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CHARACTERIZATION OF GLENWOOD SPRINGS AND DOTSERO SPRINGS SOURCE AQUIFERS

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16. ABSTRACT

The USBR (Bureau of Reclamation) is conducting studies to find disposal methods for preventing high salinity water from 16 identified sources from entering the Colorado River. Glen-Dot (Glenwood Springs-Dotsero Springs) is one source that contributes 10 percent of the identified salt load, or 227 000 metric tons (249 700 tons), annually. Basic data on physical and chemical properties of the Glen-Dot waters were needed to determine methods of disposal. Consequently, the USBR conducted a site-sampling and analytical program for 14 identified Glen springs and 11 identified Dot springs from 1972 to 1982. Data obtained were evaluated, and physical and dissolved chemical characteristics of the Glen-Dot identified springs were reported.

From October 12 to 26, 1982, the USBR contracted to have boreholes drilled approximately 30.5 m (100 ft) deep into the aquifers in the vicinities of Glen-Dot. On August 15 and 16, 1984, the USBR took water samples from the Glen-Dot boreholes for a second analytical program. The analytical data obtained were evaluated to characterize Glen-Dot aquifers for physical properties, major constituents, trace metals, trace anions, radioactivity, and organic compounds.

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by

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January 1986

Applied Sciences Branch
Division of Research and Laboratory Services
Engineering and Research Center
Denver, Colorado

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UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

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This report consolidates chemical and physical water sample data for 25 identified Glen-Dot (Glenwood Springs-Dotsero Springs) springs obtained by site samplings and off-site analyses by USBR-UCR (Bureau of Reclamation-Upper Colorado Region), GJPO (Grand Junction Project Office) with aquifer water borehole data obtained by a contractor between March 24, 1982, and April 29, 1983, and data obtained by the USBR-ERC (Engineering and Research Center), Denver, Colorado, on August 15 and 16, 1984, and on June 15, 1985. Funding and support was provided by the CRWQO (Colorado River Water Quality Office).

The following personnel contributed to the success of this Glen-Dot aquifers water characterization study:

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GLOSSARY

USBR	Bureau of Reclamation
CRWQIP	Colorado River Water Quality Improvement Program
CRWQO	Colorado River Quality Office
DOI	Department of the Interior
Dot	Refers to the vicinity of Dotsero Springs
DS	Dotsero Springs
DT	Refers to a particular Dotsero Springs borehole
EP	Extractable product
ERC	Engineering and Research Center, Bureau of Reclamation
GJPO	Grand Junction (Colorado) Project Office, Bureau of Reclamation
Glen	Refers to the vicinity of Glenwood Springs
GS	Glenwood Springs
GL	Refers to a particular Glenwood Springs borehole
PIQR	Problem Identification and Qualification Report
RCRA	Resource Conservation and Recovery Act
SLCRO	Salt Lake City (Utah) Regional Office, Bureau of Reclamation
t	metric ton (1000 kg; ≈ 1814.4 lb)
TDS	Total dissolved solids
UCR	Upper Colorado Region, Bureau of Reclamation.
USGS	U.S. Geological Survey

INTRODUCTION

The Colorado River drains a total of 663 000 km^2 (256 000 mi^2) in the United States and Mexico and carries a salinity burden that has historically averaged about 10×10^6 t (11×10^6 tons) annually. A number of sources contribute to this high salinity level. Approximately half of the present salt concentration in the Colorado River is man-induced (i.e., irrigation return flow, reservoir evaporation, exports of water, municipal and industrial consumption, or contamination), and the other half is due to natural sources (i.e., direct salt loading from natural springs and weathering of mineral-bearing rocks.

At its headwaters in the mountains of north-central Colorado, the Colorado River has a salinity of only about 50 mg/L. However, the salinity progressively increases downstream as a result of water diversions and salt contributions from a variety of sources. In 1977, salinity averaged about 820 mg/L at Imperial Dam, the last major diversion point in the United States. Unless control measures are taken, concentration will continue to increase, reaching levels, estimated by the USBR, of 1150 to 1210 mg/L at Imperial Dam by the year 2000 [1].* Water of 1000 mg/L or less salinity is generally considered to be satisfactory for irrigating most crops, although concentrations of 500 mg/L can have detrimental effects on salt-sensitive crops. The U.S. Public Health Service recommends that public drinking water supplies contain less than 500 mg/L.

Salinity not only has economic effects on water users in the lower basin States, but it is also an important factor in international relations with Mexico, which is guaranteed an annual supply of 1.85×10^9 m^3(1.5×10^6 acre-ft) of Colorado River water, by a 1944 treaty. In 1973, the United States and Mexico agreed that water delivered to Mexico from the main stem of the river would have a salinity of no more than 145 mg/L greater than the average salinity of the water at Imperial Dam.

In June 1974, Congress passed the Colorado River Basin Salinity Control Act (Public Law 93-320). Title II of this act authorized the Secretary of the Interior to construct, operate, and maintain four specific salinity control units in the Upper Basin as the initial stage of the Colorado River Basin Salinity Control Program. In addition, the Secretary was authorized and directed to expedite completion of planning reports on 12 other units, one of which is the Glenwood-Dotsero Springs Unit.

Among natural sources of dissolved solids in the Colorado River, the largest point-source contributor (e.g., springs, geysers, mine drainage, and wells) to the upper Colorado River is in the northwest quadrant of Colorado near Dotsero and west of Glenwood Springs (fig. 1). Before this study, it had been estimated [1] that in this area thermal springs rising in or near riverbed and associated ground-water systems contribute about 27 137 000 m^3 (22 000 acre-ft) of saline water, containing 399 161 t (440 000 tons) of salt annually. A PIQR (Problem Identification and Qualification Report) [2] identified average annual concentrations of 18 648 mg/L salt at GS (Glenwood Springs) and 9295 mg/L at DS (Dotsero Springs). In this study, estimated flow-weighted average values of 18 780 mg/L for GS and 9954 mg/L for DS were found. Of this amount, approximately 50 percent was contributed by known surface springs and the rest came from subsurface inputs.

Prior studies [1] of the Glenwood-Dotsero Springs Unit indicated that salinity control measures can reduce salt contribution to the Colorado River by at least 190 000 t (209 000 tons) annually from surface springs alone.

Because of the significant salt contribution to the river, the salinity control program focused on the GS and DS point sources. Studies were initiated by CRWQO (Colorado River Water Quality Office) to characterize, quantify, identify beneficial uses for, and find ways of preventing these waters from entering the Colorado River. A characterization and application study of GS and DS surface springs water was made by the USBR Engineering and Research Center, Division of Research [3].

In another study, the Bureau of Reclamation's UCR (Upper Colorado Region) contracted to investigate the control and disposal of hot saline water from springs near Glenwood Springs and Dotsero, Colorado. Chemical and physical data obtained were consolidated with water analyses obtained by the Chemical Engineering Unit [4]. This study showed that 14 GS identified springs ranged in dissolved salt content from 16 670 mg/L to 21 850 mg/L, and that 11 DS identified springs ranged in dissolved salt content from 8300 mg/L to 10 670 mg/L.

Most Glenwood-Dotsero springs emerge in and along the Colorado River at ground elevations lower than river surface. Apparently, springs originate from saltier aquifers and are diluted by surface water and by river water before emerging. A test program was needed to locate and characterize aquifers from which the Glen-Dot springs emerge. The UCR contracted the URS Corporation to locate and characterize GS-DS aquifers [5]. URS chemical and physical data were consolidated with water analyses obtained by the Chemical Engineering Unit to more thoroughly and accurately characterize GS-DS aquifer water.

* Numbers in brackets refer to entries in bibliography.

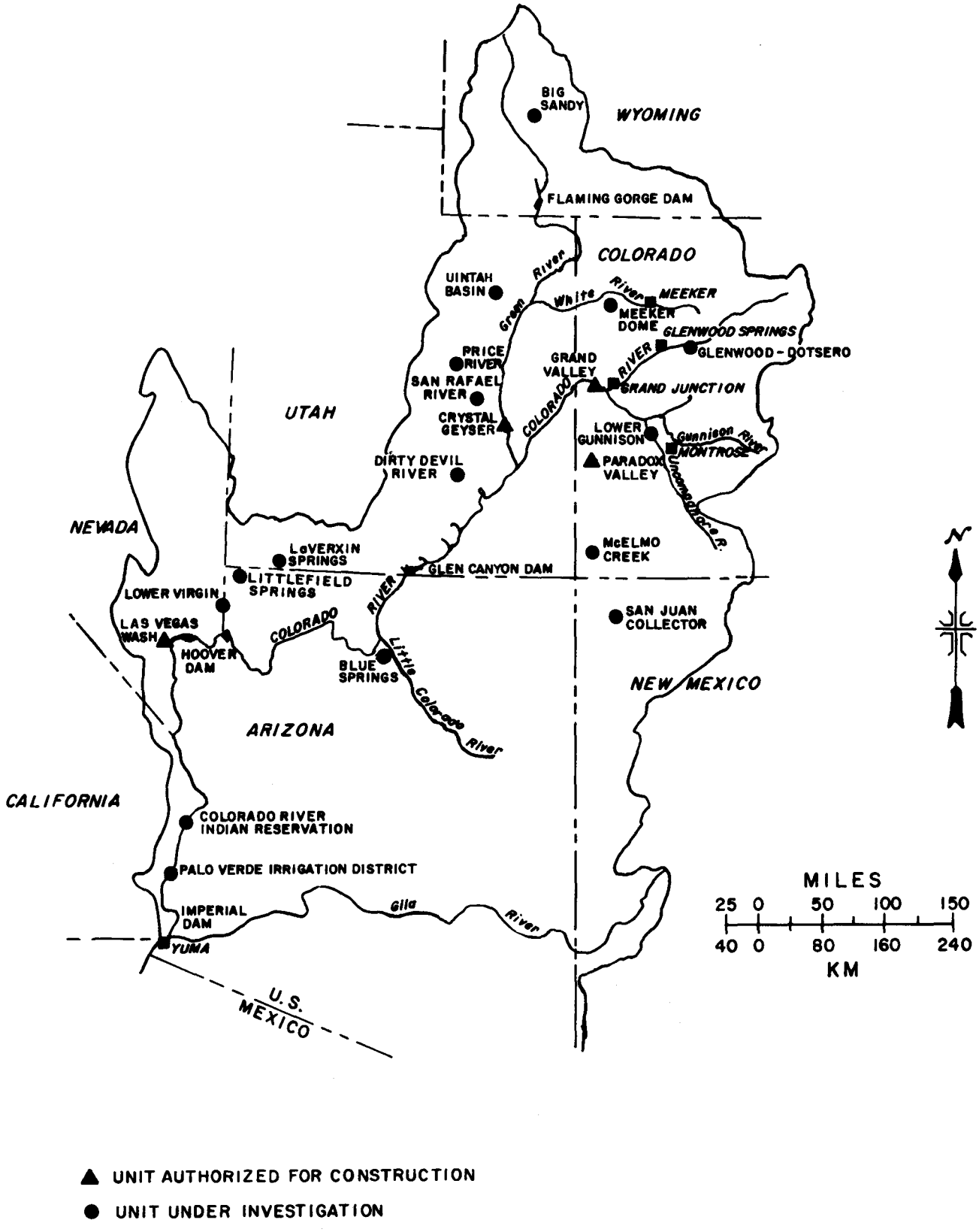

Figure 1. – Colorado River Basin map.

CONCLUSIONS

Glenwood Springs Aquifer

A salty aquifer located about 21.3 m (70 ft) below the ground elevation of 1748 m (5735 ft) emerges as 14 identified springs in and near the Colorado River in the vicinity of the town of Glenwood Springs. Here the Colorado River has a surface elevation of 1739 m (5705 ft). The aquifer has a salt content of 22 200 mg/L, or 2.2 percent, a temperature of 50 °C (122 °F), and a pH of 6.3. When brought to the surface, the aquifer water effervesces from the escaping carbon dioxide.

Major salt constituents. – TDS includes 88 percent sodium salt and 10 percent calcium salt. Potassium and magnesium account for the other 2 percent salt. Anion composition includes 78 percent chloride, 13 percent sulfate, and 9 percent bicarbonate salts.

About 60 percent of the calcium is bicarbonate, or temporary hardness, and 40 percent is chloride, or permanent hardness.

Minor dissolved constituents. – Significant amounts of minor chemicals dissolved in aquifer water include 1030 mg/L of carbon dioxide, 3 mg/L of fluoride, 40 mg/L of silica, 13 mg/L of strontium, 0.7 mg/L of sulfide, and 4 mg/L of iron. About 7 mg/L of dissolved organic nitrogen compound and 3 mg/L of total organic compounds were found.

Radioactivity. – Dissolved radioactive salts in aquifer water are well below hazardous levels. However, exposure to gross beta levels that could be retained in recovered anhydrous salts might exceed Federal Occupational Guide Limits [6] of 5000 mrem/a.

RCRA (Resource Conservation Recovery Act) considerations. – Pretreatment and/or desalting of GS aquifer water would not result in RCRA-type [7] hazardous waste.

Dotsero Springs Aquifer

A salty aquifer located about 30.5 m (100 ft) below ground elevation of 1868 m (6130 ft) emerges as 11 identified springs in and near the Colorado River in the vicinity of the area called Dotsero. Here the Colorado River has a surface elevation of 1864 m (6116 ft). The aquifer has a salt content of 10 600 mg/L, or 1.06 percent, a temperature of 35 °C (95 °F), and a pH of 6.9. When brought to the surface, the aquifer water does not exhibit any carbon dioxide bubbles.

Major salt constituents. – TDS includes 92 percent sodium salt and 6 percent calcium salt. Potassium and magnesium account for the other 2 percent salt. Anion composition includes 85 percent chloride, 7 percent sulfate, and 8 percent bicarbonate. About 30 percent of the calcium is bicarbonate, or temporary hardness, and 70 percent is chloride, or permanent hardness.

Minor dissolved constituents. – Significant amounts of minor chemicals dissolved in aquifer water includes 210 mg/L of carbon dioxide, 60 mg/L of silica, 4 mg/L of strontium, and 5 mg/L of iron. No trace anions were found above detectable limits. About 2 mg/L of total organics were found.

Radioactivity. – Dissolved radioactive salts in aquifer water are well below hazardous levels. However, exposure to gross beta levels that could be retained in recovered anhydrous salts might exceed Federal Occupational Guide Limits [6] of 5000 mrem/a.

RCRA considerations. – Pretreatment and/or desalting of DS aquifer water would not result in RCRA-type [7] anhydrous waste.

