GEOLOGY, FLOW, AND WATER QUALITY ALONG THE CANADIAN RIVER, UTE RESERVOIR, NEW MEXICO TO LAKE MEREDITH, TEXAS: SUBSURFACE GEOLOGY OF UTE RESERVOIR AREA, RESULTS OF FEBRUARY 1992 RIVER SURVEY, AND CHEMICAL ANALYSES OF WATER SAMPLES

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Draft Contract Report
Prepared for
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INTRODUCTION

In February 1992, the Bureau of Economic Geology (BEG) joined with representatives of the Canadian River Municipal Water Authority (CRMWA) and Lee Wilson & Associates (LWA) in a survey of water quality along the Canadian River between Ute Reservoir, New Mexico and Lake Meredith, Texas (Fig. 1). This report begins with a brief description of the stratigraphy of Permian salt-bearing strata in the vicinity of Logan, New Mexico, then follows with a summary of conductivity and flow patterns observed during the survey, and closes with a discussion of chemical analyses of waters sampled from the Canadian River, its tributaries, and adjacent pools and seeps.

STRATIGRAPHY OF PERMIAN SALT-BEARING STRATA

Introduction

Dissolution of bedded halite and gypsum from Permian strata is recognized in the Canadian River Valley in central Quay County, New Mexico. Approximately 340 ft (104 m) of halite was dissolved from the lower San Andres Formation and from the top of the Glorieta Formation to depths of 1,100 ft (335 m) beneath the Canadian River (Fig. 2). An additional 355 ft (108 m) of halite has been dissolved from the lower San Andres unit 5 and upper San Andres Formation from higher elevations 10 miles (16 km) south of the Canadian River. Shallow subsurface gypsum dissolution localized in the Canadian River Valley probably removed gypsum beds from the Seven Rivers Formation (member of Artesia Group). Additional dissolution of calcium sulfate probably occurred throughout the dissolution zone during the 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, Hydro Geo Chem, Inc, 1985; McGookey and others, 1988). More detailed cross sections (Figs. 2 and 3; Plates) were constructed through the area of Ute Reservoir and Revuelto Creek to constrain the depths and pathways of groundwater circulation.

These cross sections identify areas where large amounts of halite are present and where halite may be subject to modern salt dissolution. 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. Department of the Interior, Bureau of Reclamation, 1979, 1984). All available logs from the study area were examined but only gamma-ray curves are shown on the cross sections. Criteria for recognition of halite include (1) increasing bore hole 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 halite and siliciclastic mudstones and siltstones. Criteria for identification of halite dissolution are decreased thickness of halite-bearing units where thickness of other lithologies does not change, dip reversal or diminished regional structural dip over areas of missing or thin halite, and variable sonic velocity and cycle-skipping (H. S. Nance, personal communication).

Geologic Setting

The Canadian River flows west to east between the subsurface structural elements of the Tucumcari Basin and Bravo Dome (Foster and others, 1972; Budnik, 1989; Ewing, 1990). Permian units crop out only locally in the Canadian 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 in the Palo Duro Basin of the Texas Panhandle and their log facies identified in stratigraphic cross sections (Handford, 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. 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. Updip siliciclastic-halite units of the Artesia Group (Queen-Grayburg Formation, Seven Rivers Formation) contain thin, regionally traceable anhydrite beds. The top of the Permian section is characterized by depositional pinch out of evaporites into siliciclastic rocks in 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) (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).

Stratigraphy

The following variations in halite distribution were determined from logs and constrain areas where halite dissolution has occurred. Halite is absent from the Red Cave Formation, Lower Clear Fork Group, and Tubb Formation beneath the study area, probably because of depositional facies change to siliciclastic-dominated sedimentation in areas proximal to ancestral Rocky Mountains source areas. Halite units in the upper Clear Fork Group are laterally continuous through the study area. Loss of the uppermost halite beds of the Glorieta Formation, presumably because of dissolution, is observed beneath the Canadian River.

In the San Andres Formation, the thick bedded halite units recognized in the Tucumcari Basin are progressively lost to the north and completely removed beneath the Canadian River Valley (Figs. 2 and 3). 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 feet (174 m) at the Quay 14 well, 21 miles (34 km) south of the Canadian River, to 215 feet (65 m) at the Quay 13 well, 6 miles (10 km) south of the Canadian River. 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 feet (165 m) at Quay 13 to 200 feet (61 m) beneath the Canadian River. The thickness decrease of almost 700 feet (213 m) is interpreted to be entirely the result of halite dissolution. Individual San Andres carbonate and anhydrite units can be correlated to the north with only very gradual loss of thickness because of thinning and pinch out of individual cycles. The interpretation that dissolution of halite has resulted in subsidence of the overlying strata is supported by a sharp 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 of halite dissolution and may serve as zones of enhanced flow and conduits for transmission of fresh waters into preserved halite in the subsurface. 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).

Dominantly siliciclastic units, left after halite has been dissolved from the Queen-Grayburg and Seven Rivers Formations, thin by 25 % from 240 feet (73 m) to 180 feet (55 m) over the Bravo Dome. This thinning suggests significant changes in depositional environments attributed to decreased subsidence rates over a structurally positive element. Removal of minor amounts (less than 15 feet [5 m]) of upper San Andres halite beneath Queen Grayburg sandstones was recognized in central Quay County 30 miles (48 km) south of the Canadian River (H. S. Nance, unpublished cross section). This intrastratal halite dissolution also illustrates the hydrologic importance of highly permeable units within the evaporite section to the halite dissolution process. In the southern part of the study area, halite occurs within the Artesia group as halite-siliciclastic mixtures and interbeds. At the Quay 14 well, the thickness and gamma-ray character of the Artesia Group is preserved but the sonic log response suggests that the unit may be highly fractured. Partial or incipient halite dissolution is interpreted for this area.

Regional correlation indicates that only the upper part of the Artesia Group was penetrated by cores drilled for the Bureau of Reclamation downstream from Ute Dam. No gypsum beds were noted on core logs, even though units characterized by low gamma-ray response and interpreted as gypsum/anhydrite beds within the Seven Rivers Formation can be traced throughout the study area. The absence of gypsum beds in the cores may indicate gypsum dissolution in near surface environments in the Canadian River Valley. Intense gypsum dissolution was documented in very shallow subsurface environments in the San Andres Formation in the eastern Texas Panhandle (Hovorka and Granger, 1988). Additional calcium sulfate dissolution occurs when anhydrite comes in contact with low salinity water and hydrates to gypsum. In the subsurface, this hydration generally occurs without significant volume increase. Gypsum is less dense than anhydrite, therefor a volume-for-volume replacement of anhydrite by gypsum requires removal of some calcium sulfate. Both partial dissolution during hydration of anhydrite and complete dissolution of gypsum beds probably contribute to the solute load of the Canadian River.

Conclusions

The main contributor to solute loads of the Canadian River in the past was the Permian San Andres Formation as evidenced by the dissolution of nearly 700 feet (213 m) of halite. Halite preserved in the Artesia Group 20 miles (32 km) south of the Canadian River also contributed a significant amount of NaCl. If the pattern of modern halite dissolution continues along the same trends and by the same processes as past halite dissolution, then the present focus of dissolution is in the subsurface 1,100 feet (335 m) beneath Canadian and 10 miles (16 km) south of the Canadian River at depths of 1,000 feet (305 m) below land surface (Fig. 2).

PATTERNS OF CONDUCTIVITY AND FLOW ALONG THE CANADIAN RIVER

Introduction

The conductivity and sampling survey required 9 field days, from February 10 through 18, 1992, and covered a distance of about 150 miles (survey terminated at Chicken Creek, about 4 miles upstream from Lake Meredith). BEG personnel measured conductivity, temperature, Cl^- 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 non-flowing tributaries (Figs. 4 and 5; Tables 1 and 2). CRMWA and LWA personnel measured conductivity, temperature, Cl^- and SO_4^{2-} concentrations, and pH, and also measured flows in the river and in flowing tributaries (Tables 3 and 4). CRMWA 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; Fig. 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 nor 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 miles 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 miles of the river was about 1 mile (sites 43 through 61, spacing 0.4 to 1.5 mi); and (3) average spacing along the remaining length was about 3 miles (sites 61 through 103, spacing 0.2 to 5.7 mi) (see Figs. 4 and 5; Tables 1, 2, 3, and 4).

Salinity was measured in the field by two methods: (a) with a conductivity meter and (b) with chloride-indicator strips (for $Cl<6{,}000$ ppm). Indicator strips proved to be fairly accurate, giving only slightly higher readings than laboratory measurements (Fig. 6). Conductivity readings were less reliable. The line of best fit for all chloride and conductivity data has an intercept on the conductivity axis of 1,494 micromhos/cm (Fig. 7a), indicating that conductivity readings of less than that value would theoretically result in negative chloride concentrations. This lack of correlation between conductivity and chloride is caused by the fact that at low chloride concentrations, ions other than chloride are the major contributors to conductivity. The higher the chloride content, the more dominant chloride becomes, resulting in a better correlation between conductivity and chloride. The correlation between conductivity and chloride improves somewhat upon elimination of apparently abnormal data and restriction to conductivity values of less than 10,000 micromhos/cm (typical for river water) (Fig. 7b). Table 5 lists calculated chloride concentrations at all 103 measurement points of conductivity along the river, using both regression equations presented in Fig. 7. The difference between the two methods of calculation is small at low chloride contents but increases as chloride concentration increases (Fig. 8).

Conductivity Survey

The highest conductivities recorded during the survey were of waters along the first 7 miles of the Canadian River below Ute Reservoir. "Baseline" conductivity of river water increased steadily along the first 6 miles below Ute Reservoir, from less than 1000 to more than 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 six miles downstream from Ute Reservoir indicates that water in the riverbed alluvium aquifer is of high-conductivity. Indeed, measured conductivities along the first 1.5 miles 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 indicated by the occurrence of high-conductivity waters in isolated pools in the riverbed between 3.5 miles (site 26) and 6.5 miles (site 42) (Fig. 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 (<2000 micromhos/cm). The overall trend of increasing river conductivity, however, continues to approximately mile 9.5 (site 46) (Fig. 4).

Conductivity in the Canadian River remained fairly constant between 10 and 20 miles downstream from Ute Reservoir (sites 46 through 56; Fig. 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 of salinity.

River flow increased dramatically (nearly doubling, from ~12 cfs to more than 21 cfs) between about 20 and 40 miles downstream from Ute Reservoir (sites 57 through 67) (Fig. 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 ? 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 which 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 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) (Fig. 5; Table 2).

Between about 40 and 48 miles 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 miles (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. It is interesting to note that one reference (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 miles (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 (~3000 micromhos/cm). Notable features along this stretch included:

a. one isolated, saline pool in the riverbed just upstream from Punta de Agua (with an apparent corresponding increase in river conductivity);
b. 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;
c. modest conductivities (up to 2350 micromhos) in pools in Alamosa Creek and Sierrita de la Cruz;
d. very high conductivities (up to 13,000 micromhos) in Lahey Creek and in a seep immediately upstream from the creek. Although conductivities at these locations were very high, flow was very low, so that there was little net effect on river conductivity. Nevertheless, these high conductivities suggest that this is another potential salinity source area;
e. modest conductivities (up to 2300 micromhos) in pools in Tecovas Creek, Horse Creek, West Amarillo Creek, and East Amarillo Creek.

Possible Geologic Controls on Hydrology

Bedrock strata exposed along the first 23 miles of the Canadian River downstream from Ute Reservoir are resistant sandstones of the Trujillo Fm. (middle member of the late Triassic Dockum Group) (Fig. 5). It is suspected that saline water flowing from Permian strata rises through fine-grained mudstones in the Tecovas Fm. (lower member of the Dockum Group, probably along fractures, then enters the more permeable Trujillo sandstones; from there the saline water probably 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 where the river canyon cuts through the Trujillo sandstones to expose the underlying Tecovas mudstones (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 channel may be 50 ft or more below the surface of the riverbed alluvium. This is also approximately the point of the last occurrence of high-conductivity waters (up to 15,500 micromhos/cm) (Fig. 5; Table 2), with the exception of the Lahey Creek area about 100 miles further downstream, in Texas.

The only notable source of high-conductivity waters along the Texas portion 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 which exposes Permian bedrock.

