c). Instead, this difference is produced by different amounts of NaCl added to the water in the two river portions, as indicated in Piper diagrams of major cations and anions (figs. 14 and 15). Within the group of New Mexico samples, Na makes up 80–95 percent of all cations and Cl makes up 75–90 percent of all anions (fig. 14), whereas in the group of Texas samples respective ranges amount to only 70–85 percent and 60–75 percent (fig. 15). Thus, either NaCl is a more dominant contributor to ion concentration in the New Mexico portion of the river than in the Texas portion, or dilution of halite-dissolution brine by fresher sulfate dominated water (before it enters the river) is more dominant in Texas than in New Mexico.

Samples collected during this river survey appear representative of Canadian River water in general, as the data reported here are similar to those for samples collected during previous surveys of the New Mexico portion of the river and from sampling stations in Texas near Tascosa and Amarillo (fig. 16). Previous data also show the apparent difference in Ca-Cl and SO_4-Cl plots between samples from the New Mexico reach and samples from the Amarillo sample station, supporting the view that inflow of the halite brine is more dominant in the New Mexico part of the Canadian River than in the Texas part. Magnesium concentrations appear atypically high for reasons that are unclear at this time. Data from the February 1992 survey are also consistent with chemical data on samples of shallow ground-water collected from piezometers in the Canadian River alluvium (fig. 17), indicating that the saline waters in isolated pools, tributaries, seeps, and in the main channel itself have the same origin as the shallow saline ground water in the river alluvium.

CONCLUSIONS

The main contributor of solutes to the Canadian River through its history has been the Permian San Andres Formation, as evidenced by the dissolution of nearly 700 ft of halite from areas beneath the Canadian River Valley (figs. 2 and 3; plates 1 and 2). A significant amount of NaCl was also contributed by dissolution of halite from mixed halite-siliciclastic beds and discrete halite beds in the Artesia Group beneath and as far south as 20 mi from the Canadian River (fig. 2; plate 1).

Results of the February 1992 water quality survey suggest two principal areas where saline waters presently enter the Canadian River: (1) along the first 9 or 10 mi downstream from Ute Reservoir (figs. 1 and 4); and (2) between 20 and 40 mi downstream from Ute Reservoir (between sites 57 through 67) (figs. 1 and 5). Both of these segments of the river are within New Mexico. Moderately high conductivities were also encountered in the vicinity of Lahey Creek in Texas (site 96, near mile 128; fig. 1); however, inflow from the creek and from seeps in the area at the time of the survey were insignificant relative to inflows in the other salinity source areas, suggesting that this area is not a major contributor to Canadian River salinity (compare data in tables 1–4). Preliminary calculations by CRMWA, based on February 1992 chloride concentration and flow data, confirm the conclusion that most of the salt loading of the Canadian River occurs within the first 40 mi (table 5), reaching a "plateau" at about 45,000 tons-chloride/yr.

Laboratory chemical analyses suggest that saline waters in the Canadian River valley evolved by mixing of fresh water derived from meteoric precipitation and highly saline water derived from dissolution of halite at depth. The most saline water sample obtained along the Texas portion of the Canadian River (from site 96a, table 6) contains relatively high concentrations of Ca, Mg, and SO_4, relative to other samples with similar Na and Cl concentrations (figs. 9 and 10). This difference in water chemistry may reflect differences in flow paths through the dissolution zone in the New Mexico and Texas portions of the Canadian River. Flow paths in New Mexico may extend deep into the dissolution zone where halite is present, whereas flow paths in Texas may be more restricted to the upper part of the dissolution zone where anhydrite, gypsum, and dolomite remain but halite may have already been dissolved or perhaps was originally less abundant.

If halite dissolution is continuing along the same trends and by the same processes as in the past, then the focus of modern dissolution is along a front at a depth of about 1,100 ft beneath the Canadian River in the Ute Reservoir area and extending in the subsurface some 10 mi south of the Canadian River at depths of 1,000 ft below land surface (fig. 2; plate 1). A future program of drilling, sampling, and analysis of waters from various areas and depths would provide useful data to help test these hypotheses.

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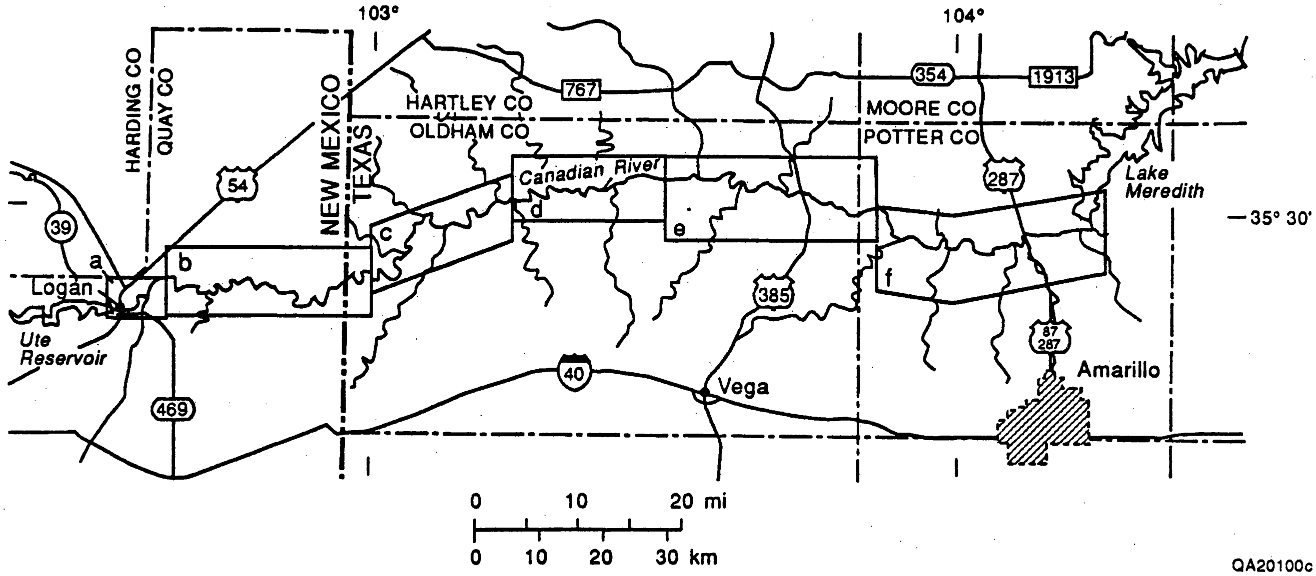
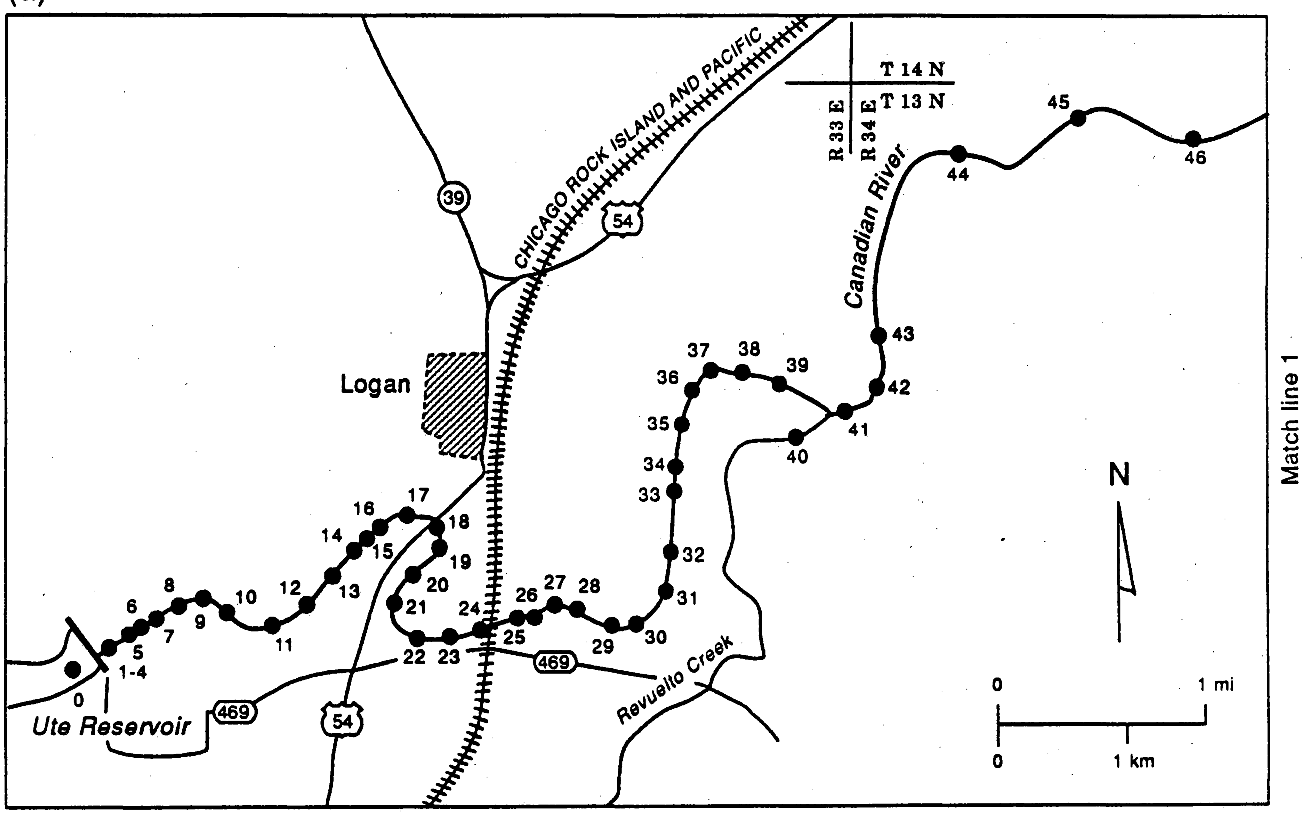


Figure 1. Locations of measurement stations along the Canadian River between Ute Reservoir, New Mexico, and Lake Meredith, Texas, conductivity survey, February 1992.

(a)



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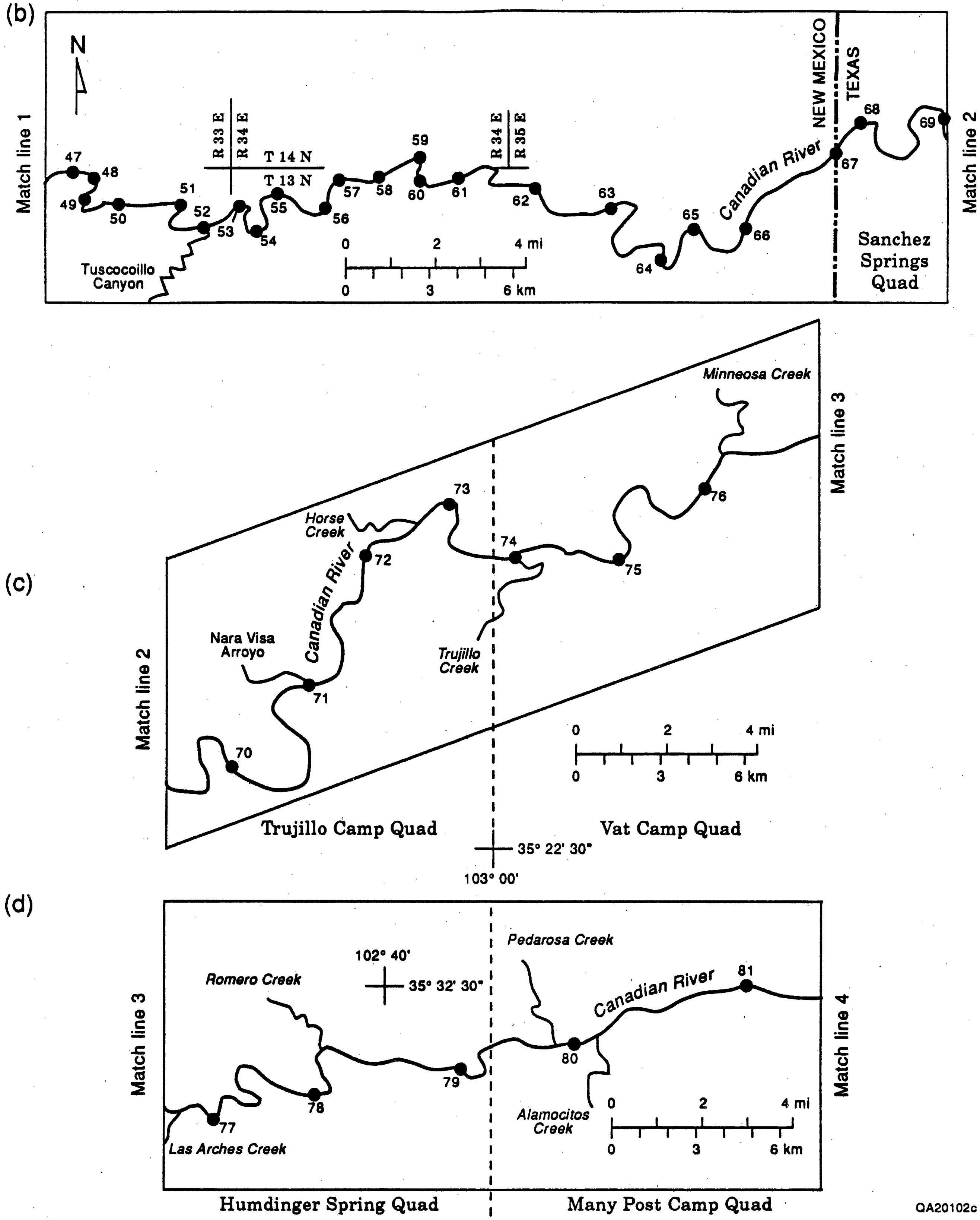

