SAN LUIS VALLEY
CONFINED AQUIFER STUDY
PHASE ONE

FINAL REPORT

APPENDIXES

PREPARED BY
HRS Water Consultants, Inc.

August 1987
APPENDIXES

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SAN LUIS VALLEY CONFINED AQUIFER STUDY
(PHASE I)
INTERIM TASK 1 REPORT
WATER DEMANDS/ECONOMIC ANALYSES

Prepared for
Colorado Water Resources and Power Development Authority
Logan Tower, Suite 620
1580 Logan Street
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Project No. 4332 August 19, 1986

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JOHN C. HALEPASKA & ASSOCIATES, INC.,
ROBERT E. MORAN AND ROBERT A. YOUNG
August 22, 1986

Mr. Ralph L. Kerr  
Project Manager  
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Logan Tower Building, Suite 620  
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Subject: San Luis Valley Confined Aquifer Study, South-Central Colorado: Submittal of Final Interim Task 1 Report.  
Project No. 4332, Task 1  

Dear Skip:

As requested, we are pleased to submit one camera-ready copy of our final Interim Task 1 Report entitled "Water Demands/Economic Analyses". To the extent possible, we have incorporated your final review comments received orally on August 18, 1986.

Yours truly,

Timothy D. Steele, Ph.D.  
Water Resources Manager and Associate  

TDS: kot  
Enclosure  
(See Page 2 for Distribution)
Mr. Ralph L. Kerr  
August 22, 1986  
Page 2

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ACRONYMS AND ABBREVIATIONS

af, acre-feet
af/a, acre-feet/acre
af/a/y, acre-feet/acre/year
af/y, acre-feet/year
bu, bushel
cwt, one-hundred weight
gpm, gallons per minute
gpd/ft, gallons per day per foot
kwh, kilowatt-hour
mgd, million gallons per day
t, ton
USBR, The United States Bureau of Reclamation
USGS, The United States Geological Survey
The purpose of this task of the San Luis Valley Confined Aquifer Study is to: (1) evaluate existing and future demands for water obtained from the deep confined aquifer; (2) estimate unit annual costs to develop various annual water withdrawals; and (3) assess the current and future range of market values for various types of water use associated with the deep confined aquifer in the San Luis Valley of south-central Colorado. The information on water demand and market prices is compared with estimated annualized construction, operation and maintenance costs. From this comparison, the preliminary assessment of the ability of a development project involving the deep confined aquifer to pay for itself is made. Estimates of water demands, unit annual costs and market prices were done parametrically so that a large number of combinations are available for evaluation.

A brief literature review is included to summarize the documents available relating to water demands, water values and potential project costs. Water demands and water use in the San Luis Valley have been summarized by Siebenthal (1910), the U.S. Soil Conservation Service (1969), Huntley (1976), the U.S. Bureau of Reclamation (1979), Radosevich and Rutz (1979), Simpson and others (1980), the U.S. Army Corps of Engineers (1983), Steffen, Robertson and Kirsten (Colorado) Inc. (1985), and Salazar (1986). Economic analyses of water use and water market values also appear in several of the above reports as well as in Johnson (1975) and Skaggs (1985). Because of the everchanging water demand and economic variables in the San Luis Valley, the above references were used with certain qualifications in making the estimates presented in this report.
2.0 CURRENT WATER DEMANDS

Water demands in the San Luis Valley currently involve agriculture, domestic municipal and non-municipal use and Rio Grande Compact delivery demands. No current water demands are known to exist in the Valley for industrial use or hydroelectric power.

2.1 MUNICIPAL DEMANDS

Municipal water demands in the San Luis Valley are based upon population estimates available from the U.S. Census Bureau for the counties of Alamosa, Conejos, Costilla, Mineral, Rio Grande and Saguache (Table 2.1). Since 1900, population in the Valley has increased, reaching a maximum in 1940 and decreasing through 1970. Population trends since 1980 indicate a slight increase in population, with the estimated 1985 population for the Valley of 40,000, which is approximately the same as the Valley's population in 1930 (Table 2.1). These erratic population time trends are consistent with the agricultural nature of the Valley and the general pattern of young-adult migration from the Valley over recent periods in search of employment.

Table 2.1 estimates municipal water demands based upon population for the period 1900 through 1985, assuming a per-capita water demand of 250 gallons per day. It is understood that not all the Valley population derives its water supply through a municipal water system. However, basing municipal water demand on population appears to be a good estimator. As will be seen later, the total municipal water demand based upon population estimates is small compared to the aggregate agricultural water demand. Estimated 1985 municipal water demand was approximately 11,200 acre feet per year (af/y), if all the population of the Valley were to derive its domestic water supply from a municipal system.
TABLE 2.1
San Luis Valley Population and Municipal Water Demand Trends (5)

<table>
<thead>
<tr>
<th>Year</th>
<th>Population (1)</th>
<th>Municipal Water Demand (3) (af/y)</th>
<th>Percent Change (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1900</td>
<td>23,272</td>
<td>6,517</td>
<td>--</td>
</tr>
<tr>
<td>1910</td>
<td>28,745</td>
<td>8,050</td>
<td>23.5</td>
</tr>
<tr>
<td>1920</td>
<td>31,868</td>
<td>8,925</td>
<td>10.9</td>
</tr>
<tr>
<td>1930</td>
<td>41,037</td>
<td>11,493</td>
<td>28.8</td>
</tr>
<tr>
<td>1940</td>
<td>49,217</td>
<td>13,783</td>
<td>19.9</td>
</tr>
<tr>
<td>1950</td>
<td>45,963</td>
<td>12,872</td>
<td>-6.61</td>
</tr>
<tr>
<td>1960</td>
<td>38,704</td>
<td>10,839</td>
<td>-15.8</td>
</tr>
<tr>
<td>1970</td>
<td>37,466</td>
<td>10,493</td>
<td>-3.19</td>
</tr>
<tr>
<td>1980 (6)</td>
<td>37,914</td>
<td>10,618</td>
<td>1.19</td>
</tr>
<tr>
<td>1985 (4)</td>
<td>40,107</td>
<td>11,232</td>
<td>5.78</td>
</tr>
</tbody>
</table>


(2) Percent change from previous number.

(3) Assuming a demand of 250 gallons per person (equivalent) per day.

(4) July 1985 estimates by the State of Colorado.

(5) For Alamosa, Conejos, Costilla, Mineral, Rio Grande and Saquache Counties.

(6) San Luis Valley Regional Planning and Development Commission.
Current agricultural water demands in the San Luis Valley were based upon inventories of current irrigated cropland totaling approximately 638,000 acres. This assessment of agricultural water demands and associated irrigated acreages has been derived from a detailed inventory by Salazar (1986). The total irrigated acreage is composed of approximately 39 percent irrigated pasture, 32 percent alfalfa and other hay, 17 percent barley, with the remaining 12 percent in grain oats, potatoes, spring wheat and vegetables. Agricultural statistics for 1960 through 1984 indicate that the total crop acreage during the period has increased from a low of about 305,000 acres in 1962 to nearly 420,000 acres in 1984, exclusive of irrigated pasture. Potato, spring wheat and barley acreages have substantially increased since 1960 at the expense of grain oats, alfalfa and other hay. Since 1974, spring wheat and potato acreages have more than doubled in the San Luis Valley.

Table 2.2 shows estimated water demands for the typical cropping patterns in the San Luis Valley. Estimated water demands were based upon consumptive-use estimates, reported irrigation efficiencies, and effective precipitation. It should be kept in mind that the agricultural water demands as considered in this study do not reflect on the water users' ability or willingness to pay for the resource. The unit water demands associated with irrigated agriculture were calculated by dividing estimated annual demand by the number of acres of irrigated crop. On the average, approximately 3.2 acre feet of water per acre of land (af/a) are needed to produce crops in the San Luis Valley. Of this amount, approximately 1.6 af/a is consumptively used by the plants, with the remaining 1.6 af/a going to other losses and return flows. The largest uncertainty in the volumes shown in Table 2.2 is associated with irrigated pasture. Estimates of total irrigated pasture acreage in the San Luis Valley range from 189,400 acres to over 247,000 acres. The actual irrigated pasture acreage is probably somewhere within this range. Also, estimates of evapotranspiration and irrigation efficiency for irrigated pasture assume that the pasture has received an adequate water supply. In some cases, farmers forego irrigation of pasture grasses, or these grasses receive only one irrigation per season because of limited water supplies in some years. The estimated unit water demands for irrigated crops in the San Luis Valley (Table
**TABLE 2.2**

Summary of Current Irrigated Cropland and Agricultural Water Demands in the San Luis Valley (1)

<table>
<thead>
<tr>
<th>Crop</th>
<th>Acres</th>
<th>Percent of Total</th>
<th>Estimated Water Demand (af/y)</th>
<th>(af/a/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alfalfa Hay</td>
<td>111,800</td>
<td>18</td>
<td>402,500</td>
<td>3.6</td>
</tr>
<tr>
<td>Other Hay</td>
<td>88,900</td>
<td>14</td>
<td>337,800</td>
<td>3.8</td>
</tr>
<tr>
<td>Barley</td>
<td>105,500</td>
<td>17</td>
<td>211,000</td>
<td>2.0</td>
</tr>
<tr>
<td>Grain Oats</td>
<td>10,700</td>
<td>2</td>
<td>23,500</td>
<td>2.2</td>
</tr>
<tr>
<td>Potatoes</td>
<td>40,600</td>
<td>6</td>
<td>73,100</td>
<td>1.8</td>
</tr>
<tr>
<td>Spring Wheat</td>
<td>28,400</td>
<td>4</td>
<td>59,600</td>
<td>2.1</td>
</tr>
<tr>
<td>Vegetables</td>
<td>4,900</td>
<td>&lt;1</td>
<td>14,200</td>
<td>2.9</td>
</tr>
<tr>
<td>Irrigated Pasture</td>
<td>247,200</td>
<td>39</td>
<td>939,000</td>
<td>3.8</td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
<td>638,100(4)</td>
<td>100</td>
<td>2,060,700</td>
<td>3.2(3)</td>
</tr>
</tbody>
</table>

**Consumptive Use** 1.6
**Losses & Return Flows** 1.6

---

(1) Adapted from Salazar (1986).

(2) Consumptive use divided by irrigation efficiency minus effective precipitation.

(3) Total demand divided by acres of irrigated crop land.

(4) All acreages rounded to nearest 100 acres; hence, total does not equal sum of individual crop acreages.
2.2) range from 1.8 acre feet per acre per year (af/a/y) for potatoes to 3.8 af/a/y for irrigated pasture and hay. The total estimated irrigation water demands in the San Luis Valley may be over 2 million af/y, based upon the estimate of about 638,000 irrigated acres. In years of below-normal water availability, probably as few as 500,000 acres are irrigated in the Valley, implying an estimated water demand of 1.6 million af/y under these conditions. If irrigated pasture were not considered in the estimates in Table 2.2, the annual estimated water demands are about 1,120,000 af/y, with a unit water demand averaging about 2.9 af/a/y.

2.3 RIO GRANDE COMPACT DEMANDS

The Rio Grande Compact of 1937 was signed by representatives of the States of Colorado, New Mexico and Texas on March 18, 1938. Minor changes have been made to the Compact in 1948 and 1966. Although the Compact was not strictly administered until 1968, it is very much in effect in recent times and essentially provides a downstream delivery obligation by the State of Colorado to the States of New Mexico and Texas. Due to large debits that were accrued by the mid-1960s, a stipulation was entered into by the three signatory states in 1968 in which the State of Colorado agreed to deliver each year's Compact commitment without building any further debt of water. Since 1968, the Colorado State Engineer has had the duty to curtail Colorado's water use in the Valley as necessary in order to meet the delivery requirements for each particular year. The Compact was intended to allocate surplus water and was not supposed to affect pre-Compact (pre-1937) water rights. However, since 1968, a severe curtailment of pre-Compact water rights has occurred in most years (however, not in 1986) in order to meet the Compact delivery requirements. One of the reasons for this curtailment has been the extensive water-well development that occurred in the San Luis Valley during the 1950s and 1960s. These ground-water rights have been more difficult to administer than surface-water diversions. This development, therefore, contributed largely to a situation whereby junior water rights (the wells) were being allowed to use water; whereas, senior water rights (some with priority dates as early as 1855) were curtailed in order to meet the provisions of the 1937 Compact (Steffen, Robertson and Kirsten (Colorado), Inc., 1985).
Two Rio Grande Compact administration tables exist for the State of Colorado: one for the Rio Grande mainstem and another for the Conejos River. The courts have ruled that these tables must be applied separately, requiring a separate delivery obligation from each sub-basin. Therefore, water demands used in this study show the Compact deliveries from the Conejos River and Rio Grande separately. Table 2.3 shows the historical annual deliveries to the Rio Grande Compact from the Conejos River and Rio Grande sub-basins. Since 1968, the historical Compact deliveries have averaged about 305,000 af/y, of which about 39 percent is from the Conejos River sub-basin with the remaining 61 percent from the Rio Grande sub-basin. A critical time of the year for agricultural water users occurs during the April-through-October irrigation season. Table 2.4 summarizes the historical April-through-October deliveries from both the Conejos River and Rio Grande sub-basins. Annual deliveries since 1968 for the April-through-October irrigation season average about 211,000 af, of which about 44 percent came from the Conejos River sub-basin, with the remaining 56 percent from the Rio Grande sub-basin. As indicated in Table 2.4 about, 61 percent of the total annual Compact delivery occurs during the April-through-October irrigation season.

For purposes of this study, it was assumed that the historical Compact deliveries were a measure of Compact demand (hence, the term "deliveries" is analogous to "demand"). Even though the 1985 delivery under the Compact terms was zero and no anticipated delivery should occur in 1986, average historical deliveries are considered to be an indicator of potential future compact-related deliveries. Therefore, an average Rio Grande Compact demand of between 211,000 af (April-through-October) and 305,000 af (annual) does not appear unreasonable.

2.4 SUMMARY

As indicated by the above review of available information, existing water demands for municipal water use in the San Luis Valley are small compared to agricultural use. Municipal water demands may average about 11,200 af/y. Agricultural water demands may be near 2,000,000 af/y, based upon 638,000 acres of irrigated acres with an average demand of 3.2 af/a/y of irrigated land.
### TABLE 2.3
Historical Annual Deliveries to
Rio Grande Compact

<table>
<thead>
<tr>
<th>Year</th>
<th>Conejos River (1000 af)</th>
<th>Rio Grande (1000 af)</th>
<th>Total (1000 af)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1968</td>
<td>116.7</td>
<td>214.1</td>
<td>330.8</td>
</tr>
<tr>
<td>1969</td>
<td>168.7</td>
<td>246.4</td>
<td>415.1</td>
</tr>
<tr>
<td>1970</td>
<td>109.4</td>
<td>214.1</td>
<td>323.5</td>
</tr>
<tr>
<td>1971</td>
<td>50.1</td>
<td>156.7</td>
<td>206.8</td>
</tr>
<tr>
<td>1972</td>
<td>32.7</td>
<td>129.6</td>
<td>162.3</td>
</tr>
<tr>
<td>1973</td>
<td>188.9</td>
<td>331.8</td>
<td>520.7</td>
</tr>
<tr>
<td>1974</td>
<td>32.7</td>
<td>88.8</td>
<td>121.5</td>
</tr>
<tr>
<td>1975</td>
<td>193.0</td>
<td>273.7</td>
<td>466.7</td>
</tr>
<tr>
<td>1976</td>
<td>89.9</td>
<td>159.1</td>
<td>249.0</td>
</tr>
<tr>
<td>1977</td>
<td>11.3</td>
<td>49.9</td>
<td>61.2</td>
</tr>
<tr>
<td>1978</td>
<td>69.4</td>
<td>105.1</td>
<td>174.5</td>
</tr>
<tr>
<td>1979</td>
<td>231.3</td>
<td>394.5</td>
<td>625.8</td>
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<tr>
<td>1980</td>
<td>212.1</td>
<td>239.6</td>
<td>451.7</td>
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<td>1981</td>
<td>32.5</td>
<td>99.0</td>
<td>131.5</td>
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<tr>
<td>1982</td>
<td>232.5</td>
<td>207.2</td>
<td>439.7</td>
</tr>
<tr>
<td>1983</td>
<td>179.8</td>
<td>207.9</td>
<td>387.7</td>
</tr>
<tr>
<td>1984</td>
<td>172.7</td>
<td>242.4</td>
<td>415.1</td>
</tr>
<tr>
<td>1985</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1986</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Mean: 118.0 | 186.7 | 304.6
Std. Dev.: 80.4 | 98.8 | 173.8
Maximum: 231.3 | 394.5 | 625.8
Minimum: 0 | 0 | 0

(1) Source: Rio Grande Compact Commission reports.

(2) Estimated by Division 3 Engineer (not included in statistical summaries).
<table>
<thead>
<tr>
<th>Year</th>
<th>Conejos River (1000 af)</th>
<th>Rio Grande (1000 af)</th>
<th>Total (1000 af)</th>
<th>Percent of Annual Delivery (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1968</td>
<td>81.9</td>
<td>148.7</td>
<td>230.6</td>
<td>69.7</td>
</tr>
<tr>
<td>1969</td>
<td>128.8</td>
<td>136.0</td>
<td>264.8</td>
<td>63.8</td>
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<tr>
<td>1970</td>
<td>69.7</td>
<td>114.8</td>
<td>184.5</td>
<td>57.0</td>
</tr>
<tr>
<td>1971</td>
<td>12.6</td>
<td>61.9</td>
<td>74.5</td>
<td>36.0</td>
</tr>
<tr>
<td>1972</td>
<td>1.4</td>
<td>46.3</td>
<td>47.7</td>
<td>29.4</td>
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<tr>
<td>1973</td>
<td>164.3</td>
<td>249.4</td>
<td>413.7</td>
<td>79.4</td>
</tr>
<tr>
<td>1974</td>
<td>12.0</td>
<td>26.9</td>
<td>38.9</td>
<td>32.0</td>
</tr>
<tr>
<td>1975</td>
<td>150.8</td>
<td>198.0</td>
<td>348.8</td>
<td>74.7</td>
</tr>
<tr>
<td>1976</td>
<td>69.4</td>
<td>97.0</td>
<td>166.4</td>
<td>66.8</td>
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<td>0.7</td>
<td>15.7</td>
<td>16.4</td>
<td>26.8</td>
</tr>
<tr>
<td>1978</td>
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<td>55.4</td>
<td>115.1</td>
<td>66.0</td>
</tr>
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<td>1979</td>
<td>215.3</td>
<td>347.5</td>
<td>562.8</td>
<td>89.9</td>
</tr>
<tr>
<td>1980</td>
<td>195.0</td>
<td>172.1</td>
<td>367.1</td>
<td>81.3</td>
</tr>
<tr>
<td>1981</td>
<td>14.5</td>
<td>36.7</td>
<td>51.2</td>
<td>38.9</td>
</tr>
<tr>
<td>1982</td>
<td>205.6</td>
<td>132.6</td>
<td>338.2</td>
<td>76.9</td>
</tr>
<tr>
<td>1983</td>
<td>148.8</td>
<td>136.0</td>
<td>284.8</td>
<td>73.4</td>
</tr>
<tr>
<td>1984</td>
<td>142.3</td>
<td>153.3</td>
<td>295.6</td>
<td>71.2</td>
</tr>
<tr>
<td>1985</td>
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<td>--</td>
</tr>
<tr>
<td>1986(2)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>--</td>
</tr>
</tbody>
</table>

Mean | 92.9 | 118.2 | 211.2 | 60.8 |
Std. Dev. | 76.8 | 88.9 | 160.0 | 20.2 |
Maximum | 215.3 | 347.5 | 562.8 | 89.9 |
Minimum | 0 | 0 | 0 | 26.8 |

(1) Source: Rio Grande Compact Commission reports.

(2) Estimated by Division 3 Engineer (not included in statistical summaries).

(3) Annual delivery shown in Table 2.3.
During dry years (below-normal precipitation), the demand may decrease to 1,600,000 af/y. Historical Rio Grande Compact deliveries have averaged 305,000 af/y with 211,000 af/y being provided, on the average, during the April-through-October irrigation season.
3.0 FUTURE WATER DEMANDS

3.1 MUNICIPAL DEMANDS

For purposes of this report, municipal water demands as indicated by Valley population are expected to increase, but with total demand remaining substantially less than agricultural demand (less than 1 percent). Therefore, we have estimated future municipal water demands to be similar or only slightly larger than existing municipal water demands, or approximately 14,000 af/y as a maximum. Hence, new municipal demands might be on the order of 3000 af/y.

3.2 AGRICULTURAL DEMANDS

Estimates of future agricultural water demands in the San Luis Valley were derived predominately from existing lands under irrigation whose water supply would either be curtailed by Compact deliveries or from a general reduction in surface-water supplies during drought years. Additionally, new lands are available which could be placed under irrigation if agricultural-product market prices were favorable.

Estimates have been made of presently irrigated lands in the San Luis Valley that are in need of supplemental irrigation supplies. Several estimates have been made, including those by the Rio Grande Water Conservation District (Ralph Curtis, personal communication, June 9, 1986) and HRS Water Consultants, Inc. (1984). The estimates of presently irrigated lands in need of supplemental irrigation ranges from 30,000 to 50,000 acres per year, although probably none of this land is irrigated pasture but rather is crop land growing hay, barley, grain oats, potatoes, spring wheat or vegetables. There may be over a 100,000 acres of irrigated pasture which does not receive an adequate water supply and would be available to receive supplemental irrigation water from a deep confined aquifer project. Exclusive of irrigated pasture, the annual unit water demand for the typical crop mix shown in Table 2.2 would be
about 2.9 af/a/y. If one-half of this unit irrigation demand (about 1.5 af/a/y came from a supplemental supply from deep confined aquifer wells, then the annual demand might range from 45,000 to 75,000 af/y for the 30,000 to 50,000 acres requiring such supplemental irrigation.

There appears to be no shortage of potential agricultural land in the San Luis Valley. However, development of new land requires large expenditures for land preparation (typically $40,000 to $50,000 for a 130-acre center pivot irrigation system) (LeRoy Salazar, personal communication, June 9, 1986). During the past several years, lower farm commodity prices have reduced the willingness of agriculturalists to expand their acreages under irrigation in the San Luis Valley. Estimates by the Rio Grande Water Conservation District (Ralph Curtis, personal communication, June 9, 1986) and HRS Water Consultants, Inc. (1984) indicate that between 40,000 and 75,000 acres of new land could be brought under irrigation with only minor favorable price adjustments in the farm-commodities picture. Assuming that these lands were used for irrigated crops other than irrigated pasture, at an annual unit demand of 2.9 af/a/y, the demand for water to irrigate these new lands would range from 116,000 to 218,000 af/y.

3.3 RIO GRANDE COMPACT DEMANDS

Future demands to deliver water under the Rio Grande Compact are based on historical deliveries to the Compact as summarized in Tables 2.3 and 2.4. Historical deliveries ranged from 0 af in 1985 to over 625,000 af in 1979, and averaged approximately 305,000 af/y for the period 1968 through 1985. Annual April-through-October deliveries were somewhat less, with a minimum of 0 af in 1985 and a maximum of nearly 563,000 af in 1979, averaging about 211,000 af/y for the 1968-through-1985 period of record. For purposes of this analysis, the historical Compact deliveries were assumed to be representative of those occurring over longer-term hydrologic conditions and to repeat themselves in the future. Therefore, annual deliveries are expected to average approximately 300,000 af/y and may range from a maximum of nearly double the average to zero for any given year.
In order to estimate future likely Compact demands, a log-normal probability distribution was fit to the annual and April-through-October deliveries (Tables 2.3 and 2.4) to estimate a likely delivery which would have to be met most of the time. The annual delivery occurring 90 percent of the time, based upon data in Table 2.3, is about 130,000 af/y. The April-through-October delivery occurring 90 percent of the time, based upon Table 2.4, is about 70,000 af/y.

3.4 CLOSED BASIN PROJECT

The U.S. Bureau of Reclamation's (1975; 1984) Closed Basin Project is undergoing completion of its final planned stages and may affect future-related Compact demands as well as in-Valley water uses. This is designed as a water-salvage project by lowering water levels in the shallow, unconfined aquifer through pumping, thereby reducing the evapotranspiration losses in the Project area. According to a USBR spokesman (Larry Parsons, personal communication, March 26, 1986), the expected maximum Closed Basin annual pumpage rates are allocated as follows:

1. 60,000 af/y to meet Colorado's commitment under the Rio Grande Compact

2. 5,300 af/y for wildlife mitigation

3. 35,300 af/y used to pay off any carryover Compact debts, or available for in-Valley use if the Compact debt has been reduced to zero (as is the case as of 1986)

Upon project completion, the first water amount (item 1) presumably could be conveyed to the Rio Grande, thereby reducing the previously described Rio Grande Compact demand reflected in historical (1968-1985) deliveries. The third water amount (item 3) would be available for in-Valley uses (predominantly for irrigated agriculture) during those years when no Compact debt exists. Given the recent years' high flows in the Rio Grande, this debt is now zero, and up to 35,300 af/y pumped from the Project area would be available to meet future water demands.
3.5 SUMMARY

Based on the above assessment, potential future water demands used as a basis for the economic analyses and future project demands are summarized as follows:

1. Municipal demand: 3,000 af/y (new demand)

2. Agricultural demand: 45,000 to 75,000 af/y (supplemental)
   116,000 to 218,000 af/y (new lands)

3. Rio Grande Compact demand: 70,000 to 130,000 af/y (90 percent probability)

4. Water salvaged through the USBR's Closed Basin Project potentially could reduce projected demands given in the above items

Combinations of these future water demands could result in a maximum annual water demand of 437,000 af/y and a maximum April-through-October water demand of 377,000 af/y. In this study task, the proposed deep confined aquifer water-development project and associated economic analyses used a range of annual deep confined aquifer withdrawals of between 50,000 and 300,000 af/y. The maximum withdrawal of 300,000 af/y is judged to be an upper limit based upon professional judgments on aquifer hydraulic characteristics, as well as realistic well spacing and well yields in the Valley. For the parametric cases examined in this study-task report, the considered range of future water demands were assumed to be uniformly distributed throughout the year (see Cost-Sensitivity Analyses below).
4.0 POTENTIAL WATER DEVELOPMENT PROJECTS AND ECONOMIC ANALYSES

Development of the San Luis Valley deep confined aquifer system would entail pumpage of the water from a wellfield located somewhere in the Valley. For purposes of this preliminary analysis, it was assumed that the wellfield would be centered at Hooper (Figure 4.1), although a typical wellfield could be located nearly anywhere in the Valley. To assess the economic impacts of pumping the wellfield, several assumptions regarding the depth and spacing of wells and the hydraulic characteristics of the deep confined aquifer system were made. The sensitivity of the assumptions are discussed in the following sections.

4.1 GENERAL CHARACTERISTICS

The costs of obtaining water from the deep confined aquifer system are sensitive to pumping lift, which is a function of annual water withdrawals as well as the estimated aquifer hydraulic properties. To estimate pumping lift, a preliminary analysis of the expected maximum wellfield drawdowns for various values of annual withdrawals, aquifer transmissivity, well spacing and individual well pumping rates was done. Figure 4.2 shows the number of pumping wells in a typical wellfield for annual withdrawals from the deep confined aquifer ranging from zero to 300,000 af/y, and for individual wells pumping 1000, 1500 and 2000 gallons per minute (gpm). For a typical annual withdrawal of 200,000 af/y, 124 wells pumping 1000 gpm would be needed. If the individual well pumping rate were increased to 1500 gpm, the same 124 wells would produce about 300,000 af/y. This 300,000 af/y also could be produced by 93 wells pumping at an average rate of 2000 gpm. Previous estimates from wells producing 3000 gpm (HRS Water Consultants, Inc., 1984) indicated that 62 wells would be needed to pump 300,000 af/y under their study assumptions.

Aquifer hydraulic characteristics of the deep confined system in the San Luis Valley are largely unknown. For purposes of our analysis, we have assumed that the transmissivity of the deep confined aquifer below 3000 feet would average 25,000 gallons per day per foot (gpd/ft), and above 3000 feet would average 250,000 gpd/ft. The higher transmissivity at shallower depths is in
general conformance with an areal map of transmissivities of the upper 1500 feet of the confined aquifer by Emery, Snipes, Dumeyer, and Klein (1973, Plate 7), which was based upon 36 Theis-recovery tests and flow-meter data, the latter being adjusted for the perforated intervals of the tested wells. The USGS analog-model study assumed a uniform transmissivity of approximately 300,000 gpd/ft for its "lower" (that is, approximately 1620 to 3120 feet below land surface) confined aquifer layer. The lower transmissivity at greater depths was based primarily upon professional judgment, with the consensus that transmissivities may well be a order of magnitude less at the depths considered in this analysis. Also, earlier artesian-well transmissivities values ranged about the smaller assumed value (Powell, 1958). The storativity was assumed to be on the order of 0.0001 (or 10⁻⁴). This represents an average value for confined aquifers reported by Driscoll (1986) and is compared to a 0.008 storativity value assumed by Emery, Patten, and Moore (1975) in the USGS analog-model study.

We have estimated the drawdown in typical wellfields for wells having pumping rates of 1000, 1500 and 2000 gpm for the above assumed transmissivities as well as for well spacings of 5 miles and 2 miles. Results of our analyses for the 5-mile well spacing is shown on Figure 4.3 for wells having pumping rates of 1000 and 2000 gpm, transmissivities of 25,000 and 250,000 gpd/ft, and annual withdrawals ranging from 50,000 to 300,000 af/y. In all cases of the drawdown estimates, we assumed that the deep confined aquifer was infinite in areal extent and that the initial water surface was coincidental with the land surface. Therefore, the maximum wellfield drawdowns shown on Figure 4.3 represent depths below ground surface.

Drawdowns for the deep confined aquifer in the San Luis Valley having a transmissivity of 25,000 gpd/ft ranges from about 700 feet (ft) to over 3,000 ft, depending on the pumping rate of the individual wells. For an assumed transmissivity of 250,000 gpd/ft, drawdowns ranged from about 100 to slightly over 500 ft, depending on the pumping rates of individual wells. The above drawdowns assume continuous pumping for a period of ten years. It was judged reasonable that if the project life was 30 years, then maximum drawdowns at the 10-year time period would be representative of average wellfield drawdowns over the assumed 30-year lifetime of the project. When the well spacing was decreased from 5 miles to 2 miles with aquifer characteristics as pre-
viously assumed, drawdowns generally doubled for the larger annual withdrawal rates at the end of one year and were about 50 percent greater at the end of 10 years of pumping (Figure 4.3).

The assumption that the deep confined aquifer is infinite in areal extent will tend to produce a best-case scenario in terms of pumping lift. Physically, it is realized that the deep confined aquifer is bounded, and therefore expected pumping lifts could be greater than those predicted by the assumption of infinite areal extent. Because there are no data on aquifer hydraulic characteristics for the deep confined system, it was judged that a more complete analysis using boundary conditions on the aquifer was not warranted.

For the economic analyses performed below, we used the drawdowns calculated at the end of ten years of continuous pumping for a wellfield having a 5-mile well spacing, well pumping rates of 2000 gpm, and a transmissivity of 25,000 gpd/ft. The drawdowns for these assumptions for various annual withdrawals ranging from 50,000 to 300,000 af/y are shown as the uppermost curve on Figure 4.3. These drawdowns range from about 900 ft for an annual withdrawal rate of 50,000 af/y to over 3,000 ft for an annual withdrawal rate of about 300,000 af/y. Our economic analyses also assumed that pumping would be year-round. The above assumptions generally conform to a reasonable but quite severe case involving water withdrawals from the deep confined aquifer system in the San Luis Valley. The consequences of these assumptions are examined below in the sensitivity analyses.

4.2 POTENTIAL WATER-DEVELOPMENT PROJECTS

Two potential water-development projects (Base Cases 1 and 2) have been identified for purposes of this study, based upon the above-described future water demands in the San Luis Valley. These projects have been analyzed at selected levels of annual withdrawal from the deep confined aquifer ranging from 50,000 to 300,000 af/y. Both of the potential projects would have a wellfield ranging from 16 to 124 wells (excluding standby wells) completed at average depths of either 3000 or 5000 ft below ground surface. The first project
(Base Case 1) would have 5000-ft deep wells and discharge its water to existing facilities for transport from the wellfield to its point of use. Because the exact location of the wellfield is unknown as well as the exact points of use, existing ditches and canals were assumed for transport to in-Valley use locations. The second project (Base Case 2) is similar to Base Case 1 except the wells are 3000 ft in depth.

An additional separate cost analysis was made whereby differing quantities of San Luis Valley deep confined aquifer water would be transported into the Arkansas River. The intent of the water-export addition to the base cases was to assess the feasibility of sale of a part of the San Luis Valley developed water to help defray the costs of project development for in-Valley use. Realistically, the water transported out of the Valley would be sold at prices substantially higher than the value of that same amount of water if used in the Valley, and such export could help to subsidize in-Valley water use.

Because the exact location of the proposed wellfield, points of use and quantities of use are not known with any degree of certainty, the in-Valley project consists of a generic wellfield, which for cost estimating purposes was assumed to be centered in the vicinity of Hooper (Figure 4.1). Changes in the location of the wellfield, while effecting costs slightly, would not in our opinion change the overall cost structure of a typical potential Valley project.

Because of the relative uncertainty as to the actual water demands in the San Luis Valley coupled with the anticipated value of water used for agriculture (the largest potential demand), it was assumed that part of the water pumped from the deep confined aquifer wellfield would be transported out of the Valley into the Arkansas River for subsequent transport and sale at prevailing Colorado Front Range municipal prices. This addition to the base-case projects has two alternative pipeline routes from the wellfield centered at Hooper (Figure 4.1). The first pipeline route is north along State Route 17 to U.S. 285 to the top of Poncha Pass and ends at the Arkansas River at Poncha Springs, comprising a distance of about 56 miles and an elevation change of approximate-
ly 1460 feet. At Poncha Pass, the pipeline would flow by gravity to confluence with the Arkansas River near Poncha Springs. An alternate pipeline route of 49 miles also would follow State Route 17 to U.S. 285 as far as Villa Grove, and then proceed east over the Sangre de Cristo Mountains through Hayden Pass (Figure 4.1). The pipeline then would flow by gravity into the Arkansas River near Coaldale. The elevation change of this alternative route is 3350 feet.

4.3 FINANCIAL ANALYSES

The economic analyses presented below examine the costs of pumping deep confined aquifer water from the wellfield in the San Luis Valley without delivering the water to any specific location within the Valley, and transport of all or any of the water outside the Valley. The average annual withdrawals from the deep confined aquifer system were assumed to range from 50,000 to 300,000 af/y. In-Valley costs were estimated for project construction, including the cost of wells, pumps and interwell pipe. For transport outside the basin, costs for booster stations and a transportation pipeline were estimated. Also included were interest during construction, start-up costs, working capital, owners' general expense, and land costs. Annual operation and maintenance costs including labor, supplies and materials, along with electric power costs were estimated. These costs were annualized with the total annual costs including annual operation and maintenance (O&M), annual depreciation and non-depreciation capital costs. Unit annual costs were obtained by dividing the total annual cost ($) by the annual water withdrawal (af). These unit annual costs ($/af) thus formed the basis for comparison of different project alternatives. The cost estimates were made using the computer-program COST as described in Appendices A and D. The detailed cost estimates for Base Case 1 and Base Case 2 are shown in Appendix B, along with the detailed cost estimates for the transport to the Arkansas River by two alternative routes.

Certain cost factors were assumed to be constant for each base case and transport additions, although they were allowed to vary during the sensitivity analyses. These cost factors include the following assumed values: $0.065/kilowatt-hour (kWh) for electricity, 70 percent pumping efficiency, pipe-
friction coefficient of 135, land costs of $1000 per acre, annual interest rate of 7 percent, annual insurance rate of 1 percent, and an annual tax rate of 0.25 percent. The unit power cost was judged to be representative of electricity made available to irrigators in the Valley (Ralph Curtis, personal communication, June 9, 1986). The assumed pumping-efficiency level incorporates a number of physical and time-dependent factors and is judged to represent a realistic average value. The pipe-friction coefficient was based upon professional engineering judgment. The economic-based cost factors were judged to represent reasonable average values. The 7 percent annual interest rate represents a non-inflationary rate judged depicting the average cost of obtaining capital for water-development projects by private-sector interests. Annualized costs were amortized over an assumed 30-year project life. Figure 4.4 shows the results of the water-development cost estimates in terms of unit annual costs in both dollars per acre-foot ($/af) and cents per thousand gallons versus annual withdrawals from the deep confined aquifer.

Base Case 1 consists of 5000-ft deep wells pumping 2000 gpm, a transmissivity of 25,000 gpd/ft, storativity of $10^{-4}$ and a 5-mile well spacing. Annual unit costs of water for annual withdrawals ranging from 50,000 to 300,000 af/y vary from $123/af to $318/af to bring the water to the surface without transport (Figure 4.4). Base Case 2 consists of 3000-ft deep wells pumping 2000 gpm, a transmissivity of 250,000 gpd/ft, storativity of $10^{-4}$ and a 5-mile well spacing. Annual unit costs of water for annual withdrawals ranging from 50,000 to 300,000 af/y vary from $42/af to $79/af to bring the water to the surface without transport (Figure 4.4). If all or a part of the annual withdrawals was transported to the Arkansas River, additional annual unit costs would be incurred. These additional annual unit costs would range from $314/af to $526/af for transport via Poncha Pass, depending on the annual quantities transported (Figure 4.5). Via Hayden Pass, the annual unit costs would range from $468/af to $653/af, depending on the annual quantities transported (Figure 4.5).

To estimate the cost of both in-Valley use and transport, both Figures 4.4 and 4.5 are needed. An example calculation for an annual withdrawal of 200,000 af/y follows. Assume that 100,000 af/y of the total 200,000 af/y is used in the Valley, and that 100,000 af/y is transported to the Arkansas River via
Poncha Pass. If the 200,000 af/y is from Base Case 1, then the cost of getting this water to in-Valley use is about $255/af (Figure 4.4). To transport 100,000 af/y to the Arkansas River would cost an additional $410/af (Figure 4.5). Therefore, the cost of the initial 200,000 af of water would be $255/af, while the cost to transport 100,000 of the 200,000 to the Arkansas River would cost about $665/af.

4.4 COST-SENSITIVITY ANALYSES

Cost-sensitivity analyses were performed on each of the two base cases to test the magnitude of the changes in the unit annual costs which would result from altering the assumptions concerning the values of several of the independent variables which are particularly subject to uncertainty. Those variables are:

1. Annual interest rate
2. Deep confined aquifer transmissivity
3. Well spacing
4. Well pumping rate
5. Well depth
6. Demand time period

In each case, alternative values of these independent variables, usually representing probable low, probable medium and probable high values, were chosen and unit annual costs (similar to the base-case costs shown in Appendix B) computed. Table 4.1 is a summary table showing the sensitivity of unit annual cost of project water for the Base Case 1, assuming that the only variable which changed was the one of interest. Table 4.2 is a similar analysis for Base Case 2.

A decrease in the assumed annual interest rate from 7 to 5 percent would reduce unit annual costs by about 3.5 to 11.9 percent (averaging 7.6 percent); whereas, an annual interest rate increase from 7 to 9 percent would increase unit annual costs by about 3.8 to 14.3 percent (averaging 9.0 percent). The
percentage increase or decrease would become less with increasing annual withdrawal of deep confined aquifer water (Table 4.1 and 4.2).

An increase in aquifer transmissivity (Base Case 1) by a factor of 10 would result in a decrease in unit annual costs by up to 71 percent for large annual withdrawals (Table 4.1). A decrease in aquifer transmissivity (Base Case 2) by a factor of 10 would result in an increase in unit annual costs of up to 268 percent for large annual withdrawals (Table 4.2). This is because drawdowns would be substantially reduced with a larger transmissivity value. As expected, a 2-mile well spacing would cause larger drawdowns than a 5-mile well spacing because of well interference, resulting in higher unit annual costs (up to 30 percent higher).

Average well pumping rates (1000, 1500 or 2000 gpm) did not affect unit annual rates to a large extent, except that, if the pumping rate were reduced to 1000 gpm, not all the wells could be located in the Valley at a 5-mile spacing to produce the maximum desired level of water development of 300,000 af/y. This assessment assumes throughout the analysis that the wells are regularly spaced in a grid-pattern.

Construction costs are affected by well depths. If the average well depths were reduced from 5000 to 3000 ft, nearly a 13 percent construction cost savings would be realized (Tables 4.1 and 4.2). However, the unit annual cost savings would be relatively small (about 6 percent), because operation and maintenance costs would not dramatically decline for this assumed reduction in average well depth. In fact, an annual yield of 300,000 af/y could not be obtained with the 3000-ft wells and a transmissivity of 25,000 gpd/ft, because the expected maximum wellfield drawdown based upon our analysis would be greater than 3000 ft (approximately 3100 ft) at this annual withdrawal.

Cost of the project would be affected if the project water were not delivered only during some months of the year such as would be the case for the Valley's irrigation season. Costs were estimated for projects having a large
### TABLE 4.1

Sensitivity of Base-Case 1 Annual Unit Costs to Changing Assumptions (S/af)

<table>
<thead>
<tr>
<th>Annual Withdrawal (af/y)</th>
<th>Assumed Interest Rate</th>
<th>Assumed Transmissivity</th>
<th>Assumed Well Spacing</th>
<th>Assumed Well Depth</th>
<th>Assumed Demand Time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low 5%</td>
<td>Medium (1) 7%</td>
<td>High 9%</td>
<td>Low 25,000 gpd/ft</td>
<td>Medium (1) 2-mile</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Medium (1) 250,000 gpd/ft</td>
<td>Medium (1) 5-mile</td>
</tr>
<tr>
<td>50,000</td>
<td>115</td>
<td>123</td>
<td>133</td>
<td>123</td>
<td>54</td>
</tr>
<tr>
<td>100,000</td>
<td>163</td>
<td>172</td>
<td>182</td>
<td>172</td>
<td>63</td>
</tr>
<tr>
<td>200,000</td>
<td>245</td>
<td>255</td>
<td>267</td>
<td>255</td>
<td>79</td>
</tr>
<tr>
<td>300,000</td>
<td>307</td>
<td>318</td>
<td>330</td>
<td>318</td>
<td>92</td>
</tr>
</tbody>
</table>

|                          | High 250,000 gpd/ft   | High 250,000 gpd/ft   |                      |                    |                     |
| 145                      | 123                   | 123                   |                      |                    |                     |
| 215                      | 172                   | 215                   |                      |                    |                     |
| 343                      | 255                   | 343                   |                      |                    |                     |
| 455                      | 318                   | 455                   |                      |                    |                     |

|                          | Low 1000 gpm          | Medium 1500 gpm       | High (1) 2000 gpm    | Low 3000 ft        | Medium (1) 4 mo     |
|                          |                      |                       |                      |                    |                     |
| 50,000                   | 108                   | 116                    | 123                  | 111                | 123                 |
| 100,000                  | 149                   | 164                    | 172                  | 160                | 172                 |
| 200,000                  | 212                   | 238                    | 255                  | 243                | 255                 |
| 300,000                  | --(2)                 | 296                    | 318                  | --(2)              | 318                 |

|                          |                      |                       |                      |                    |                     |
| 108                      | 116                   | 116                   |                      |                    |                     |
| 149                      | 164                   | 172                   |                      |                    |                     |
| 212                      | 238                   | 255                   |                      |                    |                     |
| --(2)                    | 296                   | 318                   |                      | --(2)              | 318                 |

|                          |                      |                       |                      |                    |                     |
| 215                      | 150                   | 123                   |                      |                    |                     |
| 318                      | 215                   | 172                   |                      |                    |                     |
| 318                      | 255                   | 255                   |                      |                    |                     |
| --(2)                    |                      | --(2)                 |                      | --(2)              | --(2)               |

|                          |                      |                       |                      |                    |                     |
| 318                      | 318                   | 318                   |                      |                    |                     |

(1) Base Case 1 assumes the following: Transmissivity = 25,000 gpd/ft, Storativity = 0.0001, Time = 10 years, Interest Rate = 0.07, Well Spacing = 5 mi, Pumping Rate = 2000 gpm and Well Depth = 5000 ft.

(2) -- Indicates no sensitivity analyses because of physical constraints on system.
TABLE 4.2

Sensitivity of Base-Case 2 Annual Unit Costs to Changing Assumptions ($/af)

<table>
<thead>
<tr>
<th>Annual Withdrawal (af/y)</th>
<th>Assumed Interest Rate</th>
<th>Assumed Transmissivity</th>
<th>Assumed Well Spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low 5%</td>
<td>Medium 7%</td>
<td>High 9%</td>
</tr>
<tr>
<td>50,000</td>
<td>37</td>
<td>42</td>
<td>48</td>
</tr>
<tr>
<td>100,000</td>
<td>45</td>
<td>51</td>
<td>57</td>
</tr>
<tr>
<td>200,000</td>
<td>60</td>
<td>66</td>
<td>74</td>
</tr>
<tr>
<td>300,000</td>
<td>72</td>
<td>79</td>
<td>88</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Annual Withdrawal (af/y)</th>
<th>Assumed Pumping Rate</th>
<th>Assumed Depth</th>
<th>Assumed Demand</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low 1000 gpm</td>
<td>Medium 1500 gpm</td>
<td>High 2000 gpm</td>
<td>Low 3000 ft</td>
</tr>
<tr>
<td>50,000</td>
<td>40</td>
<td>41</td>
<td>42</td>
<td>42</td>
</tr>
<tr>
<td>100,000</td>
<td>48</td>
<td>50</td>
<td>51</td>
<td>51</td>
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<tr>
<td>200,000</td>
<td>62</td>
<td>65</td>
<td>66</td>
<td>66</td>
</tr>
<tr>
<td>300,000</td>
<td>--(2)</td>
<td>77</td>
<td>79</td>
<td>79</td>
</tr>
</tbody>
</table>

(1) Base Case 2 assumes the following: Transmissivity = 250,000 gpd/ft, Storativity = 0.0001, Time = 10 years, Interest Rate = 0.07, Well Spacing = 5 mi, Pumping Rate = 2000 gpm and Well Depth = 3000 ft.

(2) -- Indicates no sensitivity analyses because of physical constraints on system.
part of an annual withdrawal and delivery occurring in a 4-month or 8-month period.

The results (Tables 4.1 and 4.2) indicate that, for typical annual withdrawals (50,000 to 100,000 af/y), the unit annual costs could increase up to 46 percent due to limited seasonal production of the water. The physical system would probably limit the 4-month demand project to about 100,000 af/y of withdrawal, and the 8-month demand project to 200,000 af/y because of limitations on numbers of wells, well pumping rates and drawdowns.

In summary, cost sensitivity analyses are performed to identify a realistic range of possible costs for a project. For this project, the variables having by far the greatest sensitivity to cost are aquifer transmissivity and the annual rates of water withdrawal from the aquifer. Within the range of values used for these two variables, unit costs can change from 250 to 350 percent.

4.5 WATER-VALUATION OVERVIEW

The value of project water has been assessed in a preliminary manner for comparison to project costs. The rationale and methodology used in estimating the value of project-developed water, with due consideration to the dominant agricultural economic base in the San Luis Valley, are detailed in Appendix C.

Tables 4.3 and 4.4 show calculations for the residual value of water. Table 4.3 adopts a "realistic" scenario, which represents the best estimate of the likely returns. This assumes what is believed to be the most likely scenario for crop yields and proportions of acreages, and a fairly high charge for clearing, leveling, and reclaiming the salinized soils most likely to be available for new development. Acreage is allocated to crops as follows: 50 percent alfalfa, 40 percent small grains (spring wheat or feed barley), and 10 percent potatoes.
TABLE 4.3
Summary of Projected Costs, Returns and Residual Return to Water, San Luis Valley, Realistic Scenario\(^{(1)(3)}\)

<table>
<thead>
<tr>
<th>Item</th>
<th>Alfalfa Hay Per Acre</th>
<th>Spring Wheat Per Acre</th>
<th>Potatoes Per Acre</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Revenues</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Projected Yields/Acre</td>
<td>4 t</td>
<td>90 bu</td>
<td>300 cwt</td>
</tr>
<tr>
<td>Projected Price/Unit</td>
<td>$70/t</td>
<td>$2.70/bu</td>
<td>$4.50/cwt</td>
</tr>
<tr>
<td>Project Gross Revenues</td>
<td>$280/t</td>
<td>$243/a</td>
<td>$1350/a</td>
</tr>
<tr>
<td><strong>Costs</strong></td>
<td>$</td>
<td>$</td>
<td>$</td>
</tr>
<tr>
<td>Land Preparation and Plant(^{(2)})</td>
<td>62</td>
<td>49</td>
<td>167</td>
</tr>
<tr>
<td>Other Pre-Harvest Machinery</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operations</td>
<td>8</td>
<td>-</td>
<td>30</td>
</tr>
<tr>
<td>Fertilizer, Pesticides</td>
<td>10</td>
<td>46</td>
<td>586</td>
</tr>
<tr>
<td>Irrigation System Operating</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Costs</td>
<td>29</td>
<td>15</td>
<td>33</td>
</tr>
<tr>
<td>Harvest and Haul</td>
<td>80</td>
<td>28</td>
<td>33</td>
</tr>
<tr>
<td>Land, Land Development and</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sprinkler System (Annualized)</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>General Overhead, Taxes, Etc.</td>
<td>29</td>
<td>26</td>
<td>90</td>
</tr>
<tr>
<td>Management</td>
<td>13</td>
<td>12</td>
<td>135</td>
</tr>
<tr>
<td><strong>TOTAL COSTS</strong></td>
<td>281</td>
<td>226</td>
<td>1124</td>
</tr>
<tr>
<td>Net Return to Water ($/a)</td>
<td>-1</td>
<td>17</td>
<td>226</td>
</tr>
<tr>
<td>Annual Water Applied (af/a)(^{(4)})</td>
<td>3.6</td>
<td>2.1</td>
<td>1.8</td>
</tr>
<tr>
<td>Return Per Acre Foot ($)</td>
<td>-0.3</td>
<td>8.1</td>
<td>126</td>
</tr>
<tr>
<td>Weighted Average Return Per Acre Foot ($/af)</td>
<td></td>
<td></td>
<td>16</td>
</tr>
</tbody>
</table>

(1) Realistic scenario assumes:
   a) $200 land-development costs amortized @ 7 percent.
   b) "normal" acreage in high-return crops (10 percent potatoes, 40 percent spring wheat, 50 percent alfalfa.

(2) Alfalfa planting costs represent cost of initial stand established amortized over four-year life.

(3) Adapted from Appendix C (Table C.1).

(4) Based on Salazar (1986); see Table 2.2.
TABLE 4.4
Summary of Projected Costs, Returns
and Residual Return to Water,
San Luis Valley, Optimistic Scenario(1)(3)

<table>
<thead>
<tr>
<th>Item</th>
<th>Alfalfa Hay</th>
<th>Malt Barley</th>
<th>Potatoes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Per Acre</td>
<td>Per Acre</td>
<td>Per Acre</td>
</tr>
<tr>
<td>Revenues</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Projected Yields/Acre</td>
<td>4 t</td>
<td>40 cwt</td>
<td>300 cwt</td>
</tr>
<tr>
<td>Projected Price/Unit</td>
<td>$70/t</td>
<td>$7.00/cwt</td>
<td>$4.50/cwt</td>
</tr>
<tr>
<td>Project Gross Revenues</td>
<td>$280/a</td>
<td>$280/a</td>
<td>$1350/a</td>
</tr>
<tr>
<td>Costs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land Preparation and Plant(2)</td>
<td>62</td>
<td>49</td>
<td>167</td>
</tr>
<tr>
<td>Other Pre-Harvest Machinery Operations</td>
<td>8</td>
<td>-</td>
<td>30</td>
</tr>
<tr>
<td>Fertilizer, Pesticides</td>
<td>10</td>
<td>46</td>
<td>586</td>
</tr>
<tr>
<td>Irrigation System Operating Costs</td>
<td>29</td>
<td>15</td>
<td>33</td>
</tr>
<tr>
<td>Harvest and Haul</td>
<td>80</td>
<td>28</td>
<td>33</td>
</tr>
<tr>
<td>Land, Land Development and Sprinkler System (Annualized)</td>
<td>36</td>
<td>36</td>
<td>36</td>
</tr>
<tr>
<td>General Overhead, Taxes, Etc. Management</td>
<td>13</td>
<td>14</td>
<td>135</td>
</tr>
<tr>
<td>TOTAL COSTS</td>
<td>267</td>
<td>214</td>
<td>1110</td>
</tr>
<tr>
<td>Net Return to Water ($/a)</td>
<td>13</td>
<td>66</td>
<td>226</td>
</tr>
<tr>
<td>Annual Water Applied (af/a)(4)</td>
<td>3.6</td>
<td>2.0</td>
<td>1.8</td>
</tr>
<tr>
<td>Return Per Acre Foot ($)</td>
<td>3.6</td>
<td>33</td>
<td>133</td>
</tr>
<tr>
<td>Weighted Average Return Per Acre Foot ($/af)</td>
<td></td>
<td>56</td>
<td></td>
</tr>
</tbody>
</table>

(1) Optimistic scenario assumes:
   a) low land-development costs.
   b) maximum acreage in high-return crops (1/3 potatoes, 1/3 malt barley, 1/3 alfalfa).

(2) Alfalfa planting costs represent cost of initial stand established amortized over four-year life.

(3) Adapted from Appendix C (Table C.2).

(4) Based on Salazar (1986); see Table 2.2.
The optimistic scenario (Table 4.4) is based on a high proportion of high return crops (potatoes and malt barley 1/3 each, together with 1/3 alfalfa) and lower land reclamation costs. This can be regarded as an upper limit on ability to pay for new water supplies.

