IMMEDIATE PHASE 2 STUDIES
LAKE MEREDITH, TEXAS
SALINITY CONTROL PROJECT

Prepared for
CANADIAN RIVER MUNICIPAL WATER AUTHORITY

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12 October 1992

CONTENTS

CONCLUSIONS

Characteristics of the brine aquifer. This report interprets newly acquired stream survey data, and reinterprets geophysical data from the USBR project reports, in order to develop a hydrogeologic cross-section of the Logan area. We believe that the segment of the Canadian River known as the gravel pit reach is important to any salinity control project. Some of the most important types of evidence related to the brine aquifer, and the interpretations they produce, are summarized below.

EVIDENCE	INTERPRETATION
WELL LOGS	We have identified the brine aquifer as Tecovas sandstone
STATE ENGINEER STUDIES	Indicate that the Tecovas is at a shallow depth in the gravel pit reach.
USBR GEOPHYSICAL STUDIES	Our reinterpretation is consistent with brine aquifer coming to surface near gravel pit reach
AERIAL OBSERVATION	Structural linears are observed which suggest fracturing or faulting in the gravel pit reach
WATER LEVEL DATA, TW-1	Quantitative analysis demonstrates that brine aquifer responds to and is connected to both Ute Reservoir and the

	Canadian River; building and enlargement both increased brine inflow.
GAGING STATION DATA, LOGAN	Show that baseflows have increased and stabilized since Ute was built; and have increased again since Ute was enlarged
STREAM SURVEYS	Indicate brine inflow occurs over 6 mile reach, including gravel pit reach; inflow probably has increased since Ute was enlarged; flows vary over time
MIXING CALCULATIONS	Quantify winter brine inflow (2/92) as 1.2 cfs, with gravel pit reach having double the inflow rate in cfs/mile compared to the upstream reach
LEAKANCE CALCULATIONS	Quantify properties of shale which confines the brine aquifer; indicates that at gravel pit reach, shale must be very thin and/or highly fractured
OTHER CALCULATIONS	We calculate transmissivity, hydraulic conductivity of brine aquifer to be significantly lower than estimated by USBR

Implications to salinity control project

There are at least three significant problems facing anyone who attempts to design and implement a project to pump the brine aquifer and reduce saline inflows to the Canadian River and Lake Meredith.

- To the extent that the brine aquifer is impacted by Ute Reservoir, future changes at the reservoir could significantly impact the distribution and amount of brine flows. A project designed to successfully control brine inflows under one scenario of Ute Reservoir operations might fail if the operational pattern changes.

↑ from survey data, it appears we may need production wells over a broader area anyway.

- Since the confining layer probably is thin and/or fractured at the gravel pit reach, it is not at all certain that control can be obtained from a simple pumping system. Wells located near Logan may have little effect on reducing brine inflows at the gravel pit reach, and vice versa.

- To even begin to deal adequately with these problems will require a reasonably good computer model of the ground-water flow system. Data sufficient to develop such a model are lacking. Key data needs include: the thickness and fracturing of the confining layer; transmissivity of the brine aquifer; head distribution over time and space in the brine aquifer.

Recommendation

USBR (1985, page e) stated that "additional fieldwork to include exploratory drilling and long-term pump testing is needed to verify the findings presented in this report and effectiveness of the (salinity control) plan". That statement is no less true today than in 1985. A next step is to drill a test/observation well in the gravel pit reach. There are several reasons why this location is important.

- The brine flow system near Logan has a west-east orientation. Existing well data on the brine aquifer are from a single area. Therefore, lateral patterns in the key west-east direction are not known. Data obtained at the gravel pit reach would allow interpretation of west-east patterns.

- The gravel pit reach is obviously an important location of brine discharge. At a minimum, data (such as water level variations in the brine aquifer) need to be acquired at this location in order to better interpret the brine flow system. Such data can be obtained only through installation of an observation well.

- It is quite possible that a brine control program would involve pumping at the gravel pit reach; and certain that the program would require computer modeling of effects at the gravel pit reach. Design and/or interpretation of the control system would require obtaining data on the confining layer, brine aquifer and heads at the gravel pit reach. These conditions can be known only through drilling and testing of at least one well.

At this time, it is appropriate to await the results of BEG's geophysical work before making a firm decision whether to drill a test well in the gravel pit reach. Assuming that those results are consistent with the analyses presented in this report, we recommend:

- drilling a single well in the gravel pit reach, within the canyon walls if access can be arranged, otherwise on the mesa top;

← Mr. Edmonds feels strongly it should not be on top.

- the well should be logged extensively to determine properties of the confining layer and brine aquifer;

- the well itself could be pumped to determine transmissivity of the brine aquifer;

- the well would then be equipped for ongoing monitoring of water levels (and, perhaps, periodic sampling).

We do not recommend drilling this well as a potential brine production facility, as that would increase costs and perhaps reduce data acquisition abilities. Moreover, even if a production well is eventually needed at the gravel pit reach, an observation well also would be required; an investment in such a well at this time is fully appropriate.

The cost of the observation well is uncertain because of numerous complications, including difficult access to the best drilling site and the probable need to dispose of or dilute produced brine. For planning purposes, we estimate a cost of $30,000, but recommend this estimate be revisited in more detail after the BEG geophysical survey is completed.

Summary

A test well at the gravel pit reach will provide for monitoring of the brine aquifer, and a better understanding of the properties of the confining layer and aquifer in an area which is key to the proper design and evaluation of a possible salinity control project. The approximate cost of the well and testing is $30,000.

1. INTRODUCTION

CRMWA has contracted with PSC/LWA to assist in evaluations of the Lake Meredith Salinity Control Project. Phase 1 of the contract was effectively completed in July, 1992, when we provided CRMWA with final copies of the Surface Water and Ground Water Notebooks. These notebooks contain extensive data compilations and some data interpretations related to the project.

Also in July, we recommended and CRMWA approved certain additional studies to further analyze factors important to the project, termed the immediate Phase 2 studies. These studies are now complete and are summarized in this report. The report assumes the reader is fully familiar with the notebooks.

It is our intent to edit the report in accordance with review comments provided by CRMWA, and then to reformat the information so that it can be incorporated into the notebooks.

2. INTERPRETATION OF FEBRUARY STREAM SURVEY

In February, 1992, CRMWA conducted a stream survey for the entire Canadian River between Ute Reservoir and Lake Meredith. PSC/LWA's participation in the field work of the survey was authorized as part of the Phase 1 studies; our work to interpret survey results is part of the immediate Phase 2 studies.

Our initial interpretations of the stream survey were included in the Phase 1 submittal; see Section 4.4 of the Surface Water Notebook. In the current report, we provide additional interpretations (see Sections 3 through 5). We also add some minor points for the notebook. Specifically, a graph (next page) will be added to illustrate the point that the 1992 survey found lower <u>concentrations</u> of chloride than in 1984, due in substantial part to the dilution effects of increased Ute seepage. The graph will be cited in the portion of the notebook which discusses how high discharge combined with lower concentrations to equal a higher chloride load than previously observed.

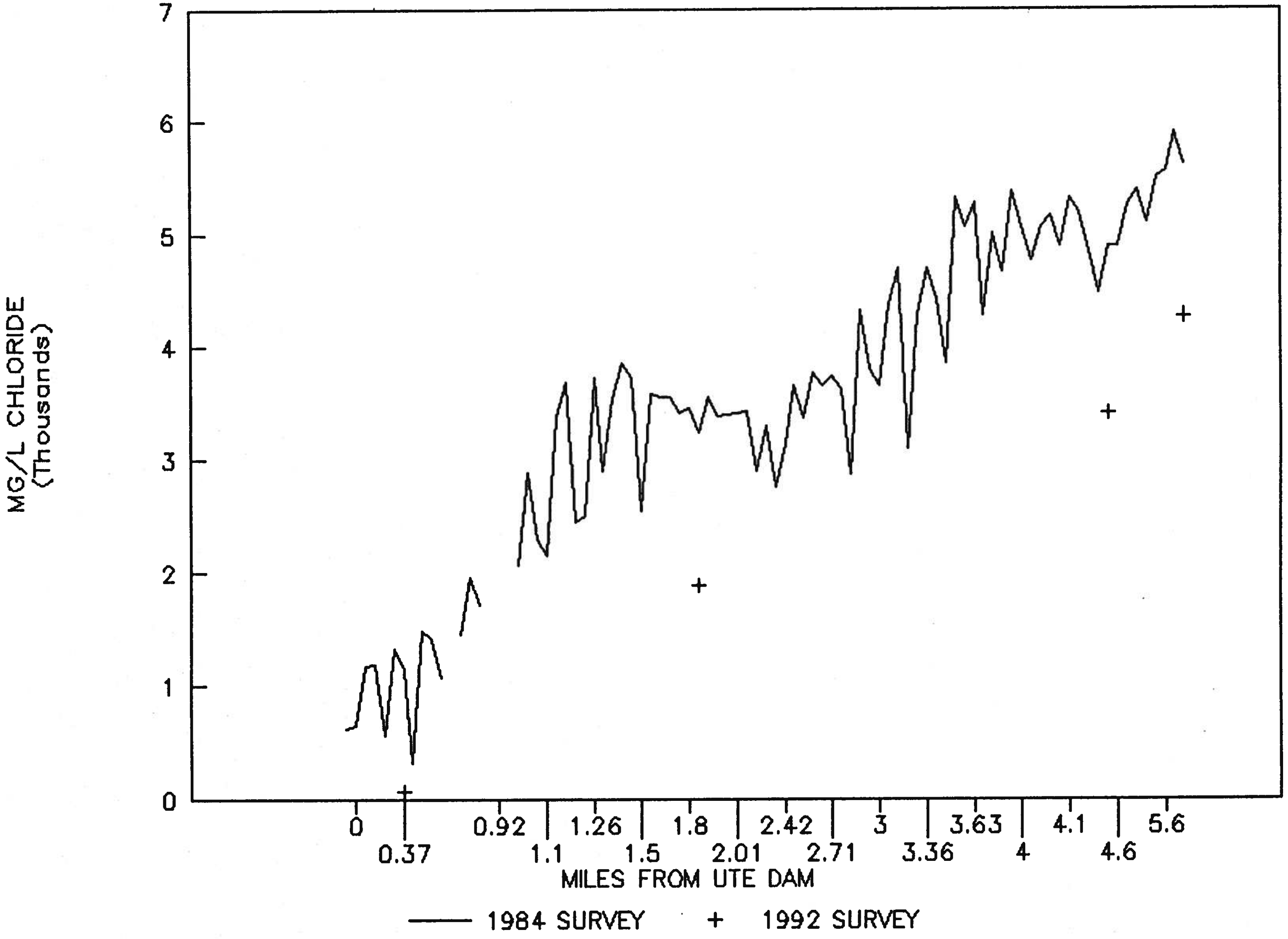
Two additional comments will be integrated into the Surface Water Notebook.