DESCRIPTION OF STUDY AREA

The CRWQIP (Colorado River Water Quality Improvement Program) was initiated in 1971 by the USBR to identify measures that would maintain salinity concentrations at or below Lower Colorado River Basin levels existing at the time. Under the CRWQIP, the Glenwood-Dotsero Springs Control Unit was one of 16 control units (table 1) authorized for feasibility-level salinity control planning by Public Law 96-375 in 1980. The locations of the 16 salinity control units are shown on the Colorado River Basin map (fig. 1).

The Glenwood-Dotsero Springs Salinity Unit lies along the Colorado River between Glenwood Springs and Dotsero in west-central Colorado (fig. 2). The major regional geographic features of the area are shown on figure 3. The area is located approximately 260 km (160 mi) west of Denver, and 150 km (90 mi) east of Grand Junction, and includes parts of Garfield and Eagle Counties.

Glenwood Springs (fig. 4) lies at the western end, and Dotsero Springs (fig. 5) lies at the eastern end of the unit. Exact locations, physical properties, and chemical compositions (app. 1 and 2) were studied and reported by Eisenhauer [4].

ORIGIN OF SPRINGS

Thermal saline springs occur along the Colorado River about 3.2 km (2 mi) southwest of the Colorado-Eagle River confluence (Dotsero) near Glenwood Springs. These springs and associated ground-water

Table 1. – Colorado River Basin saline water sources [8].

Unit	Annual average flow		Source quantity		Average TDS,	Annual load,	Salt,	Effect[1],
	m^3/s	ft^3/s	10^6 m^3/a	acre-ft/a	mg/L	t	10^3 ton	mg/L
Glenwood-Dotsero	0.48	17	15.43	12 000	14 200	227	250	23
Big Sandy River	.57	20	17.89	14 500	6 500	118	130	11
Meeker Dome	.042	1.5	1.35	1 090	19 300	25	27	3
Grand Valley	1.7	60	53.68	43 500	3 300	173	190	20
Lower Gunnison	0.66	23.5	21.22	17 200	2 900	61	67	5
Paradox Valley	.057	2	1.79	1 450	260 000	164	180	19
McElmo Creek	.24	8.5	7.65	6 200	4 700	36	40	4
Uinta Basin	.42	15	13.45	10 900	4 500	61	67	6
Price River	.92	34	30.73	24 900	4 000	122	134	13
San Rafael	.86	30.5	27.39	22 200	3 550	97	107	10
Crystal Geyser	0.006	0.2	0.185	150	14 000	3	3	1
Dirty Devil River	1.56	55	49.36	40 000	2 100	102	113	10
LaVerkin Springs	0.35	12.5	10.24	8 300	9 650	99	109	8
Lower Virgin	.28	10	8.88	7 200	8 200	73	80	9
Las Vegas Wash	3.128	110.5	98.72	80 000	1 800	189	208	20
Palo Verde	7.30	258	230.8	187 000	1 700	381	420	39
Energy development wastewater	[2]3.128	110.5	98.72	80 000	1 800	189	208	20
Total	21.76	768.7	687.4	557 090		2 166	2 333	221

[1] Effect at Imperial Dam on the Colorado River.
[2] Year 2000 estimates.

systems contribute approximately 400 000 t (440 000 tons) of dissolved solids to the Colorado River per year. Measured spring flows account for about 50 percent of this amount. Most of the remainder is attributable to unseen saline groundwater seepage through river alluvium. Springs in both areas exhibit high rates of flow and issue from solution-widened joints, bedding planes, and fractures in Mississippian Leadville Limestone. Springs occur in areas where the Leadville Limestone outcrops at the level of the river. Specific springs locations are probably fault or fracture controlled.

The mean salinity is 18 648 mg/L for GS water and 9295 mg/L for DS water. Quality analyses for both areas indicate that saline springs waters are dominated by sodium and chloride (90 percent of TDS) and contain large concentrations of calcium and sulfate. The source of these ions is dissolution of halite and gypsum/anhydrite beds in the Eagle Valley Evaporite by circulating meteoric water.

The elevated temperatures of the Glenwood, 41.7 °C (107 °F), and Dotsero, 29.5 °C (85 °F), springs waters may result from deep circulation through a normal geothermal gradient or from the presence of an elevated geothermal gradient, as evidenced by recent volcanic activity and other thermal springs and wells in the study area.

Springs and flowing wells in outcropping portions of Leadville Limestone indicate that recharge takes place away from these outcrops and in elevated interior portions of the study area. The very similar ionic contents of Glenwood and Dotsero spring waters require either common recharge areas or different recharge areas with the same lithologic characteristics. Probable areas of recharge are in the northeastern and southern portions of the study area. These areas possess structural, topographic, and lithologic attributes that may explain the physical and chemical properties of the Glenwood and Dotsero springs.

Recharge probably infiltrates downward along deep faults or volcanic necks. Downward migrating water contacts halite and gypsum deposits of the Eagle Valley Evaporite, acquiring high concentrations of sodium, chloride, calcium, and sulfate. Water is heated at depth, enters the underlying permeable Leadville Limestone, probably mixes with other water, and migrates toward areas of lower head at the surface, where it issues as thermal saline springs at GS and DS (fig. 6).

A thermal saline spring with associated seeps also occurs along South Canyon Creek about 8 km (5 mi) west of Glenwood Springs. This spring contributes about 227 t (250 tons) of dissolved solids to the Colorado River per year. The source aquifer for this spring is the Dakota Sandstone. Mean temperature is 44.5 °C (112 °F) and mean TDS is 776 mg/L. The springs salinity and heat come from deep circulation of meteoric water within the Dakota and associated

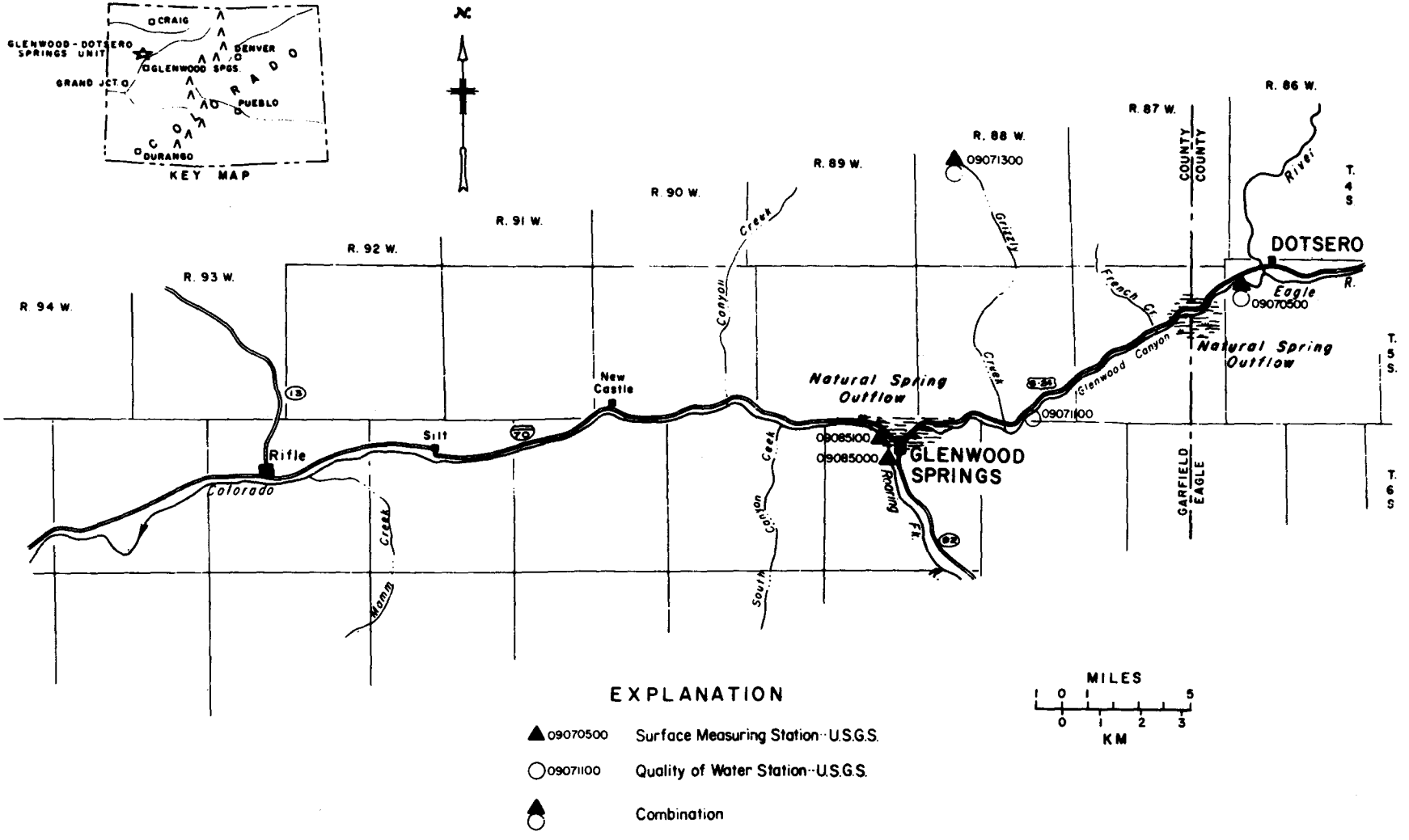

Figure 2. – Glenwood-Dotsero unit location map.

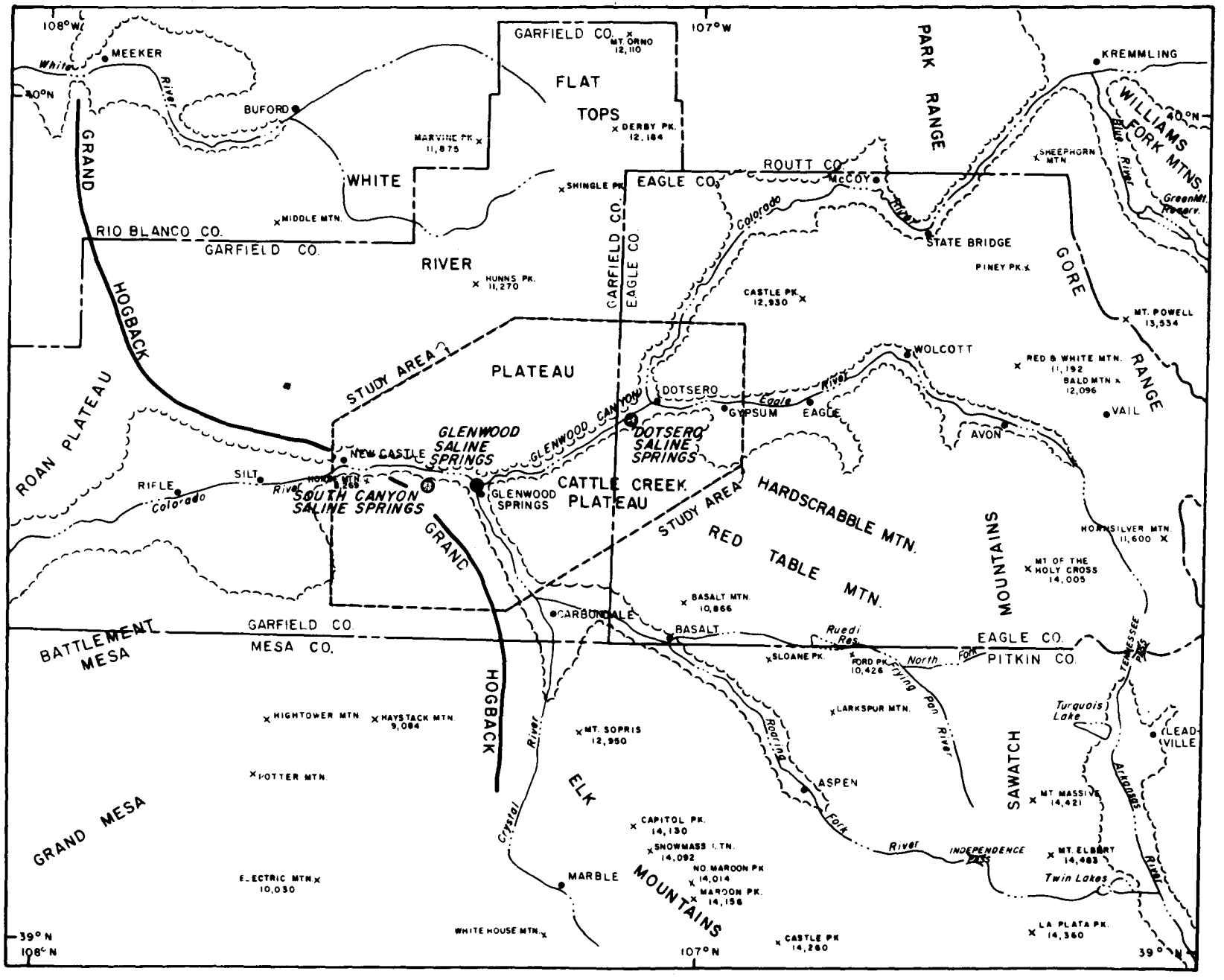

Figure 3. – Glenwood Springs – Dotsero Springs graphic features map. [5]

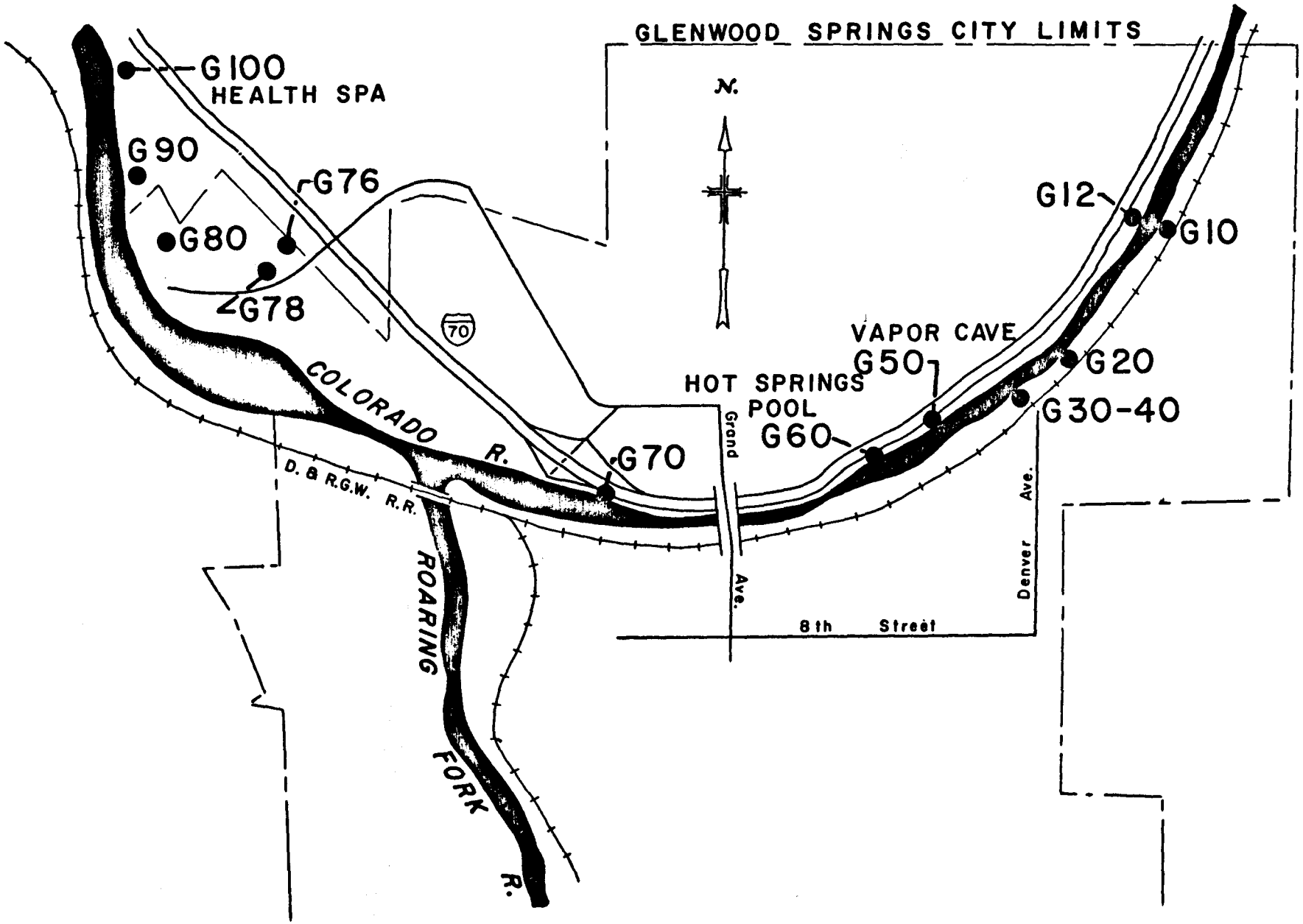

Figure 4. – Surface springs location map, Glenwood Springs (not to scale).