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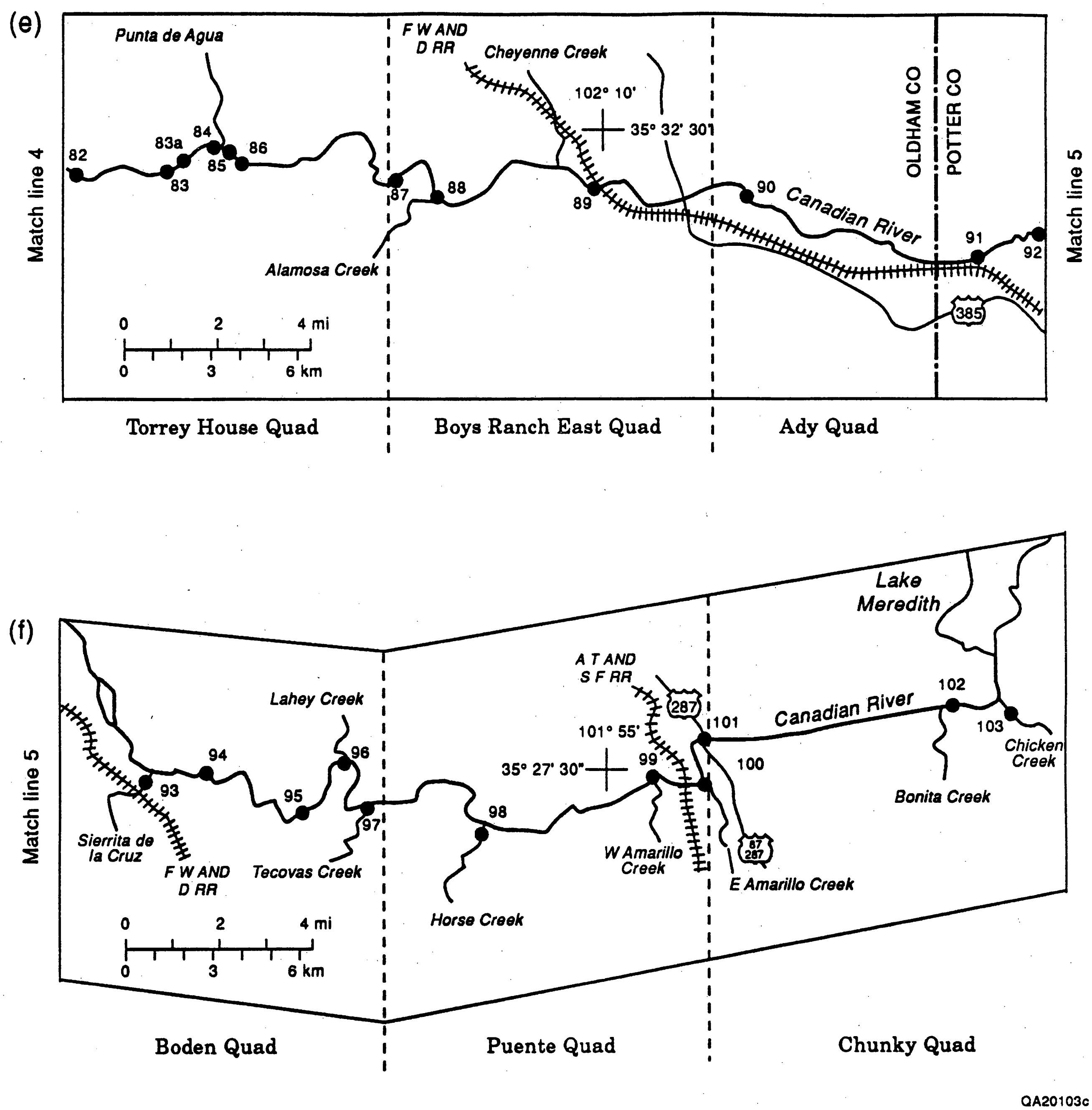

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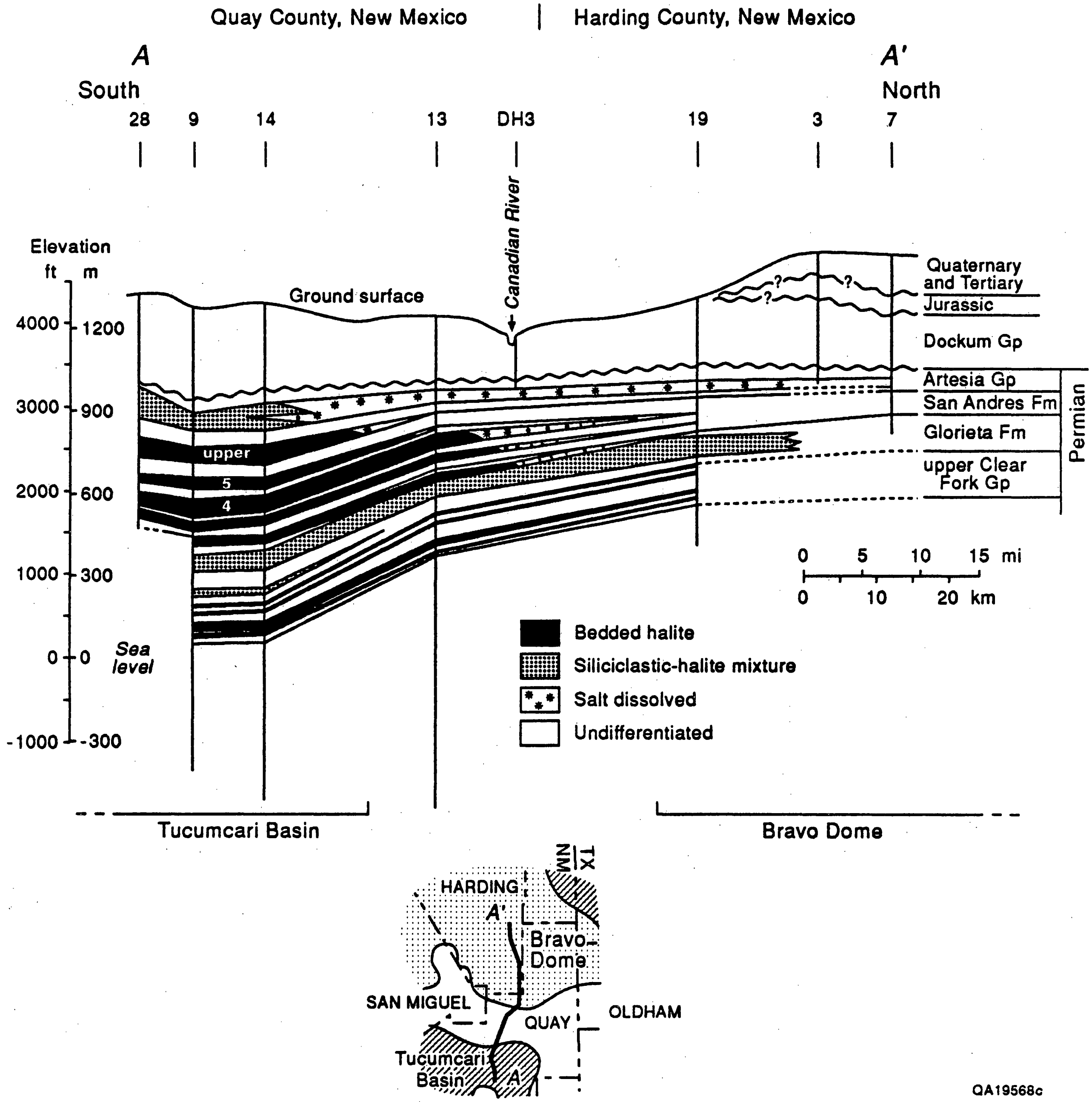


Figure 2. North-south structural cross section A–A′ through the Ute Dam area (see also plate 1).

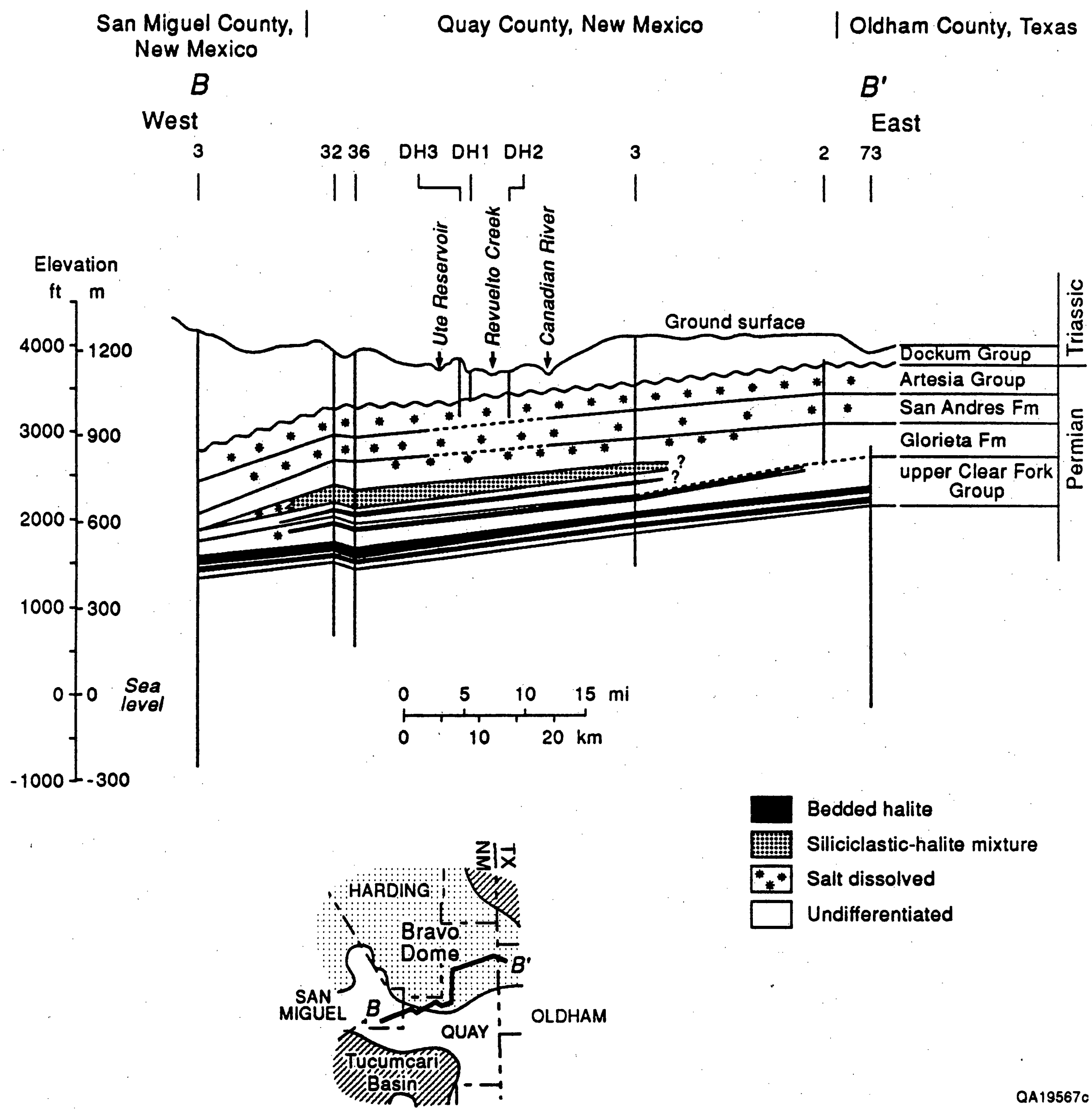


Figure 3. East-west structural cross section B–B′ through the Ute Dam area (see also plate 2).