- The specific conductance of water in flowing pools along the river indicates the salinity of water in the underlying alluvium. Salinity varies from values near that of undiluted brine to fresh water. In some pools fresh and saline water are stratified; ground water in the alluvium at those sites must also be stratified. This is consistent with the observations reported by USBR (1984). ?

- Extremely high salinities in pools downstream from the railroad bridge indicate the presence of undiluted brine in the gravel pit reach. This is a possible indication that the alluvium is in contact with the brine aquifer at that point. The farthest upstream brine pool identified in the 1992 CRMWA survey is roughly 4,000 feet east-southeast of DH-1 at an elevation near 3680 feet. ?

COMPARISON OF STREAM SURVEYS

1984 VERSUS 1992



3. MIXING CALCULATIONS

The February stream survey effectively measured inflow of ground-water in the Logan area. Based on geologic interpretations presented in the Ground Water Notebook, the inflow is a mixture of brine from the Tecovas sandstone and relatively fresh water from the Trujillo sandstone.

To assess the relative contributions of the two sources, we have performed a mixing (or mass balance) calculation which combines measured river flows, chloride concentrations and specific conductance values in the river with estimated values of chloride concentrations and specific conductance for brine and local fresh water. The method is described below. Application of the method is described in Section 4.

Overview of method. The rate of brine discharge which occurred during the 1992 stream survey can be calculated from the survey data by using a mixing calculation for conservative solutes. The load flowing past a point on the river (L_{out}) is assumed equal to the load flowing past an upstream point on the river (L_{in}) plus the load added by the accretion of fresh water (L_{fresh}) and the load added by the accretion of brine (L_{brine}):

$$L_{out} = L_{in} + L_{fresh} + L_{brine}$$

In turn, loads equal the product of discharge (Q) times solute concentration (C), with adjustments for units as appropriate:

$$L = Q * C$$

Combining equations:

$$Q_{out} * C_{out} = (Q_{in} * C_{in}) + (Q_{fresh} * C_{fresh}) + (Q_{brine} * C_{brine})$$

Q_{in} and Q_{out} were measured in the stream survey. The increase in discharge at a point on the river (Q_{out}) compared to the river discharge at an upstream point (Q_{in}) is assumed equal to the accretion of fresh water (Q_{fresh}) and of the brine (Q_{brine}) between the two points:

$$Q_{out} = Q_{in} + Q_{fresh} + Q_{brine}$$

The last two formulas can be combined to determine the two unknown discharge terms, Q_{fresh} and Q_{brine}.

$$Q_{fresh} = Q_{out} - Q_{in} - Q_{brine}$$

$$Q_{out} * C_{out} = (Q_{in} * C_{in}) + ((Q_{out} - Q_{in} - Q_{brine}) * C_{fresh}) + (Q_{brine} * C_{brine})$$

$$(Q_{out} * (C_{out} - C_{fresh})) = (Q_{in} * (C_{in}-C_{fresh})) + (Q_{brine} * (C_{brine} - C_{fresh}))$$

$$Q_{brine} = \frac{(Q_{out} * (C_{out} - C_{fresh})) - (Q_{in} * (C_{in} - C_{fresh}))}{(C_{brine} - C_{fresh})}$$

<u>Input values: streamflow</u>. The river discharge was measured at several points in the reach near Logan where brine inflows are known to occur. Measured values are tabled below.

River Mile	Description	Discharge (cfs)
0.37	Survey site 8	2.35
1.90	Site 17, Logan gage	3.84
3.08	Site 23, above RR bridge	4.03

4.41	Site 31, gravel pit reach	4.69
6.31	Site 41, below Revuelto	12.88
12.72	Site 50	12.99

The discharge in Revuelto Creek was measured at 6.76 cfs. The river discharge above Revuelto Creek (i.e. at roughly site 39, mile 5.9) was calculated to be 6.12 cfs from the difference between the flow below Revuelto Creek and the flow in Revuelto Creek. This calculation ignores any inflow between site 39 and the Revuelto confluence.

The discharge immediately below Ute Dam (approximately mile 0.08) was calculated by summing the flows estimated at discharge points around the dam:

Site	Discharge (cfs)
Toe drain outlet	1.445
Drain outlet below gate	0.12
Leakage through gate	0.03
South buttress	0.002
Below spillway	0.33
Total	1.93

The total of the fresh water and brine inflows to the river was calculated from these values by subtracting the flow into each reach from the flow out of each reach. The calculated accretions are:

River Mile	Accretion (cfs)
0.08 to 0.37	0.42
0.37 to 1.90	1.49
1.90 to 3.08	0.19
3.08 to 4.41	0.66
4.41 to 6.31	1.43
6.31 to 12.72	0.11

Input values: chloride concentration. Chloride concentrations were available or easily estimated for all of the dam leakage terms. These values are:

Site	Cl Concentration (mg/l)
Toe drain outlet	137.5
Drain outlet below gate	20
South buttress	10
Below spillway	25

The chloride concentration in water leaking through the gate was assumed equal to the concentration in water from the drain outlet below the gate. The flow-weighted mean chloride concentration was calculated from these values to be 105 mg/l. The measured chloride concentrations downstream (as reported in Section 4.4 of the Surface Water notebook) are as follows.

Site	Cl Concentration (mg/l)
Site 8	717
Site 17	1890
Site 31	3415
Site 41	2110
Site 50	2710

In addition, just as the flow at site 39 (mile 5.9) can be estimated as the value which, when added to flows at Revuelto Creek, gives flows at site 41, so also chlorides at site 39 can be estimated as the value which, when plugged into a mass balance which includes chlorides at Revuelto Creek, gives the chlorides at site 41. (As noted previously, this ignores inflow between site 39 and the Revuelto confluence.) The only input value not already identified in this report is the chloride concentration at Revuelto Creek when the survey was conducted; this value is taken at 153 mg/l, based on a laboratory analysis performed by BEG. The resulting estimate of chloride concentration at site 39 is 4442 mg/l.

The chloride concentration in the brine aquifer in the Logan area varies among samples. Values typical of water from OW-3 and OW-4 were used for the calculations: 23,000 mg/l. Both published analyses and the results of the river survey show that the chloride concentrations of fresh water near Logan are variable. The value assumed was 45 mg/l.

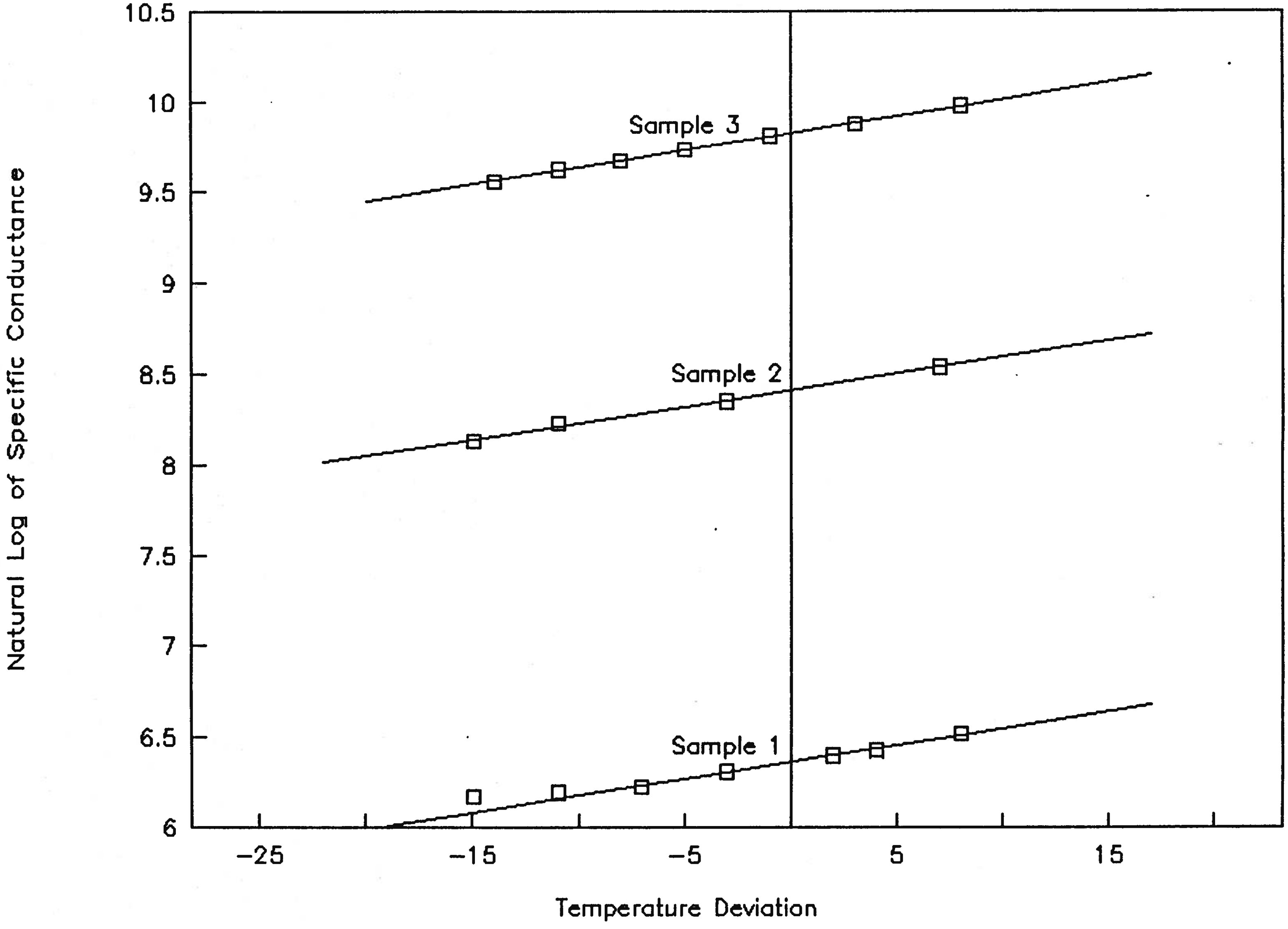
The method and input values identified above are utilized in the next section to estimate the rate of brine inflow.

Check using specific conductance: data correction procedure. Specific conductance values and temperature were measured in the field at virtually all river stations. The Surface Water Notebook observed that there were major problems in utilizing these data - for example, correlations with laboratory chloride values were poor. Subsequent to the survey, we calibrated our conductance meter against a Hach specific conductance standard. This indicated that the results measured at 25°C were correct within the accuracy of the standard but the meter failed to correct properly for the variation of specific conductance with temperature. Consequently, we revisited the specific conductance data in order to correct them for temperature and thus to make them more useful in assessing the results of the stream survey.