For both of the above scenarios, land, land development and sprinkler system costs have been included in the costs used to calculate the return per acre-foot of water. Based upon these assumptions for new land development, the realistic scenario gives an average weighted return of $16/af of water, while the optimistic scenario gives an average weighted return of $56/af of water.

If the analyses were for supplemental water only, i.e., land and development costs were not included, then the weighted average return would be higher. If the farmer needed additional water to increase yield or save the crop, then the $56/af value becomes more realistic as the farmer's willingness to pay.

Cropping pattern also influences the results of the value of water. In the realistic scenario, alfalfa and spring wheat accounted for 90 percent of the irrigated land; whereas, in the optimistic scenario, the crops were split as 33 percent for each crop. Historical cropping patterns shown in Table 2.2 indicate a typical cropping pattern consists of 32 percent alfalfa and other hay, 17 percent barley, 6 percent potatoes, 4 percent spring wheat, 2 percent oats and vegetables, and 39 percent irrigated pasture. Therefore, the historical cropping pattern is close to the assumed realistic scenario. If the analyses shown in Tables 4.3 and 4.4 was applied to the cropping pattern in Table 2.2, the average weighted value of water would be $15/af, if new land had to be developed. Without land-development costs, the value would be $18/af.

4.6 SUMMARY

Two potential base cases were identified for purposes of developing annual withdrawals of between 50,000 and 300,000 af/y from the deep confined-aquifer system of the San Luis Valley. Base Case 1 depicted a wellfield developing
water from the lower confined-aquifer system, assuming average well depths of 5000 ft and a transmissivity of 25,000 gpd/ft. Costs under these Base Case 1 assumptions to develop water ranged from $123/af to $318/af. Base Case 2 depicted a wellfield developing water from a shallower zone of the deep average confined system. Under this alternative scenario, well depths were assumed to 3000 ft with an average transmissivity of 250,000 gpd/ft. Costs under the Base Case 2 assumptions ranged from $42/af to $79/af. Incremental costs to transport developed water to the Arkansas River ranged from $314 to $526/af via Poncha Pass and $468 to $653/af via Hayden Pass. To contrast these anticipated water-development costs, a farmer's in-Valley ability to pay for water was estimated to range from $16/af (realistic economic assessment) to $56/af (optimistic and unrealistic economic assessment).
COLORADO WATER RESOURCES
AND POWER DEVELOPMENT AUTHORITY
SAN LUIS VALLEY CONFINED AQUIFER STUDY

NUMBER OF WELLS vs.
ANNUAL WITHDRAWAL
SAN LUIS VALLEY DEEP CONFINED AQUIFER

IN-SITU, INC.
HRS Water Consultants, Inc., John C. Malepaska & Assoc., Inc.,
Robert E. Moran and Robert A. Young Study Team
DATE: 8/21/86 FIGURE 4.2
TRANSMISSIVITY = 250,000 GPD/FT
STORATIVITY = 10^-4
TIME = 10 YEARS
5-MILE WELL SPACING

TRANSMISSIVITY = 25,000 GPD/FT
STORATIVITY = 10^-4
TIME = 10 YEARS
5-MILE WELL SPACING

NOTE: ASSUMES THE AQUIFER IS INFINITE IN AREAL EXTENT.
COLORADO WATER RESOURCES
AND POWER DEVELOPMENT AUTHORITY
SAN LUIS VALLEY CONFINED AQUIFER STUDY
ANNUAL UNIT COST OF SAN LUIS
VALLEY DEEP CONFINED AQUIFER
WATER FOR BASE CASES 1 AND 2
IN-SITU, INC.
HRS Water Consultants, Inc., John C. Halepesta & Assoc., Inc.,
Robert E. Moran and Robert A. Young Study Team
DATE: 8/21/86 FIGURE 4.4
5.0 ACKNOWLEDGMENTS

Analyses presented in this report were prepared under the general supervision of Dr. Timothy D. Steele, Water Resources Manager and Associate of In-Situ, Inc. The analyses were done by Dr. James R. Kunkel, Senior Project Engineer of In-Situ, Inc. and Dr. Robert A. Young, Agricultural Economist with Colorado State University. Dr. Kunkel prepared the draft of this report with assistance from Drs. Young and Steele.
6.0 REFERENCES


APPENDIX A

DESCRIPTION OF CALCULATION FACTORS
FOR THE COMPUTER-PROGRAM "COST"

The following sections describe the calculations involved in the FORTRAN computer-program COST (Appendix D) and its subroutines. The program uses functional relationships to calculate facility sizes, quantities and costs. Not all the features of the COST routine were used in this particular application (such as terminal water storage facilities).

WELLS, PUMPS AND INTERWELL PIPE (Subroutine WELL)

Number of Wells

The number of wells is equal to the peak flow rate divided by the yield per well rounded up, plus a standby capacity of 10 percent of the total number of wells, but the standby capacity, however, cannot be less than one or greater than 10 wells.

\[ NWA = \text{peak flow rate/yield per well (rounded up)} \]
\[ \text{Number of wells} = NWA + 10 \text{ percent } NWA \] (A-1)

where:

\[ 1 \leq 10 \text{ percent } NWA \leq 10 \]

Cost of Pumps

The cost of the pumps is calculated from the following equation:

\[ \text{Cost per pump} = (30 \times \text{yield per well}) + 20,000 \] (A-2)
Cost of Well Construction

The cost of well construction is calculated from the following equation.

\[
\text{Cost per well} = (150 \times \text{depth of well}) - 2200 \quad (A-3)
\]

Cost of Interwell Pipe

The cost of interwell pipe is related to peak flow rate and number of wells by the following equation:

\[
\text{Cost of interwell pipe} = 27,000 \times (\text{peak flow rate} \times \text{number of wells})^{0.65} \quad (A-4)
\]

Total Cost of Wells

The total cost of the wells equals cost of pumps + cost of interwell pipe + cost of well construction.

COST OF TRANSMISSION PIPE

Size of Pipe (Subroutine SIZE)

The diameter is derived from this pipe size optimization formula (Streeter, 1973). As pipe is available only in certain diameters, the size was rounded up to the next six inch interval for \(d_{\text{in.}} \leq 48\) in. and rounded up the next 12 in. interval for \(d_{\text{in.}} > 48\) in.

\[
d_{\text{in.}} = 83.4 \times \frac{P^{0.163} \times Q^{0.463}}{E^{0.163} \times C^{0.301}} \quad (A-5)
\]
where:

\[ P = \text{cost of electricity, } \$/\text{kWh}; \quad Q = \text{peak flow rate, } \text{mgd}; \]
\[ E = \text{pumping plant efficiency}; \quad C = \text{Hazen-Williams coefficient of pipe}. \]

**Length of Pipeline (Subroutine PIPE)**

The length of pipeline is equal to the measured miles times a factor \( > 1 \) to allow for terrain corrections.

**Cost of Pipe (Subroutine PIPE)**

The cost per foot of pipe is derived from the transmission pipe cost data in recent edition of the F.W. Dodge Manual, and from recent issues of Engineering News Record for steel pipe.

\[
\begin{align*}
\text{Cost/ft} &= 5.21 \times \text{diam. in.} - 13.36, \text{ diam. } \leq 36 \text{ in.} \\
\text{Cost/ft} &= 7.65 \times \text{diam. in.} - 95.26, \text{ diam. } > 36 \text{ in.}
\end{align*}
\]

(A-6)

**COST OF TERMINAL STORAGE (SUBROUTINE TERM)**

**Number of Storage Tanks**

There must be at least two tanks, and no tank may hold more than 25 mgd. The total storage capacity must be at least equal to two days design usage. The number of tanks is related to design usage in mgd by the following formula:

\[
\begin{align*}
\text{No. of tanks} &= 2, \text{ for avg. mgd } \leq 25 \text{ mgd} \\
\text{No. of tanks} &= \left[2 \times (\text{avg. mgd}/25)\right] \text{rounded up, for avg. mgd } > 25 \text{ mgd} \quad \text{(A-7)}
\end{align*}
\]
Size of Tanks

Arbitrarily, the height = radius of the tanks

Cost of Tanks

The cost of tanks is derived from the cost data for terminal storage tanks by Ramamurthy and Chicoine (1984). The cost is calculated by the following equation:

\[
\text{Cost per tank} = [0.0867 \text{ (avg. gpd/10}^6\text{)} + 0.0532] \times 10^6
\]  

(A-8)

COST OF BOOSTER STATIONS (SUBROUTINE BOOST)

Total Head

Friction Head - The friction head is obtained from the Hazen-Williams formula as given in Davis and Sorensen (1969).

\[
Q = 0.432 C_w d^{2.63} S^{0.54}, \text{ or }
\]

\[
S = \left[ \frac{Q}{(0.432 C_w d^{2.63})} \right]^{1/0.54}
\]  

(A-9)

where:

- \( S \) = head loss, ft/ft; \( Q \) = peak flow rate in cfs;
- \( C_w \) = Hazen-Williams coefficient.; \( d \) = pipe diameter in ft.

Total Head - Total booster station pumping head is equal to the friction loss over the length of the pipeline plus the elevation head plus the height of
the terminal storage tanks less the discharge head at the well pumps (Streeter, 1973). If the water source is surface water, the discharge head at the well pumps is equal to 0.

**Number of Booster Stations**

The number of booster stations is equal to the following:

No. of large stations = (Total head/240 ft), rounded down

(A-10)

If the remainder, R, is greater than .2, there will be one small booster station pumping at R x horsepower; if R ≤ .2, then R = 0, and additional stages are added to well pumps.

**Cost of Booster Stations**

**Horsepower** - The horsepower of each booster station is given by the following from Singh (1971).

Horsepower (H) = (0.1756) x (peak flow in mgd) x (head per station) (A-11)

x (J)/(pump efficiency).

where:

Head per Station = 240 ft.

J is given by the following:

(X = design capacity in mgd)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>X ≤ 2.0</td>
<td>J = 2.08 - .18X</td>
</tr>
<tr>
<td>2.0 &lt; X ≤ 5.0</td>
<td>J = 1.9666 - 0.1233X</td>
</tr>
<tr>
<td>5.0 &lt; X ≤ 10.0</td>
<td>J = 1.42 - 0.14X</td>
</tr>
<tr>
<td>10.0 &lt; X ≤ 20.0</td>
<td>J = 1.30 - 0.002X</td>
</tr>
<tr>
<td>20.0 &lt; X ≤ 30.0</td>
<td>J = 1.28 - 0.001X</td>
</tr>
<tr>
<td>30.0 &lt; X</td>
<td>J = 1.25</td>
</tr>
</tbody>
</table>
Cost of Booster Stations

Cost per station is given by the following formula from Singh (1971).

\[ \text{Cost of booster stations} = \left[17000. + (135 \times \text{Horsepower}^{1.01})\right] \times \text{number of stations} + \left(17000. + [135 \times (R \times \text{Horsepower}^{1.01})]\right) \]

(A-12)

CONSTRUCTION COSTS (COST)

\[ \text{Construction Costs} = \text{Cost of wells} + \text{booster stations} + \text{terminal storage} + \text{pipeline}. \]

(A-13)

INTEREST DURING CONSTRUCTION (SUBROUTINE INTR)

Months for Construction

The construction period is determined using the following formula and applied to the design capacity in mgd.

\[ \text{No. of Months (M)} = \left[8. / \left(\left(1./\text{mgd}\right)^{32}\right)\right], \text{rounded up} \]

(A-14)

Cost of Interest During Construction

The cost is given by the following formula.

\[ \text{Interest} = \left[\left(\text{annual interest rate}/12\right) \times M\right] \times (\text{Construction Costs}) \]

(A-15)
ELECTRIC POWER COSTS (SUBROUTINE ELEC)

It takes .004 kWh to lift 1000 gallons of water one foot (Streeter, 1973). The annual cost of electric power is given by the following formula:

\[
\text{Electric power costs} = \text{unit cost factor} \times [.004 \times (\text{design capacity}/1000) \times \text{head}]
\]

\(\text{Head} = \text{friction head} + \text{elevation head} + \text{height of tank} + \text{pumping lift} + \text{pump discharge head}\)

O & M LABOR, SUPPLIES AND MATERIALS (SUBROUTINE OM)

The cost of O&M (operation and maintenance) labor, supplies and materials is related to peak flow rate, number of wells and miles of transmission line by the following formula:

\[
\text{Cost of O & M labor} = 3262. \times (\text{peak flow in mgd} \times \text{no. of wells} \times \text{miles of transmission pipe})^{0.49}
\]

TOTAL O & M (COST)

Total O & M = electric power costs + O & M labor, supplies and materials.

START-UP COSTS (SUBROUTINE WCSU)

The formula for start-up costs is:

\[
\text{Start-up Costs} = .0833 \times (\text{Total O & M})
\]

Note: .0833 represents one month.
WORKING CAPITAL (SUBROUTINE WCSU)

The formula for working capital cost is:

\[
\text{Working Capital} = 0.1667 \times (\text{Total O & M})
\]  
(A-21)

Note: .1667 represents two months.

OWNERS GENERAL EXPENSE (SUBROUTINE OGE)

Cost Factor

This cost factor is derived from the scaling factors given by Streeter (1973, p. 145), which vary with total construction cost (C), by the following formula:

\[
\text{Factor} = \left( \frac{.12}{(1,000,000/C)^{-1.25}} \right) \text{ for C} \leq 10,000,000
\]
\[
\text{Factor} = \left( \frac{.09}{(10,000,000/C)^{-1.09}} \right) \text{ for C} > 10,000,000
\]  
(A-22)

Owners' General Expense

\[
\text{Owners' general expense} = C \times \text{factor}
\]  
(A-23)

LAND COSTS (SUBROUTINE LAND)

The land requirements for pumping and transmission of water are as follows: .5 acre/well site, 0.25 acre/booster station, 30 ft. right-of-way for pipeline, and 100 ft. clearance around terminal storage tanks. The total land cost is the total acreage of land times the price of land per acre.
ANNUAL DEPRECIABLE CAPITAL COSTS (COST)

Depreciable Capital Rate

Depreciable capital rate (DCR) is equal to the amortization factor + interest rate + tax rate + insurance rate (Streeter, 1973, p. 178). The amortization factor + interest rate = the Capital Recovery Factor (CRF) which is derived from the formula given by Singh and others (1972, p. 11).

\[ \text{CRF} = \text{interest rate} \times (1 + \text{interest rate})^N / [(1 + \text{interest rate})^N - 1] \]  

(A-24)

where:

- \( N \) = amortization period, years.
- \( \text{DCR} = \text{CRF} + \text{tax rate} + \text{insurance rate} \).

Annual Depreciable Capital Costs

The depreciable capital cost equal the total construction cost + interest during construction + start-up cost + owners' general expense. Annual depreciable capital costs = depreciable capital costs \( \times \) DCR.

(A-25)

ANNUAL NON-DEPRECIABLE CAPITAL COSTS (COST)

Non-depreciable capital costs = the land costs + working capital. The annual non-depreciable capital costs = non-depreciable capital costs \( \times \) interest rate.

(A-26)

TOTAL ANNUAL COSTS (COST)

Total Annual Costs = total annual O & M + total annual depreciable capital cost + total annual non-depreciable capital cost (Streeter, 1973).

(A-27)
INFLATION FACTOR

The following costs are multiplied by the inflation factor: total well costs, terminal storage, booster stations, O & M labor, supplies and materials. For this study, the inflation factor is set equal to 1.
REFERENCES


APPENDIX B

BASE-CASE AND TRANSPORTATION-PIPELINE COST ANALYSES
BASE CASE 1

5000-FT DEEP WELLS
## Detailed Cost Analysis

**Plant Designation:** SAN LUIS 3  
**Water Source Location:** Valley  
**Design Usage:** 50,000 acre-feet/year  
**Plant Location:** SAN LUIS VALLEY  
**Formation:** Deep Confined

### Cost Item  
<table>
<thead>
<tr>
<th>Cost Item</th>
<th>Estimated Cost $ \times 1000</th>
<th>Annual Cost $ \times 1000</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Capital Costs</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wells, pumps, interwell pipe (18 wells)</td>
<td>17,027</td>
<td></td>
</tr>
<tr>
<td>Transmission pipe (1 in.)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Booster stations</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Terminal storage</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td><strong>Subtotal - Construction Costs</strong></td>
<td>17,027</td>
<td></td>
</tr>
<tr>
<td>Interest during construction</td>
<td>2,682</td>
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</tr>
<tr>
<td>Start-up costs</td>
<td>346</td>
<td></td>
</tr>
<tr>
<td>Owners general expense</td>
<td>1,446</td>
<td></td>
</tr>
<tr>
<td><strong>Total - Depreciable Capital Costs</strong></td>
<td>21,501</td>
<td>2,001</td>
</tr>
<tr>
<td>(Fixed charge rate - 9.31 %)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land costs</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Working capital</td>
<td>691</td>
<td></td>
</tr>
<tr>
<td><strong>Total - Nondepreciable Capital Costs</strong></td>
<td>700</td>
<td>49</td>
</tr>
<tr>
<td>(Interest rate - 7.00 %)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Annual O & M Expense

| O & M Labor, supplies and materials            | 86                            |                           |
| Electric power costs                           | 4,062                         |                           |
| **Total - Annual O & M Expense**               | 4,148                         | 4,148                     |

*Total Annual Costs*  

| Total Annual Costs | 6,198 |

**Unit Cost:** $123/acre-foot
## Detailed Cost Analysis

**Plant Designation:** San Luis 4  
**Water Source Location:** Valley  
**Design Usage:** 100,000 Acre-Feet/Year  
**Plant Location:** San Luis Valley  
**Formation:** Deep Confined

<table>
<thead>
<tr>
<th>COST ITEM</th>
<th>ESTIMATED COST $ X 1000</th>
<th>ANNUAL COST $ X 1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wells, Pumps, Interwell Pipe (35 Wells)</td>
<td>$34096</td>
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</tr>
<tr>
<td>Transmission Pipe (1 in.)</td>
<td>0</td>
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<td><strong>Total - Depreciable Capital Costs</strong></td>
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<td>(Fixed Charge Rate - 9.31%)</td>
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<td><strong>Total Annual Costs</strong></td>
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*Total Annual Costs: $17,250

**Unit Cost:** $172/acre-feet
DETAILED COST ANALYSIS

PLANT DESIGNATION: SAN LUIS 5
WATER SOURCE LOCATION: VALLEY
DESIGN USAGE: 200,000 ACRE-FEET/YEAR

PLANT LOCATION: SAN LUIS VALLEY
FORMATION: DEEP CONFINED

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<tr>
<th>COST ITEM</th>
<th>ESTIMATED COST $ X 1000</th>
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UNIT COST $255/ACRE-FEET
DETAILED COST ANALYSIS

PLANT DESIGNATION: SAN LUIS &
WATER SOURCE LOCATION: VALLEY
DESIGN USAGE 30000 ACRE-FEET/YEAR

PLANT LOCATION: SAN LUIS VALLEY
FORMATION: DEEP CONFINED

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<th>COST ITEM</th>
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<th>ANNUAL COST $ X 1000</th>
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<td>WELLS, PUMPS, INTERWELL PIPE (103 WELLS)</td>
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<tr>
<td><strong>SUBTOTAL - CONSTRUCTION COSTS</strong></td>
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<td>7393</td>
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<td><strong>TOTAL - DEPRECIABLE CAPITAL COSTS</strong></td>
<td><strong>$ 150135</strong></td>
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<td>(FIXED CHARGE RATE - 9.31 %)</td>
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<td>LAND COSTS</td>
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<td><strong>$ 13471</strong></td>
<td>943</td>
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<td>(INTEREST RATE - 7.00 %)</td>
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ANNUAL O & M EXPENSE

| O & M LABOR, SUPPLIES AND MATERIALS                                       | $ 489                   |                      |
| ELECTRIC POWER COSTS                                                      | 80011                   |                      |
| **TOTAL - ANNUAL O & M EXPENSE**                                          | **$ 80500**             | 80500                |

* TOTAL ANNUAL COSTS                                                       | $ 95419                 |

UNIT COST $ 318 /ACRE-FEET
<table>
<thead>
<tr>
<th>PLANT DESIGNATION</th>
<th>FORMATION</th>
<th>DESIGN USAGE af/y</th>
<th>DEPREC + NONDEPREC CAPITAL COSTS $ X 1000</th>
<th>ANNUAL O&amp;M EXPENSES $ X 1000</th>
<th>TOTAL ANNUAL COSTS $ X 1000</th>
<th>UNIT COST $/af</th>
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<tr>
<td>SAN LUIS 3</td>
<td>DEEP CONFINED</td>
<td>50000</td>
<td>22201</td>
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<td>SAN LUIS 4</td>
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<td>100000</td>
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<td>12944</td>
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<td>DEEP CONFINED</td>
<td>200000</td>
<td>102590</td>
<td>41809</td>
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<td>163606</td>
<td>80500</td>
<td>95419</td>
<td>318</td>
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# DETAILED COST ANALYSIS

## PLANT DESIGNATION: SAN LUIS 3

**WATER SOURCE LOCATION:** VALLEY  
**DESIGN USAGE:** 50000 ACRE-FEET/YEAR

---

## PLANT LOCATION: SAN LUIS VALLEY  
**FORMATION:** DEEP CONFINED

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<table>
<thead>
<tr>
<th>COST ITEM</th>
<th>ESTIMATED COST ($ X 1000)</th>
<th>ANNUAL COST ($ X 1000)</th>
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<tbody>
<tr>
<td><strong>CAPITAL COSTS</strong></td>
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<tr>
<td>WELLS, PUMPS, INTERWELL PIPE (18 WELLS)</td>
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<tr>
<td>TRANSMISSION PIPE (1 IN.)</td>
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<td></td>
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<tr>
<td>BOOSTER STATIONS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TERMINAL STORAGE</td>
<td></td>
<td></td>
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<tr>
<td><strong>SUBTOTAL - CONSTRUCTION COSTS</strong></td>
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<td>$11627</td>
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<td>INTEREST DURING CONSTRUCTION</td>
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<td>OWNERS GENERAL EXPENSE</td>
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<td>$1029</td>
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<td><strong>TOTAL - DEPRECIABLE CAPITAL COSTS</strong> (FIXED CHARGE RATE - 9.31%)</td>
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<td><strong>ANNUAL O &amp; M EXPENSE</strong></td>
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<td>O &amp; M LABOR, SUPPLIES AND MATERIALS</td>
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<td><strong>TOTAL - ANNUAL O &amp; M EXPENSE</strong></td>
<td>$764</td>
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</table>

* **TOTAL ANNUAL COSTS** $2128

---

**UNIT COST** $42 / ACRE-FEET
DETAILED COST ANALYSIS

PLANT DESIGNATION: SAN LUIS 4
WATER SOURCE LOCATION: VALLEY
DESIGN USAGE 100000 ACRE-FEET/YEAR

PLANT LOCATION: SAN LUIS VALLEY
FORMATION: DEEP CONFINED

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<tr>
<th>COST ITEM</th>
<th>ESTIMATED COST</th>
<th>ANNUAL COST</th>
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<tr>
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<td>TRANSMISSION PIPE (1 IN.)</td>
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<td>BOOSTER STATIONS</td>
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<tr>
<td>TERMINAL STORAGE</td>
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<tr>
<td><strong>SUBTOTAL - CONSTRUCTION COSTS</strong></td>
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<td>OWNERS GENERAL EXPENSE</td>
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<td><strong>TOTAL - DEPRECIABLE CAPITAL COSTS</strong></td>
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<td>(FIXED CHARGE RATE - 9.31 %)</td>
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<td>LAND COSTS</td>
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<td>$ 2261</td>
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* TOTAL ANNUAL COSTS                         $ 5119

UNIT COST $ 51 /ACRE-FEET
**DETAILED COST ANALYSIS**

**PLANT DESIGNATION:** SAN LUIS 5  
**WATER SOURCE LOCATION:** VALLEY  
**DESIGN USAGE:** 200000 ACRE-FEET/YEAR  

---

**PLANT LOCATION:** SAN LUIS VALLEY  
**FORMATION:** DEEP CONFINED

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<th>ANNUAL COST</th>
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**ANNUAL O & M EXPENSE**

| O & M LABOR, SUPPLIES AND MATERIALS | $330  |
| ELECTRIC POWER COSTS                | 6879  |

**TOTAL - ANNUAL O & M EXPENSE**  
$7209  

* **TOTAL ANNUAL COSTS**  
$13388

**UNIT COST**  
$56 /ACRE-FEET
DETAILED COST ANALYSIS

PLANT DESIGNATION: SAN LUIS 6  
WATER SOURCE LOCATION: VALLEY  
DESIGN USAGE: 300000 ACRE-FEET/YEAR

PLANT LOCATION: SAN LUIS VALLEY  
FORMATION: DEEP CONFINED

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<th>COST ITEM</th>
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<th>ANNUAL COST</th>
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UNIT COST $79/ACRE-FEET
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<th>ANNUAL O&amp;M EXPENSES $ x 1000</th>
<th>TOTAL ANNUAL COSTS $ x 1000</th>
<th>UNIT COST $/af</th>
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<td>SAN LUIS 3</td>
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<td>14687</td>
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TRANSPORT TO THE ARKANSAS RIVER
VIA
PONCHA PASS
## Detailed Cost Analysis

**Plant Designation:** San Luis 3  
**Water Source Location:** Valley  
**Design Usage:** 50,000 acre-feet/year

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<th>Cost Item</th>
<th>Estimated Cost</th>
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<td><strong>Capital Costs</strong></td>
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<td>Wells, Pumps, Interwell Pipe (0 Wells)</td>
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<td>Transmission Pipe (84 in.)</td>
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<td>Booster Stations</td>
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<tr>
<td>Terminal Storage</td>
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<td><strong>Total - Depreciable Capital Costs</strong></td>
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<td><em>(Fixed Charge Rate - 9.31%)</em></td>
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<td>Working Capital</td>
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<td><strong>Total - Nondepreciable Capital Costs</strong></td>
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<td>$7,310</td>
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<td>$26,329</td>
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*Total Annual Costs

**Unit Cost** $526 /acre-feet
DETAILED COST ANALYSIS

PLANT DESIGNATION: SAN LUIS 4  
WATER SOURCE LOCATION: VALLEY  
DESIGN USAGE 100000 ACRE-FEET/YEAR

PLANT LOCATION: SAN LUIS VALLEY  
FORMATION: DEEP CONFINED

<table>
<thead>
<tr>
<th>COST ITEM</th>
<th>ESTIMATED COST</th>
<th>ANNUAL COST</th>
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<tbody>
<tr>
<td></td>
<td>$ X 1000</td>
<td>$ X 1000</td>
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<tr>
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<tr>
<td>CAPITAL COSTS</td>
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<tr>
<td></td>
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<td>WELLS, PUMPS, INTERWELL PIPE (0 WELLS)</td>
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<td>TERMINAL STORAGE</td>
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<td>O &amp; M LABOR, SUPPLIES AND MATERIALS</td>
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<td>ELECTRIC POWER COSTS</td>
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<td>TOTAL - ANNUAL O &amp; M EXPENSE</td>
<td>$ 14530</td>
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<td>* TOTAL ANNUAL COSTS</td>
<td>$ 41097</td>
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UNIT COST $ 410 /ACRE-FEET
## Detailed Cost Analysis

**Plant Designation:** San Luis 5  
**Water Source Location:** Valley  
**Design Usage:** 200,000 Acre-Feet/Year  
**Plant Location:** San Luis Valley  
**Formation:** Deep Confined

<table>
<thead>
<tr>
<th>Cost Item</th>
<th>Estimated Cost $ x 1000</th>
<th>Annual Cost $ x 1000</th>
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</thead>
<tbody>
<tr>
<td><strong>Capital Costs</strong></td>
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<td></td>
</tr>
<tr>
<td>Wells, Pumps, Interwell Pipe (10 Wells)</td>
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<tr>
<td>Transmission Pipe (144 in.)</td>
<td>$ 29,755</td>
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<td>Booster Stations</td>
<td>$ 14,819</td>
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<tr>
<td>Terminal Storage</td>
<td>$ 0</td>
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<tr>
<td><strong>Subtotal - Construction Costs</strong></td>
<td>$ 31,237</td>
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<tr>
<td>Interest During Construction</td>
<td>$ 7,835</td>
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<tr>
<td>Start-up Costs</td>
<td>$ 2,410</td>
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<tr>
<td>Owners General Expense</td>
<td>$ 1,932</td>
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<tr>
<td><strong>Total - Depreciable Capital Costs</strong></td>
<td>$ 41,245</td>
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<td>(Fixed Charge Rate - 9.31 %)</td>
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<tr>
<td>Land Costs</td>
<td>$ 206</td>
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<tr>
<td>Working Capital</td>
<td>$ 4,823</td>
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<td><strong>Total - Nondepreciable Capital Costs</strong></td>
<td>$ 5,029</td>
<td>352</td>
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<td><strong>Annual O &amp; M Expense</strong></td>
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<td>Electric Power Costs</td>
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<td><strong>Total - Annual O &amp; M Expense</strong></td>
<td>$ 2,933</td>
<td>2,933</td>
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<td>* <strong>Total Annual Costs</strong></td>
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<td>$ 6,767.9</td>
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**Unit Cost:** $ 338 /Acre-Feet
### DETAILED COST ANALYSIS

**PLANT DESIGNATION: SAN LUIS 6**  
**WATER SOURCE LOCATION: VALLEY**  
**DESIGN USAGE: 300,000 ACRE-FEET/YEAR**  

**PLANT LOCATION: SAN LUIS VALLEY**  
**FORMATION: DEEP CONFINED**

<table>
<thead>
<tr>
<th>COST ITEM</th>
<th>ESTIMATED COST $ X 1000</th>
<th>ANNUAL COST $ X 1000</th>
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<tr>
<td><strong>CAPITAL COSTS</strong></td>
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<tr>
<td>WELLS, PUMPS, INTERWELL PIPE (0 WELLS)</td>
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<td>TRANSMISSION PIPE (180 IN.)</td>
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<td>BOOSTER STATIONS</td>
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<td>TERMINAL STORAGE</td>
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<td><strong>SUBTOTAL - CONSTRUCTION COSTS</strong></td>
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<td>INTEREST DURING CONSTRUCTION</td>
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<td>START-UP COSTS</td>
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<tr>
<td>OWNERS GENERAL EXPENSE</td>
<td>$24,148</td>
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<td><strong>TOTAL - DEPRECIABLE CAPITAL COSTS</strong></td>
<td>$541,348</td>
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<td>(FIXED CHARGE RATE - 9.31 %)</td>
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<td>LAND COSTS</td>
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<td>WORKING CAPITAL</td>
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<td><strong>TOTAL - NONDEPRECIABLE CAPITAL COSTS</strong></td>
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<td>(INTEREST RATE - 7.00 %)</td>
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<td><strong>ANNUAL O &amp; M EXPENSE</strong></td>
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<td>O &amp; M LABOR, SUPPLIES AND MATERIALS</td>
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<td>ELECTRIC POWER COSTS</td>
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<td><strong>TOTAL - ANNUAL O &amp; M EXPENSE</strong></td>
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<td><strong>TOTAL ANNUAL COSTS</strong></td>
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<td>$94,229</td>
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**UNIT COST $314 / ACRE-FEET**
### Summary of Costs

**Ground-Water Withdrawal and Transmission**

<table>
<thead>
<tr>
<th>Plant Designation</th>
<th>Formation</th>
<th>Design Usage (af/y)</th>
<th>Deprec + Nondeprec Capital Costs ($ × 1000)</th>
<th>Annual O&amp;M Expenses ($ × 1000)</th>
<th>Total Annual Costs ($ × 1000)</th>
<th>Unit Cost ($/af)</th>
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<tbody>
<tr>
<td>San Luis 3</td>
<td>Deep Confined</td>
<td>50000</td>
<td>204668</td>
<td>7310</td>
<td>26329</td>
<td>526</td>
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<td>San Luis 4</td>
<td>Deep Confined</td>
<td>100000</td>
<td>286055</td>
<td>14530</td>
<td>41097</td>
<td>410</td>
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<td>San Luis 5</td>
<td>Deep Confined</td>
<td>200000</td>
<td>417487</td>
<td>28933</td>
<td>67679</td>
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<td>San Luis 6</td>
<td>Deep Confined</td>
<td>300000</td>
<td>548775</td>
<td>43317</td>
<td>94229</td>
<td>314</td>
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TRANSPORT TO THE ARKANSAS RIVER
VIA
HAYDEN PASS
# Detailed Cost Analysis

**Plant Designation:** San Luis 3  
**Water Source Location:** Valley  
**Design Usage:** 50,000 Acre-Feet/Year

<table>
<thead>
<tr>
<th>Cost Item</th>
<th>Estimated Cost $ X 1000</th>
<th>Annual Cost $ X 1000</th>
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</thead>
<tbody>
<tr>
<td><strong>Capital Costs</strong></td>
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<td></td>
</tr>
<tr>
<td>Wells, Pumps, Interwell Pipe (0 Wells)</td>
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<tr>
<td>Transmission Pipe (84 in.)</td>
<td>141,608</td>
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<td>Booster Stations</td>
<td>7,978</td>
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<tr>
<td>Terminal Storage</td>
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<tr>
<td><strong>Subtotal - Construction Costs</strong></td>
<td>$149,586</td>
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<td>Start-Up Costs</td>
<td>1,275</td>
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<td>Owners General Expense</td>
<td>10,025</td>
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<td><strong>Total - Depreciable Capital Costs (Fixed Charge Rate - 9.31%)</strong></td>
<td>$184,446</td>
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<tr>
<td>Working Capital</td>
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<td><strong>Total - Nondepreciable Capital Costs (Interest Rate - 7.00%)</strong></td>
<td>$2,734</td>
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<td><strong>Annual O &amp; M Expense</strong></td>
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<td>O &amp; M Labor, Supplies and Materials</td>
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<td>Electric Power Costs</td>
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<td><strong>Total - Annual O &amp; M Expense</strong></td>
<td>$15,306</td>
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</table>

*Total Annual Costs*  

**Unit Cost:** $653 / Acre-Feet
DETAILED COST ANALYSIS

PLANT DESIGNATION: SAN LUIS 4
WATER SOURCE LOCATION: VALLEY
DESIGN USAGE: 100,000 ACRE-FEET/YEAR

PLANT LOCATION: SAN LUIS VALLEY
FORMATION: DEEP CONFINED

<table>
<thead>
<tr>
<th>COST ITEM</th>
<th>ESTIMATED Cost</th>
<th>ANNUAL Cost</th>
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<td>WELLS, PUMPS, INTERWELL PIPE (0 WELLS)</td>
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</tr>
<tr>
<td>TRANSMISSION PIPE (108 IN.)</td>
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<td>LAND COSTS</td>
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<tr>
<td>WORKING CAPITAL</td>
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<tr>
<td>TOTAL - NONDEPRECIABLE CAPITAL COSTS (IR 7.00%)</td>
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<td>$ 55,227</td>
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UNIT COST $ 552 / ACRE-FEET
DETAILED COST ANALYSIS

PLANT DESIGNATION: SAN LUIS 5
PLANT LOCATION: SAN LUIS VALLEY
WATER SOURCE LOCATION: VALLEY
FORMATION: DEEP CONFINED
DESIGN USAGE 200000 ACRE-FEET/YEAR

<table>
<thead>
<tr>
<th>COST ITEM</th>
<th>ESTIMATED COST $ X 1000</th>
<th>ANNUAL COST $ X 1000</th>
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<tr>
<td>WELLS, PUMPS, INTERWELL PIPE (O WELLS)</td>
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<td>TRANSMISSION PIPE (144 IN.)</td>
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<td>START-UP COSTS</td>
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<td>OWNERS GENERAL EXPENSE</td>
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<td><strong>TOTAL - DEPRECIABLE CAPITAL COSTS</strong></td>
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<td>$ 36158</td>
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<td>(FIXED CHARGE RATE - 9.31 %)</td>
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<tr>
<td>LAND COSTS</td>
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<td><strong>TOTAL - NONDEPRECIABLE CAPITAL COSTS</strong></td>
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<td>724</td>
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<td>(INTEREST RATE - 7.00 %)</td>
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<td><strong>ANNUAL O &amp; M EXPENSE</strong></td>
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<td>0 &amp; M LABOR, SUPPLIES AND MATERIALS</td>
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<td><strong>TOTAL - ANNUAL O &amp; M EXPENSE</strong></td>
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<td>$ 60939</td>
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<td><strong>TOTAL ANNUAL COSTS</strong></td>
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UNIT COST $ 489 /ACRE-FEET
## Detailed Cost Analysis

**Plant Designation:** San Luis 6  
**Water Source Location:** Valley  
**Design Usage:** 300,000 Acre-Feet/Year

### Capital Costs

<table>
<thead>
<tr>
<th>Cost Item</th>
<th>Estimated Cost $ X 1000</th>
<th>Annual Cost $ X 1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wells, Pumps, Interwell Pipe (0 Wells)</td>
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<tr>
<td>Transmission Pipe (180 IN.)</td>
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<td>Booster Stations</td>
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<td>Terminal Storage</td>
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<td><strong>Subtotal - Construction Costs</strong></td>
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<tr>
<td>Interest During Construction</td>
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<td>Start-Up Costs</td>
<td>7,608</td>
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<td>Owners General Expense</td>
<td>2,295.4</td>
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<td><strong>Total - Depreciable Capital Costs</strong></td>
<td><strong>51,573.7</strong></td>
<td><strong>48,008</strong></td>
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<td>(Fixed Charge Rate - 9.31 %)</td>
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<tr>
<td>Land Costs</td>
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<tr>
<td>Working Capital</td>
<td>15,225</td>
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<td><strong>Total - Nondepreciable Capital Costs</strong></td>
<td><strong>15,407</strong></td>
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<td>(Interest Rate - 7.00 %)</td>
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### Annual O & M Expense

<table>
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<tr>
<th>Cost Item</th>
<th>Estimated Cost $ X 1000</th>
<th>Annual Cost $ X 1000</th>
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<tbody>
<tr>
<td>O &amp; M Labor, Supplies and Materials</td>
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<td>Electric Power Costs</td>
<td>90,990</td>
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<td><strong>Total - Annual O &amp; M Expense</strong></td>
<td><strong>91,330</strong></td>
<td><strong>91,330</strong></td>
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</table>

* **Total Annual Costs**                                   | **$ 140,416**           |

**Unit Cost** $468/Acre-Feet
<table>
<thead>
<tr>
<th>PLANT DESIGNATION</th>
<th>FORMATION</th>
<th>DESIGN USAGE (af/y)</th>
<th>DEPSEC + NONDEPSEC CAPITAL COSTS ($ X 1000)</th>
<th>ANNUAL O&amp;M EXPENSES ($ X 1000)</th>
<th>TOTAL ANNUAL COSTS ($ X 1000)</th>
<th>UNIT COST ($/af)</th>
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<tbody>
<tr>
<td>SAN LUIS 3</td>
<td>DEEP CONFINED</td>
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<td>187180</td>
<td>15306</td>
<td>32666</td>
<td>653</td>
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<td>100000</td>
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<td>552</td>
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<td>DEEP CONFINED</td>
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<td>398772</td>
<td>60939</td>
<td>98221</td>
<td>489</td>
</tr>
<tr>
<td>SAN LUIS 6</td>
<td>DEEP CONFINED</td>
<td>300000</td>
<td>531144</td>
<td>91330</td>
<td>140416</td>
<td>468</td>
</tr>
</tbody>
</table>
APPENDIX C

WATER VALUATION FOR AGRICULTURE
IN THE SAN LUIS VALLEY
APPENDIX C
WATER VALUATION FOR AGRICULTURE
IN THE SAN LUIS VALLEY

by
Robert A. Young, Consulting Economist

C.0 INTRODUCTION

This appendix contains the rationale and methodology for estimating the value of project water, considering the dominant agriculture economic base in the San Luis Valley. Comparison of the market value of water can be made with the water-development cost, presented in the main report, for obtaining the water from the deep confined aquifer system.
C.1 FRAMEWORK FOR INVESTMENT APPRAISAL

C.1.1 General

Benefit-cost analysis arose from concern that there be some public counterpart to the financial tests performed by private investors prior to undertaking long-term capital investments. The idea is to assure that proposed public investment programs would, in fact, result in positive economic returns.

For public sector investments, a number of considerations justify special treatment of costs, returns and interest rates. These considerations are based on the fact that markets may not exist to properly price outputs of the project, or that public intervention into markets distort such prices as may be observed. "Shadow" or "accounting" prices are developed to substitute for observed prices in such instances. In the case of water supply projects, markets for the outputs exist in only a limited fashion, if at all, so accounting prices are usually required.

C.1.2 Formulas for Assessing Economic Feasibility

Benefits are measured in terms of willingness to pay for goods and services produced. Costs of resources are measured in terms of benefit in the best foregone alternative use (the "opportunity cost" theory). This concept of costs can also be understood in willingness to pay terms, i.e. the willingness of users to pay to avoid being without the resource. An investment is said to be feasible if anticipated benefits exceed anticipated costs.

Most water resource investments generate returns over a long period. A key issue is how to make benefits and costs over the investment's life commensurate in time. This is achieved by application of an interest rate
(usually called a "discount rate"), which reflects the investor's alternative return on capital or the time value of money.

An investment is said to be economically feasible if the present value of benefits exceed the present value of costs. In symbols:

\[
\sum_{t=0}^{T} \frac{B_t}{(1+i)^t} > \sum_{t=0}^{T} \frac{C_t}{(1+i)^t} \tag{1}
\]

where:

- \( B_t \): benefits in year \( t \)
- \( C_t \): costs in year \( t \)
- \( i \): discount or interest rate
- \( T \): end of planning period

Expression (1) can be rearranged so that feasibility is defined as:

a) Present Value of Net Benefits exceed zero.

\[
\sum_{t=0}^{T} \frac{B_t}{(1+i)^t} - \sum_{t=0}^{T} \frac{C_t}{(1+i)^t} > 0 \tag{2}
\]

b) The ratio of benefits to costs exceeds 1.0.

\[
\frac{\sum_{t=0}^{T} \frac{B_t}{(1+i)^t}}{\sum_{t=0}^{T} \frac{C_t}{(1+i)^t}} > 1.0 \tag{3}
\]

C.1.3 "Associated Costs" and the Definition of Producer's Benefits

The costs of an investment usually include construction and operating and maintenance costs for the project plus the producer's costs of utilizing the water in his production process. These latter costs, called "associated costs", in the literature dealing with irrigation, include the cost of owning and operating an irrigation system, developing the land, plus the usual production costs—labor, fertilizer, machinery, etc.
In practice, irrigation benefits are usually defined as producers' revenues less producer's cost of production. In this interpretation, benefits are producers' return to water, net of associated costs. Benefits thus defined, and expressed on a per unit volume basis (i.e., $/acre foot), are often termed the "value" of water.

C.1.4 Simplifying Assumptions

When a project involves a long life and many individual producers, the analysis must be simplified to make it manageable.

One simplification is to select a "representative farm" situation for which to calculate net returns to water. The area and quality of land, the productivity of soils, the machinery and equipment inventory available for production and the acreage to be devoted to each potential alternative crop must be identified. If the situation warrants, more than one representative farm type may be needed, (such as large vs. small farms, or different types according to product specialization).

The other common simplification is to select a representative year on which to perform the analysis, rather than calculating benefits for each year. The midpoint year of the selected project life is the usual choice. Assumptions (forecasts) regarding prices, costs, productivity and technology are made for that year.

C.1.5 Special Problems

Inflation - One issue in forecasting future prices of both costs and benefits is how to represent price inflation. Accurately predicting price changes into the distant future is likely to be a futile exercise. Therefore, the usual convention is to express the price forecasts in real (constant
dollar terms. If product and input prices are in constant dollars, interest rates should be in constant dollars also.

**Interest rates** - The most contentious and complicated issue in benefit-cost analysis centers around selecting the appropriate interest rate. Market interest rates are not determined in an unfettered market context, but are influenced heavily by government control of monetary (money supply) and fiscal (tax) policies. Hence, accounting prices are usually recommended in place of market interest rates.

The proper interest rate for long term public planning is the rate on long term government bonds (15 years or longer to maturity). Accounting interest rates are usually estimated by adjusting for the effect of inflation on the market interest rate. (Lenders are assumed to raise their rates of interest on bonds or loans by the amount of anticipated inflation.)

**Costs, Prices and Technological Change** - The joint forecasting of future crop prices and technological improvements creates a particular problem. From historical experience, we expect productivity (yield per acre) to improve. Historically, prices (in constant dollars) have tended to fluctuate around a declining trend, since productivity growth has outstepped demand growth. To avoid the bias introduced by simultaneously forecasting improved productivity but not using lower constant dollar prices, a reasonable and simple solution is to use current prices (smoothed by taking a three year average) and current productivity. This is equivalent to assuming the effects exactly offset each other on net returns.

The selection of a representative year forces the analysis of costs to be commensurate in annual terms. This is readily accomplished by converting capital costs to an Equivalent Uniform Annual Cost, by the use of the capital recovery factor (James and Lee). The capital recovery factor converts a fixed
initial investment into an equivalent constant annual cost, which reflects the
selected interest rate and planning period.

The feasibility formula for the case of annualized costs and benefits
becomes:

\[
\text{Annual Net Benefit} > \text{Annual Capital and Operating Cost (per unit water)}
\]

C.2 APPROACHES TO ESTIMATING VALUE OF WATER

In the case at hand, three different techniques are applicable to
estimating project benefits. They are (1) observed market values, (2) change
in net income, and (3) least cost alternative method (also called "alternative
cost").

C.2.1 Observed Transactions Prices

If markets for water were everywhere available, the need for separate
analysis of ability to pay would be lessened, if not avoided altogether. Under
Colorado law, markets for both seasonal rentals and permanent sales are
frequently found, and the prices observed these provide useful evidence on the
value of water.

The rental price is an approximation to the annual equivalent net benefit
discussed above, since it represents actual willingness to pay for incremental
water supplies. Rental rates fluctuate depending on current water supply and
on short run crop price outlook. However, an average of observed prices over
time (corrected for inflation) could be a usable measure of the value of water.

Sale prices of water rights are another alternative. The specific
portion paid for the water rights may have to be isolated from payments for
other resources (such as land, buildings) involved in the sale. Sale price of
water rights can be directly compared with total investment costs or converted
to an annual equivalent by the formula:
\[ S_1 = R \]  \hspace{1cm} (4)

where: 
- \( S \) = sale price per acre foot
- \( i \) = interest rate
- \( R \) = annual rental value (per acre foot)

The formula (4) is an approximation for the case in which the interest rate (1) and the rental rate (R) both remain unchanged over a long (\( T \to \infty \)) planning period.

Market prices for water can be used most appropriately where the climate, production conditions and location with respect to markets is similar to that which will prevail for the investment being analyzed. Because the cost of transporting water can rapidly exceed its value in use, using market prices must also be tempered by adjustment for necessary pumping and transmission expenses.

C.2.2 The "Residual" Approach

Valuation is, in essence, a problem of assigning a price to a resource or a commodity in the absence of a market (or a properly functioning market) to perform the function. The residual approach calculates the remaining ability to pay for one resource by a producer, given the productivity of the resource, the payments required for other production inputs and the price of the products:

A formula used to measure benefits in agricultural production is:

\[ B = \frac{\sum Y_i P_{Y_i} - \sum X_j P_{X_j}}{W} \]  \hspace{1cm} (3)

where: 
- \( B \) = net benefit (ability to pay) per unit water
- \( W \) = quantity of water employed
- \( Y_i \) = production (yield) of \( i \)th crop
- \( X_j \) = quantity required of \( j \)th productive resource
The physical units \( Y_i, X_j \), and \( W \) must refer to a specified production unit, such as an acre of land or more typically, a representative farm situation. The products might include, for example, alfalfa, potatoes, barley, etc. The inputs would include labor, land, machinery, chemicals, overhead, etc. If a charge for any input is omitted, its value will be credited to the residual factor, overstating the latter's importance. Hence, care must be taken in specifying inputs. The second major concern is with commodity prices. Crop prices are likely to vary widely during the life of an investment, and choosing a representative point in the commodity cycle and within the inflationary trend is often a difficult and challenging task and one subject to high probability of error.

C.2.3 "Least-Cost Alternative" Method

The final method discussed here requires that the investment being appraised be the least-cost source of accomplishing the project purpose. If the water is to be developed, for example, for some prospective municipal or industrial demand, the benefits will be limited to the cost of the most likely alternative source, such as by developing an alternative supply of surface water or by purchase of agricultural water rights.

The alternative cost computations are normally expressed in terms of unit cost (per acre foot) of the alternative supply source.

C.3 MARKET AND PRODUCTION CONSIDERATIONS

C.3.1 Production Considerations

Climate - The San Luis Valley lies at elevations mostly exceeding 7,500
feet. Frost-free growing periods are relatively short, and very late spring frossts and very early fall frosts occur with some frequency.

**Soils and Topography** - The area which might be newly-irrigated ranges from sandy/gravelly to very heavy soils with good water-holding capacity. The terrain is generally relatively level, but much of the potential area's soils have become salinized and overgrown with brush.

**Feasible Crops** - The soil and growing season considerations noted above indicate the most feasible crops from the production viewpoint are forages (alfalfa, pasture grasses), edible dry beans (pintos), small grains (wheat, barley), potatoes and fresh vegetables.

### C.3.2 Market Considerations

Producers in southern Colorado shared in the general agricultural prosperity of the 1970s. However, the 1980s has been a period of precipitously declining real crop prices. The writer sees little prospect for return to strong profitability in the next decade or so, although some minor improvement from present disastrous prices is possible. Three factors will govern commodity price outlook for producers.

First, the international market for food commodities is characterized at present by a large over-supply relative to effective demand. The high prices of the 70s, in a fashion similar to such cyclical peaks in the past, called forth a large increase in production capacity. Further, the trend to encourage market-like institutions in formerly centrally planned and/or highly regulated nations (China, India) plus continuing technological advances will persist in adding to productive capability, and a closer balance between supply and demand will likely be some time in appearing.

Second, policies at the national level are moving in the direction of lower prices and are redirecting crop production capacity. Prices for feed

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grains (corn, barley, oats) and their close substitutes (hay, forages) are likely to continue to experience downward pressures. Federal policies aimed at reducing food and feed grain output threaten to shift making the outlook for those crops' prices even more unfavorable.

Third, local market conditions in southwest Colorado show little promise for a brighter outlook. The remoteness from markets and lack of capital, expertise and managerial capability limit prospects for higher income specialty crops (e.g., fresh vegetables) other than potatoes.
Tables 1 and 2 show calculations for the residual value of water. Table 1 adopts a "realistic" scenario, which represents the best estimate of the likely returns. This assumes what the writer believes to be the most likely scenario for crop yields and proportions of acreages, and a fairly high charge for clearing, leveling, and reclaiming the salinized soils most likely to be available for new development. Acreage is allocated to crops as follows: 50 percent alfalfa, 40 percent small grains (wheat, feed barley), and 10 percent potatoes.

The optimistic scenario is based on a high proportion of high return crops (potatoes and malt barley 1/3 each, together with 1/3 alfalfa) and lower land reclamation costs. This can be regarded as an upper limit on ability to pay for new water supplies.

CONCLUSION

Given the difficult conditions for developing new agricultural lands in the San Luis Valley, plus the short growing season and limited markets, the farmers' ability to pay for water is likely to be no more than the neighborhood of $13.00 per acre foot for a supply of good quality water delivered to the farm. If market conditions encouraged potato production, the amount might approach $49.00 per acre foot, but that is not too likely a prospect.
Table C.1 Summary of Projected Costs, Returns and Residual Return to Water, San Luis Valley, Realistic Scenario

<table>
<thead>
<tr>
<th>Item</th>
<th>Alfalfa Hay</th>
<th>Spring Wheat</th>
<th>Potatoes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Per Acre</td>
<td>Per Acre</td>
<td>Per Acre</td>
</tr>
<tr>
<td><strong>Revenues</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Projected Yields/Acre</td>
<td>4 T</td>
<td>90 bu</td>
<td>300 cwt</td>
</tr>
<tr>
<td>Projected Price/Unit</td>
<td>$70/T</td>
<td>$2.70/bu</td>
<td>$4.50/cwt</td>
</tr>
<tr>
<td>Project Gross Revenues</td>
<td>$280/A</td>
<td>243/A</td>
<td>$1350/A</td>
</tr>
<tr>
<td><strong>Costs</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land Preparation and Plant&lt;br&gt;^b</td>
<td>$62</td>
<td>$49</td>
<td>$167</td>
</tr>
<tr>
<td>Other Pre-Harvest Machinery Operations</td>
<td>8</td>
<td></td>
<td>30</td>
</tr>
<tr>
<td>Fertilizer, Pesticides</td>
<td>10</td>
<td>46</td>
<td>586</td>
</tr>
<tr>
<td>Irrigation System Operating Costs</td>
<td>29</td>
<td>15</td>
<td>33</td>
</tr>
<tr>
<td>Harvest and Haul</td>
<td>80</td>
<td>28</td>
<td>33</td>
</tr>
<tr>
<td>Land, Land Development and Sprinkler System (Annualized)</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>General Overhead, Taxes, Etc.</td>
<td>29</td>
<td>26</td>
<td>90</td>
</tr>
<tr>
<td>Management</td>
<td>13</td>
<td>12</td>
<td>135</td>
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<tr>
<td>TOTAL COSTS</td>
<td>281</td>
<td>226</td>
<td>1124</td>
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<tr>
<td><strong>Net Return to Water ($/acre)</strong></td>
<td>-1</td>
<td>17</td>
<td>226</td>
</tr>
<tr>
<td><strong>Annual Water Applied (AF/acre)</strong></td>
<td>2.0</td>
<td>1.67</td>
<td>2.33</td>
</tr>
<tr>
<td><strong>Return Per Acre Foot ($)</strong></td>
<td>-0.5</td>
<td>10</td>
<td>97</td>
</tr>
<tr>
<td><strong>Weighted Average Return Per Acre Foot</strong></td>
<td></td>
<td></td>
<td>$13</td>
</tr>
</tbody>
</table>

^aRealistic scenario assumes:
1) $200 land development costs amortized @ 7%.
2) "normal" acreage in high return crops (10% potatoes, 40% spring wheat, 50% alfalfa).