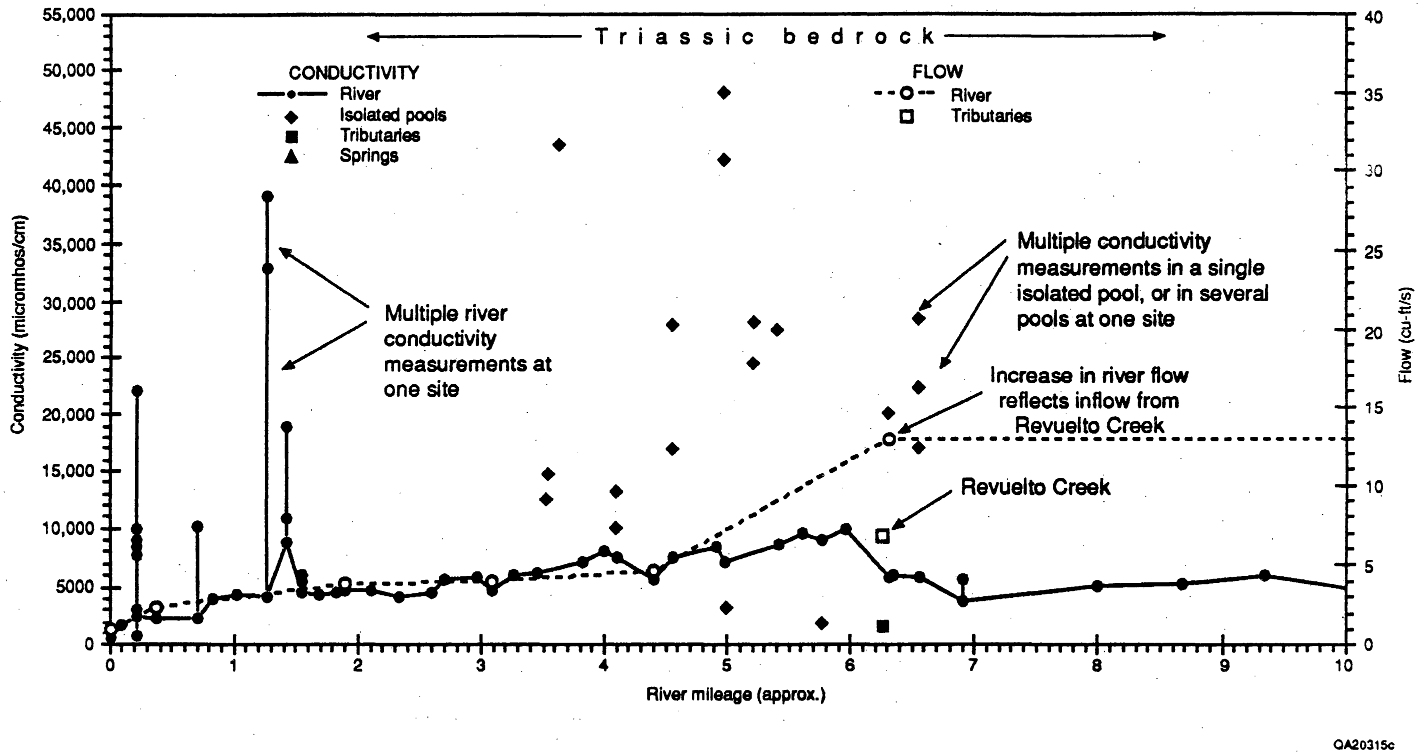


Figure 4. Plot of conductivity (scale on left) and flow (scale on right) along first 10 mi of Canadian River below Ute Reservoir, New Mexico; measurements taken in field on 2/10, 2/11, and 2/12/92 (see tables 1–4 for data). The exposed bedrock in canyon walls along this stretch of the river canyon consists almost entirely of fluvial channel sandstones of the Triassic Trujillo Formation; the bedrock floor of the canyon may be as deep as 50 ft below the surface of the alluvium.

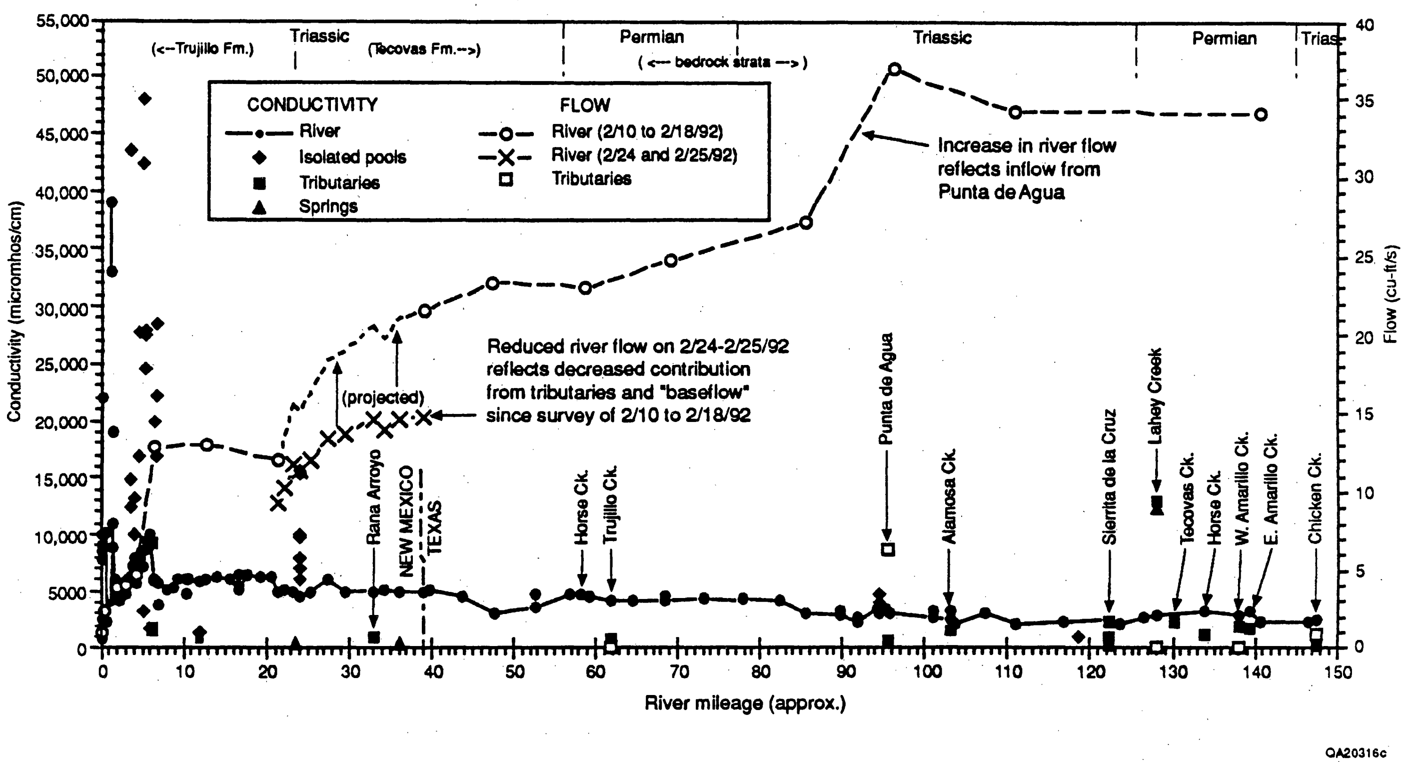


Figure 5. Plot of conductivity (scale on left) and flow (scale on right) along entire length of Canadian River survey, between Ute Reservoir, New Mexico, and Lake Meredith, Texas; measurements taken in field 2/10 through 2/18/92 (main survey), and 2/24 and 2/25/92 (detailed survey between sites 57 and 67, inclusive) (see tables 1–4 for data). The exposed bedrock in the canyon walls along the various stretches of the river is indicated at the top of the plot.

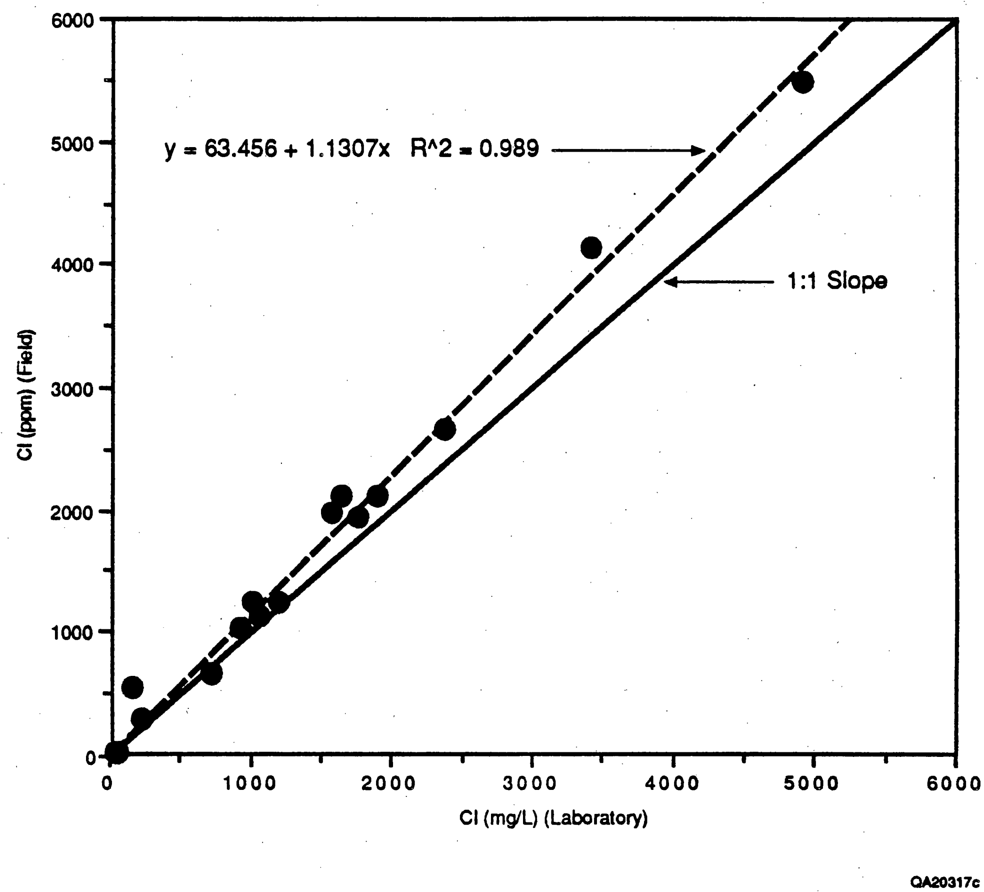


Figure 6. Comparison between chloride content determined in the field and chloride content determined in the laboratory for February 1992 river-survey samples.

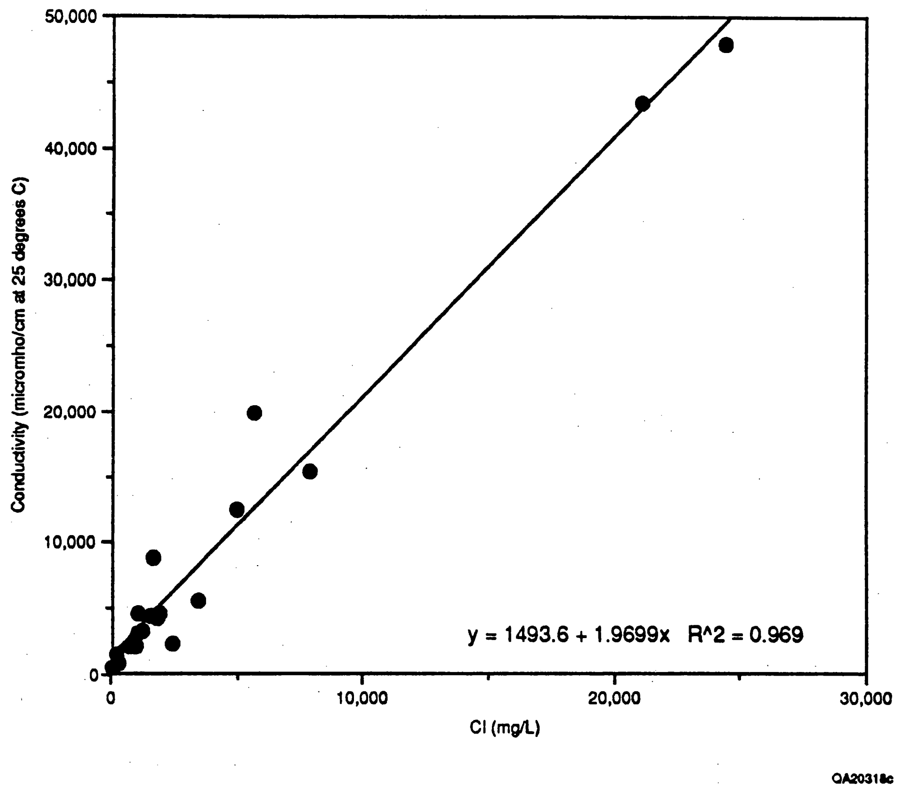


Figure 7. Relationship between conductivity measurements at field-collection sites and chloride concentrations determined in the laboratory for water samples collected during the river survey of February 1992.