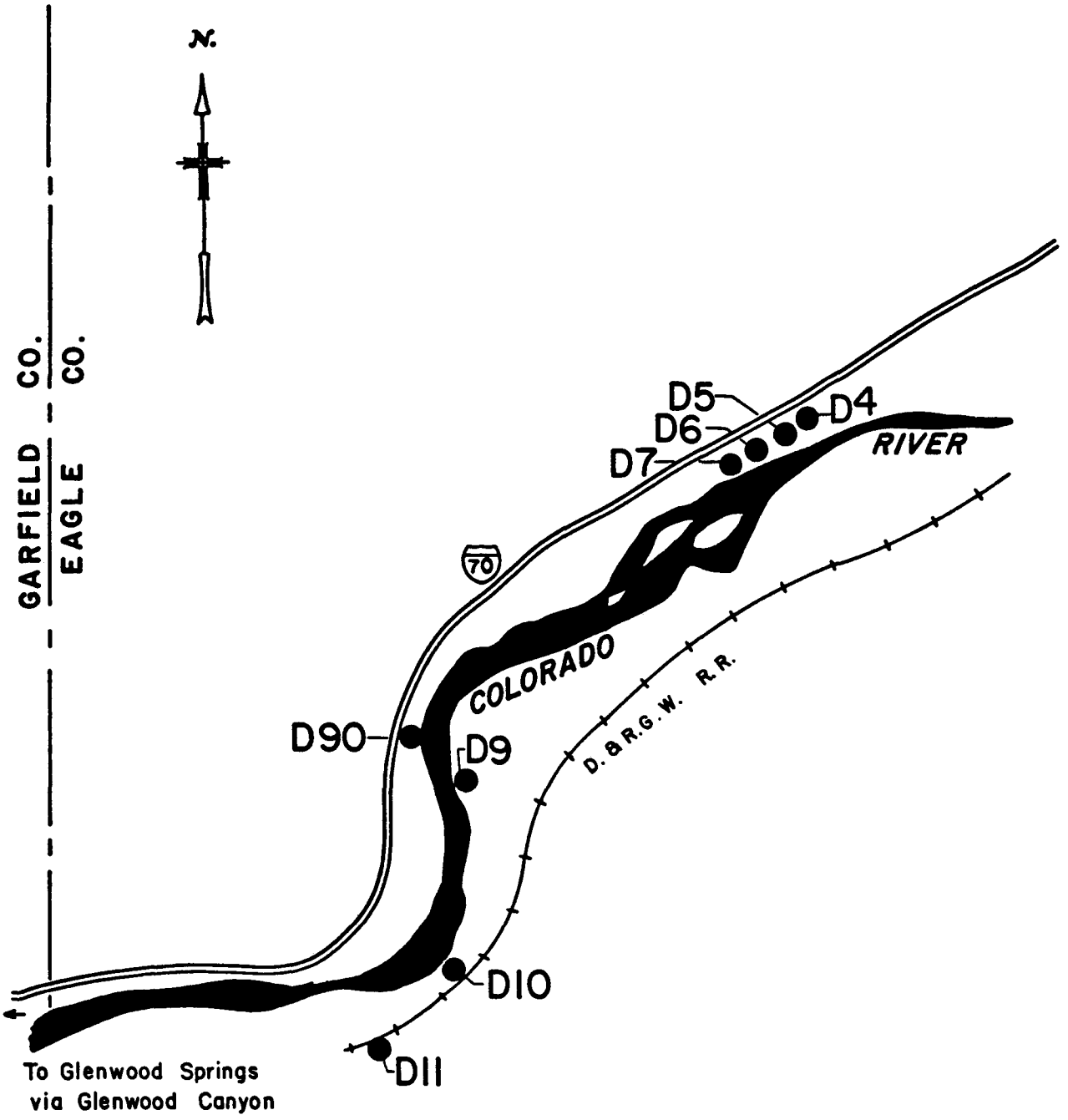

Figure 5. – Surface springs location map, Dotsero (not to scale).

formations. Recharge takes place in the upland areas of Piceance Basin to the southwest or through outcrops along Grand Hogback.

CHARACTERISTICS OF SPRING WATER

Chemical and physical properties of emerging spring waters are described in [4]. Chemical and physical properties of 14 identified GS springs and 11 identified DS springs are given in appendixes 1 and 2, respectively.

Glenwood Springs

Glenwood Springs are located in the Leadville Limestone strata. The combined flow rate of 14 identified

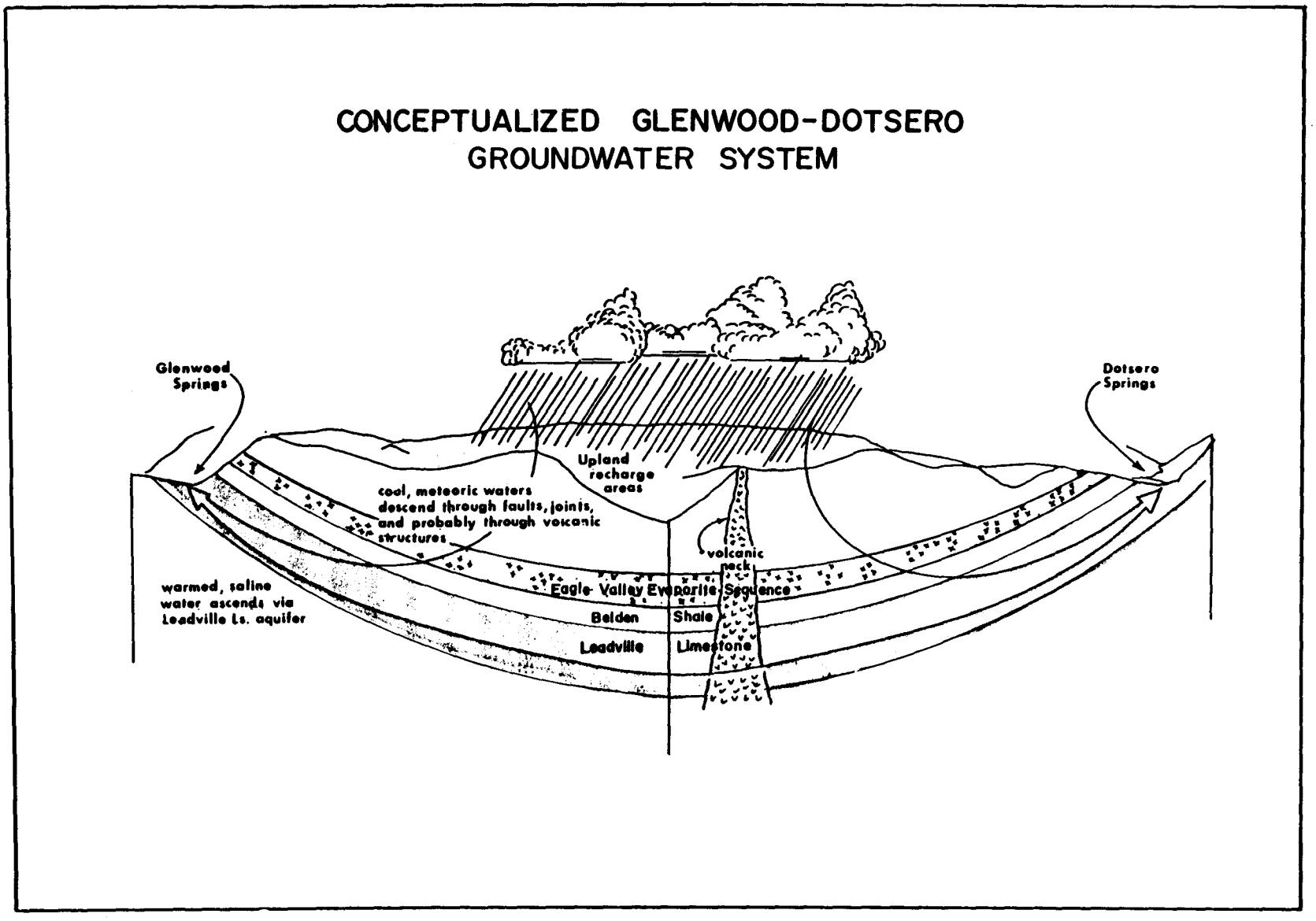

Figure 6. – Origin of Glenwood-Dotsero Springs.

springs is 0.296 m^3/s (10.46 ft^3/s). The characteristics of these springs are shown in table 2a.

Because of the high bicarbonate content of GS water, calcium could be reduced from 470 to 238 mg/L by neutralization with lime (calcium hyrdoxide) to precipitate calcium carbonate. Trace metals and trace anions are less than 0.1 mg/L. Raw water exceeds or approaches the limits of toxicity for drinking water for cadmium, chromium, fluoride, and selenium. However, chemical pretreatment and desalting necessary to bring the water below TDS limits could reduce cadmium, chromium, fluoride, and selenium below limits. Dehydrated salts or calcium carbonate sludges recovered from GS water would not exceed toxicity limits for RCRA hazardous waste. Glenwood Springs water contains a gross beta radioactivity of 226 pCi/L, primarily as K^{40} (potassium-40). The residual K^{40} levels in concentrated salt brines from either evaporation ponding or desalting process brines and sludges would be less than that encountered in salt mines.

Dotsero Springs

Dotsero springs are located in the Leadville Limestone strata. The combined flow rate of the 11 identified springs is 0.220 m^3/s (7.77 ft^3/s). The characteristics of these springs are shown in table 2b.

Table 2a. – Characteristics of Glenwood Springs water.

Temperature range	25 to 51 °C (77 to 124 °F)
pH	6.6 to 7.6
TDS	16 670 to 21 847 mg/L
Cations (by percent):	
Sodium	90
Calcium	7
Potassium	2
Magnesium	1
Anions (by percent):	
Chloride	54
Sulfate	10
Bicarbonate	6

Table 2b. – Characteristics of Dotsero Springs water.

Temperature range	23 to 32 °C (73 to 90 °F)
pH	7.2 to 7.7
TDS	8300 to 10 667 mg/L
Cations (by percent):	
Sodium	82
Magnesium	10
Calcium	7
Potassium	1
Anions (by percent):	
Chloride	84.5
Sulfate	8.7
Bicarbonate	6.8

Because of high bicarbonate content of DS water, calcium could be reduced from 260 to 125 mg/L by partial lime treatment. Most trace metals and trace anions have a concentration of 0.1 mg/L or less, and raw water meets toxicity limits for drinking water. Dehydrated salts or lime treatment sludges would not exceed toxicity limits for RCRA hazardous waste. The raw water contains a gross beta radioactivity of 36 pCi/L, primarily as K^{40}. The residual K^{40} levels in concentrated salt brines form either evaporation ponding or desalting of process brines would be less than that encountered in salt mines.

MAJOR SALT COMPONENTS IN GLEN-DOT AQUIFERS

The USBR contracted with URS Corporation in 1981, for a salinity investigation of the Glen-Dot unit. The salinity investigation was designed, first, to interpret the saline ground-water systems and associated geology, and secondly, to identify, study, and evaluate alternative plans to reduce current salt contribution from the largest point source of salinity in the Upper Colorado River Basin. To implement the salinity investigation, URS Corporation bored well holes into the GS and the DS aquifers. The contractor has reported elsewhere [2, 5] results of geology studies, resistivity soundings, test hole borings, and pumpdown tests.

Aquifer Characteristics at Glenwood Springs

Glenwood Springs aquifer characteristics were determined and reported by the contractor, URS Corporation [2, 5]. To determine aquifer surficial geology, 10 test holes were bored to provide subsurface geologic information. Figure 7 shows the locations of these holes.

Borehole depth and geology. – Between October 12 and October 26, 1982, ten holes were drilled to the depths shown on figure 8, using mud-rotary drilling techniques. Eight of the holes were in the main test area, which included the pumped well. Test hole GT-7 was drilled on the opposite side of the Colorado River from the main test area on the south bank of the river. The remaining hole, GT-9, was drilled at the eastern edge of the Interstate rest area, about 1.6 km (1 mi) west of the main test area. Geologic logs were made for each hole drilled. Close monitoring of penetration rate, mud colors, and cuttings type produced a reasonably accurate picture of subsurface geologic conditions. All holes were drilled to alluvium-bedrock contact. Geologic fence diagrams for 10 bore holes are shown on figure 9.