^bAlfalfa planting costs represent cost of initial stand established amortized over four year life.
Table C.2  Summary of Projected Costs, Returns and Residual Return to Water, San Luis Valley, Optimistic Scenario

<table>
<thead>
<tr>
<th>Item</th>
<th>Alfalfa Hay</th>
<th>Malt Barley</th>
<th>Potatoes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Per Acre</td>
<td>Per Acre</td>
<td>Per Acre</td>
</tr>
<tr>
<td>Revenues</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Projected Yields/Acre</td>
<td>4 T</td>
<td>40 cwt</td>
<td>300 cwt</td>
</tr>
<tr>
<td>Projected Price/Unit</td>
<td>$70/T</td>
<td>$7.00/cwt</td>
<td>$4.50/cwt</td>
</tr>
<tr>
<td>Project Gross Revenues</td>
<td>$280/A</td>
<td>$280/A</td>
<td>$1350/A</td>
</tr>
<tr>
<td>Costs</td>
<td>$</td>
<td>$</td>
<td>$</td>
</tr>
<tr>
<td>Land Preparation and Plant</td>
<td>62</td>
<td>49</td>
<td>167</td>
</tr>
<tr>
<td>Other Pre-Harvest Machinery Operations</td>
<td>8</td>
<td>-</td>
<td>30</td>
</tr>
<tr>
<td>Fertilizer, Pesticides</td>
<td>10</td>
<td>46</td>
<td>586</td>
</tr>
<tr>
<td>Irrigation System Operating Costs</td>
<td>29</td>
<td>15</td>
<td>33</td>
</tr>
<tr>
<td>Harvest and Haul</td>
<td>80</td>
<td>28</td>
<td>33</td>
</tr>
<tr>
<td>Land, Land Development and</td>
<td>36</td>
<td>36</td>
<td>36</td>
</tr>
<tr>
<td>Sprinkler System (Annualized)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>General Overhead, Taxes, Etc.</td>
<td>29</td>
<td>26</td>
<td>90</td>
</tr>
<tr>
<td>Management</td>
<td>14</td>
<td>14</td>
<td>135</td>
</tr>
<tr>
<td>TOTAL COSTS</td>
<td>268</td>
<td>214</td>
<td>1110</td>
</tr>
<tr>
<td>Net Return to Water ($*)</td>
<td>12</td>
<td>66</td>
<td>240</td>
</tr>
<tr>
<td>Annual Water Applied (AF)</td>
<td>2.0</td>
<td>1.67</td>
<td>2.33</td>
</tr>
<tr>
<td>Return Per Acre Foot ($)</td>
<td>6.00</td>
<td>39.50</td>
<td>103</td>
</tr>
<tr>
<td>Weighted Average Return Per Acre Foot</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1/3 of acreage to each crop)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$49</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Optimistic scenario assumes:
1) low land development costs
2) maximum acreage in high return crops (1/3 potatoes, 1/3 malt barley, 1/3 alfalfa).

Alfalfa planting costs represent cost of initial stand established amortized over four year life.

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APPENDIX D

COMPUTER-PROGRAM "COST"
PROGRAM COST

THIS PROGRAM COMPUTES COSTS FOR PUMPING AND TRANSMITTING WATER FROM A WELL FIELD OR OTHER SOURCE. THE PROGRAM IS APPLICABLE FOR FLOW RATES GREATER THAN ONE MILLION GALLONS PER DAY (1 MGD).

PROGRAM ORIGINALLY WRITTEN BY JAMES G. NALVEN, JUNE 1975.

UPDATES AND ADDITIONS BY JAMES R. KUNKEL, MAY 1986.

SUBROUTINES REQUIRED FOR THE PROGRAM: BOOST, ELEC, INTR, LAND, OGE, OM, PIPE, SIZE, TERM, THOU, WELL, WCSU

INPUTS
P: COST OF ELECTRICITY, $/KWH
E: PUMP EFFICIENCY, DECIMAL
C: HAZEN-WILLIAMS COEF. FOR PIPE BEING USED
EF: COST OF ESCALATION FACTOR, REAL NUMBER
PLI: LENGTH OF PIPELINE, AIR MILES
RF: MAXIMUM RATE FACTOR
QAF: AVERAGE FLOW, AF/YR
GPM: YIELD PER WELL, GPM
PP: PUMPING LIFT, FT
PA: PRICE PER ACRE FOR LAND, $
XINT: ANNUAL INTEREST RATE, DECIMAL
TF: TAX RATE, DECIMAL
WD: WELL DEPTH, FEET
XINS: INSURANCE RATE, DECIMAL
YR: AMORTIZATION PERIOD, YEARS
PF: PIPE LENGTH FACTOR
HE: ELEVATION HEAD, FEET
XX: IF XX.EQ.0 NO TERM STORAGE
X: IF X.EQ.0 THE COST OF WELLS WILL NOT BE INCLUDED
PLANT: PLANT DESIGNATION, ALPHA
PLOC: PLANT LOCATION, ALPHA
FORM: WITHDRAWAL AQUIFER, ALPHA
WLOC: WELL LOCATION, ALPHA
HP: DISCHARGE HEAD AT WELL PUMPS

OUTPUTS
CP: TRANSMISSION PIPELINE COST
CT: TERMINAL STORAGE COST
CW: WELL AND INTERWELL PIPELINE COST
CB: BOOSTER STATION COST
CL: LAND COST
CE: ELECTRIC POWER COST
COM: OPERATION AND MAINT. COST
CI: INTEREST DURING CONSTRUCTION COST
COG: OWNERS GENERAL EXPENSE
TC: TOTAL CONSTRUCTION COST
TDC: DEPRECIABLE CAPITAL COST
TOM: TOTAL ANNUAL O & M COST
TNDC: ANNUAL TDC
ATNDC: TOTAL ANNUAL COST
DAF: ANNUAL UNIT COST $/AF OF WATER
ALL COSTS ROUNDED TO THE NEAREST THOUSAND AND OUTPUT AS INTEGERS

INPUT IS ON UNIT 5
OUTPUT IS ON UNIT 6
OUTPUT OF SUMMARY DATA IS TEMPORARILY STORED ON UNIT 10

CHARACTER*15 FILEIN,FILEOUT
CHARACTER*20 PLANT,FORM
CHARACTER*16 PLOC,WLOC
COMMON/AI,CI
COMMON PL,NBT,RNBT,CL,CR,TH,CE,COM,CS,ITC,COG,CWC,CT,HE,ICOM,ICE,
GMGD,QGPD,QMGD2,OGPH2,OGFS2,HT,NT,P,E,C,EF,FLI,GPM,PP,PA,
XINT,DF,CP,CW,NW,WD,HP

D-1
WRITE(*,3000)
3000 FORMAT(' INPUT FILE NAME:'/
READ(*,1600) FILEIN
WRITE(*,3005)
3005 FORMAT(' OUTPUT FILE NAME:'/
READ(*,1600) FILEOUT
OPEN(S,FILE=FILEIN,STATUS='OLD')
OPEN(6,FILE=FILEOUT,STATUS='NEW')
OPEN(10,STATUS='SCRATCH')

C INPUT DATA
NC = 0
DO 999 IBIG = 1,1000
READ(S,1600,END=1001) PLANT
READ(S,1600) PLOC
READ(S,1600) WLOC
READ(S,1600) FORM
READ(S,100) P,E,C,EF,PLI,PF,QAF,RF,X,GPM,PF,WD,HE,HP, + PA,XINT,XINS,TAX,YR,XX
C CONVERSION OF AF/YR TO MGD AND GPM
QGPD = (QAF*325850./365.)
QMGD = QGPD/10.**6
C MAXIMUM RATE FOR GPM, MGD AND CFS
QGPM2 = (QGPD/1440.)*RF
QMGD2 = QMGD * RF
QCFS2 = QGPM2/448.8
C CALCULATE SIZE OF TRANSMISSION PIPE
IF(PLI.EQ.0.) GO TO 40
CALL SIZE
C CALCULATE COST OF PIPE
40 IF(PLI.EQ.0.) D = 1.
CALL PIPE
CALL THOU(CP,ICP)
C IF X.EQ.0 COST OF WELLS WILL NOT BE CALCULATED
C IF(X.LT. .1) GO TO 10
C CALCULATE COST OF WELLS AND INTERWELL PIPE
CALL WELL
CALL THOU(CW,ICW)
C CALCULATE COST OF TERMINAL STORAGE
GO TO 20
10 ICW = 0
    NW = 0
20 HT = 0.
    ICT = 0
    IF(XX.LT. ,1) GO TO 30
    CALL TERM
    CALL THOU(CT,ICT)
C
C CALCULATE COST OF BOOSTER STATIONS
C
30 CALL BOOST
    CALL THOU(CB,ICB)
C
C CALCULATE LAND COSTS
C
    CALL LAND
    CALL THOU(CL,ICL)
C
C CALCULATE COST ELECTRICAL POWER
C
    CALL ELEC
    CALL THOU(CE,ICE)
C
C CALCULATE OPERATION AND MAINTENANCE COSTS
C
    CALL OM
    CALL THOU(COM,ICOM)
C
C CALCULATE WORKING CAPITAL AND START-UP COSTS
C
    CALL WCSU
    ICWC = CWC + .5
    ICS = CS + .5
C
C CALCULATE TOTAL CONSTRUCTION COSTS, TC
C
    ITC = ICP + ICW + ICT + ICB
C
C CALCULATE INTEREST DURING CONSTRUCTION COST
C
    CALL INTR
    ICI = CI + .5
C
C CALCULATE OWNERS GENERAL EXPENSE
C
    CALL OGE
    CALL THOU(COG,ICOG)
C
C CALCULATE DEPRECIABLE AND NONDEPRECIABLE CAPITAL COSTS
C
    ITDC = ITC + ICI + ICS + ICOG
    ITNDC = ICL + ICWC
    ITRDC = ITHDC + ITDC
CALCULATE TOTAL ANNUAL OPERATION AND MAINTENANCE

ITOM = ICOM + ICE

CALCULATE TOTAL ANNUAL COSTS, ANNUAL DEPRECIABLE CAPITAL COSTS, DEPRECIABLE CAPITAL COST RATE, AND ANNUAL NON-DEPRECIABLE CAPITAL COST

DCR = ((XINT*(1. + XINT)**YR)/((1. + XINT)**YR)-1))
+ XINS + TAX
ISTDC = ITDC * DCR + .5
ISTNDC = ITNDC * XINT + .5

CALCULATE UNIT COST

ITAC = ISTNDC + ISTDC + ITOM
IDAF = ITAC * 1000./QAF
YINT = XINT * 100.
YDCR = DCR * 100.
IQAF = QAF + .5
ID = D + .5

WRITE COST SUMMARY

WRITE(6,2300)
WRITE(6,1800)
WRITE(6,1900)
WRITE(6,200) PLANT,PLOC,WLOC,FORM,IQAF
WRITE(6,300)
WRITE(6,400)
WRITE(6,500)
WRITE(6,600) NW,ICW,ID,ICP,ICB,ICT
WRITE(6,700)
WRITE(6,800) ITC,ICI,ICS,ICOG
WRITE(6,900) ITDC,ISTDC,YDCR,ICL,ICWC
WRITE(6,700)
WRITE(6,1000) ITNDC,ISTNDC,YINT
WRITE(6,1700)
WRITE(6,1100) ICOM,ICE
WRITE(6,700)
WRITE(6,1200) ITOM,ITOM
WRITE(6,1300)
WRITE(6,1400) ITAC,IDAF
WRITE(10,1500) PLANT,FORM,IQAF,ITTDC,ITOM,ITAC,IDAF

NC = NC + 1
999 CONTINUE
1001 WRITE(6,2300)
WRITE(6,1800)
WRITE(6,2000)
REWRITE 10
1010 WRITE(6,2100)
DO 99 ISML = 1,NC
READ(10,1500,END=2001) PLANT,FORM,IQAF,ITTDC,ITOM,ITAC,IDAFC
WRITE(6,2200) PLANT,FORM,IQAF,ITTDC,ITOM,ITAC,IDAFC
99 CONTINUE
2001 CALL EXIT
C FORMATS
C
100 FORMAT(10F8.0)
200 FORMAT(' DETAILED COST ANALYSIS'/
+ ' PLANT DESIGNATION: ',A20,' PLANT LOCATION: ',A16/
+ ' WATER SOURCE LOCATION: ',A16,' FORMATION: ',A20/
+ ' DESIGN USAGE',I8,' ACRE-FEET/YEAR'/IX,73('-')/T14,
+ 'COST ITEM',T42,'ESTIMATED COST',T64,'ANNUAL COST'/
+ T31,2(14X,'$ X 1000'))
300 FORMAT(1X,T14,9('-'),T42,14('-'),T64,11('-'))
400 FORMAT(' CAPITAL COSTS')
500 FORMAT(1X,13('-'))
600 FORMAT(T6,'WELLS, PUMPS, INTERWELL PIPE(',I4,' WELLS)',T48,'$ ',
+ I6/T6,
+ 'TRANSMISSION PIPE (',I3,' IN.)',T50,I6/T6,'BOOSTER ',
+ 'STATIONS',T50,I6/T6,'TERMINAL STORAGE',T50,I6)
700 FORMAT(1X,T48,8('-'))
800 FORMAT( /T6,'SUBTOTAL - CONSTRUCTION COSTS',T48,'$ ',I6//T6,
+ 'INTEREST DURING CONSTRUCTION',T50,I6/T6,'START-UP COSTS,'
+ T50,I6/T6,'OWNERS GENERAL EXPENSE',T50,I6)
900 FORMAT( /T6,'TOTAL - DEPRECIABLE CAPITAL COSTS',T48,'$',I6,T67,
+ '$ ',I6/T12,'(FIXED CHARGE RATE - ',F5.2,'%)'/T6,
+ 'LAND COSTS',T48,'$',I6/T6,'WORKING CAPITAL',T50,I6)
1000 FORMAT( /T6,'TOTAL - NONDEPRECIABLE CAPITAL COSTS',T48,'$',I6,
+ T69,I6/T12,'INTEREST RATE - ',F5.2,'%'/T6,
+ 'O & M EXPENSE')
1100 FORMAT( /T6,'O & M LABOR, SUPPLIES AND MATERIALS',T48,'$',I6/
+ T6,'ELECTRIC POWER COSTS',T50,I6)
1200 FORMAT( /T6,'TOTAL - ANNUAL O & M EXPENSE',T48,'$',I6,T69,I6)
1300 FORMAT(1X,T67,8('-'))
1400 FORMAT( /T3,* TOTAL ANNUAL COSTS',T67,'$',I6//1X,73('-')//
+ T6,'UNIT COST $ ',I6,'/ACRE-FEET')
2000 FORMAT(T43,'SUMMARY OF COSTS'/T32,'GROUND-WATER WITHDRAWAL AND '
+ 'TRANSMISSION')
2100 FORMAT(T9,'PLANT',T23,'FORMATION',T45,'DESIGN DEPREC + NONDEPREC'
+ ANNUAL O&M TOTAL ANNUAL UNIT/T6,'DESIGNATION',
+ T45,'USAGE CAPITAL COSTS EXPENSES',T87,'COSTS',
+ T97,'COST/T44,'AC-FT/YR $ X 1000',T73,'$ X 1000',
+ T85,'$ X 1000 $/AC-FT'/
+ T6,'11('-'),T20,18('-'),T44,8('-'),T57,8('-'),
+ T73,8('-'),T85,8('-'),T95,8('-'))
2200 FORMAT(2(1X,A20),T45,I6,T58,I6,T74,I6,T86,I6,T96,I5)
1500 FORMAT(2(A20),4I6,IS)
1600 FORMAT(A)
1700 FORMAT(1X,20('-'))
1800 FORMAT(1X,/) 
1900 FORMAT(1X,/) 
2300 FORMAT('1')

D-5
END

SUPROUTINE BOOST

THIS SUBROUTINE CALCULATES HEAD IN PIPES AND COST OF BOOSTER PUMPING STATIONS

REAL J
COMMON PL,NBT,RNB,CL,CL,TH,CE,COM,CS,ITC,COG,CWC,CT,HE,ICOM,ICE,
+ QMGD,QGPD,QMGD2,QGPM2,QCP2,HT,NT,P,E,C,EF,PLI,GPM,PP,PA,
+ XINT,D,PF,CP,CW,NW,WD,HP

HL IS THE FRICTION HEAD IN PIPES
HL = 5280.*PL*(QCF2/((.432*C*((ID/12.)**2.63))**(1./.54))
CALCULATE TOTAL HEAD
TH = HL + HT + HE - HP
IF(NW.EQ.0) TH = TH + HP
IF(TH.LE.0.) TH = 0.
CALCULATE COST OF BOOSTER STATIONS
NBT IS THE NUMBER OF STATIONS, 1/240 FT HEAD + ONE LOW HEAD STA.
XNB = TH/240.
RNB = XNB - IFIX(XNB)
NBT = XNB
CALCULATE FIRMING FACTOR, J
IF(QMGD.LE.2.) GO TO 30
IF(QMGD.LE.5.) GO TO 40
IF(QMGD.LE.10.) GO TO 50
IF(QMGD.LE.20.) GO TO 60
IF(QMGD.LE.30.) GO TO 70
J = 1.25
GO TO 80
30 J = 2.08 - (.18*QMGD)
GO TO 80
40 J = 1.9666 - (.1233*QMGD)
GO TO 80
50 J = 1.42 - (.014*QMGD)
GO TO 80
60 J = 1.3 - (.002*QMGD)
GO TO 80
70 J = 1.28 - (.001*QMGD)
CALCULATE REQUIRED HORSEPOWER, HORS AND HORSR
80 HORS = .176 * QMGD2 * 240. * J/E
IF(RNB.LT. 2) GO TO 90
HORSR = (HORS) * RNB
SUBROUTINE WELL

THIS SUBROUTINE CALCULATES THE COST OF WELLS AND INTERWELL PIPE

NW IS THE NUMBER OF WELLS: MAX. TOTAL GPH/GPM PER WELL, ROUNDED UP

NW = (QGPM2/GPM) + 1
NWA = (NW * .1) + 1
IF(NWA.GT.10) NWA = 10
NW = NW + NWA

COST OF WELLS

CW2 = (150. * WD) * NW

COST OF PUMPS

CW = NW * ((30. * GPM) + 20000.)

COST OF INTERWELL PIPE

CIW = 27000. * ((QMGD2 * NW)**.65)
CW = (CIW + CW + CW2) * EF
RETURN

END

SUBROUTINE LAND

THIS SUBROUTINE CALCULATES THE LAND COST

N1 = RNB * 2
CLL = PA*(.5*NW)+(.25*(NBT+N1)+((2*HT+100.)**2)/43560.)
CLP = PA * (PF * PLI * 30. * 5280./43560.)
CL = CLL + CLP
RETURN
SUBROUTINE OM

THIS SUBROUTINE CALCULATES OPERATION AND MAINTENANCE COSTS

COMMON PL,NBT,RNB,CL,CB,TH,CE,COM,CS,ITC,COG,CWC,CT,HE,ICOM,ICE,
+ QMGD,QGPD,QMGD2,QGPM2,QCF,S2,HT,NT,P,E,C,EF,PLI,GPM,PP,PA,
+ XINT,D,PF,CP,CW,NW,WD,HP

NWZ = NW
IF(PL.EQ.O.) PL = 1.
IF(NW.EQ.O) NWZ = 1
COM = (3262. * (QMGD2*NWZ*PL)**.49) * EF
RETURN
END

SUBROUTINE OGE

THIS SUBROUTINE CALCULATES OWNERS GENERAL EXPENSE COSTS

COMMON PL,NBT,RNB,CL,CB,TH,CE,COM,CS,ITC,COG,CWC,CT,HE,ICOM,ICE,
+ QMGD,QGPD,QMGD2,QGPM2,QCF,S2,HT,NT,P,E,C,EF,PLI,GPM,PP,PA,
+ XINT,D,PF,CP,CW,NW,WD,HP

TC = ITC * 1000.
IF(TC.LE.1000000.) GO TO 10
COG = TC * (.09/(1000000./TC)**(-.109))
GO TO 20
10 COG = TC * (.12/(1000000./TC)**(-.125))
20 RETURN
END

SUBROUTINE THOU(X,I)

THIS SUBROUTINE ROUNDS COSTS TO THE NEAREST THOUSAND AND
CONVERTS TO INTEGER

I = (X/1000.) + .5
RETURN
END

SUBROUTINE ELEC

THIS SUBROUTINE CALCULATES ELECTRIC POWER COST

COMMON PL,NBT,RNB,CL,CB,TH,CE,COM,CS,ITC,COG,CWC,CT,HE,ICOM,ICE,
+ QMGD,QGPD,QMGD2,QGPM2,QCF,S2,HT,NT,P,E,C,EF,PLI,GPM,PP,PA,
+ XINT,D,PF,CP,CW,NW,WD,HP

THX = TH + PP + HP
IF(NW.EQ.O) THX = TH
CE = P * (.004*QGPD*(365./1000.)*THX)
RETURN
END

SUBROUTINE SIZE

THIS SUBROUTINE CALCULATES THE SIZE OF TRANSMISSION PIPE

COMMON PL,NBT,RNB,CL,CB,TH,CE,COM,CS,ITC,COG,CWC,CT,HE,ICOM,ICE,
+ QMGD,GPD,QMGD2,QGPM2,QCF2,HT,NT,P,E,C,EF,PLI,GPM,PP,PA,
+ XINT,D,PF,CP,CW,NW,WD,HP

D IS THE PIPE DIAMETER IN INCHES

DA = 83.4*(P**.163)*(QMGD2**.463)/((E**.163)*(C**.301))
IF(DA.LE.48.) GO TO 10
D = 12*(IFIX(DA)/12) + 12
GO TO 20
10 D = 6*(IFIX(DA)/6) + 6
20 RETURN
END

SUBROUTINE TERM

THIS SUBROUTINE CALCULATES THE NUMBER OF STORAGE TANKS
THE MAX. TANK SIZE IS 25 MILLION GALLONS, AND MINIMUM
STORAGE MUST BE .GE. 2*QMGD. THE COST OF THE STORAGE TANKS
ALSO IS CALCULATED.

COMMON PL,NBT,RNB,CL,CB,TH,CE,COM,CS,ITC,COG,CWC,CT,HE,ICOM,ICE,
+ QMGD,GPD,QMGD2,QGPM2,QCF2,HT,NT,P,E,C,EF,PLI,GPM,PP,PA,
+ XINT,D,PF,CP,CW,NW,WD,HP

IF(QMGD.LT.25.) GO TO 10
NT = 1 + (2*(QMGD/25.))
X = 25.
GO TO 20
10 NT = 2
X = QMGD
20 CT = (NT*(.(0867*X) + .0532))*(10.*6)*EF
HT = (X*10.*6)/(7.48*3.14159)**(1./3.)
RETURN
END

SUBROUTINE PIPE

THIS SUBROUTINE CALCULATES THE COST OF TRANSMISSION PIPE

COMMON PL,NBT,RNB,CL,CB,TH,CE,COM,CS,ITC,COG,CWC,CT,HE,ICOM,ICE,
+ QMGD,GPD,QMGD2,QGPM2,QCF2,HT,NT,P,E,C,EF,PLI,GPM,PP,PA,
+ XINT,D,PF,CP,CW,NW,WD,HP

PL IS THE TERRAIN-CORRECTED PIPELINE LENGTH

PL = PLI * PF
IF(D.LT.36.) GO TO 10
CP = PL * 5280. * ((7.65*D) - 95.26)
GO TO 20
10 CP = PL * 5280. * ((5.21*D) - 13.36)
20 RETURN

SUBROUTINE WCSU
C THIS SUBROUTINE CALCUALTES WORKING CAPITAL
COMMON PL,NBT,RNB,CL,CB,TH,CE,COM,CS,ITC,COG,CWC,CT,HE,ICOM,ICE,
+ QMGD,QGPĐ,QMGD2,QGPM2,QCFS2,HT,NT,P,E,C,EF,PLI,GPM,PP,PA,
+ XINT,D,PF,CP,CW,NW,WD,HP

WORKING CAPITAL
CWC = .1667 * (ICOM + ICE)
RETURN
END

SUBROUTINE INTR
C THIS SUBROUTINE CALCUALTES THE INTEREST DURING CONSTRUCTION
COMMON/A/ CI
COMMON PL,NBT,RNB,CL,CB,TH,CE,COM,CS,ITC,COG,CWC,CT,HE,ICOM,ICE,
+ QMGD,QGPĐ,QMGD2,QGPM2,QCFS2,HT,NT,P,E,C,EF,PLI,GPM,PP,PA,
+ XINT,D,PF,CP,CW,NW,WD,HP

NUMBER OF MONTHS FOR CONSTRUCTION
MC = (8./(1./QMGD)**.32) + 1
INTEREST DURING CONSTRUCTION
CI = ((MC*(XINT/12.)) * ITC)
RETURN
END
APPENDIX B
(Task 2 Report)
SAN LUIS VALLEY CONFINED AQUIFER STUDY
(PHASE I)

INTERIM TASK 2 REPORT
DATA AND INFORMATION SYNTHESIS AND NEEDS

Prepared for
Colorado Water Resources and Power Development Authority
Logan Tower, Suite 620
1580 Logan Street
Denver, Colorado 80203

HRS Water Consultants, Inc.
with Robert E. Moran
87001-12 April, 1987
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ACRONYMS AND ABBREVIATIONS

af  acre-feet
af/y  acre-feet per year
Authority  Colorado Water Resources and Power Development Authority
AWD  American Water Development
C  Celsius
DS  dissolved solids
ft/sec  feet per second
gpm  gallons per minute
gpd/ft  gallons per day per foot
grams/cc  grams per cubic centimeter
GWSI  ground-water site inventory
HSU  hydrostratigraphic unit
K  hydraulic conductivity
mg/l  milligrams per Liter
micromho/cm  micromhos per centimeter
mm  millimeters
msl  mean sea level
NaCl  sodium chloride
SEO  State Engineer's Office
SP  self potential
T  transmissivity
USBR  United States Bureau of Reclamation
USGS  United States Geological Survey
EXECUTIVE SUMMARY

The present study differs from previous evaluations of ground water resources in the San Luis Valley of South-Central Colorado by attempting to characterize the hydrogeology of the confined aquifers which lie 3000 feet or deeper throughout the Valley (referred to in this report as hydrostratigraphic units 3, 4, and 5). This study used available data and assessed the physical as well as economic feasibility of ground-water development from the confined aquifer.

The study team makes the following preliminary conclusions regarding an assessment of physical characteristics affecting the feasibility of ground-water development from the confined aquifer:

1. A primary conclusion of the present study is that five hydrostratigraphic units lie beneath the San Luis Valley. The shallowest is termed HSU-1 (unconfined aquifer). The deepest is termed HSU-5.

2. Hydrostratigraphic units 4 and 5 (HSU-4 and HSU-5) generally lie below a depth of 5000 feet beneath the Valley. Due to very high well-construction and pumping costs, as well as poor water quality, HSU-4 and HSU-5 do not appear to be feasible aquifers for developing a supplemental water supply. The Phase IA and Phase IB studies therefore have concentrated on hydrostratigraphic Unit 3 (HSU-3).

3. The transmissivity of HSU-3, which is called the confined aquifer in this report, is estimated from indirect evidence to be from 10,000 to 25,000 gpd/ft in most areas, though some areas show indications of possibly higher transmissivity. The materials which comprise the hydrostratigraphic units of the confined aquifer are such that large drawdowns are expected if extensive ground-water pumping occurs.
4. Extensive ground-water pumping from the deep confined aquifer (HSU-3) is likely to cause land subsidence in the Valley. Assuming a ground-water withdrawal rate of 100,000 af/y, a subsidence rate of approximately five to ten millimeters per year is expected.

5. The dissolved solids concentration in ground water of the confined aquifer at depths below approximately 2500 feet is estimated at 3000 mg/l or greater in many areas.

6. The existing data base of reliable information on the deep confined aquifer (HSU-3) is quite sparse, particularly as to transmissivity, storativity, and ground-water quality. An inventory of available wells indicated only approximately 30 deeper than 2000 feet. Of these, some were of limited use in the study due to access, well construction, and other constraints.

The confined aquifer evaluated in this study does not appear to be as promising for ground-water supply development as anticipated. Shallower hydrostratigraphic units indicate more favorable development potential, because of better ground-water quality (generally less than 2000 mg/l dissolved solids concentration) and higher transmissivity.

At this stage of the study, the following comments and recommendations are made:

1. Work activities for the Phase I study should focus on documenting the results of completed geophysical field investigations and interpreting satellite imagery for regional geological structures.

2. Originally proposed work on institutional aspects of water development and field isotope/water quality analyses is not presently useful. Therefore, work should not be continued in these areas for this initial study phase.
3. Consideration should be given to a pilot test-well drilling and testing program for the next study phase to fill data deficiencies encountered during this initial study phase. Selection of drilling sites should be based on specific criteria including expected areas of best conditions for developing a water supply, confirmation of already-noted worst-case conditions, and geographical diversity. Before proceeding on this subsequent phase, the possible technical benefits of a pilot program must be weighed against the costs.

From the limited data and information available, definitive conclusions regarding development of the deep confined aquifer (HSU-3) unfortunately cannot be made from this initial study phase. The physical limitations of the confined aquifer system, and the economic analyses performed separately from this report do not provide promising indications that a regional water supply can be obtained from the confined aquifer system. However, future water demands could make development of HSU-3 more favorable.
1.0 INTRODUCTION

A major component of the San Luis Valley Confined Aquifer Study was to assemble and interpret available geological and hydrological data regarding the confined aquifers which lie beneath the Valley at depths greater than 3000 feet. The present study has concentrated on the water-bearing geologic units which lie approximately 3000 feet to 5000 feet below the ground surface of the San Luis Valley. These geologic units comprise hydrostratigraphic Unit 3 (HSU-3), which is called the deep confined aquifer in this report. The water-bearing units below approximately 5000 feet are also part of the deep confined aquifer system, but these units (HSU-4 and HSU-5) were judged to be non-feasible for large scale water-supply development early in the present studies. HSU-4 and HSU-5 are therefore not treated in great detail in this report.

The two shallowest hydrostratigraphic units, termed HSU-1 and HSU-2, lie above HSU-3. HSU-1 is the unconfined aquifer. HSU-2 is the portion of the confined aquifer system which lies above HSU-3.

The area of detailed geologic and hydrologic study comprises approximately 3500 square miles. It includes the valley floor of the San Luis Valley (Figure 1.1), and the adjacent mountainous areas. In addition, less detailed analyses were made of the area defined by the drainage basin of the Rio Grande and its tributaries in Colorado and northern New Mexico, including those subdrainages in the northern San Luis Valley which have no surface outlet for water flow.

This report integrates several interrelated studies which are intended to achieve in part the stated objectives of the Plan of Study for the San Luis Valley Confined Aquifer Study (In-Situ, Inc., 1986).

1.1 ACKNOWLEDGEMENTS

The San Luis Valley Confined Aquifer Study was authorized by the Colorado Water Resources and Power Development Authority (Authority). The study is
conducted on behalf of the San Luis Valley Water Conservancy District.

The Phase IA study team was comprised of In-Situ, Inc., as the prime contractor, with HRS Water Consultants, Inc., John C. Halepaska & Associates, Inc., Robert E. Moran, and Robert A. Young, as subcontractors. Task 2 studies were conducted during Phase IA of the project. A draft Task 2 report was provided to the Authority during Phase IA.

The Phase IB study team has made minor revisions to this Interim Task 2 Report at the request of the Authority. The Phase IB study team is comprised of HRS Water Consultants, Inc., as the prime contractor with Robert E. Moran as subcontractor.
2.0 HYDROGEOLOGIC CHARACTERIZATION OF THE SAN LUIS VALLEY

2.1 REVIEW OF PREVIOUS CONCEPTS

The delineation of two major aquifer systems in the San Luis Valley, the confined and the unconfined, has long been accepted. The material types and physical and chemical characteristics of the unconfined aquifer, and the shallower parts of the confined aquifer have been known and relatively well understood by local ground-water users for over 80 years (Siebenthal, 1910a). Local well drillers, pump installers, and agricultural ground-water users have known for over 50 years that differences occur in temperature, chemical quality, and well production from zones at various depths within the shallow confined aquifer system.

Studies by the U. S. Geological Survey (USGS), the Colorado Water Conservation Board, and local and regional special water districts during the 1950's through the 1980's have added to the technical knowledge and understanding of ground water/surface water interactions in the Valley, as well as to the knowledge of interactions between the unconfined aquifer and the confined aquifer. The extensive references in geologic and hydrologic publications on the San Luis Valley (see Appendix A) indicate that the level of interest in the geology and hydrology of the Valley has steadily increased.

Until recently, there were little data collected relating to the deep confined aquifer (primarily HSU-3, with less emphasis on HSU-4 and HSU-5) of interest to this study, with the exception of several geophysical logs from oil and gas test wells drilled in the Valley during the 1950's through the 1970's. A recent renewed interest in the oil and gas potential of the western edge of the Valley and the eastern San Juan region has aided the present study by providing geophysical and geological data for that part of the study area.

Several major structural elements of the Valley, i.e., the Monte Vista Graben, the Alamosa Horst, and the Baca Graben, were discussed with respect to the hydrogeology of the confined aquifer by Burroughs (1981). Earlier
researchers, notably Gaca (1964), also recognized the existence of these major horst/graben structures. Prior to that time, the entire geologic sequence between the near-surface unconfined aquifer and the deeper subsurface Precambrian crystalline basement rock was assumed to be relatively continuous and unbroken.

The present study differs from previous evaluations by attempting to use available data to characterize the hydrogeology of the confined aquifer which lies deeper than 3000 feet throughout the basin, and by attempting to assess the physical as well as economic feasibility of ground-water development from the deep confined aquifer system.

2.2 IDENTIFICATION OF UNITS

The sequence of water-bearing geologic units beneath the San Luis Valley can be described as a series of layered hydrostratigraphic units. For purposes of the study, a hydrostratigraphic unit is defined as an individually-identifiable aquifer, or sub-unit of an aquifer, which can be described in terms of its unique physical, hydraulic, and chemical characteristics, as well as its interconnections with adjacent units and areas of ground-water recharge and discharge. It should be noted that a hydrostratigraphic unit can, and often does, consist of more than a single formation, lithology, or stratigraphic horizon. In the San Luis Valley, the different hydrostratigraphic units typically include more than one formation or stratigraphic horizon.

For this study, five distinct hydrostratigraphic units (HSU) have been identified (Figure 2.1). These hydrostratigraphic units are referred to herein as HSU-1 for the shallowest unit identified, progressing downward through HSU-5, the deepest unit identified. Though the shallowest (HSU-1 and HSU-2) of these are not the subject of the present study, they will be discussed briefly for comparison. HSU-4 and HSU-5 were judged to be non-feasible for ground-water development early in the present study, and are therefore not analyzed in as much detail as HSU-3.
2.2.1 HSU-1

HSU-1 constitutes the unconfined aquifer, which is the shallowest aquifer present in the Valley. This unit is comprised of the unconsolidated sand and gravel layers of the uppermost Alamosa Formation. It is located in the northern and central parts of the Valley and is typically less than 200 feet thick. The hydraulic, physical, and chemical characteristics will not be discussed in this report. The reader is referred to the Bibliography (Appendix A) for further data and/or information on this unit.

2.2.2 HSU-2

HSU-2 is identified as the upper part of the confined aquifer. Its top is the base of the uppermost relatively continuous confining clay unit of the Alamosa Formation (Figure 2.2). In the northern and central parts of the Valley, its base is identified as the top of the Carpenter Ridge Tuff (Figure 2.3). Figure 2.4 provides an isopach-contour map of HSU-2. Its thickness varies from zero at the eastern and western edges of the Valley, to 2000 to 2500 feet within the central parts of the Monte Vista Graben and atop the Alamosa Horst (see Figure 2.5 for the locations of the major structural and physiographic features of the Valley). Although HSU-2 is shallower than the targeted depth of this study, this unit may provide a future source for ground water development. In the northern and central parts of the San Luis Valley, the upper interval of HSU-2 is comprised of the unconsolidated sand and gravel layers of the lower Alamosa Formation. Along the western edge of the Valley, in the Monte Vista Graben, and atop the Alamosa Horst, the lower part of HSU-2 is comprised of the unconsolidated sands and gravels of the Los Pinos Formation. In the Baca Graben, HSU-2 is comprised of unconsolidated to semi-consolidated sand and sandstone of the upper Santa Fe Formation.

South of the Río Grande River, the vertical extent of HSU-2 is less defined because the upper boundary, a confining clay, does not appear to be present over most of that part of the Valley. HSU-2 in that area is probably confined, but by near-surface overbank deposits of silt and clay, rather than
by the more continuous and easily-identifiable blue-gray lacustrine clays of the Alamosa Formation as in the north-central part of the basin. The San Luis Hills serve to truncate HSU-2, and to separate it geologically from the Costilla Plain and the Culebra Re-entrant to the south and east of the main part of the Valley.

2.2.3 HSU-3

HSU-3 is identified as the uppermost unit of the deep confined aquifer. This unit is the primary unit analysed in the present study, since it usually occurs below a depth of 2500 to 3000 feet in most areas of the San Luis Valley. However, because of the lack of detailed data regarding HSU-3, it cannot presently be as well defined as HSU-1 or HSU-2.

In the northern and central parts of the Valley, HSU-3 is comprised of the Carpenter Ridge and Fish Canyon ash-flow tuffs, and the complex of unconsolidated to consolidated silts, clays, volcanic ash, occasional lava flows and sands, mudflows, and laharc breccias designated collectively as the volcaniclastic facies of the Conejos Formation. At the western edge of the Valley (the Del Norte area), and beneath the eastern San Juan Mountains, HSU-3 consists of the interfingered near-vent facies (primarily lava flows and flow breccias) and volcaniclastic facies of the Conejos Formation. In the Baca Graben area of the Valley, HSU-3 is comprised of the sands, silts, clays, and occasional poorly-cemented sandstones of the middle and lower Santa Fe Formation.

The base of HSU-3 lies at a depth ranging from approximately 3500 feet in the Del Norte/eastern San Juan Mountains area and on the Alamosa Horst, to approximately 4000 feet in the Baca Graben, to approximately 5000 feet in the central part of the Monte Vista Graben, near the town of Center.

2.2.4 HSU-4

HSU-4 is comprised primarily of sandstone and siltstone of the Vallejo/Blanco Basin Formations, beneath the Monte Vista Graben and its southern
extension into the Conejos River basin. Beneath the Baca Graben, HSU-4 is comprised of early-Tertiary sedimentary rocks, probably contemporaneous with the Vallejo/Blanco Basin. It is doubtful whether this unit exists in the Alamosa Horst area, due to erosion of the Vallejo/Blanco Basin during the late Tertiary. Beneath the eastern San Juan Mountains, it is likely also comprised of Cretaceous and Jurassic shales and sandstones. It is not known whether HSU-4 exists in the Culebra Re-entrant and the Costilla Plain areas of the Valley. It probably does not exist beneath the San Luis Hills.

The top of HSU-4 lies at a depth of at least 3500 to 4000 feet and probably averages 1500 feet thickness beneath the eastern San Juan Mountains. In the Monte Vista Graben and the Baca Graben, the top of HSU-4 lies at a depth of approximately 4000 to 5000 feet, and may be as thick as 3000 feet. If it exists in the Alamosa Horst area, which is doubtful, it is probably no more than 500 feet thick.

2.2.5 HSU-5

HSU-5 is comprised of consolidated sedimentary and metamorphic rocks of pre-Vallejo/Blanco Basin age. In the western parts of the Valley, these rocks are probably predominantly Cretaceous and Jurassic-age sedimentary formations. In the Baca Graben area, HSU-5 may be comprised of Paleozoic sedimentary and metamorphic rocks. It is unlikely that HSU-5 exists in the Alamosa Horst area. HSU-5 is not considered as a water-supply target, due to expected very poor water quality, poor hydraulic characteristics, and deep drilling depths. Beneath HSU-5 lies Precambrian crystalline rock, which is not considered a hydrostratigraphic unit, because of extremely poor hydraulic characteristics of this rock type.

2.3 CHARACTERISTICS OF SELECTED UNITS

HSU-1 and HSU-2 do not constitute the primary focus of the present study; therefore, their characteristics will not be discussed. Likewise, the
characteristics of HSU-4 and HSU-5 will not be discussed, because these hydrostratigraphic units appear to have minimal potential for water-supply development.

Many of the characteristics of HSU-3 are inferred from analysis of geophysical data, because very few water wells in the San Luis Valley penetrate this unit. Based upon ratios of sand thickness to total thickness within this unit (see Appendix C), the transmissivity of HSU-3 is expected to be relatively low, on the order of 10,000 gallons per day per foot (gpd/ft) throughout most parts of the Valley. Within the Baca Graben, areas of even lower transmissivity may occur, due to the presence of thick sections of clay within the lower Santa Fe Formation. An exception to this generally low transmissivity may occur along the western edge of the valley. Here, basin-margin extensional faulting and interfingering of the volcaniclastic and near-vent facies deposits of the Conejos Formation may enhance the hydraulic conductivity of HSU-3. Other localized areas of higher transmissivity may occur near the horst/graben faults and the Sangre de Cristo Fault at the eastern edge of the Baca Graben.

Because no aquifer tests are known to have been conducted in HSU-3, no measured values of storativity are available. However, because this unit constitutes a confined aquifer, it is likely that the storativity is on the order of 0.0001 or less.

It is probable that faults control the hydrogeologic characteristics of HSU-3. Tensional features, such as the NNW-trending horst-graben faults and the basin-margin faults, are likely to locally increase the transmissivity of this hydrostratigraphic unit. The NE-SW trending features, which are thought to be faults along shear planes, are likely to reduce the local transmissivity. Evidence of this occurs at the Manassa Fault, a NE-SW trending feature which defines the northwest boundary of the San Luis Hills (Figure 2.5). An extensive ground-water discharge area appears to occur along this fault. At present it is not known whether the discharge is related more to the hydraulic characteristics of the rocks in the San Luis Hills or to the Manassa Fault itself.
Ground-water recharge to HSU-3 is thought to occur primarily through the downward and then eastward movement of water in the eastern San Juan Mountains. The mechanism for this is the expected high-elevation piezometric surface in the San Juan Mountains area relative to the San Luis Basin, and the enhanced hydraulic conductivity along the extensional faults and fractured volcanic rocks of the near-vent facies and welded tuffs in that area. There also may occur a component of recharge via downward ground-water movement in the San Juans from HSU-2 into HSU-3. HSU-2 is thought to be more transmissive than HSU-3 and is also thought to receive recharge in the western basin margin/Eastern San Juan region.

Patterns or mechanisms of ground-water movement and discharge from HSU-3 cannot be ascertained with the data that is presently available. Ground-water movement appears to be primarily basinward towards the east, and possibly to some extent to the south, towards New Mexico. Locally, ground-water discharge from HSU-3 may be controlled to some extent by the extensional faulting at the Monte Vista Graben/Alamosa Horst area, and the Alamosa Horst/Baca Graben area. AWD and USBR have observed some indications of upward leakage of poor-quality ground-water and natural gas occurring along these faults from HSU-3 upward into HSU-2, according to Mr. Timothy F. Giles of AWD.

The quality of ground water within HSU-3 is expected to be relatively poor in most areas of the Valley. Better quality ground water may occur in the recharge area in and near the eastern San Juan Mountains area, and possibly in localized zones along the Sangre de Cristo Fault, which forms the eastern edge of the Baca Graben. In general, analysis of geophysical logs indicates a dissolved solids (DS) (NaCl equivalent) concentration of at least 3000 milligrams per liter (mg/l). An exception to this is in a 4300-foot deep water well near the town of Hooper, which is reportedly producing water from the depth interval 3500 feet to 4300 feet. Water from this well appears to have a DS of about 400 to 500 mg/l. Rapid ground-water recharge and movement within certain zones of HSU-3 may produce this more desirable water quality. Also, the Fish Canyon/Carpenter Ridge Formations are not present at the location of this well. Absence of these units may allow vertical mixing of
ground water between HSU-2 and HSU-3, which could account for the indication of good-quality water at a depth greater than 3000 feet. Further testing of this well is recommended, in order to ascertain the specific depth zone(s) from which the better-quality water is produced, and to better define the hydraulic characteristics of HSU-3 at that location.

HSU-3 is expected to have relatively slow ground-water movement in most areas. This expectation is based upon the indications of poor water quality and the presence of large thicknesses of fine-grained, low-permeability materials within HSU-3, both of which indicate slow ground-water movement.

As discussed in an earlier section of this report, HSU-4 is comprised predominantly of the Vallejo/Blanco Basin Formations, and, in the Baca Graben, the lower members of the Santa Fe Formation (Figure 2.1). The transmissivity of HSU-4 is expected to be low to moderate, probably in the range of 10,000 to 50,000 gpd/ft in most areas beneath the Valley. Beneath the San Juan Mountain front, where HSU-4 may be comprised in part of sandstones of Cretaceous age, and where there is extension due to the eastward hinging of the San Luis Basin, the transmissivity may be somewhat higher. In the Baca Graben, where HSU-4 is comprised of the lower, clayey members of the Santa Fe Formation, and deeply-buried sandstone and siltstone of early Tertiary age, transmissivity is expected to be 10,000 gpd/ft or less.

As with HSU-3, the storativity of HSU-4 is unknown, due to lack of aquifer test data. However, the storativity is expected to be 0.0001 or smaller, since the unit comprises a confined system.

Effects of faulting on HSU-4 are expected to be relatively moderate. At the large burial depths and pressures of this unit, even the large-scale regional extensional faulting may not serve to enhance the hydraulic conductivity of the rock materials significantly. The effect of the Alamosa Horst, however, is considerable: it appears to have bifurcated HSU-4 into two parts (Figure 2.1). If HSU-4 exists on top of the horst, it is expected to be relatively thin, so that there would be very little hydraulic communication between the HSU-4 in the Monte Vista Graben and the HSU-4 in the Baca Graben.
Mechanisms and directions of ground-water recharge, movement, and discharge of HSU-4 are largely unknown, due to the lack of hydrologic data in this depth range beneath the Valley. In general, HSU-4 is thought to be a moderately passive flow system, with little active ground-water movement, though possibly more than HSU-3. This is presumed not because of a lack of permeable sediments, but rather due to lack of proximity to, or a driving force for, ground-water recharge and discharge.

Water quality within HSU-4 is thought to be generally poor, with a DS (NaCl equivalent) concentration of 5000 mg/l or greater. This is based on interpretation of geophysical logs of a limited number of wells in the Valley, measurement of the specific conductance of the water from approximately 5000 feet in the Alamosa Geothermal Test Well, and drill-stem test information from a zone below 5000 feet in the Amoco-Mapco No. 1-32 well, near San Luis Lake northeast of Alamosa (Figure 2.6).

Analysis of available data on the confined aquifer below 3000 feet indicates three distinct hydrostratigraphic units within the aquifer system: HSU-3, HSU-4, and HSU-5. The deeper two, HSU-4 and HSU-5, are most likely not feasible as a source of usable ground water. The feasibility of developing HSU-3 as a ground-water source cannot be determined adequately with the data available.

2.4 MECHANISMS OF GROUND-WATER MOVEMENT

Two primary mechanisms of ground-water movement are believed to occur within the confined aquifer. Downward movement in the recharge zones (primarily at the western Valley margin and beneath the eastern San Juan Mountains), and upward movement in the area near the extensional horst-graben features, are most likely controlled by enhanced vertical hydraulic conductivity due to fracture openings at and near the major tensional faults. Basinward movement of ground water downdip to the east from the San Juans along the bedding planes within HSU-3, and, to a lesser extent HSU-4 and HSU-5 may occur, due to the horizontal component of hydraulic conductivity within...
the primary porosity of the sediments and volcanics which comprise these units. Enhancement of horizontal hydraulic conductivity may occur in certain of the volcanic members within HSU-3, due to cooling joints, horizontal jointing along flow-layer planes, fracture in the center of welded-tuff units, and minor faulting. The driving force which allows these water-movement mechanisms to take place is the high piezometric head within the volcanic units in the major recharge area, occurring in the high-elevation eastern San Juan Mountains, compared to the elevation of these hydrostratigraphic units beneath the Valley. The same driving mechanism for ground water flow is thought to take place from the Sangre de Cristo Mountains to the east into the Valley, but to a much lesser extent due to a small recharge area, and extensive discontinuities in the bedding planes through which ground water moves. Most downward movement into HSU-3 from the Sangre de Cristos appears to occur within a relatively narrow fault zone, rather than through bedding planes as is more commonly the case in the San Juans (Huntley, 1976).

2.5 HYDROSTRATIGRAPHIC UNIT INTERCONNECTIONS

Adequate data are not available at present to analyze the interconnections which may exist between HSU-3 and HSU-4, or the interconnections of the deep confined aquifer with other hydrostratigraphic units within the San Luis Valley. The seismic data, borehole-geophysical data, and limited water-quality data all suggest that such interconnections are extremely limited and are localized within the confined aquifer. The bedding planes within each of these units are relatively continuous and unbroken, suggesting that the ratio of horizontal to vertical hydraulic conductivity is quite large, possibly 10:1 or 100:1. The basin-margin faulting and the horst/graben faulting may be the only areas where extensive upward or downward movement and mixing of groundwater occur within the confined aquifer.
<table>
<thead>
<tr>
<th>Hydrostratigraphic Unit</th>
<th>Monte Vista Group</th>
<th>Conejos River Valley</th>
<th>Alamosa Group</th>
<th>San Luis Hills</th>
<th>Basal Group</th>
<th>Coalita Re-Entrant/ Costilla Plains</th>
<th>Estimated Depth and Thickness (feet)</th>
<th>Estimated Transmissivity (gpd/ft)</th>
<th>Estimated Dissolved Solids Concentration (mg/liter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HSU-1 (Unconfined Aquifer)</td>
<td>Recent Alluvium (where present)</td>
<td>Lower Alamosa Formation</td>
<td>Sand &amp; Gravel</td>
<td>Lower Alamosa Formation</td>
<td>Sand &amp; Gravel</td>
<td>Recent Alluvium (where present)</td>
<td>Depth to top 6'</td>
<td>1000 to 250,000</td>
<td>72 to 31,200</td>
</tr>
<tr>
<td>HSU-2 (Upper Confined Aquifer)</td>
<td>Hinsdale Formation</td>
<td>Lower Alamosa Formation</td>
<td>Sand &amp; Gravel</td>
<td>Lower Alamosa Formation</td>
<td>Sand &amp; Gravel</td>
<td>Detrital Formation</td>
<td>Depth to top 6' to 500'</td>
<td>1500 to 1,500,000</td>
<td>68 to 34,400</td>
</tr>
<tr>
<td>HSU-3 (Deep Confined Aquifer)</td>
<td>Carpenter Ridge/Fish Canyon Formation</td>
<td>Lower Santa Fe Formation</td>
<td>Sand &amp; Gravel</td>
<td>Lower Santa Fe Formation</td>
<td>Sand &amp; Gravel</td>
<td>Depth to top 1000' to 2000'</td>
<td>10,000 to 50,000</td>
<td>Greater than 3000</td>
<td></td>
</tr>
<tr>
<td>HSU-4</td>
<td>Vallejo/Blanco Basin Formation</td>
<td>Sandstone &amp; Siltstone</td>
<td>Vallejo/Blanco Basin Formation</td>
<td>Sandstone &amp; Siltstone</td>
<td>Valley/Blanco Basin Formation</td>
<td>Sandstone &amp; Siltstone</td>
<td>Depth to top 1000' to 2000'</td>
<td>10,000 to 50,000</td>
<td>Greater than 3000</td>
</tr>
<tr>
<td>HSU-5</td>
<td>Pre-Vallejo/Blanco Basin sedimentary &amp; metamorphic rocks</td>
<td>Recession</td>
<td>Pre-Vallejo/Blanco Basin Formation</td>
<td>Sedimentary and Metamorphic Rocks</td>
<td>Pre-Vallejo/Blanco Basin Formation</td>
<td>Sedimentary and Metamorphic Rocks</td>
<td>Depth to top greater than 10,000'</td>
<td>10,000 to 50,000</td>
<td>Greater than 3000</td>
</tr>
</tbody>
</table>

1 Information from Emery and others (1972)
2 Based on geophysical log interpretation during these Phase I studies
3 For locations of these major structural elements, see Figure 3.10

COLORADO WATER RESOURCES AND POWER DEVELOPMENT AUTHORITY
SAN LUIS VALLEY CONFINED AQUIFER STUDY
HYDROSTRATIGRAPHIC UNITS OF THE SAN LUIS VALLEY
HRS WATER CONSULTANTS, INC.
DATE: APRIL, 1987
EXPLANATION

ELEVATION OF TOP OF CONFINED AQUIFER (BASE OF UPPERMOST CONFINING CLAY LAYER) IN FEET ABOVE MAL (FOOT CONTOUR INTERVAL)

ESTENT OF UPPERMOST CONFINING CLAY LAYER
EXPLANATION

ELEVATION OF TOP OF CARPENTER RIDGE TUFF IN FEET ABOVE MSL (50-FOOT CONTOUR INTERVAL)

- EXTENT OF CARPENTER RIDGE TUFF IN SAN LUIS VALLEY

COLORADO WATER RESOURCES AND POWER DEVELOPMENT AUTHORITY
SAN LUIS VALLEY CONFINED AQUIFER STUDY

STRUCTURE-CONTOUR MAP
TOP OF CARPENTER RIDGE TUFF

HRS WATER CONSULTANTS, INC.
WITH ROBERT E. MORAN
DATE: APRIL, 1987
FIGURE: 7.3
EXPLANATION

APPROXIMATE LOCATION
OF MAJOR FAULT (BALL AND
BAR ON SOUTHWARDS SIDE)

SOURCES:
Burroughs (1981), A Summary of the Geology
of San Luis Basin, Colorado; Cordell and Others (1982),
Extension in the Rio Grande Rift; Ziehl and Kirby (1972),
Aeromagnetic Map of Colorado.
COLORADO:
INDEX MAP

EXPLANATION
• WELLS INTERPRETED FOR WATER QUALITY FROM SP LOGS
PROFILE LINE LOCATION

COLORADO WATER RESOURCES AND POWER DEVELOPMENT AUTHORITY
SAN LUIS VALLEY CONFINED AQUIFER STUDY
LOCATION MAP, PROFILES OF DEPTH VERSUS GROUND WATER QUALITY.