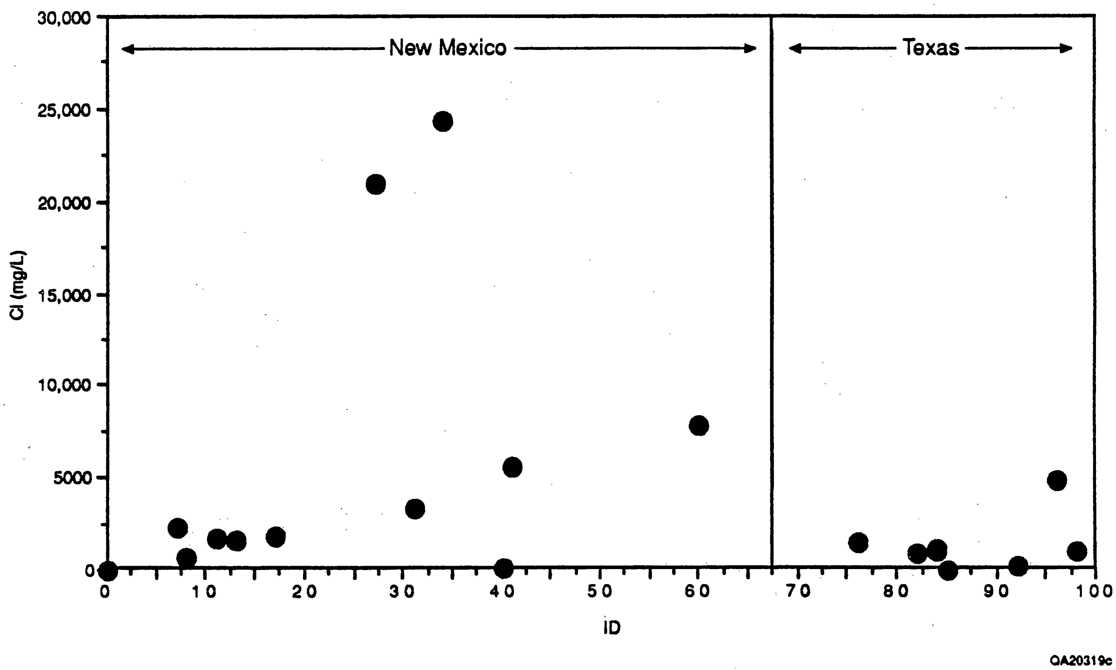


Figure 8. Chloride concentration in river-survey samples collected between Ute Reservoir, New Mexico, and Lake Meredith, Texas, February 1992.

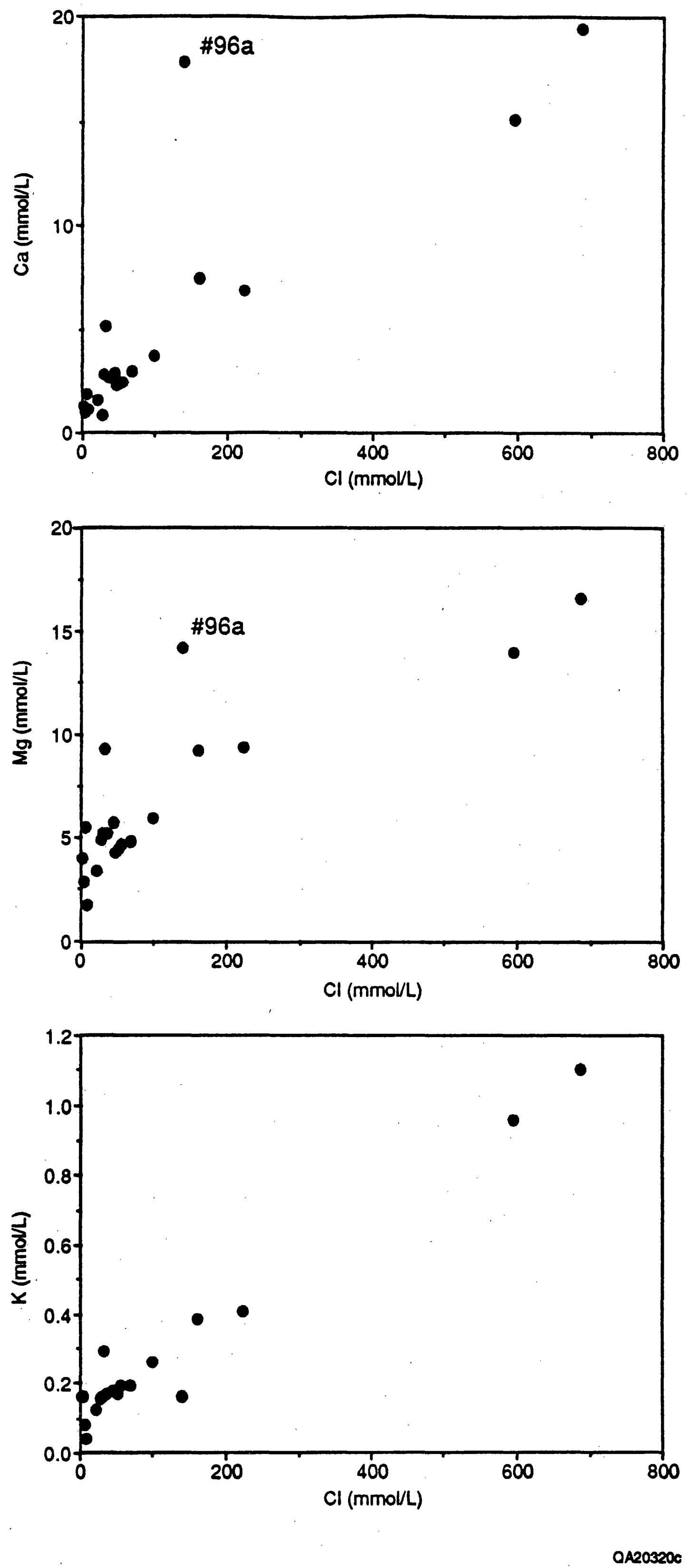


Figure 9. Bivariate plots of Ca, Mg, and K versus Cl for river-survey samples. The plots suggest mixing trends between low-Cl and high-Cl waters.

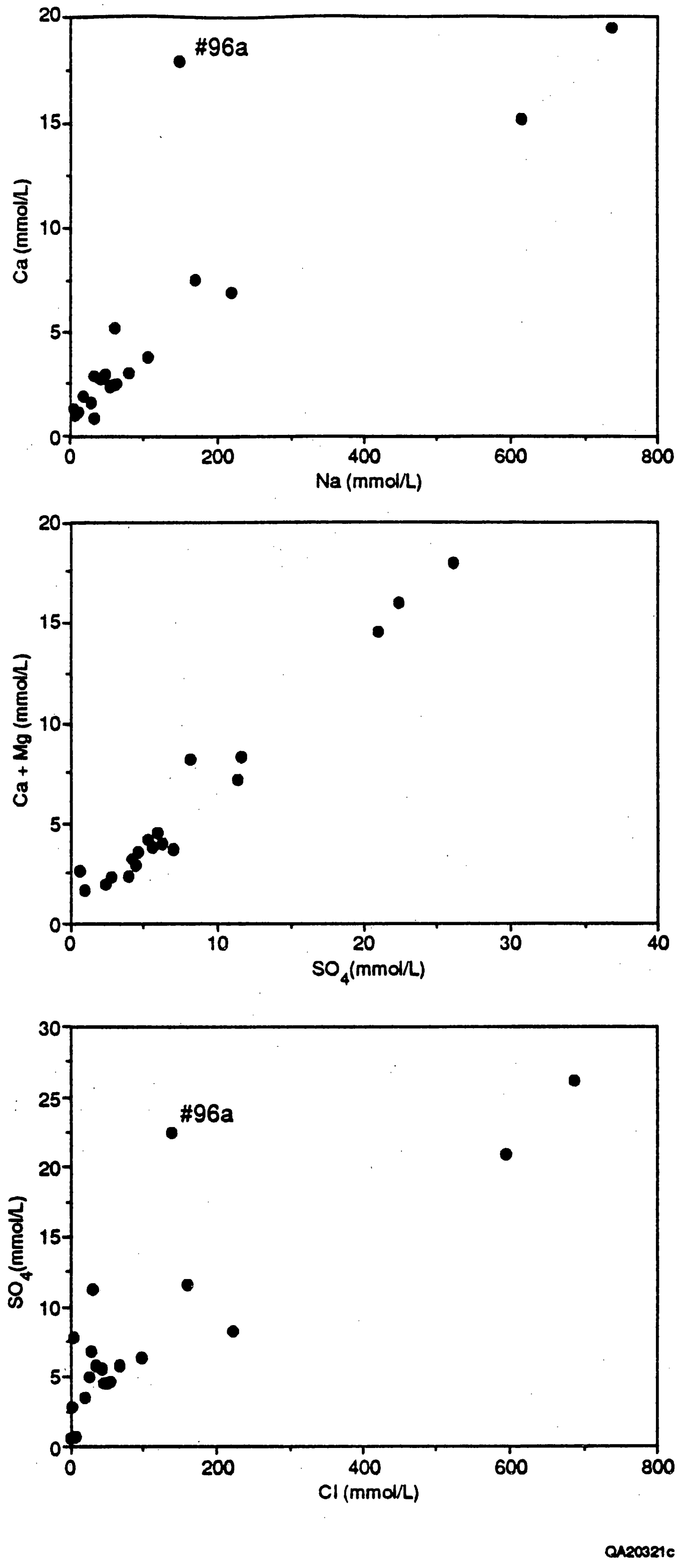


Figure 10. Bivariate plots of major cations and anions for river-survey samples. The plots suggest mixing trends.

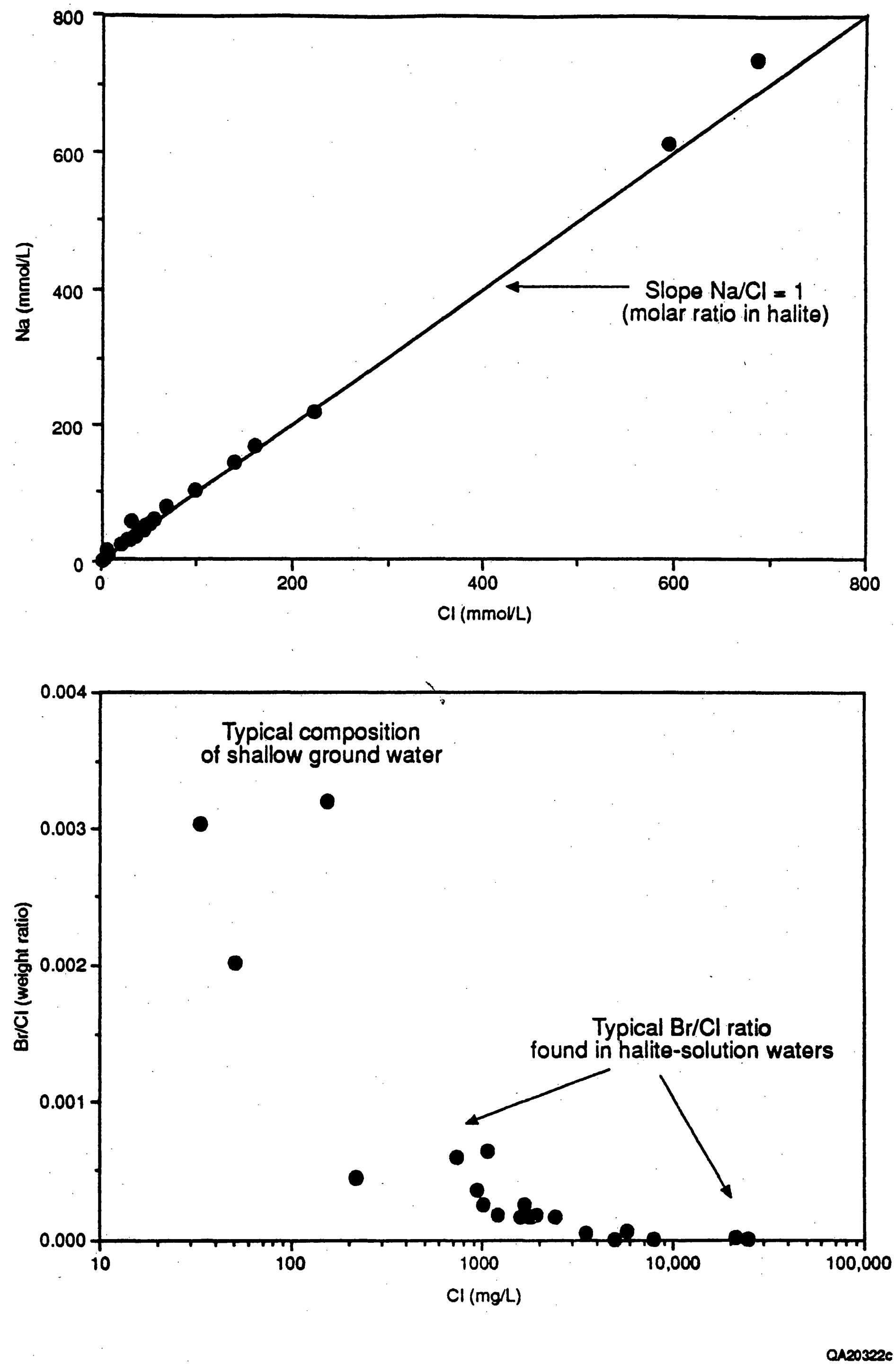


Figure 11. Constituent plots of (a) Na versus Cl and (b) Br/Cl versus Cl for river-survey samples. The plots suggest halite dissolution as the major source of salinity.

