DAUB & ASSOCIATES, INC.

1985 ½ SOUTH BROADWAY
GRAND JUNCTION, CO 81507-9649
(970) 254-1224
FAX (970) 242-8438
email: gjdaub@daubandassociates.com
www.daubandassociates.com

NATURAL SODA

2010 Mine Plan
Volume 4, Section 5.0
Hydrologic Conditions

Prepared for:

Natural Soda, Inc.
Piceance Creek Basin
Rio Blanco County, Colorado

Prepared by:

Daub & Associates, Inc.
Grand Junction, Colorado

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

APPENDICES

SECTION 5.0 HYDROLOGIC CONDITIONS

5.1. INTRODUCTION

The information used in the development of this mine plan included publications of the U.S. Geological Survey, data from groundwater investigations conducted by Rio Blanco Oil Shale Company, Multi Mineral Corporation, and investigations conducted by Industrial Resources, Inc., NaTec, White River Nahcolite and Natural Soda, Inc. (NSI) in support of the original mine permit application and subsequent mine plan updates.

5.2. SURFACE WATER

5.2.1. Regional Setting

The NSI nahcolite solution mine project area is located in the Piceance Creek Basin, in northwestern Colorado (see Figure 5-1). The climate of the area is semi-arid, with annual precipitation ranging from about 12 inches at 6,000 feet to about 15 inches at 6,800 feet (Ege et al, 1978). Precipitation generally occurs as snow from November to March and as rain during the remainder of the year. Annual potential evapotranspiration for horizontal surfaces ranges from 46 inches at 6,000 feet to 43 inches at 6,800 feet. The sodium lease is located between Yellow Creek and Ryan Gulch which are part of the Yellow Creek and Piceance hydrologic basin. The primary source of streamflow to Ryan Gulch and Yellow Creek is groundwater discharge. The primary flow periods include runoff from snowmelt beginning in March and continuing through June or July. Streamflow for the remainder of the year is maintained almost totally by groundwater discharge with approximately 80 percent of streamflow in the basin being supplied by groundwater (Weeks et al, 1974).