HRS WATER CONSULTANTS, INC. WITH ROBERT E. MORAN
DATE: APRIL, 1987
FIGURE 2.6
3.0 ANALYSIS OF AVAILABLE DATA

3.1 OBJECTIVES AND METHODS OF ANALYSIS

3.1.1 Objectives and Types of Data Available

The objective of this study is to analyze the available hydrogeological, geophysical, and geochemical data of the San Luis Valley in order to better understand the confined aquifer system of the Valley below 3000 feet in depth. A related objective was to determine the approximate depth to base of the potentially usable confined aquifer system. Available data were analyzed, including computer data bases, and an inventory was made of deep wells which penetrated the confined aquifer. Geologic maps and cross sections were generated from existing geological and geophysical data, and water quality and subsidence potential analyses were performed.

3.1.2 Types of Data Available

The types and sources of data which are available and which were utilized are as follows:

1. Geophysical well logs
2. Surface geophysical survey data
3. Generalized geologic maps of the San Luis Valley and peripheral areas
4. Ground-water quality data from study-area wells
5. Ground-surface elevation-profile data
6. Deep water well data

In addition to analysis of the available data, previous studies of the hydrogeology of the San Luis Valley were used for basic hydrogeologic information.
3.2 WELL INVENTORY

An inventory of deep wells in the San Luis Valley was made to enlarge the database on the confined aquifer, and to assess the suitability of wells for inclusion in a subsequent aquifer testing and/or geophysical logging program.

3.2.1 Identification of Deep Wells

Two primary sources of data were used to identify the confined aquifer water wells in the San Luis Valley. These sources are 1) the governmental agencies involved in administration and/or investigation of the ground water in the Valley, and 2) the ground-water users in the area. All existing well data was obtained from the two agencies which maintain up-to-date databases of water wells in the Valley. Also, selected persons were interviewed who are knowledgeable about the confined aquifer in the Valley.

The two agencies that maintain databases of water wells in the San Luis Valley are the U. S. Geological Survey's (USGS) Water Resources Division and the Colorado State Engineer's Office (SEO). The USGS database is the GWSI (Ground Water Site Inventory) part of the WATSTORE database system, mentioned earlier in this report. The SEO database is the Water Division 3 (Rio Grande Basin) Master List of wells. Both databases were computer searched for wells in the Valley which met depth and completion-interval criteria for inclusion in the confined aquifer. The following subsections discuss these inventory procedures in detail. Following the database search, interviews were held with several well owners, local officials, and ground-water users in the Valley to verify and augment the well data. Selected wells were then assessed by on-site observation and measurements for inclusion in a program of well logging and testing.

3.2.1.1 Division 3 Master-List Database Analysis

Colorado Water Division 3 (the Rio Grande River Basin within Colorado) maintains a database on all registered water wells within the basin. This
database is called the Master List of wells. The Master List was obtained on a computer tape and translated into an on-line, retrievable database for microcomputers. The master list/database was then subjected to a series of searches to obtain the number of water wells within the San Luis Valley which produce water from the confined aquifer. The Division 3 database of deep wells was also cross-checked with the WATSTORE database, to take advantage of any complementary data which might be available.

Table 3.1 and Appendix E tabulate results from the analysis of the Water Division 3 database. This tabulation shows that only 28 wells registered with the SEO within the Valley are deeper than 2000 feet. The full records for those 28 wells were obtained from the State Engineer's Office, and reviewed to assess if they produce water from the confined aquifer, and if so, to assess whether they should be field-checked for suitability for testing. The records analyzed included Well Permits, Statements of Beneficial Use of Ground Water, Well Driller's and Pump Installer's Completion Reports, and lithologic logs. Of the 28 wells, only three appear to be completed in HSU-3. All three also appear to be partially completed in HSU-2.

TABLE 3.1

TABULATION OF WATER WELLS IN THE SAN LUIS VALLEY ACCORDING TO DEPTH
(Source: SEO Well Master List, Water Division 3)

<table>
<thead>
<tr>
<th>DEPTH RANGE</th>
<th>HOUSEHOLD &amp; DOMESTIC USES ONLY</th>
<th>ALL OTHER USES</th>
<th>TOTAL WELLS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-50ft.</td>
<td>1899</td>
<td>976</td>
<td>2875</td>
</tr>
<tr>
<td>50-100ft.</td>
<td>899</td>
<td>1932</td>
<td>2831</td>
</tr>
<tr>
<td>100-200ft.</td>
<td>874</td>
<td>2124</td>
<td>2998</td>
</tr>
<tr>
<td>200-500ft.</td>
<td>683</td>
<td>1293</td>
<td>1976</td>
</tr>
<tr>
<td>500-1000ft.</td>
<td>294</td>
<td>708</td>
<td>1002</td>
</tr>
<tr>
<td>1000-2000ft.</td>
<td>17</td>
<td>154</td>
<td>171</td>
</tr>
<tr>
<td>2000+ ft.</td>
<td>0</td>
<td>28</td>
<td>28</td>
</tr>
<tr>
<td>TOTALS</td>
<td>4666</td>
<td>7215</td>
<td>11,881</td>
</tr>
</tbody>
</table>
The three wells are:

1. Hooper Pool Well, Permit No. 20782
2. Hill/Myers Well, Permit No. 25353-F
3. Owens Well, Permit No. 2745-F.

(see Figure 3.1 for the locations of these wells)

3.2.1.2 WATSTORE Database Analysis

The WATSTORE database was set up and is maintained by the USGS. Access to WATSTORE was gained through the PRIME computer located in the Lakewood, Colorado offices of the USGS. As mentioned previously, WATSTORE includes GWSI (Ground Water Site Inventory). GWSI contains information on the physical characteristics of the well and aquifer(s) as well as water-quality information.

GWSI was searched for wells with depths greater than 1000 feet; 73 wells were found to meet this criterion. The information obtained is found in Appendix E. Of the 73 wells, 19 have total depths greater than 2000 feet. The water-quality search yielded information from five wells that are more than 2000 feet deep. Information from this search is shown in Appendix E. The information in Appendix E also shows chemical-analysis data from ten wells greater than 2000 feet deep, obtained from Emery and others (1973).

Considering the size of the area of investigation, physical data for 19 wells and chemical data from five wells represents a data set which is quite sparse.

Although well depths are reported as being greater than 2000 feet, it was found that most often the completion interval of the well extends into the upper part of the confined aquifer (HSU-2). Due to this, relationships of depth and water quality or depth and potentiometric head are difficult to establish or quantify. General trends may be discernable; however, more site-specific information from geophysical logs, or from wells completed within much shorter intervals in the confined aquifer is required.
3.2.1.3 Interviews

Following the analysis of the Division 3 well Master List and the WATSTORE database, telephone and in-person interviews were held with selected residents of the San Luis Valley. The interviews were held with the following:

1. farmers
2. special-district officers
3. present and former Water Division 3 Engineers
4. local well drillers and pump installers

The interviews confirmed much of the information gained through the database searches, and also provided information on the possibility of locating and entering abandoned oil and gas wells in the Valley. These interviews were followed by on-site observations and measurements of selected deep wells.

3.2.2 Wells Inventoried in the Field

The deep wells selected for the on-site inventory were those which appeared to be perforated exclusively or at least primarily in the deep confined aquifer (HSU-3). Very few wells appeared to meet this criterion. This may indicate poor ground-water quality and/or low production rates available from the deep confined aquifer. Alternatively, it may indicate that, as yet, there has been no need to drill deeper than 1000 to 2000 feet in the Valley to obtain adequate ground-water supplies.

3.2.2.1 Criteria for Selection

The primary criterion for selection of wells for the inventory was that they appear, with a reasonable level of confidence, to be perforated exclusively, or at least primarily, within the confined aquifer HSU-3. Well location within the basin was a secondary criterion. In the northern and
central parts of the basin, reported well depths corresponding to the depth interval of HSU-3 (ranging from about 2000 feet to 5000 feet) on a township-by-township basis were used to select wells for on-site assessment of general physical condition, suitability for logging or testing, water-quality sampling, and field measurements of quality and flow.

3.2.2.2 Characteristics of Wells Inventoried

Six wells were found to meet all or most of the required criteria. These wells include the three SEO-registered water wells which appeared to meet the necessary depth criterion, and three additional wells which were identified through interviews with Valley residents. Following are the names of the six wells:

1. Alamosa Geothermal Well
2. Carr No. 1 Kennedy-Williams Well
3. Owens Well
4. Carroll Well
5. Hill/Myers Well
6. Hooper Pool Well

Figure 3.1 shows the locations of the wells. The data obtained from field measurements and records of the wells are contained in Appendix F of this report.

Of the six wells, two (Hill/Myers and Carr No. 1 Kennedy-Williams) do not appear to produce water from the confined aquifer HSU-3, based upon the relatively low temperature of the water which flows from them, and the lack of additional data to indicate a well completion in HSU-3.

The Owens Well (Permit No. 3380-F) was not suitable for logging and/or testing due to its wellhead construction and the fact that it supplies water on a continuous basis to a house, shopping center, RV park, and a swimming pool.
Of the six wells selected, all except one, the Alamosa Geothermal Well, flow at the surface. However, pumps are installed in the Hill/Myers Well and the Hooper Pool Well.

3.2.2.3 On-site Measurements

During the well inventory, the following measurements or estimates were made:

1. Water temperature
2. Water pH
3. Water specific conductivity
4. Estimated flow rate (if flowing)
5. Suitability of well casing and wellhead for testing
6. Casing diameter at wellhead
7. Horsepower rating, type of pump, and setting depth (if installed)
8. General physical condition of the well
9. Suspicious odors, gas production, etc.

A tabulation of the above parameters was made for each of the six wells. The well inventory tabulations were combined with the database that includes well completion depths, owner, permit number, and location. This information is included as Appendix F of this report.

3.2.2.4 Water-Quality Analysis Results

Water samples were collected from four of the six wells chosen for inventory. The water samples were analyzed by Core Laboratories, Inc., of Aurora, Colorado, for major ions and selected metals. This was done to aid in the selection of wells for testing and to add data to the confined aquifer database. The four wells from which water samples were collected are:

1. Alamosa Geothermal Well
Appendix B tabulates the results of the water-quality analyses performed on the water samples from the four wells. Figure 3.2 is a trilinear diagram of the major ion concentrations from each of the four wells. A trilinear diagram shows general chemical similarities or differences between water samples, and can also be used as an indicator of ground-water paths of movement. The water from the Carroll Well, the Carr No. 1 Kennedy-Williams Well, and the Hooper Pool Well are all chemically similar, and are sodium-bicarbonate type. The Alamosa Geothermal Well indicates water of sodium-chloride type. At present, it is believed that the Alamosa Geothermal Well is completed in a deep portion of HSU-3, or possibly HSU-4. The other three are believed to be completed in both HSU-2 and HSU-3.

The Alamosa Geothermal Test Well indicates very poor water quality from a depth of approximately 5000 feet. The Hooper Pool Well indicates acceptable water quality, at a relatively warm temperature (40 degrees C) at a reported depth of 3500 feet to 4300 feet.

3.2.3 Selection of Test Wells

Of the six wells assessed, three appeared to be suitable for further logging and/or testing to gather data on the hydrogeology of the deep confined aquifer:

1. Alamosa Geothermal Well
2. Carroll Well
3. Hooper Pool Well

The other three wells inventoried did not appear to be suitable, for various reasons. The Carr No. 1 Kennedy-Williams Well and the Hill/Myers Well have poor completion records, and a substantial fraction of the water produced
by each of these wells appears to be from within a few hundred feet of the ground surface (HSU-2). The Owens Well is in use on a continuous basis, and could not be readily taken out of use for the period of one or more days needed for logging or testing.

Results of the logging and testing from the three wells found to be suitable are presently being processed and analyzed, and will be presented in the Interim Task 5 Report.

3.3 GEOLOGIC DATA ANALYSIS

During the present Phase 1 studies, geologic data analyses were performed which have led to a new understanding of the materials which comprise the deep confined aquifer beneath the San Luis Valley. Following are several major conclusions which have resulted from these studies:

- The most promising confined aquifer for water-supply development may be HSU-2, comprised of the Los Pinos and Santa Fe Formations.

- The Fish Canyon and Carpenter Ridge tuffs appear to mark a significant degradation in water quality with increasing depth.

- The Conejos Formation in the San Juan Mountains exhibits moderate to high fracture permeability; the Conejos beneath the Valley appears less permeable.

- HSU-4 and HSU-5 (Vallejo/Blanco Basin formations) are probably not feasible as a source of water supply due to high development cost and possible poor water quality.

- The geologic cross-sections generated during these studies indicate greater structural and stratigraphic complexity than was previously thought to be the case.
Analysis of geologic data within the study area involved the complementary use of the geophysical data (both surface and borehole) and lithologic logs of several deep wells in the San Luis Valley. On-site geologic mapping was performed in the ground-water recharge area along the western periphery of the Valley and into the San Juan Mountains, and normal and false-color infrared photography was analyzed to delineate near-surface structure and areas of active ground-water recharge.

Geologic data analyses from different areas of the San Luis Valley were combined in a series of geologic cross sections and geologic maps. These maps and cross sections illustrate the geologic structure and stratigraphy which define the physical characteristics of the confined aquifer.

3.3.1 Development of Geologic Cross Sections

Figure 3.3 shows the locations of the six geologic cross sections which were constructed for this study. These six geologic cross sections are included in this report as Figures 3.4 through 3.9, inclusive.

The four generally east-west geologic cross sections, A-A', B-B', C-C', and D-D', show considerable similarity in the Valley's geologic structure. This similarity is largely the result that the younger geologic units beneath the San Luis Valley were derived from the San Juan Mountains to the west. These four cross sections illustrate the subsurface geology approximately in line with the direction from which these units were deposited. The major geologic units shown on the cross sections which are of importance to the hydrogeology of the confined aquifer are discussed below.

3.3.1.1 Discussion of Geologic Units

The geologic units which comprise the subsurface beneath the San Luis Valley shown on the geologic cross sections are primarily of four types:
1. unconsolidated to semi-consolidated sediments
2. volcanic rocks
3. pre-San Luis Valley sedimentary or metamorphic rocks
4. Precambrian crystalline rocks

The Alamosa Formation, the Los Pinos Formation, the Santa Fe Formation, and some localized members of the Conejos Formation volcaniclastic facies are unconsolidated to semi-consolidated sediments.

Quaternary-age Alamosa Formation, which is the youngest unit in the Valley, consists of clays (including the well-known blue clay layers), silts, sands, and gravels. The Alamosa Formation comprises the unconfined aquifer, and the upper part of the confined aquifer in the Valley. As indicated in the cross sections, the Alamosa Formation varies from zero thickness near the edges of the Valley to more than 1000 feet thick in the Baca Graben, in the east-central part of the Valley. The blue clays within the Alamosa Formation were likely deposited in a lacustrine (lake or swamp) environment. In contrast, the intervening sands and silts were likely deposited in a moderate-energy fluviatile (stream) environment.

Los Pinos Formation and Santa Fe Formation are both of late Tertiary age and are interfingered beneath the San Luis Valley. The Santa Fe Formation occurs beneath most of the Baca Graben area and consists of relatively fine-grained sands (and, in part, weakly-cemented sandstones), silts, and clays. The Santa Fe Formation was deposited in a variety of environments, including lacustrine, low-energy fluviatile, and to a lesser extent, eolian (wind deposition). The Santa Fe Formation ranges from zero thickness near the Valley edges to over 2000 feet in the Baca Graben.

Los Pinos Formation is interfingered with Santa Fe Formation and is approximately the same age (i.e. late Tertiary). Los Pinos Formation consists of buried, coalesced alluvial fans composed of sands, gravels, silts, and clays derived from erosion of the San Juan volcanic field immediately to the west of the San Luis Valley. Los Pinos Formation sediments, which are largely unconsolidated, were deposited relatively near their source, and are therefore
somewhat coarser-grained than Santa Fe Formation units with which they
interfinger. Seismic sections of the Valley show that the Los Pinos Formation
is quite extensive throughout the San Luis Valley, more so than the Santa Fe
Formation, but is not as thick as the latter. Maximum Los Pinos Formation
thickness, which is over 1000 feet, occurs in the central part of the Valley.
Because the Los Pinos was deposited close to its source in a relatively high-
energy depositional environment, it generally has higher hydraulic
conductivity than the Santa Fe Formation.

The Santa Fe Formation and Los Pinos Formation together comprise what is
probably the most promising hydrostratigraphic unit (the lower part of HSU-2)
for water supply development, because of their better ground water quality
(generally less than 2000 mg/l dissolved solids concentration) and higher
transmissivity than the deeper hydrostratigraphic units.

Beneath the Los Pinos/Santa Fe Formations lies a series of ash-flow
tuffs. These rock units, of which the primary two are the Fish Canyon and the
Carpenter Ridge, were derived from cooling and cementation of molten particles
of volcanic ash. The ash erupted during episodes of volcanic activity in the
San Juan volcanic field to the west.

These ash-flows, shown on the generalized geologic cross sections as a
single unit, outcrop along the western edge of the northern and central parts
of the San Luis Valley, and in the San Juan Mountains and the Cochetopa Hills
to the west and northwest of the Valley. They are buried beneath the Alamosa
Formation and the Los Pinos/Santa Fe Formations in the Valley, and dip
eastward. Their easternmost extent, according to the seismic and borehole
information, is approximately the eastern edge of the Alamosa Horst. The ash-
flow tuff units appear to be a maximum of approximately 500 feet thick beneath
the Monte Vista Graben, and to become progressively thinner to the east. Due
to areas of non-deposition, the units are thought to be absent throughout
most of the southern San Luis Valley, including the Conejos River basin, the
Culebra Re-entrant and Costilla Plain, San Luis Hills, and also throughout
most of the Baca Graben.
Ash-flow tuffs are of importance to the present study due to an apparent correlation between the presence of the tuffs and the presence of poorer-quality ground water at and beneath the depths at which these units occur. Transmissivity (T) and hydraulic conductivity (K) of the Fish Canyon/Carpenter Ridge ash-flow tuffs beneath the San Luis Valley are unknown. It is likely that K and T become smaller toward the east (into the Valley) due to thinning of the tuffs and greater distance from the San Juan volcanic field source area. In the San Juans, Huntley (1976) estimates hydraulic conductivities are the order of $5 \times 10^{-2}$ cm/sec for the Fish Canyon Tuff in T44N, R6E, Section 18, in the upper Saguache Creek area. This range of K is quite high; in Huntley's words, "...as great as the most permeable alluvium in the San Luis Valley." (Huntley, 1976, p. 55).

Volcanic and volcaniclastic rocks of the Conejos Formation underlie the Fish Canyon/Carpenter Ridge Formations in the Valley as well as in the San Juan Mountains. The Conejos Formation is a thick (generally greater than 2000 feet) formation which is stratigraphically complex. Within the San Juan Mountains, the Conejos Formation can be separated into two primary facies. One of these is a near-vent volcanic facies consisting primarily of lava flows, flow breccias, and explosion breccias. The second of these is a primarily volcaniclastic facies which was deposited at greater distances from the volcanic vents. The volcaniclastic facies consists predominantly of ash-fall and ash-flow units, mudflows, and laharc breccias. From the analysis of well logs and seismic sections, it appears that the relatively-permeable near-vent facies is predominant in the potential ground-water recharge area in the San Juan Mountains, and that there is a facies change to the less-permeable volcaniclastic facies eastward into and beneath the San Luis Valley.

Rocks and unconsolidated materials of the volcaniclastic facies of the Conejos Formation appear to be very widespread throughout the study area. Seismic and borehole data show that this facies occurs everywhere except possibly in limited parts of the Baca Graben, the Culebra Re-entrant, and the Costilla Plain.
Conejos Formation rock and unconsolidated materials extend from near the ground surface in the western edge of the San Luis Valley, to a depth of approximately 4000 feet beneath the north-central part of the Valley. The deepest portion of the confined aquifer is judged to be the Conejos Formation. Due to indications of possible poor water quality and low hydraulic conductivity within the volcanlastic facies of the Conejos (HSU-3) beneath the San Luis Valley, the feasibility of developing this unit for water supply is poor.

Underlying the Conejos Formation throughout most of the San Luis Valley is the Vallejo Formation, an early-Tertiary sedimentary unit which consists predominantly of silty and clayey sand deposited in a fluvial environment (Burroughs, 1981). Based upon the seismic and borehole data, the Vallejo Formation appears to be up to several thousand feet thick in the Monte Vista Graben and may be continuous to some degree to the west, beneath the San Juan Mountains in a newly-discovered structural downwarp called the San Juan Sag (Gries, 1985). The Vallejo Formation is probably not practical as a significant water supply source. This is because the DS concentrations are estimated in excess of 5000 mg/l, the transmissivity is estimated from 10,000 to 50,000 gpd/ft, and drilling depths are greater than 4000 feet.

Below the Vallejo Formation lie several much older formations, probably from late Mesozoic to mid-Paleozoic in age, designated as Pre-Vallejo units on the geologic cross sections (Figures 3.3 through 3.8), which are not of interest to this study.

The deepest rock unit on the geologic cross sections is the Precambrian crystalline basement rock. The Precambrian rock is much too deep and too low in hydraulic conductivity to be of importance as an aquifer. There are, however, major structural features, especially faults, which cut and offset the Precambrian rocks, and which subsequently have affected all of the formations which overlie them. This is evident on the cross sections and geologic maps of the study area.
3.3.2 Development of Geologic Maps

During the analysis of available data, several geologic maps were generated for interpretation of the hydrogeology of the confined aquifer. These maps are included in this report as Figures 2.2 through 2.5, inclusive, and Figure 3.10.

The generalized geologic map of the study area (Figure 3.10) and the map of major structural features (Figure 2.5) show the major geologic features of interest to the present study. Of particular importance on Figure 3.10 are the geologic units in the San Juan Mountains and Cochetopa Hills areas to the west and northwest of the Valley. These units have relatively high hydraulic conductivity and are capable of recharging substantial amounts of ground water to the confined aquifer beneath the San Luis Valley.

Most of the geologic units in the ground-water recharge area of the San Juan Mountains are consolidated volcanic rocks. These units were analyzed for the presence of faults, fractures, and jointing which could indicate substantial secondary permeability, using on-site geological reconnaissance and, as a cross-check data set, normal color and infrared false-color low-level oblique aerial photos.

Also indicated on Figure 3.10 are the major geologic and physiographic features which have been identified and are generally accepted for the San Luis Valley. These include the following:

1. Monte Vista Graben
2. Alamosa Horst
3. Baca Graben
4. San Luis Hills
5. Culebra Re-entrant
6. Rio Grande Fan
7. Costilla Plain
8. Conejos River Valley
The map showing major structural features of the study area (Figure 2.5) was constructed using 1) interpretation of published regional gravity and aeromagnetic maps of the San Luis Valley area, 2) interpretation of seismic data, and 3) field reconnaissance of the surficial geology and structural features of the area.

Two predominant directions of faulting can be seen on Figure 2.5 in the northern and central parts of the study area. These directions are approximately 15 degrees west of north (N15W) and 75 degrees west of north (N75W). The very large-scale features are thought to be related to regional extensional tectonic features of the Rio Grande Rift, of which the San Luis Valley is a part. If these faults are primarily tensional, then the rock units which are intersected by them would likely exhibit enhanced hydraulic conductivity. Upward or downward leakage of ground water between the rock units could be expected, and could provide a mechanism for mixing waters from different depths within the confined aquifer.

The structural features which are at approximately N75W in direction may be predominantly strike-slip shear faults which are conjugate to the stress regime which is thought to have caused the N15W extensional features. These shear faults are not expected to cause enhanced hydraulic conductivity or greater leakage or mixing of ground water in various zones within the confined aquifer.

South of the Rio Grande, a major change in the direction of the major structural features can be seen on Figure 2.5. The major direction of faulting in that area is approximately N30E. Southern extensions of the Monte Vista Graben, the Alamosa Horst, and the Baca Graben can be inferred, but the hydrogeologic significance of this change in primary fault direction is largely unknown. The ground-water discharge area along the Manassa Fault, near the northwest flank of the San Luis Hills in the area of Dexter Spring, McIntire Spring, and Sego Springs, may indicate that faults with this strike may act as barriers to horizontal ground-water flow.
The structure-contour maps (Figures 2.2 and 2.3) and the isopach map (Figure 2.4) were developed to help define the depth, thickness, and areal extent of the confined aquifer beneath the San Luis Valley. The structure contour map of the top of the confined aquifer (figure 2.2) is defined by the elevation of the base of the uppermost continuous confining clay which can be readily identified. At present, the upper portion of the confined aquifer (HSU-2) is used for agricultural wells. The lower portion of the confined aquifer system (HSU-3) has not been developed to any extent.

The structure contour map of the top of the ash flow tuff units (Figure 2.3) was developed using the following correlations: 1) DS concentration less than 3000 mg/l, 2) transmissivity greater than 10,000 to 25,000 gpd/ft, 3) lithology. For most of the northern and central San Luis Valley, the top of the ash flow tuff units may indicate the deepest extent of the confined aquifer in which ground water is of adequate quality and availability for presently-anticipated uses.

Figure 2.3 is the present interpretation for the top of the Fish Canyon/Carpenter Ridge Formations (Figure 2.1), or HSU-3. In the parts of the Valley where the Fish Canyon/Carpenter Ridge units are present, the top of those units are considered to be the base of HSU-2, and hence the top of HSU-3 (Figure 2.1). In areas of the Valley where the Fish Canyon/Carpenter Ridge formations do not exist, borehole information, drillers' reports, and seismic data have been used to estimate the elevation of the top of the volcaniclastic facies of the Conejos Formation, which appears to have a relatively low hydraulic conductivity. In certain portions of the Baca Graben and the Culebra Re-entrant, water-quality changes with depth have been calculated from geophysical logs. These changes have been used to estimate the location of the base of the confined aquifer.

The isopach map of that part of the confined aquifer that lies above the ash-flow tuff units (Figure 2.4), that is, the central-Valley portion of HSU-2, was generated from the top and base-elevation structure contour maps. The
isopach map allows estimation of the volume, areal extent, and changes in thickness of HSU-2 over the central portion of the San Luis Valley.

3.4 GEOPHYSICAL DATA ANALYSIS

3.4.1 Well Log Analysis

Geophysical logs of oil and gas test wells in the San Luis Valley were analyzed to assist in developing a hydrostratigraphic model of the confined aquifer. The locations of the wells for which geophysical logs are available are shown on Figure 3.11. Table 3.2 tabulates the geophysical logs used in this study, and includes well names, locations, depths, and the types of logs available for each well.

There are several other wells which were geophysically logged. However, these wells were not used because the logs are of questionable quality or the wells did not penetrate the confined aquifer system.

Geophysical logs provided a good source of data for the confined aquifer, and most of the available well logs were analyzed using several qualitative and quantitative methods. Qualitative methods of analysis included:

1. stratigraphic correlation from well to well
2. identification of facies changes across the study area in the confined aquifer
3. identification of environments of deposition of aquifer materials
4. identification of marker beds which could be used to aid interpretation of seismic data

Quantitative methods of analysis included:

1. estimation of sand thickness to total thickness ratios of stratigraphic units
2. estimation of ground-water quality
### TABLE 3.2
DEEP WELLS FROM WHICH GEOPHYSICAL LOGS WERE INTERPRETED

<table>
<thead>
<tr>
<th>NAME</th>
<th>WELL LOCATION</th>
<th>TOTAL DEPTH (feet)</th>
<th>LOGS AVAILABLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milestone AMF No. 1</td>
<td>Sec. 20, T40N, R5E 1946 FSL, 2109 FEL</td>
<td>9,447</td>
<td>Long Spaced Sonic W/Waveforms; Dual Induction SFL; Litho-Density Compensated Neutron; Waveform Derived Sonic Log</td>
</tr>
<tr>
<td>Tennessee Gas Trans. 1 State B</td>
<td>Sec. 14, T41N, R 7E C,SW,SE</td>
<td>10,350</td>
<td>Induction-Electric Log; Micro-Logging</td>
</tr>
<tr>
<td>Tucker No.1 Thomas</td>
<td>Sec. 13, T41N, R 8E NE,NE,NE</td>
<td>8,023</td>
<td>Electric Micro Log</td>
</tr>
<tr>
<td>Carr No. 1 Kennedy Williams</td>
<td>Sec. 11, T41N, R 9E C,SW</td>
<td>6,831</td>
<td>Electrical Log</td>
</tr>
<tr>
<td>Amerada No. 1 State F</td>
<td>Sec. 11, T39N, R10E C,SE,SW</td>
<td>6,070</td>
<td>Induction-Electric Log; Sonic Log</td>
</tr>
<tr>
<td>Amoco/Mapco No.1-32 State</td>
<td>Sec. 32, T40N, R12E 2515 FNL, 2164 FWL</td>
<td>7,982</td>
<td>Dual Induction Laterolog; Borehole Compensated Sonic Log - Gamma Ray; Compensated Formation Density Log</td>
</tr>
<tr>
<td>Sunny Valley #1 Blanca</td>
<td>Sec. 2, T30S, R72W C,NW,SW</td>
<td>3,940</td>
<td>Electrical Log</td>
</tr>
</tbody>
</table>

NOTES: FNL means distance in feet from north section line. FEL means distance in feet from east section line. FSL means distance in feet from south section line. FWL means distance in feet from west section line.

See well locations on Figure 3.11.
3. estimation of elastic parameters
4. estimation of hydraulic conductivities
5. identification of lithologies
6. identification of permeable rock units

3.4.1.1 Results of Analysis

The analyses of the geophysical well logs within the San Luis Valley study area were used together with other types of analyses to develop a hydrostratigraphic-unit (HSU) model of the confined aquifer beneath the San Luis Valley.

The products resulting from analysis of the geophysical well logs were:

1. Cross sections of water quality versus depth across the Valley
2. Elastic parameter estimates, to use in evaluating the subsidence potential due to pumping the confined aquifer
3. Geologic maps and cross sections
4. Transmissivity estimates for the hydrostratigraphic units which comprise the confined aquifer

3.4.2 Surface Geophysical Survey Data Analysis

Two types of surface geophysical survey data, seismic-reflection time sections and regional gravity and aeromagnetic maps, were analyzed.

3.4.2.1 Seismic Data Analysis

The seismic-reflection profile lines known to have been completed in the San Luis Valley are shown on Figure 3.12. Of these, the lines run by the Colorado School of Mines (CSM) were in the public domain or were part of thesis work, and were analyzed in detail in the present study. In addition, four seismic-reflection profiles run by Chevron primarily over the Baca Grant
and two profiles run by Amerex east-west across the central part of the San Luis Valley were analyzed.

Analysis of the seismic data consisted of conversion of the distance versus reflection-time profiles into distance-versus-depth profiles, using seismic velocity information from geophysical well logs. This data provided the basis for construction of geologic cross sections of the San Luis Valley.

Seismic reflection-time profiles also provided information on the lateral continuity of the geologic units of interest, possible facies changes within the confined aquifer, the presence of faulting beneath the San Luis Valley, especially in the basin-margin areas, and the thickness of the units which comprise the confined aquifer. Several of the geologic cross sections, discussed in a previous section of this report, were drawn across the areas where seismic lines were available for analysis.

3.4.2.2 Gravity and Magnetic Data Analysis

Potential-field geophysical data analyzed consisted of regional gravity and aeromagnetic contour maps. These maps were analyzed to determine large-scale geologic structure and tectonic features in the San Luis Valley and the surrounding mountainous areas. These features may strongly influence regional ground-water flow paths in the study area.

3.4.2.3 Results of Analysis

Surface geophysical survey data provided information to construct six geologic cross sections (four predominately east-west and two predominately north-south) across the San Luis Valley, and several geologic maps of the study area (Section 3.3). Seismic reflection profiles were used for detailed information on stratigraphy and depths to the units which comprise the confined aquifer. Regional gravity and aeromagnetic maps were used to interpret the location, direction, and extent of large-scale tectonics in and surrounding the study area.
3.5 GROUND-WATER QUALITY ANALYSIS

Several analyses were performed to assess whether the confined aquifer contains water of acceptable quality for intended agricultural uses. These analyses were:

1. Review of previous studies of water quality in the confined aquifer; determine if such data are applicable to the present study
2. Calculation of NaCl-equivalent Dissolved Solids (DS) concentration from geophysical logs
3. Measurement of water-quality constituents and laboratory analysis of water from selected confined-aquifer wells

3.5.1 Review of Previous Analyses

Most previous analyses of ground-water chemical quality in the aquifers of the San Luis Valley were of the unconfined aquifer (HSU-1) or the shallow confined aquifer (HSU-2). No studies are known on the confined aquifer at a depth of 3000 feet or greater. Appendix B contains available water-quality data from wells greater than 2000 feet deep.

3.5.2 Water-Quality Data Analysis and Results

The self-potential (SP) geophysical logs of seven oil and gas test wells were used to estimate the dissolved solids (DS) concentration of water from the confined aquifer. The DS concentration was used to characterize the water quality of that aquifer. Between 20 and 40 data points at varying depths were analyzed for each well. From these data, water quality was interpreted in terms of DS (NaCl equivalent). The method of analysis used is described by Dresser Atlas (1982). A professional log analyst reviewed the methods and interpretation, and concluded that they were applicable to the San Luis Basin, and were correctly applied.
A depth-versus-specific-conductance graph (an indicator of water quality) was constructed for each well using the self-potential (SP) logs. These graphs were combined to produce two depth/conductance cross sections (Figures 3.13 and 3.14). The cross sections show the changes of water quality with depth in the confined aquifer. Figure 2.6 shows the locations of the wells and the cross section lines used in the analysis.

Four of the wells analyzed show generally good water-quality conditions (based on specific conductance) from ground surface to a depth of approximately 2000 to 2500 feet beneath the San Luis Valley. Three wells, Milestone Petroleum No. 1 AMF, Tucker No. 1 Thomas, and Amoco/Mapco No. 1-32 State, show relatively poor water-quality at all depths. This is indicated by a specific conductance greater than approximately 5000 micromhos per centimeter (micromho/cm). Using a generally accepted conversion factor, this value of specific conductance is equivalent to a DS (NaCl equivalent) concentration of approximately 2500 to 3000 milligrams per liter (mg/l) (corrected for measured borehole temperature).

At a depth of approximately 2000 to 3000 feet in the central part of the Valley, all wells except two (Sunny Valley Blanca No. 1 and Tucker No. 1 Thomas) showed an abrupt change in water quality. In those two wells, an abrupt water-quality change is seen between depths of 3000 and 4000 feet. This change occurs approximately at the contact of the Los Pinos/Santa Fe Formations with the underlying Fish Canyon/Carpenter Ridge Formations (Figure 2.1). Below the Fish Canyon/Carpenter Ridge, no improvement in water quality (based on specific conductance) is observed in the volcaniclastic facies of the Conejos Formation.

The Sunny Valley Blanca No. 1 well, which did not show decreased water quality below 2000 to 2500 feet, is located in an area where relatively rapid ground-water recharge to the Alamosa and Santa Fe Formations may occur. The Fish Canyon and Carpenter Ridge Formations are not present at this location.
An attempt was made to evaluate the accuracy of the results of the SP-log water quality interpretation, by comparing the results with existing water-quality data from confined aquifer wells. The only pertinent data were specific-conductance measurements from the Alamosa Geothermal Well (Energy Services, Inc., 1983) and a drillstem test (DST) performed during the drilling of the Amoco/Mapco No. 1-32 State test well.

The Alamosa Geothermal Well indicated a DS concentration of approximately 1800 mg/l at a depth of 2000 feet. The drillstem test of the Amoco/Mapco No. 1-32 State well indicated a DS concentration of 6000 to 11,000 mg/l at a depth of 5304 to 5491 feet (Burroughs, 1981).

Field measurements of specific conductance performed for this study agree closely with the SP water-quality interpretation in Figures 3.13 and 3.14. The one exception to this is for a 4300-foot well located in the Baca Graben, approximately 1.5 miles northeast of the town of Hooper. The DS concentration of water flowing from this well is approximately 300 to 400 mg/l, and the temperature of the water is approximately 40 degrees C. The absence of the Fish Canyon and Carpenter Ridge Formations, and the presence of N15W-trending faults, may allow vertical mixing of water between HSU-2 and HSU-3 at this location. However, it is possible that the 60-year old well casing has corroded or collapsed, and that shallow ground water is mixing with deep ground water at the well. In this case, the measurements would not indicate actual conditions in HSU-3. The overall result of the water-quality analysis of the confined aquifer beneath the San Luis Valley is that the water in HSU-3 in most areas of the valley appears to be of DS concentration greater than 3000 mg/L.

However, the water quality of the confined aquifer (HSU-3) has not been evaluated sufficiently to determine if it is suitable for domestic and/or commercial use. At present, there is less than one reliable data point per 100 square miles of aquifer area, and the complex stratigraphic and structural controls on ground-water flow paths are not well understood.
The San Luis Valley basin has been filled over geologic time, since the mid- to late-Tertiary age, with unconsolidated clays, silts, sands, and gravels of the Los Pinos/Santa Fe Formations and the Alamosa Formation. Rapid deposition of large thicknesses of water-saturated sediments in a relatively short time generally does not allow the geologic materials to become consolidated and cemented, i.e., to develop any physical strength. Pumping of ground water from these sediments can, under certain conditions, cause subsidence of the ground surface. This phenomenon has been noted in the San Joaquin Valley of California, in the Mexico City area, and in many other places. Subsidence is caused by compaction of the unconsolidated sediments, particularly the clay units, as water is drawn out of an aquifer under the stress of extensive pumping.

Preliminary analyses of the potential for land subsidence have been made for the confined aquifer of the San Luis Valley, where geologic conditions are similar to other areas of the world where subsidence has occurred.

Two types of analysis were performed. The first was an evaluation of measured subsidence in the San Luis Valley during the time period from 1933 to 1985. The second was an evaluation of the elastic parameters of the confined aquifer to assess the extent to which compaction of sediments would occur as a result of large-scale ground-water withdrawals.

3.6.1 Ground Elevation-Profile Analysis

The U.S. Geological Survey (USGS) completed a First-Order, Class I elevation-profile line from Ojo Caliente, New Mexico, north along Highway 285 and Highway 17 (approximately), to a point near Poncha Pass at the north end of the Valley. Figure 3.15 shows the location of the ground elevation-profile line. The elevation profile was first measured in 1933, and the same stations along the profile were remeasured in 1985. The exact dates of the survey during those years are unknown.
For a First Order, Class I elevation survey, the maximum closure error for a given station is four millimeters multiplied by the square-root of the distance, in kilometers, from the starting point of the profile to that station. Figure 3.16 shows the change in ground elevation along the profile between 1933 and 1985 measurement surveys, along with the error envelope. The maximum decline in ground elevation along the profile is approximately 250 mm. This decline occurs at a point roughly ten kilometers north of Alamosa. Another area of ground-elevation decline during the 52-year period occurs approximately at the town of Moffat, at about kilometer 190 along the profile.

Figure 3.17 shows the elevation-change profile, with the three highest and lowest elevation-change points removed, and smoothed with a five-point running average. There is a long-distance trend of ground-elevation rise from south to north along the entire length of the profile. It is hypothesized that the long-distance trend may be due to regional tectonic movement causing slow downwarp of this part of the Rio Grande Rift, with a shorter-distance trend of more pronounced ground-elevation decline in the San Luis Valley part of the regional ground-elevation profile (Figures 3.15 and 3.17).

Figure 3.18 shows the same smoothed profile as in Figure 3.17, except with a linear-regression best-fit line to all data points. The position of the long-distance ground-elevation-trend line was subtracted from the elevation-change data, so that the elevation-change trend in the San Luis Valley is more apparent. This figure shows an apparent trend of elevation drop averaging 100 to 200 mm for the 52-year period (approximately two to four millimeters per year) between the two measurement surveys in the San Luis Valley between Alamosa and Moffat.

The ground-elevation drop is likely due to land subsidence caused entirely by ground water withdrawals from the unconfined and the shallow confined aquifers during the period 1933-1985. Assuming this, the observed average rate of two to four millimeters per year of ground-elevation subsidence was caused by an average annual ground-water withdrawal of
approximately 550,000 acre-feet per year, provided that the average annual withdrawals for the period 1933 - 1985 were about the same as for the period 1940 - 1970 (Emery and others, 1973).

At a given ground-water withdrawal rate, transmissivity is inversely proportional to drawdown, and drawdown is directly proportional to subsidence. To estimate the potential for subsidence due to ground-water withdrawals from the confined aquifer, it is necessary to estimate the ratio of transmissivities between the unconfined/shallow-confined aquifers and the confined aquifer HSU-3. Geophysical log analyses indicate that the transmissivity ratio may be in the range of 10:1 to 20:1 (the smaller transmissivity is for HSU-3).

Assuming the sedimentary material types and elastic parameters within HSU-3 are approximately the same as those in the unconfined and shallow-confined aquifers, there would be approximately five to ten millimeters per year of land subsidence due to a withdrawal of 100,000 acre-feet per year of ground water from HSU-3.

3.6.2 Elastic-Parameters Analysis

The mechanical strength of an aquifer determines whether ground-water withdrawals will cause compaction of the aquifer materials. The aquifer strength can be directly measured by laboratory methods or can be estimated by geophysical well-log interpretation.

The potential for subsidence due to compaction can generally be estimated by determining whether the fine-grained layers of a detrital sediment (formed by accumulation of individual rock grains) are predominantly clay, which is unconsolidated and compactible, or whether they are predominantly shale, which is consolidated and not compactible. The two parameters from a geophysical log which indicate the degree of consolidation of a formation are density and acoustic velocity. Table 3.3 gives average values for these parameters for clay, shale, and for the fine-grained intervals in the depth range between 2000 feet to 5000 feet in selected geophysical logs in the San Luis Valley:
### TABLE 3.3
**RANGES OF DENSITY AND VELOCITY**

<table>
<thead>
<tr>
<th>Material</th>
<th>Density Range (grams/cc)</th>
<th>Velocity Range (feet/second)</th>
</tr>
</thead>
<tbody>
<tr>
<td>clay</td>
<td>1.5 - 2.4</td>
<td>1500 - 7500</td>
</tr>
<tr>
<td>shale</td>
<td>2.4 - 2.7</td>
<td>7500 - 14,000</td>
</tr>
<tr>
<td>Cougar-Crow #1</td>
<td>2.0 - 2.6</td>
<td>(not available)</td>
</tr>
<tr>
<td>Milestone AMF #1</td>
<td>2.4 - 2.6</td>
<td>8000 - 10,000</td>
</tr>
<tr>
<td>Amoco-Mapco #1-32</td>
<td>2.2 - 2.4</td>
<td>4500 - 6500</td>
</tr>
<tr>
<td>Reserve Oil #1-33</td>
<td>2.2 - 2.4</td>
<td>(not available)</td>
</tr>
</tbody>
</table>

These ranges of density and acoustic velocity indicate that the Los Pinos/Santa Fe Formations, which comprise most of HSU-3, are relatively unconsolidated, and the clays within the unit are therefore susceptible to compaction induced by ground-water withdrawals. The Milestone AMF No. 1 well, located several miles northwest of Del Norte, penetrated both the near-vent facies and parts of the volcaniclastic facies of the Conejos Formation in the depth interval from 2000 to 5000 feet below ground surface. It appears that the Conejos Formation volcaniclastics are relatively well consolidated in this area. The other three wells whose logs were analyzed are located in the east-central part of the San Luis Valley, northeast of Alamosa, and are believed to represent conditions prevalent in HSU-3.

#### 3.6.3 Results of Analysis

Analysis of a measured change in ground elevation in a general north-south profile across the San Luis Valley over a 52-year period indicates that there has been an elevation drop of approximately 100 to 200 mm in the ground surface of the San Luis Valley over that time period. The most pronounced elevation drop occurred in parts of the San Luis Valley which are underlain by...
thick sequences of unconsolidated and semi-consolidated sediments. The drop in elevation corresponds to areas with relatively large ground-water withdrawals from the unconfined aquifer and the shallow-confined aquifer.

Analysis of geophysical logs indicates the sediments which comprise HSU-3 are primarily unconsolidated, and would likely be compacted if large-scale ground-water withdrawals occur. Land subsidence may result, and it is estimated that the withdrawal of 100,000 acre-feet per year from HSU-3 may cause subsidence of approximately five to ten millimeters per year.
COLORADO WATER RESOURCES
AND POWER DEVELOPMENT AUTHORITY
SAN LUIS VALLEY CONFINED AQUIFER STUDY

WATER QUALITY TRILINEAR DIAGRAM

HRS WATER CONSULTANTS, INC.
WITH ROBERT E. MORAN

DATE: APRIL, 1987

FIGURE 3.2
**LEGEND**

- Q - Alluvium
- Qa - Alamosa Formation
- Tm - Hinsdale Basalt
- Tpm - Mesozoic Park Tuff
- Trt - Treasure Mountain Tuff
- Ts - Seriotes Formation
- TSf/Tc - Santa Fe/Los Plios Formation
- Tfp - Fish Canyon/Carpenter Ridge Tuffs
- TV - Volcanic Intrusive
- TC - Conejos Formation
- TVb - Vallejo/San Juan Formation
- pTv - pre-Vallejo Paleozoic Formations
- pE - Pre-Byobton Crystalline Rock

**EXPLANATION**

- FORMATION CONTACT
- FAULT (ARROW INDICATES RELATIVE MOVEMENT)
- GROUND SURFACE

**SOURCES**

- The diagram is based on the San Luis Valley Confined Aquifer Study by Colorado Water Resources and Power Development Authority.

**DATE:** April 1987
COLORADO WATER RESOURCES
AND POWER DEVELOPMENT AUTHORITY
SAN LUIS VALLEY CONFINED AQUIFER STUDY

EAST-WEST GEOLOGIC CROSS-SECTION

HRS WATER CONSULTANTS, INC.
WIT ROBERT E. MORGAN
DATE: APRIL, 1987
FIGURE: 3.8
LEGEND
Q - Alluvium
Qa - Alamosa Formation
Tm - Miscellaneus Formations
Tm-a - Alamosa Formations
Tm-b - Mesozoic Park Tuff
Tm-c - Treasure Mountain Tuff
Tm-d - Serrillete Formation
Tm-f - Santa Fe/Los Pinos Formation
Tm-g - Fish Canyon/Carpenter Ridge Tuffs
Tm-h - Volcanic Intrusive
Tc - Conata Formation
Tv - Vallejo/Blanco Basin Formation
preTv - pre-Vallejo Paleozoic Formations
pE - Pre cambrian Crystalline Rock

EXPLANATION
- FORMATION CONTACT
- FAULT (ARROW INDICATES RELATIVE MOVEMENT)
- GROUND SURFACE

SOURCES
- Colorado Geological Survey (COGS) - Map of the San Luis Valley
- United States Geological Survey (USGS) - Map of the Treasure Mountain Tuff
- Colorado Water Resources and Power Development Authority - Map of the San Luis Valley

DATE: APRIL, 1987
FIGURE: 2.7
LEGEND

**Q** - Alluvium
**Qa** - Alamosa Formation
**Tb** - Hinsdale Basalt
**Ta** - Mancos Park Tuff
**Te** - Treasure Mountain Tuff
**Tc** - Senecat Formation
**Tc** - Senecat Formation
**TS** - Santa Fe/Los Pillos Formation
**Tg** - Fish Canyon/Carpenter Ridge Tuffs
**To** - Volcanic Intrusive
**Tv** - Conejos Formation
**Tv** - Conejos Formation
**Tv** - Conejos Formation
preTv - pre-Conejos Paleozoic Formations
preTv - pre-Conejos Paleozoic Formations
preTv - pre-Conejos Paleozoic Formations
pE - Precambrian Crystalline Rock

EXPLANATION

FORMATION CONTACT

FAULT (ARROW INDICATES RELATIVE MOVEMENT)

GROUND SURFACE

SOURCES

COLORADO WATER RESOURCES AND POWER DEVELOPMENT AUTHORITY
SAN LUIS VALLEY CONFINED AQUIFER STUDY

NORTH-SOUTH GEOLOGIC CROSS-SECTION E - E'

HRS WATER CONSULTANTS, INC.
WITH ROBERT E. MORAN

DATE APRIL, 1967 FIGURE: 3.8
COLORADO WATER RESOURCES
AND POWER DEVELOPMENT AUTHORITY
SAN LUIS VALLEY CONFINED AQUIFER STUDY
NORTH-SOUTH
GEOLOGIC CROSS-SECTION
F - F'

HRS WATER CONSULTANTS, INC.
WITH ROBERT E. MORAN
DATE: APRIL, 1987
FIGURE 3.11

LEGEND

Q - Alluvium
QA - Alamosa Formation
TM - Hinsdale Basalt
TP - Treasure Mountain Tuff
TS - Saratoga Formation
Tl/TM - Santa Fe/Los Piños Formation
Tf - Fish Canyon/Carpenter Ridge Tuffs
Tc - Volcanic Intrusive
Tv - Conejos Formation
Tv - Vallejo/Blanco Basin Formation
P/E - pre-Vallejo Paleozoic Formations
P/E - Precambrian Crystalline Rock

EXPLANATION

- FORMATION CONTACT
- FAULT (ARROW INDICATES RELATIVE MOVEMENT)
- GROUND SURFACE

SOURCES

Graph is a cross-section of the San Luis Valley's aquifer system, showing various geological formations and contacts. The north-south cross-section is labeled F-F' and includes annotations for each formation and contact indicated in the lower part of the graph. The legend provides a key to the symbols used in the cross-section.
COLORADO WATER RESOURCES AND POWER DEVELOPMENT AUTHORITY
SAN LUIS VALLEY CONFINED AQUIFER STUDY

LOCATIONS OF SEISMIC LINES IN THE SAN LUIS VALLEY

HRS WATER CONSULTANTS, INC.
WITH ROBERT E. MORGAN

DATE: APRIL, 1987

FIGURE 3.12
**NOTE:** THESE ARE FROM FIELD MEASUREMENTS, HRS WATER CONSULTANTS, JUNE, 1986.

1 **CARROLL WELL**
(AVERAGE FOR INTERVAL 1685'-2885')

2 **OWENS WELL**
(AVERAGE FOR INTERVAL 2325'-2955')

3 **ALAMOSA GEOTHERMAL WELL**
(AVERAGE FOR INTERVAL 5400'-6000')

**COLORADO WATER RESOURCES**
AND POWER DEVELOPMENT AUTHORITY
SAN LUIS VALLEY CONFINED AUERFER STUDY

**NORTH-SOUTH WATER QUALITY**
CROSS-SECTION ACROSS
THE SAN LUIS VALLEY

HRS WATER CONSULTANTS, INC.
WITH ROBERT E. MORAN
DATE: APRIL, 1987
FIGURE 3.13
COLORADO WATER RESOURCES AND POWER DEVELOPMENT AUTHORITY
SAN LUIS VALLEY CONFINED AQUIFER STUDY

DISTANCE VS. CHANGE IN ELEVATION
RAW DATA AND ERROR ENVELOPE

HRS WATER CONSULTANTS, INC.
WITH ROBERT E. MORAN

DATE: APRIL, 1987  FIGURE 3.16
COLORADO WATER RESOURCES
AND POWER DEVELOPMENT AUTHORITY
SAN LUIS VALLEY CONFINED AQUIFER STUDY
ELEVATION CHANGE 1933-1985
NORTH-SOUTH PROFILE,
SAN LUIS VALLEY
HRS WATER CONSULTANTS, INC.
WITH ROBERT E. MORAN
DATE: APRIL, 1987
FIGURE 3.18

SOUTH NORTH

ELEVATION CHANGE

CHANGE IN ELEVATION (mm)

DISTANCE (km)

BEST FIT LINE

DIFFERENCE

LINEAR REGRESSION BEST
FIT LINE, KM 20-100
AND KM 200-245

SOURCE: USGS ELEVATION DATA
4.0 COMPUTER MODEL EVALUATION

4.1 STATUS OF CURRENT COMPUTER-MODEL EVALUATION

Study-team members met with personnel of the U.S. Geological Survey's (USGS) Water Resources Division regarding the Survey's recent ground-water modeling efforts in the San Luis Basin. Study-team members met with Mr. Glenn Hearne regarding the regional ground-water flow model of the aquifers of the San Luis Valley, which he and other USGS personnel have developed. USGS personnel stated that their model and its associated data input are presented in a draft report recently approved for publication. This report is available for inspection only, until it is formally published. Though the Colorado State Engineer's Office (SEO) have indicated their intention to develop a computerized ground-water model of the Valley, the SEO staff have indicated that no results are anticipated until Spring of 1987.