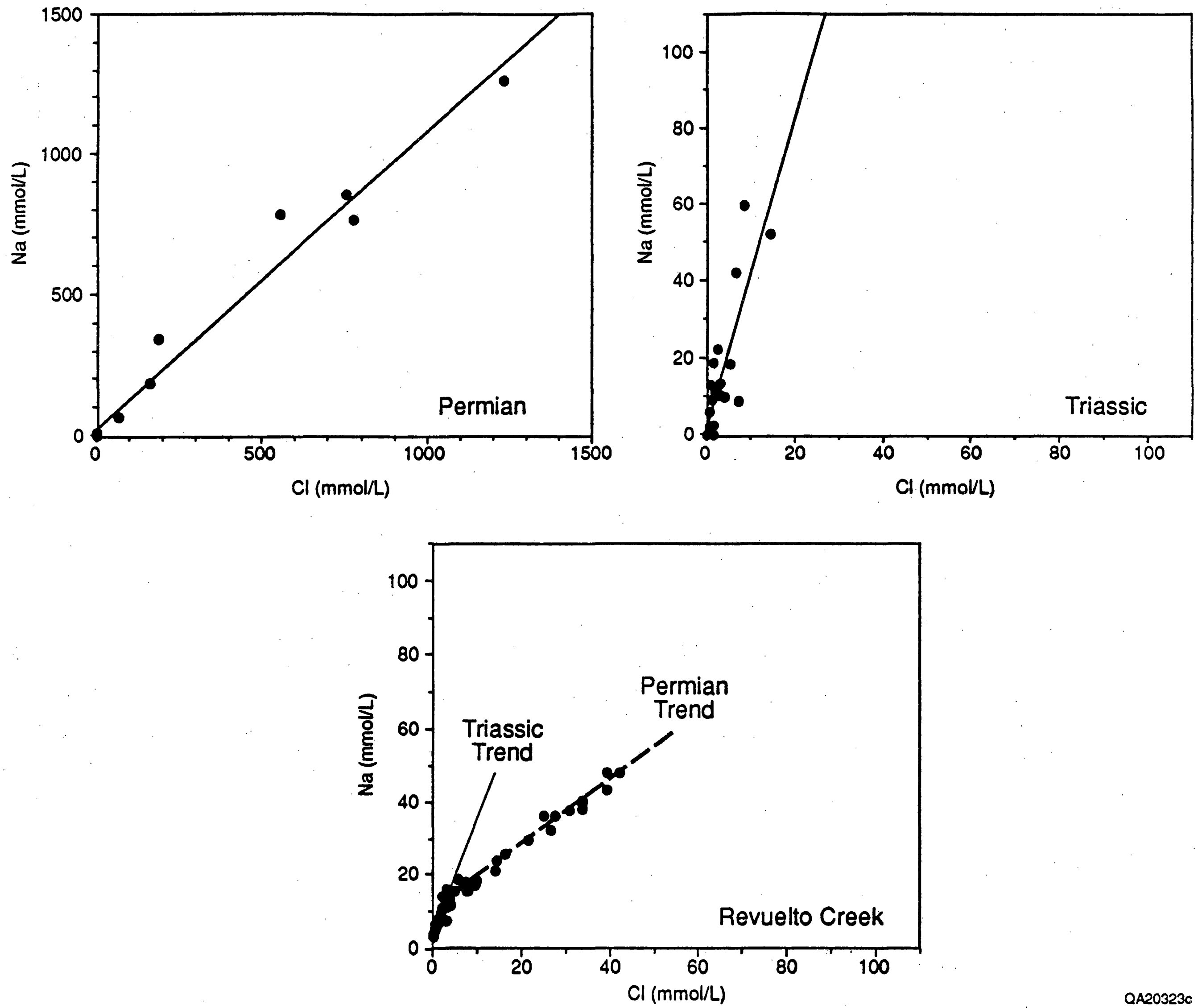


Figure 12. Comparison among water samples from (a) wells producing from Permian strata, (b) wells producing from Triassic strata, and (c) Revuelto Creek, New Mexico. Water salinity in Revuelto Creek is low when flow is dominated by discharge of water from Triassic formations; salinity is high when flow is dominated by contributions from Permian water-bearing units (data from Hydro Geo Chem, Inc., 1984).

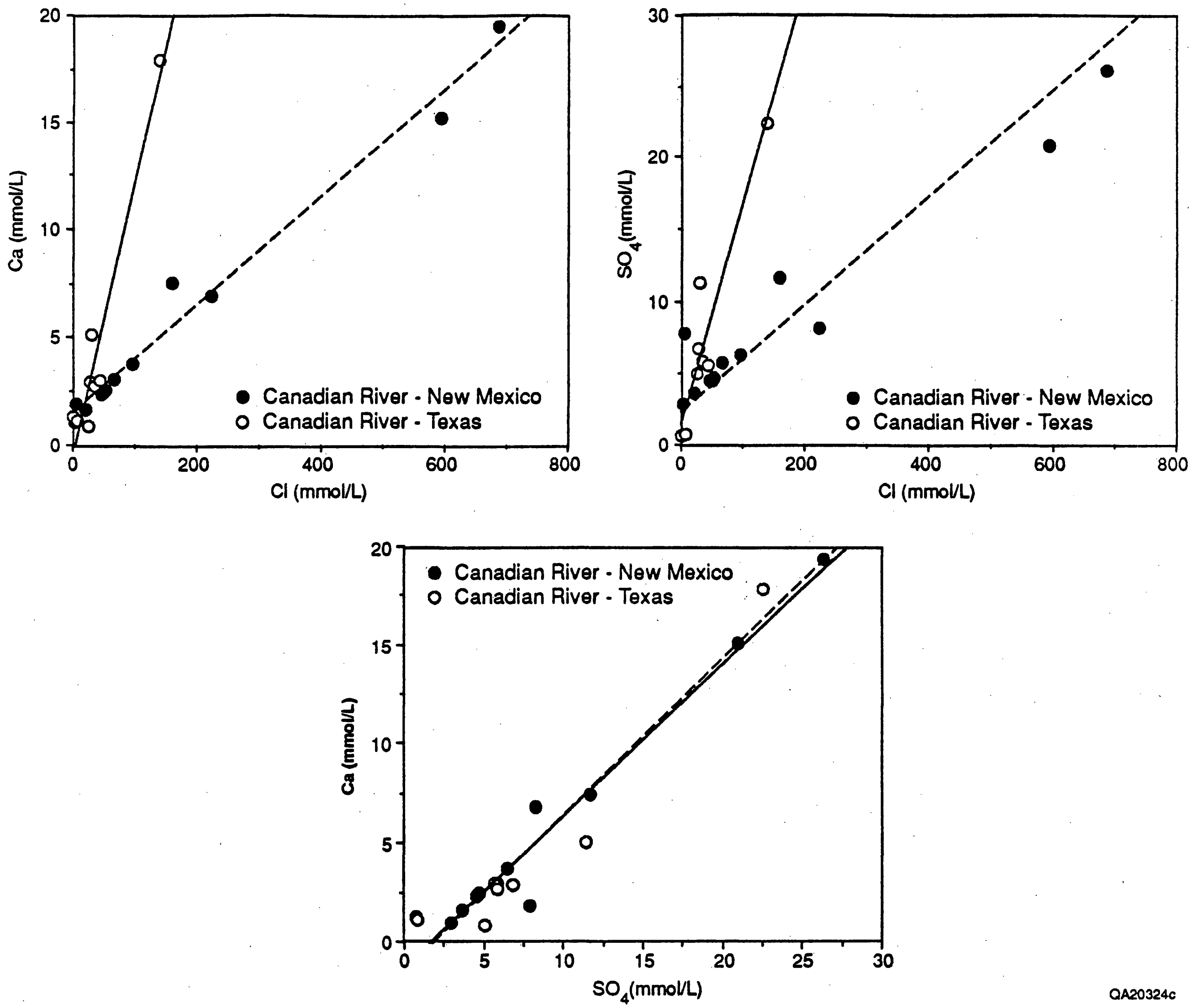
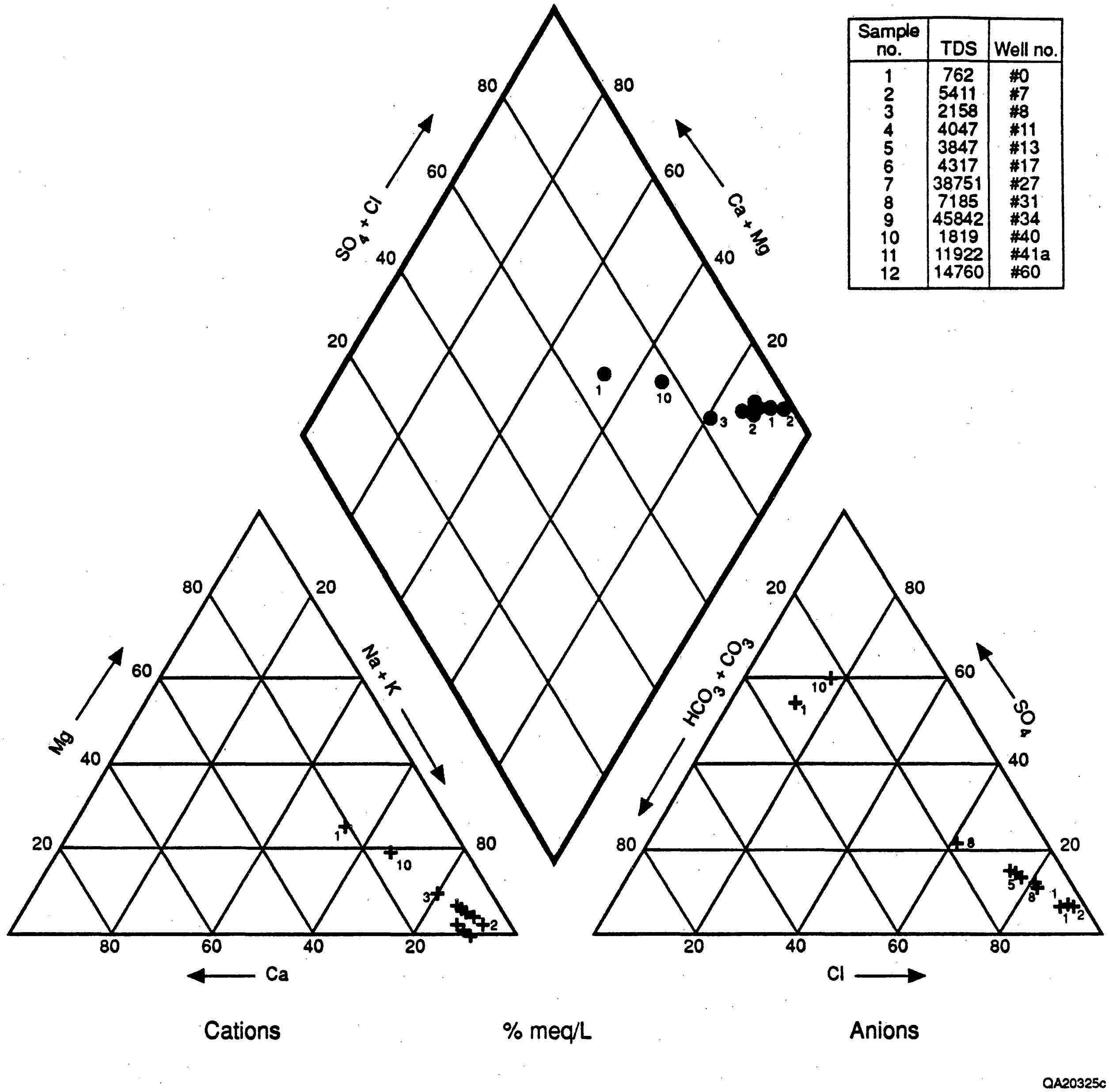
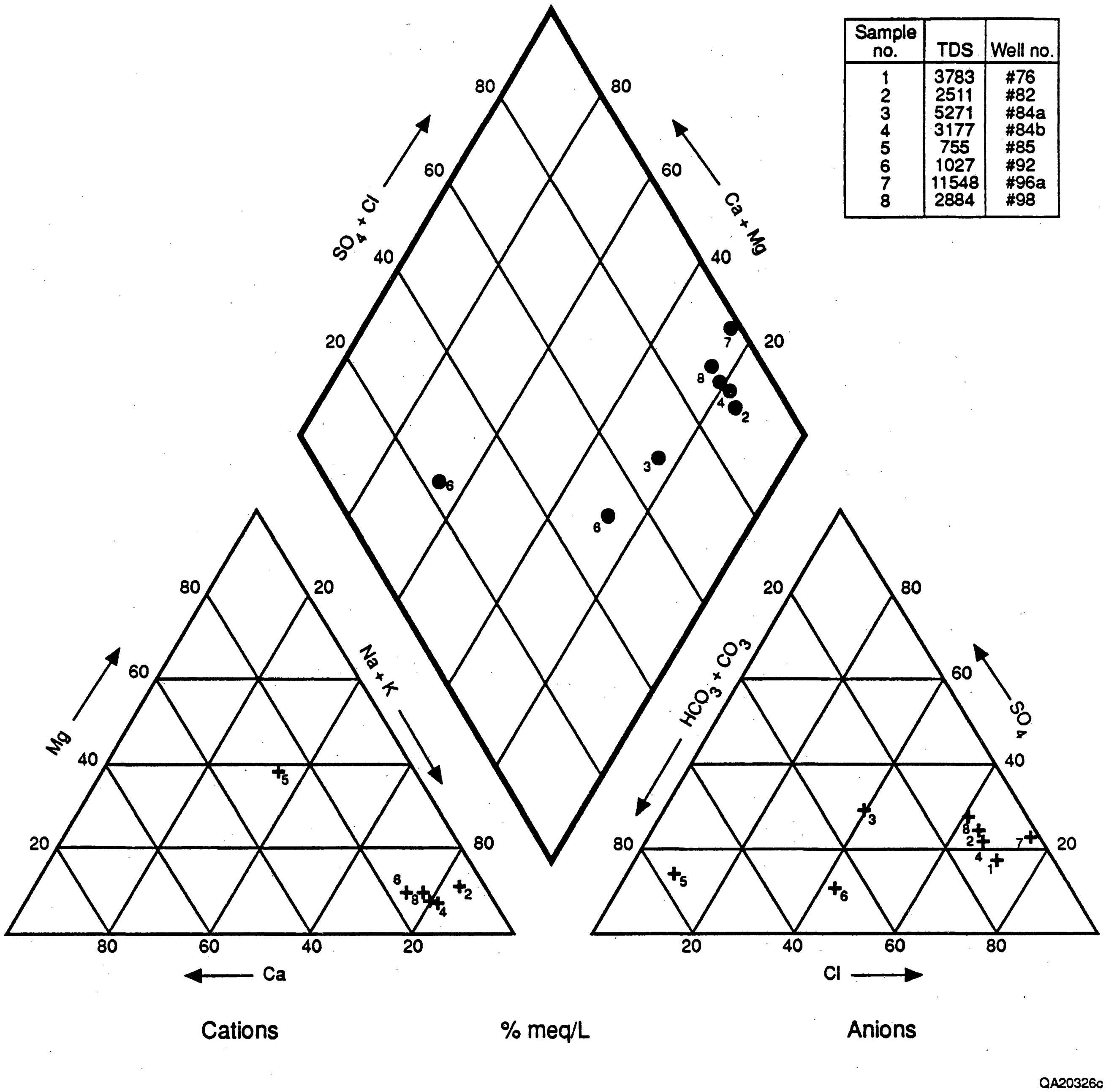