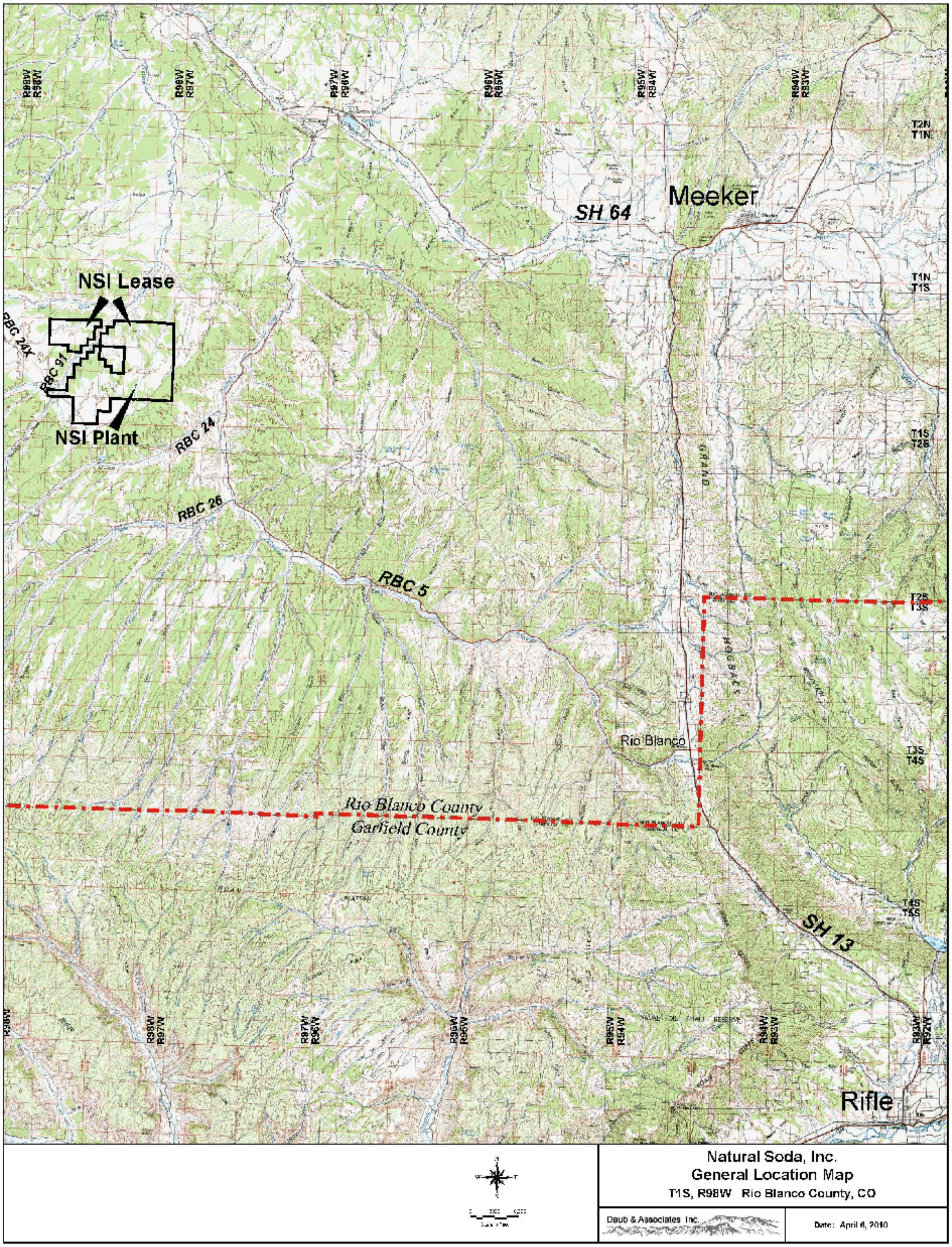

Figure 5-1. Location of the project area in the Piceance Creek Basin.

5.2.2. Site Drainages

The four sodium lease tracts are primarily located in the Yellow Creek drainage. One lease tract, C-0118327, partially extends into Horse Draw drainage, a tributary to Piceance Creek. Site drainages are shown on Figure 5-2.

Surface drainage from the sodium lease tracts is controlled by a series of intermittent streams, all of which flow toward Yellow Creek with the exception of Horse Draw. Yellow Creek is predominantly an intermittent stream, though some reaches and the mouth of the stream will flow year-round.

The drainage area of Yellow Creek, measured at the USGS Yellow Creek station, near White River is 262 square miles. Average annual discharge was 1.11 cfs (804 acre-feet per year) for the period from October 2007 to September 2008, with a maximum daily flow of 11.0 cfs on March 2, 2008, and a maximum instantaneous flow of 29.0 cfs on March 1, 2008 (http://co.water.usgs.gov).

5.2.3. Diversions and Water Rights

The majority of surface waters in the region are used for agricultural purposes including irrigating hay meadows in the low land areas and stock watering. The BLM established that there are 52,720 acres of irrigated pastures, hay land, and cropland within the White River Conservation District. Irrigation diversions usually begin in mid-March and continue through early November. The amount of water diverted and number of acres irrigated at any one time are dependent on water availability, water-right priorities, crop type and weather conditions. Wymore (1974) estimated annual streamflow depletions due to irrigation as 3,950 acre-feet in the Piceance Creek Basin and 50 acre-feet in the Yellow Creek Basin.