The temperature correction should be approximately 2% per degree C, but a more accurate value was needed for correcting the measured values. Therefore, LWA recorded the uncorrected specific conductance of three different NaCl solutions in tap water, over a temperature range from about 4°C to 28°C. The natural logarithm of the measured specific conductance is linearly related to the sample temperature, as shown by the graph following this page. Thus, the temperature coefficient is given by the slope of the

Determination of temperature correction

measured values and regressions



regression between the sample temperature and the natural logarithm of the measured specific conductance. The temperature coefficient was determined to be 1.84% per degree C.

We also found it necessary to adjust the data depending on which scale of the meter was used. "Low scale" results (results on the first meter scale) were 0.91 times the values obtained on the second and third scales, for the same or equivalent solutions.

The complete correction, including both the temperature coefficient and the scale factor, was used to adjust the field measurements to calibrated conditions at 25°C. With the field temperature (T, in degrees C) and measured specific conductance (SC_{field}), the corrected specific conductance ($SC_{corrected}$) is:

$$SC_{corrected} = (0.91 * SC_{field}) * \exp^{(0.0184 \times (25-T))}$$

Specific conductance values, as corrected, were used to check brine inflows calculated using chloride values. The formula for Q_{brine} reduces to:

$$Q_{brine} = \frac{(Q_{out} * (SC_{out} - SC_{fresh})) - (Q_{in} * (SC_{in} - SC_{fresh}))}{((1.25 * SC_{brine}) - SC_{fresh})}$$

The factor of 1.25 in this equation is to adjust the SC values to their equivalent total dissolved solids concentrations, since the original equation is based on such concentrations. The expected coefficient to convert brine SC to TDS is 0.75. The expected coefficient for fresh water is 0.60. The value of 1.25 is the ratio of 0.75 to 0.60.

Field measured specific conductance and temperature and the corrected specific conductance values are:

River site	Temperature (C)	Specific Conductance Field (micromhos/cm)	Specific Conductance Corrected (micromhos/cm at 25C)
Site 8	18.5	2620	2786
Site 17	11.0	4980	6079
Site 23	8.0	5800	7481
Site 31	9.0	5600	7092
Site 41	13.0	6000	7059
Site 50	10.5	6000	7391

Temperature and specific conductance on Revuelto Creek were 13.5 degrees and 1800 micromhos/cm and the corrected value is 2098 micromhos/cm at 25°C. Specific conductance at site 39, upstream from Revuelto Creek was corrected to a value of 12,206 micromhos/cm. The flow-weighted conductance for the river below its confluence with Revuelto is ((6.12 cfs * 12,206) + (6.76 * 2,098) / 12.88 =) 6900 micromhos/cm. This is in good agreement with the corrected value measured at Site 41, 7059 micromhos/cm. The fact that actual conductance exceeds calculated conductance may reflect a small amount of brine inflow between site 39 and the Revuelto confluence.

The specific conductance of the brine varies from sample to sample. A value typical of water from OW-3 and OW-4 was used - 63,000 micromhos/cm at 25°C. As with chloride, published analyses and the results of the river survey show that the specific conductance of fresh water near Logan is variable. A typical value was assumed - 1300 micromhos/cm at 25°C.

4. INFLOW RATES

Calculation based on chloride. The following table gives the results of the mixing analysis based on chloride values (Q in cfs, C in mg/l).

River reach (site,	miles)	Q_{in}	Q_{out}	C_{in}	C_{out}	C_{brine}	C_{fresh}	Q_{fresh}	Q_{brine}
8	0.37	1.93	2.35	105	717	23000	45	0.356	0.064
17	1.90	2.35	3.84	717	1890	23000	45	1.250	0.240
31	4.41	3.84	4.69	1890	3415	23000	45	0.470	0.380
39	5.9	4.69	6.12	3415	4442	23000	45	0.946	0.484

A comparison of values for sites 41 and 50 indicates a very large increase in chloride but a very small increase in flow between the sites; solving the equation in this situation gives a negative value of fresh water inflow, which is not considered realistic. An explanation for this problem is that the precision of the available data is not adequate to assess changes in a reach where overall changes are very small.

Calculation based on conductance. For comparison, inflow rates calculated from specific conductance data indicted:

- a brine inflow of 0.07 cfs above mile 0.37, which is in good agreement with the value of 0.064 cfs given above;
- a brine inflow of 0.19 cfs in the reach from mile 0.37 to mile 1.90, in reasonable agreement with the value of 0.24 cfs given above;
- a brine inflow of 0.11 cfs in the reach from mile 1.90 to mile 4.41, less than one-third the value of 0.38 cfs given above (note that since

conductance data were collected along with flows at site 23, mile 2.08, it is possible to determine that most inflow occurred in the first half of this reach);

- a brine inflow of 0.54 cfs in the reach from mile 4.41 to about 5.9, in good agreement with the value of 0.484 cfs calculated above.

In addition, the conductance data indicate about 0.06 cfs of brine inflow from mile 6.1 (site 41) to mile 12.72 (site 50).

Calculation based on sulfate. The downstream change in sulfate concentrations can be used to check the inflow values. Data from the 1992 river survey allow the check to be made on two reaches: site 8 to site 17 and site 17 to site 31. The check cannot be completed on the reach from site 31 to Revuelto Creek because river water samples were not taken below Revuelto at site 41.

The sulfate concentration in the brine is taken to be 2,750 mg/l from the average of three samples from wells OW-3 and OW-4 reported by USBR (1984). The sulfate concentration in the fresh water inflow is estimated at 416 mg/l - the average cited in HGC (1984) from 26 samples of water from Triassic aquifers.

The flow at site 8 was 2.25 cfs, with a sulfate concentration of 349 mg/l. On the reach from site 8 to site 17 the chloride-mixing calculation shows 1.25 cfs of fresh water inflow and 0.24 cfs of brine inflow. The flow-weighted average of these terms should be approximately the concentration in the river at site 17. The measured sulfate concentration at site 17 was 451 mg/l; the calculated concentration is higher at 521 mg/l.

Repeating the calculation for the reach from site 17 to site 31, the flow at site 17 was 3.84 cfs, with a sulfate concentration of 451 mg/l and the reach received 0.47 cfs of fresh water inflow and 0.38 cfs of brine inflow. The calculated sulfate concentration is 634 mg/l - only slightly higher than the analysed concentration of 615 mg/l.

There is good agreement between calculated and analysed concentrations for the reach from site 17 to site 31. The agreement is not quite as good for the reach from site 8 to site 17. Both temperature and specific conductance varied with depth at site 8 and we expect that sulfate concentrations also varied with depth. The difference between the calculated and analysed concentrations at site 17 would be easily explained if the water sampled at site 8 was typical of deep water at the site, with a higher sulfate concentration than the water flowing out of the pool into the river.

Summary. At the time of the stream survey early in 1992, we estimate the total ground-water inflow from below Ute Dam (i.e. below the area impacted by dam seepage) to Revuelto Creek was 4.19 cfs. Of this, based on a chloride mass balance, 1.17 cfs was brine inflow. The rate of brine inflow is substantially higher than previously reported. Inflow rates by reach are:

above mile 0.37	0.17 cfs/mile
mile 0.37 to 1.90	0.16 cfs/mile
mile 1.90 to 4.41	0.15 cfs/mile
mile 4.41 to 5.9	0.32 cfs/mile

Based on Feb survey (would be less for Sept & Nov. data)

These numbers support an essentially constant rate of brine inflow between Ute and the gravel pit reach, and a much larger inflow rate in the gravel pit reach. The conductance and sulfate data support the results calculated from chloride data.

5. LEAKANCE CALCULATIONS

Introduction. Leakance is a hydrologic parameter used to quantify vertical flow across a confining bed. High leakance values imply good hydraulic communication across a confining bed and low leakance values imply a poor hydraulic communication. Poor communication can result from a thick confining bed and/or a unit having very low hydraulic conductivity. Because of the way it is calculated, leakance has the unusual units of time^{-1} (i.e., per second, per hour or per day). It can be thought of as the volume of water that could pass through a unit area of the confining bed in unit time if the head gradient across the bed were 1:1. Numerically, leakance values can be calculated from either:

$$\text{Leakance} = Q/(A * H)$$

$$\text{Leakance} = K_v/b$$

where Q is the discharge, A is the cross-section area of flow, H is the head difference across the confining bed, K_v is the vertical permeability and b is the confining bed thickness. Both formulas can (and will in this section) be manipulated in a variety of ways to calculate any one term in the formula from values for the remaining variables.

As discussed in the Ground Water Notebook, based on information used in the USBR computer model, leakance across the 50-foot thick shale above the brine aquifer would be 2.2×10^{-5} per day. However, the inflow rates calculated from the stream survey data suggest higher values.

Leakance values, if the head difference is constant. One leakance calculation we made was based on the water-level elevation in the USBR 22-foot piezometer at site 1 (3666.7 feet in August, 1983), which was about 10.8 feet lower than the water level elevation in the brine aquifer at OW-4 (3677.5 feet in July, 1984). If this 10.8 foot head difference applies to all reaches at all times (an unrealistic assumption, but useful to make the calculation), then combining it with the brine flows calculated in Section 4 (which are assumed to be vertical flows) and using an average alluvium width of 500 feet ?? produces the following leakance values.

River Reach (miles)	Leakance (per day)
0.08 to 0.37	6.69×10^{-4}
0.37 to 1.90	4.75×10^{-4}
1.90 to 4.41	4.59×10^{-4}
4.41 to 5.9	9.84×10^{-4} (
0.37 to 4.41	4.65×10^{-4}

As calculated, these values represent the integrated leakance properties of all materials between the brine aquifer and the river, i.e. it includes the effects of the alluvium and Trujillo sandstone. Typically in such situations, the leakance of the tightest unit (in this case the confining bed) dominates the calculated value. The leakance value is relatively high in the first reach near the dam, then approximately constant over the next two reaches. The leakance more than doubles in the gravel pit reach (mile 4.41 to 5.9), compared to the reaches immediately upstream.

Sept -
Nov.
Varies

There is no geological reason to expect a higher leakance near the dam. The high value for this particular calculation probably occurs because the real-world head difference near the dam is greater than the 10.8 feet assumed in the calculation. The real-world head difference near the dam is greater than measured in the area of OW-4 because of the localized pressure effects from high water levels in the reservoir (see subsequent discussion of TW-1). These effects occur in the brine aquifer, but not in the alluvium where water levels are controlled by the stage of the river. Going eastward, real-world head gradients decline slightly in the alluvium and more steeply in the brine aquifer. The assumption of 10.8 foot head difference underestimates the actual difference near the dam, thus this particular calculation overstates leakance.

The high leakance calculated at the gravel pit reach is inconsistent with the relationship just described. This is evidence that some other factor is controlling leakance in the area of the gravel pit reach.