Summary

Measurements of conductivity and flow of the Canadian River, its tributaries, and isolated pools in the riverbed suggest two areas where saline waters enter the river: (1) along the first 9 or 10 miles downstream from Ute Reservoir (Fig. 4); and (2) between 20 and 40 miles downstream from Ute Reservoir (between sites 57 through 67) (Fig. 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); 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, 2, 3, and 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 (expressed in terms of chloride load) occurs within the first 40 miles (Table 6), reaching a "plateau" at about 45,000 tons-chloride/yr. Beyond that point (site 67, near Texas-New Mexico state line), the chloride load trend remains approximately constant to about 96 miles 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, HCO3 [field determination], SO4, and Cl) and for Br (Table 7).

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. 9). 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. 10 and 11). 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. 12). 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 that is distinctively different from that in overlying Triassic aquifer units (Fig. 13a and 13b). Revuelto Creek, the only significant tributary along the 10-mile stretch downstream from Ute Reservoir (where saline inflows are significant), appears to be influenced by discharge from both Permian and Triassic units (Fig. 13c). At times, Revuelto Creek carries water of low salinity with Na/Cl ratios that follow a trend typical for Triassic well waters in the area (Figs. 13b and 13c). At other times, the creek carries water of much higher salinities with Na/Cl ratios that approach 1, which is typical for halite-dissolution waters encountered within Permian units in the area (Figs. 13a and 13c), 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 7) contains relatively high concentrations of Ca, Mg, and SO4, relative to other samples with similar Na and Cl concentrations (Figs. 10 and 11). This sample and others collected along the Texas portion of the Canadian River show trends in bivariate plots of Ca versus Cl and of SO4 versus Cl that are distinctly different than those for samples collected along the New Mexico portion (Figs. 14a and 14b). This difference is not the result of different CaSO4 concentrations, as indicated by the overlap of data points for the two areas in a Ca-versus-SO4 plot (Fig. 14c). 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. 15 and 16). Within the group of New Mexico samples, Na makes up 80-95% of all cations and Cl makes up 75-90% of all anions (Fig. 15), whereas in the group of Texas samples respective ranges amount to only 70-85% and 60-75% (Fig. 16). Thus, 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 water (before entering 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 very 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. 17). It is interesting to note that previous data also show the apparent difference in Ca-Cl and SO4-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. 18), 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.

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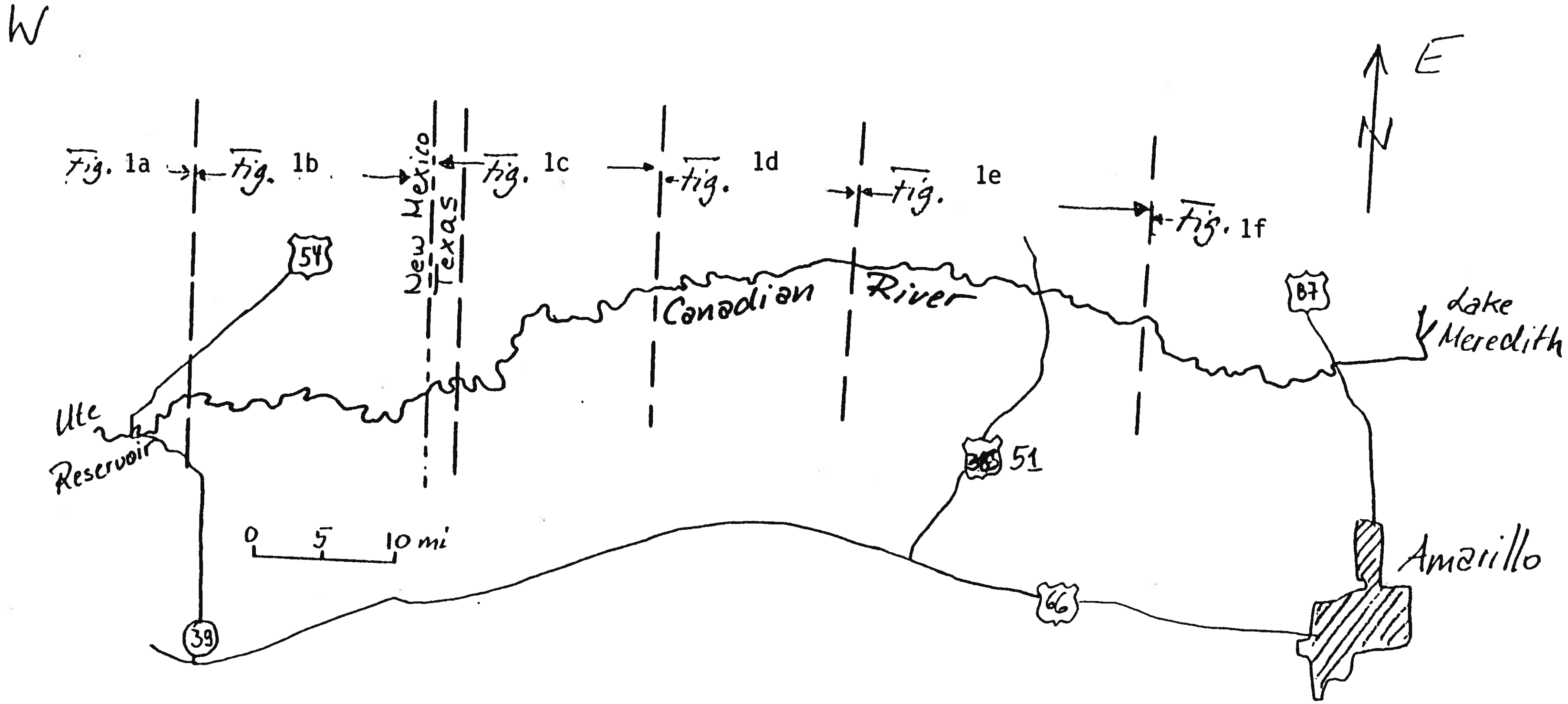


Fig. 1 Locations of measurement stations along the Canadian River between Ute Reservoir, New Mexico, and Lake Meredith, Texas, conductivity survey February '92.