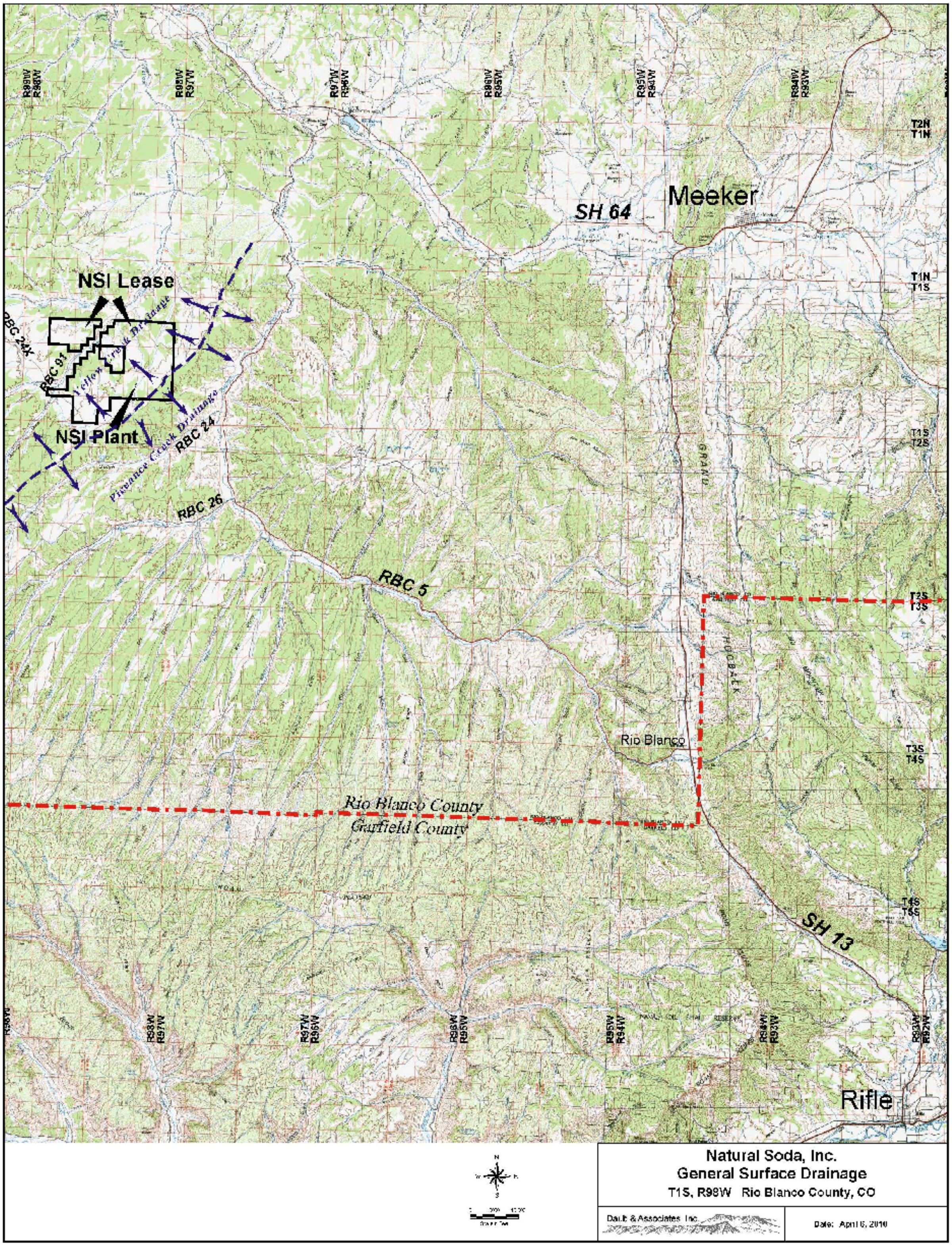

Figure 5-2. General Surface Drainage Map of the Piceance Creek Basin.

Although some of the current uses of water within the Piceance Creek and Yellow Creek Basin are for agricultural purposes, most of the senior water rights and large volume water rights are owned by energy and natural resource development companies or governmental entities, such as the Colorado River Water Conservation District (MacDonnell, 2009). As discussed below, Natural Soda owns several water rights within the Piceance Creek Basin.