Water quality testing by contractor. – Water quality efforts at aquifer test sites involved collection of

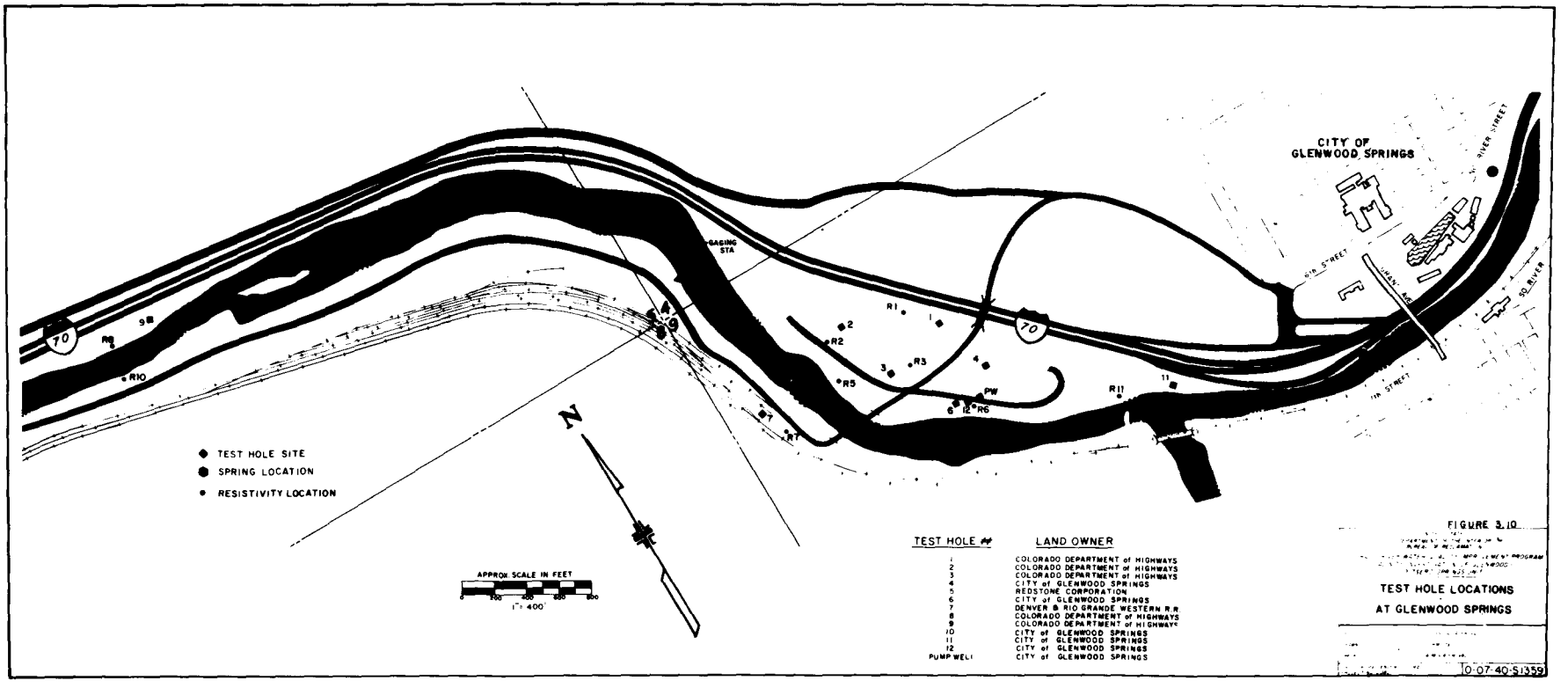

Figure 7. – Locations of drilled test holes at Glenwood Springs.

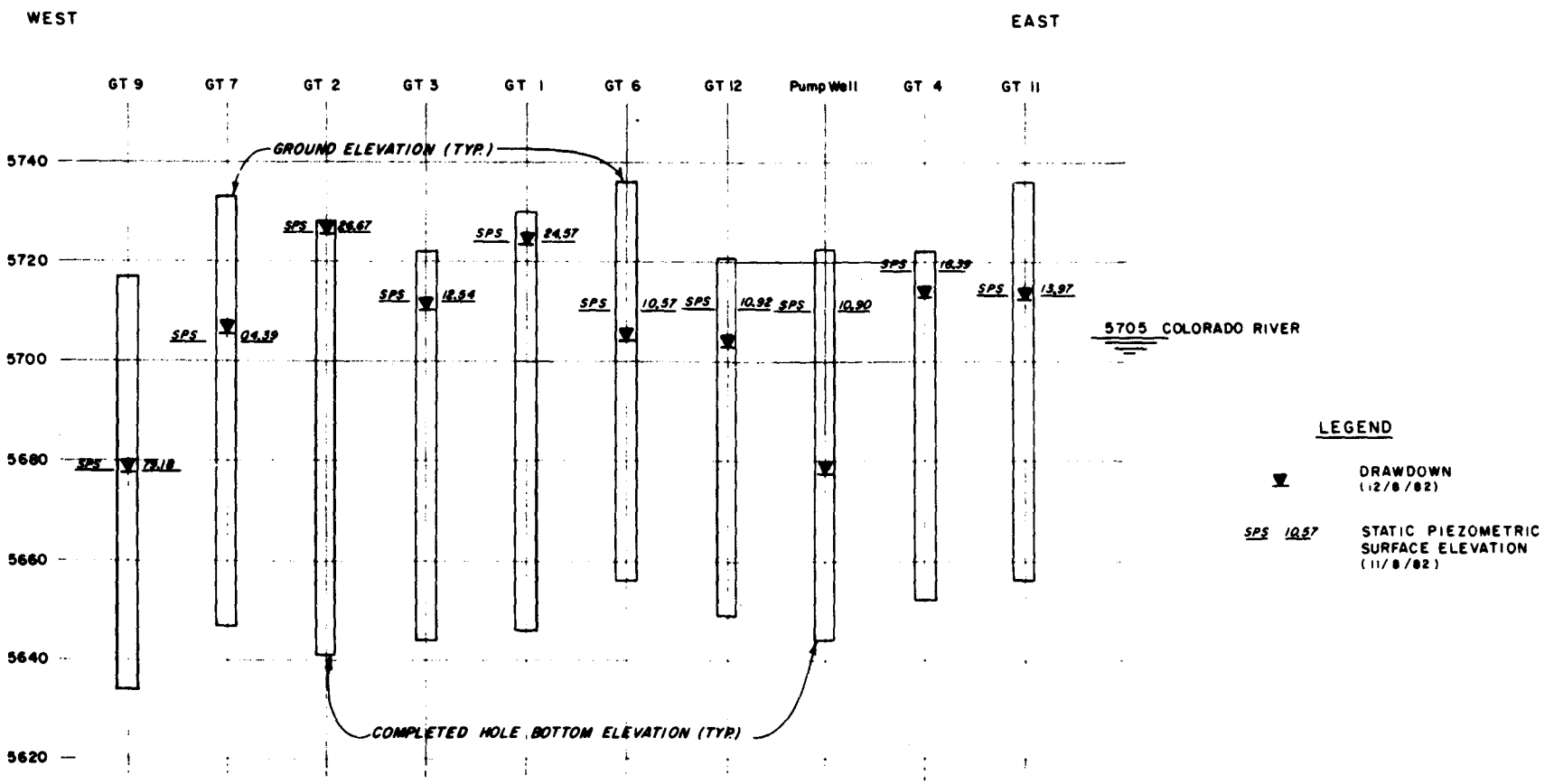

Figure 8. – Depths of 10 bore holes at Glenwood Springs site.

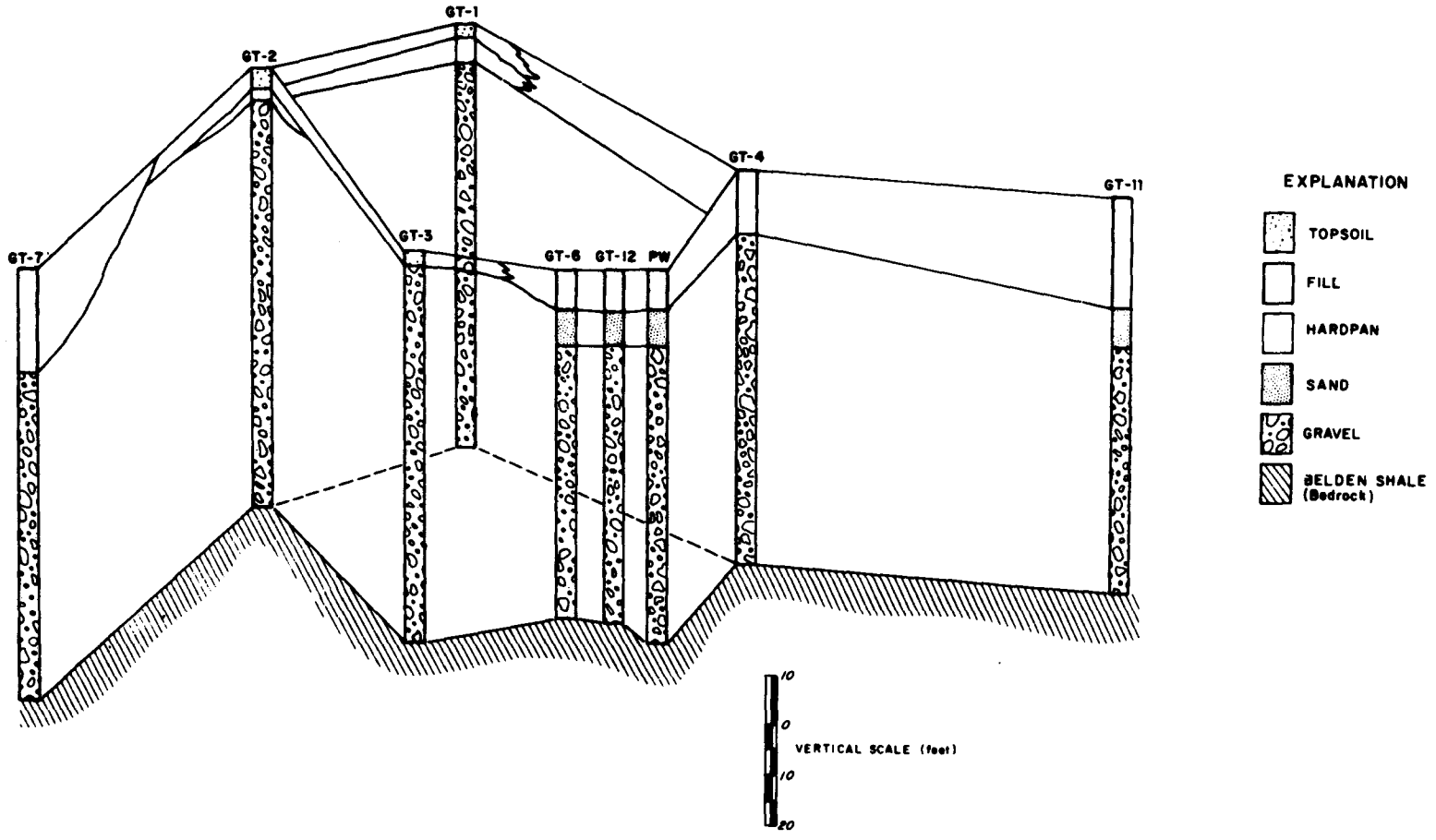

Figure 9. – Geology of Glenwood test site determined from borehole cuttings.

one water sample from each monitor hole and from the production well. Each sample was analyzed for principal constituents to provide background chemical information on the test site.

On November 5, 1982, the contractor collected water samples from the production hole and from eight of nine monitor holes. The remaining hole, GT-11, was sampled on December 23, 1982. For each sample, the hole was first bailed to a constant temperature, conductivity, and pH. The sample was then filtered through a 0.45-micron (0.45×10^{-3} mm) filter before analysis.

The samples were analyzed at a commercial laboratory in Denver for calcium, magnesium, sodium, potassium, chloride, sulfate, total alkalinity, TDS, and specific conductance. Table 3 shows the results for nine monitoring holes including means calculated for all constituents. The concentrations of constituents in the holes found by the contractor were 10 to 20 percent higher than those previously reported by Eisenhauer [4] for the surface springs. Lower concentrations in the springs indicate a higher degree of mixing of bedrock water with meteoric water.

Aquifer Characteristics at Dotsero Springs

Dotsero Springs aquifer characteristics were determined and reported by the contractor [2, 5]. Fifteen test holes drilled at 8 locations provided subsurface geologic information used to define surficial geology. Figure 10 shows the locations of these test holes.

Borehole depth and geology. – The drilling program began in July 1982. Fifteen test holes were drilled to depths shown on figure 11, at eight locations along the north side of the Colorado River, south of Interstate I-70. With the exception of DT-10, a hole was drilled to bedrock at each location as shown. Because of dual aquifer system within the alluvium, a second hole was drilled at each location, with the exception of DT-4, to a depth of approximately 7 m (23 ft).

Geologic logs were made for each hole drilled. Depth to bedrock varied from 27 to 32 m (89 to 105 ft) and averaged 29.2 m (95.7 ft) (fig. 12). The eight locations drilled at the Dotsero site indicate presence of a two-aquifer system. These aquifers are separated by a thick clayey silt. The appearance of two gravels is quite similar both in lithology and in grain size. Sand-gravel alluvium overlying bedrock ranged in thickness from 3.3 to 9.1 m (11 to 30 ft) with an average of 5.4 m (17.75 ft). Overlying basal alluvial gravel is the clayey silt, which ranged in thickness from 10.0 to 15.8 m (33 to 52 ft) with an average of 12.6 m (41.4 ft). The upper gravel ranged from 3.3 to 8.8 m (11 to 29 ft) thick and averaged 6.1 m (19.9 ft). Fill or natural topsoil was encountered at the surface and generally was less than 4.6 m (15 ft) thick.

Both upper and lower gravels are predominantly pebbles and small cobbles with a matrix of course sand to silt-sized material. Upper gravel is composed of unequal amounts of light brown, fine-grained, well-indurated sandstone fragments and black carbonaceous shale along with a minor amount of granitic fragments. The sand in the upper gravel is primarily silica with some very small sandstone and shale fragments. Lower gravel pebbles and cobbles make up 15 percent maroon sandstone fragments, 35 percent black carbonaceous shale, and 50 percent granitic rock fragments. Discrete silica particles predominate in the sandy portion of the lower gravel.

The confining layer separating the two gravels consists of alternating layers of silty clay and sandy, clayey silt. In samples collected, the layers appeared

Table 3. – Contractor's chemical analyses from Glenwood test holes.