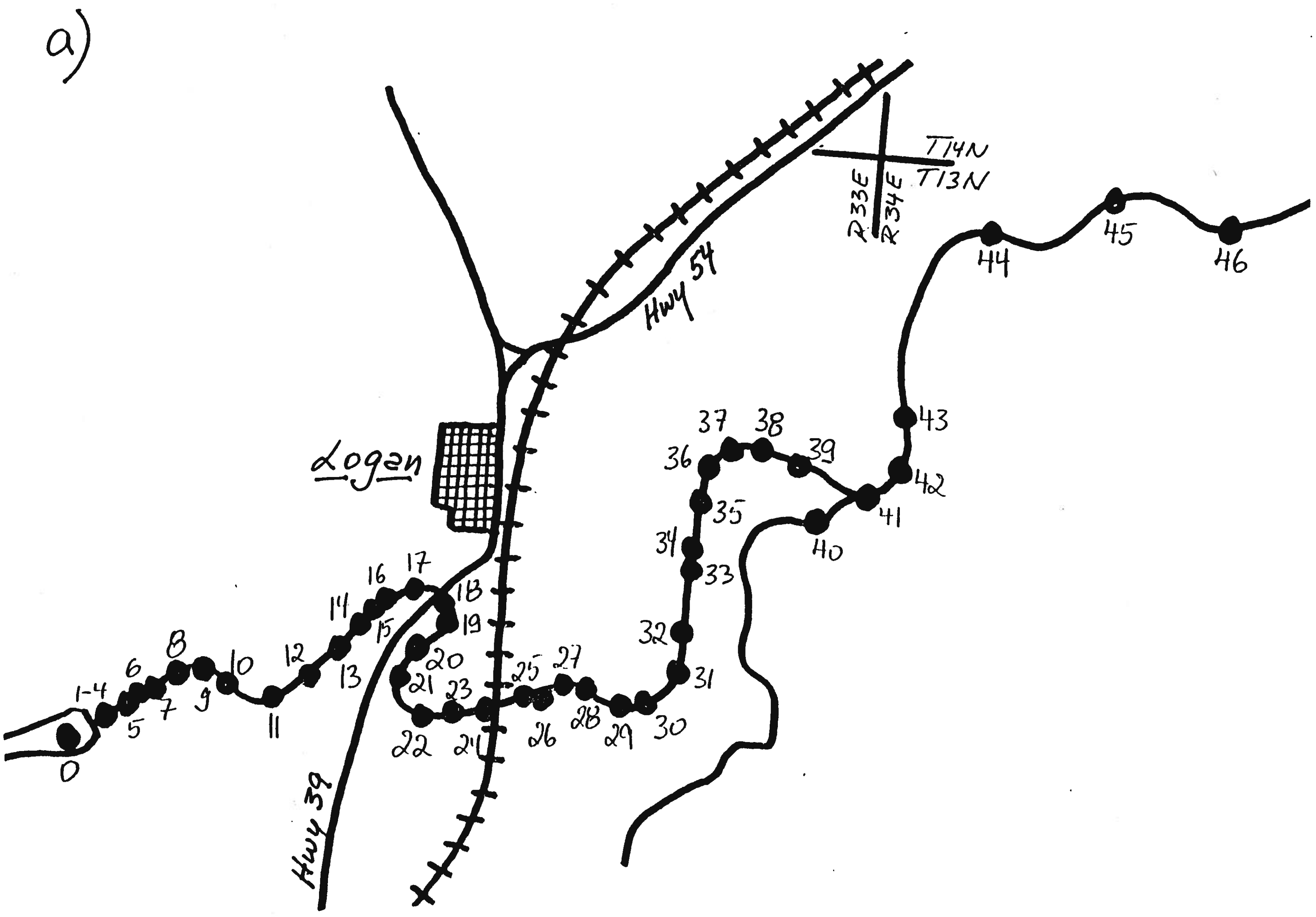


Fig. 1 continued

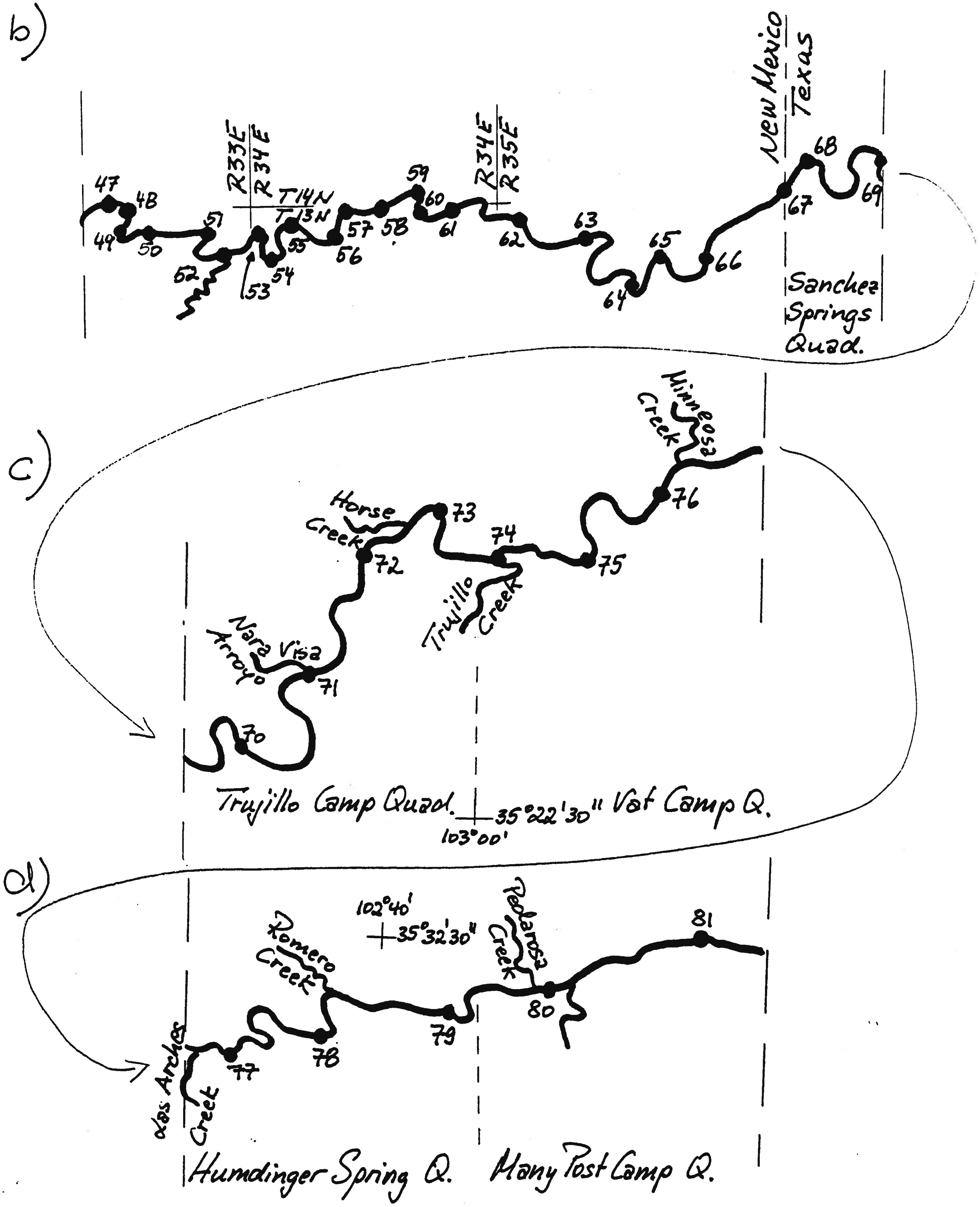


Fig. 1 continued

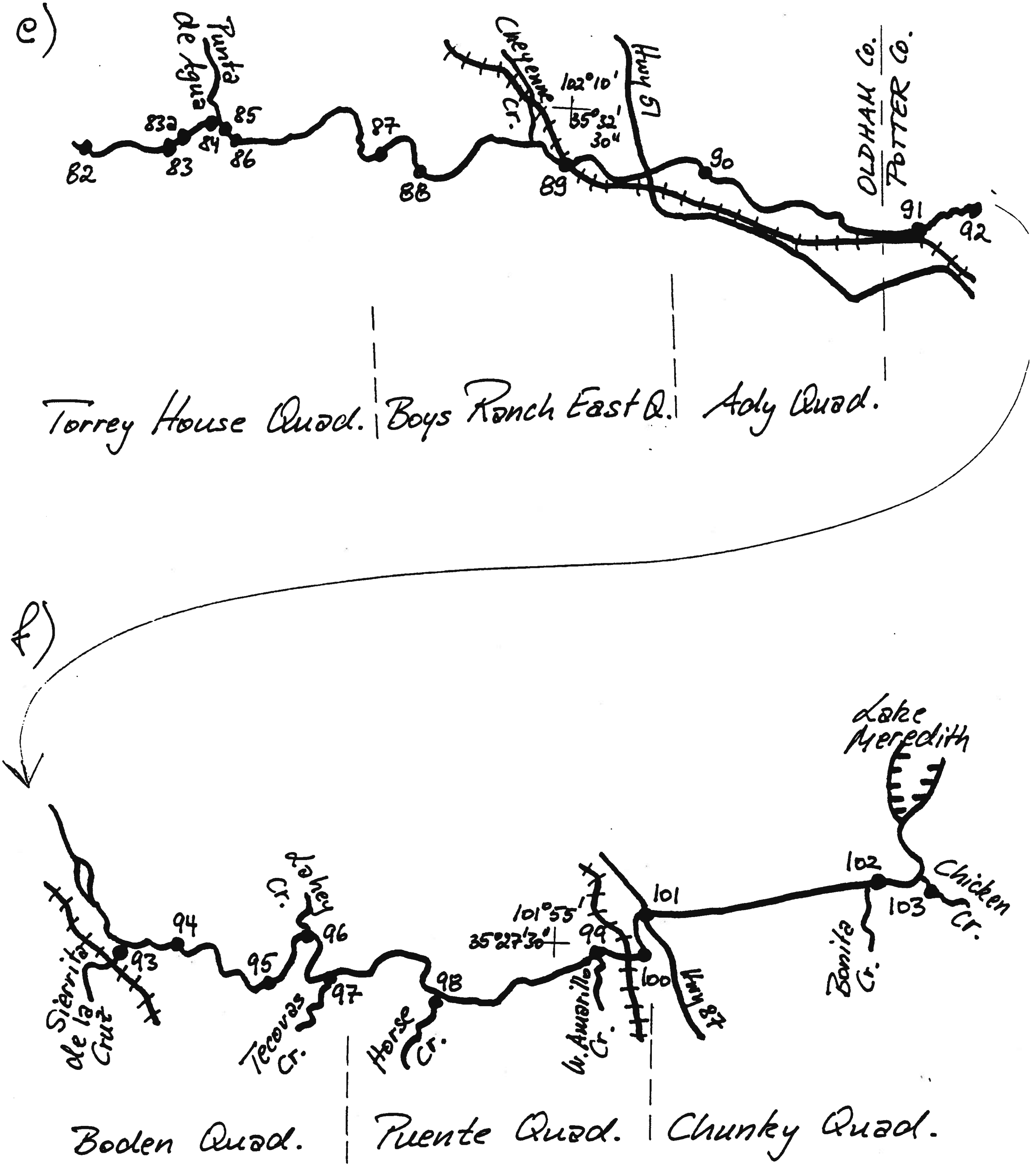


Fig. 1 continued

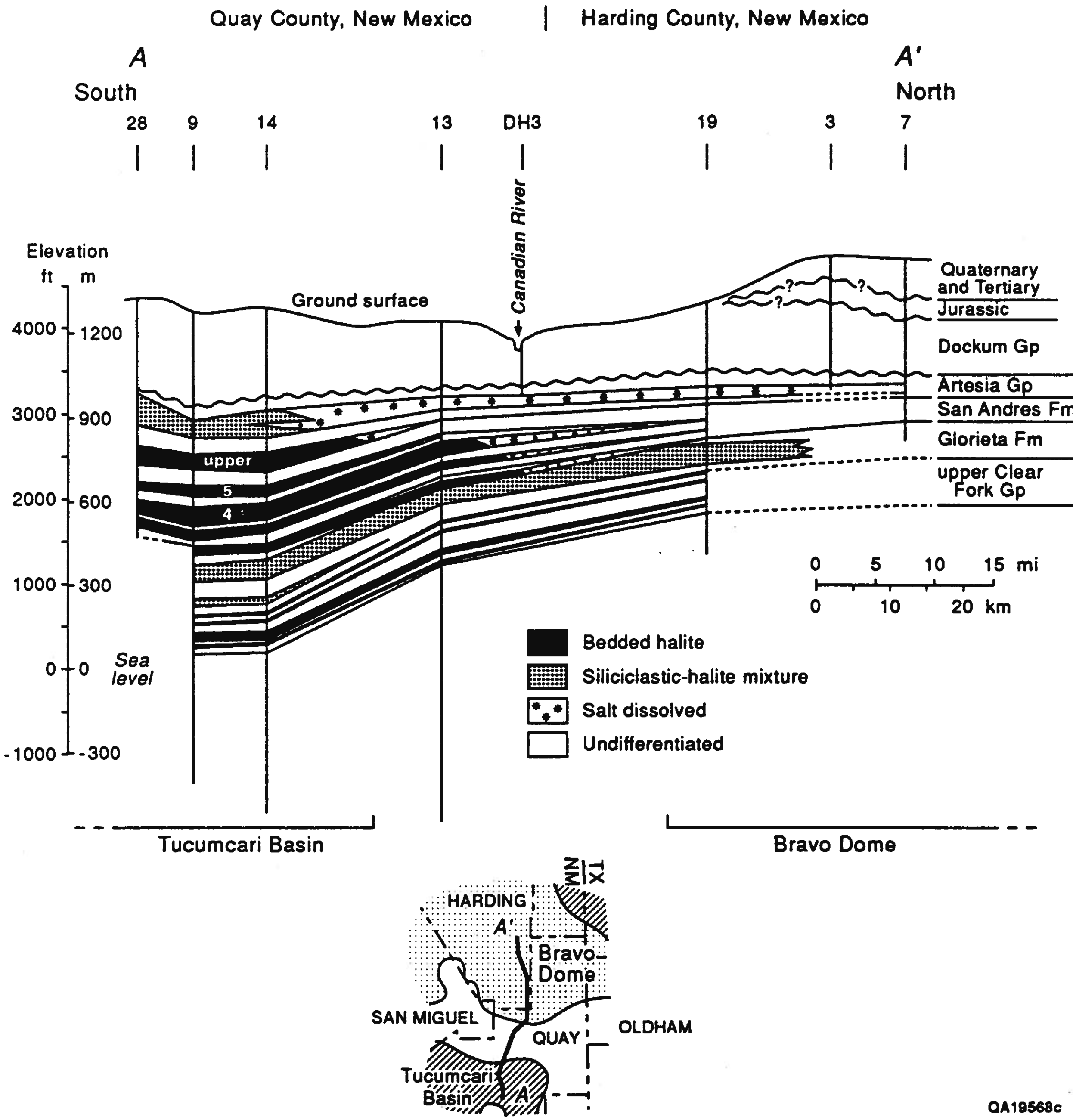


Figure 2. North-South structural cross section through the Ute Dam area.

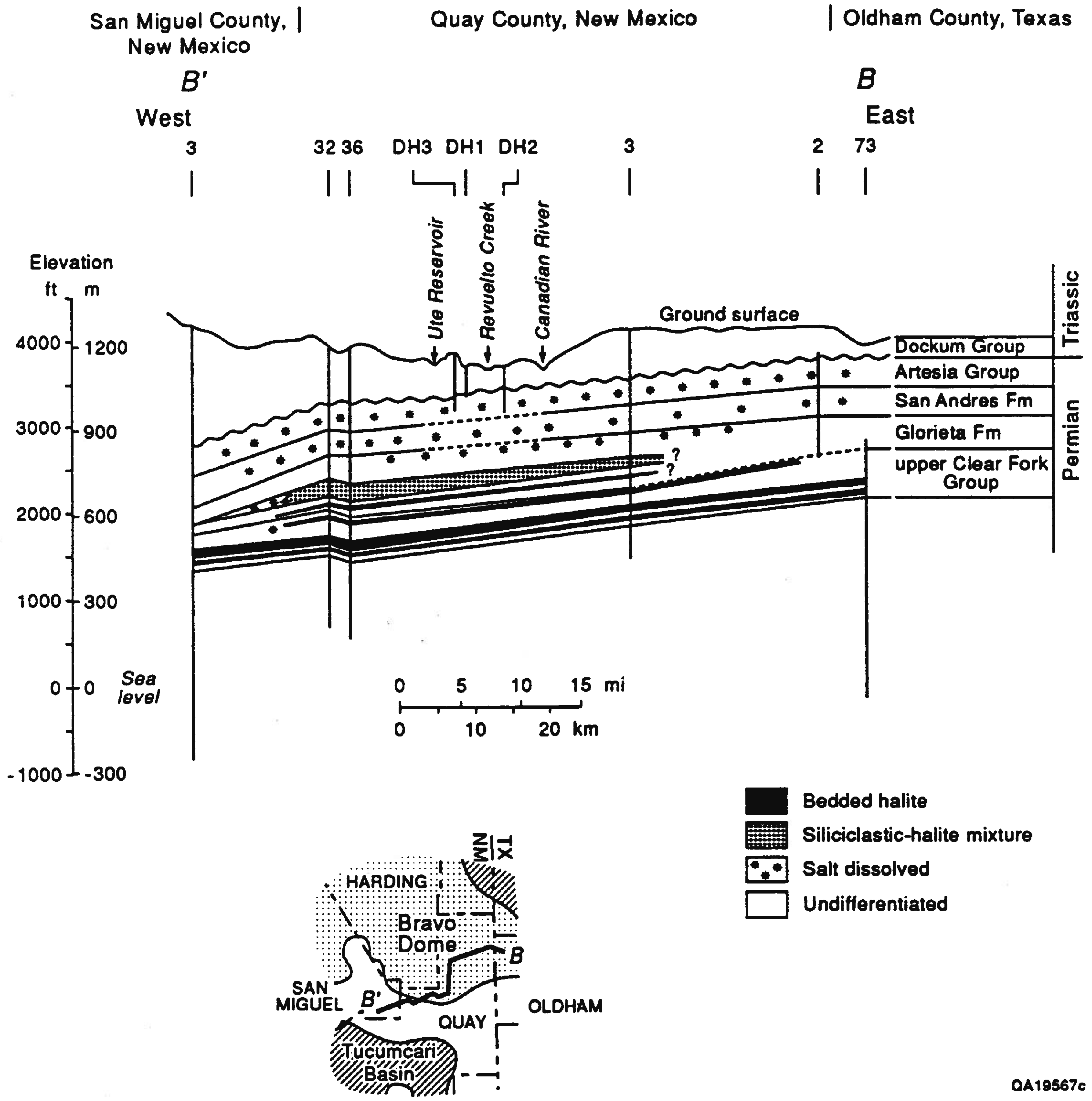


Figure 3. East-West structural cross section through the Ute Dam area.