4.2 SAN LUIS BASIN WATER BALANCE

One of the most important aspects of a computerized ground-water flow model is the water balance of the modeled area. The following summary and comparison of previous investigations of the San Luis Valley water balance by the USGS is intended for use in a preliminary assessment of model-data needs.

Limited data are available to accurately define all water-balance components for the San Luis Valley. Ignoring changes in storage, which are negligible in comparison to the other components of the water balance, the major components of the water balance of the San Luis Valley are:

1. Surface-water and ground-water inflows from the San Juan Mountains
2. Surface-water and ground-water inflows from the Sangre de Cristo Mountains
3. Direct precipitation to the Valley floor
4. Evapotranspiration from the Valley floor
5. Surface-water and ground-water outflow at the southern end of the San Luis Valley.

Attempts to define these components for all or large parts of the Valley have been made by Emery and others (1973), Huntley (1976), and most recently by Hearne and Dewey (1986 in press).

Emery's water-balance estimates for the Valley attributed all inflows to surface water and direct precipitation, and assumed minimal ground water inflow to the system except as recharge from surface sources within the Valley. Huntley (1976), in his study of ground water recharge to the northern part of the Valley, identified a large component of ground-water inflow, particularly from the San Juan Mountains. Hearne and Dewey (1986, in press), in their model of the Alamosa Basin (the San Luis Valley to the north and west of the San Luis Hills), estimated total yields from each of the subbasins in the San Juan Mountains and the Sangre de Cristo Mountains to calculate the amount of surface-water and ground-water inflow to the Valley. By comparing these total yield estimates to existing surface-water records, they also identified a large component of ground-water inflow from the San Juan Mountains, particularly in the northern part of the Rio Grande Basin.

Based on an evaluation of the three water-balance estimates and independent calculations of the various components, the results of Hearne and Dewey's (1986, in press) water-balance model appear to best represent the actual conditions within the basin. Table 4.1 lists estimates of the various components as provided by Hearne and Dewey (1986, in press).

The inflow components exceed the outflow components by approximately nine percent. Hearne and Dewey (1986, in press) attempted to analyze each component in the water balance individually and did not adjust any components to balance the model; therefore, this difference probably represents the level of error in the data used for analysis.
TABLE 4.1
WATER BUDGET FOR THE ALAMOSA BASIN

<table>
<thead>
<tr>
<th>INFLOW SOURCE</th>
<th>INFLOW IN AF/Y * 1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sangre de Cristo Mountains</td>
<td>246</td>
</tr>
<tr>
<td>San Juan Mountains</td>
<td>2009</td>
</tr>
<tr>
<td>Precipitation</td>
<td>1085</td>
</tr>
<tr>
<td>TOTAL INFLOW</td>
<td>3340</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OUTFLOW SOURCE</th>
<th>OUTFLOW IN AF/Y * 1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evapotranspiration</td>
<td>2820</td>
</tr>
<tr>
<td>Rio Grande River</td>
<td>330</td>
</tr>
<tr>
<td>Ground-Water Outflow</td>
<td>(not estimated)</td>
</tr>
<tr>
<td>TOTAL OUTFLOW:</td>
<td>3150</td>
</tr>
</tbody>
</table>

It is unlikely that all of this difference can be attributed to the change in ground-water storage or ground-water outflow. Based on an analysis of evapotranspiration and precipitation for the Valley performed by Agro Engineering (Salazar, 1986; See Appendix D of this report), and existing streamflow records for the Rio Grande, it appears that the most likely source of error may be in the inflow estimates for the surrounding mountains, particularly the San Juan Mountains. The quality of the streamflow records for the subdrainages in the San Juan Mountains is good, and Emery's estimates of surface inflows to the Valley are considered reliable. Therefore, any error in the inflow estimates to the Valley is likely due primarily to the ground-water inflow estimates.

Using Hearne and Dewey's (1986) estimates of total yield, and Emery's estimates of surface-water yields, ground-water inflows to the Valley were estimated for various mountain subbasins within the San Luis Basin. Figure 4.1 summarizes the calculated inflows to the Valley. The possibility of error

4-3
in the yield estimates is apparent for those subbasins which show negative ground-water yields. These figures indicate a probable underestimate of total subbasin water yield. Large ground-water yields in comparison to surface-water yields may represent overestimates of total subbasin yield. Errors in either case are unlikely to be greater than about 20 percent, judging from the available data and the types of analyses performed. Figure 4.1 may therefore be useful in identifying the general magnitude and relationships of surface-water and ground-water inflows to the Valley. Future data collection and study efforts are necessary to more accurately define the nature of the inflow components from the San Juan Mountains.
NOTE:
GROUND WATER INFLOW CALCULATED AS DIFFERENCE BETWEEN TOTAL YIELD AS ESTIMATED BY HEARNE AND DEWEY AND SURFACE WATER YIELD AS ESTIMATED BY EMERY.
5.0 DATA AND INFORMATION NEEDS

5.1 IDENTIFICATION OF DATA NEEDS

The present study is based entirely on data currently available for the confined aquifer which lies beneath the San Luis Valley. An assessment of the feasibility of using the confined aquifer as a source of ground-water supply is the primary goal of this Phase I study. An attempt was made to use all possible sources of data which relate to this issue.

5.1.1 Physical Aquifer Characteristics

One of the largest deficiencies in the existing database on the confined aquifer is the lack of site-specific aquifer-test data to aid in estimating the aquifer transmissivity and storativity. Because of the lack of reliable data on aquifer characteristics, the estimation of the volume of recoverable ground water, the economics of pumping the water, and the degree to which the aquifer may be judged non-tributary are all dependent on indirect geologic and hydrologic evidence.

5.1.2 Ground-Water Quality

The existing database on the deep confined aquifer (HSU-3) contains fewer than ten wells for the entire San Luis Valley for which water-quality data are available. Four of these are based on preliminary field investigations carried out during the well inventory. The others are from drillstem tests, airlift tests, and pumping tests of deep wells in the Valley. Indirect methods of estimating water quality have also been used. Analysis of the data indicates that relatively poor quality water may predominate in the deep confined aquifer (HSU-3). Site-specific water-quality data would assist in evaluating this tentative conclusion, and help assess the feasibility of using the confined aquifer as a water-supply source.
5.1.3 Data Needs by Geographical Location

No area in the San Luis Valley has sufficient data on aquifer characteristics or water quality for a detailed description of the confined aquifer system. The area of the Rio Grande Fan and the ground-water recharge zones at the western edge of the Valley appear to have the greatest potential for ground-water development in the confined aquifer system. These areas especially need site specific data.

The apparent ground-water discharge areas near the faults which form the Alamosa Horst and the northwest side of the San Luis Hills are important in order to assess whether the confined aquifer is tributary to surface streams. Site-specific hydrologic data on the confined aquifer in these areas is needed, as none is presently available.
6.0 RECOMMENDATIONS

The study team makes the following recommendations, based on their analysis of existing data:

1. Work activities for the Phase I study should focus on documenting the results of completed geophysical field investigations and interpreting satellite imagery for regional geologic structures.

2. Originally proposed work on institutional aspects of water development and field isotope/water-quality analyses is presently not useful. Therefore, work should not be continued in these areas for this initial study phase.

3. Consideration should be given to a pilot test-well drilling and testing program for the next study phase to fill data deficiencies encountered during this initial study phase. Selection of drilling sites should be based on specific criteria including expected areas of best conditions for developing a water supply, confirmation of already-noted worst-case conditions, and geographical diversity. Before proceeding on this subsequent phase, the possible technical benefits of a drilling program must be weighed against costs.

6.1 ADDITIONAL DATA REQUIREMENTS

Some additional data on the confined aquifer system was obtained through recently completed well testing and field investigations. Results of these investigations will be published separately.

Priority should be given to acquiring additional aquifer-test data which provides estimates for the transmissivity and storativity of the confined aquifer system. At present, no aquifer-test data are known to exist on the confined aquifer from which these parameters can be calculated. Secondly, additional data is needed on the confined aquifer system.
By geographic area, the Rio Grande Fan and western periphery of the Valley are of primary importance for collecting additional data on the confined aquifer. From the indirect data available, this area appears to provide the greatest potential for development, in terms of water quality, production capacity, economics of development, and water use. Indications of possible good water quality in the Hooper area (near the southwest corner of the Baca Grant) suggest that this might be the second priority area for further investigation. Third priority should be given to investigation of the area near the northwest side of the San Luis Hills, to evaluate the possibility of ground-water discharge in that area and whether water from the confined aquifer is tributary to any surface streams.
7.0 REFERENCES


SAN LUIS VALLEY CONFINED AQUIFER STUDY
(PHASE I)
APPENDIXES

INTERIM TASK 2 REPORT
DATA AND INFORMATION SYNTHESIS AND NEEDS

Prepared for
Colorado Water Resources and Power Development Authority
Logan Tower, Suite 620
1580 Logan Street
Denver, Colorado 80203

HRS Water Consultants, Inc.
with Robert E. Moran
87001-12 April, 1987
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### ACRONYMS AND ABBREVIATIONS

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<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<tr>
<td>af</td>
<td>acre-feet</td>
</tr>
<tr>
<td>af/y</td>
<td>acre-feet per year</td>
</tr>
<tr>
<td>Authority</td>
<td>Colorado Water Resources and Power Development Authority</td>
</tr>
<tr>
<td>AWD</td>
<td>American Water Development</td>
</tr>
<tr>
<td>C</td>
<td>Celsius</td>
</tr>
<tr>
<td>DS</td>
<td>dissolved solids</td>
</tr>
<tr>
<td>ft/sec</td>
<td>feet per second</td>
</tr>
<tr>
<td>gpm</td>
<td>gallons per minute</td>
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<tr>
<td>gpd/ft</td>
<td>gallons per day per foot</td>
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<tr>
<td>grams/cc</td>
<td>grams per cubic centimeter</td>
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<td>GWSI</td>
<td>ground-water site inventory</td>
</tr>
<tr>
<td>HSU</td>
<td>hydrostratigraphic unit</td>
</tr>
<tr>
<td>K</td>
<td>hydraulic conductivity</td>
</tr>
<tr>
<td>mg/l</td>
<td>milligrams per Liter</td>
</tr>
<tr>
<td>micromho/cm</td>
<td>micromhos per centimeter</td>
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<tr>
<td>mm</td>
<td>millimeters</td>
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<tr>
<td>msl</td>
<td>mean sea level</td>
</tr>
<tr>
<td>NaCl</td>
<td>sodium chloride</td>
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<td>SEO</td>
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<tr>
<td>SP</td>
<td>self potential</td>
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<tr>
<td>T</td>
<td>transmissivity</td>
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<td>USGS</td>
<td>United States Geological Survey</td>
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APPENDIX A

Bibliographies of San Luis Valley
Geology and Hydrology
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<td>Selected Data Sets Pertaining to the San Luis Valley</td>
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TABLE A.1

SELECTED DATA SETS PERTAINING TO THE SAN LUIS VALLEY

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EXPLANATORY NOTES TO ANNOTATED BIBLIOGRAPHY

The following compilation of references is intended as a guide for the Colorado Water Resources and Power Development Authority, and the study team of Phase I, to previous geologic and hydrologic work in the study area.

The references contained in this compilation have been selected from the complete bibliography as those which, in our judgement, offer the Authority and the study team the most concise and accurate interpretations of the geology and hydrology related to the deep confined aquifer which underlies the San Luis Valley.

For this reason, and also to aid the Authority and the study team in selecting references for a particular task or subtask, each of the references has a brief annotation which addresses: 1) the level of interest or importance of the reference to the present study, 2) the disciplines addressed, and 3) the specific geographic area.

It should be noted that the following compilation (Appendix A) is on an interactive, computerized DBMS file (Data-Base Management System; pfs: FILE format, MS-DOS). The DBMS file allows the user to sort or retrieve the references on the basis of the following criteria:

1) author
2) title
3) publisher
4) year of publication
5) type of publication (i.e., thesis, conference proceedings, etc.)
6) any of several general subject headings (e.g. geology, geochemistry, geothermal, specific geographic area, etc.)
7) whether or not the reference contains data pertaining to:
   a. The confined aquifer
   b. The unconfined aquifer
   c. Water quality in general

Copies of the annotated reference - list file, in MS-DOS/pfs: FILE format can be obtained by the Authority and study-team members, upon request, to HRS Water Consultants, Inc.
Annotated Bibliography

TITLE: RESISTIVITY STUDIES IN THE UPPER ARKANSAS VALLEY AND NORTHERN SAN LUIS VALLEY, COLORADO
AUTHOR: ARESTAD, J.F.
PUBLICATION DATE (YY/MM): 1977
ABSTRACT OR COMMENTS: THIS THESIS MAY BE OF SECONDARY IMPORTANCE, USEFUL IN CORRELATING SEISMIC INFORMATION WITH POTENTIAL-FIELD GEOPHYSICAL SURVEYS WITHIN THE SAN LUIS VALLEY.

TITLE: PHYSIOGRAPHY AND QUATERNARY GEOLGY OF THE SAN JUAN MOUNTAINS
AUTHOR: ATWOOD, W. W., K. F. MATHER
PUBLICATION DATE (YY/MM): 1932

TITLE: APPRAISAL OF COLORADO'S GEOTHERMAL RESOURCES
AUTHOR: BARRETT, J. K., R. H. PEARL
PUBLICATION DATE (YY/MM): 1978
ABSTRACT OR COMMENTS: A GENERAL BACKGROUND TO THE GEOTHERMAL POTENTIAL OF THE SAN LUIS VALLEY; LITTLE DETAIL HOWEVER RELEVANT TO THE PRESENT STUDY.

TITLE: GEOLOGY AND HYDROTHERMAL ALTERATION OF THE SUGARLOAF PROSPECT, SAN LUIS HILLS, CONEJOS AND COSTILLA COUNTIES, COLORADO
AUTHOR: BARTLETT, R.D.
PUBLICATION DATE (YY/MM): 1983
ABSTRACT OR COMMENTS: THIS PAPER DISCUSSES GROUND-WATER MOVEMENT THROUGH THE BEDROCK UNITS PRESENT IN THE SOUTHEASTERN SAN LUIS VALLEY AND THE CULEBRA RANGE.

TITLE: BOUGER GRAVITY MAP OF COLORADO
AUTHOR: BEHRENDT, J. C., L. Y. BAJWA
PUBLICATION DATE (YY/MM): 1974
ABSTRACT OR COMMENTS: MAP, AT A SCALE OF 1:1,000,000, WHICH IS USEFUL IN ASSESSING DEEP CRUSTAL STRUCTURE OF THE RIO GRANDE RIFT. OTHER RELEVANT AND AVAILABLE STUDIES ARE MORE DETAILED FOR THE SAN LUIS VALLEY, NOTABLY BACA AND KARIG (1965) AND DAVIS (1978).
TITLE: EVIDENCE FOR EARLY TERTIARY RIO GRANDE DRAINAGE
AUTHOR: BELCHER, R.C., W.E. GALLOWAY
PUBLICATION DATE (YY/MM): 1977
ABSTRACT OR COMMENTS: THIS MAY BE OF INDIRECT IMPORTANCE TO THE PRESENT STUDY, WITH REGARD TO THE POSSIBLE CHANGES IN DRAINAGE FROM THE SAN LUIS VALLEY INTO THE RIO GRANDE.

TITLE: GEOPHYSICAL SURVEY OF AN AREA IN THE SAN LUIS VALLEY, SOUTH OF MOFFAT, COLORADO
AUTHOR: BELLATTI, JOHN F.
PUBLICATION DATE (YY/MM): 1981
ABSTRACT OR COMMENTS: PRESENTS INTERPRETATIONS OF THE STRATIGRAPHY AND STRUCTURE OF A SHORT SEISMIC LINE SOUTH OF THE TOWN OF MOFFAT. USEFUL IN THE PRESENT STUDY WITH REGARD TO THE HYDROSTRATIGRAPHY OF THE DEEPER UNITS IN THE BACA GRABEN AREA.

TITLE: AN INTEGRATED GEOPHYSICAL STUDY OF THE SHAW WARM SPRINGS AREA, SAN LUIS VALLEY, SOUTH-CENTRAL COLORADO
AUTHOR: BOND, M.A.
PUBLICATION DATE (YY/MM): 1981
ABSTRACT OR COMMENTS: USEFUL IN CORRELATING SEISMIC COVERAGE OF THE AREA NORTH OF DEL NORTE WITH OTHER GEOPHYSICAL METHODS WHICH HAVE BEEN ATTEMPTED.

TITLE: SOME HYDROLOGIC PROBLEMS IN THE SAN LUIS BASIN, COLORADO-NEW MEXICO
AUTHOR: BURROUGHS, R. L., D. H. MC FADDEN
PUBLICATION DATE (YY/MM): 1976
ABSTRACT OR COMMENTS: THIS PROVIDED A GOOD OVERVIEW DISCUSSION OF THE HYDROLOGIC PROBLEMS FACING THE WATER USERS OF THE SAN LUIS VALLEY. PERTAINS TO BOTH SURFACE-WATER AND GROUND-WATER SUPPLIES, ESPECIALLY WITH REGARD TO THE RIO GRANDE COMPACT REQUIREMENTS.

TITLE: A SUMMARY OF THE GEOLOGY OF THE SAN LUIS BASIN, COLORADO
AUTHOR: BURROUGHS, R.L.
PUBLICATION DATE (YY/MM): 1981
TITLE: NEOGENE VOLCANISM IN THE SOUTHERN SAN LUIS BASIN
AUTHOR: BURROUGHS, R. L.
PUBLICATION DATE (YY/MM): 1974b
ABSTRACT OR COMMENTS: THIS ARTICLE FROM THE NMGS FIELD CONFERENCE IS A GOOD SUMMARY OF THE CENOZOIC VOLCANIC HISTORY OF THE SOUTHERN SAN LUIS VALLEY AREA.

TITLE: GEOLOGY OF THE SAN LUIS HILLS
AUTHOR: BURROUGHS, R.L.
PUBLICATION DATE (YY/MM): 1971
ABSTRACT OR COMMENTS: CAN BE CONSIDERED AS A SUMMARY PAPER OF THE AUTHOR'S PH.D. THESIS ON THE GEOLOGY OF THE SAN LUIS HILLS. THIS REPORT IS A GOOD OVERVIEW OF THE LAVA FLOW FACIES OF THE CONEJOS FORMATION.

TITLE: PROPOSAL TO THE U.S. DEPARTMENT OF ENERGY FOR THE ALAMOSA GEOTHERMAL WELL DRILLING PROGRAM
AUTHOR: CITY OF ALAMOSA
PUBLICATION DATE (YY/MM): 1980
ABSTRACT OR COMMENTS: USEFUL IN TRACING THE HISTORY AND INTENT OF GEOTHERMAL TESTING IN THE SAN LUIS VALLEY.

TITLE: INTEGRATED GEOPHYSICAL SURVEY, SAN LUIS VALLEY
AUTHOR: COLORADO SCHOOL OF MINES EXPLORATION RESEARCH LABORATORY
PUBLICATION DATE (YY/MM): 1983
ABSTRACT OR COMMENTS: THIS THREE-VOLUME REPORT SUMMARIZES THE RECENT EFFORTS OF THE COLORADO SCHOOL OF MINES, DEPARTMENT OF GEOPHYSICS, TO EXPLORE AND INTERPRET THE BASEMENT STRUCTURE, GEOTHERMAL POTENTIAL, AND PETROLEUM POTENTIAL OF THE NORTHERN AND WESTERN SAN LUIS VALLEY. THE REPORT IS OF PRIMARY INTEREST TO THE PRESENT STUDY, WITH REGARD TO THE STRUCTURE OF THE MONTE VISTA GRABEN AREA.

TITLE: GEOTHERMAL RESOURCES OF SOUTH CENTRAL COLORADO AND THEIR RELATIONSHIP TO GROUND AND SURFACE WATER
AUTHOR: COLORADO DIVISION OF WATER RESOURCES
PUBLICATION DATE (YY/MM): 1978
ABSTRACT OR COMMENTS: THIS PAPER IS COMPLEMENTARY TO COLORADO GEOLOGICAL SURVEY SPECIAL PUBLICATION 17 (BURROUGHS, 1981).
TITLE: APPLICATION OF REMOTE SENSOR DATA TO GEOLOGIC ANALYSIS OF THE BONANZA TEST SITE
AUTHOR: COLORADO SCHOOL OF MINES
PUBLICATION DATE (YY/MM): 1973
ABSTRACT OR COMMENTS: IS OF INDIRECT IMPORTANCE TO THE PRESENT STUDY, WITH REGARD TO COMPARISON WITH PAST USE OF REMOTE-SENSING METHODS FOR GEOLOGIC INTERPRETATIONS IN VOLCANIC PROVINCES.

TITLE: REVIEW OF GEOPHYSICAL STUDIES IN THE RIO GRANDE RIFT
AUTHOR: CORDELL, L.
PUBLICATION DATE (YY/MM): 1976
ABSTRACT OR COMMENTS: GOOD COMPILEDATION OF THE DEEP CRUSTAL AND TECTONIC-REGIME STUDIES OF THE RIO GRANDE RIFT, INCLUDING THE SAN LUIS BASIN.

TITLE: POTENTIALISTIC SURFACE AND WATER-LEVEL CHANGES IN THE UNCONFINED VALLEY FILL AQUIFERS OF THE SAN LUIS BASIN, COLORADO AND NEW MEXICO
AUTHOR: CROUCH, T. M.
PUBLICATION DATE (YY/MM): 1985
ABSTRACT OR COMMENTS: THIS IS THE MOST RECENT UPDATE OF THE U.S. GEOLOGICAL SURVEY'S ONGOING EFFORTS TO MONITOR THE UNCONFINED AQUIFER IN THE SAN LUIS VALLEY. THE MAPS ARE OF PARTICULAR INTEREST TO THE ASSESSMENT OF REGIONAL GROUND-WATER MODELING EFFORTS IN THE SAN LUIS VALLEY.

TITLE: A GRAVITY STUDY OF THE SAN LUIS VALLEY, COLORADO
AUTHOR: DAVIS, G.H.
PUBLICATION DATE (YY/MM): 1978

TITLE: APPENDIX A: A PRELIMINARY EVALUATION OF GEOTHERMAL PROSPECTS AT BACA GRANDE DEVELOPMENT IN THE SAN LUIS VALLEY
AUTHOR: DAVIS, RICHARD
PUBLICATION DATE (YY/MM): 1978
ABSTRACT OR COMMENTS: THIS APPENDIX IS USEFUL TO THE PRESENT STUDY WITH REGARD TO COMPARING THE GEOTHERMAL POTENTIAL OF THE BACA GRABEN WITH OTHER PARTS OF THE SAN LUIS VALLEY.
TITLE: INTERPRETATION OF SEISMIC REFLECTION DATA FROM THE NORTHERN SAN LUIS VALLEY, SOUTH-CENTRAL COLORADO
AUTHOR: DAVIS, T. L., D. STOUGHTON
PUBLICATION DATE (YY/MM): 1979
ABSTRACT OR COMMENTS: THIS ARTICLE IS COMPLEMENTARY TO STOUGHTON'S THESIS WORK (1977) REGARDING THE STRUCTURE AND STRATIGRAPHY OF THE NORTHERN SAN LUIS VALLEY.

TITLE: QUALITY OF GROUND WATER IN AGRICULTURAL AREAS OF THE SAN LUIS VALLEY, SOUTH-CENTRAL COLORADO
AUTHOR: EDELMANN, P., D. R. BUCKLES
PUBLICATION DATE (YY/MM): 1983
ABSTRACT OR COMMENTS: THIS REPORT IS A USEFUL UPDATE OF EARLIER WORK (VARIOUS AUTHORS AND AGENCIES) ON THE WATER QUALITY OF THE SAN LUIS VALLEY, PARTICULARLY WITH REGARD TO THE UNCONFINED AQUIFER.

TITLE: WATER IN THE SAN LUIS VALLEY, SOUTH-CENTRAL COLORADO
PUBLICATION DATE (YY/MM): 1973
ABSTRACT OR COMMENTS: THIS IS AN OVERVIEW REPORT, USEFUL FOR FAMILIARIZATION WITH THE HYDROLOGY OF THE SAN LUIS VALLEY.

TITLE: HYDROLOGIC DATA FOR THE SAN LUIS VALLEY, COLORADO
AUTHOR: EREMY, P. A., R. J. SNIPES, J. M. DUMEYER
PUBLICATION DATE (YY/MM): 1972

TITLE: ANALOG MODEL STUDY OF THE HYDROLOGY OF THE SAN LUIS VALLEY, SOUTH-CENTRAL COLORADO
AUTHOR: EREMY, P. A., E. P. PATTEN JR, J. E. MOORE
PUBLICATION DATE (YY/MM): 1975
ABSTRACT OR COMMENTS: THIS REPORT CAN BE CONSIDERED AS AN UPDATE OF THE USGS'S EARLIER ANALOG MODELING EFFORTS IN THE SAN LUIS VALLEY. AS WITH THE EARLIER WORK, SOME OF THE GEOLOGIC AND HYDROLOGIC CONCEPTS HAVE UNDERGONE SCRUTINY BASED ON LATER ANALYSES.
TITLE: IRRIGATION AND MUNICIPAL WELLS IN THE SAN LUIS VALLEY, COLORADO
AUTHOR: EMERY, P. A., J. M. DUMEYER, A. J. MCINTYRE JR
PUBLICATION DATE (YY/MM): 1969

TITLE: HYDROLOGY OF THE SAN LUIS VALLEY, SOUTH-CENTRAL COLORADO
AUTHOR: EMERY, P. A., A. J. BOETTCHER, F. J. SNIPES, H. R. MCINTYRE JR
PUBLICATION DATE (YY/MM): 1971
ABSTRACT OR COMMENTS: THIS HYDROLOGIC ATLAS IS A GOOD COMPANION REPORT TO EMERY'S ELECTRIC ANALOG MODEL EFFORTS IN THE SAN LUIS VALLEY (EMERY, 1970).

TITLE: ELECTRIC ANALOG MODEL EVALUATION OF A WATER SALVAGE PLAN, SAN LUIS VALLEY, SOUTH-CENTRAL COLORADO
AUTHOR: EMERY, P.A.
PUBLICATION DATE (YY/MM): 1970
ABSTRACT OR COMMENTS: THIS IS TO BE CONSIDERED A LANDMARK PAPER WITH REGARD TO GROUND WATER MODELING IN THE SAN LUIS VALLEY. MANY OF THE GEOLOGIC AND HYDROLOGIC CONCEPTS PROPOUNDED BY THIS PAPER HAVE SINCE COME INTO QUESTION, BASED ON LATER INVESTIGATIONS IN THE VALLEY (VARIOUS AGENCIES AND AUTHORS).

TITLE: GRAVITY SURVEY IN THE SAN LUIS VALLEY AREA, CO
AUTHOR: BACA, J. R., D. E. KARIG
PUBLICATION DATE (YY/MM): 1966
ABSTRACT OR COMMENTS: THIS REPORT CONTAINS THE GRAVITY SURVEY DATA WHICH LED TO THE FIRST ESTIMATES OF BASIN DEPTH IN THE BACA GRABEN. LATER WORK (DAVIS, 1978) HAS REVISLED THESE ESTIMATES.

TITLE: OIL AND GAS POTENTIAL OF SAN LUIS BASIN, SOUTH-CENTRAL COLORADO
AUTHOR: GRIES, R.R.
PUBLICATION DATE (YY/MM): 1980
ABSTRACT OR COMMENTS: GOOD OVERVIEW OF THE RECENT INTEREST IN THE HYDROCARBON POTENTIAL OF THE WESTERN SAN LUIS VALLEY AND THE EASTERN SAN JUAN MOUNTAIN REGION.
TITLE: CORRELATION CHART 1; MAJOR QUATERNARY STRATIGRAPHIC AND GEOMORPHIC UNITS IN THE RIO GRANDE RIFT REGION
AUTHOR: HAWLEY, J.W.
PUBLICATION DATE (YY/MM): 1978
ABSTRACT OR COMMENTS: USEFUL IN THE PRESENT STUDY WITH REGARD TO STANDARDIZATION OF FORMATION NAMES IN USE FOR THE UNITS WHICH COMPREHEND THE DEEP CONFINED AQUIFER.

TITLE: A CONTRIBUTION TO THE HYDROLOGY OF THE SAN LUIS VALLEY, COLORADO
AUTHOR: HEADDEN, W.P.
PUBLICATION DATE (YY/MM): 1919
ABSTRACT OR COMMENTS: THIS EARLY ARTICLE UPDATES, TO SOME EXTENT, THE EARLIER WORK OF SIEBENTHAL (1910) REGARDING THE EARLY WATER USE AND HYDROLOGY OF THE SAN LUIS VALLEY.

TITLE: HYDROLOGIC ANALYSIS OF THE RIO GRANDE BASIN ABOVE EMBUDO, NEW MEXICO
AUTHOR: HEARNE, G., J. DEMEY
PUBLICATION DATE (YY/MM): 1986 (EXPECTED)
ABSTRACT OR COMMENTS: THIS WORK, CURRENTLY BEING COMPLETED, PROVIDES AN UPDATE OF THE U.S. GEOLOGICAL SURVEY'S ONGOING EFFORTS TO INTERPRET AND ANALYZE THE HYDROLOGY OF THE SAN LUIS VALLEY, INCLUDING THE CURRENT DIGITAL MODEL OF THE VALLEY, DEVELOPED BY THE USGS.

TITLE: HYDROGEOLOGY OF NORTHERN SAN LUIS VALLEY, COLORADO
AUTHOR: HUNTLEY, D.
PUBLICATION DATE (YY/MM): 1976b
ABSTRACT OR COMMENTS: THIS ARTICLE IS A CONCISE SUMMARY OF THE AUTHOR'S THESIS WORK IN THE NORTHERN SAN LUIS VALLEY. RECOMMENDED AS REVIEW MATERIAL FOR FAMILIARIZATION WITH SEVERAL OF THE HYDROGEOLOGIC CONCEPTS OF GROUND-WATER RECHARGE AND MOVEMENT INTO THE AQUIFERS OF THE SAN LUIS VALLEY.

TITLE: GROUND WATER RECHARGE TO THE AQUIFERS OF THE NORTHERN SAN LUIS VALLEY, COLORADO-- A REMOTE SENSING INVESTIGATION
AUTHOR: HUNTLEY, D.
PUBLICATION DATE (YY/MM): 1976a
ABSTRACT OR COMMENTS: THIS THESIS REPRESENTS WHAT MAY BE THE MOST COMPLETE ANALYSIS TO DATE OF THE CHARACTERISTICS AND MECHANISMS OF THE AQUIFERS OF THE SAN LUIS VALLEY, PARTICULARLY WITH RESPECT TO THE POTENTIAL FOR RECHARGE FROM THE EASTERN SAN JUAN MOUNTAINS. THIS WORK SHOULD BE CONSIDERED A PRIMARY REFERENCE FOR THE PRESENT STUDY.
TITLE: THE GREAT SAND DUNES OF COLORADO
AUTHOR: JOHNSON, R.B.
PUBLICATION DATE (YY/MM): 1971
ABSTRACT OR COMMENTS: THIS PAPER MAY BE OF INDIRECT INTEREST FROM THE STANDPOINT OF FAMILIARIZATION WITH THE GEOGRAPHY/PHYSIOGRAPHY/CLIMATOLOGY OF THE PLEISTOCENE AND HOLOCENE OF THE SAN LUIS VALLEY.

TITLE: GEOLOGIC MAP OF THE TRINIDAD QUADRANGLE, SOUTH-CENTRAL COLORADO
AUTHOR: JOHNSON, R.B.
PUBLICATION DATE (YY/MM): 1969
ABSTRACT OR COMMENTS: THIS IS A GOOD REGIONAL GEOLOGIC MAP FOR THE EASTERN HALF OF THE SAN LUIS BASIN. LATER WORK HAS CHANGED SOME OF THE GEOLOGIC INTERPRETATIONS WITH RESPECT TO STRUCTURAL FEATURES AND FORMATION NAMES.

TITLE: COSTS AND RETURNS FOR SELECTED IRRIGATED CROPS, CLOSED BASIN, SAN LUIS VALLEY
AUTHOR: JOHNSON, S. H., III
PUBLICATION DATE (YY/MM): 1975a
ABSTRACT OR COMMENTS: USEFUL IN RESEARCH ON CROPPING PATTERNS AND LONG-TERM CHANGES IN THE AGRICULTURAL ECONOMIC BASE OF THE SAN LUIS VALLEY.

TITLE: ECONOMICS OF WATER MANAGEMENT TO REDUCE WATERLOGGING, SAN LUIS VALLEY
AUTHOR: JOHNSON, S. H., III
PUBLICATION DATE (YY/MM): 1975b
ABSTRACT OR COMMENTS: THIS WORK CAN BE CONSIDERED AS A BASIS FOR CERTAIN ASPECTS OF THE PRESENT STUDY, ESPECIALLY WITH REGARD TO THE LONG-TERM ECONOMICS AND FEASIBILITY OF DEVELOPING A WATER SUPPLY FROM THE DEEPER CONFINED AQUIFER.

TITLE: GEOPHYSICAL INVESTIGATION SURROUNDING MINERAL HOT SPRINGS IN SAGUACHE COUNTY, CO
AUTHOR: JORDAN, J.M.
PUBLICATION DATE (YY/MM): 1974
ABSTRACT OR COMMENTS: DISCUSSES SEVERAL GEOPHYSICAL SURVEYS PERFORMED TO AID IN THE INTERPRETATION OF THE GEOTHERMAL POTENTIAL OF THE NORTHERN SAN LUIS VALLEY. THIS PAPER MAY BE OF SECONDARY USE IN THE PRESENT STUDY.
TITLE: A RECONNAISSANCE MICROEARTHQUAKE SURVEY OF THE SAN LUIS VALLEY
AUTHOR: KELLER, G. R., H. E. ADAMS
PUBLICATION DATE (YY/MM): 1976
ABSTRACT OR COMMENTS: THIS PAPER PERTAINS TO CRUSTAL STRUCTURE AND POSSIBLE
EARTHQUAKE POTENTIAL AND FAULT MOVEMENT IN THE SAN LUIS VALLEY. OF SECONDARY
IMPORTANCE TO THE PRESENT STUDY; THERE MAY BE USEFUL INFORMATION WITH REGARD TO
RECENT FAULT MOVEMENT AND THE POTENTIAL FOR VERTICAL GROUND WATER LEAKAGE ALONG
SUCH FEATURES.

TITLE: RECONNAISSANCE INVESTIGATION OF GROUND WATER IN THE RIO GRANDE DRAINAGE
BASIN, WITH SPECIAL EMPHASIS IN SALINE GROUND-WATER RESOURCES
AUTHOR: KELLY, T.E.
PUBLICATION DATE (YY/MM): 1974
ABSTRACT OR COMMENTS: THIS STUDY MAY BE OF PRIMARY IMPORTANCE IN ASSESSING THE
POTENTIAL FOR HIGH SALINITY FROM THE AQUIFERS UNDER CONSIDERATION IN THE
PRESENT STUDY.

TITLE: CHEMISTRY OF SILICA IN GROUND WATER OF THE SAN LUIS VALLEY, COLORADO
AUTHOR: KLEIN, J.M.
PUBLICATION DATE (YY/MM): 1976
ABSTRACT OR COMMENTS: MAY BE OF INTEREST WITH RESPECT TO THE CHEMISTRY OF
THERMAL WATERS AT DEPTH BENEATH THE SAN LUIS VALLEY.

TITLE: TECTONIC ANALYSIS OF THE RIO GRANDE RIFT ZONE, CENTRAL COLORADO
AUTHOR: KNEPPER, D. H., JR
PUBLICATION DATE (YY/MM): 1974
ABSTRACT OR COMMENTS: OF SECONDARY IMPORTANCE TO THE PRESENT STUDY. THIS IS
ONE OF MANY RECENT STUDIES ON THE TECTONICS AND REGIONAL STRUCTURE WHICH
CONTROLS THE BASINS WHICH COMprise THE RIO GRANDE RIFT; AS SUCH, IT MAY BE OF
INTEREST FOR GENERAL FAMILIARIZATION WITH THE STRUCTURE OF THE STUDY AREA.

TITLE: WATER USE BY NATIVE GRASSES IN HIGH ALTITUDE COLORADO MEADOWS
AUTHOR: KRUZE, E. G., H. R. HAISE.
PUBLICATION DATE (YY/MM): 1973
ABSTRACT OR COMMENTS: THIS PUBLICATION MAY BE OF USE IN FUTURE WATER-BALANCE
STUDIES OF THE SAN JUAN OR SANGRE DE CRISTO REGIONS WHICH BORDER THE SAN LUIS
VALLEY.
TITLE: FREQUENCY DOMAIN ANALYSIS OF LEAST-SQUARES POLYNOMIAL SURFACES WITH APPLICATION TO GRAVITY DATA IN THE PEDREGOSA BASIN, MEXICO
AUTHOR: LANCE, J. O., JR
PUBLICATION DATE (YY/MM): 1982
ABSTRACT OR COMMENTS: MAY BE USEFUL IN THE PRESENT STUDY WITH REGARD TO METHODS BY WHICH TO ANALYZE THE EXISTING GRAVITY-SURVEY DATA IN THE SAN LUIS VALLEY FOR STRUCTURAL FEATURES WHICH MAY AFFECT GROUND-WATER MOVEMENT WITHIN THE DEEPER CONFINED AQUIFER.

TITLE: GEOLOGY AND PETROLOGY OF THE SAN JUAN REGION, SOUTHWESTERN COLORADO
AUTHOR: LARSEN, E. S., W. CROSS
PUBLICATION DATE (YY/MM): 1956
ABSTRACT OR COMMENTS: THIS PAPER WAS THE FIRST TO MAP AND IDENTIFY MANY OF THE VOLCANIC AND VOLCANICLASTIC ROCKS OF THE SAN JUAN MOUNTAINS, WHICH ARE OF IMPORTANCE TO THE PRESENT STUDY DUE TO THE POTENTIAL FOR GROUND-WATER RECHARGE TO THE CONFINED AQUIFER OF THE SAN LUIS VALLEY. LATER WORK (LIPKAN ET AL, VARIOUS DATES) HAS TO SOME EXTENT SUPERSEDED THIS WORK.

TITLE: SIMULATED RESPONSE OF THE UNCONFINED AQUIFER TO PUMPAGE IN THE CLOSED BASIN DIVISION, SAN LUIS VALLEY, COLORADO
AUTHOR: LEONARD, G. J.
PUBLICATION DATE (YY/MM): 1986 (EXPECTED)
ABSTRACT OR COMMENTS: COMPLEMENTS THE EARLIER AND CONCURRENT USGS MODELING EFFORTS (EMERY ET AL, VARIOUS DATES, AND HEARNE AND DEWEY, IN PROGRESS).

TITLE: LATE CENOZOIC BASALTIC VOLCANISM AND DEVELOPMENT OF THE RIO GRANDE DEPRESSION IN THE SOUTHERN ROCKY MOUNTAINS
AUTHOR: LIPKAN, P. W., H. H. MEHNERT
PUBLICATION DATE (YY/MM): 1975

TITLE: VOLCANIC HISTORY OF THE SAN JUAN MOUNTAINS, COLORADO, AS INDICATED BY POTASSIUM-ARGON DATING
AUTHOR: LIPMAN, P. W., T. A. STEVEN, H. H. MEHNERT
PUBLICATION DATE (YY/MM): 1970
ABSTRACT OR COMMENTS: MAY BE OF SECONDARY USE TO THE PRESENT STUDY, WITH REGARD TO THE STRATIGRAPHIC RELATIONSHIPS OF THE MANY VOLCANIC-ROCK FORMATIONS WHICH COMPOSE THE SAN JUAN MOUNTAINS.
TITLE: GEOLOGY OF SUMMER COON VOLCANIC CENTER, EASTERN SAN JUAN MOUNTAINS, CO
AUTHOR: LIPMAN, P.W.
PUBLICATION DATE (YY/MM): 1968
ABSTRACT OR COMMENTS: EXPLAINS THE GENESIS OF THE CONEJOS FORMATION VOLCANICS AND VOLCANICLASTIC DEPOSITS, WHICH ARE OF INTEREST TO THE PRESENT STUDY WITH REGARD TO THE RECHARGE POTENTIAL TO THE CONFINED AQUIFER.

TITLE: TWO-DIMENSIONAL FINITE-DIFFERENCE MODEL DEVELOPED FOR THE CLOSED-BASIN AREA OF SAN LUIS VALLEY
AUTHOR: LONQVIST, C.J.
PUBLICATION DATE (YY/MM): 1978
ABSTRACT OR COMMENTS: THIS PAPER IS OF PRIMARY INTEREST WITH REGARD TO THE GROUND WATER HYDROLOGY OF THE CLOSED-BASIN AREA. COMPLEMENTARY TO U.S. BUREAU OF RECLAMATION CLOSED BASIN REPORTS (VARIOUS DATES).

TITLE: MAGNETOTELLURIC INVESTIGATION IN THE SAN LUIS VALLEY, COLORADO
AUTHOR: NDALA, C.L.
PUBLICATION DATE (YY/MM): 1980
ABSTRACT OR COMMENTS: THIS THESIS PRESENTS INTERPRETATIONS OF THE GEOTHERMAL POTENTIAL OF THE NORTHERN SAN LUIS VALLEY, FROM MAGNETOTELLURIC SOUNDING INVESTIGATIONS IN THE AREA. MAY BE OF SECONDARY USE IN DELINEATING DEEP STRUCTURE IN THE DEEP CONFINED AQUIFER.

TITLE: COMPARISON BETWEEN COCORP AND MAGNETOTELLURIC PROFILING ACROSS THE CENTRAL RIO GRANDE RIFT
AUTHOR: MITCHELL, P. S., G. R. JIRACEK, R. REDDIG
PUBLICATION DATE (YY/MM): 1983
ABSTRACT OR COMMENTS: THIS ARTICLE MAY BE OF INTEREST WITH REGARD TO CORRELATION OF THE SEISMIC DATA AND THE MAGNETOTELLURIC DATA WHICH HAVE BEEN ACQUIRED IN THE SAN LUIS VALLEY.

TITLE: THE GEOLOGY OF THE TRACY CANYON AREA, SAGUACHE COUNTY, COLORADO
AUTHOR: NEWMAN, J.W.
PUBLICATION DATE (YY/MM): 1976
ABSTRACT OR COMMENTS: MAY BE OF SECONDARY IMPORTANCE WITH REGARD TO THE GROUNDWATER RECHARGE POTENTIAL OF THE VOLCANIC UNITS IN THE TOPOGRAPHICALLY HIGH AREAS OF THE EASTERN SAN JUAN MOUNTAINS.
TITLE: EVALUATION OF STREAMFLOW DEPLETION, CONEJOS RIVER BASIN, SOUTH-CENTRAL COLORADO
AUTHOR: NICKERSON, E. L.
PUBLICATION DATE (YY/MM): 1986 (EXPECTED)
ABSTRACT OR COMMENTS: THIS USGS REPORT (PRESENTLY AVAILABLE ONLY IN DRAFT FORM) PRESENTS DISCUSSION OF INFERENCE MADE REGARDING THE GAIN/LOSS MECHANISMS OF THE CONEJOS RIVER. SEVERAL CRITICAL REVIEWS OF THIS DRAFT REPORT ALSO HAVE BEEN MADE.

TITLE: USE OF HYDROGEOLOGY, GEOCHEMISTRY, AND GEOTHERMOMETER MODELS IN RECONNAISSANCE EXPLORATION FOR A HYDROGEOTHERMAL RESOURCE
AUTHOR: PEARL, R. H., J. K. BARRETT
PUBLICATION DATE (YY/MM): 1977
ABSTRACT OR COMMENTS: DISCUSSES VARIOUS ATTEMPTS TO DEFINE THE POTENTIAL FOR ECONOMIC GEOTHERMAL RESOURCES IN THE RIO GRANDE RIFT. USEFUL IN EVALUATING THE EFFECTIVENESS OF VARIOUS WATER-CHEMISTRY GEOTHERMOMETER TECHNIQUES FOR EVALUATION OF THE GROUND-WATER TEMPERATURES WITHIN THE DEEPER CONFINED AQUIFER.

TITLE: PROCEEDINGS OF THE SYMPOSIUM ON GEOTHERMAL ENERGY AND COLORADO
AUTHOR: PEARL, R. H.
PUBLICATION DATE (YY/MM): 1974b
ABSTRACT OR COMMENTS: A GENERAL SYMPOSIUM ON THE GEOTHERMAL ENERGY POTENTIAL AND UTILIZATION IN THE STATE OF COLORADO. OF INDIRECT INTEREST TO THE PRESENT STUDY. MAY BE OF GENERAL INTEREST AS A COMPARISON PAPER WITH RESPECT TO THE GEOTHERMAL POTENTIAL OF THE STUDY AREA VERSUS OTHER PARTS OF THE STATE OF COLORADO.

TITLE: GEOTHERMAL RESOURCES OF THE UPPER SAN LUIS AND ARKANSAS VALLEYS, CO
AUTHOR: PEARL, R. H., J. K. BARRETT
PUBLICATION DATE (YY/MM): 1976
ABSTRACT OR COMMENTS: A FAIRLY GENERAL AND BRIEF PAPER ON THE GEOTHERMAL POTENTIAL AND EXISTING THERMAL SPRINGS OF THE SAN LUIS VALLEY.

TITLE: A MAGNETOTELLURIC INVESTIGATION OF THE DEEP ELECTRICAL STRUCTURE OF THE RIO GRANDE RIFT AND ADJACENT TECTONIC PROVINCES
AUTHOR: PEDERSEN, J.
PUBLICATION DATE (YY/MM): 1980
ABSTRACT OR COMMENTS: MAY BE OF SECONDARY USE IN THE PRESENT STUDY, WITH REGARD TO COMPARISON WITH SIMILAR GEOPHYSICAL SURVEYS IN THE SAN LUIS VALLEY, TO DEFINE THE DEEPER STRUCTURAL FEATURES OF THE BASIN.
TITLE: FINAL REPORT, GEOTHERMAL EXPLORATION WELL FOR THE CITY OF ALAMOSA
AUTHOR: PHETTEPLACE, D., AND KUNIE, J.
PUBLICATION DATE (YY/MM): 1983
ABSTRACT OR COMMENTS: THIS REPORT IS OF USE TO THE PRESENT STUDY WITH REGARD TO POTENTIAL DRILLING AND WELL-COMPLETION PROBLEMS WHICH CAN ARISE IN THE GEOLOGIC ENVIRONMENT OF THE DEEPER CONFINED AQUIFER OF THE SAN LUIS VALLEY.

TITLE: GROUND-WATER RESOURCES ON THE SAN LUIS VALLEY, COLORADO
AUTHOR: POWELL, W. J.
PUBLICATION DATE (YY/MM): 1958

TITLE: SAN LUIS VALLEY WATER PROBLEMS: A LEGAL PERSPECTIVE
AUTHOR: RADOSEVICH, G. E., R. W. RUTZ
PUBLICATION DATE (YY/MM): 1979
ABSTRACT OR COMMENTS: PROVIDES AN OVERVIEW OF THE WATER USE ADMINISTRATION IN THE SAN LUIS VALLEY. THIS IS A GOOD COMPANION PAPER TO BURROUGHS AND MC FADDEN (1976).

TITLE: GROUND WATER IN THE SAN LUIS VALLEY, COLORADO; A CONTRIBUTION TO THE RIO GRANDE JOINT INVESTIGATION
AUTHOR: ROBINSON, T. W., AND H. A. WAITE
PUBLICATION DATE (YY/MM): 1938

TITLE: GEOTHERMAL RESOURCES OF SOUTH CENTRAL COLORADO AND THEIR RELATIONSHIP TO GROUND AND SURFACE WATERS
AUTHOR: ROMERO, J., D. FAWCETT
PUBLICATION DATE (YY/MM): 1978
ABSTRACT OR COMMENTS: THIS PAPER IS OF INTEREST TO THE STUDY OF GEOTHERMAL POTENTIAL OF THE PRESENT STUDY AREA. COMPLEMENTARY TO PEARL ET AL (VARIOUS DATES).
TITLE: AN INTEGRATED GEOPHYSICAL STUDY OF THE WEST-CENTRAL PART OF THE SAN LUIS VALLEY, COLORADO
AUTHOR: SANTIAGO, R.S.
PUBLICATION DATE (YY/MM): 1983
ABSTRACT OR COMMENTS: THIS THESIS WORK PRESENTS INTERPRETATIONS OF SEISMIC WORK CONDUCTED IN THE DEL NORTE-CENTER-MONTE VISTA AREA. THE INTERPRETATIONS, AND THE SEISMIC SECTIONS, ARE OF CONSIDERABLE VALUE TO THE PRESENT STUDY WITH REGARD TO THE HYDROSTRATIGRAPHY OF THE DEEP CONFINED AQUIFER IN THE MONTE VISTA GRABEN.

TITLE: GEOLOGY AND WATER RESOURCES OF THE SAN LUIS VALLEY, COLORADO
AUTHOR: SIEBENTHAL, C. E.
PUBLICATION DATE (YY/MM): 1910a
ABSTRACT OR COMMENTS: THIS LANDMARK PAPER WAS THE FIRST RELATIVELY COMPLETE INVENTORY OF WATER USE AND WELLS IN THE SAN LUIS VALLEY. THE AUTHOR ALSO PROPOUNDED SEVERAL IDEAS REGARDING THE SOURCE MECHANISMS FOR THE ARTESIAN FLOW IN THE VALLEY, WHICH STILL HAVE MERIT. THIS IS CONSIDERED AN ESSENTIAL REFERENCE WORK FOR THE PRESENT STUDY.

TITLE: WATER LOGGING CONTROL FOR IMPROVED WATER AND LAND USE EFFICIENCIES: A SYSTEMATIC ANALYSIS
AUTHOR: SIMPSON, MOREL-SEYTOUX, R. A. YOUNG, B.E. RADOSEVICH, W.T. FRANKLIN.
PUBLICATION DATE (YY/MM): 1980
ABSTRACT OR COMMENTS: OF INTEREST FROM A SALINITY-CONTROL AND ECONOMIC-ANALYSIS STANDPOINT.

TITLE: COSTS AND RETURNS AND PROFITABILITY ANALYSIS FOR SAN LUIS VALLEY, COLORADO
AUTHOR: SKAGGS, R.K.
PUBLICATION DATE (YY/MM): 1985
ABSTRACT OR COMMENTS: THIS STUDY IS OF INTEREST TO THE PRESENT STUDY, WITH REGARD TO THE ECONOMIC ANALYSES AND THE ABILITY-TO-PAY EVALUATIONS AND WITH RESPECT TO THE PRESENT AGRICULTURAL ECONOMIC BASE OF THE SOUTHERN SAN LUIS VALLEY.

TITLE: IMPACT OF INCREASING STREAMFLOW IN THE RIO GRANDE RIVER
AUTHOR: STEFFEN, ROBERTSON AND KIRSTEN, INC.
PUBLICATION DATE (YY/MM): 1985
ABSTRACT OR COMMENTS: THIS REPORT IS OF IMPORTANCE TO THE PRESENT STUDY, WITH REGARD TO THE WATER DEMAND/ECONOMIC ANALYSIS OF THE EFFECTS OF AN INCREASED SUPPLY OF WATER WITH WHICH TO BUFFER THE DEMANDS OF THE RIO GRANDE COMPACT AND IRRIGATION WATER USERS OF THE SAN LUIS VALLEY.
TITLE: INTERPRETATION OF SEISMIC REFLECTION DATA FROM THE SAN LUIS VALLEY, SOUTH-CENTRAL COLORADO
AUTHOR: STOUGHTON, D.
PUBLICATION DATE (YY/MM): 1977
ABSTRACT OR COMMENTS: THIS THESIS PRESENTS INTERPRETATIONS OF SEVERAL SEISMIC REFLECTION GEOPHYSICAL SURVEYS, CONDUCTED IN THE NORTHERN SAN LUIS VALLEY, AND IN THE SAN LUIS LAKES AREA. THIS STUDY MAY BE OF PRIMARY INTEREST IN DEFINING THE HYDROSTRATIGRAPHY OF THE DEEPER CONFINED AQUIFER IN THESE AREAS.

TITLE: ARTIFICIAL GROUNDWATER RECHARGE, SAN LUIS VALLEY, COLORADO
AUTHOR: SUNADA, D. K., J. W. WARNER, D. J. MOLDEN
PUBLICATION DATE (YY/MM): 1983
ABSTRACT OR COMMENTS: MAY BE OF INTEREST WITH REGARD TO THE POTENTIAL FOR GROUND-WATER RECHARGE IN THE CENTRAL SAN LUIS VALLEY, AND WITH REGARD TO THE PHYSICAL CHARACTERISTICS OF THE UNCONFINED AQUIFER IN THE STUDY AREA.

TITLE: REGIONAL GROUNDWATER CHEMISTRY STUDIES IN THE RIO GRANDE RIFT AND ADJACENT TECTONIC PROVINCES
AUTHOR: SWANBERG, C. A., G. H. STOYER
PUBLICATION DATE (YY/MM): 1976
ABSTRACT OR COMMENTS: GOOD COMPILATION OF THE STUDIES RELATING TO GROUND-WATER CHEMISTRY IN THE AREA UNDER PRESENT STUDY.

TITLE: GEOTHERMAL HYDROLOGY IN THE RIO GRANDE RIFT, NORTH-CENTRAL NEW MEXICO
AUTHOR: TRAINER, F.W., AND LYFORD, F.P.
PUBLICATION DATE (YY/MM): 1979
ABSTRACT OR COMMENTS: THIS ARTICLE IS OF INTEREST WITH REGARD TO THE SIMILARITY BETWEEN THE DEEP GROUND-WATER CIRCULATION SYSTEMS OF THE SAN LUIS VALLEY AND OTHER PARTS OF THE RIO GRANDE RIFT SYSTEM TO THE SOUTH.