Head difference, if leakance is constant. The leakance calculated for the reach 0.37 to 4.41 miles averages about $4.65x10^{-4}$. This appears to be a reasonable real-world estimate for leakance between the brine aquifer and the river in the Logan area. If this leakance is assumed constant throughout the Logan area, the head differences necessary to achieve the observed rates of brine inflow are:

River Reach (miles)	Head Difference (feet)
0.08 to 0.37	15.5
0.37 to 1.90	11.0
1.90 to 4.41	10.7
gravel pit reach	22.9 ← ?

For the first three reaches, these results are consistent with the regional trend in head differential which was discussed above. However, the water level calculated for the gravel pit reach is more than double the water level difference in the reach immediately upstream; it's even higher than the water level difference near the dam.

We cannot completely rule out the possibility that some hydrologic factor causes water levels in the brine aquifer to increase substantially in the gravel pit reach; but no independent evidence whatsoever exists for such a factor.

Leakance and hydraulic conductivity of confining layer. Mathematically, the leakance between the brine aquifer and the river is the geometric mean of the leakance across the 50-foot shale bed above the brine aquifer, the leakance across perhaps 150 feet of Trujillo sandstone, and the leakance across the 60 feet (approximately) of alluvium. For purposes of an initial analysis, the leakance of the alluvium and Trujillo can be approximated by using vertical permeability values typical of these geologic units elsewhere in New Mexico. For the alluvium, using a representative vertical permeability of 0.2 feet per day and the 60-foot thickness, leakance is calculated at 3.3×10^{-3}. For the Trujillo sandstone, using a representative vertical permeability for a fractured rock of 0.5 foot/day and a 150 foot thickness, leakance is 3.33×10^{-3}.

Given a net leakance of 4.65×10^{-4} and the approximated leakances for alluvium and sandstone, the leakance of the shale is 6.45×10^{-4}, or nearly 30 times larger than calculated by USBR. If the shale is 50 feet thick, its vertical hydraulic conductivity is 0.032 feet per day.

Thickness of confining layer in gravel pit reach. The high rates of brine inflow at the gravel pit reach are evidence that leakance in the area of that reach is higher than elsewhere in the area. In fact, given that the probable head difference in that reach is relatively small, the leakance almost certainly is higher than the value of 9.84×10^{-4} calculated at the beginning of this section. In turn, this indicates a geologic change in the confining unit, i.e. an increase in hydraulic conductivity, or a decrease in thickness, or both.

If leakance in the gravel pit reach really is as little as 9.84×10^{-4}, the head difference is 10.8 feet, and the hydraulic conductivity of the shale is as calculated above, the confining layer beneath the gravel pit reach is only 23 feet thick. However, as noted previously, the head difference near the gravel pit reach probably is less than 10.8 feet, in which case the leakance is more than 9.84×10^{-4}. If the head difference is 5 feet, then leakance of the shale is 2.12×10^{-3}, and it is only 5.5 feet thick.

What these calculations really mean is that a lot of water is moving across a tight shale despite relatively little driving force from the difference in water levels: this can only occur if the shale is relatively thin. In turn, this indicates that in the gravel pit reach, the Canadian River has eroded substantially into the shale layer, and possibly entirely through it. The most plausible alternative interpretation would be that in the gravel pit reach, the shale is fractured and has an unusually high vertical hydraulic conductivity. It is possible that both factors - erosional thinning and structural fracturing - combine to account for the high leakance in the gravel pit reach.

6. INTERPRETATION OF WATER-LEVEL CHANGES IN WELL TW-1

Water levels at TW-1. Well TW-1 near Logan (see location map in Ground Water Notebook) is completed in the brine aquifer and equipped with a continuous water level recorder. The graph on the next page illustrates water levels in TW-1 over time, and compares them to water levels in Ute Reservoir and base flows in the Canadian River at Logan. The values on the graph have been scaled so that all the curves can be viewed on the same vertical scale.

From the time when TW-1 was initially installed through 1984, there was no long-term rise or fall in the brine aquifer water levels. Minor fluctuations in levels occurred, but data are not available to correlate the changes with other phenomena (e.g. Ute Reservoir stage, barometric pressure). Reconstruction of a higher spillway at Ute Dam was completed in late 1984 and the reservoir was filled during 1985 through early 1987 to the new spillway elevation. The water level in the reservoir rose 40 feet over the period from September 8, 1984 to August 6, 1987. Water levels recorded at TW-1 began rising at approximately the same time the reservoir elevation began to rise. The water level in TW-1 eventually stabilized about 2 feet above previous levels.

The water level rise at TW-1 was apparently a response to the increased elevation in the water level in Ute Reservoir. When a measured change in a ground water flow system can be related back to a specific cause it is sometimes possible to use the relationship to learn more about the nature of the ground water system.

Looking more closely at the graph, the water levels at TW-1 began rising at essentially the same time that water levels in the reservoir began rising. Water levels in the reservoir stabilized during 1988, but the water level in TW-1 continued rising for about two more years, stabilizing in late

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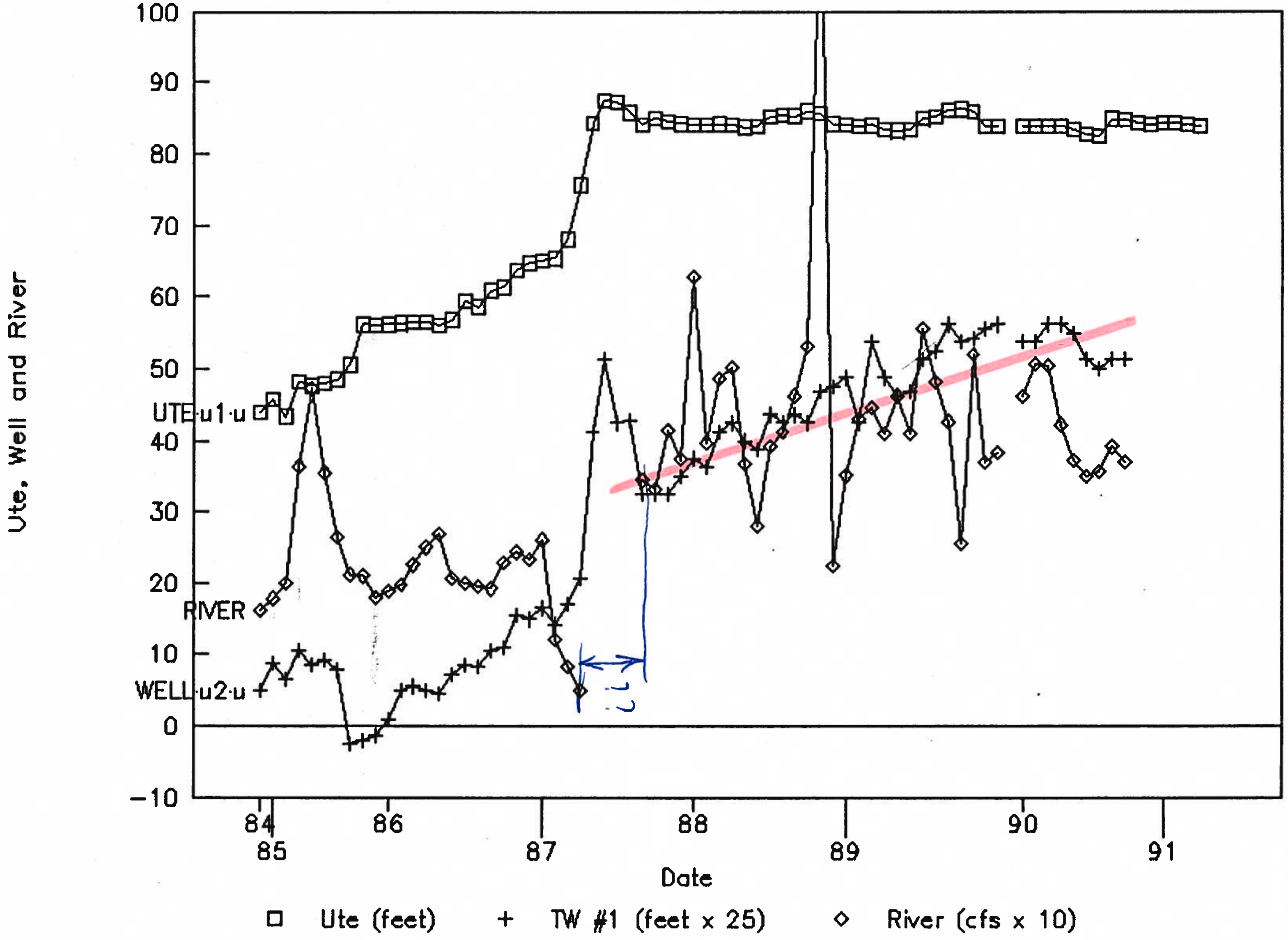
What about when Ute was lowered?



Ute Reservoir, TW #1 and Canadian River

1989. Over that period the water levels rose along a fairly smooth, curving trend interrupted only for a period during the spring and summer of 1987.

During 1987 the reservoir spilled and the water level at TW-1 rose sharply. Continuous recorder charts obtained from CRMWA show that the response began about 10 hours after the start of the spill. The spill lasted through July, 1989 and as it ended the water level at TW-1 fell abruptly. The water level fell approximately to the point it would have reached if it had followed the smooth, long-term trend of water level rise. The water level record from the onset of a second spill in September of 1991 shows consistent behavior; the water level responded within about 10 hours of the start of the spill.

Overview of interpretation. The record at TW-1 appears to show the influence of two different behaviors, one reflecting a slow response to reservoir conditions and the second a fast response to river conditions.

In terms of hydrogeology, the connection between the reservoir and the brine aquifer is through the Trujillo sandstone and the confining shale. Water levels at TW-1 required several years to stabilize after a comparatively abrupt change in the reservoir level. The slow stabilization implies that the reservoir rise affected ground water storage over a large volume of the aquifer. This is reasonable, given the large area of the reservoir and the large volume of Trujillo which would be impacted by changes in reservoir stage. The slow rise also implies that the brine aquifer responded over a long term as an unconfined aquifer.

The comparatively rapid response of water levels at TW-1 (both rise and fall) to the reservoir spill in 1987 can't reflect conditions in the reservoir, and must reflect a response to the rise in river stage. For the response to be fast, the hydraulic connection to the river must be relatively good, which in turn means that the aquifer does not behave as a well-confined, isolated hydrologic unit. The hydrographs don't allow direct determination of where the aquifer-river connection occurs, but geologic information in the Ground Water Notebook points to the gravel pit reach as a prime candidate.

Quantitative analysis. The behavior of water levels at TW-1 can be used to provide an indication of the brine aquifer hydraulic parameters. The hydrologic conditions governing water levels at TW-1 are too complex for a simple analysis to produce meaningful results. LWA has approached the problem by constructing an analytic ground water model that represents, in a simplified fashion, the flow system in the brine aquifer and the steady-state changes in water levels induced by the increased elevation of Ute Reservoir.