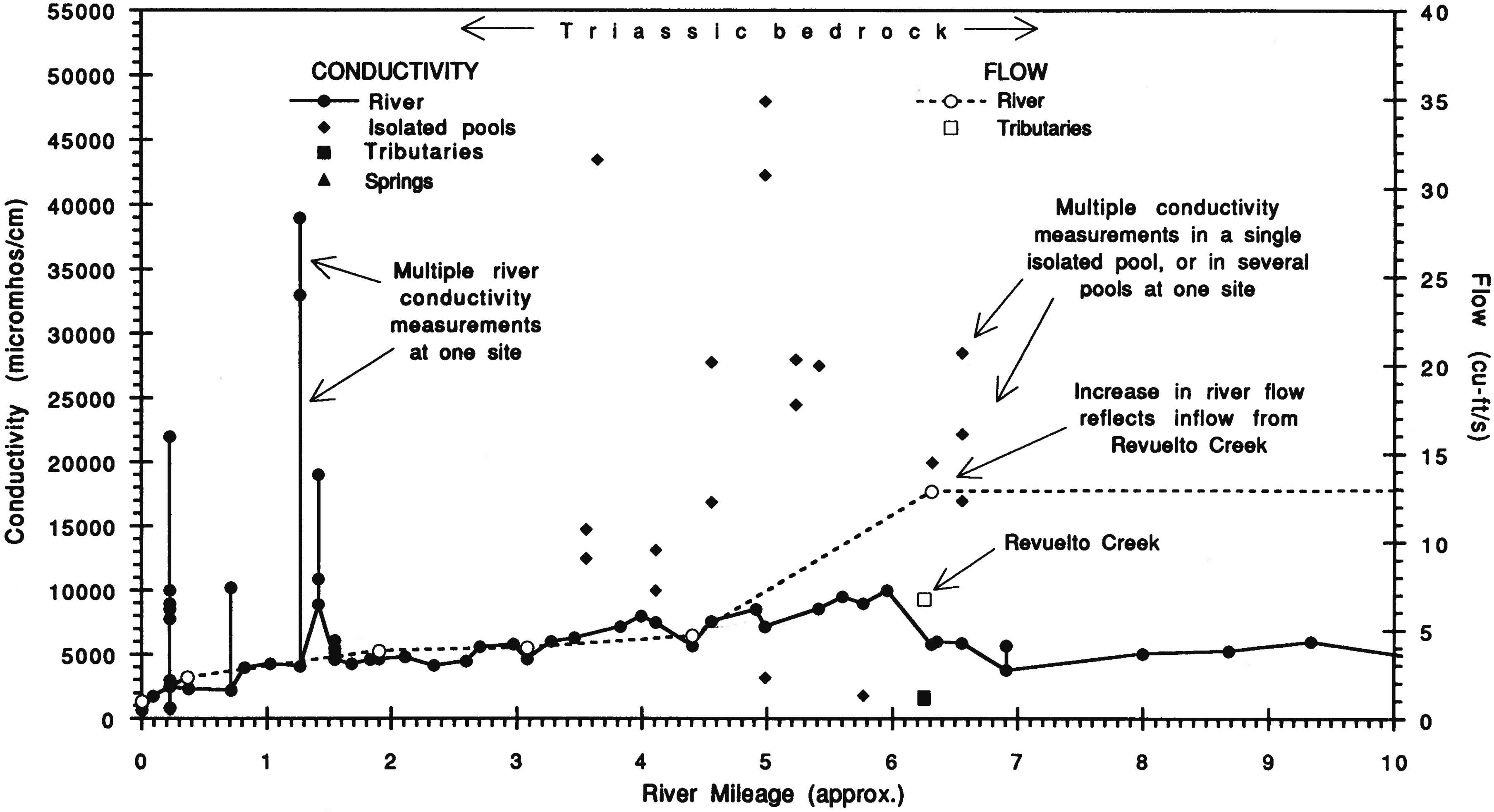


Figure 4. Plot of conductivity (scale on left) and flow (scale on right) along first 10 miles of Canadian River below Ute Reservoir, New Mexico; measurements taken in field on 2/10, 2/11, and 2/12/92 (see tables 1,2, 3, and 4 for data). The exposed bedrock along this stretch of the river canyon consists almost entirely of fluvial channel sandstones of the Triassic Trujillo Formation.

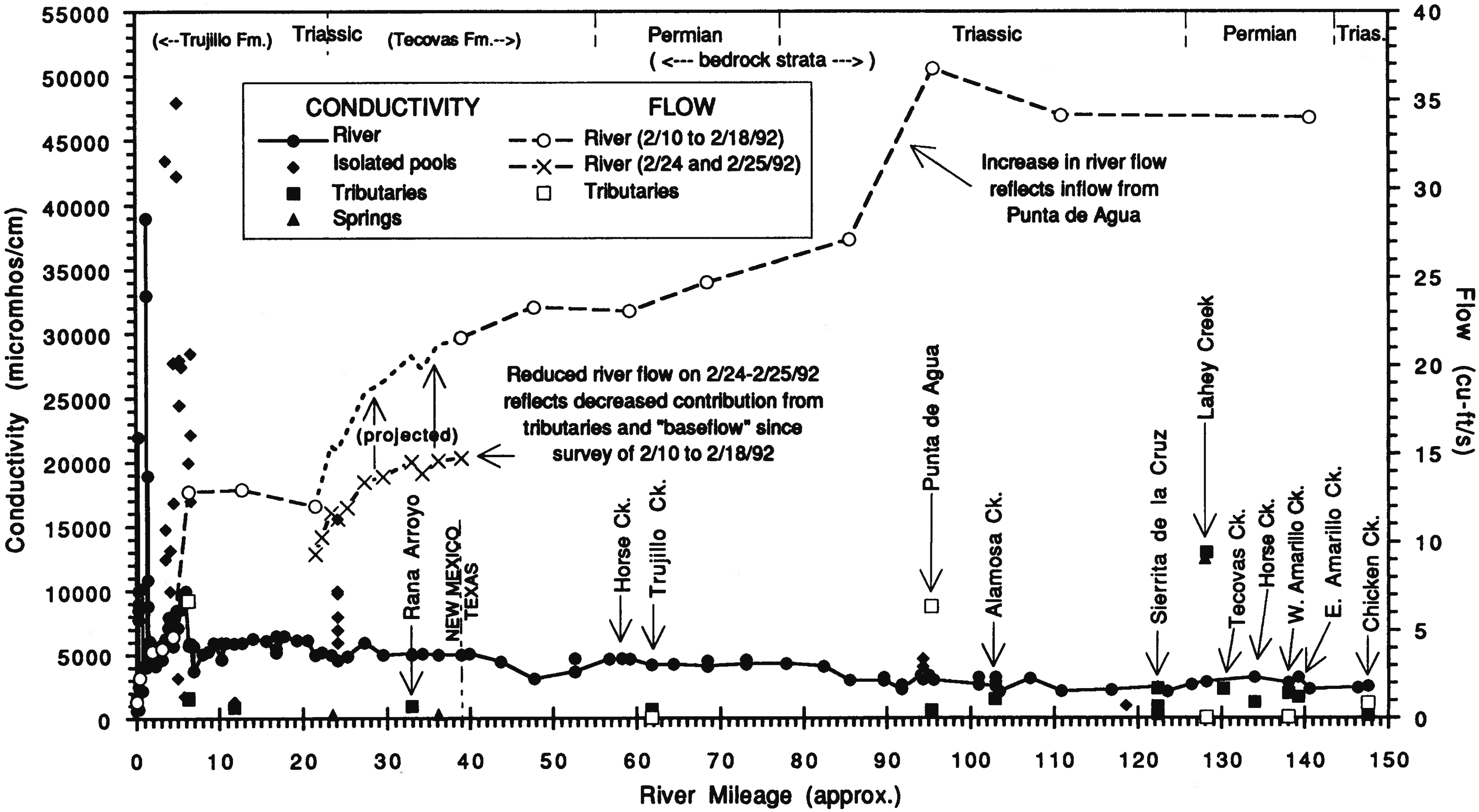


Figure 5. Plot of conductivity (scale on left) and flow (scale on right) along entire length of Canadian River survey, between Ute Reservoir, New Mexico and Lake Meredith, Texas; measurements taken in field 2/10 through 2/18/92 (main survey), and 2/24 and 2/25/92 (detailed survey between sites 57 and 67, inclusive) (see tables 1,2, 3, and 4 for data). The exposed bedrock along the various stretches of the river is indicated at the top of the plot.

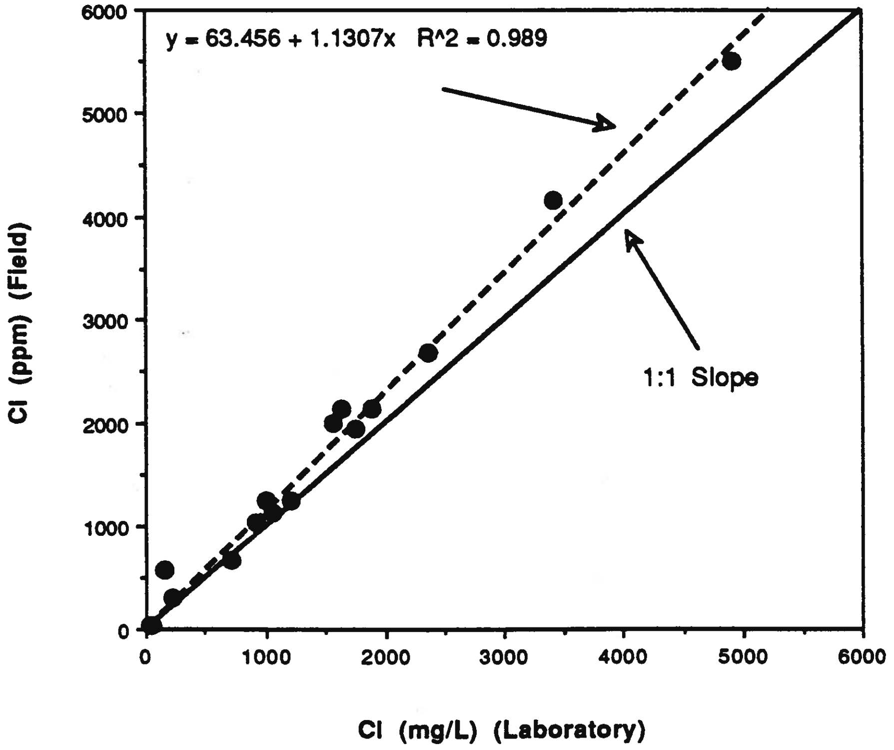


Fig. 6: Comparison between chloride content determined in the field and chloride content determined in the laboratory for February '92 river-survey samples.