Natural Soda is the owner of several direct flow and storage rights as well as groundwater rights in the White River/Piceance Creek/Yellow Creek drainage basin in Rio Blanco County. The White River/Piceance Creek/Yellow Creek water rights have been secured to function as an integrated system of providing a water supply for uses associated with Natural Soda's sodium leases.

The water supply for the sodium mining operations is presently supplied through a single water production well (90-1). The annual amount of water delivered for the current sodium mining operations (May 2009 through April 2010) is approximately 146 acre feet of water per year. This water usage amount is below the permitted volume of 169 acre feet as indicated in the final Environmental Impact Statement (EIS, Table 4-3). The annual water withdrawals from the water production well for use in the sodium mining operations between the years 1990 and 2008 are illustrated in Figure 5-3. Under Colorado law, the withdrawal of the water supply through a water production well requires the replacement of depletions to stream systems caused by the withdrawal of the water from the aquifer. The replacement obligation associated with past and current water well withdrawals is currently less than two and one-half (2.5) acre feet of water per year. However, the withdrawal of water from the water production well causes ongoing depletions to the stream systems that will need to be replaced in the future. As of 2009, the calculated maximum annual replacement of depletions associated with past pumping of the water well is approximately 7 acre feet over the next approximately 250 years.

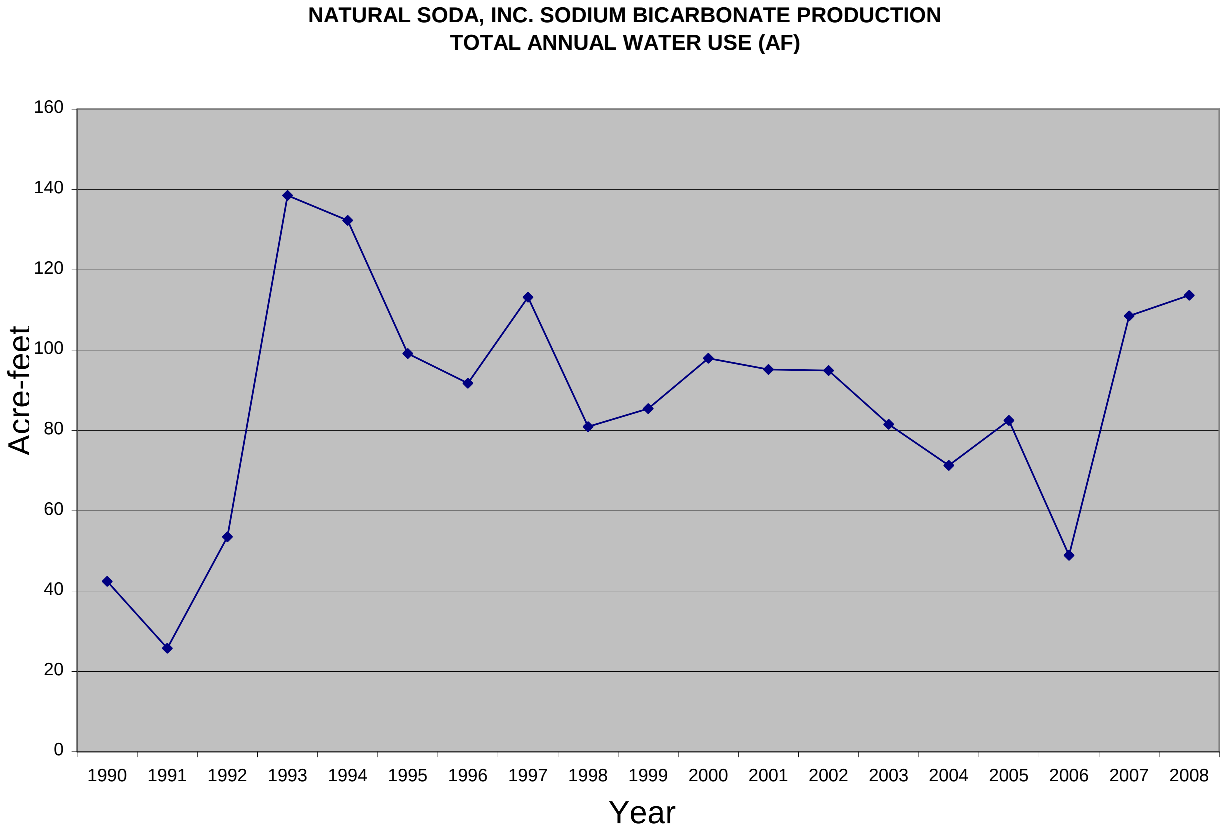

Figure 5-3. Annual water usage in acre feet per year by Natural Soda, Inc.