The model is mathematically complicated. Details of the model development and application won't be described in this short report, but are available upon request. The salient features of the model are important and can be briefly listed.

1) Vertical flow across the shale layer above the brine aquifer is assumed to occur only beneath Ute reservoir and the Canadian River; the flow direction is elsewhere parallel the aquifer boundaries.

2) Vertical flow to deeper units is negligible.

3) The rate of vertical ground water discharge in or out of the brine aquifer is proportional to the difference between the brine aquifer head and the elevation of the overlying surface water body.

4) Water in Ute Reservoir is at an elevation of 40 feet above datum, and water in the Canadian River is at datum; the vertical datum is provided by the elevations that existed prior to reconstruction of the spillway at Ute Reservoir.

5) The meandering course of the Canadian River can, at the scale of the model, be reasonably treated as a straight line; appropriate adjustments for the linearization of the river can be made in interpreting the model results.

6) The brine aquifer is under perfectly confined conditions west of Ute Creek, where the Chinle Formation separates the lower Triassic aquifers from the surface. In the absence of ground water discharge to the surface out of the confined area, a line perpendicular to the linear course of the Canadian River near its confluence with Ute Creek can be reasonably treated as a no-flow boundary.

7) The head in the brine aquifer is completely controlled by the stage of the Canadian River approximately at the mid-point of the gravel pit reach; a line perpendicular to the linear course of the Canadian River at that point is reasonably regarded as a constant head boundary.

8) The brine aquifer is unbounded in the direction perpendicular to the river.

9) The system described above is symmetric about the Canadian River, so there is no ground water flow beneath the river perpendicular to the linear course of the river.

The model is capable of calculating the eventual increase in the ground water level due to an increase in the elevation of Ute Reservoir. The only hydraulic parameter in the model is the ratio of the leakance between the brine aquifer and the overlying surface water body to the transmissivity of the brine aquifer. For the sake of simplifying the calculations, TW-1 was regarded as being at the center line of the linear course of the river.

The ratio of leakance to transmissivity was adjusted by trial and error until the calculated water level change at TW-1 was approximately 2 feet. The ratio at that point was 6.86×10^{-7}. The transmissivity of the brine aquifer can be calculated from the ratio if the leakance is known. In section 5 we concluded that the best value for the leakance was 4.65×10^{-4} per day.

The model simulates the course of the river as a straight line and so the area where leakage can occur in the model is smaller than it is along the actual course of the river. The leakance value used to calculate transmissivity is increased somewhat to account for the shortening. The actual river distance simulated in the model extends from Ute Dam to the midpoint of the gravel-pit reach, a distance of about 5 miles along the river channel. The linear distance simulated by the model is only 3.03 miles. The leakance of 4.65×10^{-4} is increased by a factor of 5.0/3.03 to 7.67×10^{-4} to account for that difference.

The estimated transmissivity is calculated as leakance divided by 6.86×10^{-7}, or 1,118 square feet per day. The permeability of the brine aquifer is given by dividing the transmissivity by the aquifer thickness from DH-3 of 147 feet. The permeability is estimated at 7.6 feet per day. The USBR pump test resulted in higher values, which we have judged questionable: 2,500 square feet per day for transmissivity and 36 feet per day for permeability. The USBR ground water model also used higher values, a permeability of 24 feet per day and a thickness of 100 feet, giving a transmissivity of 2,400 square feet per day.

The values estimated by applying the analytic model are approximate because of the simplicity of the model. Uncertainty in the result stems largely from two sources: 1) the model simulates only the final, steady-state condition at TW-1 and the accuracy of the result can't be verified by calculating the complete transient record from TW-1, and 2) the simple construction of the model ignores potentially significant details like variations in the leakance or transmissivity, the meandering course of the river and the potentially complicating role of ground water flow within the Trujillo Formation. Greater certainty would require the use of a digital model capable of more accurately representing the ground water flow system.

7. REINTERPRETATION OF USBR GEOPHYSICAL SURVEYS

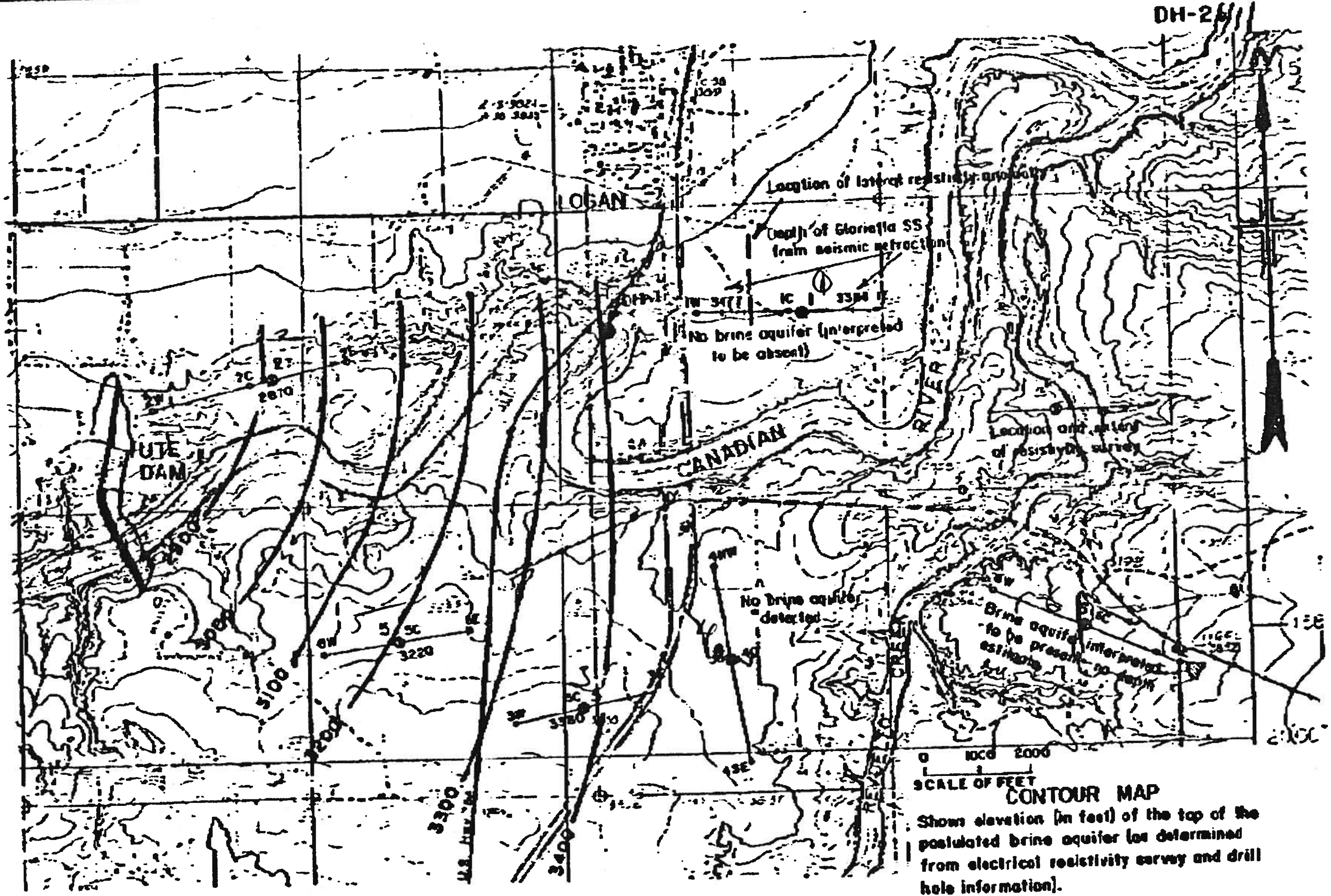
USBR geophysical surveys. During May and June, 1976, the USBR conducted seismic refraction and vertical resistivity surveys along the Canadian River near Logan. USBR (1979) sets forth the principal findings.

- The brine aquifer at Logan dips roughly 4 degrees (300 to 400 feet/mile) westward from an altitude of 3420 feet at well DH-1 to an altitude of 2870 feet approximately 1.5 miles west of DH-1.
- The brine aquifer existed below three sounding sites southwest of Logan, but it was absent in two soundings south of Logan. A sixth sounding southeast of Logan seemed to detect the brine aquifer at depth but the data were deemed unreliable.
- A "lateral resistivity anomaly" was detected in one sounding.

The map on the following page is Figure 5 from USBR (1979) and it shows the location of electrical resistivity soundings, and USBR's interpretation as to the elevation of the top of the brine aquifer. The aquifer is shown as terminating at about the longitude of Logan, and thus would not occur in the area of the gravel pit reach.

USBR (1979) does not provide specifics about the study results, methods used or the reliability of the findings. USBR (1976) is the detailed report which does contain specifics regarding the geophysical surveys.

Assessment of USBR resistivity data. The author(s) of USBR (1976), who were at the USBR Engineering and Research Center, noted that the equipment used for the resistivity survey "has only marginal power for this area." The data were erratic by USBR's own assessment, and only 4 out of the 6 soundings (#s 2, 3, 4 and 5) were believed to produce "reasonably reliable results."



Drill Hole - DH

FIGURE 5

CONTOUR MAP

Shows elevation (in feet) of the top of the postulated brine aquifer (as determined from electrical resistivity survey and drill hole information).

Lake Meredith Salinity Study

rw G-42,

USBR's interpretations regarding the brine aquifer are based primarily on evidence from drill hole DH-1 and on 3 of the 4 soundings that USBR considered reliable. Our examination of the survey field data and computer analysis shows that 2 of the 3 soundings (soundings 2 and 3) were based on raw data that appear to be consistent and dependable. The third sounding (sounding 5) contained an anomalous data point that was disregarded during processing. USBR (1976) provides no justification for neglecting that datum. Despite the possible problem with sounding 5, the conclusion from these three soundings appears to be reasonable and supportable.

The fourth sounding which USBR considered reliable, number 4, did not detect the brine aquifer. Our inspection of the raw and processed data for site 4 confirms that there is no evidence that the brine aquifer existed at the site. However, the sounding also failed to detect the water table. Failure to detect the water table is unusual, since the presence of water is one of the determining factors in rock resistivities. A second unusual feature of the sounding is that readings were reported "off the chart" at electrode spacings less than 60 feet. Spacings of less than 150 feet were not attempted at sounding 1, but at all of the remaining sites readings were successful at three spacings below 60 feet. These problems cast doubt on the reliability of the data from sounding 4.