Figure 13. Bivariate plots of Ca, SO_4, and Cl for river-survey samples. The plots differentiate between samples collected in New Mexico (solid dots) and those collected in Texas (open circles). Samples from the Texas reach typically exhibit larger Ca/Cl and SO_4/Cl ratios than do samples from the New Mexico portion of the river.



Sample no.	TDS	Well no.
1	762	#0
2	5411	#7
3	2158	#8
4	4047	#11
5	3847	#13
6	4317	#17
7	38751	#27
8	7185	#31
9	45842	#34
10	1819	#40
11	11922	#41a
12	14760	#60

Figure 14. Piper diagram of river samples collected along the New Mexico portion of the Canadian River.



Sample no.	TDS	Well no.
1	3783	#76
2	2511	#82
3	5271	#84a
4	3177	#84b
5	755	#85
6	1027	#92
7	11548	#96a
8	2884	#98

Figure 15. Piper diagram of river samples collected along the Texas portion of the Canadian River.

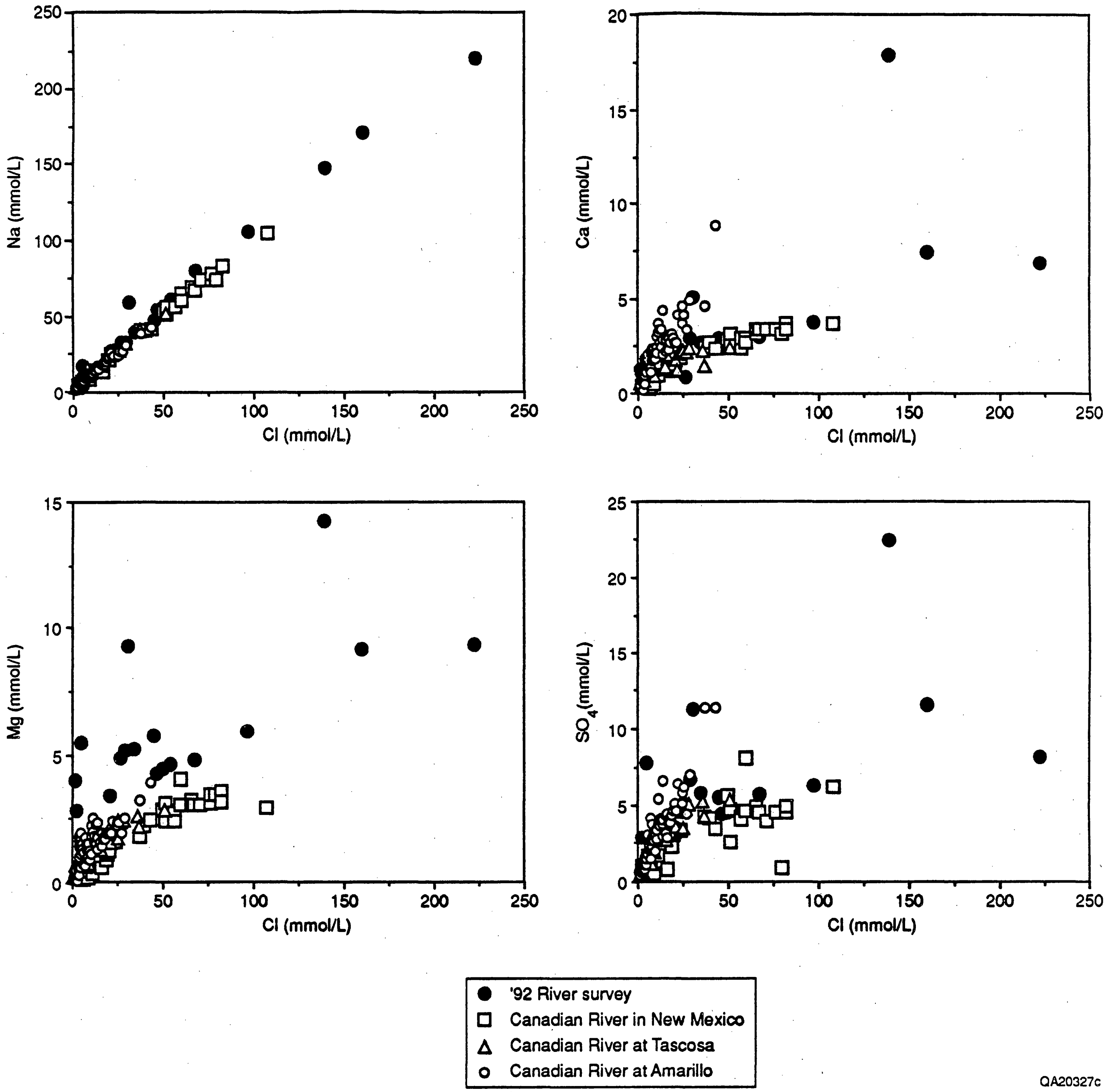


Figure 16. Comparison between February 1992 river-survey data (solid dots) and data from previous investigations in New Mexico (open squares), at Tascosa, Texas (open triangles) and at Amarillo, Texas (open circles) (previous data from Hydro Geo Chem, 1984).

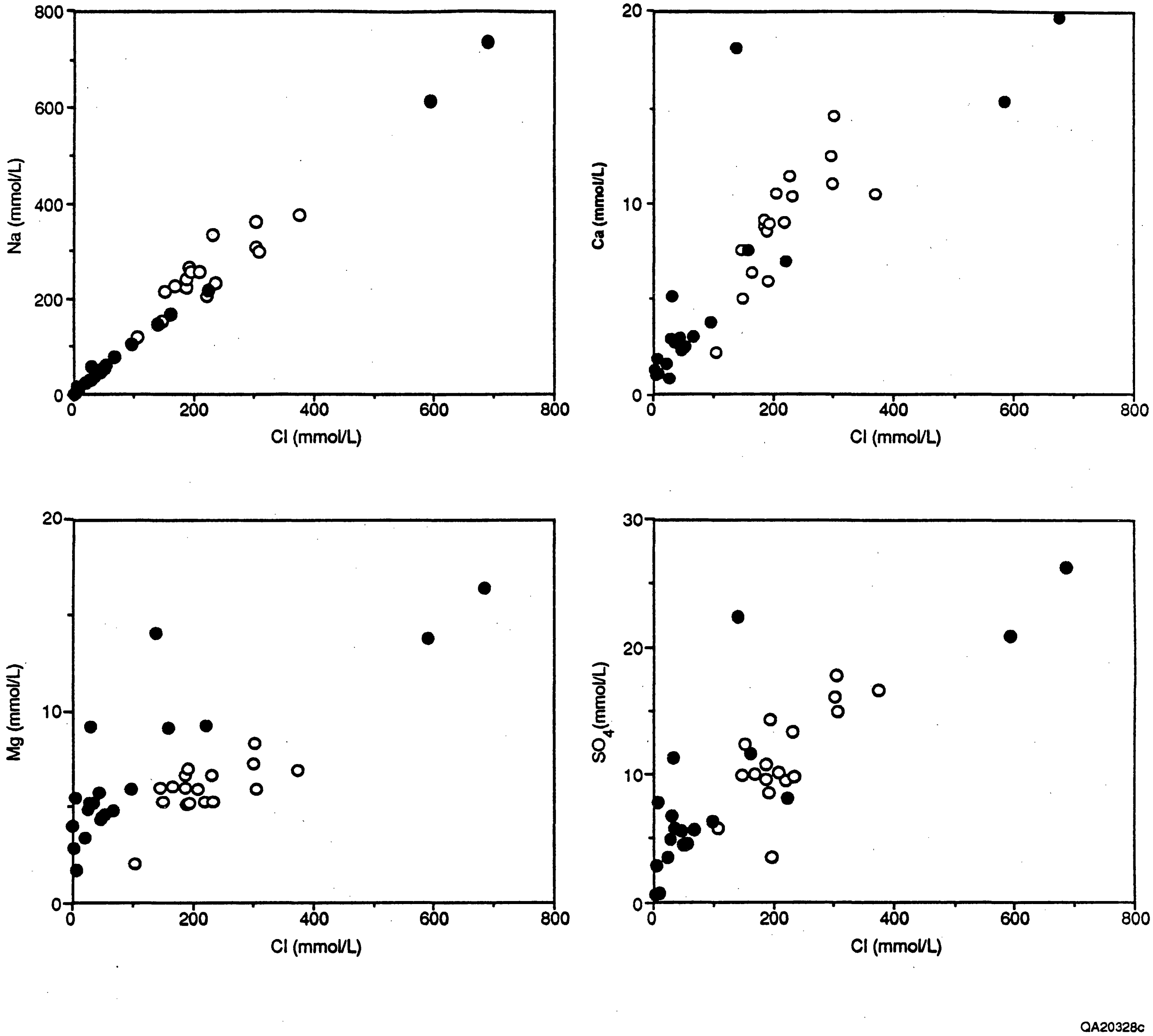


Figure 17. Comparison between February 1992 river-survey data (solid dots) and data from piezometers collected during previous investigations (open circles) (previous data from U.S. Bureau of Reclamation, 1984).

Table 1. Conductivity of waters in Canadian River, Ute Reservoir, New Mexico, to Lake Meredith, Texas.