Test hole	Ca, mg/L	Mg, mg/L	Na, mg/L	K, mg/L	Cl, mg/L	SO_4, mg/L	Alk, mg/L	TDS, mg/L	Sp. Cond. Mmho/cm
GT-1	830	140	7400	190	11 600	1620	630	21 900	34 500
GT-2	820	160	7600	200	12 010	1730	640	21 980	34 500
GT-3	820	125	7400	195	11 900	1650	640	22 000	37 000
GT-4	820	135	6800	195	10 760	1650	715	20 390	34 600
GT-6	790	150	5900	160	9 590	1400	640	18 150	30 200
GT-7	485	80	1600	40	2 840	705	325	6 280	10 800
GT-9	190	51	1500	26	2 300	390	390	4 750	8 320
GT-11	780	96	7090	280	11 300	1320	735	21 300	35 600
GT-12	730	130	5450	150	8 800	1220	680	16 730	28 800
MEAN	811	138.3	6805	194	10 856	1548	673	20 403	–

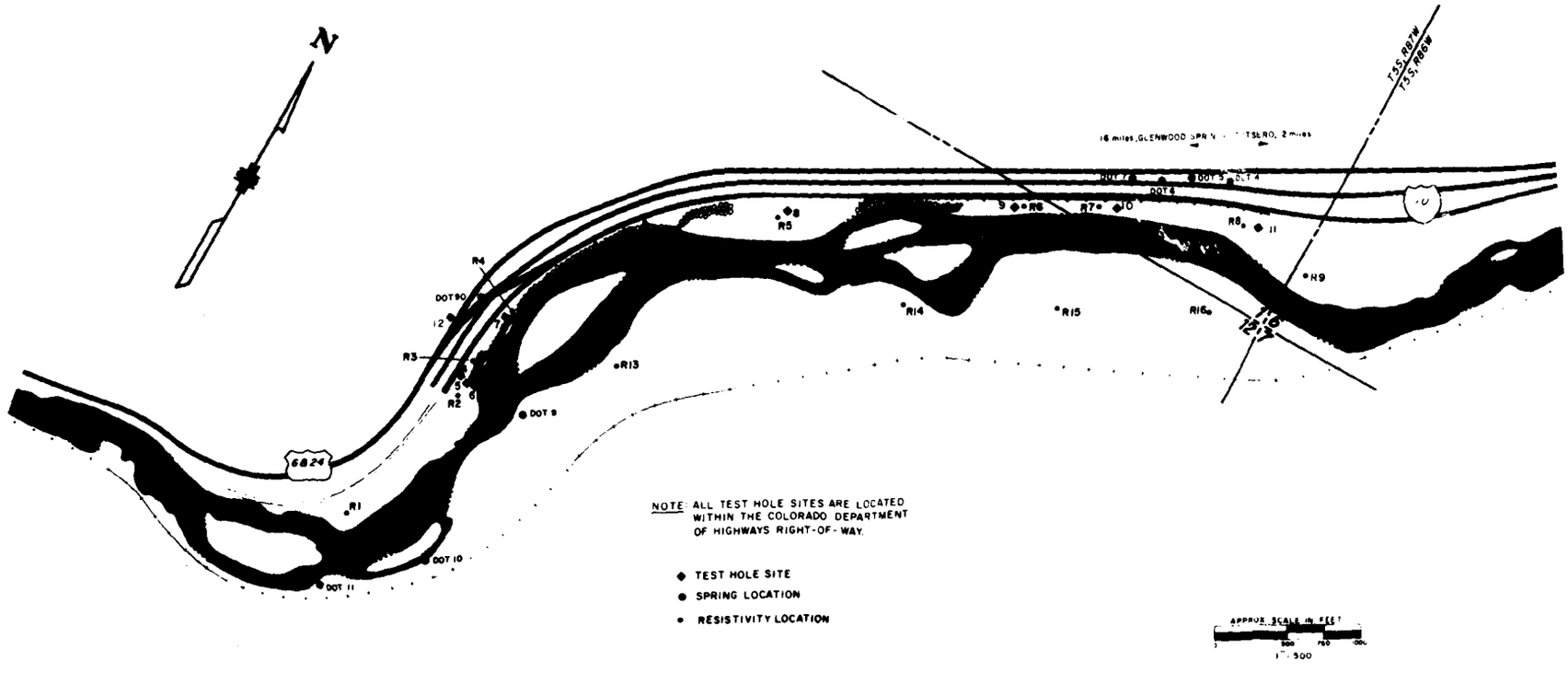

Figure 10. – Locations of drilled test holes at Dotsero Springs.

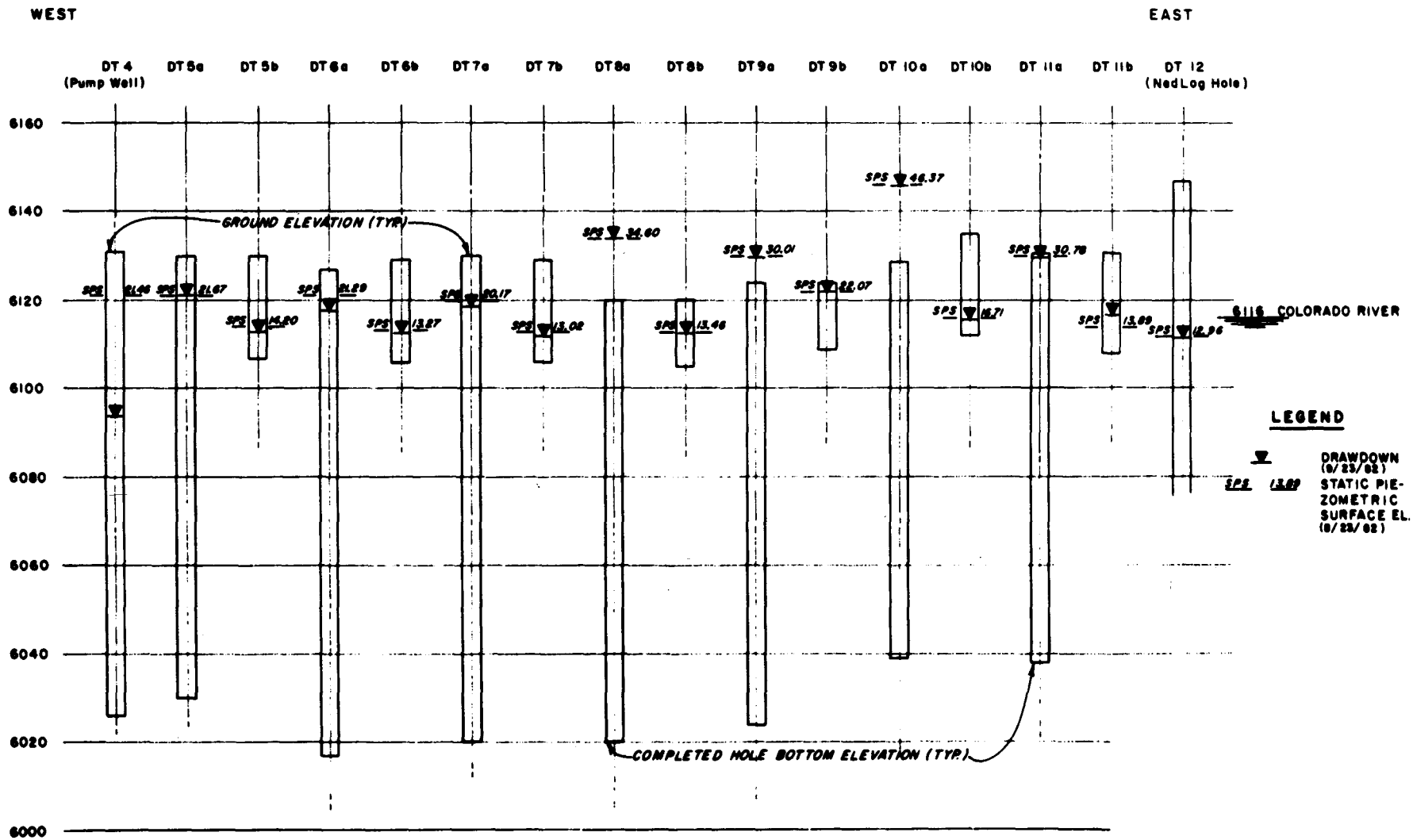

Figure 11. – Depths of 15 bore holes at Dotsero Springs site.

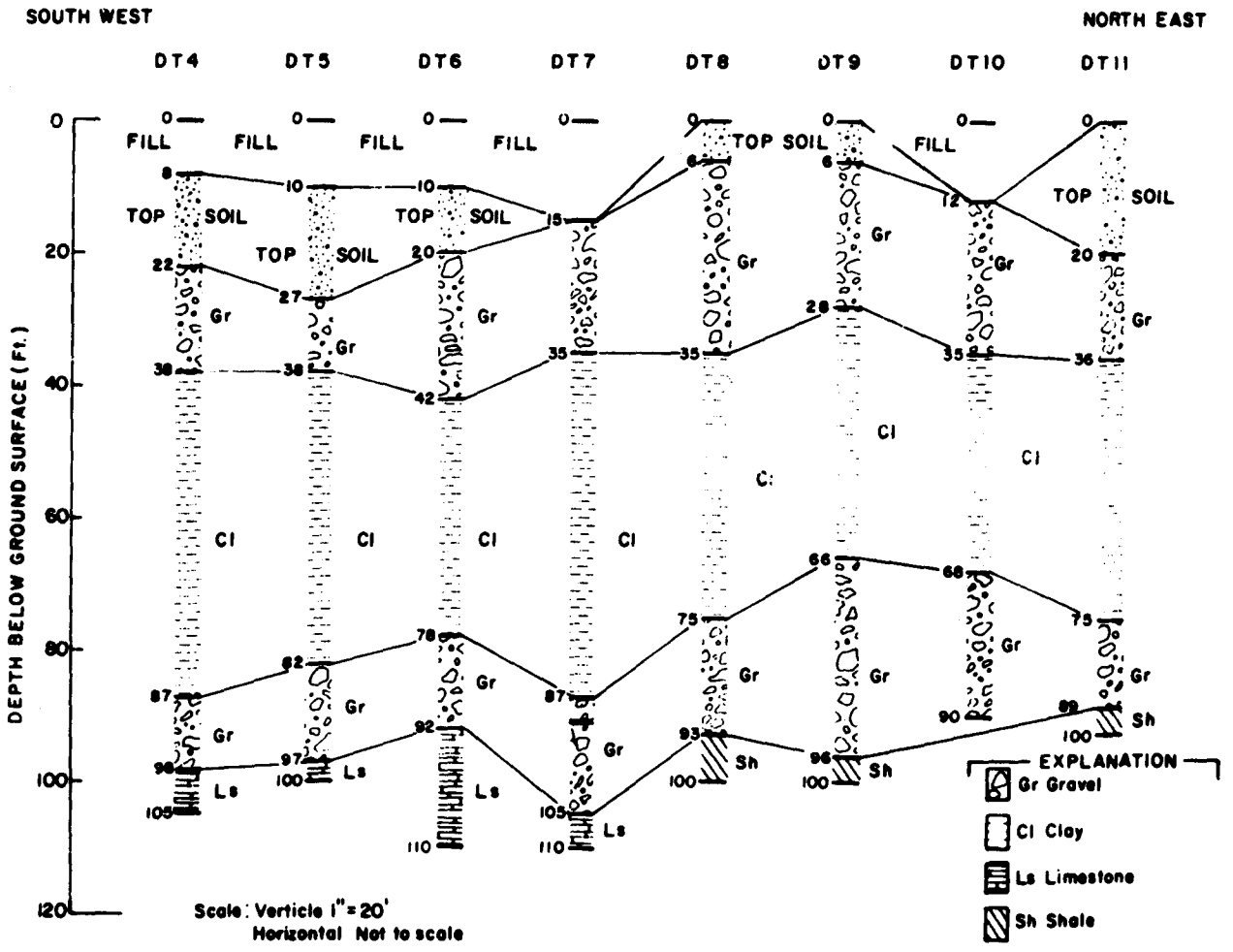

Figure 12. – Geology of Dotsero test site determined from borehole cuttings.

to be about 15.2 cm (6 in) thick. The data are insufficient to accurately define any relationships between clay and silt layers throughout the area.

Water quality testing by contractor. – Water quality testing at the aquifer test sites involved collection of one water sample from each monitor hole and from the production well. Each sample was analyzed for principal constituents to provide background chemical information on the test site.

On August 2 and 3, 1982, the contractor collected water samples from the production hole and eight of nine monitoring holes. For each sample, the hole was first bailed to a constant temperature, conductivity, and pH. The sample was then filtered through a 0.45-micron (0.45×10^{-3} mm) filter.

Samples were analyzed at a commercial laboratory in Denver for calcium, magnesium, sodium, potassium, chloride, sulfate, total alkalinity, TDS, and specific conductance. Results are summarized in table 4.

CHARACTERISTICS OF GLENWOOD-DOTSERO AQUIFERS

Contractor's data reported in tables 3 and 4 were evaluated to determine which boreholes at GS and DS were most representative of source aquifers. Boreholes GT-3 (Glenwood 3) and DT-9A (Dotsero 9A) were selected for further study as being most representative of Glenwood and Dotsero aquifers, respectively.

Glenwood Springs Aquifer

Major salt component analyses of nine Glenwood Springs boreholes reported by the contractor [5] are given in table 3. Borehole GT-3 was selected for further study for the following reasons:

Table 4. – Contractor's chemical analyses from Dotsero test holes.

Test hole	Ca, mg/L	Mg, mg/L	Na, mg/L	K, mg/L	Cl, mg/L	So_4, mg/L	Alk, mg/L	TDS, mg/L	Sp. Cond., Mmho/cm
DT-4A	280	52	3190	50	4960	490	380	8 880	14 112
DT-5A	275	47	3200	50	4960	510	315	8 980	13 944
DT-6A	260	57	3150	49	4780	485	340	8 990	14 070
DT-7A	265	55	3570	49	5500	490	340	9 500	16 346
DT-8A	310	66	4490	53	5970	650	340	10 780	15 492
DT-9A	255	55	3750	54	5830	415	340	10 600	17 308
DT-10A	260	50	4200	54	6420	415	320	10 630	17 544
DT-11A	310	716	3940	59	6100	560	380	10 440	17 045
MEAN	280	57	3686	52	5565	502	344	9 850	–
DT-5B	275	86	4940	48	7490	635	575	13 300	17 778
DT-6B	265	74	4050	53	6050	590	435	11 240	16 333
DT-7B	470	88	3800	54	5760	970	390	10 950	17 708
DT-10B	600	110	6190	84	9580	1380	380	17 370	24 500
DT-11B	290	86	4040	59	6280	580	320	10 770	13 176
MEAN	380	89	4604	60	7032	831	420	12 276	–

- It has the highest salt content, or TDS (22 000 mg/L).
- Its calcium, sodium, potassium, chloride, and sulfate contents were higher than the means for nine boreholes.
- It is located about 150 m (500 ft) away from and 5.5 m (18 ft) above the Colorado River. The bottom of borehole GT-3 is 17.7 m (58 ft) below the Colorado River.
- It was maintained under pressure by means of a 4-in (10 cm) PVC pipe cap pressed on the top of the borehole pipe.
- Water in borehole GT-3 was saturated under pressure with dissolved carbon dioxide. (Copious amounts of carbon dioxide were released whenever the pressure cap was removed from borehole GT-3.)