Sounding 1, which also did not detect the brine aquifer, was not regarded by USBR as reliable data. Eight readings were taken at electrode spacings increasing from 150 feet to 1200 feet; six of the readings show an increase in resistivity with depth (indicating absence of the brine aquifer), but the remaining two readings produce anomalously low results. The anomaly was attributed to an abrupt lateral change in resistivity that could be caused by a fault, joint or cultural noise. The anomaly is shown in figures presenting the survey results to trend north-south through the western arm of the vertical profile. No basis is given for selecting that location or trend and the report does not state that the anomaly should be attributed to the margin of saline ground water.

Sounding 6 was made southeast of Logan. Data from the sounding were regarded as being unreliable. The measured resistivity drops sharply with electrode spacing and may indicate the presence of brine at depth. The only unusual feature in the raw data was that the resistivity measured at a 10 foot spacing was substantially lower than soundings taken at 30 and 45 feet. In soundings 2 and 5 the resistivity changed very little from 30 to 45 feet, but in "reliable" sounding 3, the resistivity increased from 10 to 30 feet, so the behavior at sounding 6 was not unique. USBR apparently made no attempt to process data from sounding 6, possibly because of the low reading at the 10 foot spacing. It is not clear to us why, if sounding 4 could be analysed without data from 10, 30 and 45 feet and still be regarded as reliable and sounding 5 could be analysed while neglecting an anomalous data point and still be regarded as reliable, USBR regarded sounding 6 as unreliable and did not attempt to process the results. Since the record from Site 6 was never processed, we cannot easily interpret the data.

Assessment of USBR seismic data. The seismic refraction survey was interpreted by USBR (1979) to show a sequence of weathered material at the surface, underlain by sandstone, then shale, then sandstone. Our review of the survey is based on the detailed analysis contained in USBR (1976).

The seismic line was 2,400 feet long and consisted of 7 shot points and 24 geophones. Additional lines were shot to establish the velocity of shallow, weathered material. The line was laid out roughly east-west and corresponds closely to resistivity sounding 1, which is on the plateau west of the gravel pit reach. The seismic profile has never been illustrated by USBR (not even in the 1976 report). Data in the appendices of the 1976 report have been used to construct the profile shown on the following page.

USBR reported that four layers were detected in a time-distance plot of first arrivals and that the velocity for each layer was determined from the plot. The time-distance plot is included in the 1976 report, but the USBR

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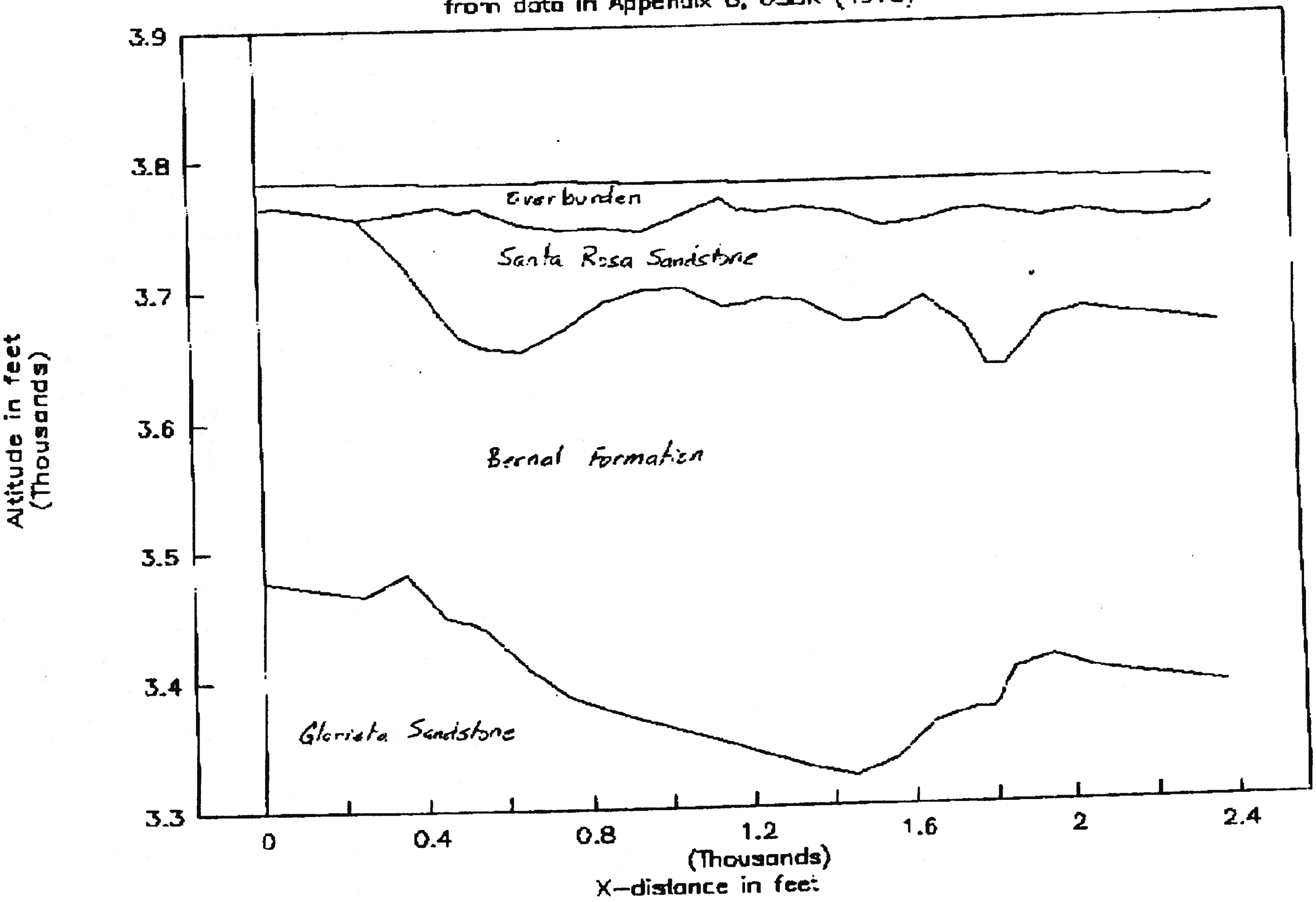
Seismic Refraction Profile, Logan NM

from data in Appendix B, USBR (1976)



velocity interpretation is not indicated on the plot. The plot indicates a low velocity layer at shallow depths, probably the overburden and shallow weathered zone. The slope of the time-distance curves do decline slightly with distance but there are no distinct breaks in the slope of the time-distance plots. The time-distance plots contain no clear evidence for layering at depth.

The velocities used for the lower three layers, listed with increasing depth, are 7,467, 8,100 and 9,600 feet/second. The contrast between these velocities is small and any interpretation based on them is questionable. Refracted waves would be detected only if the sequence of layer thicknesses met specific minimum requirements set by the small velocity contrasts. Digital interpretation of the survey probably forced the required sequence of thicknesses on the calculated profile.

USBR assigned velocities to specific lithologies and stratigraphic units (overburden, Santa Rosa, Bernal and Glorieta, in descending order) based on the stratigraphy identified by USBR in well DH-1. That stratigraphy is incorrect because the San Andres Formation, which should insert several hundred feet of carbonates between the Bernal and Glorieta, has been omitted from the section.

The interpretation of the seismic study appears to be arbitrary. This is because there is no evidence for well-defined layering in time-distance plots, because of the low velocity contrasts used in the interpretation and because of the clear error in interpreting the stratigraphic section.

The seismic profile resulting from the study also is unrealistic. The sandstone layer interpreted to be the Santa Rosa Sandstone pinches out near the west end of the profile. But the Trujillo Formation of the Santa Rosa is prominently exposed along the Canadian River just west of the point were the profile shows it pinching out, so the survey is obviously wrong.

The interpreted pinchout of the Santa Rosa Sandstone, despite its being obviously wrong, is the only evidence that USBR could use to support their interpretation of anomalous results from resistivity sounding 1. The "lateral resistivity anomaly" shown by USBR on the map at the beginning of the this section corresponds closely to the location of the interpreted Santa Rosa pinchout. The seismic survey does not contain information to support the north-south orientation of the anomaly.

Configuration of brine aquifer. Our assessment of the geophysical data supports USBR's conclusion regarding the general dip and orientation of the brine aquifer west of Logan. However, the finding of "no brine aquifer" east of Logan appears to be based on data which are unreliable (sounding 1) or of relatively poor quality (sounding 4).

If one accepts USBRs general assessment of the brine aquifer, but assumes that the aquifer extends further east than mapped by USBR, then the aquifer clearly approaches the land surface in the vicinity of the gravel pit reach. For the brine aquifer to be at the base of the alluvium in that reach (the configuration we have interpreted based on other data), the dip of the aquifer from DH-1 to the reach would be about 2 degrees. This could indicate that the dip is flattening eastward. An alternative interpretation is that the strike of the aquifer is more to the northwest than shown by USBR, in which case the apparent dip along an east-west line would be less than the true dip along a northeast-southwest line.

In our judgment, the USBR geophysical data do not demonstrate that the brine aquifer terminates in the Logan area, and are consistent with an interpretation that the aquifer reaches near the land surface in the vicinity of the gravel pit reach.

8. COMMENTS ON PROPOSED BEG SURVEY

Proposed study. The USBR shallow geophysical studies failed to provide a reliable interpretation of conditions near Logan. Despite the failure, there is every indication that geophysical investigations using modern methods could produce useful information at Logan and other sites along the Canadian River. The Texas Bureau of Economic Geology has proposed such an investigation, using electromagnetic methods (EM) along three reaches of the Canadian River: at Logan, near Salinas Plaza (Oldham County, Texas) and near Lake Meredith.

In the first phase of their study, BEG would use a frequency-domain electromagnetic method to study the apparent resistivity of alluvium along the river. The frequency-domain method allows rapid assessment of earth resistivity, but it does not provide depth resolution and may be limited in the total effective depth of the survey. In the second phase BEG would use a time-domain electromagnetic method at selected sites to obtain more detailed information about the electromagnetic section, particularly the depth distribution of resistivity.

Comments on study. LWA has discussed the proposed study at length with Dr. Jeff Paine and Arten Avakian at BEG. The results and findings discussed in earlier sections of this report, and in the Ground Water Notebook, led us to make suggestions for an effective use of the proposed EM survey. The summary below identifies those suggestions, and our underlying reasoning.

With respect to locations for study, we indicated that data from the Salinas Plaza area would be of little interest to CRMWA because the area has not been identified as a significant source of salt loads in the Canadian River. A study of the Dunes damsite area, which is at least an intermittent source of salt, would be more useful. The Dunes site may pose access problems because of rugged terrain and the absence of roads.

With respect to methods, the preliminary frequency-domain study appears to be of little value for studying conditions in alluvium near Logan because conditions there are already reasonably well known (e.g. from the USBR intensive studies in 1983-84). Also, an EM survey at Logan could be very useful if applied to the problem of defining the areal extent and depth of the brine aquifer. The frequency-domain method may not be capable of resolving conditions at the depths near Logan where the brine is known to occur and will provide no information about depth to the brine. For Logan, therefore, we believe emphasis should be on use of the time-domain method.