In compliance with Colorado law, Natural Soda, and its predecessors, have operated a judicially approved "plan for augmentation" to replace the stream depletions associated with water well production. Pursuant to a decree entered by the District Court in and for Water Division No. 5 in Case No. 88CW420 on August 13, 1991, the District Court approved a plan for augmentation for the sodium mining operations and other operations. The plan for augmentation provides for the construction of such wells as are required by Natural Soda for the mining operations on the sodium leases, and for the replacement of depletions associated with such well operation. Natural Soda has applied for two (2) additional water well production permits from the Colorado State Engineer. The water produced pursuant to the construction and operation of the additional wells will provide additional water supplies and redundancy in the water supply for the sodium mining operations.

A core hole (2010-26-198-2C) scheduled to be drilled in 2010 will be converted into a water supply well as a back-up for the current 90-1 water supply well, and to accommodate the increase in water demand with upcoming plant expansion. Natural Soda anticipates a total water use of 306 acre feet per year at maximum plant expansion (producing 250,000 tons per year).

Natural Soda owns several water rights that are useable for the replacement of stream depletions associated with the operation of the water production wells. Included within the water rights are several "senior" ditch water rights. The significance of the "senior" status is that under Colorado law, the right to withdraw water from the surface streams is based on seniority. As a result, a senior water right is entitled to divert water prior to a junior water right. The senior ditch water rights owned by Natural Soda are among the most senior water rights in the Piceance Creek Basin, and the water rights produce approximately 270 acre feet of fully consumable water each year. Natural Soda owns water rights that will produce in excess of 79,000 acre feet of fully consumable water per year. The decreed water rights for Natural Soda are displayed in Table 5-1.

5.2.4. Existing and Potential Regional Uses

The majority of the surface waters of the area are used for irrigation or stock water purposes. Alley (1982) has suggested an annual consumptive use of surface water for irrigation purposes of 1 to 3 acre-feet per acre for the area drained by the White River. Weeks et al, (1974) has estimated that depletions resulting from irrigation constitute about 25 percent and 5 percent of the natural flow of Piceance and Yellow Creeks, respectively.

Vast deposits of oil shale are contained in the Piceance Creek Basin. Future development of this oil shale resource will require a large amount of water. In addition, the increases in population accompanying oil shale development will require additional water. Alley (1982) suggested that water use estimates for an oil shale industry would vary from 1 to 6 barrels of water per barrel of oil (BW/BO) produced, with an average consumptive use of 3 BW/BO. The wide range in projected use is, in part, related to different methods of oil shale mining, extraction, processing and reclamation. Assuming a one-million-barrel-per-day oil shale industry, the water demand would be equivalent to 141,000 acre-feet/year.

Table 5-1. Natural Soda, Inc. White River/Yellow Creek water rights summary of decree information.