Sampling methods. – Water samples were obtained from borehole GT-3 by a chemist and chemical engineers from the USBR, on August 15, 1984. Water representative of the aquifer was obtained by means of a 3-in (7.6-cm) diameter submerged pump operated from ground level by another hydraulic pump. The following procedure was used to obtain representative water:

1. Removed pressure cap from top of the 4-in (10-cm) PVC borehole pipe.

2. Lowered pump until the bottom was reached [23.1 m (76 ft) deep] and then raised pump 0.3 m (1 ft) off the bottom.

3. Continued to pump water from aquifer [22.8 m (75 ft) deep] to the surface. After 5 min, initial turbidity in water disappeared.

4. Continued flow of water at 18.9 L/min (5 gal/min) for 2 h to remove 1136 L (300 gal) before filling the 1-qt (0.95L) and 1-gal (3.79 L) sample bottles for off-site analysis. Since a 4-in (10-cm) diameter pipe 23.2-m (76-ft) long holds 189.3 L (50 gal), 2 h of pumping at 18.9 L/mm (5 gal/min) removes content of the borehole 12 times and, in effect, the bore pipe refills from the aquifer 11 times.

Sample analyses procedures. – During the 2 h pump-out period, effluent water flowed through a probe holder that provided continuous monitoring of temperature, pH, and conductivity. Titrations were also made at the site to monitor alkalinity. Alkalinity, temperature, pH, and conductivity stabilized after ½ h. After 2 h of pumping, water samples were collected in 1-qt (0.94-L) and 1-gal (3.79 L) glass and polyethylene bottles. Some sample bottles were filled directly with raw water from borehole GT-3, and other samples were adjusted to pH 1 in the bottles with nitric acid.

Water samples were later analyzed at qualified Denver commercial laboratories for physical properties,

major constituents, minor elements, trace anions, radioactivity, and organic compounds. Results are summarized in table 5.

Physical properties. – As indicated in table 5, the source aquifer for Glenwood Springs is located about 23.2 m (76 ft) below ground level. Its water temperature is 49 °C (120.2 °F). Surface pH measured 6.3. Aquifer pH would be about 5.5, because under aquifer pressure, water is saturated with carbon dioxide. Aquifer water contains 22 200 mg/L of dissolved solids.

Major salt constituents. – Based on data in table 5, Glenwood Springs GS source aquifer contains 0.222 weight percent dissolved salt. This salt, on a dry basis, is 9 percent bicarbonates, 13 percent sulfates, and 78 percent chlorides. Assuming all bicarbonate ions are combined with calcium and all sulfate ions are associated with sodium ions, the total salt weight composition on a dry basis can be represented as follows:

6 percent calcium bicarbonate
4 percent calcium chloride
0.5 percent magnesium chloride
11 percent sodium sulfate
77 percent sodium chloride
1.5 percent potassium chloride

Other chemicals present in significant amounts include:

1031 mg/L carbon dioxide
3.1 mg/L fluoride
41 mg/L silica
13 mg/L strontium
0.7 mg/L sulfide
0.6 mg/L barium
4.3 mg/L iron

GS aquifer water has a dissolved calcium concentration of 824 mg/L. Under aquifer pressure, water contains 1314 mg/L of bicarbonate ion. Because it was shown above that dry basis salt contains 6 percent calcium bicarbonate and 4 percent calcium chloride, 60 percent of the calcium in the water, or 494 mg/L, is in the form of bicarbonate, or temporary hardness. Because GS water contains 1031 mg/L carbon dioxide under aquifer pressure, it can be calculated that 276 mg/L of calcium temporary hardness is solubilized by dissolved carbon dioxide. Consequently, 276 mg/L of calcium can be precipitated as calcium carbonate by aeration. Processing GS aquifer water through aeration, clarification, and filtration would reduce calcium content to 548 mg/L. Following aeration with partial lime treatment would remove the remaining temporary hardness and reduce dissolved calcium to 330 mg/L.

The remaining 330 mg/L of calcium is in the form of highly water-soluble calcium chloride. This permanent hardness could be removed from solution by further treatment with soda ash or by ion exchange.

Minor metals. – Items 28 through 53 of table 5 are trace metals found in GS aquifer water. Most trace metal concentrations were less than 0.1 mg/L, or below detectable limits. The following significant amounts were found:

0.4 mg/L aluminum
0.4 mg/L boron
0.2 mg/L chromium
0.19 mg/L cobalt
0.16 mg/L iodine
4.3 mg/L iron
1.1 mg/L lithium
0.2 mg/L vanadium
0.6 mg/L barium

Trace anions. – Trace anions are listed as items 54 through 59 of table 5. Except for ammonia with a concentration of 0.23 mg/L and organic nitrogen compounds with a concentration of 1.2 mg/L, trace anion concentrations are less than 0.02 mg/L.

Radioactivity. – Some of the radioactive constituents of GS water, including alpha, beta, radium, and potassium are shown as items 60, 61, 62, 63, and 64, respectively, in table 5 and on table 6. The gross alpha radioactivity was estimated as 30 mrem/a, and the gross beta radioactivity as 320 mrem/a. Both are well below the Federal Occupational Guide Limits [6] of 5000 mrem/a. Raw GS water contains 60 pCi/L of gross alpha, 640 pCi/L of gross beta, and 11 pCi/L of total radium. The radioactivity limits for drinking water for these items are 15, 50, and 5 pCi/L respectively.

Although the gross alpha, gross beta, and radium radioactivities exceed the drinking water limits, the water could be used as a source of drinking water. The treatment necessary to reduce Glenwood's TDS concentration in the raw water from 22 000 mg/L to the 500 mg/L TDS drinking water limit would also remove about 97.5 percent of the radioactivity.

Disposal of GS water by evaporation ponding would result in an increased radiation exposure to the environment. Assuming complete water evaporation, the salt and radioactivity concentration in the raw water would be concentrated 49 times. If the gross alpha radioactivity concentration in the raw water was 60 pCi/L, and the gross beta concentration was 640 pCi/L, and if these radioactivities increased 49 times in the dry salt, then the estimated accumulated body radiation exposure could reach 1470 mrem/a for gross alpha and 15 000 mrem/a for gross beta.

Table 5. – Physical and chemical characteristics of Glenwood and Dotsero salty aquifers.

(1) Item	(2) Characteristic	(3) Units	(4) Glenwood	(5) Dotsero
Well index No.			3	9A
Date sampled			9/15/83	9/29/83
Samples analyzed			2	2
Physical properties				
1	Conductivity at 25 °C	mS/m	2857	2000
2	Flow	m^3/s	–	0.000132
3	pH (low)	pH	6.3	6.9
4	TDS (total dissolved solids)	mg/L	22 200	10 600
5	Temperature	°C	49	35
6	Total suspended solids	mg/L	51	344
7	Turbidity	JTU		
8	Ground elevation	ft	5722	6124
9	Well depth	ft	76	Artesian (100)
10	Ground elevation	m	1744	1867
11	Well depth	m	23	Artesian (30)
12	–	–	–	–
Major constituents				
13	Alkalinity as CaCO3	mg/L	630	395
14	Bicarbonate	mg/L	748	390
15	Bicarbonate (corrected total)	mg/L	1314	545
16	Calcium	mg/L	824	270
17	Chloride	mg/L	11 400	5800
18	Carbon dioxide (measured/corrected)	mg/L	826/1031	140/208
19	Fluoride	mg/L	3.1	0.44
20	Magnesium	mg/L	93	47
21	Potassium	mg/L	220	55
22	Silica	mg/L	41	60
23	Sodium	mg/L	7780	3990
24	Strontium	mg/L	13	4
25	Sulfate	mg/L	1860	460
26	Sulfide	mg/L	0.7	<0.1
27	Sulfite	mg/L	<0.1	<0.1
Minor elements				
28	Aluminum	mg/L	0.4	1.0
29	Antimony	mg/L	0.09	0.06
30	Arsenic	mg/L	0.001	0.01
31	Boron	mg/L	0.4	<0.05
32	Cadmium	mg/L	ND	ND
33	Chromium	mg/L	0.2	0.2
34	Cobalt	mg/L	0.19	0.08
35	Copper	mg/L	0.04	0.02
36	Gallium	mg/L	<0.01	<0.01
37	Germanium	mg/L	<0.2	<0.2
38	Iodine	mg/L	0.16	0.05
39	Iron	mg/L	4.3	4.7
40	Lead	mg/L	ND	ND
41	Lithium	mg/L	1.1	0.16
42	Manganese	mg/L	0.09	0.02
43	Mercury	mg/L	0.001	0.001
44	Nickel	mg/L	ND	ND
45	Selenium	mg/L	0.001	0.002

Table 5. – Physical and chemical characteristics of Glenwood and Dotsero salty aquifers. – Continued

(1) Item	(2) Characteristic	(3) Units	(4) Glenwood	(5) Dotsero
46	Silver	mg/L	0.003	0.003
47	Tin	mg/L	<1.0	<1.0
48	Titanium	mg/L	0.04	<0.01
49	Uranium	mg/L	<0.002	0.007
50	Vanadium	mg/L	0.2	0.1
51	Zinc	mg/L	ND	ND
52	Zirconium	mg/L	0.07	0.01
53	Barium	mg/L	0.6	ND
Trace anions				
54	Ammonia	mg/L	0.23	0.04
55	Nitrite	mg/L	0.015	0.012
56	Nitrate	mg/L	0.002	0.004
57	Organic $N+NH_3$	mg/L	1.2	0.10
58	Orthophosphate	mg/L	0.004	0.002
59	Total phosphate	mg/L	0.007	0.004
Radioactivity				
60	Gross alpha	pCi/L	60	28
61	Gross beta	pCi/L	640	190
62	Radium – 226	pCi/L	5.4	1.0
63	Radium – 228	pCi/L	5.6	0.8
64	Potassium – 40	pCi/L	19.6	4.18
65	–	–	–	–
Organic Compounds				
66	Total organic carbon	mg/L	2.5	1.5
67	Pesticide: Endrin	mg/L	ND<0.0001	ND<0.0001
68	Lindane	mg/L	ND<0.001	ND<0.001
69	Methoxy chlor	mg/L	ND<0.001	ND<0.001
70	Toxaphene	mg/L	ND<0.002	ND<0.002
71	Herbicides: 2,4-D	mg/L	ND<0.01	ND<0.01
72	Silex	mg/L	ND<0.005	ND<0.005
73	–	–	–	–
Desalting % water recovery ($CaSO_4$ solubility)				
74	0 °C	%	35.5	85.3
75	20 °C	%	49.1	88.1
76	50 °C	%	54.0	89.4
77	90 °C	%	48.7	88.8

Dry salt produced directly from raw GS water could exceed Federal Occupational Guide Limits of 5000 mrem/a for gross beta radioactivity.

RCRA considerations. – The "Salinity Investigation of Glenwood-Dotsero Springs Unit Phase I Report" [5] proposed various plans for removing approximately 180 000 t/a (198 000 ton/yr) of salt from the Colorado River Basin. Some of these schemes would isolate and store essentially anhydrous salt from various water evaporation processes. Other schemes would involve lime neutralization of the bicarbonate content of the water with subsequent precipitation, isolation, and storage of calcium carbonate sludge. Isolation of salts and sludges from GS water would greatly concentrate the toxic metals in the raw springs water. Handling and storage of these salts and sludges require consideration of the generation and storage of hazardous waste covered by RCRA regulations [8].

The RCRA maximum criteria for hazardous waste classifications are compared in table 7 with pollutants that would be present in GS lime treatment

Table 6. – Glenwood Springs water radioactivity data and guide limits.

(1) Radioactivity	(2) Activity, pCi/L	(3) Estimated yield, mrem/a	(4) Federal Occupational Guide Limits, mrem/a	(5) Drinking water limits, pCi/L
Gross alpha	60	30	5000	15
Gross beta	640	320	5000	50
Radium 226, 228	11	–	–	5

sludges. Based on the bicarbonate content of 1314 mg/L, aeration followed by partial lime treatment of GS water would precipitate 2160 mg/L of calcium carbonate. For every 1000 parts of GS water dewatered (60 percent solids) 3.61 parts of calcium carbonate sludge would result. Assuming all toxic materials coprecipitate with the calcium carbonate, they would concentrate 1000/3.61 or 277 times in the sludge. The EP (extractable product) toxicity limits in column 3 of table 7 are for a 20:1 water extract of a solid waste. Therefore, column 4 (table 7), EP toxicity, was derived by multiplying the values for the items in column 4 (table 5) by 277/20 or 13.9. All the values in column 4 (table 6) are well below the maximum RCRA limits in column 3 (table 6). Consequently, calcium carbonate sludges recovered from lime treatment of GS water need not be stored or transported as an RCRA hazardous waste.

GS raw aquifer water contains an average TDS concentration of 22 200 mg/L, or approximately 22 g/1000 mL. If the TDS in GS water were isolated, approximately 174 700 t/a (192 170 ton/yr) of dried salt would result, and the toxic materials in the raw water would be concentrated 1000/22 or 45 times. Isolation of all the TDS as dried salt would concentrate toxic materials less than precipitation of calcium carbonate sludge. Consequently, calcium carbonate sludges and dried salts are not RCRA hazardous waste.

Dotsero Springs Aquifer

Major salt component analyses of 13 Dotsero Springs boreholes reported by the contractor [5] are given in table 4. Borehole DT-9A was selected for further study for the following reasons:

- It is a 100-ft-deep borehole (fig. 11).
- It contains water with a salt content of 10 600 mg/L, which is an average TDS for four boreholes with the highest concentration of TDS.
- It is accessible from Interstate I-70, and located on a flat section of land about 6.1 m (20 ft) from the Colorado River.
- It was maintained under pressure by means of a PVC 4-in (10.2 cm) pipe cap.

Sampling methods. – Water samples were obtained from borehole DT-9A by a chemist and chemical engineers from the USBR, on August 16, 1984. Water representative of the aquifer was obtained by means of a 3-in (7.6-cm) diameter submerged pump operated from ground level by another hydraulic pump. The following procedure was used to obtain representative water:

1. Removed pressure cap from top of the 4-in (10-cm) PVC borehole pipe.

2. Lowered pump until bottom was reached [30.5-m (100-ft) deep] and then raised pump 0.3 m (1 ft) off the bottom.

3. Continued to pump water from aquifer [30.2-m (99 ft) deep] to the surface. After the first 5 min initial turbidity in water disappeared.