The two-phase approach is appropriate for both the Dunes damsite area and the reach near Lake Meredith. The first phase frequency domain study should provide information on the areal extent of saline water in the alluvium at both sites. This would be particularly useful near Lake Meredith where the existence of saline water in the alluvium has been known for many years but where detailed studies have never been made to identify its source or extent (particularly its upstream extent, including upstream from Lahey Creek). The second phase time-domain study should also be useful at both sites for indicating the source of saline water and possibly for distinguishing between saline water related to deep sources and saline water created by an alluvial effect.

9. SEPTEMBER STREAM SURVEY

A stream survey in September, 1992, obtained the following data.

Location	Flow (cfs)	Sulfate (mg/l)	Chloride (mg/l)	Chloride (tons/yr)
8	0	425	650	0
17	4.25	500	650	2,719
28	4.6	638	2750	12,452
31A	4.1	575	2750	11,099
35	3.85	675	3100	11,748
36	3.6	725	3250	11,517
41	20.99	538	750	15,496
56	19.84	625	1200	28,547 X s/B ~23436
57	19.24	638	1150	21,788
60A	19.71	575	1150	22,312
62	20.08	588	1100	21,742
64	25.33	500	1150	28,674
66A	18.85	613	1250	23,194
67	20.77	575	1200	24,534

Conditions at site 39, above the Revuelto confluence, can be obtained by subtracting out the 17.23 cfs of flow observed at Revuelto (which had a chloride concentration of only 25 mg/l, but a sulfate of 475 mg/l). The result is an estimated flow at site 39 of 3.76 cfs, containing a chloride concentration of 4,070 mg/l, with a chloride load of 15,072 tons/year.

Discussions with CRMWA staff indicate that, as with previous surveys, obtaining accurate flow measurements is difficult. This is a common problem in channels with an unstable sand bed; it means that any interpretations (especially as to total chloride load) must be made with care. For example, the ups and downs of chloride loading below site 41 could be a data artifact; it probably is prudent to conclude only that a significant salt load did enter the river downstream of Revuelto Creek during the September survey.

Our conversation was with regard to sites 31,35,& 36 where the flow varied by only ± cfs.

In the February, 1992 survey, the chloride load at Site 31A (near the head of the gravel pit reach) was almost exactly that found in September. However, the location of inflows above the point were different: in September, inflows were not uniform, but were concentrated downstream of the USGS gage. This too may be somewhat of a data artifact.

Our surveys, (past & planned) should begin to clear this up.

The load at site 39 (above the confluence with Revuelto Creek) was roughly half that in September, and on the order of what was observed in the 1980's surveys. However, while brine inflow was much reduced in September, it was still significant - especially given that the streamflow data indicate the Canadian was losing flow in this reach. The drop in brine inflow during summer is consistent with USBR studies in 1983-84, and with our analysis of the Dunes area presented in the Surface Water Notebook. Presumably, this relates to seasonal changes in regional heads.

The existence of brine inflow to a losing stream is more difficult to explain. Given the approximate nature of the data, it may be that the real-world was a situation of a small brine inflow, offset by evapotranspiration, with little or no net change in stream discharge in the gravel pit reach. If instead the Canadian experienced substantial seepage losses in September at the same time that it experienced some brine inflow, this suggests that the flow system is compartmentalized in some fundamental way (e.g. in September, brine flow occurred only in a few locations, as at points of faulting or severe fracturing).

10. HYDROGEOLOGICAL CROSS-SECTION IN LOGAN AREA, NEW MEXICO

Introduction. The final product of the immediate Phase 2 studies is a hydrogeologic cross-section of the Logan area. This cross-section was provided in the Ground Water Notebook and is repeated here on the next page. In the notebook, we indicated that the Phase 2 studies would provide an expanded discussion of the section. That expanded discussion follows.

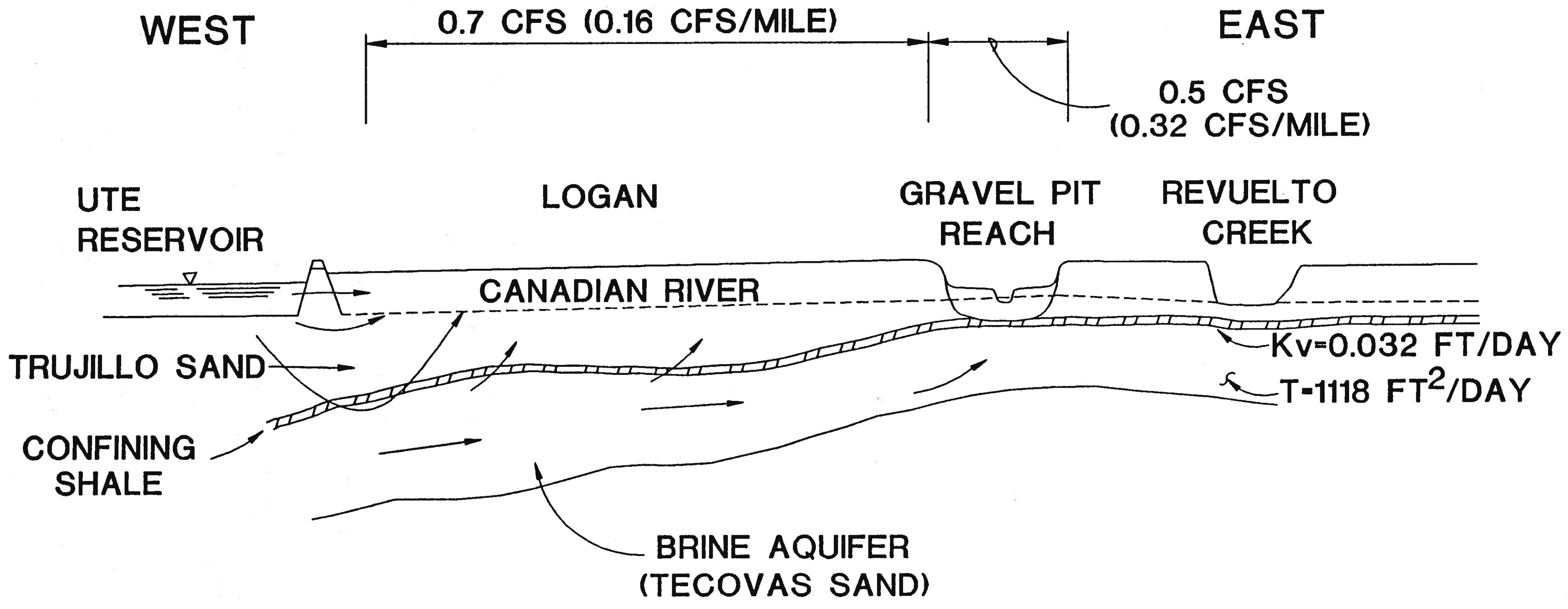
Important features shown on the cross-section include the following four points which were discussed in the USBR project reports and/or in the Ground Water Notebook:

- a brine aquifer capped by a confining layer exists at a depth of a few hundred feet in the Logan area;
- the aquifer can be identified as the Tecovas Sandstone member of the Santa Rosa Formation;
- upward flow of brine occurs through the confining layer to the Canadian River;
- the brine mixes with fresh water in the Trujillo sandstone before it discharges to the river.

Important features shown on the cross-section also include the following points which are based mostly on analyses presented in this report.

- several properties of the brine aquifer and confining bed can be quantified;
- Ute Reservoir significantly impacts flows in the brine aquifer;

HYDROGEOLOGIC CROSS-SECTION FOR THE AREA OF LOGAN, NEW MEXICO



- the brine aquifer approaches the land surface near the gravel pit reach;
- the gravel pit reach is a critical area for the understanding and control of brine discharge.

Each of these points is discussed separately below. Then we present a synthesis of our understanding of the brine aquifer flow system and comment on the mixing model described in HGC (1984). Finally, we discuss implications of these findings to a salinity control project and give initial recommendations for field testing.

Quantification. The immediate Phase 2 studies have provided quantification with respect to the brine aquifer, confining unit and brine flow in the Logan area:

transmissivity of brine aquifer	1,118	ft^2/day
hydraulic conductivity of brine aquifer	7.6	ft/day
vertical hydraulic conductivity of confining unit:	0.032	ft/day
rate of brine inflow above gravel pit reach:	0.7	cfs
rate of brine inflow in gravel pit reach:	0.5	cfs
fresh water dilution ratio above gravel pit reach	3:1	
fresh water dilution ratio in gravel pit reach	2:1	

Inflow rates and dilution ratios are specific to conditions in February, 1992. All other values are based on limited data and are approximate.

Effects of Ute Reservoir. The analysis of water-level changes in TW-1 demonstrate a good, regional connection between the stage in Ute Reservoir and water levels in the brine aquifer. An important consequence of this relationship is that when Ute Reservoir was enlarged in the mid-1980's, water levels in the brine aquifer increased over a large area. Water levels at the Canadian River did not change. Consequently, the head difference or pressure gradient between the brine aquifer and the river increased, and this must have increased the discharge of brine to the Canadian River.

The fact that brine inflow rates observed in February, 1992 were higher than any observed in the mid-80's is not coincidental, but represents a real change in system hydrology. The same reasoning indicates that the original construction of Ute Reservoir also increased brine discharge rates. The rise in head must also have impacted the Trujillo Sandstone, increasing fresh water inflows as well. The rise in head is relative, in that seasonal fluctuations in regional heads still are important, causing brine inflows to be greater (typically, and on average) in winter than in summer.

Ute Reservoir also impacts the location and timing of discharges. In the 1960's, with the creation of a continuous major source of head, downward flows would have been established near the lake, and diverting any brine flow which used to discharge in the lake area to an area downstream. Also, the brine aquifer would have been pressurized relatively uniformly over a large area. The probable result of this effect would be to make brine discharges more uniform in time, and perhaps to occur more easterly along the Canadian River than before Ute was built. The data available for the Canadian River gage at Logan confirm that baseflows have increased and become more constant since Ute was built.

In the late 1980's, the rise in reservoir stage would increase the area of downflow, further displacing the zone of brine discharge eastward. Quite likely, this caused the gravel pit reach to substantially increase in importance as a location for brine discharge.

Brine aquifer configuration. An important feature of the cross-section is that the brine aquifer dips westward. Thus, it nears the land surface in the area of the gravel pit reach. This relationship is based on: geologic mapping studies done by the New Mexico State Engineer Office, when Ute Reservoir was being planned; the USBR electrical resistivity study, discussed earlier in this report.