NATURAL SODA, INC. WATER RIGHTS

Name of Structure	Decreed Amount[1]	Decreed Location	Approp. Date[2]	Adjudic. Date[3]	Case Number[4]	Decreed Uses	Remarks
Morgan Ditch Nc 1	1 cfs, absolute	The headgate is located on the north bank of Piceance Creek, about two hundred yards abov the government road crossing in Rio Blanco County.	4/15/1883	4/28/1890		Domestic, industrial, commercial, irrigation, stockwatering, recreation, and fish and wildlif purposes. Additionally, the water will be directly used, stored and subsequently used, and used for substitution and exchange, for replacement of depletions and for augmentation purposes, including the right to fully consume by first use and by subsequent use the water diverted under the water rights.	Use changed in 88CW420
Enlargement an Extension of Morgan Ditch Nc 1	0.4 cfs, absolute	The headgate is located on the north bank of Piceance Creek, about two hundred yards abov the government road crossing in Rio Blanco County.	9/27/1886	4/28/1890		Domestic, industrial, commercial, irrigation, stockwatering, recreation, and fish and wildlif purposes. Additionally, the water will be directly used, stored and subsequently used, and used for substitution and exchange, for replacement of depletions and for augmentation purposes, including the right to fully consume by first use and by subsequent use the water diverted under the water rights.	Use changed in 88CW420
Morgan No. 2 Ditch	0.4 cfs, absolute	The headgate is located on the south bank of Piceance Creek, about one fourth of a mile abov the government road crossing.	9/27/1886	4/28/1890		Domestic, industrial, commercial, irrigation, stockwatering, recreation, and fish and wildlif purposes. Additionally, the water will be directly used, stored and subsequently used, and used for substitution and exchange, for replacement of depletions and for augmentation purposes, including the right to fully consume by first use and by subsequent use the water diverted under the water rights.	Use changed in 88CW420
Home Supply Ditch	1 cfs, absolute	The headgate is located on the south bank of Nineteen Creek, also known as Nineteen Mile Creek, about one mile above the junction of Nineteen Creek and Piceance Creek, in Rio Blanco County.	9/19/1886	5/10/1889		Domestic, industrial, commercial, irrigation, stockwatering, recreation, and fish and wildlif purposes. Additionally, the water will be directly used, stored and subsequently used, and used for substitution and exchange, for replacement of depletions and for augmentation purposes, including the right to fully consume by first use and by subsequent use the water diverted under the water rights.	Use changed in 88CW420

NATURAL SODA, INC. WATER RIGHTS
(Continuted)

Name of Structure	Decreed Amount[1]	Decreed Location	Approp. Date[2]	Adjudic. Date[3]	Case Number[4]	Decreed Uses	Remarks
Larson Ditch	2.5 cfs, absolute	The headgate is located on the north bank of Piceance Creek, about thirty five miles above th mouth thereof and about one half mile from where the government road crosses said creek in Ri Blanco County.	9/17/1886	5/10/1889		Domestic, industrial, commercial, irrigation, stockwatering, recreation, and fish and wildlif purposes. Additionally, the water will be directly used, stored and subsequently used, and used for substitution and exchange, for replacement of depletions and for augmentation purposes, including the right to fully consume by first use and by subsequent use the water diverted under the water rights.	Use changed in 88CW420
Larson Reservoir	62 AF, absolute	Southeastern portion of the N.E. forty acres of said Larson's land about 200 yards east of the government road crossir Piceance Creek.	7/20/1888	5/10/1889		Domestic, industrial, commercial, irrigation, stockwatering, recreation, and fish and wildlif purposes. Additionally, the water will be directly used, stored and subsequently used, and used for substitution and exchange, for replacement of depletions and for augmentation purposes, including the right to fully consume by first use and by subsequent use the water diverted under the water rights.	Use changed in 88CW420
Wolf Ridge Reservoir	7379.7 AF, conditional	Initial point of survey of the high water line of reservoir is located at a point whence the NE corner of Sec. 12, T1S, R98W of 6th P.M. bears N 08°44'E a distance of 4,663'	11/19/1966	12/31/1971	W-358	Irrigation, domestic, stock watering, municipal and industrial, and all water diverted under th water rights shall be fully consumable	Diligence: W-358-75; 79CW143; 83CW153, 87CW140, 93CW147, 99CW265 and 06CW13 (pending); Changed in 88CW420
Wolf Ridge Feed Pipline	100 cfs, conditional	Point of diversion is located on the left bank the White River whence corner No. 2 of Tract 46, Sec. 34, T2N, R97W of 6th P.M. bears N 77°44' a distance of 545'	11/19/1966	12/31/1971	W-459	Domestic, municipal, industrial, including all uses pertaining of oil and other products from oil shale, irrigation, and other beneficial uses, and all water diverted under the water rights shall be fully consumable	Diligence: W-459-75,79CW144, 83CW15 87CW139, 93CW146, 99CW264, and 06CW13 (pending); Changed in 88CW420

Table 5-1. Natural Soda, Inc. White River/Yellow Creek water rights summary of decree information (continued).