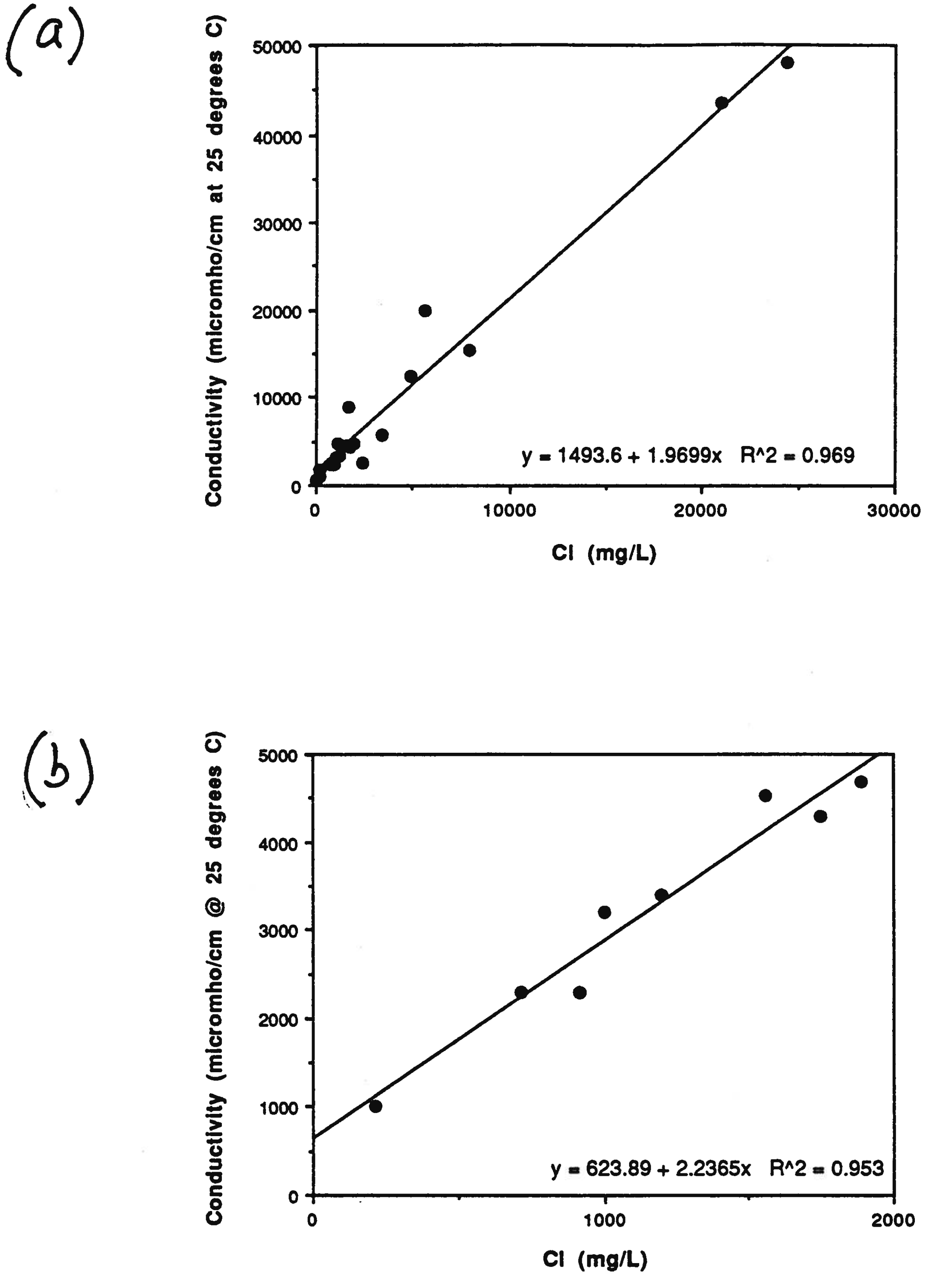


Fig. 7: Relationship between conductivity measurements in the field and chloride concentrations determined in the laboratory for (a) all river-survey data and (b) selected representative samples from the river survey.

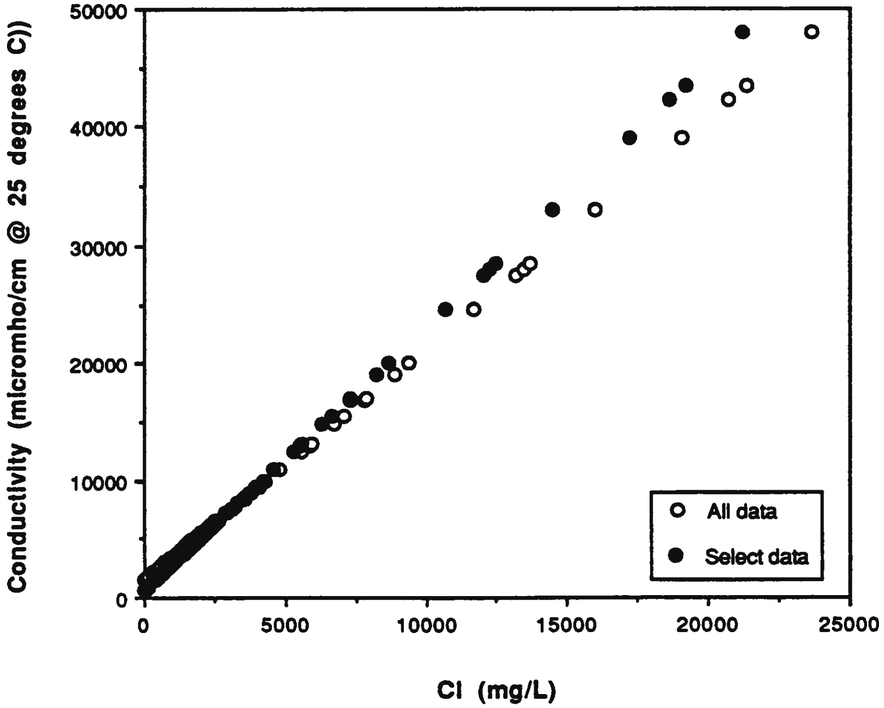


Fig. 8: Chloride concentrations calculated from conductivity measurements in the field for all 103 stations using best-fit-of-data equations as shown on Fig. 7, (see Table 5 for data and Fig. 1 for locations).

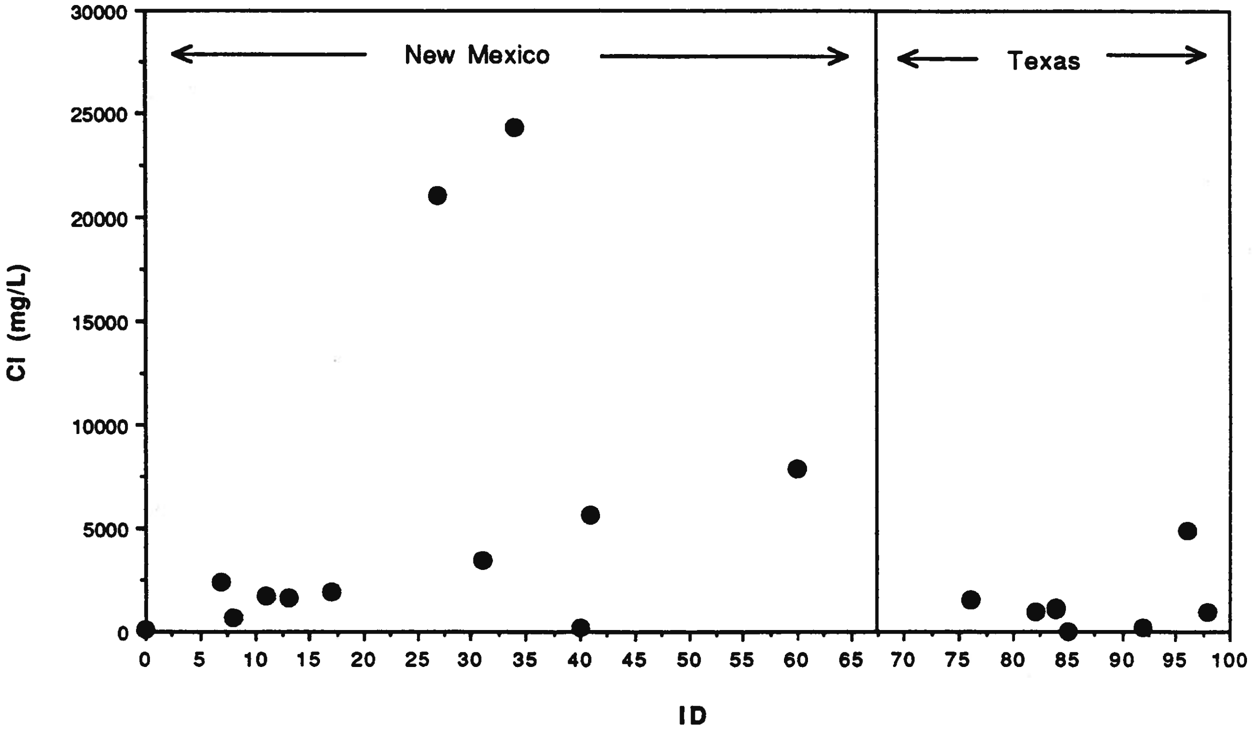


Fig. 9: Chloride concentration in river-survey samples collected between Ute Reservoir, New Mexico, and Lake Meredith, Texas, February, 1992.

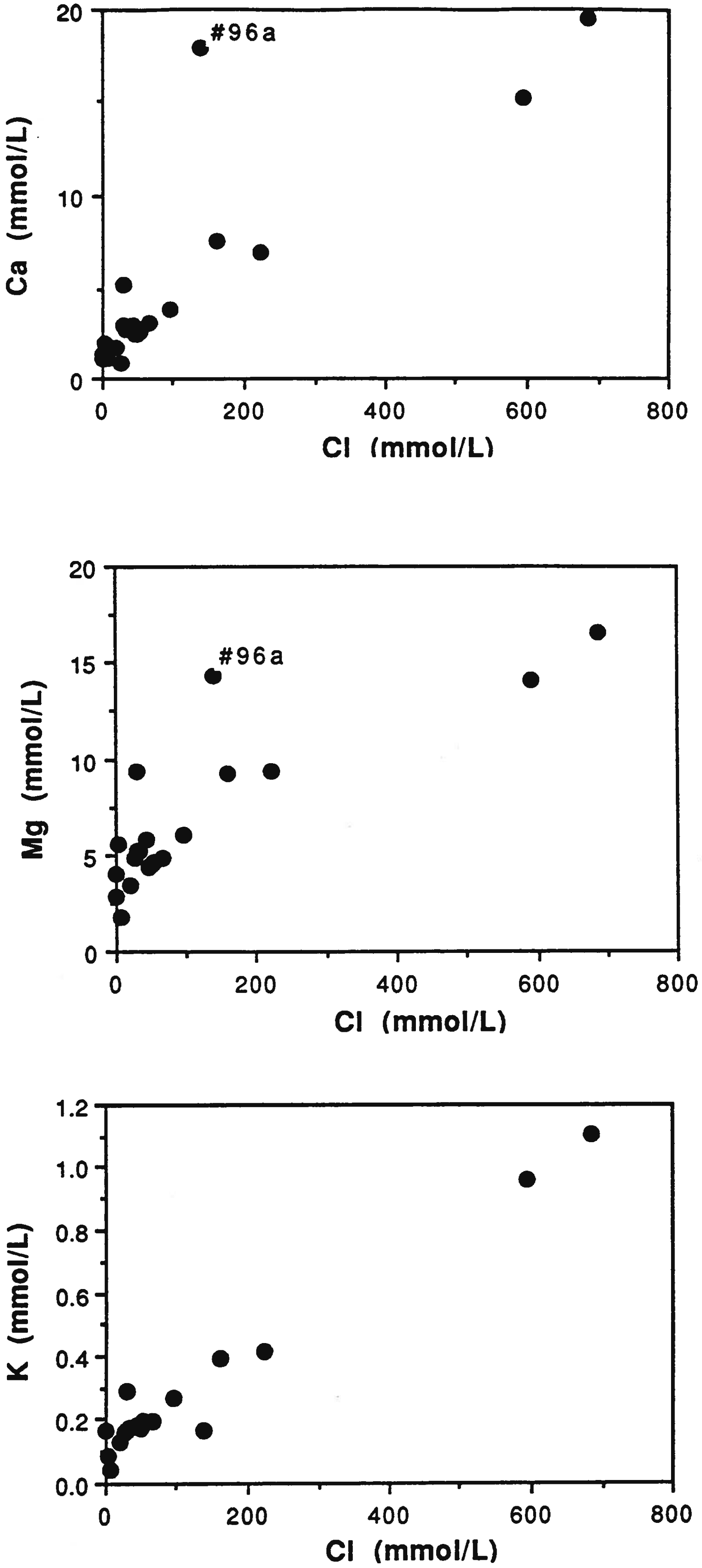


Fig. 10: Bivariate plots of Ca, Mg, and K versus Cl for river-survey samples, suggesting mixing between low-Cl and high-Cl waters.