The leakance analysis demonstrates that the gravel pit reach is the area of best connection between the brine aquifer and the Canadian River. This also implies minimal intervening rock units between the aquifer and the river, and thus that the aquifer is relatively near the land surface. However, it is important to note that the gravel pit reach is a very linear topographic feature, which aligns with similarly straight reaches of Revuelto Creek to the south. This alignment must reflect structural control, such as fracturing at the apex of an anticline, or faulting. Consequently, structural features may contribute to the high leakance in the gravel pit reach.

Brine discharge in the gravel pit reach. For practical purposes, the USBR project reports showed the impacts of the brine aquifer being concentrated in the reach between Ute Reservoir and about the railroad bridge, south of Logan. However, as shown on the cross-section, for the February, 1992 survey we have calculated a brine inflow rate of 0.32 cfs/mile in the gravel pit reach, double the inflow upstream.

While this high value was not observed in the September, 1992 stream survey, we have confirmed the probable importance of the gravel pit reach through: USBR piezometer data which show the greatest salinity and stratification in this reach; observations during the February, 1992 stream survey, showing the most briny pools in this reach; reinterpretation of the USBR geophysical data, indicating the brine aquifer should come near the land surface in the reach; and analysis of the water levels at TW-1 (which make the best sense if there is a constant head discharge in the gravel pit reach).

In part, the fact that the USBR reports did not recognize the importance of the gravel pit reach may reflect inaccurate data interpretations (see especially our discussion of the geophysical surveys in this report). However, it probably also is true that the importance of the gravel pit reach has significantly increased since Ute Reservoir was enlarged.

One implication of the cross-section is that most of the brine which is in the Tecovas sandstone in the Logan area discharges to the Canadian River in the first six miles below Ute Reservoir. That is, little of the brine which reaches Logan passes out of the area, except through discharge to the river. The brine which does by-pass the gravel pit reach has a relatively low head and does not flow to the river readily. Based on the cross-section, we would not expect to find important discharges of brine immediately downstream of the gravel pit reach; and, in fact, the stream surveys show no such discharges for many miles. If brines do come into the river downstream of Revuelto, they probably relate to a flow system which is substantially independent of the one at Logan.

<u>Summary of brine flow system</u>. On a regional scale, brine in the Logan area originates in the Permian rocks and flows through the Santa Rosa sandstone eastward to discharge along the Canadian River. Interpreting all of the information presented previously in this report, and in the Ground Water Notebook, two types of discharge occur.

- Significant brine flow occurs upwards through the confining zone in the area from Ute Dam to the railroad bridge-gravel pit reach. Past project reports have described efforts to identify structures that would serve as conduits for brine flow from the Permian section into the brine aquifer and from the brine aquifer to the river. Several features related to salt dissolution and collapse have been identified, but there is no evidence that the local occurrence of brines in the Triassic aquifer is related to those structures. Our interpretation is that the upflow is simply the result of high heads in the brine aquifer, which force flows up through the confining shale and to the river. Pressurizing effects of Ute Reservoir appear to dominate the head distributions in this reach. We speculate that brine inflows are minimal in the area where Ute water moves downward, then are substantial where pressurizing effects of Ute are large, and then decrease eastward as those effects decrease.

- Significant quantities of brine flow laterally through the brine aquifer to the gravel pit reach. The gravel pit reach is a natural discharge zone for the brine because the aquifer is very near the land surface and the overlying confining layer is thinned (removed?) by erosion and/or has a greater vertical hydraulic conductivity because of fracturing. The eastward lateral flow shown on the cross-section reflects a natural head gradient, with highest artesian heads relatively near Ute Reservoir, attenuating toward the gravel pit reach discharge zone.

The real world clearly is more complicated than the above discussion might indicate. For example, at least some small structures undoubtedly exist and do allow localized upflow of brine to be greater in some reaches than in others. Zones of fresh water inflow may displace brines in some areas; density stratification of the brine must have an impact; seasonal variations in head will impact brine inflows; and factors such as local evapotranspiration, recharge and river stage will be important periodically. Analysis of these complications will require more data than now available, and the building of a digital computer model.

<u>HGC mixing-cell model</u>. HGC's mixing-cell model simulated the transport of total dissolved solids between the alluvium and the river, and in this sense also interprets flow conditions. The model was used to predict the effect of salinity control at Logan on the salt load at Lake Meredith. The model's representation was simplified by omitting many of the actual characteristics and processes that affect salt transport within the system. Most of the omissions should not seriously affect the model's validity.

However, some omissions may affect the model's validity. The effect from depressurizing the brine aquifer was simulated simply by reducing the rate of brine inflow to the river. Depressurizing the brine aquifer would not simply reduce the brine inflow rate, but also would reverse the direction of flow between the brine aquifer and the alluvium. The area over which the reversal occurs and the flow rates realized will depend on specifics of the depressurization plan.

The model allows salts to leave the alluvium by discharging to the river but it does not allow salts to leave the alluvium by leaking back to the brine aquifer. As a result, the model overestimates the amount of salt that would reach Meredith after depressurization and the amount of time required to accomplish the improvement.

Stratification of fresh water and brine in the alluvium was neglected and this also may affect the model's validity. Stratification is an inherent part of the system's natural behavior and the model construction and calibration procedure accounted for stratification indirectly, through an empirical transfer coefficient. Reducing the brine discharge will lower the boundary between fresh water and brine and alter the physical process of transfer. The empirical coefficient cannot account for changes in the physical process.

Other features omitted from the model may be accounted for by careful interpretation or may simply be neglected. While these omissions may not be directly important they do increase the difficulty in judging the model's validity.

The model omits tributary flows, ground water gains, brine inflows in Texas and possible saline sources in New Mexico outside of the Logan area. Those omissions are not necessarily critical to the model, but they do require careful interpretation of the model inputs and results.

The model was constructed so that the brine aquifer at Logan provided 70% of the total dissolved solids load to Lake Meredith. The report estimates that 70% of the chloride load at Lake Meredith originates at Logan but the total salt load is not calculated. As discussed in the Surface Water

Notebook, the brine aquifer at Logan probably provides less than 70% of the total salt load.

Evaporation and evapotranspiration were not included in the model. Simple calculations indicate that their effects are not negligible. At an evaporation rate of 70 inches per year and a channel width of 60 feet, the river would lose an average of about 0.06 cfs per mile to direct evaporation. In the reach from Ute Dam to the state line evaporation would total 2.4 cfs; for the entire reach from Ute to Meredith evaporation would amount to 9 cfs.

Evapotranspiration by phreatophytes along the river also can cause the river to lose water (and salt) to the surrounding alluvium. The resulting decrease in the salt load may, especially over dry periods, divert a large part of the river's base flow salt load. This process is probably responsible for an observed reduction in the base flow load between the state line and Tascosa and also is likely to operate at lower reaches on the river. The losses during dry periods may be balanced by salt load gains from the alluvium during periods of rainfall and tributary flow.

<u>Implications for a salinity control project</u>. The analyses presented in this report, and in the Surface and Ground Water Notebooks, indicate that development of a cost-effective salinity control project, through pumping of the brine aquifer, will be very difficult. Downstream factors such as other salinity sources, and uncertain losses of salt are important, but even without considering these, there are at least three significant problems facing anyone who attempts to design and implement a project.

- To the extent that the brine aquifer is impacted by Ute Reservoir, future changes at the reservoir could significantly impact the distribution and amount of brine flows. A project designed to successfully control brine inflows under one scenario of Ute Reservoir operations might fail if the operational pattern changes.

Could the changes at Ute be <u>that</u> significat

- The USBR project concept relies on a low rate of pumping from one or a few wells to depressurize the brine aquifer over a wide area. In turn, this effectively assumes the brine aquifer is rather tightly confined throughout the area. Since confining conditions appear minimal, it is not at all certain that control can be obtained from a simple pumping system. Wells located near Logan may have little effect on reducing brine inflows at the gravel pit reach, and vice versa.

- To even begin to deal adequately with these problems will require a reasonably good computer model of the ground-water flow system. Data sufficient to develop such a model are lacking. Thus, at this time the tools appropriate to designing and implementing a project are not available.

<u>Recommended field testing program</u>. USBR (1985, page e) stated that "additional fieldwork to include exploratory drilling and long-term pump testing is needed to verify the findings presented in this report and effectiveness of the (salinity control) plan". That statement is no less true today than in 1985.

In our view, the most essential location where drilling is needed is the gravel pit reach. There are several reasons why this location is important.

- The brine flow system in the Logan area has a west-east orientation. USBR's deep drilling only tested the system in one location, near Logan, and provides no information on the important variations in the system which occur from west to east. Ideally, the brine aquifer would be tested both west and east of the existing deep-hole locations. However, the area east is much easier to test because the brine aquifer is so shallow.

- The gravel pit reach is obviously an important location of brine discharge. At a minimum, data (such as water level variations in the brine aquifer) need to be developed at this location in order to better interpret the brine flow system. Such data can be obtained only through installation of an observation well.

- It is quite possible that a brine control program would involve pumping at the gravel pit reach; or that the program would require computer modeling of effects at the gravel pit reach. Design and/or interpretation of the control system would require knowing several things about conditions in the gravel pit reach, including: the thickness and fracturing of the confining layer; transmissivity of the brine aquifer; head distribution in the brine aquifer. These conditions can be known only through drilling and testing of at least one well.

At this time, it is appropriate to await the results of BEG's geophysical work before proceeding further. Assuming the results of the BEG study are consistent with the analyses presented in the report, we recommend drilling a single well in the gravel pit reach. The well log would be interpreted with respect to the properties of the confining layer; the well itself could be pumped to determine transmissivity of the brine aquifer; and the well would then be equipped for ongoing monitoring of water levels (and, perhaps, periodic sampling).

We do not recommend drilling this well as a potential brine production facility, as this would increase costs and perhaps reduce data acquisition abilities. If a production well is eventually needed at the gravel pit reach, this observation well also would be required. Even if no salinity control project is constructed, monitoring of conditions at the gravel pit reach is important, especially as CRMWA can reasonably expect changes to occur as Ute Reservoir operations change. In short, nothing is lost if the well is drilled for observation and not production purposes.

Numerous factors bear on the cost of the observation well, including: level of detail in project planning and specifications; the exact site chosen (e.g. a mesa site, with more drilling, or a canyon site with difficult access); casing type (plastic versus stainless steel); whether extensive geophysical logging is done; length and complexity of aquifer test; permanent equipment to be installed (e.g. recorders); extent of data authorized (e.g. simple analytical data reduction versus computer model interpretations); nature of project report; costs of disposing or diluting pumped brine; and level of competitive interest among potential contractors.

For planning purposes, a low-end cost estimate for a well, to include very limited testing, would be $10,000. A high-end estimate would be $25,000. Adding 20% contingency to both estimates gives a budget range of $12,000 to $30,000. Given the importance of the well, we recommend that if the well is approved, the higher budget estimate be adopted.