NATURAL SODA, INC. WATER RIGHTS
(Continuted)

Name of Structure	Decreed Amount[1]	Decreed Location	Approp. Date[2]	Adjudic. Date[3]	Case Number[4]	Decreed Uses	Remarks
Colorado Minera Well No. 28-1	5.0 cfs; 4.94 cfs conditional, 0.06 cfs absolute	Located in the NE, NW, Sec. 28, T1S, R98W of 6th P.M. at a point 270.5 South of the north line and 1365.2' east of west line	2/28/1967	12/31/1973	W-1922	Industrial, domestic, and livestock	Diligence: W-1922-77, 81CW129, 85CW160, 89CW119, 95CW245, 02CW103 and 10CW1((pending); augmented b 88CW420
Colorado Minera Well No. 14-1	5.0 cfs; 4.94 cfs conditional, 0.06 cfs absolute	Located in the NW, NE, Sec. 14, T1S. R98W of 6th P.M. at a point 641.2 south of the north line ar 1698.94' west of the eas line	2/28/1967	12/31/1973	W-1923	Industrial, domestic, and livestock	Diligence: W-1923-77; 81CW130, 85CW161, 89CW118, 95CW247 ar 03CW128; augmented t 88CW420
Savage Well Nc 24-1	5.0 cfs; 4.94 cfs conditional, 0.06 cfs absolute	Located in the NE, NE, Sec. 24, T1S, R98W of 6th P.M. at a point 342.9 south of the north line ar 331.71' west of the east line	2/28/1967	12/31/1973	W-1924	Industrial, domestic, and livestock	Diligence: W-1924-77, 81CW131, 85CW162, 89CW117, 95CW246 ar 03CW127; augmented t 88CW420
Dunn Well No. 2(1	5.0 cfs; 4.94 cfs conditional, 0.06 cfs absolute	Located in the NE, NW, Sec. 20, T1S, R98W of 6th P.M. at a point 1197.37' south of the north line and 1172.25' west of the east line	2/28/1967	12/31/1973	W-1925	Industrial, domestic, and livestock	Diligence: W-1925-77, 81CW132, 85CW163, 89CW116, 95CW248 ar 03CW129; augmented t 88CW420
IRI Well D-20-1-1	5.0 cfs, conditional	Located in the NE, NE, Sec. 20, T1S, R98W of 6th P.M. at a point south 45°58' 20" W 1718.35' from the NE corner of Sec. 20	11/8/1974	12/31/1975	W-2884	Domestic, livestock, commercial, industrial, irrigation, and municipal	Diligence: 81CW311, 85CW304, 89CW224, 96CW069, 03CW11, an 10CW13 (pending); augmented by 88CW42
IRI Well D-14-1-2	5.0 cfs, conditional	Located in the SE, NE, Sec. 14, T1S, R98W of 6th P.M. at a point south 19°16' west 2791.11' fro the NE corner of Sec. 14	11/8/1974	12/31/1975	W-2885	Domestic, livestock, commercial, industrial, irrigation, and municipal	Diligence: 81CW312, 85CW305, 89CW225, 96CW070, 03CW10, an 10CW12 (pending); augmented by 88CW42

Table 5-1. Natural Soda, Inc. White River/Yellow Creek water rights summary of decree information (continued).