TITLE: PLAN OF STUDY, RIO GRANDE AND TRIBUTARIES, WATER CONSERVATION/MANAGEMENT
AUTHOR: U.S. ARMY CORPS OF ENGINEERS
PUBLICATION DATE (YY/MM): 1983
ABSTRACT OR COMMENTS: THIS REPORT IS OF INTEREST FROM THE STANDPOINT OF LARGE-SCALE INTEREST OF VARIOUS GOVERNMENTAL AGENCIES TO THE PRESENT STUDY, AND THE IMPACTS OF THE RESULTS OF THE PRESENT STUDY ON THE OVERALL UPPER RIO GRANDE BASIN WATER USE.
TITLE: SAN LUIS VALLEY PROJECT - COLORADO CLOSED BASIN DIVISION, FACTS AND CONCEPTS
AUTHOR: U.S. BUREAU OF RECLAMATION
PUBLICATION DATE (YY/MM): 1984
ABSTRACT OR COMMENTS: THIS IS A GENERAL OVERVIEW OF THE CONCEPTS AND RATIONALE OF THE SAN LUIS VALLEY CLOSED-BASIN WATER SALVAGE-PROJECT.

TITLE: FINAL ENVIRONMENTAL STATEMENT, SAN LUIS VALLEY PROJECT- CLOSED BASIN DIVISION
AUTHOR: U.S. BUREAU OF RECLAMATION
PUBLICATION DATE (YY/MM): 1982
ABSTRACT OR COMMENTS: OF INTEREST TO THE PRESENT STUDY, WITH REGARD TO THE EVAPOTRANSPIRATION AND SYNTHETIC DRAINAGE FRACTIONS OF THE WATER BALANCE IN THE CLOSED BASIN PART OF THE SAN LUIS VALLEY.

TITLE: IRRIGATION WATER MANAGEMENT STUDY OF THE SAN LUIS VALLEY, COLORADO
AUTHOR: U.S. DEPARTMENT OF AGRICULTURE
PUBLICATION DATE (YY/MM): 1969
ABSTRACT OR COMMENTS: THIS REPORT IS OF INTEREST AS A COMPLEMENTARY STUDY TO SIMILAR, MORE RECENT EFFORTS (COLORADO WATER RESOURCES RESEARCH INSTITUTE, VARIOUS DATES).

TITLE: INTERPRETATION OF SEISMIC REFLECTION DATA FROM THE SOUTHERN SAN LUIS VALLEY
AUTHOR: UIUTTI, P.
PUBLICATION DATE (YY/MM): 1980
ABSTRACT OR COMMENTS: THIS THESIS IS OF SECONDARY IMPORTANCE TO THE PRESENT STUDY, FROM THE STANDPOINT OF STRATIGRAPHIC CORRELATION OF THE FORMATIONS WITHIN THE DEEPER CONFINED AQUIFER, TO THE SOUTH INTO COSTILLA AND CONEJOS COUNTIES.

TITLE: PHYSIOGRAPHIC SUBDIVISIONS OF THE SAN LUIS VALLEY, SOUTHERN COLORADO
AUTHOR: UPSON, J.E.
PUBLICATION DATE (YY/MM): 1939
ABSTRACT OR COMMENTS: THIS PAPER IS USEFUL TO GIVE AN UNDERSTANDING OF THE GENERAL PHYSIOGRAPHIC PROVINCES WHICH COMPRISSE THE SAN LUIS BASIN. IT IS CONSIDERED ESSENTIAL READING FOR AN UNDERSTANDING OF THE GENERAL SETTING OF THE STUDY AREA FOR THE PRESENT STUDY. THIS ARTICLE WAS REPRINTED IN THE NEW MEXICO GEOLOGICAL SOCIETY'S 1971 FIELD CONFERENCE GUIDEBOOK ON THE SAN LUIS BASIN.

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TITLE: SUMMARY APPRAISALS OF THE NATIONS GROUND-WATER RESOURCES-RIO GRANDE REGION
AUTHOR: WEST, S.W., AND W.L. BROADHURST
PUBLICATION DATE (YY/MM): 1975
ABSTRACT OR COMMENTS: THIS REPORT PROVIDES A GENERAL OVERVIEW OF THE HYDROLOGY OF THE UPPER RIO GRANDE BASIN, WITH PARTICULAR REGARD TO THE GROUND-WATER SUPPLY AVAILABILITY AND ADMINISTRATION.

TITLE: EVALUATION OF GROUND-AND SPRING-WATER QUALITY DATA IN THE SAN LUIS BASIN, COLORADO AND NEW MEXICO
AUTHOR: WILLIAMS, R.S., JR., AND HAMMOND, S.E.
PUBLICATION DATE (YY/MM): 1986 (EXPECTED)
ABSTRACT OR COMMENTS: OF USE IN THE PRESENT STUDY FROM THE STANDPOINT OF EVALUATING THE CHEMICAL CHARACTERISTICS OF SELECTED WELLS AND SPRINGS IN THE SAN LUIS VALLEY.

TITLE: GROUND WATER CONDITIONS AND GEOLOGY OF SUNSHINE VALLEY AND WESTERN TAOS COUNTY, NEW MEXICO
AUTHOR: WINograd, I.J.
PUBLICATION DATE (YY/MM): 1959
ABSTRACT OR COMMENTS: THIS STUDY IS OF IMPORTANCE TO THE PRESENT STUDY, FROM THE STANDPOINT OF THE POTENTIALISTIC SURFACE IN AN AREA WHICH MAY BE CONSIDERED CONTIGUOUS TO THE AQUIFERS UNDER CONSIDERATION IN THE SAN LUIS VALLEY. IN ADDITION, THIS REPORT CONTAINS INFORMATION ON THE HYDROLOGIC PROPERTIES OF THE VOLCANIC AND INTERVOLCANIC UNITS OF THE TAOS PLATEAU.

TITLE: TECTONICS OF CENTRAL-NORTHERN NEW MEXICO
AUTHOR: WOODWARD, L. A.
PUBLICATION DATE (YY/MM): 1974
ABSTRACT OR COMMENTS: THIS ARTICLE MAY BE OF SECONDARY IMPORTANCE TO THE PRESENT STUDY, WITH REGARD TO THE HYDROGEOLOGIC EFFECTS OF THE FAULTING WITHIN THE DEEP CONFINED AQUIFER.

TITLE: GEOLOGY OF THE HAYDEN PASS-ORIENT MINE AREA, NORTHERN SANGRE DE CRISTO MOUNTAINS, COLORADO-- A GEOLOGIC REMOTE-SENSING INVESTIGATION
AUTHOR: WYCHRAM, D.C.
PUBLICATION DATE (YY/MM): 1972
ABSTRACT OR COMMENTS: OF SECONDARY INTEREST TO THE PRESENT STUDY, WITH RESPECT TO COMPARISON OF THE EFFECTIVENESS OF VARIOUS FORMS OF REMOTE-SENSING ANALYSES FOR USE ON THE STUDY AREA.
TITLE: GEOTHERMAL RESOURCE ASSESSMENT OF WESTERN SAN LUIS VALLEY, COLORADO
AUTHOR: ZACHARAKIS, T.S., R.H. PEARL, AND C.D. RINGROSE
PUBLICATION DATE (YY/MM): 1983
ABSTRACT OR COMMENTS: THIS REPORT HAS USEFUL INFORMATION REGARDING THE THERMAL
WATERS OF THE MONTE VISTA GRABEN AREA, PARTICULARLY THE SHAW WARM SPRINGS AREA.
IT INCLUDES RESULTS OF SOME OF THE COLORADO SCHOOL OF MINES GEOPHYSICAL STUDIES
OF THIS AREA.


Ander, M. E., 1981b. Structural Relationship Between a Northeast-Trending Precambrian Shear System and a Mafic Intrusion Beneath the Lucero Uplift, New Mexico. Transactions, American Geophysical Union, Fall Meeting.


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No. 22, pp. 73-77.

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Fort Garland to Romeo, via San Luis, San Acacio and Manessa.
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Mexico, 2 Sheets, Scale 1:250,000.

Newman, J. W., 1976. The Geology of the Tracy Canyon Area,
State University.

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APPENDIX B

Confined-Aquifer Water-Quality Data
Table of Contents

Core Laboratories, Inc. Analytical Report

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| Table B.2 | Chemical Analyses from Selected Wells in the Closed Basin, San Luis Valley, Colorado | B-1 |
### TABLE B.1

**CHEMICAL ANALYSES OF WATER FROM SELECTED WELLS IN THE CLOSED BASIN, SAN LUIS VALLEY, COLORADO**

**SELECTED WATER QUALITY DATA FROM**

*Emery, et al., 1972,* and *Edelmann and Buckles, 1983*

**WELLS > 2000 FT DEEP**

<table>
<thead>
<tr>
<th>WELL LOCATION</th>
<th>SPECIFIC PERFORMANCE DATA</th>
<th>DEPTH (ft)</th>
<th>COLLECTION (deg C)</th>
<th>Ca (ppm)</th>
<th>Mg (ppm)</th>
<th>Na (ppm)</th>
<th>K (ppm)</th>
<th>COND. (μS/cm)</th>
<th>HCO₃ (ppm)</th>
<th>CO₃ (ppm)</th>
<th>SO₄ (ppm)</th>
<th>CI (ppm)</th>
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<th>pH (ppm)</th>
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**SELECTED WATER QUALITY DATA FROM**

*WATSTORE*

**WELLS > 2000 FT DEEP**

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<tr>
<th>WELL LOCATION</th>
<th>SPECIFIC PERFORMANCE DATA</th>
<th>DEPTH (ft)</th>
<th>COLLECTION (deg C)</th>
<th>Ca (ppm)</th>
<th>Mg (ppm)</th>
<th>Na (ppm)</th>
<th>K (ppm)</th>
<th>COND. (μS/cm)</th>
<th>HCO₃ (ppm)</th>
<th>CO₃ (ppm)</th>
<th>SO₄ (ppm)</th>
<th>CI (ppm)</th>
<th>FIELD TDS (ppm)</th>
<th>pH (ppm)</th>
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<td>07/18/68</td>
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<td>77</td>
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<td>135</td>
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*NOTE:* These wells appear in at least two of the following sources: *WATSTORE, Emery et al., 1972,* or *Edelmann and Buckles, 1983*

B-1
Core Laboratories, Inc.
Analytical Report

W86506

HRS Water Consultants

These analyses, opinions or interpretations are based on observations and material supplied by the client to whom, and for whose exclusive and confidential use, this report is made. The interpretations or opinions expressed represent the best judgment of Core Laboratories, Inc. (all errors and omissions excepted); but Core Laboratories, Inc. and its officers and employees, assume no responsibility and make no warranty or representations, as to the productivity, proper operations, or profitableness of any oil, gas, coal or other mineral property, well or sand in connection with which such report is used or relied upon.
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RESULTS OF WATER QUALITY ANALYSIS  
ON SAMPLES COLLECTED AT LOCATION:

<table>
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<th>JOB NO.</th>
<th>SAMPLE ID</th>
<th>GEO. WELL</th>
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<th>DATE/TIME RECEIVED</th>
<th>DATE/TIME ANALYZED</th>
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<td>KENNEDY</td>
<td>06-30-86/1000</td>
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<td>6307-4</td>
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</table>

CHEMIST: RIF/DRH  
LOCATION: AURORA, CO

--ALL VALUES REPORTED ON A TOTAL BASIS (MG./L.) UNLESS INDICATED OTHERWISE

These analyses, opinions or interpretations are based on observations and material supplied by the client to whom, and for whose exclusive and confidential use, this report is made. The interpretations or opinions expressed represent the best judgment of Core Laboratories, Inc. (all errors and omissions excepted); but Core Laboratories, Inc. and its officers and employees, assume no responsibility and make no warranty or representations, as to the productivity, proper operations, or profitableness of any oil, gas, coal or other mineral, property, well or sand in connection with which such report is used or relied upon.
**CORE LABORATORIES, INC.**  
**ANALYTICAL REPORT**

17-JULY-86

### RESULTS OF WATER QUALITY ANALYSIS
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<td>WELL</td>
<td>2745-F</td>
</tr>
<tr>
<td>W86506 - 3</td>
<td>WELL CARR-</td>
<td>KENNEDY</td>
</tr>
<tr>
<td>W86506 - 4</td>
<td>HOOPER</td>
<td>POOL WELL</td>
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</table>

#### MAJOR CATIONS

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<th>Sample 3</th>
<th>Sample 4</th>
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<tbody>
<tr>
<td>Calcium (Ca)</td>
<td>26 (1.30)</td>
<td>2.1 (0.10)</td>
<td>5.0 (0.25)</td>
<td>2.8 (0.14)</td>
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<td>Magnesium (Mg)</td>
<td>0.51 (0.04)</td>
<td>0.03 (0.00)</td>
<td>0.44 (0.04)</td>
<td>0.03 (0.00)</td>
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<td>Sodium (Na)</td>
<td>1910 (83.08)</td>
<td>120 (5.22)</td>
<td>82 (3.57)</td>
<td>84 (3.65)</td>
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<td>Potassium (K)</td>
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<td>4.1 (0.10)</td>
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<td>Sum of Major Cations (meq/l)</td>
<td>(84.74)</td>
<td>(5.39)</td>
<td>(3.96)</td>
<td>(3.94)</td>
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#### MAJOR ANIONS

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<td>Bicarbonate (HCO3)</td>
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<td>&lt;0.5 (0.00)</td>
<td>&lt;0.5 (0.00)</td>
<td>&lt;0.5 (0.00)</td>
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<tr>
<td>Sulfate (SO4)</td>
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<td>Chloride (Cl)</td>
<td>2400 (67.70)</td>
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<td>5.6 (0.16)</td>
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<td>(5.12)</td>
<td>(4.00)</td>
<td>(3.56)</td>
</tr>
</tbody>
</table>

*These analyses, opinions or interpretations are based on observations and material supplied by the client to whom, and for whose exclusive and confidential use, this report is made. The interpretations or opinions expressed represent the best judgment of Core Laboratories, Inc. (all errors and omissions excepted); but Core Laboratories, Inc. and its officers and employees, assume no responsibility and make no warranty or representations, as to the productivity, proper operations, or profitability of any oil, gas, coal or other mineral, property, well or sand in connection with which such report is used or relied upon.*
RESULTS OF WATER QUALITY ANALYSIS
ON SAMPLES COLLECTED AT LOCATION:

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<th>JOB NO.</th>
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<th>SAMPLE REMARKS</th>
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<td>ALAMOSA WELL</td>
<td>WB6506 - 2</td>
<td>WB6506 - 1</td>
<td>GEO, WELL 2745-F</td>
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GENERAL PARAMETERS—TOTAL BASIS

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<th>WB6506 - 3</th>
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<td>PHOSPHATE, TOTAL (PO4-P)</td>
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<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
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<td>FLUORIDE (F)</td>
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<td>10.9</td>
<td>1.5</td>
<td>6.8</td>
</tr>
</tbody>
</table>

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RESULTS OF WATER QUALITY ANALYSIS
ON SAMPLES COLLECTED AT LOCATION:

JOB NO. 6307-
SAMPLE ID:
SAMPLE REMARKS:

TOTAL METALS

SILICA (SiO2), total

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<td>WELL 2745-F</td>
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<td>HOOPER POOL WELL</td>
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<td>2</td>
<td>85</td>
<td>87</td>
<td>120</td>
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APPENDIX C

Ratios of Sand Thickness to Total Thickness
<table>
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<tr>
<th>Table C.1</th>
<th>Carr-Kennedy Williams Well #1</th>
<th>Page</th>
</tr>
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<tr>
<td>Table C.2</td>
<td>Orrin Tucker #1 Thomas</td>
<td>C-2</td>
</tr>
<tr>
<td>Table C.3</td>
<td>Tennessee Gas #1-B State</td>
<td>C-3</td>
</tr>
<tr>
<td>Table C.4</td>
<td>Milestone-AMF #1</td>
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<td>Table C.5</td>
<td>Reserve 1-38 NHB</td>
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<td>Table C.6</td>
<td>Amerada No. 1-F State</td>
<td>C-6</td>
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<tr>
<td>Table C.7</td>
<td>Amoco/Mapco No. 1-32</td>
<td>C-7</td>
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</tbody>
</table>
**TABLE C.1**

LOG NAME: CARR-KENNEDY WILLIAMS WELL #1  
WELL LOCATION: C, SW SEC. 11, T41N, R9E  
TYPE OF LOG USED FOR ANALYSIS: RESISTIVITY  
ANALYSIS BY: HRS WATER CONSULTANTS, INC.

<table>
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<th>SAND THICKNESS (FT)</th>
<th>FORMATION</th>
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<td>500-1000</td>
<td>273</td>
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<td>70</td>
<td>SANTA FE</td>
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<td>3500-4000</td>
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<td>4110-4350</td>
<td>228</td>
<td>FISH CANYON/CARPENTER RIDGE</td>
</tr>
<tr>
<td>4540-5230</td>
<td>87</td>
<td>CONEJOS</td>
</tr>
<tr>
<td>5230-6190</td>
<td>312</td>
<td>VALLEJO/BLANCA BASIN</td>
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</tbody>
</table>
TABLE C.2

LOG NAME: ORRIN TUCKER #1 THOMAS
WELL LOCATION: NE,NE,NE SEC. 13, T41N, R8E
TYPE OF LOG USED FOR ANALYSIS: RESISTIVITY
ANALYSIS BY: HRS WATER CONSULTANTS, INC.

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<thead>
<tr>
<th>DEPTH INTERVAL (FT)</th>
<th>SAND THICKNESS (FT)</th>
<th>FORMATION</th>
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<tbody>
<tr>
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<td>213</td>
<td>ALAMOSA</td>
</tr>
<tr>
<td>500-1000</td>
<td>392</td>
<td>ALAMOSA</td>
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<tr>
<td>1000-1500</td>
<td>381</td>
<td>LOS PINOS</td>
</tr>
<tr>
<td>1500-2000</td>
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<td>3000-3340</td>
<td>98</td>
<td>SANTA FE</td>
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<tr>
<td>3340-4020</td>
<td>545</td>
<td>FISH CANYON/CARPENTER RIDGE</td>
</tr>
<tr>
<td>4020-5190</td>
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<td>CONEJOS</td>
</tr>
<tr>
<td>5190-6190</td>
<td>320</td>
<td>VALLEJO/BLANCA BASIN</td>
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<tr>
<td>6190-6840</td>
<td>451</td>
<td>VALLEJO/BLANCA BASIN</td>
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<tr>
<td>6840-7560</td>
<td>278</td>
<td>VALLEJO/BLANCA BASIN</td>
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<tr>
<td>7560-8600</td>
<td>529</td>
<td>MANCOS SHALE</td>
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</table>
### TABLE C.3

**LOG NAME:** TENNESSEE GAS #1-B STATE  
**WELL LOCATION:** C,SW,SE SEC. 14, T41N, R7E  
**LOG TYPE USED FOR ANALYSIS:** RESISTIVITY  
**ANALYSIS BY:** HRS WATER CONSULTANTS, INC.

<table>
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<td>500-1000</td>
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<td>LOS PINOS/SANTA FE</td>
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<td>1000-1500</td>
<td>331</td>
<td>LOS PINOS/SANTA FE</td>
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<tr>
<td>1500-2020</td>
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<td>LOS PINOS/SANTA FE</td>
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<td>4400-5310</td>
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<td>5310-7055</td>
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<td>MANCOS SHALE</td>
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<td>8090-9100</td>
<td>297</td>
<td>SANGRE DE CRISTO</td>
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<tr>
<td>9100-10350</td>
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<td>SANGRE DE CRISTO</td>
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TABLE C.4

LOG NAME: MILESTONE - AMF #1
WELL LOCATION: NW,SE SEC. 20, T40N, R5E
TYPE OF LOG USED FOR ANALYSIS: RESISTIVITY
ANALYSIS BY: HRS WATER CONSULTANTS, INC.

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<th>Formation</th>
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<td>Conejos</td>
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<td>1940-3400</td>
<td>530</td>
<td>Conejos</td>
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<td>3400-4220</td>
<td>112</td>
<td>Conejos</td>
</tr>
<tr>
<td>4220-6190</td>
<td>1160</td>
<td>Vallejo/Blanco Basin</td>
</tr>
<tr>
<td>6190-7780</td>
<td>62</td>
<td>Mancos Shale</td>
</tr>
<tr>
<td>7780-8810</td>
<td>782</td>
<td>Intrusive</td>
</tr>
<tr>
<td>8810-9450</td>
<td>224</td>
<td>Mancos Shale</td>
</tr>
<tr>
<td>DEPTH INTERVAL (FT)</td>
<td>SAND THICKNESS (FT)</td>
<td>FORMATION</td>
</tr>
<tr>
<td>---------------------</td>
<td>---------------------</td>
<td>----------------------------</td>
</tr>
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<td>0-1550</td>
<td>117</td>
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<tr>
<td>1550-3660</td>
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<td>UPPER SANTA FE (?)</td>
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<td>3660-7002</td>
<td>1118</td>
<td>LOWER SANTA FE (?)</td>
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<td>Sand Thickness (ft)</td>
<td>Formation</td>
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<td>---------------------</td>
<td>---------------------</td>
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<td>0-800</td>
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<td>Alamosa</td>
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<td>800-2500</td>
<td>909</td>
<td>Los Pinos/Santa Fe</td>
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<tr>
<td>2500-2800</td>
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<td>Conejos (?)</td>
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<tr>
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<td>Conejos (?)</td>
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<tr>
<td>4100-6070</td>
<td>710</td>
<td>Vallejo/Blanco Basin (?)</td>
</tr>
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<td>DEPTH INTERVAL (FT)</td>
<td>SAND THICKNESS (FT)</td>
<td>FORMATION</td>
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<tr>
<td>---------------------</td>
<td>---------------------</td>
<td>----------------------------</td>
</tr>
<tr>
<td>0-1060</td>
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<td>ALAMOSA</td>
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<tr>
<td>1060-2500</td>
<td>904</td>
<td>SANTA FE</td>
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<tr>
<td>2500-4020</td>
<td>60</td>
<td>SANTA FE</td>
</tr>
<tr>
<td>4020-7981</td>
<td>198</td>
<td>VALLEJO/BLANCO BASIN (?)</td>
</tr>
</tbody>
</table>
APPENDIX D

Irrigated Acreages, Consumptive Use, and Irrigation Efficiencies in the San Luis Valley of Colorado
IRRIGATED ACREAGES, CONSUMPTIVE USE,
AND IRRIGATION EFFICIENCIES
IN THE SAN LUIS VALLEY
OF COLORADO
April 21, 1986

Mr. Peter Bodie
HRS Water Consultants, Inc.
Union Plaza Building
200 Union Blvd., Suite #400
Lakewood, CO 80228

Dear Sir:

Enclosed is a summary of irrigated, phreatophyte, and open-range acreages for the San Luis Valley. Also included is the consumptive use of the various crops and plant communities, as well as estimated irrigation efficiencies. There are many inconsistencies in the data which was available for the study, as you will note in the report. The data base is also very incomplete, especially with regard to consumptive use of non-crop vegetation and irrigation efficiencies. I believe the figures on total consumptive use are somewhat unrealistic. We are convinced that the greatest errors are in the consumptive use estimates for phreatophytes. There is also probably significant error in the consumptive use of irrigated pastures, as their use varies widely with irrigation water availability and water table depth. Estimates of phreatophyte acreages also vary by as much as 70,000 acres, depending on the criteria used and the data base.

It actually took much longer than we expected to compile the information, analyze it, and decide what values were more nearly correct. We could do a lot more work on phreatophytes and pasture grasses to improve the estimates; however, this would take several weeks to accomplish. We would need to study water availability records and water table elevations. Some ground truthing and aerial observations would be required.

We are looking forward to your comments on the report. If we can be of any further assistance, please let us know. Thank you.

Sincerely,

LeRoy J. Salazar, P. E.
Agricultural Engineer

LJS/nb
Enclosures
A summary of crop acreages, estimated consumptive use, and irrigation efficiencies is attached as Tables I-A through I-F.

In developing estimates of irrigated acreages, various S.C.S. and A.S.C.S. offices and extension service personnel were consulted and many documents were reviewed.

Crop acreages are probably quite close to the actual. Acreages of major crops (small grains, potatoes, and alfalfa) are from the Colorado Agricultural Statistics. Appendix A has a summary discussion of crop acreages and trends. Vegetable acres were estimated from verbal communication with A.S.C.S. personnel, as there were no readily available statistics for the Valley.

Irrigated pasture was much more difficult to determine. Estimates range from 189,400 acres to 247,859 acres. The actual acreage is probably somewhere between the two figures. Irrigated pasture acreages from a 1978 report entitled, "Water and Related Land Resources, Rio Grande Basin", is 207,775 acres, and more recently estimated acreages (S.C.S. Multiyear Plan, 1982, or revisions), as indicated in Appendix A, are about 247,859 acres. To obtain actual irrigated pasture acreages would require a very time consuming review of aerial photos, as well as significant ground truthing to determine whether some areas were actually irrigated, or received their water supply from a high water table.

The acreages of phreatophytes and wetlands are considered to be those areas as described in Appendix C with shallow water tables generally less than 6 feet, and include salt flats, salt meadows, alkali overflows, wet meadows, and mountain meadows. These were also difficult to establish. The actual amount of these areas which are not cropped is probably between 320,000 and 400,000 acres. A final estimate of 338,000 acres was used. A discussion of these acreages is presented in Appendix C, as is the summary of rangeland.

The consumptive use, or evapotranspiration (ET), estimates for each crop (Appendix B) are averages of different varieties. For example, the ET for Centennial and Russet Burbank potatoes may be more than an inch different, as may be the difference between Moravian barley and Steptoe barley.

The equation for grain reference ET or ETo calibrated for the San Luis Valley is as follows:

\[ ETo = F \times T^\circ f \times RS \]

where F is a factor depending on wind (.008 to .009), \( T^\circ f \) is the average temperature for a period in \(^\circ f\), and RS is the solar radiation in appropriate units.
We have solar radiation measurements for five years, but have estimated long-term Rs by calibrating an equation for the San Luis Valley of the type that George Hargreaves of Utah State University has used successfully in many places throughout the world. The equation is:

$$Rs = K_t \times T_d^{1/2} \times Ra$$

where $K_t$ is calibrated from known Rs and Ra values (i.e. values which we have measured since 1980), $T_d$ is the difference between average daily maximum and minimum temperatures for the period under consideration, and Ra is the extraterrestrial solar radiation.

The crop coefficients are FAO (1977) type coefficients with values which have provided excellent results for irrigation scheduling in the San Luis Valley. The length of growth stages have been developed from field observations in our six years in the Valley.

Based on our close monitoring of potato, grain, and alfalfa fields, as well as recent lysimeter studies which are nearing completion, we are quite confident in our values for these crops. Pasture grasses provide a much greater challenge, since these are seldom maintained at optimum conditions. Measurements of water use by grasses with high water tables in the San Luis Valley have historically ranged from 17.9 inches to 32.4 inches. We feel that 25 inches (with water tables at less than two feet) is a good estimate for wetland conditions. However much of the irrigated pasture is irrigated with highly unreliable, low priority water rights on soils with little or no contribution from shallow groundwater. These pastures may get no irrigations in low water years, and one to two irrigations during the season in most years. In this case, ET is limited to the available water which these soils may hold, along with any effective rainfall. A water supply from May until late June or early July will mean that the grasslands can provide a hay crop, even where water tables are not high. However, usually between irrigation and effective rainfall, approximately 15 inches are required before grass can be cut for hay.

The ET estimates for irrigated pasturelands by county are based only on a general knowledge of maximum possible ET, water table elevations and water supply. For example, more than half of the area in Conejos County gets less than .94 acre-feet per acre per year. Part of this area, though, does have a high water table. Thus, water use may vary from perhaps 8 inches (including contribution of effective precipitation) where only flood water is available, to 25 inches where water tables are near the surface. A high judgement factor has entered into these estimates. A more refined estimate could be obtained by analyzing water supply, water table depths, rooting depths, textures, etc. However, this would probably take several weeks, and the data base may be incomplete.

Water tables have varied significantly over the last several years. Thus, vegetation and water use in areas with high water tables
have tended to change. The soil surveys and water table surveys used may not be quite accurate, but they did assist us in estimating those areas with significant groundwater contribution.

We have included estimates of phreatophyte water use, but feel uncomfortable with these estimates. The water use by phreatophytes is greatly dependent on plant densities and depth to water table. Hopefully, ARS Bureau of Reclamation efforts will yield some useful results by this Fall. Accurate estimates of water table depths, vegetation distribution, and soil textures would be required to improve our estimates. The effort would consume much more time than we were allotted.

We feel that the estimated values for phreatophyte use and pastures are almost impossibly high. Even subtracting effective precipitation from ET estimates gives us over a million acre-feet of water supply from irrigation needed to meet crop and phreatophyte ET. This is less than is available from mountain runoff after subtracting compact curtailments.

Irrigation efficiencies vary from crop to crop, depending primarily on irrigation method, soil type, and crop type. We have measured surface irrigation efficiencies as low as 20%, and sprinkler efficiencies as high as 90%. However, Valley average sprinkler efficiencies are approximately 65%, and controlled surface irrigation (border and furrows) efficiencies are about 40%. Wild flooding can produce irrigation efficiencies of 30% and lower. This may not be a true measure of efficiency, though, as subwater is built up so that it supplies the plant needs later in the season. Also, where the water supply is short, the high moisture storage capacity of the soil at the time of irrigation does offset the typically low efficiencies associated with wild flood irrigation.

I have estimated irrigation efficiencies based on our general knowledge of the crop type and irrigation method. We are quite confident in our estimates of efficiencies except in the case of pasture grasses, where efficiencies may range from 20% to over 50%.

Government programs, farm economics, problems with water supply, etc., have resulted in several thousand irrigable acres not being farmed in the Valley. A.S.C.S. personnel indicate that perhaps 17,000 acres per year have been set aside due to government programs in the past three years. Several thousand irrigable acres are not being farmed in the corners of center pivot fields due to the economics of irrigating these acres. This acreage could be twenty to thirty thousand acres. These areas would represent a potentially significant increase in irrigated acreage if the agricultural economy improves. Some of the decrease in surface irrigation of corners of fields has been made up by new land brought into production. An estimated 20,000 acres of sprinkler irrigation have been developed in lands not farmed previous to 1976, mostly in Saguache and Alamosa counties.
Table 1-A

ACREAGE, CONSUMPTIVE USE, IRRIGATION EFFICIENCIES

Rio Grande County

<table>
<thead>
<tr>
<th>Crop</th>
<th>Acreage</th>
<th>Yearly Consump. Use</th>
<th>Net Requirement</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potatoes</td>
<td>22,273</td>
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<td>29,697</td>
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<tr>
<td>Barley</td>
<td>31,255</td>
<td>16.8&quot;</td>
<td>43,757</td>
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<td>17.9&quot;</td>
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<tr>
<td>Oats (grain)</td>
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<td>Alfalfa</td>
<td>15,009</td>
<td>24.4&quot;</td>
<td>30,518</td>
<td>0.50</td>
</tr>
<tr>
<td>Other Hay</td>
<td>14,327</td>
<td>20.0&quot;</td>
<td>23,878</td>
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<tr>
<td>Vegetables</td>
<td>1,000</td>
<td>13.7&quot;</td>
<td>1,142</td>
<td>0.35</td>
</tr>
<tr>
<td>Grasses (pasture)</td>
<td>15,318</td>
<td>22.0&quot;</td>
<td>28,083</td>
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<td>TOTAL</td>
<td>110,372</td>
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<td>173,767</td>
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</tbody>
</table>

| Phreatophytes    | 22,000* | 20.4"               | 37,400          |            |
| Rangeland        | 21,237  | 7.1"                | 12,565          |            |

* Includes Monte Vista Wildlife Refuge and cottonwoods along the Rio Grande.
Table 1-B

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<th>Crop</th>
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<th>Net Requirement (acre-feet)</th>
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<td>Rangeland</td>
<td>304,550</td>
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<td>167,503</td>
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Table 1-C

**Alamosa County**

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<th>Yearly Consump. Use</th>
<th>Net Requirement</th>
<th>Efficiency</th>
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<td>5,153</td>
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<td>Oats (grain)</td>
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<td>17.9&quot;</td>
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<td>Alfalfa</td>
<td>27,227</td>
<td>24.4&quot;</td>
<td>55,362</td>
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<td>20.0&quot;</td>
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<tr>
<td>Grasses (pasture)</td>
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<td>110,730</td>
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<td>TOTALS</td>
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<td>232,551</td>
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<tr>
<td>Phreatophytes</td>
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<td>20.4&quot;</td>
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</tr>
<tr>
<td>Rangeland</td>
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<td>78,574</td>
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<tr>
<td>Crop</td>
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<td>Efficiency</td>
</tr>
<tr>
<td>-----------------</td>
<td>---------</td>
<td>--------------------</td>
<td>-----------------</td>
<td>------------</td>
</tr>
<tr>
<td>Potatoes</td>
<td>1,991</td>
<td>16.0&quot;</td>
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<tr>
<td>Barley</td>
<td>17,700</td>
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<tr>
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<td>17.9&quot;</td>
<td>3,322</td>
<td>0.50</td>
</tr>
<tr>
<td>Oats (grain)</td>
<td>3,236</td>
<td>17.9&quot;</td>
<td>4,827</td>
<td>0.50</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>40,273</td>
<td>24.4&quot;</td>
<td>81,888</td>
<td>0.50</td>
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<tr>
<td>Other Hay</td>
<td>28,218</td>
<td>20.0&quot;</td>
<td>47,030</td>
<td>0.40</td>
</tr>
<tr>
<td>Vegetables</td>
<td>640</td>
<td>13.7&quot;</td>
<td>731</td>
<td>0.35</td>
</tr>
<tr>
<td>Grasses (pasture)</td>
<td>53,429</td>
<td>15.0</td>
<td>66,786</td>
<td>0.40</td>
</tr>
<tr>
<td>TOTALS</td>
<td>147,714*</td>
<td></td>
<td>232,019</td>
<td></td>
</tr>
<tr>
<td>Phreatophytes</td>
<td>20,000</td>
<td>20.4&quot;</td>
<td>34,000</td>
<td></td>
</tr>
<tr>
<td>Rangeland</td>
<td>162,153</td>
<td>9.2&quot;</td>
<td>124,317</td>
<td></td>
</tr>
</tbody>
</table>

* A total of 147,714 acres are reportedly irrigated in Conejos County. Even though some of the alfalfa used as a rotation crop is supposedly not included under the irrigated pasture and hayland, apparently a majority of it is, as the irrigated acreage totals would be off by almost 40,000 acres. Thus, irrigated pasture is estimated as total irrigated acreage, minus all other crops acreages.
## Costilla County

<table>
<thead>
<tr>
<th>Crop</th>
<th>Acreage</th>
<th>Yearly Consump. Use</th>
<th>Net Requirement</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potatoes</td>
<td>2,391</td>
<td>16.0&quot;</td>
<td>3,188</td>
<td>0.60</td>
</tr>
<tr>
<td>Barley</td>
<td>7,155</td>
<td>16.8&quot;</td>
<td>10,017</td>
<td>0.55</td>
</tr>
<tr>
<td>Wheat</td>
<td>4,145</td>
<td>17.9&quot;</td>
<td>6,183</td>
<td>0.55</td>
</tr>
<tr>
<td>Oats (grain)</td>
<td>645</td>
<td>17.9&quot;</td>
<td>962</td>
<td>0.55</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>12,618</td>
<td>24.4&quot;</td>
<td>25,656</td>
<td>0.50</td>
</tr>
<tr>
<td>Other Hay</td>
<td>3,064</td>
<td>20.0&quot;</td>
<td>5,107</td>
<td>0.40</td>
</tr>
<tr>
<td>Vegetables</td>
<td>1,000</td>
<td>13.7&quot;</td>
<td>1,142</td>
<td>0.35</td>
</tr>
<tr>
<td>Grasses (pasture)</td>
<td>28,996</td>
<td>20.0&quot;</td>
<td>48,327</td>
<td>0.40</td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
<td><strong>60,014</strong></td>
<td></td>
<td><strong>100,582</strong></td>
<td></td>
</tr>
<tr>
<td>Phreatophytes</td>
<td>5,000</td>
<td>20.4&quot;</td>
<td>8,500</td>
<td></td>
</tr>
<tr>
<td>Rangeland</td>
<td>387,746</td>
<td>7.8&quot;</td>
<td>252,035</td>
<td></td>
</tr>
</tbody>
</table>
### Table 1-F

<table>
<thead>
<tr>
<th>Crop</th>
<th>Acreage</th>
<th>Yearly Consump. Use</th>
<th>Net Requirement</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potatoes</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barley</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wheat</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oats (grain)</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alfalfa</td>
<td>109</td>
<td>24.4&quot;</td>
<td>222</td>
<td>0.50</td>
</tr>
<tr>
<td>Other Hay</td>
<td>1,073</td>
<td>20.0&quot;</td>
<td>1,788</td>
<td>0.40</td>
</tr>
<tr>
<td>Vegetables</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grasses (pasture)</td>
<td>3,992</td>
<td>20.0&quot;</td>
<td>6,653</td>
<td>0.40</td>
</tr>
<tr>
<td>TOTALS</td>
<td>5,174</td>
<td></td>
<td>8,663</td>
<td></td>
</tr>
<tr>
<td>Phreatophytes</td>
<td>1,000</td>
<td>20.4&quot;</td>
<td>1,700</td>
<td></td>
</tr>
</tbody>
</table>

### SAN LUIS VALLEY SUMMARY

Total irrigated acreage ≈ 638,074 (in low water years, probably is as low as 500,000).

Total consumptive use from irrigation = 1,024,978 acre-feet.

Total phreatophyte acreage = 338,000.

Total phreatophyte consumption = 574,600.
APPENDIX A
CROP DISTRIBUTION AND TRENDS FOR THE SAN LUIS VALLEY

This section of the report will summarize in graphic form crop distribution (by counties) in the San Luis Valley. Data for the following counties are included:

1) Alamosa
2) Conejos
3) Costilla
4) Mineral
5) Rio Grande
6) Saguache

The data used here were obtained from Colorado Agricultural Statistics, the annual publication of the Colorado Crop and Livestock Reporting Service of the Colorado Department of Agriculture. Data for the years 1960-84 are presented. Data for 1985 will not be available until July, 1986.

The Colorado Crop and Livestock Reporting Service (CLRS) uses the following crop categories when reporting acreages, yields, and total production in the San Luis Valley:

1) Alfalfa Hay (including mixtures)
2) Other Hay (including wild hay, millet hay, grain hay, and miscellaneous tame hays)
3) Barley (for malting and feed)
4) Oats (for grain)
5) Potatoes
6) Spring Wheat

The CLRS does not report acreages for carrots, lettuce, spinach, and the other miscellaneous vegetable crops grown in the San Luis Valley. Valley crops are included in grand totals of such vegetable crops for the entire state. The CLRS estimates there are 3,000 - 3,500 acres of lettuce grown annually in the San Luis Valley. There are probably 1,500 acres of other vegetable crops (other than potatoes) in the area.

The Colorado Crop and Livestock Reporting Service publishes annual data for the state of Colorado. Every three to four years, the CLRS publishes a revised version of data from the past four to five years. This results in slight inconsistencies between the years whenever the original and revised versions of the data are compared. In this report, we have used the revised versions of Colorado Agricultural Statistics whenever possible.
The following figures summarize crop production for the six San Luis Valley counties for the years 1960-84:

<table>
<thead>
<tr>
<th>Figure Number</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-1</td>
<td>Alfalfa Hay Acreage, 1960-84 Alamosa County</td>
</tr>
<tr>
<td>A-2</td>
<td>Other Hay Acreage, 1960-84 Alamosa County</td>
</tr>
<tr>
<td>A-3</td>
<td>Barley Acreage, 1960-84 Alamosa County</td>
</tr>
<tr>
<td>A-4</td>
<td>Oats (Grain) Acreage, 1960-84 Alamosa County</td>
</tr>
<tr>
<td>A-5</td>
<td>Potato Acreage, 1960-84 Alamosa County</td>
</tr>
<tr>
<td>A-6</td>
<td>Spring Wheat Acreage, 1960-84 Alamosa County</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>A-7</td>
<td>Alfalfa Hay Acreage, 1960-84 Conejos County</td>
</tr>
<tr>
<td>A-8</td>
<td>Other Hay Acreage, 1960-84 Conejos County</td>
</tr>
<tr>
<td>A-9</td>
<td>Barley Acreage, 1960-84 Conejos County</td>
</tr>
<tr>
<td>A-10</td>
<td>Oats (Grain) Acreage, 1960-84 Conejos County</td>
</tr>
<tr>
<td>A-11</td>
<td>Potato Acreage, 1960-84 Conejos County</td>
</tr>
<tr>
<td>A-12</td>
<td>Spring Wheat Acreage, 1960-84 Conejos County</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>A-13</td>
<td>Alfalfa Hay Acreage, 1960-84 Costilla County</td>
</tr>
<tr>
<td>A-14</td>
<td>Other Hay Acreage, 1960-84 Costilla County</td>
</tr>
<tr>
<td>A-15</td>
<td>Barley Acreage, 1960-84 Costilla County</td>
</tr>
<tr>
<td>A-16</td>
<td>Oats (Grain) Acreage, 1960-84 Costilla County</td>
</tr>
<tr>
<td>A-17</td>
<td>Potato Acreage, 1960-84 Costilla County</td>
</tr>
<tr>
<td>A-18</td>
<td>Spring Wheat Acreage, 1960-84 Costilla County</td>
</tr>
<tr>
<td>Figure Number</td>
<td>Title</td>
</tr>
<tr>
<td>---------------</td>
<td>-------</td>
</tr>
<tr>
<td>A-19</td>
<td>Alfalfa Hay Acreage, 1960-84</td>
</tr>
<tr>
<td>A-20</td>
<td>Other Hay Acreage, 1960-84</td>
</tr>
<tr>
<td>A-21</td>
<td>Alfalfa Hay Acreage, 1960-84</td>
</tr>
<tr>
<td>A-22</td>
<td>Other Hay Acreage, 1960-84</td>
</tr>
<tr>
<td>A-23</td>
<td>Barley Acreage, 1960-84</td>
</tr>
<tr>
<td>A-24</td>
<td>Oats (Grain) Acreage, 1960-84</td>
</tr>
<tr>
<td>A-25</td>
<td>Potato Acreage, 1960-84</td>
</tr>
<tr>
<td>A-26</td>
<td>Spring Wheat Acreage, 1960-84</td>
</tr>
<tr>
<td>A-27</td>
<td>Alfalfa Hay Acreage, 1960-84</td>
</tr>
<tr>
<td>A-28</td>
<td>Other Hay Acreage, 1960-84</td>
</tr>
<tr>
<td>A-29</td>
<td>Barley Acreage, 1960-84</td>
</tr>
<tr>
<td>A-30</td>
<td>Oats (Grain) Acreage, 1960-84</td>
</tr>
<tr>
<td>A-31</td>
<td>Potato Acreage, 1960-84</td>
</tr>
<tr>
<td>A-32</td>
<td>Spring Wheat Acreage, 1960-84</td>
</tr>
<tr>
<td>A-33</td>
<td>Alfalfa Hay Acreage, 1960-84</td>
</tr>
<tr>
<td>A-34</td>
<td>Other Hay Acreage, 1960-84</td>
</tr>
<tr>
<td>A-35</td>
<td>Barley Acreage, 1960-84</td>
</tr>
<tr>
<td>A-36</td>
<td>Oats (Grain) Acreage, 1960-84</td>
</tr>
<tr>
<td>A-37</td>
<td>Potato Acreage, 1960-84</td>
</tr>
<tr>
<td>A-38</td>
<td>Spring Wheat Acreage, 1960-84</td>
</tr>
<tr>
<td>A-39</td>
<td>Total Crop Acreage, 1960-84</td>
</tr>
</tbody>
</table>
The principal method used by CLRS to collect crop and livestock production information is the mailed questionnaire. The questionnaire is sent to a large sample of farmers, with a small number of non-respondents then being interviewed by telephone. The CLRS follows up these procedures by on-site enumeration of specific land areas chosen through mapping procedures.

The following table will summarize crop acreages for the San Luis Valley for 1984, including the addition of 4,500 acres of vegetable crops not reported for the San Luis Valley by the Crop and Livestock Reporting Service.

**Table A-2**

<table>
<thead>
<tr>
<th>Crop</th>
<th>Acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alfalfa Hay</td>
<td>109,000</td>
</tr>
<tr>
<td>Other Hay</td>
<td>81,000</td>
</tr>
<tr>
<td>Barley</td>
<td>117,000</td>
</tr>
<tr>
<td>Oats (for Grain)</td>
<td>14,500</td>
</tr>
<tr>
<td>Potatoes</td>
<td>53,500</td>
</tr>
<tr>
<td>Spring Wheat</td>
<td>49,000</td>
</tr>
<tr>
<td>Vegetables</td>
<td>4,500</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>428,500</td>
</tr>
</tbody>
</table>

**ESTIMATION OF IRRIGATED PASTURE LAND IN THE SAN LUIS VALLEY**

Until now, this Appendix has included discussion only of irrigated and harvested cropland. The Colorado Crop and Livestock Reporting Service does not keep a record of land that is irrigated for use as pasture.

The Colorado Water Conservation Board (CWCSB) and the United States Department of Agriculture have estimated there are approximately 206,000 acres of irrigated pasture in the San Luis Valley. These pastures are irrigated depending upon water availability, and many do not receive adequate water supplies for optimum forage production. Table A-3 presents an estimate of irrigated pasture acreages from more recent data. Table A-5 presents data from the 1982 National Resource Inventory, Colorado Resource Tables, which indicates about 189,400 acres of irrigated grazed and ungrazed pasture.

TOTAL IRRIGATED ACREAGE IN THE SAN LUIS VALLEY

By summing irrigated crop acreage (CLRS data), idle crop land, and irrigated pasture acreage (CWSB estimate), we can develop an estimate of the total amount of irrigated land used for crop and livestock production in the San Luis Valley. The estimate (using 1984 CLRS data) is 634,500 total irrigable and irrigated acres. By the estimates of Tables 1-A through 1-F the actual irrigated acreage is 638,074. This is quite realistic considering the land which has been brought into production by sprinkler irrigation in Saguache and Alamosa Counties since 1978.
Table A-3

IRRIGATED PASTURE OTHER THAN HAYLAND

<table>
<thead>
<tr>
<th>County</th>
<th>Irrigated Pasture + Hay Land</th>
<th>Hay Land</th>
<th>Irrigated Pasture (Not Hayed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saguache</td>
<td>111,640</td>
<td>32,600</td>
<td>79,040</td>
</tr>
<tr>
<td>Rio Grande</td>
<td>29,645</td>
<td>14,327</td>
<td>15,318</td>
</tr>
<tr>
<td>Conejos</td>
<td>118,997</td>
<td>28,218</td>
<td>90,779 (53,429)</td>
</tr>
<tr>
<td>Alamosa</td>
<td>76,074</td>
<td>9,636</td>
<td>66,438</td>
</tr>
<tr>
<td>Costilla</td>
<td>32,060</td>
<td>3,064</td>
<td>28,996</td>
</tr>
<tr>
<td>Mineral</td>
<td>5,711</td>
<td>1,073</td>
<td>4,638</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>285,209 (247,859)</td>
</tr>
</tbody>
</table>

Wetlands (wildlife areas, etc.)

Monte Vista and Alamosa Wildlife Refuges: 26,000 acres - 606 acres cropped = 25,394 acres

Russell Lakes: 750 acres + 3,200 (to be added) = 3,950

Blanca Wildlife Refuge: 5,400 = 5,400

1. Irrigated pasture and hayland. Obtained from Multiyear Plan, 1982, A.S.C., or updated estimates from A.S.C. personnel. Assume pasture and hayland have not changed significantly in 10 years.

2. Data obtained from 10-year average of Colorado Agricultural Statistics.

3. Irrigated pasture not hayed is considered to be the difference between the first 2 columns in the table.

4. Apparently Conejos County included most alfalfa acreage as hayland. Thus the estimate of ( ) irrigated pastures not hayed was determined by subtracting all crops including hay and alfalfa from the total (147,714) irrigated acres reported. Thus, total irrigated pasture acreage is 247,859. This is somewhat higher than the 189,400 acres which were reported as irrigated grazed and non-grazed pasture by the NRI 1982 report and the 205,795 acres reported by the 1978 Water and Land Resources report for the Rio Grande Basin.
### Table A-4

**IRRIGATED PASTURE AND HAY LAND BY COUNTY**

<table>
<thead>
<tr>
<th>County</th>
<th>In San Luis Valley</th>
<th>Vegetable Acreages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saguache</td>
<td>127,800</td>
<td>111,640^2</td>
</tr>
<tr>
<td>Conejos</td>
<td>118,997</td>
<td>118,997^3</td>
</tr>
<tr>
<td>Costilla</td>
<td>32,060</td>
<td>32,060</td>
</tr>
<tr>
<td>Rio Grande</td>
<td>29,645</td>
<td>29,645</td>
</tr>
<tr>
<td>Alamosa</td>
<td>76,074</td>
<td>76,074</td>
</tr>
<tr>
<td>Mineral</td>
<td>5,711</td>
<td>5,711</td>
</tr>
</tbody>
</table>

1. Acreages are from 1982 Multiyear Plan, except as indicated below by specific field offices.

2. Personal communication with Ron Miller, S.C.S.

3. Personal communication with Pete Gallegos; revision end of 1985 by S.C.S. field office. 1982 Multiyear Plan indicated only 95,000; however, this did not account for all irrigated pasture and hay land, including alfalfa.

4. Vegetable acreages are estimated by specific field offices.

5. Other comments by S.C.S. personnel concerning water supply to meadows:

    Saguache – normally an adequate supply of water between irrigation supply and ground water.

    Conejos County – over 50% will have only low priority flood type water, and will receive possibly one irrigation. An S.C.S. overlay map by the former area conservationist indicates over 50% of area gets less than .94 acre-feet per acre, 20% gets ample irrigation supply, and some 30% gets ample supply when irrigation and subwater are accounted for.
Table A-5

NRI REPORTED ACREAGES FOR SAN LUIS VALLEY FLOOR*

<table>
<thead>
<tr>
<th>Hay Land</th>
<th>Crop Land</th>
<th>Pasture Land</th>
<th>Range Land</th>
<th>Small Water Areas</th>
<th>Row Crops</th>
<th>Close Growing</th>
</tr>
</thead>
<tbody>
<tr>
<td>150,900</td>
<td>396,800</td>
<td>208,800</td>
<td>1,050,800</td>
<td>8,500</td>
<td>33,100</td>
<td>191,300</td>
</tr>
</tbody>
</table>

LAND COVER AND USE

<table>
<thead>
<tr>
<th>Crop Land</th>
<th>Pasture Land</th>
<th>Range Land</th>
<th>Small Water Areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>396,800</td>
<td>208,800</td>
<td>1,050,800</td>
<td>8,500</td>
</tr>
</tbody>
</table>

CROP LAND USE

<table>
<thead>
<tr>
<th>Close</th>
<th>Ground Crops</th>
<th>Other Crops</th>
<th>Hay Land</th>
<th>Crop Land (total)</th>
</tr>
</thead>
<tbody>
<tr>
<td>33,100</td>
<td>191,300</td>
<td>21,500</td>
<td>150,900</td>
<td>396,800</td>
</tr>
</tbody>
</table>

NON-IRRIGATED CROP LAND USE

Other cultivated crops - 10,600

IRRIGATED CROP LAND USE

<table>
<thead>
<tr>
<th>Row Crops</th>
<th>Close Grown Crops</th>
<th>Other Cultivated Crops</th>
<th>Total</th>
<th>Hay Land</th>
<th>Total Irrig. Crop Land</th>
</tr>
</thead>
<tbody>
<tr>
<td>33,100</td>
<td>191,300</td>
<td>10,900</td>
<td>235,300</td>
<td>150,900</td>
<td>386,200</td>
</tr>
</tbody>
</table>

PASTURE LAND USE IN 1982

<table>
<thead>
<tr>
<th>Non-Irrigated Grazed</th>
<th>Irrigated Grazed</th>
<th>Irrigated Ungrazed</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>19,400</td>
<td>186,500</td>
<td>2,900</td>
<td>208,800</td>
</tr>
</tbody>
</table>

* Source: 1982 National Resource Inventory (NRI), Colorado Resource Tables
FIGURE A-1
ALFALFA HAY ACREAGE, 1960–84

FIGURE A-2
OTHER HAY ACREAGE, 1960–84
FIGURE A-5
POTATO ACREAGE, 1960–84
Alamosa County

FIGURE A-6
SPRING WHEAT ACREAGE, 1960–84
Alamosa County
FIGURE A-11
POTATO ACREAGE, 1960–84
Conejos County

FIGURE A-12
SPRING WHEAT ACREAGE, 1960–84
Conejos County
FIGURE A-15
BARLEY ACREAGE, 1960–84
Costilla County

FIGURE A-16
OATS (GRAIN) ACREAGE, 1960–84
Costilla County
FIGURE A-17
POTATO ACREAGE, 1960–84
Costilla County

FIGURE A-18
SPRING WHEAT ACREAGE, 1960–84
Costilla County
FIGURE A-27
ALFALFA HAY ACREAGE, 1960–84
Saguache County

FIGURE A-28
OTHER HAY ACREAGE, 1960–84
Saguache County
FIGURE A-31
POTATO ACREAGE, 1960–84
Saguache County

FIGURE A-32
SPRING WHEAT ACREAGE, 1960–84
Saguache County
FIGURE A-37
POTATO ACREAGE, 1960–84
San Luis Valley

FIGURE A-38
SPRING WHEAT ACREAGE, 1960–84
San Luis Valley
FIGURE A-39
TOTAL CROP ACREAGE, 1960–84
San Luis Valley

YEAR
1960 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84

ACRES (Thousands)
300 310 320 330 340 350 360 370 380 390 400 410 420

San Luis Valley
TRENDS

A number of trends can be noted when the preceding figures are reviewed...