Survey Site No. (1)	River Mileage (2)	Conductivity (3)	Location and Remarks
0*	0.00	(not measured)	Ute Reservoir, from state park area on south shore, about 0.1 mi from dam; 2/13/92
1	0.00	975	Toe drain outlet, Ute Dam; 2/10/92
2	0.00	675	Secondary drain outlet, Ute Dam gateworks?; 2/10/92
3	0.00	725	Outlet channel from Ute Dam gate; 2/10/92
4	0.00	650	At base of canyon wall, near south abutment of dam; 2/10/92
5	0.22	775	Spillway, at canyon rim; 2/10/92
6	0.09	1790	Pool in river; 2/10/92
7*	0.22	2500	Pool in river (probe 6 inches from bank, on bottom, 3-inch depth); 2/10/92
"	0.22	7800	" (probe 4 ft from bank, in mud on bottom, 1.5 ft depth); 2/10/92
"	0.22	9000	" (probe 6 ft from bank, in mud on bottom, 2.5–3 ft depth); 2/10/92
"	0.22	10000	" (probe 8 ft from bank, in mud on bottom, 3–4 ft depth); 2/10/92
"	0.22	22000**	" (probe in middle of channel in mud on bottom); 2/10/92
7A	0.22	810	"Tributary" from spillway; downstream from site 5; 2/10/92
7B	0.22	3000	River,10 ft downstream from site 7A (probe suspended to 1 ft depth in water 1.5 ft deep); 2/10/92
"	0.22	8500	" (probe in mud on bottom, 1.5 ft depth); 2/10/92
8*	0.37	2300	River, below point where all sources join; 2/10/92
9	0.71	2250	Pool in river (probe 2 ft from bank, suspended to 0.5 ft depth in water 1.5 ft deep); 2/10/92
"	0.71	10200	" (probe 8 ft from bank, in mud on bottom, 3.5–4 ft depth); 2/10/92
10	0.82	3990	Riffle in river, at exit from beaver pond; 2/10/92
11*	1.03	4290	Riffle in river; 2/10/92
12	1.27	4100	Pool in river (probe 5–6 ft from bank, on bottom, 1.5 ft depth); 2/10/92
"	1.27	33000	" (probe in middle of channel, on bottom, >2 ft depth); 2/10/92
"	1.27	39000	" (probe in middle of channel, on bottom, >2 ft depth); 2/10/92
13*	1.42	8900	River (probe 1–1.5 ft from bank, on bottom, 1 ft depth); 2/10/92
"	1.42	10900	" (probe 8 ft from bank, on bottom, 2-2.5 ft depth); 2/10/92
"	1.42	19000	" (probe 18–20 ft from bank, on bottom, 4? ft depth); 2/10/92

(continued on next page)

Table 1 (cont.)

Survey Site No. (1)	River Mileage (2)	Conductivity (3)	Location and Remarks
14	1.55	5200	Pool in river (probe 3 ft from bank, suspended to 0.5-ft depth in water 1 ft deep); 2/10/92
"	1.55	4600	" (probe 3 ft from bank, on bottom, 1-ft depth); 2/10/92
"	1.55	5500	" (probe 10 ft from bank, on bottom, 1.5–2 ft depth); 2/10/92
"	1.55	6100	" (probe 20 ft from bank, on bottom, 3?-ft depth); 2/10/92
15	1.68	4300	Riffle and pool section (probe 3 ft from bank, suspended to 6-inch depth in water 8–12-inches deep); 2/1
16	1.83	4600	Pool in river (probe 3 ft from bank, on bottom, 1-ft depth); 2/10/92
"	1.83	4550	" (probe 4 ft from bank, suspended to 8-inch depth in water 1–1.5 ft deep); 2/10/92
17*	1.91	4675	River, at gauging station just upstream from NM Hwy. 54 bridge; 2/10/92
18	2.11	4800	Pool in river, under NM Hwy. 54 bridge (probe 2 ft from bank, on bottom, 1-ft depth); 2/10/92
"	2.11	4800	" (probe 8 ft from bank, on bottom, 2–2.5-ft depth); 2/11/92
19	2.33	4150	Pool in river (probe 3 ft from south bank, on bottom, 6–8-inch depth); 2/11/92
"	2.33	4150	" (probe 12 ft from south bank, on bottom, 1.5-ft depth); 2/11/92
20	2.60	4525	Riffle in river; 2/11/92
21	2.71	5600	Pool in north channel of 2 channels (probe 6 ft from N bank, on bottom, 8–12-inch depth); 2/11/92
"	2.71	5600	" (probe 10–12 ft from N bank, on bottom, 1–1.5-ft depth); 2/11/92
"	2.71	5600	Pool in south channel of 2 channels (probe middle of 10-ft channel, on bottom, 1.5-ft depth); 2/11/92
22	2.97	5800	Riffle in river (channel 8 ft wide; probe on sandy bottom, 6-inch depth); 2/11/92
23	3.08	4680	Deep riffle section of river; 2/11/92
24	3.27	6000	Braided section of river ~50 ft upstream from railroad bridge (two channels, same conductivity); 2/11/92
25	3.46	6300	Riffle section of river, 500–600 ft downstream from bridge (~8 ft wide, 1 ft deep, gravel bottom); 2/11/92
28	3.83	7200	River; 2/11/92
29	4.00	8000	Deep, murky green pool in river (probe 5 ft from north bank, on bottom, 2.5–3-ft depth); 2/11/92
"	4.00	8000	" (probe suspended to 6 inches in water 2 ft depth); 2/11/92
30.2	4.11	7500	River; water murky green; 2/11/92
31*	4.41	5700	Flowing pool section of river (probe 6 ft from bank, on rippled, sandy bottom, 6–8-inch depth); 2/11/92
32	4.56	7600	Flowing pool section of river (probe 6 ft from bank, on sandy bottom, 6–8-inch depth); 2/11/92

(continued on next page)

Table 1 (cont.)

Survey Site No. (1)	River Mileage (2)	Conductivity (3)	Location and Remarks
33	4.91	8500	Slowly-flowing pool section of river, 3 ft deep (probe 6 ft from N bank, on sandy bottom, 1-ft depth); 2/11/92
34D	4.99	7200	Flowing riffle and pool section of river (probe on sandy bottom, 8-inch depth); 2/11/92
36	5.42	8600	Riffle in river (probe on sandy bottom, 6–12-inch depth); 2/11/92
37	5.60	9500	Murky green pool (3 ft deep?) in marshy section of river; 2/11/92
38B	5.77	9000	Murky green pool (2–3 ft deep?); 2/11/92
39	5.96	10000	Murky green pool (20–25 ft wide, >3 ft deep); 2/11/92
41	6.31	5800	River, 200–300 ft downstream from confluence with Revuelto Creek; 2/11/92
41B	6.35	6000	River, ~100–200 ft downstream from site 41; 2/11/92
42	6.56	5900	River; 2/11/92
43	6.91	6000	South channel of 2 channels (probe on bottom, 2–3-ft depth); 2/11/92
"	6.91	5700	North channel of 2 channels (probe on bottom, 1-ft depth); 2/11/92
"	6.91	3730	" ; revisited on 2/12/92
44	7.99	5100	River; 2/12/92
45	8.68	5300	Riffle in river; 2/12/92
46	9.34	6000	River; 2/12/92
47	10.27	6000	River; 2/12/92
"	10.27	4690	River; 2/12/92
48	10.72	6000	River; 2/12/92
49	11.80	5900	River; 2/12/92
50	12.72	6000	River; 2/12/92
51	14.04	6300	River; 2/12/92
52	15.59	6100	River, at Tuscocoillo Canyon; 2/12/92
53	16.77	5200	River; 2/12/92
"	16.77	6500	River; 2/12/92
"	16.77	5500	River; 2/12/92
54	17.72	6500	River, where tributary from Cottonwood tank enters; 2/12/92

(continued on next page)

Table 1 (cont.)

Survey Site No. (1)	River Mileage (2)	Conductivity (3)	Location and Remarks
55	19.24	6200	River; 2/12/92
56	20.51	6200	River, opposite mouth of small, unnamed tributary; 2/12/92
57	21.44	5000	River; 2/13/92
58	22.24	5200	"
59B	23.34	5000	River at spring; 2/13/92
60A	24.09	4600	River; 2/13/92
61	25.23	4900	"
62	27.32	6000	"
63	29.53	5000	"
64	32.91	5100	River, ~0.25 mi downstream from mouth of Rana Canyon; 2/13/92
64A	32.91	5000	River, ~0.5 mi downstream from mouth of Rana Canyon; 2/13/92
65	34.18	5100	River; 2/13/92
66	36.14	5000	"
67	38.94	5000	River, ~0.1 mi upstream from New Mexico-Texas state line; 2/13/92
68	39.87	5100	River, at fenceline, ~0.75 mi downstream from New Mexico–Texas state line; 2/13/92
69	43.70	4480**	River, just downstream from point where two braids rejoin; 2/14/92
70	47.71	3125	River; 2/14/92
71	52.57	3710	River, adjacent to mouth of Nara Visa Arroyo; 2/14/92
"	52.57	4750**	"
72	56.77	4700	River channel, beneath Permian outcrop with active seep; 2/14/92
72B	58.23	4725	River, across from mouth of Horse Creek; 2/14/92
73	59.16	4650	River; 2/14/92
74	61.85	4225	River immediately downstream from mouth of Trujillo Creek (flowing–see table 4); 2/14/92
75	64.47	4258	River; 2/15/92
76*	68.44	4110	"
"	68.44	4520	"

(continued on next page)

Table 1 (cont.)

Survey Site No. (1)	River Mileage (2)	Conductivity (3)	Location and Remarks
77	73.08	4300	River; 2/15/92
"	73.08	4575	"
78	77.86	4275	River; 2/15/92
"	77.86	4325	"
79	82.39	4125	River; 2/15/92
80	85.53	3000	River; just downstream from Old Farm Crossing; 2/16/92
81	89.68	2950	River, near Many Post Camp; 2/16/92
"	89.68	3250	"
82*	91.83	2300	River, at mouth of Goodnight Canyon; 2/16/92
"	91.83	2675	"
83	94.09	3375	River, just downstream from Torrey House ruins; 2/16/92
83A	94.31	3100	River, across from area of heavy, white crust on bank sediments; 2/16/92
84B*	95.06	3400	River, across from area of heavy, white crust on bank sediments, farther downstream; 2/16/92
86	95.62	3000	River, immediately downstream from Punta de Agua (flowing–see table 4); 2/16/92
87	100.98	3200	River; 2/16/92
"	100.98	2675	"
88A	102.99	2500	River, at mouth of Alamosa Creek; 2/16/92
88C	103.03	2500	River, just downstream from Alamosa Creek/Canadian River confluence (probe on bottom); 2/16/92
"	103.03	3200	" (probe on bottom); 2/16/92
"	103.03	2900	" (probe suspended in water column); 2/16/92
88.1	103.46	2100	River; 2/16/92
89	107.20	3150	River, at railroad bridge; 2/16/92
90	110.93	2150	River; 2/17/92
91	116.83	2250	River, adjacent to gravel pits and railroad track (to south); 2/17/92
93	122.36	2450	River, at mouth of Sierrita de la Cruz; 2/17/92
94	123.48	2110**	River; 2/17/92

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Table 1 (cont.)

Survey Site No. (1)	River Mileage (2)	Conductivity (3)	Location and Remarks
95	126.39	2690	River, just downstream from suspended pipeline; 2/17/92
96C	128.11	2900**	River, at mouth of Lahey Creek; 2/17/92
98*	133.90	2910	River, across from mouth of Horse Creek; 2/17/92
99	138.05	2800	River, at mouth of West Amarillo Creek; 2/17/92
100	139.20	3200**	River, at mouth of East Amarillo Creek; 2/17/92
101	140.53	2300	River, under Hwy. 87-287 bridge; 2/18/92
102	146.32	2410	River, in vicinity of Bonita Creek; 2/18/92
103A	147.53	2500**	River, near mouth of Chicken Creek; 2/18/92

Notes:

(1) asterisk (*) denotes sites at which water samples were collected and analyzed; multiple entries for a single site indicate repeat measurements at that site

(2) mileage from Ute Dam, increasing in downstream direction;

(3) conductivity in micromhos/cm at 77°F, measured by Bureau of Economic Geology (values marked by two asterisks (**) were measured by Lee Wilson & Associates).

Table 2. Conductivity of waters in isolated pools, tributaries, and springs along Canadian River, Ute Reservoir, New Mexico, to Lake Meredith, Texas.