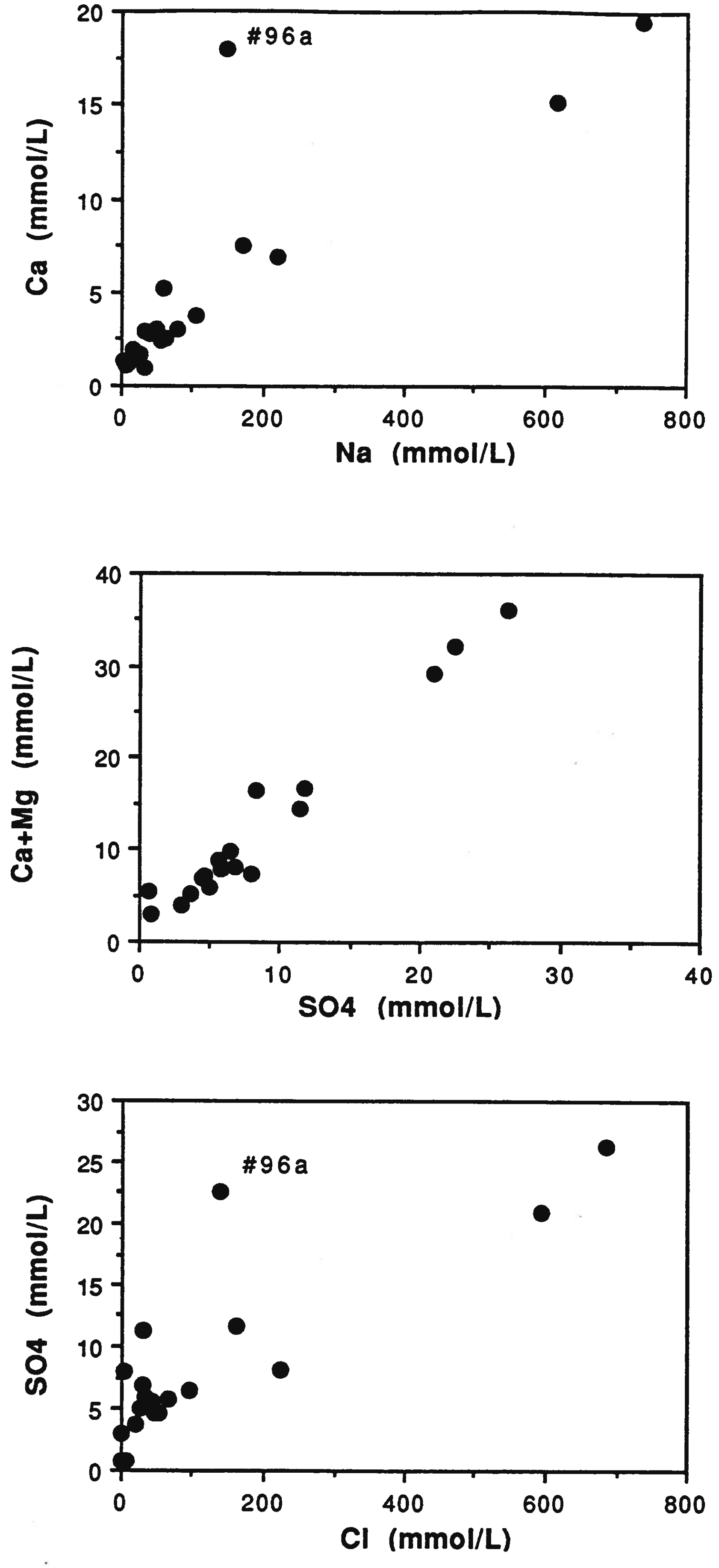


Fig. 11: Bivariate plots of major cations and anions for river-survey samples, suggesting mixing trends.

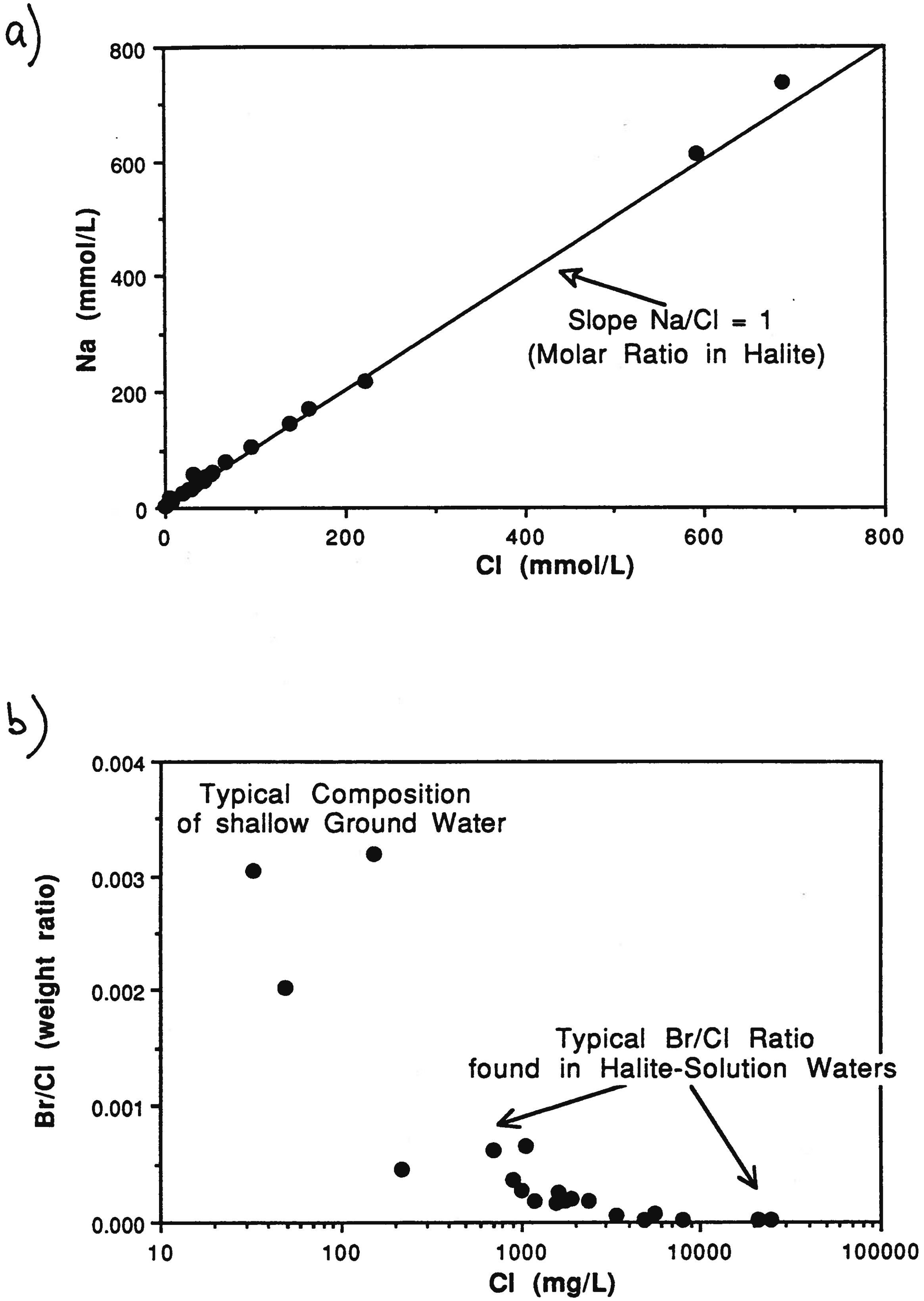


Fig. 12: Constituent plots of (a) Na versus Cl and (b) Br/Cl versus Cl for river-survey samples, indicating halite-dissolution as the major source of salinity.

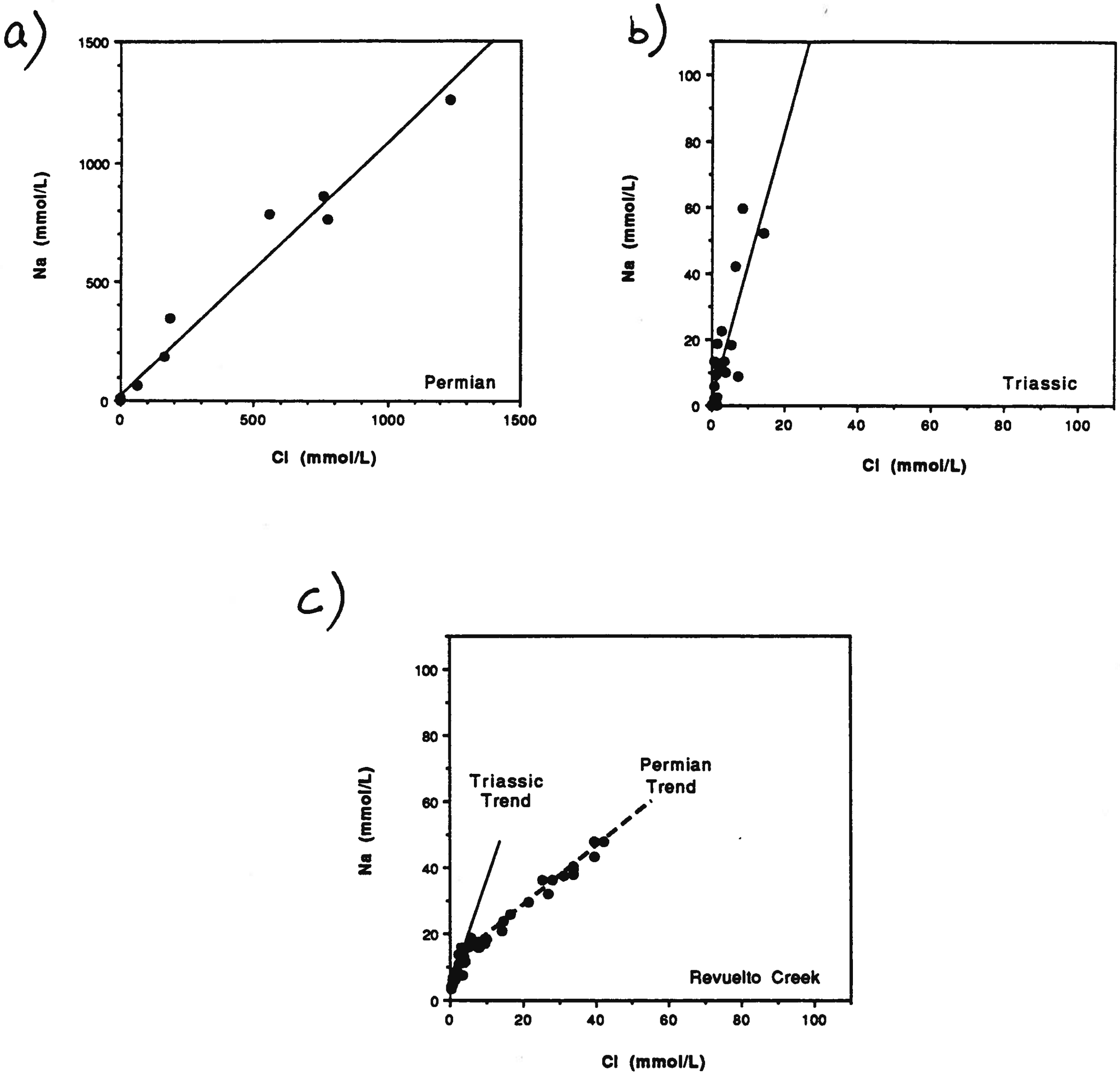


Fig. 13: Comparison among water samples from (a) wells producing from Permian strata, (b) wells producing from Triassic strata, and (c) Revuelto Creek. Revuelto Creek water salinity is low when flow is dominated by discharge of water from Triassic formations; salinity is high when flow is dominated by contributions from Permian water-bearing units (data from Hydro Geo Chem, Inc., 1984).