Since 1960, total crop acreage in the San Luis Valley has increased due to increased well water availability in parts of the Valley. The general trend toward larger acreages is obvious; however, Figure A-39 demonstrates great variability in total crop acreages throughout the years (despite the general trend). Variation in crop acreages can be partly explained by inconsistencies in data reporting. The CLRS data is developed from a sample of respondents, and may not be perfectly representative of the actual situation which has existed in the San Luis Valley. Variation in total crop acreage from one year to the next is also influenced by participation in government set-aside programs. Despite variability through the years, the fact remains that total cropped (and therefore irrigated) acreage in the San Luis Valley has steadily increased in the years since 1960.

Until the early 1970's, spring wheat acreage in the San Luis Valley was negligible. With the expansion in total irrigated acreage and consequent increase in potato production, (see Figures A-37 and A-38), and no major changes in Coors malting barley allotments, spring wheat became the next best alternative for the potato/grain rotation. Spring wheat production costs are slightly higher than those of feed barley, but prices to the grower are historically higher for wheat.

The expansion in total irrigated acreage in the San Luis Valley partly explains the steady, although less dramatic, increase in barley acreage. Coors' malting barley allotments to growers in the Valley have remained steady (at approximately 45,000 acres) for the years 1970-84. The increase in total barley acreage presented in Figure A-35 is therefore due to the increase in total irrigated acreage, and the concurrent drop in alfalfa and oat acreage. Throughout the 1960's and 1970's, many farmers in the northern counties switched from these lower value crops to the higher value grains and potatoes. Barley from the San Luis Valley is also subject to on-and-off demand by brewers outside of Colorado. Quality and transportation factors influence the amount of malting and dual-purpose barley purchased by out-of-state brewers.

In the southern counties, the use of oats and feed barley as rotation crops and cover crops for alfalfa establishment help to explain the unevenness of Figures A-33 and A-36. The steady, yet highly variable, reduction in hay (other than alfalfa and alfalfa mixtures) acreage is correlated with the overall increase (from 1970-80) in alfalfa hay acreage. All hay acreage has declined since 1980 as farmers continue to seek higher value alternatives to the forage crops.
ET ESTIMATES FOR VARIOUS CROPS  
(Historical Average)

Table B-1  
Crop | Date | High Estimate | Low Estimate
--- | --- | --- | ---
**Potatoes**
Russet | May 15 | 17.4 | 16.5
Centennial | May 15 | 15.4 | 14.6
**Alfalfa** | May 10 | 23.5 | 22.3
**Barley**
Steptoe | April 15 | 18.0 | 17.1
Moravian | April 15 | 16.5 | 15.7
**Wheat**
Yecorah | April 15 | 18.0 | 17.1
Twin | April 15 | 18.8 | 17.8
**Oats**
(for grain) | April 15 | 18.8 | 17.8
**Oats**
(for hay) | April 15 - July 15 | 13.0 | 12.4
Grasses irrigated May 1
for Hay | | 25.5* | 15.0**
Grasses irrigated
for pasture | | 25.0 (wetlands) | 8.0***
Vegetables (eg. lettuce -
June 1 - Aug. 10) | | 14.0 | 13.3

* High water table where grasses can transpire without limit.
** Irrigated until July 15 and cut August 1 with no more irrigation.
*** ET is limited to what soil can hold from irrigation + effective precipitation.
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**Precipitation Normals (Inches)**

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References


This portion of the Valley floor acreage is broken down into two major classifications. The first classification will be considered as phreatophytes, where the average depth to groundwater is usually less than or equal to 6 ft. In this category of vegetative species, both woody and grass phreatophytes are included. It is thus assumed that a substantial portion of the consumptive use is derived from the groundwater. Some of the types of plants and grasses in this category are greasewood, rabbit brush, willows, alkali sacaton, sedges, rushes, and salt grass.

The other classification is for those plants or grasses that do not derive a significant portion of their water requirements from the groundwater, as the depth to groundwater is greater than 6 ft.

Procedure

Using the S.C.S. Soil Survey's SRIS Data Base, a listing of all soil types having depth to water table less than or equal to 6 ft. was obtained. From this group all the pertinent range sites (Mountain Meadow, Wet Meadows, Salt Flats, Salt Meadow, Alkali Overflow) were selected.

Consumptive use values for each range site were determined based upon a review of literature values and the vegetative composition of each site. Also used in making acreage determinations were the "Land Use and Natural Plant Communities Maps", 1976, (for each county) by the U. S. Department of Agriculture, Soil Conservation Service.

Two of the range sites (Salt Flats and Salt Meadows) have a portion of their acreage converted into irrigated crop or pasture lands.

For the non-phreatophyte group, consumptive use is equal to the average annual precipitation for the area.
Recommendations for further study would be as follows:

-- Improve the detail of the consumptive use of each species related to water table depth.

-- Use two or three thinner layers of depth to water table, such as 0-2, 2-4, and 4-6.

-- Improve the accuracy of the percentage of crop/pasture vs. phreatophyte acreage for each range site through ground-proofing and/or aerial photography.

References and Appendices

-- Isopluvial Map in Rio Grande Basin Study

-- Soils Data Base - S.C.S., by four counties

At the present time there is no recently published data updating or verifying the original consumptive use values from the U.S.B.R. Closed Basin Project. The basic planning document is the Report on Closed Basin Division, San Luis Valley Project, Colorado, House Document No. 91-369, 91st Congress, 2nd Session. There has also been some considerable work done at the Winnemucca site in the Humboldt River Valley (Prof. Paper 491-D).

Verification studies are underway by both the U.S.B.R. and Colorado State University on evapotranspiration of the salvage area vegetation of the Closed Basin Project. By the end of this year, results of these studies should be available for the public.

-- Entire Closed Basin: 2,940 mi², 1.881 million acres.
-- Original plan: to salvage non-beneficially consumed waters.
  (that water lost to evaporation/transpiration by salt grass, rabbit brush, greasewood, etc., within project area).
-- Means: by maintaining groundwater below 8 ft.


-- Two-thirds of annual ET by greasewood, rabbitbrush occur in June, July, August.
-- Winnemucca site: in 5" - 8" rainfall zone @ 4,260' elevation.
-- Report expresses consumptive use by areal (which does not take into account density of plants and size), or by volume foliage, which is equal to product of cover density and thickness of foliage.
-- Of the four species studied (greasewood, rabbitbrush, willow, and wild rose), ground water supplied 70% of use.
Table C-1

RANGE SITE DESCRIPTIONS
(S.C.S.)

Salt Flats - 263

(A good percentage is cropped.)

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<tr>
<th>Plant</th>
<th>Composition</th>
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<td>Alkali Sacaton</td>
<td>40% - 50%</td>
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<tr>
<td>Rubber Rabbitbrush</td>
<td>10%</td>
</tr>
<tr>
<td>Black Greasewood</td>
<td>10%</td>
</tr>
<tr>
<td>Inland Saltgrass</td>
<td>10%</td>
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<tr>
<td>Alkali Cordgrass</td>
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<tr>
<td>Western Wheatgrass</td>
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<tr>
<td>Blue Grama</td>
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Salt Meadow - 267

(Minor amount cropped)

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<td>Alkali Sacaton</td>
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<td>Slender Wheatgrass</td>
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<td>Sedge</td>
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<td>Willow</td>
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<td>Rush</td>
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#### Wet Meadow - 315

(0% Cropped)

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<td>Sedge</td>
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<td>Bluejoint Wheatgrass</td>
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<td>Rush</td>
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#### Alkali Overflow - 314

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<td>Creeping Rye</td>
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<td>Saltgrass</td>
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<td>Nutall Alkali</td>
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<td>Wirerush, Spikegrass</td>
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#### Mountain Meadow - 241

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Table C-2

PHREATOPHYTE WATER USE

Less than 6-foot water table
5 primary range sites

WINNEMUCCA STUDY
(Using 3-foot Water Table)

Consumptive use of:

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Table C-3

1931 - 1960 AVERAGE ANNUAL PRECIPITATION
Rio Grande Basin, Colorado - 1978
(Study by U.S.D.A.)

Weighted average rainfall by county:

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<td>(.6) 7.5 + .3 + 9 + (.1) 11 = 8.3&quot;</td>
<td></td>
</tr>
<tr>
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<td>(.05) 14 + (.15) 11 + .45 (7.5) + (.35) 9 = 8.88&quot;</td>
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<td>(.35) 6 + .5 (7.5) + (.15) 9 = 7.20&quot;</td>
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<tr>
<td>Conejos</td>
<td>.55 (7.5) + (.15) 9 + (.15) 11 + (.15) 14 = 9.23&quot;</td>
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</tr>
<tr>
<td>Costilla</td>
<td>.3 (7.5) + .35 (9) + .20 (11) + (.15) 14 = 9.70&quot;</td>
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Table C-4

PHREATOPHYTE DETAIL
(Less than 6 feet to water table)

Consumptive Use by Range Site Description

1. Salt Flats - 263

Composite consumptive use =

Saltgrass Greasewood Rabbitbrush Bare soil
(1.6) .75 + .10 (2.3) + .10 (2.2) + .05 (.6) = 1.68 acre-feet

2. Salt Meadow - 267

Composite consumptive use =

Grass Willow
(.90) 1.6 + (.10) 3.4 = 1.78 acre-feet

3. Wet Meadow - 315

Grasses = 1.6 acre feet

4. Alkali Overflow - 314, and Mountain Meadow - 241

Same as Wet Meadow (1.6 acre-feet)

Table C-5

APPROXIMATE ACREAGES BY COUNTY OF PHREATOPHYTE CLASSIFICATION

<table>
<thead>
<tr>
<th>County</th>
<th>Total (≤ 6' to Water Table)</th>
<th>Less Irrigated Crop/Irrigated Pasture Land on Soils with Water Table Less Than or Equal to 6'</th>
<th>Balance Phreatophyte Consumption (acres)</th>
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Table C-6

CONSUMPTIVE USE SUMMARY BY COUNTY AND RANGE SITE

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<tr>
<th>County</th>
<th>Total Phreatophyte Area*</th>
<th>Range Site Consumptive Use</th>
<th>Total Consumptive Use (Acre-Feet)</th>
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* The estimated phreatophyte uses are quite similar for the various range site descriptions (see Table C-4); thus, an approximation of 1.7 feet was used. Much of the area typically classed as salt flat or salt meadow by the soils descriptions is irrigated by low priority flood rights or is used for crop production. Because of the lack of good data of distribution of phreatophytes, irrigated pasture, and cropland within the area with water tables at less than 6 feet, the phreatophyte areas are estimated to the nearest 1,000 acres, and are probably within 20% - 30% accuracy. Many irrigated pastures have a significant contribution from the ground water. These are not included in the above, but are included separately in the consumptive use summary under "Irrigated Pastures".

By other estimates (eg. taking vegetal cover maps such as Plate 4 of Water and Related Land Resources, Rio Grande Basin, the phreatophyte area could be said to exceed 400,000 acres. However, maps such as those entitled "Land Use and Natural Plant Communities" would indicate the phreatophyte area to be closer to 300,000 acres.
### Table C-7

CONSUMPTIVE USE FOR NON-IRRIGATED, NON-PHREATOPHYTE AREA

<table>
<thead>
<tr>
<th>County</th>
<th>Non-Phreatophyte Area</th>
<th>Avg. Rainfall Inches (Acre-Feet)</th>
<th>Effective Precipitation Inches (Acre-Feet)</th>
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<td>Saguache</td>
<td>304,550</td>
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<td>6.64 (.553)</td>
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<td>Rio Grande</td>
<td>21,237</td>
<td>8.88 (.74)</td>
<td>7.10 (.592)</td>
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<td>Alamosa</td>
<td>162,567</td>
<td>7.20 (.60)</td>
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<td>162,153</td>
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<td>387,746</td>
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<td>7.76 (.647)</td>
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Assume effective rainfall on range sites is 80% of mean rainfall due to high moisture storage capacity of soil at any given rainfall event.
APPENDIX E

Division 3 and WATSTORE Listings of Deep Wells in the San Luis Valley
List of Tables

<table>
<thead>
<tr>
<th>Table E.1</th>
<th>Database, Division 3 Master List of Wells</th>
<th>Page</th>
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<tbody>
<tr>
<td>Table E.2</td>
<td>Source: USGS WATSTORE (GWSI) Database</td>
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## TABLE E.1

Database, Division 3 Master List of Wells

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Non-Domestic and Non-Household Use only

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| DEPTH | SITE-ID | COUNTY | LOCAL WELL NUMBER | LAND- | LOCATION | AQUIFER | ALTITUDE OF LAND | SURFACE | WATER LEVEL | MEASURED | WATER | TRAVEL/SECIETY | DISCHARGE | OWNER | DATE | QUALITY | TYPE | WATER | LEVEL | MEASURED | TYPE | WATER | LEVEL | DATE | AVAILABILITY | WATER | LEVEL | FEET |
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| DEPTH | SITE-ID | COUNTY | LOCAL WELL NUMBER | LAND- | LOCATION | AQUIFER | ALTITUDE OF LAND | SURFACE | WATER LEVEL | MEASURED | WATER | TRAVEL/SECIETY | DISCHARGE | OWNER | DATE | QUALITY | TYPE | WATER | LEVEL | MEASURED | TYPE | WATER | LEVEL | DATE | AVAILABILITY | WATER | LEVEL | FEET |
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| DEPTH | SITE-ID | COUNTY | LOCAL WELL NUMBER | LAND- | LOCATION | AQUIFER | ALTITUDE OF LAND | SURFACE | WATER LEVEL | MEASURED | WATER | TRAVEL/SECIETY | DISCHARGE | OWNER | DATE | QUALITY | TYPE | WATER | LEVEL | MEASURED | TYPE | WATER | LEVEL | DATE | AVAILABILITY | WATER | LEVEL | FEET |
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E-13
APPENDIX F

Confined-Aquifer Well Inventory Database
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WELL: ALAMOSA GEOTHERMAL TEST WELL

LOCATION: SW SE 15, T 37 N, R 10 E, ALAMOSA COUNTY

SAMPLED (Y/N): Y
DATE SAMPLED: 6/27/86

SAMPLED BY: EJH
TIME SAMPLED: 0815

CONDUCTIVITY (CORR. TO 25°C): 9100
pH: 9.1
TEMP (°C): 14

WELL FLOWING (Y/N): N
EST. FLOW RATE (GPM): N/A
EST. WATER LEVEL (FT): 0

TOTAL DEPTH: 6084(?)
PRODUCING INTERVAL: 5439-6043(?)
PUMP INSTALLED (Y/N): N

SUITABLE FOR TESTING (Y/N): Y
SUITABLE FOR LOGGING (Y/N): Y

IN STATE RECORDS (Y/N): N
IN WATSTOR (Y/N): N
HAVE LITH LOG (Y/N): Y

COMMENTS: SAMPLE MAY BE SUSPECT SINCE WELL WAS NOT FLOWING. WATER LEVEL WITHIN ONE FOOT OF GROUND SURFACE; SMELLED STRONGLY OF METHANE. FOR COMPLETION INFORMATION, REFER TO COMPLETION REPORT BY ENERGY SERVICES, INC., IDAHO FALLS, IDAHO, APRIL 1983 (U.S. DOE CONTRACT NO. DE-FC07-81ID12259).

CONDITIONS OF COMPLETION: (SEE ATTACHED WELL SECTIONS, FROM DOE REPORT). THERE IS A 12" GATE VALVE AT THE SURFACE.

UNKNOWNs: THE 7-INCH CASING MAY HAVE BEEN PLACED OPPOSITE A THICK CLAY INTERVAL. EVIDENTLY, NO GEOPHYSICAL LOGS HAVE BEEN RUN IN THIS WELL. CASING PERFORATION WOULD BE NECESSARY TO TEST THE INTERVAL ABOVE 5439 FEET.

POSSIBLE TESTS: CASED-HOLE GEOPHYSICAL LOGS, SPINNER AND FLUID CONDUCTIVITY LOGS, AND A PUMPING OR AIRLIFT TEST COULD BE RUN.

ESTIMATED TESTING COSTS: LOGGING: $4000 - $8000
AIRLIFT TEST: $8000 - $20,000 + ENERGY COSTS
PERFORATION: $8000 - $15,000

POSSIBLE RISKS: LOGGING WOULD BE POSSIBLE WITHOUT SPECIAL EQUIPMENT OR PREPARATION. LITTLE RISK IS ANTICIPATED. PERMISSION WOULD HAVE TO BE OBTAINED FROM THE CITY OF ALAMOSA (AND THE COLO. DIVISION OF WATER RESOURCES) PRIOR TO CASING PERFORATION OR OTHER WELL MODIFICATIONS. RISK HAS NOT BEEN ASSESSED FOR CASING PERFORATION.
WELL: CARR KENNEDY-WILLIAMS OIL & GAS TEST PERMIT NO.: N/A
LOCATION: C SW 11, T 41 N, R 9 E, SAGUACHE COUNTY
SAMPLED (Y/N): Y
DATE SAMPLED: 6/26/86
SAMPLED BY: EJH
TIME SAMPLED: 1630
CONDUCTIVITY (CORR. TO 25°C): 360
pH: 8.3
TEMP (°C): 27.5
WELL FLOWING (Y/N): Y
EST. FLOW RATE (GPM): 200
EST. WATER LEVEL (FT): N/A
TOTAL DEPTH: 6831 (?) PRODUCING INTERVAL: UNKNOWN
PUMP INSTALLED (Y/N): N
SUITABLE FOR TESTING (Y/N): Y
SUITABLE FOR LOGGING (Y/N): Y
IN STATE RECORDS (Y/N): N
IN WATSTOR (Y/N): N
HAVE LITH LOG (Y/N): N
COMMENTS: APPEARS TO HAVE BEEN CONVERTED TO A WATER WELL; EVIDENTLY NOT REGISTERED WITH STATE ENGINEER.
WOULD NEED TO BE LOGGED TO DETERMINE PRODUCING INTERVAL. OWNERSHIP OF PROPERTY IS CURRENTLY BEING RESEARCHED.
CONDITIONS OF COMPLETION: TEE WITH VALVE AT 90 DEGREES AND BOLT-ON PLATE AT TOP. SURFACE CASING 16 INCHES. DOWNHOLE CONDITIONS UNKNOWN.
UNKNOWNS: NOT KNOWN FOR CERTAIN THAT OBSERVED WELL IS CARR-KENNEDY WILLIAMS. COMPLETION CONDITIONS/DEPTHS ARE UNKNOWN.
POSSIBLE TESTS: SHUT-IN TEST, CASED-HOLE GEOPHYSICAL LOGS, SPINNER AND FLUID-CONDUCTIVITY LOGS.
ESTIMATED TESTING COSTS: SHUT-IN TEST: $3000 - $5000
LOGGING: $3000 - $6000
POSSIBLE RISKS: SINCE COMPLETION IS UNKNOWN, THERE WOULD BE A RISK THAT THE WELL IS NOT OPEN BELOW SOME SHALLOW DEPTH INTERVAL, AND THAT NO DATA ON THE DEEPER CONFINED AQUIFER WOULD RESULT FROM TESTING. THE WELL CASING MAY BE OLD, AND SUBJECT TO COLLAPSE IF ENTERED WITH A LOGGING PROBE.
WELL: CARROL NORTH WELL  
PERMIT NO.: 3380-F

LOCATION: SW NW 5, T 37 N, R 10 E, ALAMOSA COUNTY

SAMPLED (Y/N): N  
SAMPLED BY: N/A  
DATE SAMPLED: N/A  
TIME SAMPLED: N/A

CONDUCTIVITY (CORR. TO 25C): 250  
PH: 9.3  
TEMP (C): 29

WELL FLOWING (Y/N): Y  
EST. FLOW RATE (GPM): 500  
EST. WATER LEVEL (FT): N/A

TOTAL DEPTH: 2585  
PRODUCING INTERVAL: 1545-2585  
PUMP INSTALLED (Y/N): N

SUITABLE FOR TESTING (Y/N): Y  
SUITABLE FOR LOGGING (Y/N): N

IN STATE RECORDS (Y/N): Y  
IN WATSTOR (Y/N): Y  
HAVE LITH LOG (Y/N): Y

COMMENTS: USED TO PROVIDE WATER FOR SWIMMING POOL, PRIVATE LAKE, AND DOMESTIC USE. OWNERS WOULD BE AMENABLE TO TESTING.

CONDITIONS OF COMPLETION: 10" CASING 0' - 1885'; 7" CASING 1870'-2585'. NO PUMP. COMPLEX VALVING SYSTEM AT WELLHEAD. SURFACE PIPE ONLY GROUTED.

UNKNOWNCS: CASING CONDITION IS UNKNOWN. SINCE ONLY THE SURFACE PIPE IS GROUTED, THERE MAY BE WATER ENTERING THE WELL FROM ZONES OTHER THAN THOSE PERFORATED.

POSSIBLE TESTS: SHUT-IN TEST. IT WOULD NOT BE POSSIBLE TO LOG THIS WELL, DUE TO INACCESSIBILITY TO THE WELL LOCATION, AND INACCESSABILITY INTO THE WELL ITSELF.

ESTIMATED TESTING COSTS: SHUT-IN TEST: $3000 - $5000

POSSIBLE RISKS: LITTLE RISK TO THE WELL OR PROPERTY IS FORESEEN IN EQUIPPING THE WELL FOR A SHUT-IN TEST. IT IS POSSIBLE THAT A SHUT-IN TEST WOULD NOT YIELD GOOD DATA ON THE DEEPER CONFINED, SINCE THE WELL IS COMPLETED OVER A WIDE DEPTH RANGE.
WELL: CARROL SOUTH WELL
LOCATION: NW SE 5, T 37 N, R 10 E, ALAMOSA COUNTY
SAMPLED (Y/N): Y
DATE SAMPLED: 6/27/86
SAMPLED BY: EJH
TIME SAMPLED: 1030
CONDUCTIVITY (CORR. TO 25C): 600
pH: 8.9
TEMP (C): 30
WELL FLOWING (Y/N): Y
EST. FLOW RATE (GPM): 50
EST. WATER LEVEL (FT): N/A
TOTAL DEPTH: 3080
PRODUCING INTERVAL: 2325-2955
PUMP INSTALLED (Y/N): N
SUITABLE FOR TESTING (Y/N): Y
SUITABLE FOR LOGGING (Y/N): Y
IN STATE RECORDS (Y/N): Y
IN WATSTOR (Y/N): Y
HAVE LITH LOG (Y/N): Y
COMMENTS: OWNERS WOULD BE AMENABLE TO OUT TESTING THIS WELL. THE WELL IS NOT BEING USED AT PRESENT.
CONDITIONS OF COMPLETION: 16" SURFACE CASING 0' - 58'; 10" CASING 0' - 2330'; 7" CASING 2325' - 2955'; OPEN HOLE 2955' - 3080'. SURFACE PIPE ONLY IS GROUTED. PERFORATED 1950'-2300'; SLOTTED 2325' - 2955'.
UNKNOWN: SINCE ONLY THE SURFACE PIPE WAS GROUTED, THERE MAY BE WATER COMING FROM ZONES OTHER THAN THOSE SLOTTED OR PERFORATED.
POSSIBLE TESTS: SHUT-IN TEST, CASED-HOLE GEOPHYSICAL LOGS, SPINNER AND FLUID-CONDUCTIVITY LOGS.

ESTIMATED TESTING COSTS: SHUT-IN TEST: $3000 - $5000
LOGGING: $3000 - $6000

POSSIBLE RISKS: LITTLE OR NO RISK IS FORESEEN TO THE WELL OR THE PROPERTY. THERE IS SOME RISK IN OBTAINING DATA FROM A ZONE OR ZONES OTHER THAN THOSE WHICH ARE SLOTTED OR PERFORATED.
WELL: HILL/MYERS WELL
PERMIT NO.: 25353-F
LOCATION: NE NE 13, T 41 N, R 8 E, SAGUACHE COUNTY
SAMPLED (Y/N): N
DATE SAMPLED: N/A
SAMPLED BY: N/A
TIME SAMPLED: N/A
CONDUCTIVITY (CORR. TO 25C): 180
PH: 8.2
TEMP (C): 26
WELL FLOWING (Y/N): Y
EST. FLOW RATE (GPM): 5
EST. WATER LEVEL (FT): N/A
TOTAL DEPTH: 6000(?) PRODUCING INTERVAL: UNKNOWN
PUMP INSTALLED (Y/N): N
SUITABLE FOR TESTING (Y/N): Y
SUITABLE FOR LOGGING (Y/N): N
IN STATE RECORDS (Y/N): Y
IN WATSTORE (Y/N): N
HAVE LITH LOG (Y/N): N
COMMENTS: THIS WELL MAY BE THE REMNANT OF THE SNOWDEN #1 KILLIAM OIL & GAS TEST
WELL, DRILLED TO 3985 FEET IN 1952. THE LOCATION DISCREPANCY IS ONE
QUARTER/QUARTER SECTION. RAY NEWMYER RECALLS THAT THIS WELL WAS INDEED DRILLED
AS AN OIL AND GAS TEST. LAND OWNERSHIP IS CURRENTLY BEING RESEARCHED.
CONDITIONS OF COMPLETION: THE WELL IS EQUIPPED WITH A TEE AND GATE VALVE AT THE
SURFACE. THE WATER IS PIPED THROUGH THE GATE VALVE TO A CENTER-PIVOT SYSTEM
APPROXIMATELY ONE-QUARTER MILE SOUTHWEST. NO PUMP IS INSTALLED.
UNKNOWN: NOTHING IS KNOWN ABOUT THE DEPTH, CASING, OR COMPLETION OF THIS WELL.
TEMPERATURE OF THE DISCHARGED WATER (26 C) INDICATES A RELATIVELY SHALLOW
SOURCE.
POSSIBLE TESTS: NOT RECOMMENDED, UNLESS GEOPHYSICAL LOGGING, OR, AT THE VERY
LEAST, SOUNDING THE WELL DEPTH, INDICATES A RELATIVELY DEEP WELL DEPTH.
ESTIMATED TESTING COSTS: N/A
POSSIBLE RISKS: VERY HIGH RISK OF OBTAINING DATA WHICH IS OF NO USE TO THE DEEP
CONFINED AQUIFER STUDY. GEOPHYSICAL LOGGING, AND SOUNDING OF WELL DEPTH, WOULD
NEED TO PRECEDE ANY FURTHER TESTING. CASING CONDITION MAY BE POOR AND SUBJECT
TO COLLAPSE.
WELL: HOOPER SWIMMING POOL WELL

LOCATION: NE NE 27, T 41 N, R 10 E, SAGUACHE COUNTY

SAMPLED (Y/N): Y
DATE SAMPLED: 6/26/86
SAMPLED BY: EJH
TIME SAMPLED: 1400

CONDUCTIVITY (CORR. TO 25C): 350
pH: 8.5
TEMP (C): 40

WELL FLOWING (Y/N): Y
EST. FLOW RATE (GPM): 5
EST. WATER LEVEL (FT): N/A

TOTAL DEPTH: 4308
PRODUCING INTERVAL: 3500-4308
PUMP INSTALLED (Y/N): Y

SUITABLE FOR TESTING (Y/N): Y
SUITABLE FOR LOGGING (Y/N): N

IN STATE RECORDS (Y/N): Y
IN WATSTOR (Y/N): Y
HAVE LITH LOG (Y/N): Y

COMMENTS: REPORTEDLY FLOWS 900 GPM OPEN DISCHARGE; REPORTEDLY PUMPS 1500 GPM FROM DEPTH OF 70 TO 80 FEET. REPORTEDLY COMPLETED WITH 16-INCH PLAIN CASING 0'-100'; 8-INCH PLAIN CASING 100'-3500'; OPEN HOLE 3500'-4308' (RAY NEWMYER, VERBAL COMM., 6-26-86).

CONDITIONS OF COMPLETION: 16-INCH CASING FROM 0 TO APPROXIMATELY 100 FEET; 8-INCH PLAIN CASING FROM APPROXIMATELY 100 FEET TO APPROXIMATELY 3500 FEET; OPEN HOLE FROM 3500 TO 4308 FEET. REPORTEDLY GROUTED BEHIND 16-INCH CASING AND UPPER 100 FEET OF 8-INCH CASING. WELL IS EQUIPPED WITH A LINESHAFT TURBINE PUMP. UNKNOWNS: CONDITION AND EXACT PLACEMENT OF CASING; INTEGRITY AND EXACT PLACEMENT OF GROUT SEAL; CONDITION OF BOREHOLE BELOW 3500 FEET.

POSSIBLE TESTS: PUMPING TEST WITH EXISTING PUMP WOULD REQUIRE LIFTING AND TURNING THE PUMP AND MOTOR. SHUT-IN TEST COULD BE PERFORMED, BUT WOULD REQUIRE A NEW STUFFING BOX INSTALLED IN MOTOR SHAFT TO PREVENT LEAKAGE. COULD BE LOGGED ONLY IF LINESHAFT TURBINE PUMP IS REMOVED.

ESTIMATED TESTING COSTS: SHUT-IN TEST: $4000 - $6000
PUMPING TEST: $3000 - $5000 + ENERGY COST
LOGGING: $3000 - $6000

POSSIBLE RISKS: THE WELL CASING IS OLD, AND MAY BE SUBJECT TO COLLAPSE IF ENTERED WITH A LOGGING PROBE.
SAN LUIS VALLEY CONFINED AQUIFER STUDY  
(PHASE I)  
INTERIM TASK 5 REPORT  
DEEP WELL TESTING AND FIELD INVESTIGATIONS

Prepared for

Colorado Water Resources and Power Development Authority  
Logan Tower, Suite 620  
1580 Logan Street  
Denver, Colorado 80203

HRS Water Consultants, Inc.  
with Robert E. Moran  
87001-13 June, 1987
EXECUTIVE SUMMARY

As part of the Phase IB portion of the San Luis Valley Confined Aquifer Study, the study team consisting of HRS Water Consultants, Inc., and Robert Moran, has performed analyses of:
- geophysical logs of four deep wells in the Valley
- aquifer test data from three deep wells in the Valley
- satellite imagery of the Valley.

The objective of the analyses was to add to the database of existing information on the hydrogeology of the deep confined aquifer, particularly hydrostratigraphic unit 3 (HSU-3), which lies at a depth of 2500 feet or more beneath most of the Valley. The studies of Phase IB, of which the analyses presented in this report are a part, are to determine the feasibility of the deep confined aquifer as a source of supplemental water supply for water users in the San Luis Valley.

The primary conclusions arrived at by the study team, based on the analyses discussed above, are as follows:

Aquifer tests conducted during Task 5 of Phase IA have yielded transmissivity estimates thought to be more representative of HSU-2 than HSU-3, the target of this study, due to apparent well completion in both HSU's and apparently much higher transmissivity in HSU-2. Aquifer tests and geophysical logs of the Hooper Pool Well and the Carroll Well (Figure 2.1), run for the present study, indicate that most of the water produced from these wells is from the upper confined aquifer (HSU-2) above a depth of about 2000 feet. The transmissivity estimates derived from aquifer testing of these wells thus is reflective of HSU-2 to a larger extent than HSU-3. This condition is likely to be the case in any deep water well which presently exists in the San Luis Valley.

Geophysical logs run for this study in deep wells in the Alamosa area indicate an abrupt groundwater quality degradation and increase in clay content below a depth of approximately 2000 feet. This is interpreted to be
the contact between HSU-2 and HSU-3. Fluid resistivity, downhole flowmeter, and temperature logs of the Carroll Well indicate a water-quality change from about 220-240 mg/L DS above 2080 feet, to about 400 mg/L DS below that depth. Gamma and neutron logs of the Alamosa Geothermal Well indicate an abrupt increase in clay content below about 2000 feet. This change is strongly evident for the Alamosa area, but may be present only in areas in and near rift-related faults. With the present data set on the deep confined aquifer, we are not able to say with confidence whether this change between HSU-2 and HSU-3 is present beneath most of the Valley, or only at specific locations.

Temperature logging in the Alamosa Geothermal Well indicates upward leakage of ground water within HSU-3 at depths greater than 4000 feet and downward leakage in HSU-2 at a depth of 2000 - 2500 feet. This apparent movement into the 2500 to 4000-foot stratum may imply that there is also attendant lateral movement at the HSU-2/HSU-3 contact. These conclusions have been reached by analysis of local temperature variations with depth, as measured by the temperature logging of the Alamosa Geothermal Well. The temperature log yielded accurate data with which to perform the analysis with adequate precision. This is the only known deep well in the Valley to which this method can be applied, so the leakage conditions at other locations in the Valley remain unknown.

Transmissivity of HSU-2 is estimated to be approximately 132,000 gpd/ft in the Hooper area, based on testing of the Hooper Pool Well. This agrees well with earlier studies of the upper confined aquifer (Emery et al, 1973). In the Alamosa area, testing of the Carroll Well yielded estimates of transmissivity of HSU-2 ranging from 4500 to 13,900 gpd/ft. This range is significantly lower than earlier studies have estimated (Emery et al, 1973), and may be due to plugging of casing slots in the well.

Dissolved solids concentration is expected to be in the range of 400 mg/L to greater than 10,000 mg/L in the Hooper and Alamosa areas. It is expected that the rift-related fault zone in the Alamosa area would exhibit poorer water quality in HSU-3 than in non-rifted areas, due to the presence of poor-quality thermal waters circulating upward from great depth. This conclusion
has been derived from analysis of geophysical logs and water samples from the Hooper Pool Well at Hooper, and the Carroll Well and Alamosa Geothermal Well at Alamosa (Figure 2.1). At these locations, which are thought to be at or near rift-related fault zones, this conclusion is fairly well documented. Away from these areas, water quality in the deep confined aquifer can be inferred only from analysis of sparsely-located geophysical logs, with no supporting water-quality data. Therefore, extension of this conclusion to other areas of the Valley is not possible without corroborating data in non-rift-related areas.

In the San Juan foothills of the Del Norte area, hydraulic conductivity of approximately the upper 1700 feet of the Conejos Formation is estimated to be on the order of $10^{-3}$ cm/sec. At that hydraulic conductivity, the transmissivity of the interval 180-1710 feet in Well No. 1-19 SFC, about five miles south of Del Norte, is expected to be approximately 30,000 gpd/ft. This has been estimated by comparison with hydraulic conductivity analyzed in a Conejos Formation well drilled through very similar lithologies (Huntley, 1976). Accuracy of this hydraulic conductivity estimate is expected to be good for similar Conejos lithologies. Where the Conejos is composed predominantly of much finer-grained materials, as appears to be the case beneath the San Luis Valley, $10^{-3}$ cm/sec may be considered to be an upper limit of hydraulic conductivity.

Transmissivity of the Conejos Formation is expected to decrease considerably to the east, from the San Juan foothills into the San Luis Valley. The effect of this would be to force ground water moving down-gradient (into the Valley) into pathways less resistant to ground water flow. The most likely pathway appears upward, into HSU-2. This inference is based on analysis of seismic-reflection sections and geophysical logs. Since no direct evidence to support or deny this hypothesis is presently available, it should not be considered as a definite conclusion.

There may be a component of ground water movement from sub-basins of the Rio Grande (e.g., San Francisco Creek and Pinos Creek) southward into the drainage basins of the Alamosa River, La Jara Creek, and the upper reaches of
the Conejos and Los Pinos Rivers. Evidence for this so far is indirect. Geophysical logs show limited continuity between highly conductive layers within the Conejos Formation from north to south. In addition, there appears to be a deficit of water in the sub-basins of the Rio Grande, and a surplus of water in the sub-basins of the Conejos River (Interim Task 2 Report, this study). At present, this should be considered only as an hypothesis, and not as a definite conclusion.

Several known hot spring areas in and surrounding the Valley occur along lineations, interpreted to be faults, identified on satellite imagery. This is strong evidence of structural control on upwelling thermal waters into the aquifers of the Valley. These lineations, and the locations of the hot springs, have been verified through on-site geologic reconnaissance by study team members. It is felt that this conclusion is definite, and that further work would substantiate this conclusion for the Valley as a whole.

Deep ground water in the San Luis Valley shows evidence of chemical evolution from a predominantly bicarbonate-rich chemistry near the basin-margin recharge areas, to a chloride-rich chemistry toward the center of the Valley. Mixing of ground waters due to upward movement of poorer-quality thermal waters through faulted areas apparently complicates the chemical evolution of the water, and, in most cases, degrades the water quality. These conclusions, which are considered to be quite definite for the rift-related faulted areas of the San Luis Valley, have been based on review of previous studies, on comparison with ground water evolution in other, better-documented basins, and on water-chemistry analysis of several deep wells in the Valley.

The geothermal gradient in the Alamosa area appears to be greater than estimated by earlier studies. Temperature logging of the Alamosa Geothermal Well indicates a gradient of 2.9 degrees F per 100 feet of depth. This is equivalent to about 47 degrees C per kilometer of depth. Extrapolation indicates an expected temperature of 340 to 350 degrees F at a depth of 10,000 feet in the Alamosa area. This is considered to be well within the range of temperature gradients expected for an active rift zone. Though it is likely that there will be local areas of lower gradient within the Valley, the
faulted rift zones are expected, with good confidence, to show temperature gradients in that range.

Thermal waters in the Valley appear to occur preferentially along two lines: one north-south through Villa Grove and the San Luis Hills, and the other east-west through the Summer Coon volcanic area. There is evidence for structure along the two lines, as seen weakly on the TM satellite imagery for the east-west line, and strongly on the TM imagery and seismic sections for the north-south line.

At the locations of fault zones which allow upward leakage from great depths (deeper than HSU-3), wells and springs may show waters with unusually high concentrations of organic carbon, dissolved gasses, silica, and fluoride, as well as sodium and chloride, uranium and similar heavy metals, and certain anionic complexes stable at high pH levels. There is only limited direct evidence for this at present, at localized areas near Alamosa and Moffat. Unless more data becomes available, this conclusion will remain inferential and not definite.

Where shallow waters mix with deep waters, dilution may mask the chemistry of the deeper contributions. This is expected to be the case at some distance from deep-seated, rift-related fault zones. It has been shown with good confidence that there are water quality differences with depth, and that there is upward leakage within HSU-3. The areal extent of such mixing, however, has not been well defined in the Valley.

The sump area of the closed basin in the Valley lies in an area where several major, deep-seated fault zones intersect. Upwelling ground water along such faults may have contributed to the near-surface waterlogging in that area. This should be considered as a hypothesis, and not a definite conclusion, unless more data becomes available.
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Table 2.1  Leakage Rate Analysis of Alamosa Geothermal Well
ACKNOWLEDGEMENTS

Phase IB of the San Luis Valley Confined Aquifer Study was authorized by the Colorado Water Resources and Power Development Authority. The study is being undertaken on behalf of the San Luis Valley Water Conservancy District. The study team for the Phase IB studies is comprised of HRS Water Consultants, Inc., as the prime contractor, with Robert E. Moran as subcontractor.
1.0 INTRODUCTION

As part of the Phase IB studies for the San Luis Valley Confined Aquifer Study, the study team of HRS Water Consultants, Inc., and Robert Moran, has performed analyses of selected data sets from the San Luis Valley. These data sets analyzed were part of several earlier (Phase IA) investigations for the Confined Aquifer Study. The analyses performed were as follows:

1. Analysis of deep-well aquifer test data
2. Analysis of deep-well geophysical logs
3. Analysis of satellite imagery of the Valley

The aquifer test data analyzed were acquired during the summer of 1986 as part of the Phase IA, Task 5 activities. Three deep confined aquifer wells (the Hooper Pool Well, the Carroll Well, and the Owens Well) were tested at that time. The Owens Well did not yield usable data, due to background noise problems with constant use of the well. The Carroll Well and the Hooper Pool Well yielded transmissivity estimates on the confined aquifer, but, due to well construction, it is felt that the estimates are more representative of HSU-2 than of HSU-3.

Geophysical logs were run in the Hooper Pool Well, the Carroll Well, and the Alamosa Geothermal Well. The logging probes could not penetrate below a depth of about 280 feet in the Hooper Pool Well, due to the condition of the well. The Carroll Well and the Alamosa Geothermal Well both were logged to their total depths (2620 feet and 6075 feet, respectively). Both wells yielded logs which have been useful in determining the hydrologic, lithologic, and thermal properties of the confined aquifer.

Also included in this report is an interpretation of geological and geophysical data from a new oil test well, No. 1-19 San Francisco Creek, located about five miles south of Del Norte. The data from this new test well were obtained through a data exchange agreement between the Colorado Water Resources and Power Development Authority (through HRS Water Consultants, Inc.) and Waggoner-Baldridge Energy Co. of Dallas, Texas.
Landsat thematic mapper (TM) satellite images of the San Luis Valley and the surrounding mountainous areas were interpreted during these studies. The results of that interpretation are:

1. A map of the geologic structures (lineations) identified
2. A matrix of information which identifies each major structure, its attributes, and its interpreted effect on ground water quality and availability.
3. A narrative discussion of the study team's interpretation of how the large-scale geologic structures affect ground water availability and quality in the San Luis Valley.
2.0 DEEP-WELL TESTING AND LOGGING

2.1 INTRODUCTION

Aquifer testing and geophysical logging of four confined-aquifer wells was performed and supervised by members of the Phase IA study team during the week of August 24, 1986. The logging and testing was performed on wells selected during the deep-well inventory part of the confined aquifer study (see Interim Task 2 Report, this study). The four wells, which are depicted on Figure 2.1, are as follows:

1. Hooper Pool Well (reported total depth of 4308 ft.)
2. Carroll Well (reported total depth of 2585 ft.)
3. Owens Well (reported total depth of 3080 ft.)
4. Alamosa Geothermal Well (reported total depth of 6084 ft.)

The purpose of the logging and testing was to supplement the existing database regarding the aquifer characteristics and water quality of the deep confined aquifer, particularly hydrostratigraphic unit 3 (HSU-3).

Flow tests and/or shut-in tests were performed on the Hooper Pool Well, the Carroll Well, and, to a limited extent, the Owens Well. The Alamosa Geothermal Well was not tested, because it does not flow, and because it is doubtful whether a pumping test of that well would yield reliable aquifer parameters due to indications of inadequate well development following drilling and well completion.

Geophysical logs were run in the Carroll Well and the Alamosa Geothermal Well. No logs were run in the Owens Well, due to its proximity (1880 feet) to the Carroll Well, and because logging would have caused several dozen homes and businesses to be without water for the duration of the logging. An attempt to log the Hooper Pool Well was only marginally successful due to problems with the condition of the well.
2.2 AQUIFER TESTING

2.2.1 Hooper Pool Well Testing

Two aquifer tests, a constant-drawdown flow test and a shut-in recovery test, were performed on the Hooper Pool Well. Both tests were conducted on August 25, 1986, in conjunction with the attempted geophysical logging. A flow test, also called a constant-head or constant-drawdown test, consists of allowing a previously shut-in artesian well to flow without restricting the amount of water which is produced. During the period of flow, measurements were made of time and rate of flow.

A shut-in test consists of recapping a well which had previously reached a stable rate of flow, and measuring the pressure (artesian head) buildup over a period of time. Graphs of time versus head buildup also can be used to interpret aquifer transmissivity.

Flow rate at the Hooper Pool Well was measured for a period of approximately six hours, during which time the flow stabilized. Upon recapping the well, head buildup was measured for approximately two hours, until the head no longer increased. Due to apparent inflow of water to the well at a depth interval between 200 and 280 feet, as inferred from the geophysical logging, results of the testing are not expected to be representative of the deep confined aquifer (HSU-3). The test results were interpreted, however, to add to the existing database of information on HSU-2.

Figure 2.2 is a graph of the time versus flow rate measured during the constant-drawdown portion of the testing at Hooper Pool Well. The straight line drawn through the data points represents the best fit (linear regression) line for the data collected following the first minute of the flow period. Interpretation of the data carried out using the best-fit line shows the transmissivity to be approximately 132,000 gallons per day per foot (gpd/ft) (Appendix A).

The data collected during the first minute of the flow period were not
used in the analysis because they were suspected to be non-representative of true aquifer conditions due to casing storage effects in the well.

Transmissivity of HSU-2 at the Hooper Pool Well was calculated to be approximately 9600 gpd/ft from a straight-line Jacob approximation analysis (Driscoll, 1986) of the time-recovery data (Figure 2.3). From a residual-drawdown graph of the recovery data (Figure 2.4) the transmissivity was calculated to be approximately 11,000 gpd/ft (Appendix A).

The values of transmissivity (T) calculated from the recovery position of the test are not expected to be as accurate as the T value calculated from the flow pattern of the test, due to change in the flow rate over the flow period. Such a change violates a required mathematical assumption of constant flow rate prior to capping the well.

2.2.2 Carroll Well and Owens Well Testing

A flow test and a shut-in test were performed on the Carroll Well in conjunction with the geophysical logging of that well. The flow test duration was approximately 48 hours, beginning on August 27 and ending on August 29, 1986. The shut-in test followed the flow test, and was performed over a period of approximately one hour on August 29, 1986.

During the flow test and shut-in test of the Carroll Well, head (pressure) measurements were taken at the Owens Well, 1880 feet to the east-southeast, to determine whether a head change could be detected over the flow period. No formal flow tests or shut-in tests were performed on the Owens well, because the well was in use to supply water to two swimming pools, a shopping center, a convenience store, irrigation of several acres of lawn, an RV park, one private residence, and a large mobile home park. Though measurable head change in the Owens Well was expected over the 48-hour flow period of the Carroll Well, none was observed with any confidence due to the extreme "noise" of head fluctuations caused by rapid on-off cycling of flow to many of the users of water from the Owens Well.
Results of the aquifer testing of the Carroll Well and the Owens Well are thought to be representative of HSU-2 and the upper several hundred feet of HSU-3. This is expected due to confirmation by geophysical logging of the depths from which water is produced in the 2620-foot deep Carroll Well. Since water from the Owens Well and the Carroll Well flow at the same temperature and at nearly the same specific conductance, it is likely that they produce water from almost the same portions of HSU-2 and HSU-3.

Figure 2.5 is a graph of normalized time versus flow-rate data collected during the flow test of the Carroll Well. Based upon the best-fit (linear regression) line through these data, the transmissivity was calculated to be approximately 13,900 gpd/ft for HSU-2 and the upper several hundred feet of HSU-3 (Appendix A).

The straight-line approximation time versus head-recovery plot for the one-hour recovery period at the Carroll Well (Figure 2.6) indicates a transmissivity of approximately 4900 gpd/ft (Appendix A). A graph of residual drawdown versus time (Figure 2.7) indicates a transmissivity of approximately 4500 gpd/ft (Appendix A).

The values of T for HSU-2 calculated from the Carroll Well test are a factor of approximately 10 to 20 less than expected (Emery et al, 1973). The reason for this may be that the Carroll Well casing slots are partially plugged due to corrosion or encrustation, or possibly that the well had never been developed (cleaned) adequately after it was drilled.

2.3 GEOPHYSICAL LOGGING

2.3.1 Hooper Pool Well Logging

An attempt was made to run borehole temperature and fluid-resistivity logs in the Hooper Pool Well on August 25, 1986. The purpose of the logging was to characterize the water quality of HSU-2 and HSU-3 in the Hooper area. At a depth of approximately 165 feet, a casing restriction was noted due to
difficulty in getting the logging probe to drop below that depth. The logging probe would not go below a depth of 284 feet, even after repeated attempts.

Because of the desirability of obtaining geophysical logs from the Hooper Pool Well, a downhole-TV camera survey of the well was performed on August 28, to attempt to determine why the logging probe would not drop below 284 feet. The TV survey found that eight-inch diameter casing begins at 156.5 feet in the well, and is off-center inside the 16-inch casing. At 161.5 feet inside the eight-inch casing is a grillwork iron or steel basket, with slots approximately one-half inch wide and four to six inches in length, through which water is moving upward. Whether the grillwork was welded in place intentionally, or whether this is a pump-intake screen which had fallen to this depth, could not be determined. No attempt was made to remove the grillwork basket.

Between the 8-inch and the 16-inch casing, at a depth of 162.5 feet, is a plug of what appeared to be cement. Along one side, the cement evidently had cracked and fallen away, because there was a crescent-shaped hole through which water could be seen to move upward toward the surface. This was the hole through which the geophysical logging probe dropped to a depth of 284 feet, at which point either there is a break in the 16-inch casing, or that casing ends, or there is another obstruction. That hole was not large enough for entry of the downhole TV camera.

From the geophysical logs it is apparent that there is water entering the well from a depth of approximately 200 to 280 feet. The water which flows at the surface evidently is a mixture of shallow confined aquifer (HSU-2) ground water from outside the 8-inch casing, and ground water from an unknown depth inside the 8-inch casing. This has been inferred from an abrupt change in temperature and fluid resistivity which occurs in the depth interval 200 to 280 feet.

2.3.2 Carroll Well Logging

Geophysical logging of the Carroll Well took place between August 27 and
29, 1986. The purpose of the logging was to determine the flow characteristics and general water-quality characteristics of HSU-2 and HSU-3 in the Alamosa area. The logs run in the Carroll Well were:

1. Temperature
2. Borehole-fluid resistivity
3. Casing-collar locator
4. Borehole flowmeter ("spinner")

Borehole temperature and fluid-resistivity logs, as well as the spinner log, were run to attempt to ascertain the zones of water production from HSU-2 and HSU-3. The casing-collar locator was used to verify the reported slotted intervals in the well casing. All of the logs were successfully run in the Carroll well, though a problem with the electronics in the spinner probe caused a one-day delay for repair. Following repair, that log was run successfully.

The suspected water-quality degradation from HSU-2 to HSU-3 appears to have been confirmed for the Carroll Well vicinity by the geophysical logging. Interpretation of the spinner log indicates that less than ten percent of the flow from the Carroll Well is contributed from the depth interval 2180 feet to 2620 feet (Figure 2.8). This zone is interpreted to be the upper portion of HSU-3. About 90 to 95 percent of the flow is contributed from the interval 1820 feet to 2180 feet. From the casing-collar locator log, the casing appears to be perforated in the interval 1750 feet to about 2500 feet. The interval 2500 feet to 2620 feet appears to be open hole. There is no contribution or loss to flow from the well above 1820 feet.

The fluid-resistivity log and the temperature log indicate an abrupt water-quality change at a depth of about 2080 feet. These two logs have been used to compute the DS concentration with depth in the well. At 2080 feet, down to a depth of about 2160 feet, the water quality changes from about 220-240 mg/L DS concentration (NaCl equivalent) to about 400 mg/L. Measurements of specific conductance of the water flowing from the Carroll Well indicated a NaCl-equivalent DS concentration of about 200 to 250 mg/l. By comparison, a laboratory analysis of water from the Carroll Well showed a DS concentration
about 400 mg/l. The difference between the laboratory value and the field values is due to the fact that the dissolved ions in the water are not predominantly sodium (Na) and chloride (Cl).

The change in water quality and flow contribution with depth is interpreted to be the boundary between HSU-2 and HSU-3. Though no unusual lithologic change was reported on the driller's completion log of the well, a seismic reflection line run by the Colorado School of Mines along Highway 160 shows a strong reflector at a depth of about 2000 feet. That reflector is interpreted to be the Fish Canyon and Carpenter Ridge tuffs at the top of HSU-3.

2.3.3 Alamosa Geothermal Well Logging

Geophysical logging of the Alamosa Geothermal Well was performed between August 26 and August 29, 1986. The logs run in that well were as follows:
1. Natural gamma (to 3960 feet)
2. Neutron (to 3960 feet)
3. Casing-collar locator (to 6075 feet)
4. Temperature (to 5735 feet)
5. Borehole-fluid resistivity (to 5740 feet)
6. Borehole flowmeter ("spinner") (to 6040 feet).

The natural-gamma and the neutron logs were run in the Alamosa Geothermal Well because no reliable information regarding lithologies (rock types) is known to exist for that well. Those logs have been used to fill gaps in our knowledge of the lithologies of the deep confined aquifer at that location. The other logs were run to determine changes of water quality with depth, to estimate the geothermal gradient of the deep confined aquifer in the Alamosa area, and to estimate the rate and direction of vertical ground water leakage within the deep confined aquifer. The casing-collar locator log was run to try to verify the reported completion intervals in the well. Due to high temperatures deep in the well, electronics modules in several of the logging probes did not operate properly. The deepest log able to be recorded was the
casing-collar locator log, which was recorded to the total well depth of 6075 feet.

The most abrupt lithologic change seen on the gamma and neutron logs is at a depth of approximately 2000 feet. At that depth, the log character shows a general lithologic change from a clay-poor material to a clay-rich material. This change is depicted on Figure 2.9. This is interpreted to correlate to the change in DS and flow contribution seen in the Carroll Well at about the same depth, three miles to the northwest.

Below a depth of 2000 feet, clay-rich materials predominate. This may be due to the presence of Conejos Formation volcanioclastic-facies rocks in HSU-3 at this location, or it may be due at least in part to clay-rich alteration products of more permeable rocks localized in a geothermally-active rift-related fault zone. The drilling conditions reportedly encountered in the Alamosa Geothermal Well indicate agreement with a generally clay-rich material in HSU-3. The neutron, gamma, and temperature logs indicate, however, that there are sporadic sand-or gravel-rich zones within the predominantly clay-rich HSU-3 materials.

The casing-collar locator log verified that slotted intervals of casing were placed at approximate depth intervals of 5440 feet to 5520 feet, and 5720 feet to 6040 feet.