Survey	River	Conductivity (3)				
Site No. (1)	Mileage (2)	Isolated Pools	Tributaries	Springs	Location (4)	Remarks
26A	3.55	14800			Isolated pool in riverbed (S)	Water is milky, grayish-green, with fetid odor; 2/11/92
26B	3.55	12500			Isolated pool in riverbed (S)	Water is relatively clear; 2/11/92
27*	3.64	43500			Abandoned channel in riverbed (S)	Water in channel is seeping from riverbed sediments and entering river; 2/11/
30.1	4.11	13200			Pool, mostly connected to river (S)	Water is murky yellowish-green, with rust-brown film around edges; 2/11/92
30A	4.11	10000			Isolated pool, base of canyon wall (S)	2/11/92
32A	4.56	16900			Isolated pool in riverbed (N)	2/11/92
"	4.56	27800			"	"
34A	4.99	48000			Isolated pool in riverbed (N)	Water is murky, yellowish-brown, with rusty brown mud film on bottom; 2/1
34B	4.99	3200			Isolated pool in riverbed (N)	Water is clear; 2/11/92
34C*	4.99	42300			Isolated pool in riverbed (N)	Pool is contiguous with pool at site 34A; 2/11/92
35A	5.23	24500			Isolated pool in riverbed (S)	2/11/92
35B	5.23	28000			Isolated pool in riverbed (S)	2/11/92
36B	5.42	27500			Semi-isolated pool connecting to river (N)	Some flow from pool into river; 2/11/92
38	5.77	1800			Semi-isolated pool connecting to river (S)	Water in pool is clear; 2/11/92
40*	6.26		1690		Revuelto Creek (S)	Tributary flowing on 2/11/92 (see table 4)
40B	6.26		1550		"	2/11/92
41A*	6.31	20000			Isolated pool in riverbed (N)	2/11/92
42A	6.55	28500			Isolated pool in riverbed (S)	Conductivity probe suspended in water; 2/11/92
"	6.55	22200			"	Conductivity probe in mud on bottom of pool; 2/11/92
42B	6.55	17000			Semi-isolated pool connecting to river (S)	2/11/92
49A	11.80		900		Pool in unnamed tributary (S)	2/12/92
49B	11.80	1340			Isolated pool in riverbed (S)	Pool is along portion of tributary channel that crosses riverbed; 2/12/92
59A	23.53			395	Spring at base of canyon wall (N)	Spring is at or near contact of Trujillo sandstone with underlying Tecovas mudstone; flowing on 2/13/92
60B	24.09	15500			Pool connecting to river (S)	Pool receives flow from tributary (site 60C); 2/13/92
"	24.09	9800			"	"
60C*	24.09	6000			Pool in unnamed tributary (S)	Tributary flowing on 2/13/92 (see table 4)
"	24.09	7000			"	"
"	24.09	8000			"	"
"	24.09	10000			"	"
64	32.91		1000**		Rana Arroyo (S)	Tributary flowing on 2/13/92 (flow not measured)
66A	36.14			380**	Spring? (N)	Spring flowing on 2/13/92
74A	61.85		780		Trujillo Creek (S)	Tributary flowing on 2/14/92 (see table 4)

(continued on next page)

Table 2 (cont.)

Survey Site No. (1)	River Mileage (2)	Conductivity (3) Isolated Pools	Tributaries	Springs	Location (4)	Remarks
84A*	94.31	4700			Isolated pool in riverbed (S)	Conductivity probe suspended in water; water is murky greenish-brown; 2/16/92
"	94.31	4075			"	Conductivity probe in mud on bottom; 2/16/92
85*	95.34		650		Punta de Agua (N)	Tributary flowing on 2/16/92 (see table 4)
88B	102.99		1500		Alamosa Creek (S)	Isolated pool at mouth of creek; 2/16/92
92*	118.57	1000			Isolated pool flowing into river (S)	Flowing on 2/17/92; spring source?
93A	122.36		2350		Sierrita de la Cruz (S)	Not flowing; measured in river water backed-up into tributary channel; 2/17/92
93B	122.36		975		"	Isolated pool in dry portion of tributary, upstream from site 93A; 2/17/92
93C	122.36		325		"	Puddle on tributary floodplain, about 5 ft above tributary channel bottom; 2/17/92
96A*	127.92			12500	Pool below seep from canyon wall (N)	Seepage from strata just above Alibates dolomite; 2/17/92
96B	128.11		13000		Lahey Creek (N)	Tributary flowing on 2/17/92 (see table 4)
97	130.17		2300		Tecovas Creek (S)	Isolated pool at mouth of creek - creek water?; 2/17/92
98A	133.90		1280**		Horse Creek (S)	Isolated pool at mouth of creek; 2/17/92
99A*	138.05		2025		West Amarillo Creek (S)	Flowing? on 2/17/92; measurements in pool at mouth of creek; creek sometimes carries discharge from helium plant near Amarillo
100A	139.20		1700**		East Amarillo Creek (S)	Isolated pool at mouth of creek; 2/17/92
103	147.53		240**		Chicken Creek (S)	Tributary flowing on 2/18/92 (see table 4)

Notes:

(1) asterisk (*) denotes sites at which water samples were collected and analyzed; multiple entries for a single site indicate repeat measurements at that site;

(2) mileage from Ute Dam, increasing in downstream direction;

(3) conductivity in micromhos/cm at 25°F, measured by Bureau of Economic Geology (values marked by two asterisks (**) were measured by Lee Wilson & Associates);

(4) "(N)" and "(S)" denote features on the north and south sides of the river, respectively; "semi-isolated" refers to pools that are connected to the Canadian River but appear to have sufficient flow to prevent backflow of river water.

Table 3. Measured flow along Canadian River, Ute Reservoir, New Mexico, to Lake Meredith, Texas.

Survey Site No. (1)	River Mileage (2)	Flow (3)	Location	Remarks (4)
1	0.00	1.00	Toe drain outlet, Ute Dam	Estimated on 2/10/92
8*	0.37	2.35	River, below point where all sources join	Measured on 2/10/92
17*	1.90	3.84	River, at gauging station just upstream from Hwy. 54 brid	Measured on 2/10/92
23	3.08	4.03	River, deep riffle/pool section	Measured on 2/11/92
31*	4.41	4.69	River, flowing pool section	Measured on 2/11/92
41	6.31	12.88	River, just downstream from Revuelto Creek	Measured on 2/11/92
50	12.72	12.99	River	Measured on 2/12/92
57	21.44	12.08	River	Measured on 2/13/92**
"	21.44	9.36	River	Measured on 2/24/92**
58	22.24	10.32	River, at spring	Measured on 2/24/92
59B	23.34	11.71	River	Measured on 2/24/92
60A*	24.09	11.34	River	Measured on 2/24/92
61	25.23	11.98	River	Measured on 2/24/92
62	27.32	13.41	River	Measured on 2/24/92
63	29.53	13.72	River	Measured on 2/24/92
64	32.91	14.68	River, just downstream from Rana Canyon	Measured on 2/24/92
"	32.91	14.49	"	Measured on 2/25/92
65	34.18	13.90	River	Measured on 2/25/92
66	36.14	14.55	River, just upstream from spring in north wall	Measured on 2/25/92
"	36.14	14.69	River, just downstream from spring	Measured on 2/25/92
67	38.94	21.58	River	Measured on 2/13/92**
"	38.94	14.77	River	Measured on 2/25/92**
70	47.71	23.34	River	Measured on 2/14/92
73	59.16	23.08	River	Measured on 2/14/92
76*	68.44	24.72	River	Measured on 2/15/92
80	85.53	27.16	River, just downstream from Old Farm Crossing	Measured on 2/16/92
86	95.62	36.77	River, just downstream from Punta de Agua	Measured on 2/16/92
90	110.93	34.16	River	Measured on 2/17/92
101	140.53	34.04	River, beneath Hwy. 87-287 bridge	Measured on 2/18/92

Notes:

(1) asterisk (*) denotes tributaries from which water samples were collected and analyzed;

(2) downstream distance from Ute Dam, in miles;

(3) flow in cubic feet per second, measured by Canadian River Municipal Water Authority;

(4) main survey conducted 2/10 through 2/18/92; detailed flow survey between sites 57 and 67 by Canadian River Municipal Water Authority on 2/24 and 2/25/92 - difference in flow at sites measured during both surveys (**) reflects decreased inflow from Revuelto Creek (upstream), Rana Arroyo (enters ~0.25 mi upstream from site 64), and probably also decreased baseflow along section of detailed survey.

Table 4. Discharge of Canadian River tributaries, Ute Reservoir, New Mexico, to Lake Meredith, Texas.

Survey Site No. (1)	River Mileage (2)	Flow (3)	Location (4)	Remarks
40*	6.26	6.76	Revuelto Creek (S)	Measured on 2/11/92 (this inflow approximately doubled flow in river)
74A	61.85	0.04	Trujillo Creek (S)	Measured on 2/14/92
85*	95.34	6.37	Punta de Agua (N)	Measured on 2/16/92 (this inflow increased river flow approximately 20 percent)
96B	128.11	0.04	Lahey Creek (N)	Estimated on 2/17/92 (Lahey Creek conductivity 13,000 micromhos – see table 2)
99A*	138.05	0.08	West Amarillo Creek (S)	Measured on 2/17/92
103	147.53	0.90	Chicken Creek (S)	Measured on 2/18/92

Notes:

(1) asterisk (*) denotes tributaries from which water samples were collected and analyzed;
(2) distance of tributary mouth from Ute Dam, in miles;
(3) flow in cubic feet per second, measured by Canadian River Municipal Water Authority;
(4) "(N)" and "(S)" indicate whether tributary enters from north or south side of river.

Table 5. Salt loading in Canadian River, Ute Reservoir, New Mexico, to Lake Meredith, Texas.

Survey Site No. (1)	River Mileage (2)	Salt (chloride) Loading (3)	Location and Remarks
31*	4.41	11073	Flowing pool section of river; 2/11/92
40	6.26	466	Revuelto Creek; 2/11/92
41	6.31	31065	River, 200–300 ft downstream from confluence with Revuelto Creek; 2/11/92
50	12.72	30690	River; 2/12/92
57	21.44	28547	River; 2/13/92
67	38.94	44601	River, ~0.1 mi upstream from New Mexico-Texas state line; 2/13/92
70	47.71	43647	River; 2/14/92
80	85.53	40106	River; just downstream from Old Farm Crossing; 2/16/92
85*	95.34	125	Punta de Agua; 2/16/92
86	95.62	45242	River, immediately downstream from Punta de Agua (flowing–see table 4); 2/16/92
90	110.93	33627	River; 2/17/92
101	140.53	36007	River, under Hwy. 87-287 bridge; 2/18/92
102	146.32	2410	River, in vicinity of Bonita Creek; 2/18/92
103	147.53	18	Chicken Creek; 2/18/92

Notes:

(1) asterisk (*) denotes sites from which water samples were collected and analyzed

(2) mileage from Ute Dam, increasing in downstream direction

(3) salt loading, expressed in tons-chloride/yr, calculated from chloride concentration and flow data by Canadian River Water Authority; salt loading is a measure of the total quantity of salt (or chloride component, as in this case) in solution that is carried past any particular cross section over a period time.

Table 6. Results of chemical analyses of water samples collected during the February 1992 conductivity survey of the Canadian River between Ute Reservoir, New Mexico, and Lake Meredith, Texas.

Survey Site No. (1)	State	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	SO4 (mg/L)	Cl (mg/L)	Br (mg/L)	Quantab Cl (ppm) (2)	HCO3 (mg/L) (3)
0	NM	43.4	34.8	131	6.47	281	49.4	0.10	45	216
7	NM	123	58.4	1840	7.66	555	2370	0.42	2678	457
8	NM	67.1	41.7	625	5.13	349	717	0.44	670	353
11	NM	99.9	54.3	1310	6.89	439	1750	0.32	1958	387
13	NM	96.9	52.4	1250	7.16	436	1630	0.43	2138	375
17	NM	103	56.2	1420	7.70	451	1890	0.38	2138	389
27	NM	609	169	14140	37.6	2010	21010	0.48	>6000	775
31	NM	153	72.3	2434	10.4	615	3415	0.20	4150	485
34	NM	782	200	16950	43.3	2520	24350	0.46	>6000	997
40	NM	76.8	66.5	407	3.44	757	153	0.49	570	355
41a	NM	303	111	3920	15.3	1120	5650	0.38	>6000	803
57*	NM								2680	388
60	NM	279	113	5050	16.1	790	7870	0.10	n.a.	642
67*	NM								2500	360
70*	TX								n.a.	346
73*	TX								n.a.	332
76	TX	121	69.5	1110	7.17	538	1560	0.27	2000	377
80*	TX								1500	277
82	TX	36.7	59	757	6.34	482	919	0.34	1040	251
84a	TX	208	112	1370	11.5	1090	1060	0.70	1145	1419
84b	TX	110	63.3	918	6.83	563	1200	0.23	1250	316
85	TX	53.7	48.6	78.4	6.50	66.4	32.8	0.10	<45	469
89*	TX								1200	335
92	TX	47	21.2	247	1.81	78.3	217	0.10	<300	415
95*	TX								935	313
96a	TX	719	172	3390	6.47	2160	4910	0.10	5500	191
98	TX	118	63.1	764	6.49	652	1000	0.27	1250	280
99*	TX								436	291

Notes:

(1) asterisk (*) indicates sample analysis in progress at time of report

(2) chloride value measured in field using Quantab chloride titrator strips no. 1175 (45–600 ppm) and no. 1176 (300–6000 ppm)

(3) alkalinity measured in field by acid titration