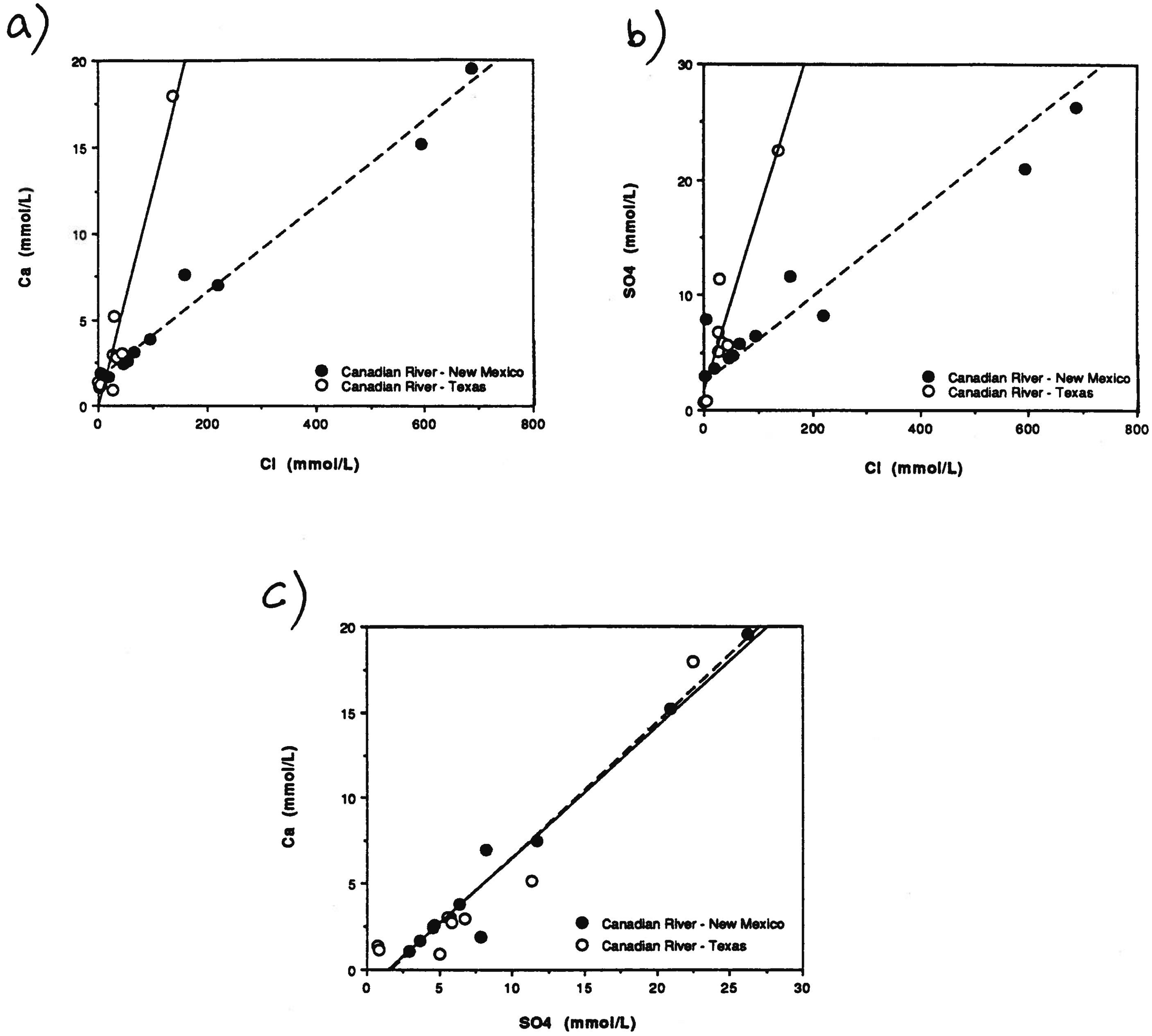
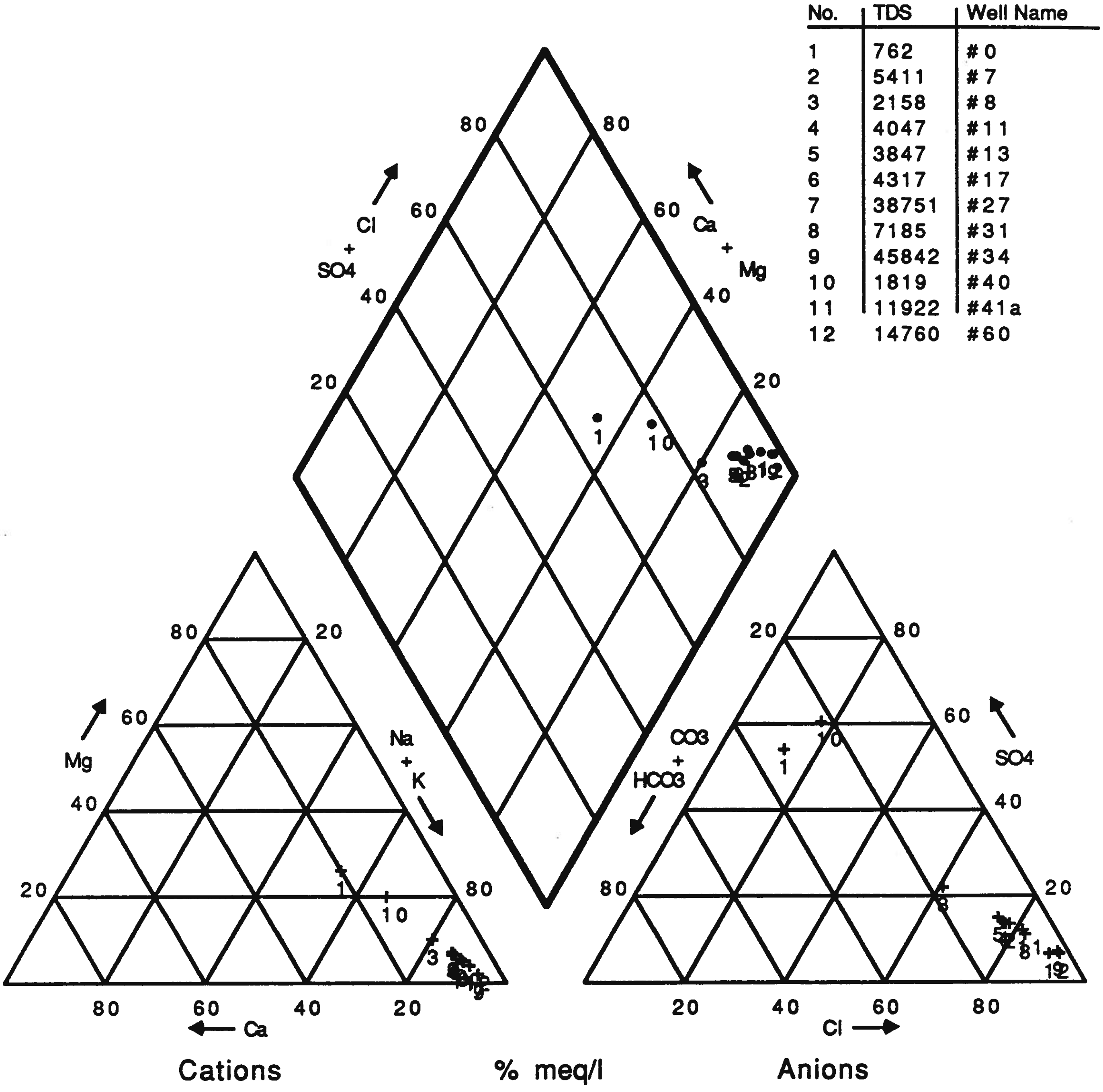
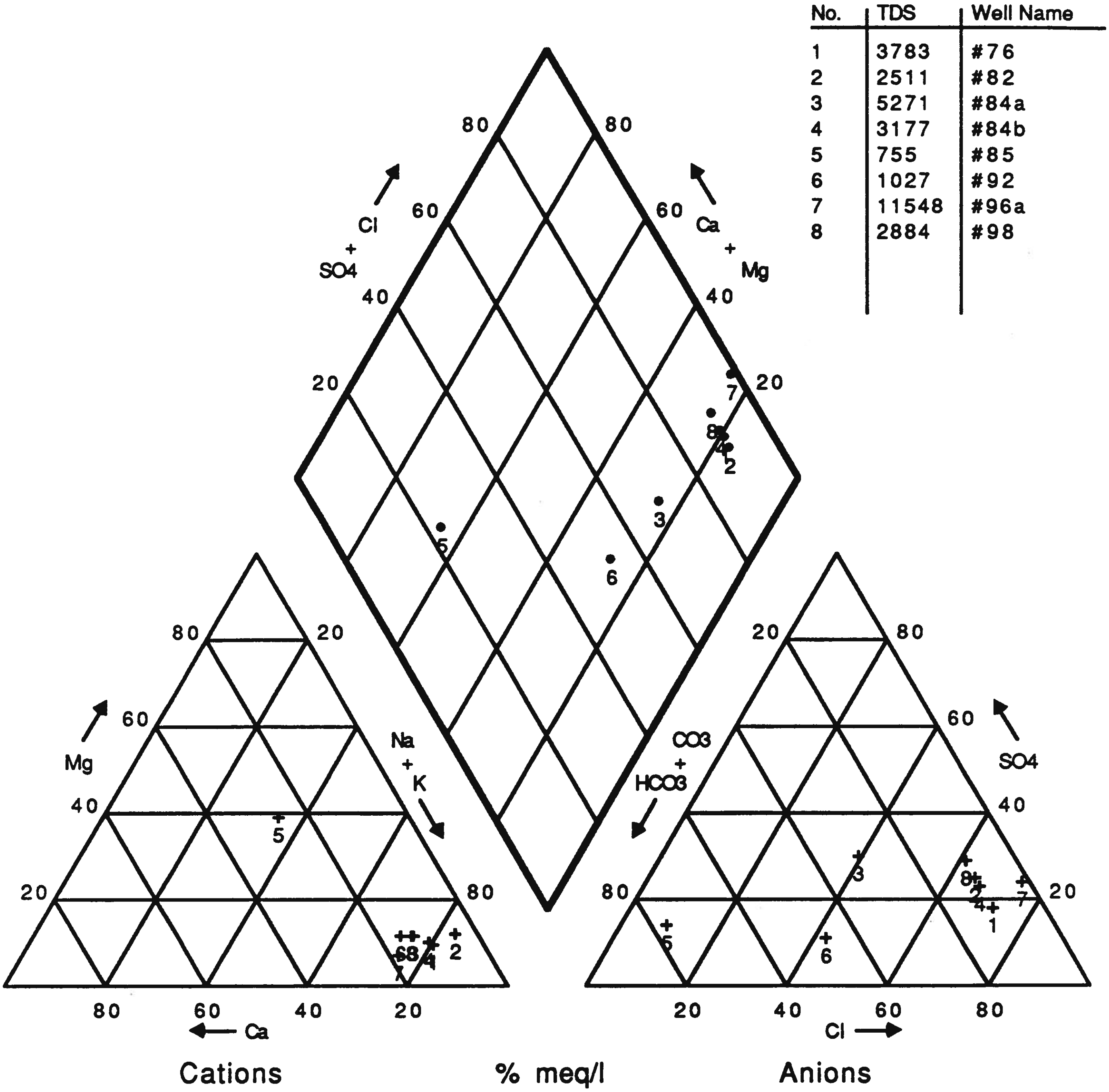


Fig. 14: Bivariate plots of Ca, SO4, and Cl for river-survey samples, differentiating between samples collected in New Mexico (solid dots) and those collected in Texas (open circles). Samples from the Texas reach typically exhibit larger Ca/Cl and SO4/Cl ratios than samples from the New Mexico portion of the river.



No.	TDS	Well Name
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

Fig. 15: Piper diagram of river samples collected along the New Mexico portion of the Canadian River.



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

Fig. 16: Piper diagram of river samples collected along the Texas portion of the Canadian River.