4. Continued flow of water at 18.9 L/min (5 gal/min) for 2 h to remove 1136 L (300 gal) before filling the 1-qt (0.95-L) and 1-gal (3.79 L) sample bottles for off-site analysis. Since 4-in (10 cm) diameter pipe 30.5-m (100-ft) long holds 250 L (66 gal), 2 h of pumping at 18.9 L/min (5 gal/min) removes content of the borehole nine times and, in effect, the bore pipe refills from aquifer eight times.

Sample analyses procedures. – During 2 h pump-out period, effluent water flowed through a probe holder that provided continuous monitoring of temperature, pH, and conductivity. Titrations were also made at the site to monitor alkalinity. Alkalinity, temperature, pH, and conductivity stabilized after ½ h. After 2 h of pumping, water samples were collected in 1-qt (0.95-L) and 1-gal (3.79 L) glass and polyethylene bottles. Some sample bottles were filled directly with water from borehole DT-9A, and other samples were adjusted in the bottles with nitric acid to pH 1.

Water samples were later analyzed by qualified Denver commercial laboratories for physical properties, major constituents, minor elements, trace anions, radioactivity, and organic compounds. Results are summarized in table 5.

Physical properties. – As is evident from table 5, the source aquifer for Dotsero Springs is located about 30.5 m (100 ft) below ground level. Its water temperature is 35 °C (95 °F). Surface pH measured 6.9. Aquifer water contains 10 600 mg/L of dissolved solids.

Table 7. – Comparison of GS sludge and dried salt with RCRA maximum limits.

(1) Table 5 item	(2) Parameter	(3) RCRA hazardous waste criteria [8] (20:1 extract)	(4) Pretreatment sludge (20:1 extract)
	EP Inorganic Toxicity (max. conc.)., mg/L		
30	Arsenic	5.0	0.5
53	Barium	100.0	3.1
32	Cadmium	1.0	0.3
33	Chromium	5.0	1.7
40	Lead	5.0	1.6
43	Mercury	0.2	<0.003
45	Selenium	10	0.3
46	Silver	5.0	0.3
	EP Organic Toxicity (max. conc.), mg/L		
67	Endrin	0.02	<0.005
68	Lindane	0.04	<0.01
69	Methoxychlor	10.0	<2.6
70	Toxaphene	0.5	<0.13
71	Herbicide 2,4-D	10.0	<2.6
72	Silex, 2,4-5 TP	1.0	<0.3

Major constituents. – Based on data in table 5, Dotsero Springs source aquifer contains 0.106 weight percent dissolved salt. This salt on a dry basis is composed of 3 percent bicarbonates, 7 percent sulfates, and 90 percent chlorides. Assuming all bicarbonate ions are combined with calcium and all sulfate ions are associated with sodium ions, the total salt weight composition on a dry basis can be represented as follows:

2 percent calcium bicarbonate
5 percent calcium chloride
1 percent magnesium chloride
13 percent sodium sulfate
78 percent sodium chloride
1 percent potassium chloride

Other chemicals present in significant amounts include:

208 mg/L carbon dioxide
0.4 mg/L fluoride
60 mg/L silica
4 mg/L strontium
4.7 mg/L iron

DS aquifer water has a dissolved calcium concentration of 270 mg/L. Under aquifer pressure, water contains 545 mg/L of bicarbonate ion. Because it was shown above that dry basis salt contains 2 percent calcium bicarbonate and 5 percent calcium chloride, 28 percent (76 mg/L) of the calcium in the water is in the form of bicarbonate, or temporary hardness. Under aquifer pressure, DS water contains 208 mg/L carbon dioxide. By calculation it can be shown that 56 mg/L of temporary hardness is solubilized by dissolved carbon dioxide. Consequently, 56 mg/L of calcium can be precipitated by aeration. Processing GS aquifer water through aeration, clarification, and filtration would reduce calcium content to 152 mg/L. Following aeration with partial lime treatment would remove the remaining temporary hardness and reduce dissolved calcium to 52 mg/L.

The remaining 52 mg/L of calcium is in the form of highly water-soluble calcium chloride. This permanent hardness could be removed from solution by further treatment with soda ash by ion exchange.

Minor metals. – Items 28 through 53 of table 5 are trace metals found in DS aquifer water. Most trace metals concentrations were less than 0.1 mg/L or below detectable limits. The following significant amounts were found:

1.0 mg/L aluminum
0.2 mg/L chromium
0.16 mg/L lithium

Trace anions. – Trace anions are listed as items 54 through 59 of table 5. Trace anion constituents were below detectable limits.

Radioactivity. – Some of the radioactive constituents of DS water including alpha, beta, radium, and potassium, are shown as items 60, 61, 62, 63, and

64, respectively, in table 5 and on table 8. The gross alpha radioactivity was estimated as 14 mrem/a and the gross beta radioactivity as 95 mrem/a. Both are well below the Federal Occupational Guide Limits [6] of 5000 mrem/a. The raw DS water contains 28 pCi/L of gross alpha, 190 pCi/L of gross beta, and 1.8 pCi/L of total radium. The radioactivity limits for drinking water for these items are 15, 50, and 5 pCi/L, respectively.

Although the gross alpha and gross beta radioactivity of the raw water exceeds drinking water limits, this water could be used as a source of drinking water. Treatment necessary to reduce Dotsero's TDS concentration from 1000 mg/L in raw water to the 500 mg/L TDS drinking water limit would also remove about 95 percent of radioactivity from the water.

Disposal of DS water by evaporation ponding would result in an increased radiation exposure to the environment. Assuming complete water evaporation, the salt and radioactivity concentration in the raw water would be concentrated 99 times. If the gross alpha radioactivity concentration in raw water was 28 pCi/L, and the gross beta concentration was 190 pCi/L, and if these radioactivities increased 99 times in the dry salt, then the estimated accumulated body radiation exposure could reach 1390 mrem/a for gross alpha and 9400 mrem/a for gross beta. Dry salt produced directly from raw DS water could exceed Federal Occupational Guide Limits of 5000 mrem/a for gross beta radioactivity.

RCRA considerations. – The "Salinity Investigation of Glenwood-Dotsero Springs Unit Phase I Report" [5] proposed various plans for removing approximately 2 000 000 t/a (2 200 000 tons/yr) of salt from the Colorado River Basin. Some of these schemes would isolate and store essentially anhydrous salt from various water evaporation processes. Other schemes would involve lime neutralization of the bicarbonate content of the water with subsequent precipitation, isolation, and storage of calcium carbonate sludge. Because isolation of salts and sludges from DS water would greatly concentrate the toxic metals present in raw spring water, consideration was given to potential generation and storage of hazardous waste covered by RCRA regulations.

Table 8. – Dotsero Springs water radioactivity data and guide limits.

(1) Radioactivity	(2) Activity, pCi/L	(3) Estimated yield, mrem/a	(4) Federal Occupational Guide Limits, mrem/a	(5) Drinking water limits, pCi/L
Gross alpha	28	14	5000	15
Gross beta	190	95	5000	50
Radium 226, 228	1.8	–	–	5

The RCRA criteria for hazardous waste classifications are compared in table 9 with pollutants that would be present in DS lime treatment sludges. Based on the bicarbonate content of 545 mg/L, partial lime treatment of DS water would precipitate 894 mg/L of calcium carbonate. For every 1000 parts of raw water processed, 1.12 parts of dewatered (60 percent solids) calcium carbonate sludge would result. Assuming all toxic materials coprecipitate with calcium carbonate, they would concentrate 1000/1.12 or 893 times in the sludge. The EP (extractable product) toxicity limits in column 3 of table 9 are for a 20:1 water extract of a solid waste. Therefore, column 4 (table 9) for EP toxicity was derived by multiplying the values for items in column 5 (table 5) by 893/20 or 44.7. All values in column 4 (table 9) are well below maximum RCRA limits. Consequently, calcium carbonate sludges recovered from lime treatment of DS water need not be stored or transported as an RCRA hazardous waste.

DS raw water contains an average TDS concentration of 10 600 mg/L or approximately 10 g/1000 mL. The toxic materials in the raw water would be concentrated 1000/10 or 100 times in the 63 000 t/a (69 000 tons/yr) of dried salt recoverable from DS water. Isolation of all the TDS as 10 600 mg/L of dried salt would concentrate toxic materials less than precipitation of only the dissolved 254 mg/L of calcium associated with dissolved bicarbonate as calcium carbonate. Consequently, calcium carbonate sludges and dried salts would not concentrate EP toxicity sufficiently to be classified as hazardous waste.

UPDATE OF GLENWOOD SPRING AND AQUIFER ANALYSES

Water samples were obtained by a contractor for USBR chemical engineers on June 15, 1985, from GS artesian spring No. S-GL-60 and from capped borehole No. BH-GL-3. Analyses for these water samples are compared with earlier analyses in table 10.

Constancy of spring analysis. – The June 15, 1985 analyses of spring No. S-GL-60 water show generally little change from averages of 32 spring analyses taken between April 21, 1972, and November 7, 1979. Temperature and TDS are the same. All major constituents, except chloride, appear to fall within the expected analytical variance. The anomaly in chloride concentration may have been caused by

Table 9. – Comparison of DS sludge and dried salt with RCRA maximum limits.

(1) Table 5 item	(2) Parameter	(3) RCRA hazardous waste criteria [8] (20:1 extract)	(4) Pretreatment sludge (20:1 extract)
	EP Inorganic Toxicity (max. conc.), mg/L		
30	Arsenic	5.0	0.22
53	Barium	100.0	2.2
32	Cadmium	1.0	0.045
33	Chromium	5.0	1.3
40	Lead	5.0	<1.0
43	Mercury	0.2	0.005
45	Selenium	1.0	<0.2
46	Silver	5.0	<0.7
	EP Organic Toxicity (max. conc.), mg/L		
67	Endrin	0.02	<0.009
68	Lindane	0.04	<0.02
69	Methoxychlor	10.0	<4.5
70	Toxaphene	0.5	<0.2
71	Herbicide 2,4-D	10.0	<0.45
72	Silex, 2,4-5 TP	1.0	<0.45

changes in analytical techniques during the 6- to 13-year interim.

Constancy of aquifer analysis. – The June 15, 1985 analysis of borehole BH-GL-3 for calcium, chloride, fluoride, magnesium, potassium, sodium, and strontium remained about the same (within expected analytical variance) as the August 15, 1984 borehole analysis. Anomalies in alkalinity, bicarbonate, carbon dioxide, sulfate, and TDS are consequences of sampling techniques. A high degree of confidence in analytical results was obtained on August 15, 1984 water samples, because of carefully planned and controlled sampling procedures by USBR personnel. Water samples were taken at that time to ensure the measurement of all carbon dioxide dissolved in water at aquifer pressure.

Variance between spring and aquifer analyses. – The effects of loss of carbon dioxide on dissolved salt constituents concentrations can be explained by comparing aquifer water (BH-GL-3, August 15, 1984) analysis with typical spring water (S-GL-60, June 15, 1984) analysis. Spring water shows weight-percent reductions of 13, 27, 47, 89, and 38 (for TDS, bicarbonate, calcium, carbon dioxide, and sulfate, respectively) over aquifer water. These losses in dissolved constituents can be explained by the escape of carbon dioxide from solution when an emergent spring equilibrates with the atmospheric air. When carbon dioxide leaves solution, calcium bicarbonate converts to insoluble calcium carbonate and precipitates. In addition, the loss of acid anhydride carbon dioxide lowers the calcium sulfate solubility, and it precipitates. Losses in calcium, carbon dioxide, bicarbonate, and sulfate result in a lower TDS.

Table 10. – Physical and chemical characteristics of Glenwood Springs spring and aquifer.

Table 5 item	Characteristics	Units	Glenwood Springs water			
			Spring sample No. S-GL-60		Borehole sample No. BH-GL-3	
			4-21-72 to 11-7-79	6-15-85	[1] 8-15-84	6-15-85
	Number of samples analyzed		32	2	2	2
	Physical properties					
1	Conductivity at 25 °C	mS/m	2 940	2 880	2 860	3 080
2	Flow	m^3/s	0 085	–	–	–
3	pH (lowest measured)	pH	6.6	–	6.3	–
4	TDS (total dissolved solids)	mg/L	19 400	19 300	22 200	21 700
5	Temperature	°C	50	50	49	40
6	TSS (total suspended solids)	mg/L	18	–	51	–
7	Turbidity	JTU	0.3	–	–	–
10	Borehole depth	ft	–	–	76	76
	Major constituents					
13	Alkalinity as $CaCO_3$	mg/L	630	630	630	400
14	Bicarbonate	mg/L	750	750	748	500
15	Bicarbonate (corrected for pressure)	mg/L	–	–	1 031	775
16	Calcium	mg/L	494	440	824	[2]820
17	Chloride	mg/L	10 900	9 800	11 400	11 400
18	Carbon dioxide (measured/corrected)	mg/L	–	100	826/948	125/-
19	Fluoride	mg/L	2.4	35	3.1	4.5
20	Magnesium	mg/L	82	78	93	110
21	Potassium	mg/L	160	140	220	180
22	Silica	mg/L	29	16	41	24
23	Sodium	mg/L	6 630	6 400	7 780	7 300
24	Strontium	mg/L	9	5	13	10
25	Sulfate	mg/L	1 150	1 160	1 860	2 090
26	Sulfide	mg/L	–	1.0	0.7	3.2

[1] Extraordinary sampling procedures taken on 8-15-84 to prevent loss of dissolved carbon dioxide.
[2] Acidified to <pH 2 at site.

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[5] URS Corporation, "Salinity Investigation of Glenwood-Dotsero Springs Unit," Bureau of Reclamation Contract No. 0-07-40-S1359 Grand Junction, CO, March 24, 1982, and April 29, 1983.

[6] "Drinking Water Regulations – Radionuclides," Environmental Protection Agency, Federal Register, July 9, 1979.

[7] "Hazardous Waste and Consolidated Permit Regulations," Environmental Protection Agency, Federal Register, May 19, 1980.

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* Former name of Bureau of Reclamation.