Neither the fluid-resistivity log nor the spinner log proved to be very helpful in defining the characteristics of HSU-3. The well appears to be hydraulically isolated from the formation, possibly due to the low permeability of the formation, or possibly due to residual drilling-mud cake on the borehole walls in the two slotted intervals. The reported drilling problems and lack of well development following drilling points to the latter reason as the more probable.

The temperature log of the Alamosa Geothermal Well proved to be very helpful in defining the geothermal gradient and vertical ground water leakage within HSU-3 precisely because of the apparent hydraulic isolation of the well.
from its surroundings. The well flows, but at a rate too small to be measured easily; the flow is probably on the order of one gallon per day. Since the piezometric head is at the ground surface, and the well had remained undisturbed from June 9, 1982 (Energy Services, Inc., 1983) to August 26, 1986, (a period of 1539 days) the geothermal well constitutes an ideal temperature-monitoring hole.

To reduce turbulence within the well casing, the temperature log was the first to be run in the geothermal well. In addition, the temperature log was run going down the hole, rather than up the hole after tagging bottom.

Figure 2.10 is a graph of temperature versus depth for the Alamosa Geothermal Well, along with other measured and calculated borehole temperatures for the San Luis Valley (Burroughs, 1981). This graph shows that the geothermal gradient at this location is greater than has been estimated in earlier studies. The gradient is approximately 2.9 degrees F per 100 feet of depth. This is equivalent to about 47 degrees C per kilometer of depth. Downward extrapolation of a linear best-fit gradient line to the temperature data for the Alamosa Geothermal Well indicates that temperatures in the range of 330 to 350 degrees F at a depth of 10,000 feet can be expected. This temperature gradient falls within the range estimated for the Alamosa area of the Rio Grande Rift by a study of shallow heat-flow test holes less than 300 feet deep (Zacharakis et al, 1983).

Vertical leakage of ground water through confining beds from the shallow confined aquifer to the unconfined aquifer has been recognized in the San Luis Valley. There is also potential for a component of vertical leakage between aquifer layers of the deep confined aquifer. The temperature log of the Alamosa Geothermal Well has enabled the study team to identify vertical leakage within HSU-3, between HSU-3 and HSU-2, and to estimate the rate of the leakage. It is believed that this is the first direct evidence of the rate of vertical leakage in the deep confined aquifer.

The method used is described in papers by Robert W. Stallman (1963), J.D. Bredehoeft and I.S. Papadopulos (1965) and Michael L. Sorey (1971). By making
temperature measurements in a nonflowing well which is in thermal equilibrium with its surroundings, estimates of vertical leakage rates, and whether the leakage is upward or downward, can be made. The Alamosa Geothermal Well appeared ideally suited for this type of analysis. The temperature log of the Carroll Well was unsuitable, since the well was flowing at the time of the temperature logging.

Since piezometric head data were not available for the deep confined aquifer, we were not able to take the analysis one desirable step further, which would be computation of hydraulic conductivity values for the deep confined aquifer.

Table 2.1 is a tabulation of calculated vertical leakage rates for three depth intervals of the Alamosa Geothermal Well. These three intervals exhibited measurable local changes in geothermal gradient, as compared with the rest of the borehole. There were three to four different calculations of leakage rate made for each interval, due to the difficulty in choosing the exact depth points at which the temperature log shows a departure from the average geothermal gradient. Other intervals exhibited noticeable local departure from the average gradient, but were not of sufficient amplitude to be usable in this type of analysis.

The results of the leakage-rate analysis show there is upward leakage at depths greater than 4000 feet, at a rate probably on the order of several tenths of a foot per year. This is a substantial fraction of the rate of upward leakage earlier studies have shown for the upper confined aquifer into the unconfined aquifer. Emery and others (1973) indicate an estimated upward leakage rate from the upper confined aquifer into the unconfined aquifer of 0.6 foot per year to 0.8 foot per year. Zorich-Erker Engineering, Inc. (1980) estimated upward leakage to be approximately 0.055 foot per year.

The analysis of depth interval A shown in Table 2.1 appears to indicate a downward vertical component of leakage from HSU-2 into HSU-3. This may imply that there are active zones of ground water circulation between HSU-2 and HSU-3 not only vertically, but also laterally either along nearly-
horizontal bedding planes, or laterally in the near-vertical plane of a fault zone.

If upward leakage rates from the upper confined aquifer to the unconfined aquifer are relatively slow (Zorich-Erker Engineering, 1980), then this factor along with the downward leakage may be indicative of considerable deep confined aquifer ground water movement out of the central Valley area, most likely to the south.

### TABLE 2.1
LEAKAGE RATE ANALYSIS OF ALAMOSA GEOTHERMAL WELL

<table>
<thead>
<tr>
<th>INTERVAL</th>
<th>DEPTH INTERVAL (feet)</th>
<th>THICKNESS (feet)</th>
<th>LEAKAGE RATE (feet/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>2000 - 2400</td>
<td>400</td>
<td>+0.08</td>
</tr>
<tr>
<td></td>
<td>2100 - 2300</td>
<td>200</td>
<td>+0.17</td>
</tr>
<tr>
<td></td>
<td>2200 - 2400</td>
<td>200</td>
<td>+0.17</td>
</tr>
<tr>
<td>B.</td>
<td>4140 - 4200</td>
<td>60</td>
<td>-1.7</td>
</tr>
<tr>
<td></td>
<td>4075 - 4200</td>
<td>125</td>
<td>-0.14</td>
</tr>
<tr>
<td></td>
<td>4252 - 4290</td>
<td>38</td>
<td>-0.46</td>
</tr>
<tr>
<td></td>
<td>4150 - 4300</td>
<td>150</td>
<td>-0.45</td>
</tr>
<tr>
<td>C.</td>
<td>5082 - 5156</td>
<td>76</td>
<td>-1.45</td>
</tr>
<tr>
<td></td>
<td>5160 - 5460</td>
<td>300</td>
<td>-0.34</td>
</tr>
<tr>
<td></td>
<td>5220 - 5360</td>
<td>140</td>
<td>-0.48</td>
</tr>
</tbody>
</table>

**NOTE:** A positive value (+) indicates downward leakage. A negative value (-) indicates upward leakage.
It should be kept in mind that the Alamosa Geothermal Well is located near the fault zone which separates the Alamosa Horst and the Monte Vista Graben. As such, the leakage rates implied by this analysis may be indicative of vertical ground water movement which is characteristic of faults related to the Rio Grande Rift, but not characteristic of the Valley in general.

2.4 RESULTS OF DEEP-WELL LOGGING AND TESTING

2.4.1 Characteristics of HSU-2

Though HSU-2 was not the primary target of these studies, the deep-well logging and testing generated information regarding that HSU. Following are the characteristics of HSU-2 which were noted during the logging and testing:

1. The transmissivity of HSU-2 at the Hooper Pool Well is approximately 132,000 gpd/ft.

2. The transmissivity of HSU-2 at the Carroll Well and the Owens Well were measured to be in the range of 4500 to 13,900 gpd/ft, though these values may not be reflective of true aquifer conditions, due to possible encrustation of slots in the well casing.

3. The DS concentration of water predominantly from HSU-2 at the Hooper Pool Well is approximately 340 mg/L.

4. The DS concentration of water predominantly from HSU-2 at the Carroll Well and the Owens Well is approximately 400 mg/L.

2.4.2 Characteristics of HSU-3

The logging and testing performed in these studies indicate that there is substantial degradation in water quality and transmissivity from HSU-2 to HSU-3. This was seen at the Carroll Well and the Alamosa Geothermal Well. The temperature log and the downhole flowmeter (spinner) log of the Carroll Well indicated the change, as did the neutron and gamma log of the Alamosa Geothermal Well. Due to problems in the condition of the Hooper Pool Well, this could not be proved or disproved at that location.
In the Alamosa area, it appears that HSU-3 is composed predominantly of clay-rich materials, probably from the Fish Canyon and Carpenter Ridge tuffs and the volcaniclastic facies of the Conejos Formation. In the horst/graben fault zone near the Alamosa Geothermal Well and the Carroll and Owens Wells, it appears likely that clay-rich materials predominate due to chemical alteration of volcanic rocks into clays by upwelling geothermal waters.

Following are further conclusions regarding HSU-3 derived from the deep-well logging and testing:

1. None of the wells logged or tested were constructed such that testing would yield a value of transmissivity for HSU-3.

2. Ground water quality in HSU-3 appears to vary in DS concentration from a low of between 400 and 600 mg/L to a high range possibly greater than 10,000 mg/L. In the rift-related fault zone of the Alamosa area, it is likely that the water quality in HSU-3 is worse than in non-rift areas due to the presence of poor-quality thermal waters circulating upward from great depth.

3. There appear to be sand and gravel layers within HSU-3 at depths of 4000 to 5000 feet in the Alamosa area, though the total thickness of these permeable units likely comprises 20 percent or less of the total thickness of HSU-3 in that area.

4. There is evidence of active upward ground water leakage through low-permeability (clay) units within HSU-3 in the Alamosa area. This activity may be due to proximity to rift-related faulting. The rates of upward leakage within HSU-3 appear to average about 0.7 feet per year.

5. There is evidence of downward vertical leakage from HSU-2 into HSU-3 in the Alamosa area. The one-dimensional view provided by the well logs may imply that there is attendant lateral movement of ground water through bedding planes or fault planes at the boundary of HSU-2 and HSU-3, or that there may be ground water movement out of the central Valley area, most likely to the south.
DATA POINT
BEST FIT LINE
CALCULATED T = 132,000 gpd/ft (see Appendix A).

\[ \frac{V}{Q} \]

FLOW RATE GRAPH

HOOPER POOL WELL
NORMALIZED TIME VS
WATER CONSERVATION
COLORADO WATER
RESOURCES
AND POWER
DEVELOPMENT
AUTHORITY
SAN LUIS VALLEY
CONFINED AQUIFER
STUDY

DATE: JUNE, 1987

FIGURE 2.2
CALCULATED $T = 9,600$ gpd/ft (see Appendix A).

$s = \text{Residual Drawdown in Feet}$

$t' = \text{Time Since Well Capped in Minutes}$
DATA POINT
BEST FIT LINE
CALculated $T = 11,000 \text{ gpd/ft}$ (see Appendix A).

$s - s' = \text{Original Static Head in Feet} - \text{Residual Drawdown in Feet}$
$t / t' = \text{Time Since Well Opened in Minutes} / \text{Time Since Well Capped in Minutes}$
DATA POINT

BEST FIT LINE

CALCULATED T = 13,900 gpd/ft (see Appendix A).

\( t/r_w^2 \) = Time in Minutes / Well Radius in Feet Squared
\( Sw/Q \) = Drawdown of Discharging Well in Feet / Discharge Rate in GPM
DATA POINT ⊙

BEST FIT LINE ———

CALCULATED $T = 4,900$ gpd/ft (see Appendix A).

$s =$ Residual Drawdown in Feet
$t =$ Time Since Well Capped in Minutes
DATA POINT
BEST FIT LINE
CALCULATED T = 4,500 gpd/ft (see Appendix A).

\[ s = s' = \text{Original Static Head in Feet} \]
\[ t / t' = \text{Time Since Well Opened in Minutes} / \text{Time Since Well Capped in Minutes} \]
COLORADO WATER RESOURCES
AND POWER DEVELOPMENT AUTHORITY
SAN LUIS VALLEY CONFINED AQUIFER STUDY

CARROLL WELL
DEPTH vs CALCULATED DS
AND FLOWMETER RESPONSE

HRS WATER CONSULTANTS, INC.
WITH ROBERT E. MORAN

DATE: JUNE, 1987
FIGURE: 2.11

DOWNHOLE FLOWMETER RESPONSE

CALCULATED DISSOLVED SOLIDS (mg/l)

SPINNER COUNTS

DEPTH BELOW GROUND SURFACE (feet)

CALCULATED DISSOLVED SOLIDS (mg/l)

0.00  0.50  1.00  1.50  2.00  2.50  3.00

450  350  250  150  50  0

COLORADO WATER RESOURCES
AND POWER DEVELOPMENT AUTHORITY
SAN LUIS VALLEY CONFINED AQUIFER STUDY

CARROLL WELL
DEPTH vs CALCULATED DS
AND FLOWMETER RESPONSE

HRS WATER CONSULTANTS, INC.
WITH ROBERT E. MORAN

DATE: JUNE, 1987
FIGURE: 2.11
COLORADO WATER RESOURCES
AND POWER DEVELOPMENT AUTHORITY
SAN LUIS VALLEY CONFINED AQUIFER STUDY
ALAMOSA GEOTHERMAL WELL
DEPTH vs GAMMA COUNT
AND NEUTRON COUNT
HRS WATER CONSULTANTS, INC.
WITH ROBERT E. MORAN
DATE: JUNE, 1987
FIGURE: 2.9
Electric Log Bottom-Hole Temperatures

- Temperature Survey (Mapco-Amoco)
- Expected Formation Temperatures
- Alamosa Geothermal Well Temperature Log (this study)

Wells

3.0 WAGGONER-BALDRIDGE WELL DATA ANALYSIS

3.1 INTRODUCTION
At the authorization of the Colorado Water Resources and Power Development Authority, HRS Water Consultants, Inc. coordinated acquisition and interpretation of data from a new oil and gas test well located in the San Luis Valley of Colorado. The well, named No. 1-19 San Francisco Creek (SFC), is owned by the Waggoner-Baldridge Energy Co. of Dallas, Texas. No. 1-19 SFC is located in the northwest quarter of the southwest quarter of Section 19, T 39 N, R 6 E, Rio Grande County, Colorado; approximately five miles south of the town of Del Norte (Figure 3.1). This test well was drilled during the period November 13 through November 26, 1986.

Under a written agreement with Waggoner-Baldridge Energy, the Authority (through HRS) has provided Waggoner-Baldridge with geophysical logs in the interval 0 to 1000 feet and geologic information in the interval 0 to 3000 feet. In return, Waggoner-Baldridge has provided HRS with geophysical logs in the interval of approximately 1000 to 5872 feet (total depth), and geologic information in the interval of approximately 3000 to 5872 feet.

The objective of acquiring geological and geophysical data from Well No. 1-19 SFC was to enlarge the database of existing information relating to the confined aquifer which lies beneath the San Luis Valley by taking advantage of the opportunity to acquire meaningful and good-quality data. This chapter describes the types of data which were obtained, discusses the approach to interpretation, and presents the results of the interpretation.

3.2 TYPES OF DATA ANALYZED
Two general types of data were acquired during the present effort: 1) geological or drilling-related, and 2) geophysical. Figure 3.2 is a graphical tabulation of the data which are now owned by the Authority as a result of the present effort, along with the depth interval from which each data set was obtained.
3.2.1 Geologic and Drilling-Related Data

Washed, bagged, and labeled drill-cuttings samples at ten-foot intervals have been prepared by Ms. Robbie Gries, subcontractor to HRS, for the interval 70 to 5300 feet. Unless requested otherwise by the Authority, these samples will remain at the HRS offices. In addition, Ms. Gries prepared a lithologic strip-log, which contains her interpretations of the rock types encountered, as well as a drilling-rate log, for the interval 40 to 5872 feet. A commercial mud log, which also includes interpreted lithologies encountered, has been obtained for the interval 1003 to 5872 feet. A copy of the original geolograph record of drilling rate has been obtained.

3.2.2 Geophysical Well Log Data

Under a data-exchange agreement, the Authority and Waggoner-Baldridge Energy Co. have each received copies of all geophysical logs obtained from this well. Geophysical logs obtained directly through funding provided by the Authority include the following:

1. Dual-Induction/Guard Log (with Self-Potential): 0-1014'
2. Compensated-Density/Dual-Spaced Neutron: 0-1014'
3. Compensated Spectral Natural Gamma Log: 0-1014'.

The geophysical logs funded by Waggoner-Baldridge for its own uses, and of which copies have been provided to the Authority under the data-exchange agreement with Waggoner-Baldridge, are as follows:

1. Cyberlook log: 4600'-5560'
2. Dipmeter raw data: 4600'-5560'
3. Computed Mean-Square Dip Log: 4600'-5560'
4. Litho-Density/Compensated Neutron Log: 1000'-5872'
5. Borehole-compensated Sonic Log: 1000'-5838'
6. EPT/Microlog: 1000'-5841'
7. Dual-Induction/Spherically-Focused Log: 1000'-5872'.

3.3 DATA INTERPRETATION APPROACH AND METHODS

The geophysical logs listed in Section 2.0 have been interpreted for
various hydrogeologic properties, including:

1. lithology
2. presence and extent of faulting and fracturing
3. inflow and outflow of water to and from the borehole
4. porosity and permeability
5. ground water quality.

In addition, a correlative study of surrounding borehole geophysical logs and seismic data has been performed, to estimate lateral continuity of rock layers within the Conejos Formation of importance to ground-water movement.

3.3.1 Lithologic Interpretation

Conejos Formation lithologies (rock types) have been determined from resistivity and gamma logs, the commercial mud-log descriptions, Robbie Gries' cuttings descriptions, and a recheck by HRS of samples in intervals where descriptions are not in agreement between Gries and the mud logger.

Density and sonic logs, as well as the drilling-time log, were used to estimate the depth intervals and extent of fracturing which could enhance porosity and permeability within the Conejos Formation. Since there was no noticeable fluid loss or gain in the borehole of No. 1-19 San Francisco Creek, little could be inferred regarding potentiometric-head distribution with depth in the Conejos Formation at that location.

3.3.2 Aquifer Characteristics Interpretation

Porosities and permeabilities have been estimated for the Conejos Formation in No. 1-19 SFC by using the resistivity and SP logs, cuttings descriptions, and the neutron, density, and porosity logs of the hole.

Estimates of water quality (specific conductance or NaCl-equivalent DS concentration) have been made from the SP and resistivity logs, and from the drilling-mud and downhole temperature information.
3.4 AQUIFER CHARACTERISTICS OF THE CONEJOS FORMATION

3.4.1 Aquifer Porosity

The interval 0 to 1700 feet in No. 1-19 SFC appears to be predominantly high-porosity volcanic and volcaniclastic rock materials with a relatively high degree of fracturing. Below 1700 feet to a depth of approximately 3470 feet, very low hydraulic conductivity materials occur almost exclusively. From 3470 feet to the base of the Conejos Formation (at a depth of 4310 feet) relatively high-porosity and high-hydraulic conductivity lava flows predominate.

In the upper 1700 feet, average porosities indicated on the geophysical logs are as high as 50 to 60 percent. This is erroneous, and is caused by miscalibration of the logs in volcanic-rock terrain. Re-calibration spot checks indicate average porosities in the range of 30 to 40 percent, with several fractured intervals reaching porosities in excess of 50 percent. The interval 0 to 1700 feet is approximately 80 percent permeable material.

3.4.2 Aquifer Hydraulic Conductivities

Average hydraulic conductivities for the Conejos Formation as a whole in No. 1-19 SFC appears to be relatively low over the entire Conejos depth interval of 0 to 4310 feet. However, the interval 180 to 1710 feet appears to have relatively high hydraulic conductivity (K), possibly on the order of $10^{-3}$ cm/sec. This estimate is not based on direct calculation; it is based on comparisons of resistivity and porosity in No. 1-19 SFC with resistivity and porosity measurements in volcanic areas of known hydraulic conductivity. A value of $10^{-3}$ cm/sec agrees well with a range of $1.3 \times 10^{-3}$ cm/sec to $1.6 \times 10^{-3}$ cm/sec calculated for a 524-foot interval of Conejos Formation lava flows, laharic breccia, and water-laid tuff in a municipal well owned by the Town of Saguache (Huntley, 1976).

Over the 1530-foot interval of relatively permeable Conejos Formation rock material (in the interval 180 to 1710 feet) in No. 1-19 SFC, an average K
of $10^{-3}$ cm/sec calculates to a transmissivity ($T$) of approximately 30,000 gpd/ft. It should be noted that a large contributing factor to the relatively high estimated transmissivity is fracture in competent rocks (lava flows and welded tuffs) of the Conejos Formation. Heterogeneity of the Conejos, as seen in poor log correlation from borehole to borehole in the San Juan Mountains and beneath the San Luis Valley, indicates that $T$ and $K$ may be highly variable. Intense fracturing (whether of primary or secondary origin) of competent rocks within the Conejos is likely to have enhanced the horizontal hydraulic conductivity more than the vertical hydraulic conductivity (Huntley, 1976). It is possible that such fracturing in areally-extensive lava flows or welded tuffs could provide a path for enhanced ground water recharge into HSU-2 and HSU-3 of the Valley, or possibly a short-circuiting path for ground water movement from one stream sub-basin to another within the Rio Grande drainage of the San Juan Mountains.

3.4.3 Aquifer Specific Yield

Specific yield, or storage coefficient, could not be estimated from the geophysical or geological data of No. 1-19 SFC. Since there appeared to be no evidence for a confining layer of rock or artesian pressure on top of the 180 - 1710 foot permeable depth interval of the Conejos, it is likely that this zone constitutes an unconfined aquifer, with an expected specific yield in the range of one or two percent to about 15 percent.

3.5 IMPLICATIONS FOR GROUND WATER RECHARGE

It appears probable that there is considerable ground water recharge to the aquifers of the San Luis Valley via permeable layers of the Conejos Formation in the eastern San Juan Mountains. There are several factors which contribute to this conclusion:

1. There is a near-surface (180 - 1710 ft.) layer of Conejos Formation rock at Well No. 1-19 SFC which is continuous downdip into the San Luis Valley, as interpreted from existin seismic geophysical data.

2. In the San Juan Mountains, that rock layer has an hydraulic conductivity estimated to be on the order of $10^{-3}$ cm/sec, for an
estimated transmissivity of approximately 30,000 gpd/ft.

3. There is a source of water (relatively high precipitation and streamflow) with which the upper Conejos Formation can be recharged.

4. There appears to be a driving force, i.e. a considerable elevation difference, for ground water movement between the San Juan Mountains and the San Luis Valley.

Due to lack of well logs with which to correlate the data of No. 1-19 SFC, the continuity of the relatively-conductive upper Conejos Formation rock materials is in doubt. There appears to be greater continuity of the units within the Conejos to the north and south, within the San Juans, than there is downdip to the east, into the San Luis Valley. It appears that most if not all of the relatively permeable material seen in the upper Conejos in No. 1-19 SFC is missing in the Tennessee Gas test well and in the other deep test wells further east in the Valley. Whether the permeable rocks of the Conejos have been eroded, or never had been deposited in the Valley, is not known.

The overall effect of decreased hydraulic conductivity in the upper Conejos Formation (probably equivalent to HSU-3 of the San Luis Valley) to the east of the recharge area would be to force ground water to move out of that unit along pathways less resistant to ground water flow. The most probable pathway for movement of deep ground water in the western Monte Vista Graben area is upward into the highly-conductive Los Pinos Formation gravel layers; i.e., from HSU-3 upward into HSU-2.

It appears that there may be a component of ground water movement in the upper Conejos Formation from sub-basins of the Rio Grande (e.g. San Francisco Creek and Pinos Creek) southward into the Alamosa River, La Jara Creek, upper Conejos River, and Los Pinos River drainage basins. Though there is no potentiometric head data available as direct evidence for this, there is indirect evidence in the form of:
1. Similarity in log character in the permeable rocks of the upper Conejos Formation between No. 1-19 SFC and Champlin No. 1 Federal 34A-13, located in the upper Conejos River canyon (Section 25, T35N, R4 1/2 E) approximately 25 miles south.

2. A deficit in calculated water yield of the Rio Grande and Pinos Creek/San Francisco Creek sub-basins is offset by a nearly equal surplus of yield in the Alamosa/La Jara/Conejos/Los Pinos River sub-basins.
TYPE OF LOG OR LOGGED DATA ACQUIRED DEPTH INTERVAL (FEET)

---------------------I-----------~--------I----------I-~--------I-~--------I-~--------I

CYBERLOOK LOG
COMPUTED MEAN-SQUARE DIP LOG
DIPMETER RAW DATA LOG
LITHO-DENSITY/ COMPENSATED NEUTRON LOG
BOREHOLE-COMPENSATED SONIC LOG
EPT/MICROLOG
DUAL INDUCTION/ SPHERICALLY-FOCUSED LOG
COMPENSATED SPECTRAL/ NATURAL GAMMA LOG*
COMPENSATED DENSITY/ DUAL-SPACED NEUTRON LOG*
DUAL INDUCTION/GUARD LOG (WITH SELF POTENTIAL) *
GEOLOGRAPHS RECORD
COMMERCIAL MUD LOG
DRILL-CUTTINGS SAMPLES (10' SAMPLE INTERVAL) *
DRILLING-TIME LOG
GEOLOGIST'S LITHOLOGIC DESCRIPTIONS

* PAID FOR BY CWRPDA.
4.0 INTERPRETATION OF SATELLITE IMAGERY

4.1 INTRODUCTION

HRS Water Consultants, Inc. worked with Robert Moran to perform a structural interpretation of the satellite image of the San Luis Valley produced by Earth Satellite Corp. (Earthsat). The goal of this part of the Phase IB studies is to determine the existence of large geologic structures and to attempt to define their relationships to ground water movement and quality in the Valley. Of particular interest is the effect of the geologic structures on HSU-3, the deep confined aquifer.

The effect of geologic structure on the ground water system is discussed in terms of
- recharge to and discharge from the Valley
- water movement within the unconsolidated valley sediments
- water quality in the confined aquifers (particularly HSU-3), and
- water supply.

The primary data source used in this analysis was the satellite image created by Earthsat from information gathered by the NASA Thematic Mapper. The image covers the entire Valley and much of the area West of the Valley in the Rio Grande basin. The image is not a photograph of the Valley, but is a computer processed presentation of data gathered from three different frequency bands of reflected electromagnetic energy detected from satellite orbits in November, 1982, and December, 1984. The result of the processing is an image in which snow is blue, healthy vegetation is pale green, and bare soil color varies depending on water content and soil type. This image shows only surface features, though some inferences can be made about subsurface phenomena based on surface expressions of these features. Resolution of the image is about 30 meters meaning that the smallest feature that can be seen is about 30 meters in diameter. Roads can be seen fairly well, though buildings are poorly defined. The image provides good differentiation of plant types and geology.
Also used in the interpretation were several images produced in the NASA Heat Capacity Mapping Mission (HCMM). These images show an area of approximately 220,000 square miles, including the San Luis Valley with relatively poor resolution, but are very useful in discerning large geologic structures. One image shows thermal effects which are the result of both heat flow from the subsurface and surface heating and cooling. In light of the thermal characteristics of the Valley, the HCMM images can show some features better than the thematic mapper image.

Results of seismic, magnetic, and gravity surveys in the Valley were used for comparison with the image interpretation. In many cases, analysis of these large, deep-seated geologic structures resulted in the identification of basement features which align well with the surficial lineations.

Additional information was gathered from published reports, maps, and papers covering the Valley and its drainage basin. Ground surface expression of some of the features was investigated during a field trip to the San Luis Valley.

4.2 APPROACH TO INTERPRETATION

Initial analysis of the imagery consisted of attempts to identify linear features, or lineations, in the Valley and surrounding areas. These can be loosely defined as any natural features which appear to be roughly straight.

4.2.1 Identification of Linear Features

These linear patterns can be interpreted in several ways. In hard-rock areas surrounding the valley, lineations on the surface are considered to be the surface expression of fault planes, joints, dikes, or upturned bedding planes in the rock. These structures can appear on the surface as
- linear sections of stream valleys
- ridge lines
- termination points of adjacent mountain chains
- changes in visible rock type, or
- lines of vegetation change.

Since these may all be related to faults, they are termed faults in the discussions, though they may not have been checked on the ground or mapped.

4.2.2 Association of Features

In some areas of both hard rock and unconsolidated sediments, several linear features may appear close together with similar orientations. In some cases, these types of structures appear to be associated with successive periods of faulting and volcanic activity and may represent zones of weakness in the rock units. Highly fractured zones associated with faulting activity can act as efficient conduits for ground water flow. For this report, these features have been called shear zones, and are thought to be very important to both the movement and quality of ground water and to thermal activity.

Several lineations have been identified in the unconsolidated sediments in the Valley. Linear features in the unconsolidated sediments may represent:
- slippage along planes in the sediments
- changes in surface water or ground water movement
- surface expression of deep structural phenomena such as faults, or
- evidence of surface water flow, agricultural patterns, wind patterns, human intervention, cloud shadows, or any other interferences.

Because of all the possible interferences, an effort has been made to organize the linear features in the unconsolidated sediments into several groups.

Several linear features were identified in the unconsolidated sediments which appear to be collinear with trends identified in geophysical surveys of the basement structure beneath the sediments. The existence of such
correlative data between a surface feature and a subsurface trend suggests a connection between the deep feature and the surficial feature. This connection may be a zone of material of different hydraulic properties than the surrounding material.

Some lineations in the unconsolidated sediments appear to be the surface expression of faults which have been mapped previously, and thus have geologic backup. Other linear features may be associated with some physical phenomena (such as springs), indicating that they are not merely surface features.

Some lineations in the sediments are visible only on the HCMM image with no other backup. Because of the nature of this image, these lineations are expected to be the result of both surface and subsurface influences, though their relationship to subsurface flow is unknown.

Many lineations in the unconsolidated materials are visible only on the Earthsat image with no supportive data from other sources. In some cases, lineations in the unconsolidated material appear to be extensions of features identified in the hard-rock areas, indicating possible structural control. In other cases, lineations may be seen as tonal changes of unknown origin.

4.3 EFFECTS ON GROUND WATER AVAILABILITY AND MOVEMENT

Linear features identified on the imagery are shown on Figure 4.1. Probable shear zones are indicated as dashed lines in this figure. The most important features are numbered and further described in Appendix B of this report. Features which appear to be related or the result of the same forces are grouped together in the table.

4.3.1 Correlative On-Site Evidence

During a field trip to the Valley, the surface expression of several of the features discussed in Appendix B was explored. This comparison of features seen on the satellite image to their expression at ground level showed strong evidence of deep-seated faulting in several instances. Some
results of the field trip are discussed below.

Several of the features crossing the Sangre de Cristo Mountains are quite visible from ground level. The intersection of features 1 and 58 (Figure 4.1) appears to be a very wide, shallow-sloping valley extending far into the mountain range. Valley View Hot Springs is located where this wide bedrock valley meets the unconsolidated sediments of the San Luis Valley floor. A similar wide valley is seen along feature 27, although no hot springs are mapped where this valley empties out into the unconsolidated sediments.

Evidence of the Sangre de Cristo fault can be seen along the western side of the mountains as roughly triangular facets of rock facing the Valley above the alluvial fan deposits which extend into the Valley. These facets can be seen clearly along the northern part of the Sangre de Cristos and along the southern exposure of the mountains north of Mount Blanca.

Many of the tonal changes seen on the image show up as vegetation changes on the ground. Specifically, features 48 and 55 were visible from ground level as changes in the dominant plant species. It is expected that this sort of change is a good indicator of changes in water availability and/or quality.

Very high reflectance areas which are white on the image appear to be related to alkali deposits. These can be seen on the ground in many areas of the valley: along San Luis Creek, near Russell Lakes, south and west of the Great Sand Dunes National Monument, and interspersed in the irrigated areas of the Valley. In some cases, these deposits appear to be related to the linear features described in Appendix B. This may imply that some lineations affect the upwelling of water to the ground surface. Features 47 and 48 appear to be strongly associated with alkali deposits.

4.3.2 Geothermal Evidence

Several light green spots less than ten acres in area can be seen on the image at locations which appear to have hot spring activity. The most noticeable of these is at Mineral Hot Springs. Additional locations where
this color appeared were investigated on the ground. At Mineral Hot Springs, the color may be related to the buff colored soil, geyserite deposits, and other effects of the highly mineralized water. At a smelter northwest of Saguache, this color appears in an area where the ground surface is covered with weathered sulfide ore, waste rock, and tailings piles. In an area about five miles northwest of Del Norte, a small patch of this green color was seen at the mud pit of one of the Kirby Petroleum wells. This may imply that the mineral content of the water and cuttings washed up during drilling, or exposed at the smelter site, is similar to what is found at the surface near some of the Valley's hot springs. The mineral or minerals responsible for this reflectance are not known, though this could probably be determined with the help of Earthsat. The reflectance producing this color may be diagnostic of a particular mineral assemblage which is often associated with geothermal activity.

Several warm springs are located at areas of highly fractured rock along features identified on the image. Diamond Spring is located along feature 53 at the edge of the Hinsdale Formation volcanic flow in an area of broken rock. McIntire Warm Spring is located in an area of highly fractured rock associated with features 48 and 53. Water can be seen flowing out of fractures in Conejos Formation rocks. High transmissivity due to fractured rock may allow the spring a very high production rate. The fractures vastly increase the effective transmissivity of the formation over that of the rock itself.

Features 49 and 57 both appear to extend entirely across the Valley. These are thought to be expressions of ancient, deep-basement zones of weakness, possibly shear zones. The features are visible on the HCMM images as linear bands of tonal variation extending beyond the Valley into the adjacent physiographic provinces. The present course of the Rio Grande may be controlled by feature 49 in the reach from Del Norte to a point about six miles northwest of Alamosa. This apparent geologically-recent control of the course of a major river by a Precambrian zone of weakness may be evidence for reactivation of the zone through many epochs. The effect of such reactivation on the deep confined aquifer may be to enhance vertical hydraulic conductivities and increase the rate of vertical ground water leakage.
4.4 EFFECTS ON GROUND WATER QUALITY

4.4.1 Correlative Water Quality Information

A review of all the pertinent data in both state and federal (Watstore) files yielded useful, deep aquifer (depths greater than 2000 feet) water quality data from eleven wells. Of these eleven wells, four were sampled and analyzed for major ions during the deep well inventories of the Valley. The analyses are reported and discussed in the Interim Task 2 Report of this study. Because these wells are all completed in both HSU-2 and HSU-3, the water quality analytical results represent composite samples of ground water from these two aquifers. Tests performed on one of the wells (the Carroll Well) indicate that the majority of the flow from the wells is probably from HSU-2. Because of this, the results give little indication of water quality in the deeper aquifer.

Geophysical logs from seven oil test wells in the Valley were interpreted to give an estimate of changes in dissolved solids (DS) concentration with depth in the confined aquifers of the Valley (HSU-2, 3, 4, and 5). Four of the wells completed to between 2000 and 2500 feet had DS concentrations less than 500 mg/L. Three had poor water quality (approximately 2500 to 3000 mg/L DS) throughout their entire well depths. At depths of approximately 2000 to 2500 feet, six of the seven wells showed an abrupt increase in DS to greater than 3000 mg/L (Interim Task 2 Report, this study).

These very limited data would suggest that untreated HSU-3 ground water in most areas of the valley are unsuitable for drinking water purposes, especially in areas where the Fish Canyon and Carpenter Ridge Formations are present. However, most of the wells with depths greater than 3000 feet originally were drilled for oil and gas exploration tests. They would have been located using geologic mapping and limited geophysical information, and were probably intended to intercept structural features. As such, they may not be representative of the water quality from the unfaulted areas of HSU-3. Given the size and complexity of the San Luis Valley and the small number of locations for which water quality data exist, it must be concluded that almost
Grant in conversations with T. Giles, and from areas near feature 51 in the center of the closed basin (Siebenthal, 1910).

4.4.3 Structure Effects on Water Quality

Several lines of indirect evidence indicate that the geologic structure, e.g. fractures, faults, and rifting, significantly impacts deep, and possibly shallow water quality. Figure 4.2 depicts the locations of known thermal springs and wells in the San Luis Valley and surrounding areas. The thermal waters seem to occur preferentially along two lines, one running roughly east-west through the Summer Coon Volcanic region and the other along a roughly north-south line through Villa Grove and the San Luis Hills. The alignment of thermal water along trends corresponding to structural features noted on Figure 4.1 is readily apparent. As noted in Appendix B, several of the major spring localities are at the intersections of structural features noted on the TM and HCMM imagery. Such patterns indicate that faults act as conduits for upward movement of heat. Heat flow may eventually result in convective flow cells in the ground water system, even if the heat source is dry (Romero and Fawcett, 1978).

Structures which intersect the crystalline basement rocks may allow hot, less dense, high DS water to rise from deep in the basin and mix with waters from shallower zones. Since an increase in temperature results in an increase in the solubility of most constituents, it is natural to expect these deep-sourced, ascending waters to have high DS concentrations. The high DS concentrations may result when the deep waters contact geothermal source rocks, and/or when these waters dissolve soluble minerals from shallower zones as they ascend. An example of the type of water which might be expected from these chemical reactions is found in the Alamosa Geothermal Well. This well appears to have intersected hydrothermally-altered rock, and appears to yield predominantly sodium-chloride-rich water at a temperature of about 200 to 215 degrees F, from depths between approximately 5000 and 6000 feet below ground surface.

Well data from several studies in the San Luis Valley indicate that some
Grant in conversations with T. Giles, and from areas near feature 51 in the center of the closed basin (Siebenthal, 1910).

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Well data from several studies in the San Luis Valley indicate that some

4-9
deep fault zones, especially those oriented parallel to the axis of the basin, may be transmitting heat and high DS waters upward from underlying units. The deep-seated faulting oriented parallel to the axis of the Valley (roughly north-south to NW - SW) is thought to be caused by east-west tensional stress in the Rio Grande Rift, of which the Valley is a part. The tensional stresses have caused large-scale normal and strike-slip faulting, possibly local thinning of the earth's crust, and have allowed heat, hot fluids and magma to move upward along the fault zones. At the locations of fault zones allowing upward leakage of water, well and spring samples are expected to contain unusually high concentrations of organic carbon, dissolved gasses (carbon dioxide, methane, and hydrogen sulfide), dissolved solids, silica, and fluoride. This expectation is based on comparison of the chemistry of San Luis Valley deep water and water from the Valles Caldera geothermal area of northern New Mexico. Such wells are expected to exhibit anomalously high temperature gradients and artesian pressures in comparison to wells located farther from the fault zones. In addition, it is possible that ascending hot water contains unusually high concentrations of strontium, lithium, boron, sodium, chloride, and anionic complexes stable at high pH's (e.g., uranium, arsenic, selenium, molybdenum, and vanadium). Where relatively large volumes of shallow waters mix with deep waters, dilution would mask the deep contributions. This is expected to be the case at some distance from deep-seated rift-related fault zones.

It is interesting to note that the "sump" area of the closed basin lies in an area where several major fault zones intersect. Traditionally, it has been assumed that the sump contained poor quality water simply because it was the lowest part of the basin, and that salts from natural weathering and irrigation return flows accumulated there. The HRS satellite imagery interpretation suggests that, in addition to these processes, the sump area receives significant volumes of ground water that have moved upward along deep-seated fault zones and have mixed with water from shallower zones (HSU-1, HSU-2, and HSU-3). The complexity of the water chemistry and physical framework of the Valley are believed to have masked the effect of deep-seated structures on the valley, to the point of obscuring the importance of structure in earlier studies.
At present, we expect the fault zones to yield high temperature water with high DS content, at relatively high production rates. Wells located away from the fault zones are expected to yield water of better quality, in general, though at lower production rates. Until more information is gathered, this relationship will remain speculative rather than certain.
REFERENCES


APPENDIX A

Deep Well Test Analysis
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<td>A-1</td>
</tr>
<tr>
<td>Hooper Pool Well, Recovery-Test Analysis</td>
<td>A-2</td>
</tr>
<tr>
<td>Carroll Well, Constant-Drawdown Test Analysis</td>
<td>A-3</td>
</tr>
<tr>
<td>Carroll Well, Recovery-Test Analysis</td>
<td>A-4</td>
</tr>
</tbody>
</table>
Hooper Pool Well
Constant Drawdown Test Analysis

A. Input Parameters

\[
\frac{\Delta S_w}{Q} / \Delta \log_{10} t = 0.058 - 0.066 = 0.002 \text{ ft-min/gal}
\]

(from linear-regression best-fit line shown in Figure 2.2)

B. Equations

\[
T = \frac{2.30}{4\pi \left( \frac{\Delta S_w}{Q} \right) \left( \Delta \log_{10} t \right)} \quad \text{(Lohman, 1979, p. 24)}
\]

C. Calculations

\[
T = \frac{(2.30)(1440 \text{ min/day})}{4\pi (0.002 \text{ ft-min/gal})(7.48 \text{ gal/ft}^3)} = 132,000 \text{ gpd/ft}
\]
Hooper Pool Well
Recovery - Test Analysis

A. Input Parameters

\[ \Delta(S - S') = 15 \text{ feet} \]
\[ Q = 548 \text{ gpm (weighted average)} \]
\[ \Delta S' = 13.1 \text{ feet} \]
(see Figure 2.3 and 2.4)

B. Equations

\[ T = \frac{264 Q}{\Delta(S - S')} \]
(Driscoll, 1986, p. 255)

\[ T = \frac{264 Q}{\Delta S'} \]
(Driscoll, 1986, p. 256)

C. Calculations

\[ T = \frac{(264)(548 \text{ gpm})}{15 \text{ feet}} = 8,600 \text{ gpd/ft} \]

\[ T = \frac{(264)(548 \text{ gpm})}{13.1 \text{ feet}} = 11,000 \text{ gpd/ft} \]
Carroll Well
Constant Drawdown Test Analysis

A. Input Parameters

\[
\frac{\Delta S_w}{Q} / \Delta \log 10 t = 0.501 - 0.482
\]

\[
= 0.019 \text{ ft-min/gal}
\]

(from linear-regression best-fit line shown in Figure 2.5)

B. Equations

\[
T = \frac{2.30}{4\pi \left( \frac{\Delta S_w}{Q} \right) \left( \Delta \log 10 t \right)}
\]

(Lohman, 1979, p. 24)

C. Calculations

\[
T = \frac{(2.30)(1440 \text{ min/day})}{4\pi (0.019 \text{ ft-min/gal})(7.48 \text{ gal/ft}^3)}
\]

\[
T = 13,900 \text{ gpd/ft}
\]
Carroll Well
Recovery – Test Analysis

A. Input Parameters
$\Delta(S - S') = 5.6$ feet
$Q = 104$ gpm (weighted average)
$\Delta S' = 8.1$ feet
(see Figure 2.6 and 2.7)

B. Equations
$T = \frac{264 \cdot Q}{\Delta(S - S')} \quad$ (Driscol, 1988, p. 255)

$T = \frac{284 \cdot Q}{\Delta S'} \quad$ (Driscol, 1988, p. 256)

C. Calculations
$T = \frac{(264)(104 \text{ gpm})}{5.6 \text{ feet}} = 4,900 \text{ gpd/ft}$

$T = \frac{(284)(104 \text{ gpm})}{8.1 \text{ feet}} = 4,500 \text{ gpd/ft}$
APPENDIX B

Table B.1

San Luis Valley Image Interpretation
## San Luis Valley Image Interpretation

<table>
<thead>
<tr>
<th>Group</th>
<th>Feature Type</th>
<th>Azimuth (degrees)</th>
<th>Source</th>
<th>Physiographic Province</th>
<th>Expected Effect on HSU-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Hard-rock fault with extension</td>
<td>42</td>
<td>Earthsat</td>
<td>Sangre de Cristo Mts., Baca Graben</td>
<td>11. Faulting near &quot;Del Norte High&quot; should increase hydraulic conductivity in a possible recharge area for HSU-3.</td>
</tr>
<tr>
<td></td>
<td>Seen in sediments</td>
<td></td>
<td></td>
<td></td>
<td>12. Ground water movement along feature may be evidenced by Russell Lakes occurrence. Water table near Russell Lakes is very close to the ground surface, resulting in extensive alkali deposition.</td>
</tr>
<tr>
<td>50</td>
<td>Lineation in unconsolidated sediments, continuation of hard rock features, no other</td>
<td>34</td>
<td>Earthsat</td>
<td>Monte Vista, Braben, Alamosa Horst</td>
<td>13. Mineral Hot Springs is at the intersection of feature 50 and the group C features. This indicates that the feature is related to movement of hot water from depth to the surface.</td>
</tr>
<tr>
<td></td>
<td>Backup</td>
<td></td>
<td></td>
<td></td>
<td>14. Beyserite deposits near Mineral Hot Springs indicate high mineralization of the water rising to the surface at the springs. Sulphurous odors also imply high mineral content in the water.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>15. May act with feature 57 in moving water to and within the Valley.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>16. Parallel to many other features in the San Juan Mts. Some of these may also continue into the Valley, though not as easily visible as group A.</td>
</tr>
<tr>
<td>B</td>
<td>Hard-rock fault with extension</td>
<td>65</td>
<td>Earthsat</td>
<td>San Juan Mts.</td>
<td>11. Feature appears to be continuous across unconsolidated valley sediments. This is direct evidence that a hard-rock feature can cause a lineation (fault) in the sediments.</td>
</tr>
<tr>
<td></td>
<td>Seen in Valley sediments, may be related to deep structure</td>
<td></td>
<td>HCM</td>
<td>Braben</td>
<td>12. Just East of the center of the Valley, there is a small, cross-faulted area with additional plant growth. This is evidence that water can move in the unconsolidated zone along the fault trace, upwelling from the deep feature to the ground surface.</td>
</tr>
<tr>
<td></td>
<td>Through relation to Clayton Dome</td>
<td></td>
<td></td>
<td></td>
<td>13. Visible extension of fault into unconsolidated sediments is evidence of recurrent movement.</td>
</tr>
</tbody>
</table>
### TABLE B.1 PAGE 2

**San Luis Valley Image Interpretation**

<table>
<thead>
<tr>
<th>Group</th>
<th>Feature</th>
<th>Type of Feature</th>
<th>Azimuth</th>
<th>Image</th>
<th>Physiographic Province</th>
<th>Water Availability and Movement</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>18</td>
<td>Hard-rock lineation</td>
<td>135</td>
<td>Earthsat</td>
<td>Bonanza</td>
<td>11. Feature 19 appears to be the extension of</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Volcanic</td>
<td>features 18 and 20 across the unconsolidated Valley deposits.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Center</td>
<td>12. Small localized color differences in the Earthsat image appear to be associated with hot spring activity.</td>
</tr>
<tr>
<td></td>
<td>19</td>
<td>Lineation in sediments with geologic backup inferred from location of hot springs as seen on Earthsat image</td>
<td>135</td>
<td>Earthsat</td>
<td>Baca Graben</td>
<td>13. The feature appears to be able to move hydrothermal fluids upward. Hydrothermal alteration products are seen in intrusives in this area. The basement faulting seems to have an effect on water movement in the unconsolidated Cristo Mts. materials.</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>Hard-rock fault</td>
<td>122</td>
<td>Earthsat</td>
<td>Sangre de Cristo Mts.</td>
<td>14. This group may also be related to hydrothermal copper enrichment in the west flank of the Sangre de Cristos.</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>Hard-rock fault</td>
<td>130</td>
<td>Earthsat</td>
<td>Sangre de Cristo Mts.</td>
<td>15. The feature is also marked by a tone change between the area North of number 19 and the area South of 19. This may indicate that the depth to near-surface ground water is greater South of 19.</td>
</tr>
<tr>
<td>D</td>
<td>5</td>
<td>Hard-rock fault, possible</td>
<td>120</td>
<td>Earthsat</td>
<td>San Juan Mts.</td>
<td>16. Tonal changes can be seen in Earthsat and HCM images extending into the Valley from Saguache Creek, implying the existence of probable changes in the pattern of water movement.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Surface expression of truncating feature at N. end of San Juan Sag (Gries, 1985)</td>
<td>HCM</td>
<td>San Juan Mts.</td>
<td>17. Ground water from the upper Saguache Creek recharge area into the confined aquifer in the Northern part of the Valley.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>23</td>
<td>May delineate shear zone with feature 5, contributing to general rock weakness seen in broadening of upper Saguache Creek basin</td>
<td>117</td>
<td>Earthsat</td>
<td>San Juan Mts.</td>
<td>18. Expect that the feature will act to make water movement easier in both vertical and horizontal directions in the Valley in the area of feature 51.</td>
</tr>
<tr>
<td></td>
<td>51</td>
<td>Linear zone in unconsolidated sediments, no geologic backup; may be related to hydrothermal copper enrichment in Crestone area</td>
<td>120</td>
<td>Earthsat</td>
<td>Monte Vista</td>
<td>Feature 51.</td>
</tr>
</tbody>
</table>

B-2
<table>
<thead>
<tr>
<th>Group</th>
<th>Feature Type</th>
<th>Azimuth (degrees)</th>
<th>Source</th>
<th>Physiographic Province</th>
<th>Water Availability and Movement</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>Lineation in unconsolidated sediments, strong expression</td>
<td>115</td>
<td>Earthsat</td>
<td>Monte Vista</td>
<td>1. Expression of this deep basement feature in the unconsolidated sediments may indicate that this feature can act as a control for the upward leakage of water from sources in the Sangre de Cristos, and for leakage of hydrothermal fluids into localized areas of HSU-3.</td>
</tr>
<tr>
<td></td>
<td>Lineation in deep geophysical data, extending upward into the upper Santa Fe formation</td>
<td>120</td>
<td>HCM9</td>
<td></td>
<td>12. The feature lies along a marked change in tone in the sediments which may be the result of changes in water quality, vegetation, or both.</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td>13. The feature appears to terminate in the water-logged areas Southwest of the Great Sand Dunes. This may indicate that it is instrumental in the movement of water from North to South in the Valley.</td>
</tr>
<tr>
<td>F</td>
<td>Linear zone in unconsolidated sediments, appears to be associated with Dumer Coon caldera and Dunes re-entrant, may be a shear zone, associated with several episodes of tectonic activity</td>
<td>87</td>
<td>Earthsat</td>
<td>Monte Vista</td>
<td>11. Several hot springs are located in the Western ledge of feature 57 and in the extension of the feature to the West. This may indicate that this area is associated with the movement of hot water and the upwelling of hot water in the Valley; though there is no direct evidence for this.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>12. Shear zones in the unconsolidated sediments may act to enhance vertical movement of water in the unconsolidated sediments both within and between the several units.</td>
</tr>
<tr>
<td></td>
<td>Lineation in unconsolidated sediments with geophysical backup, roughly parallel to group D features, strong gravity anomaly</td>
<td>115-123</td>
<td>Earthsat</td>
<td>Monte Vista</td>
<td>13. Feature 49 may be the southern edge of a shear zone similar to feature 57. North edge of feature appears to be poorly defined except as the extension of the Sangre de Cristo fault on the Costilla Plain; South side of the Blanca Massif.</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>14. Parallel of feature 49 to deep basement feature defined by geophysics along this section of the Rio Grande may indicate structural control of river morphology.</td>
</tr>
<tr>
<td></td>
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<td></td>
<td>15. Expect enhanced water movement in the plane of this feature in both vertical and horizontal directions.</td>
</tr>
<tr>
<td></td>
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<td></td>
<td>16. Also may enhance surface water - ground water interactions along the stream.</td>
</tr>
<tr>
<td>Group</td>
<td>Feature Number</td>
<td>Feature Type</td>
<td>Azimuth (degrees)</td>
<td>Source</td>
<td>Physiographic Province</td>
</tr>
<tr>
<td>-------</td>
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</tr>
<tr>
<td>B</td>
<td>48</td>
<td>Linear zone in unconsolidated sediments with backup in deep geophysical data which indicates that this may be a large scale rift feature extending to the San Luis Hills</td>
<td>19</td>
<td>Earthsat</td>
<td>Alamosa Horst</td>
</tr>
<tr>
<td>H</td>
<td>56</td>
<td>Hard-rock ridge line, linear</td>
<td>90</td>
<td>Earthsat</td>
<td>San Juan Mts.</td>
</tr>
<tr>
<td></td>
<td>52</td>
<td>Lineation in unconsolidated sediments, no backup</td>
<td>89</td>
<td>Earthsat</td>
<td>Alamosa Horst</td>
</tr>
</tbody>
</table>

B-4
<table>
<thead>
<tr>
<th>Group</th>
<th>Feature Type</th>
<th>Degree</th>
<th>Image</th>
<th>Physiographic Province</th>
<th>Expected Effect on HSU-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Lineation in unconsolidated</td>
<td>67</td>
<td>Earthsat</td>
<td>San Luis</td>
<td>1. May be related to feature 48 zone, with feature 48 crosses along the North end of the San Luis Hills.</td>
</tr>
<tr>
<td></td>
<td>sediments, backup in magnetic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>data, most visible in lava</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>flow North of Conejos River</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>12. These features may act to move water upward to discharge at the surface by juxtaposing the Los Pinos formation of higher hydraulic conductivity against the Conejos formation of lower hydraulic conductivity.</td>
</tr>
<tr>
<td>J</td>
<td>Lineation in unconsolidated</td>
<td>60</td>
<td>Earthsat</td>
<td>Conejos River</td>
<td>1. May act in concert with lower hydraulic conductivity materials in San Luis Hills area to isolate the Costilla Plain ground water system from the rest of the Valley.</td>
</tr>
<tr>
<td></td>
<td>sediments, no backup</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>data, roughly parallel to 53</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>may indicate existence of</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>features at similar azimuth</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>Hard-rock faults and fractures</td>
<td>0</td>
<td>Earthsat</td>
<td>San Juan Mts.</td>
<td>1. Smaller scale faulting and fracture pattern may be related to anticline-axis tensional forces, resulting in open fractures and joints, and a good recharge area.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>95</td>
<td></td>
<td></td>
<td>12. Recharge in upper Sagache Creek and Carnero Creek drainages should reach HSU-3.</td>
</tr>
<tr>
<td>L</td>
<td>Hard-rock fault</td>
<td>130</td>
<td>Earthsat</td>
<td>San Juan Mts.</td>
<td>1. Faults along stream channels may enhance recharge, though the effect of these particular features may be small. Additional fault sets in the mountains may add up to give a significant effect on HSU-3 by enhancement of recharge.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>12. Features appear to be associated with volcanic activity and may also have hydrothermal effects as evidenced by several springs in the area.</td>
</tr>
</tbody>
</table>