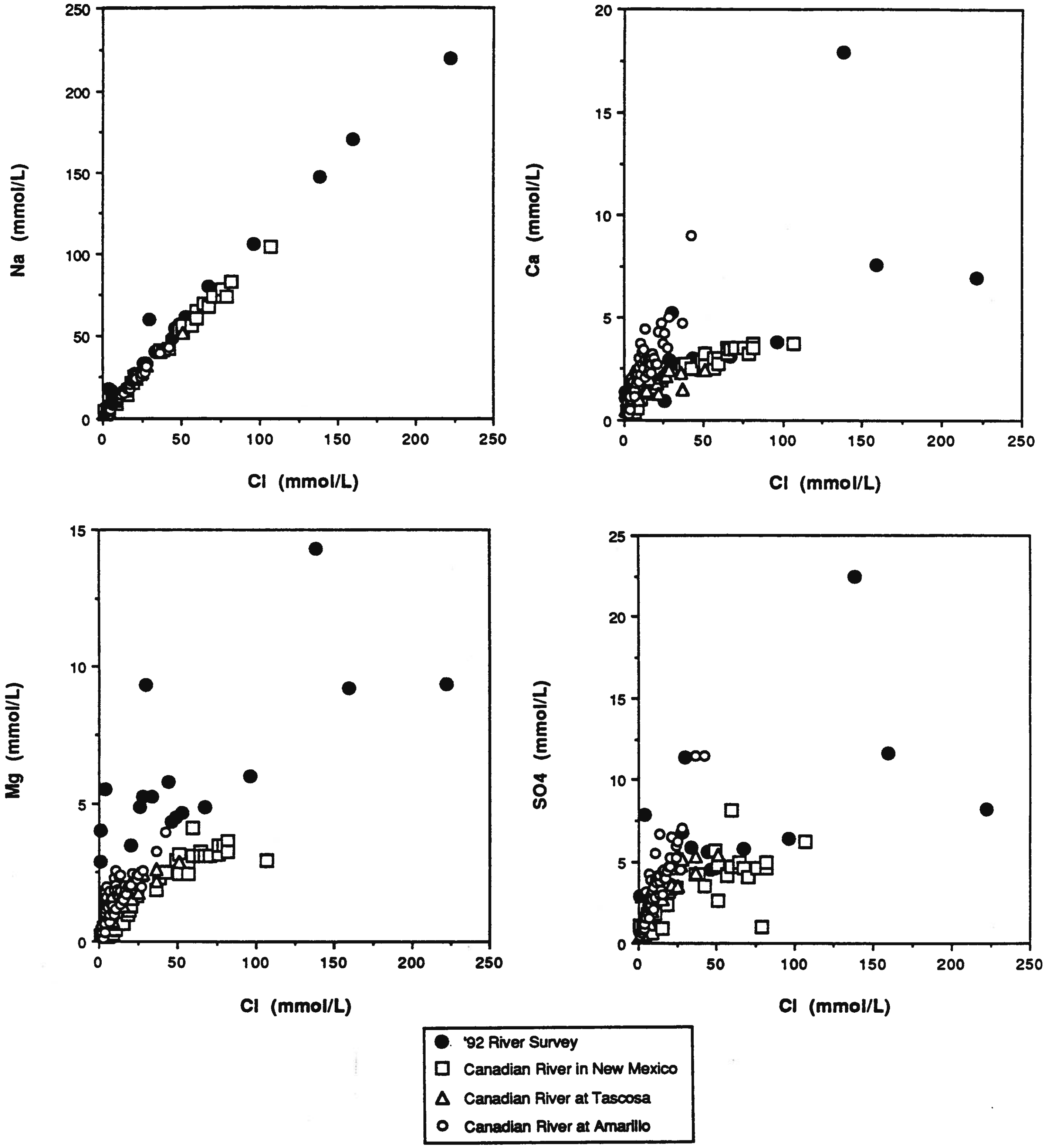


Fig. 17 : Comparison between February '92 river-survey data (solid dots) and data from previous investigations in New Mexico (open squares), at Tascosa, Texas, (open triangles), and at Amarillo, Texas (open circles) (previous data from Hydro Geo Chem, 1984).

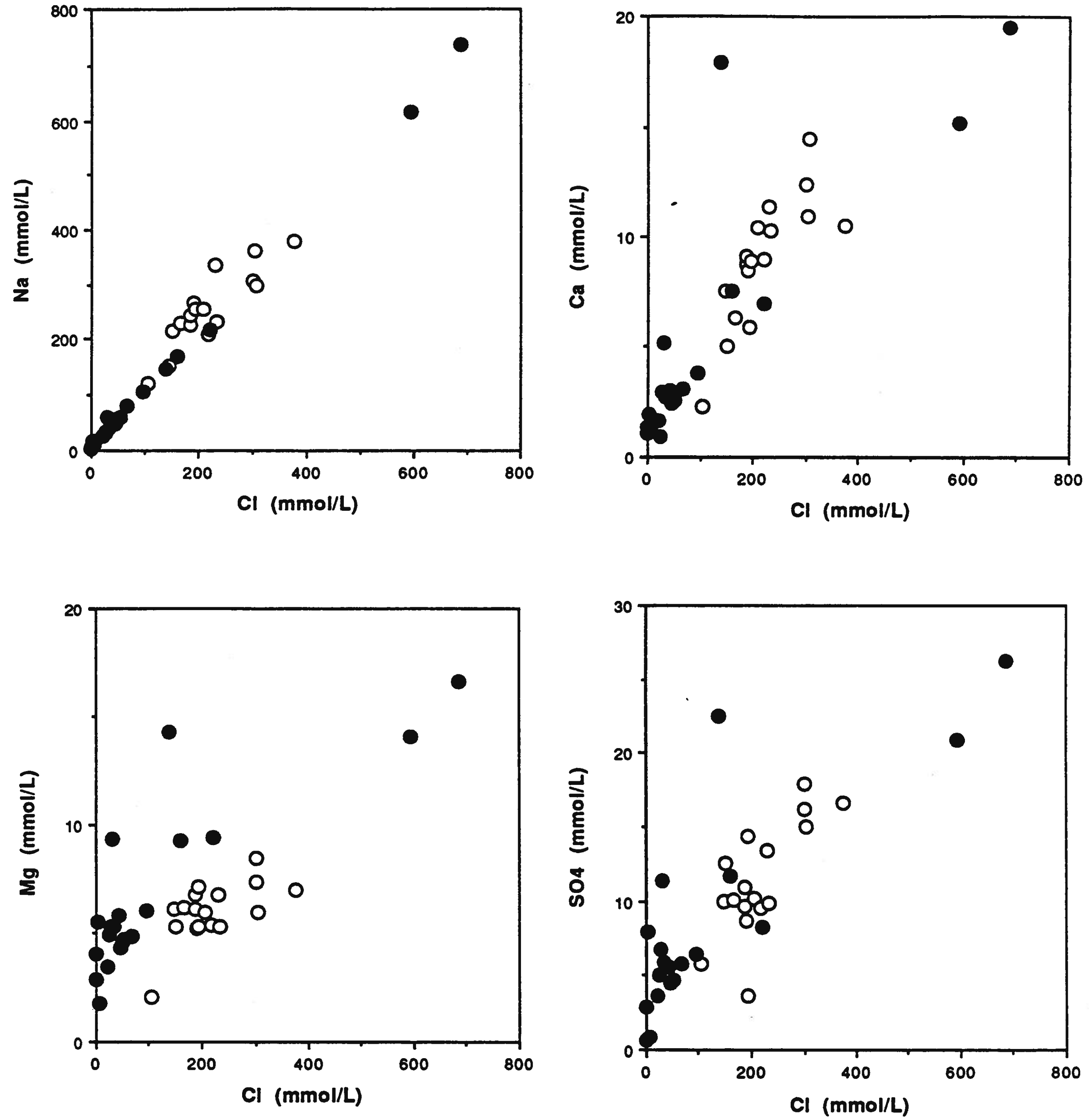


Fig. 18: Comparison between February '92 river-survey data (solid dots) and data from piezometers collected during previous investigations (open circles) (previous data from Bureau of Reclamation, 1984).

Table 1. Conductivity of waters in Canadian River, Ute Reservoir, NM to Lake Meridith, TX.

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" from bank, on bottom, 3" 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 (continued).

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" depth in water 8-12" deep); 2/10/92
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" 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" 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" 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" 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" 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" depth); 2/11/92
32	4.56	7600	Flowing pool section of river (probe 6 ft from bank, on sandy bottom, 6-8" depth); 2/11/92

(continued on next page)

Table 1 (continued).

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" depth); 2/11/92
36	5.42	8600	Riffle in river (probe on sandy bottom, 6-12" 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	Northth 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 (continued).

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, 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, NM to Lake Meridith, TX.

Survey Site No. (1)	River Mileage (2)	Conductivity (3) 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; 2/11/92
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; 2/11/92
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 (continued).

Survey Site No. (1)	River Mileage (2)	Conductivity (3)			Location (4)	Remarks
		Isolated Pools	Tributaries	Springs		
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 flood plain, 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, 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 which 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, NM to Lake Meridith, TX.

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 bridge	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 Ol 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, NM to Lake Meridith, TX.

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 side or south side of river.

Table 5: Results of field measurements of conductivity from and calculated chloride concentrations of tributaries, pools, seeps, and the channel of the Canadian River between Ute Reservoir, New Mexico, and Lake Meredith, Texas, February, 1992. (for locations see Fig. 1).

ID	Conductivity	Cl (a)	Cl (b)
	micromho/cm	mg/L	mg/L
NEW MEXICO			
1	975		157
2	675		23
3	725		45
4	650		12
5	775		68
6	1790	150	521
7	2500	511	839
7	7800	3201	3209
7	9000	3811	3745
7	10000	4318	4192
7A	810		83
7B	3000	765	1062
8	2300	409	749
9	2250	384	727
10	3990	1267	1505
11	4290	1420	1639
12	4100	1323	1554
12	33000	15994	14476
12	39000	19040	17159
13	8900	3760	3700
13	10900	4775	4595
13	19000	8887	8216
14	5200	1882	2046
14	5500	2034	2180
14	6100	2338	2449
15	4300	1425	1644
16	4600	1577	1778
17	4675	1615	1811
18	4800	1678	1867
19	4150	1348	1577
20	4525	1539	1744
21	5600	2085	2225
22	5800	2186	2314
23	4680	1618	1814
24	6000	2288	2404
25	6300	2440	2538
26A	14800	6755	6339
26B	12500	5587	5310
27	43500	21324	19171
28	7200	2897	2940
29	8000	3303	3298
30	13200	5943	5623
30A	10000	4318	4192
31	5700	2135	2270
32	7600	3100	3119
32A	16900	7821	7277
33	8500	3557	3522
34A	48000	23609	21183
34B	3200	866	1152
34C	42300	20715	18635
34D	7200	2897	2940
35	24500	11679	10676
35B	28000	13456	12241
36	8600	3607	3566
36B	27500	13202	12017
37	9500	4064	3969
38	1800	156	526
38B	9000	3811	3745
39	10000	4318	4192
40	1690	100	477
40B	1550	29	414
41	5800	2186	2314
41A	20000	9395	8664
41B	6000	2288	2404
42	5900	2237	2359
42A	28500	13710	12464
42B	17000	7872	7322
43	5700	2135	2270
43	3750	1145	1398
44	5100	1831	2001
45	5300	1932	2091
46	6000	2288	2404
47	6000	2288	2404
48	6000	2288	2404
49	5900	2237	2359
49A	900		123
49B	1340		320
50	6000	2288	2404
51	6300	2440	2538
52	6100	2338	2449
53	5500	2034	2180
54	6500	2541	2627
55	6200	2389	2493

Table 6. Salt loading in Canadian River, Ute Reservoir, NM to Lake Meridith, TX.

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 7: Results of chemical analyses from 20 water samples collected during the February '92 conductivity survey of the Canadian River between Ute Reservoir, New Mexico, and Lake Meredith, Texas.

ID	STATE	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	HCO3 (mg/L)	SO4 (mg/L)	Cl (mg/L)	Br (mg/L)
0	NM	43.3	34.8	131	6.5	216	281	49	0.1
7	NM	123.0	58.4	1840	7.7	457	555	2370	0.42
8	NM	67.1	41.7	625	5.1	353	349	717	0.44
11	NM	99.9	54.3	1310	6.9	387	439	1750	0.32
13	NM	96.9	52.4	1250	7.1	375	436	1630	0.43
17	NM	103.0	56.2	1420	7.7	389	451	1890	0.38
27	NM	609.0	169.0	14140	37.6	775	2010	21010	0.48
31	NM	153.0	72.3	2434	10.4	485	615	3415	0.2
34	NM	782.0	200.0	16950	43.3	997	2520	24350	0.46
40	NM	76.8	66.5	407	3.4	355	757	153	0.49
41a	NM	303.0	111.0	3920	15.3	803	1120	5650	0.38
60	NM	279.0	113.0	5050	16.1	642	790	7870	0.1
76	TX	121.0	69.5	1110	7.2	377	538	1560	0.27
82	TX	36.7	59.0	757	6.3	251	482	919	0.34
84a	TX	208.0	112.0	1370	11.5	1419	1090	1060	0.7
84b	TX	110.0	63.3	918	6.8	316	563	1200	0.23
85	TX	53.7	48.6	78	6.5	469	66	33	0.1
92	TX	47.0	21.2	247	1.8	415	78	217	0.1
96a	TX	719.0	172.0	3390	6.5	191	2160	4910	0.1
98	TX	118.0	63.1	764	6.5	280	652	1000	0.27