APPENDIX A

CHARACTERISTICS OF GLENWOOD SPRINGS WATER

Table A-1. – Chemical and physical characteristics of Glenwood Springs water[1]

(1) Item	(2) Characteristic	(3) Units	(4) Glen 2/ 10	(5) Glen 12	(6) Glen 20	(7) Glen 30	(8) Glen 40	(9) Glen 30-40	(10) Glen 50	(11) Glen 60	(12) Glen 70	(13) Glen 76	(14) Glen 78	(15) Glen 80	(16) Glen 90	(17) Glen 100	(18) Glen 3/ 115	(19) Average	(20) RCRA EP 4/ limits	(1) Item
Samples Analyzed			32	4	19	23	23	7	32	32	33	19	1	28	32	31	26	316		
Physical Properties																				
1	Conductivity at 25 °C	mS/m	3 040	3 060	2 820	2 840	2 850	2 820	2 890	2 940	2 640	2 830	2 780	2 440	3 260	2 970	140	8/ 2 870		1
2	Flow	m³/s	0.011	0.0084	0.022	0.0028	0.0057	0.0020	0.0028	0.085	0.096	0.0028	0.0028	0.0057	0.0085	0.014	0.0085	5/ 0.296		2
3	pH	-	6.9	6.6	6.8	7.0	7.1	6.9	7.0	6.6	7.2	7.3	6.7	7.4	7.0	6.8	7.6	7.0		3
4	TDS (total dissolved solids) 10/	mg/L	18 932	19 600	18 114	18 116	18 350	18 283	18 224	19 354	16 674	20 233	18 567	16 670	21 847	19 952	778	18 780		4
5	Temperature	°C	50	49	51	51	50	51	50	50	36	27	25	28	41	38	46	6/ 51		5
6	Total suspended solids	mg/L						12		18							5	5/ 18		6
7	Turbidity	NTU						0.96		0.30							0.96	6/ 0.96		7
8	Water bearing unit	LL 7/																LL 7/		8
Major Constituents																				
9	Alkalinity as $CaCO_3$	mg/L	632		611			617	610	632				583	769	720	2 485	620		9
														8 227	11 167	10 204	8.7	8/ 470		10
10	Calcium	mg/L	468	477	448	455	455	442	443	494	419	713	670	499	711	711	218	8/ 9 900		11
11	Chloride	mg/L	10 357	10 646	9 895	9 890	9 955	9 842	9 822	10 904	9 064	10 460	9 240	118	139	133	298	8/ 706		12
12	Bicarbonate	mg/L	764	772	725	703	683	706	700	750	646	630	720	140	185	167	1.40	8/ 91		13
13	Magnesium	mg/L	85	86	83	83	83	78	73	82	78	136	119				7.1	8/ 169		14
14	Potassium	mg/L	185	200	163	162	164	156	160	162	151	167	201				4.1	29		15
15	Silica	mg/L	29		30			27	28	29				5 217	7 260	6 646	286	8/ 6 458		16
16	Sodium	mg/L	6 550	6 900	6 329	6 434	6 461	6 171	6 406	6 629	5 860	6 782	6 031	1 629	2 142	1 990	101	8/ 1 200		17
17	Sulfate	mg/L	1 088	1 191	1 069	1 153	1 136	1 319	1 119	1 146	1 052	1 977	1 772							
Trace Metals 1/ [2]																				
18	Aluminum	mg/L			0.650			0.500		0.235							0.075	0.46		18
19	Antimony	mg/L						0.02		0.046							<0.005	0.033		19
20	Arsenic	mg/L						0.002		0.017							0.002	0.02	5.0	20
21	Barium	mg/L																1/ 0.12 [4]	100.0	21
22	Boron	mg/L																1/ 0.9 [4]		22
23	Cadmium	mg/L			0			<0.010	0	0.010							0.001	0.01	1.0	23
24	Chromium	mg/L			<0.090			0.050		0.06							0.033	0.067	5.0	24
25	Cobalt	mg/L			<0.090			0.080		0.055							0.033	0.075		25
26	Copper	mg/L			<0.020			0.040		0.050							0.023	0.037		26
27	Fluoride	mg/L	2.2		2.1			2.2	1.9	2.35							3.7	2.2		27
28	Gallium	mg/L			<0.040			0.040		<0.050							<0.003	0.043		28
29	Germanium	mg/L			<0.090			0.090		<0.100							<0.005	0.093		29
30	Iodide	mg/L						0.01		0.155							0.01	0.083		30
31	Iron	mg/L	0.030		0.030			0.070	0.080	0.059							0.16	0.054		31
32	Lead	mg/L			<0.090			0.048		0.053							<0.005	0.064	5.0	32
33	Lithium	mg/L			0.800			0.830	0.670	0.85							0.150	0.78		33
34	Manganese	mg/L	0.075		0.070			0.064	0.070	0.080							0.053	0.072		34
35	Mercury	mg/L			0			<0.0001	0	<0.0001							<0.0001	<0.0001	0.2	35
36	Nickel	mg/L			<0.090			0.075		0.055							0.028	0.073		36
37	Selenium	mg/L			0			0.011	0	0.013							<0.005	0.012		37
38	Silver	mg/L			<0.009			0.015		0.015							<0.020	0.013	1.0	38
39	Strontium	mg/L								9.2							0.220	9.2	5.0	39
40	Tin	mg/L			<0.090			<0.090		<0.150							<0.005	<0.11		40
41	Titanium	mg/L			<0.040			<0.040		<0.050							<0.003	<0.043		41
42	Uranium	mg/L						0.006		0.006							<0.001	0.006		42
43	Vanadium	mg/L			<0.040			<0.040		<0.050							<0.005	<0.043		43
44	Zinc	mg/L			0.010			0.035	0.020	0.030							0.007	0.024		44
45	Zirconium	mg/L			<0.140			<0.140		<0.200							<0.008	<0.14		45
Trace Anions 1/ [2]																				
46	Ammonia	mg/L						0.5		0.9							0.3	0.7		46
47	Nitrite	mg/L						<0.05		<0.05							<0.05	0.05		47
48	Nitrate	mg/L						<0.05		0.09							<0.05	0.07		48
49	Nitrogen	mg/L	0.01		0.01			0.07	0.1	0.01							0.06	0.02		49
50	Orthophosphate	mg/L	0.04		0.03			0.03	0.03	0.04							0.01	0.034		50
51	Total phosphate	mg/L	0.12		0.09			0.09	0.09	0.12							0.04	0.10		51
Radioactivity 1/ [2]																				
52	Gross alpha	pCi/L						85 ± 61		115 ± 66						100 ± 113	4 ± 3	100 ± 80		52
53	Gross beta	pCi/L						132 ± 76		195 ± 79						350 ± 140	8 ± 12	226 ± 98		53
54	Total Ra	pCi/L						28 ± 6		68 ± 7						24 ± 5		40 ± 6		54
55	226 Ra	pCi/L						28 ± 5		28 ± 5						9.0 ± 3.1	1.2 ± 0.17	22 ± 4		55
56	228 Ra	pCi/L						18 ± 3		40 ± 5						15 ± 4	0.65 ± 0.62	24 ± 4		56
57	Total K	pCi/L						140		140						140		140		57
58	40 K	pCi/L						120		120						120		120		58
59	90 Sr	pCi/L						0.4 ± 0.8		0.4 ± 0.7						0.4 ± 0.8		Nil		59
60	210 Bi	pCi/L						-1.1 ± 2.2		<1.3 ± 1.6						0.8 ± 1.7		Nil		60
61	210 Pb	pCi/L						0.1 ± 3.1		0.5 ± 2.0						0.5 ± 2.0		Nil		61
Organic Compounds 1/ [4]																				
62	Total organics	mg/L																	1/ 3 [4]	62
	Pesticide:																			
63	Endrin	mg/L						9/ <0.0002										<0.0002	0.02	63
64	Lindane	mg/L						9/ <0.004										<0.0004	0.4	64
65	Methoxychlor	mg/L						9/ <0.10										<0.10	10.0	65
66	Toxaphene	mg/L						9/ <0.005										<0.005	0.5	66
	Herbicide:																			
67	2,4-D	mg/L						9/ <0.10										<0.10	10.0	67
68	2,4-5 TP (Silvex)	mg/L						9/ <0.01										<0.01	1.0	68

1/ All data provided by Upper Colorado Region for water samples taken April 10, 1972 through November 7, 1979, except as noted for references [2] and [4].
2/ Number assigned to identified spring.
3/ Physical properties and major constituents not included in column (19).
4/ The EP (extractable product) toxicity limits are for a 20:1 water extract of a solid waste.
5/ Summation of flow rate for 15 springs.
6/ Maximum measured values.
7/ All identified Glenwood springs are located in Leadville limestone.
8/ Flow rate weighted averages.
9/ Analysis previously not reported.
10/ TDS by evaporation at 105 °C to constant weight.

APPENDIX B

CHARACTERISTICS OF DOTSERO SPRINGS WATER

Table B-1. – Chemical and physical characteristics of Dotsero Springs water[1]

(1) Item	(2) Characteristic	(3) Units	(4) Dot 2/ 4	(5) Dot 5	(6) Dot 6	(7) Dot 7	(8) Dot 9	(9) Dot 10	(10) Dot 11	(11) Dot 20	(12) Dot 30	(13) Dot 40	(14) Dot 90	(15) Average	(16) RCRA EP 3/ limits	(1) Item
Samples analyzed			1	31	31	1	28	32	29	22	21	22	10	228		
Physical Properties																
1	Conductivity at 25 °C	mS/m	1 790	1 770	1 780	1 790	1 570	1 390	1 460	1 690	1 670	1 670	1 730	1 640		1
2	Flow	m^3/s	0.0028	0.0028	0.0028	0.0028	0.051	0.031	0.040	0.011	0.011	0.020	0.045	4/ 0.220		2
3	pH	-	7.7	7.6	7.6	7.5	7.2	7.5	7.4	7.3	7.2	7.2	7.4	7.4		3
4	TDS (total dissolved solids) 3/	mg/L	10 652	10 667	10 600	10 667	9 200	8 300	9 557	10 143	9 570	9 950	10 235	7/ 9 954		4
5	Temperature	°C	23	26	26	32	32	29	31	32	32	32	32	5/ 32		5
6	Total suspended solids	mg/L	15						6					5/ 15		6
7	Turbidity	NTU	1.9						0.21					5/ 1.9		7
8	Water bearing unit	LL 6/												LL 6/		8
Major Constituents																
9	Alkalinity $CaCO_3$ as $CaCO_3$	mg/L	340				345		320				371	344		9
10	Calcium	mg/L	301	251	239	250	255	254	253	259	258	252	253	7/ 254		10
11	Chloride	mg/L	5 936	5 766	5 837	5 825	4 937	4 412	4 640	5 607	5 537	5 486	5 604	7/ 5 073		11
12	Bicarbonate	mg/L	407	373	369	392	413	357	378	443	442	442	445	7/ 410		12
13	Magnesium	mg/L	63	59	55	53	56	54	54	61	60	61	64	7/ 58		13
14	Potassium	mg/L	57	63	68	57	38	35	37	44	44	43	53	7/ 42		14
15	Silica	mg/L	15				13		13				13	13.5		15
16	Sodium	mg/L	3 397	3 740	3 724	3 724	3 183	2 843	2 703	3 610	3 577	3 538	3 562	7/ 3 204		16
17	Sulfate	mg/L	646	533	517	522	519	567	540	519	504	505	475	7/ 520		17
Trace Metals 1/ [2]																
18	Aluminum	mg/L											0.100	0.1		18
19	Antimony	mg/L	0.010						0.011					0.01		19
20	Arsenic	mg/L	0.008						0.002					0.005	5.0	20
21	Barium	mg/L												1/ 0.05 [4]	100.0	21
22	Boron	mg/L												1/ 0.07 [4]		22
23	Cadmium	mg/L	0.010				0		0.010				0.002	0.001	1.0	23
24	Chromium	mg/L	0.020						<0.010				<0.060	0.03	5.0	24
25	Cobalt	mg/L	<0.060						<0.060				<0.060	<0.060		25
26	Copper	mg/L	0.040						0.040				<0.012	0.031		26
27	Fluoride	mg/L	0.7				0.3		0.4				0.6	0.5		27
28	Gallium	mg/L											<0.030	<0.03		28
29	Germanium	mg/L											<0.100	<0.1		29
30	Iodide	mg/L							<0.01					<0.01		30
31	Iron	mg/L	1.90				0.010		0.070				0.030	0.503		31
32	Lead	mg/L	<0.005						<0.005				<0.060	<0.023	5.0	32
33	Lithium	mg/L					0.080						0.100	0.09		33
34	Manganese	mg/L	0.050										0.020	0.035		34
35	Mercury	mg/L	<0.0001				0		<0.0001				0.0001	0.0001	0.2	35
36	Nickel	mg/L	<0.05						<0.05				<0.060	<0.053		36
37	Selenium	mg/L	<0.005				0						0	<0.005	1.0	37
38	Silver	mg/L	<0.020						<0.020				<0.006	<0.015	5.0	38
39	Strontium	mg/L							2.600					2.600		39
40	Tin	mg/L											<0.085	<0.085		40
41	Titanium	mg/L											<0.030	<0.030		41
42	Uranium	mg/L							0.003					0.003		42
43	Vanadium	mg/L											<0.030	<0.030		43
44	Zinc	mg/L	0.040				0.010		0.040				0.010	0.025		44
45	Zirconium	mg/L											<0.100	<0.100		45
Trace Anions 1/ [2]																
46	Ammonia	mg/L							<0.2					0.2		46
47	Nitrite	mg/L							<0.05					<0.05		47
48	Nitrate	mg/L							<0.05					<0.05		48
49	Nitrogen	mg/L					0.09						0.06	0.075		49
50	Orthophosphate	mg/L					0.02							0.02		50
51	Total phosphate	mg/L					0.06							0.06		51
Radioactivity 1/ [2]																
52	Gross alpha	pCi/L	41 ± 35						42 ± 27					44 ± 31		52
53	Gross beta	pCi/L	33 ± 44						39 ± 32					36 ± 38		53
54	Total Ra	pCi/L							10 ± 7					10 ± 7		54
55	228 Ra	pCi/L							2.8 ± 5					2.8 ± 5		55
56	40 K	pCi/L							5.7					5.7		56
57	90 Sr	pCi/L							0.0 ± 0.08					0		57
58	210 Bi	pCi/L							1.7 ± 1.6					1.7 ± 1.6		58
59	210 Pb	pCi/L							3.4 ± 2.1					3.4 ± 2.1		59
Organic Compounds 1/ [4]																
60	Total organics	mg/L												1/ 3 [4]		60
	Pesticide:															
61	Endrin	mg/L					8/ <0.0002							<0.0002	0.02	61
62	Lindane	mg/L					8/ <0.004							<0.0004	0.04	62
63	Methoxychlor	mg/L					8/ <0.10							<0.10	10.0	63
64	Toxaphene	mg/L					8/ <0.005							<0.005	0.5	64
	Herbicide:															
65	2,4-D	mg/L					8/ <0.10							<0.01	10.0	65
66	2,4-5 TP (Silvex)	mg/L					8/ <0.01							<0.01	1.0	66

1/ All data provided by Upper Colorado Region for water samples taken April 20, 1972 through November 7, 1979 except as noted from references [2] and [4].
2/ Number assigned to identified spring.
3/ The EP (extractable product) toxicity limits are for a 20:1 water extract of a solid waste.
4/ Summation of flow rate for 11 springs.
5/ Maximum measured values.
6/ All identified Dotsero Springs are located in Leadville limestone.
7/ Flow rate weighted averages.
8/ Analysis previously not reported.
9/ TDS by evaporation at 105 °C to constant weight.

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