NATURAL SODA, INC. WATER RIGHTS
(Contintuted)

Name of Structure	Decreed Amount[1]	Decreed Location	Approp. Date[2]	Adjudic. Date[3]	Case Number[4]	Decreed Uses	Remarks
IRI Well D-14-1-1	5.0 cfs, conditional	Located in the SE, NE, Sec. 14. T1S, R98W of 6th P.M. at a point south 16°57'30" west 2635.85' from the NE corner of Sec. 14	11/8/1974	12/31/1975	W-2886	Domestic, livestock, commercial, industrial, irrigation, and municipal	Diligence: 81CW313,85CW306, 89CW226, 96CW071, 03CW09 and 10CW11 (pending); augmented b 88CW420
IRI Well D-20-1-2	5.0 cfs, conditional	Located in the NE. NE, Sec. 20, T1S, R98W of 6th P.M. at a point south 41°l3' west 1688.29' fron the NE corner of Sec. 2C	11/8/1974	12/31/1975	W-2887	Domestic, livestock, commercial, industrial, irrigation, and municipal	Diligence: 81CW314, 81CW314, 85CW307, 89CW227, 96CW068, 03CW12 and 10CW14 (pending); augmented b 88CW420
MMC-IRI Well 4	1.0 cfs, conditional	Located 1120 feet from the East line and 410 fee from the South line in Section 23, TIS, R98W, the 6th P.M.	1/31/1981	11/22/1985	82CW429	Industrial, mining, domestic, municipal, and irrigation	Diligence: 86CW308, 93CW171, 00CW09, an 07CW91 (pending); augmented by 88CW42
MMC-IRI Well 5	1.0 cfs, conditional	Located 1370 feet from the East line and 650 fee from the South line in Section 23, TIS, R98W, the 6th P.M.	1/31/1981	11/22/1985	82CW429	Industrial, mining, domestic, municipal, and irrigation	Diligence: 86CW308, 93CW171, 00CW09, an 07CW91 (pending); augmented by 88CW42
MMC-IRI Well 6	1.0 cfs, conditional	Located 1120 feet from the East line and 700 fee from the South line in Section 23,T1S, R98W, the 6th P.M	3/31/1981	11/22/1985	82CW429	Industrial, mining, domestic, municipal, and irrigation	Diligence: 86CW308, 93CW171, 00CW09, an 07CW91 (pending); augmented by 88CW42
MMC-IRI Well 7	1.0 cfs, conditional	Located 1300 feet from the East line and 510 fee from the South line in Section 23, TIS, R98W, the 6th P.M	4/30/1981	11/22/1985	82CW429	Industrial, mining, domestic, municipal, and irrigation	Diligence: 86CW308, 93CW171, 00CW09, an 07CW91 (pending); augmented by 88CW42

Table 5-1. Natural Soda, Inc. White River/Yellow Creek water rights summary of decree information (continued).

NATURAL SODA, INC. WATER RIGHTS
(Contunted)

Name of Structure	Decreed Amount[1]	Decreed Location	Approp. Date[2]	Adjudic. Date[3]	Case Number[4]	Decreed Uses	Remarks
MMC-IRI Well 8	1.0 cfs, conditional	Located 1230 feet from the East line and 580 fee from the South line in Section 23, TIS, R98W, the 6th P.M.	5/31/1981	11/22/1985	82CW429	Industrial, mining, domestic, municipal, and irrigation	Diligence: 86CW308, 93CW171, 00CW09, an 07CW91 (pending); augmented by 88CW42
Larson Reservo Enlargement	600 AF per year, conditional, and an additional 600 acre-fe per year to fill and refil the Larson Reservoir Enlargement conditional. The water right will be diverted a a rate of 10.0 cfs from Piceance Creek and 1 cfs from the unnamed tributary to Piceance Creek, sometimes known as Nineteen Mi Creek.	A parcel of land situated in the W1/2NE1/4 and th W1/2SE1/4 of Section 3 Township 3 South, Rang 94 West of the Sixth Principal Meridian	4/5/1988	8/13/1991	88CW420	Domestic, industrial, commercial, and irrigatio purposes. The water may be used for a) immediate application to beneficial uses; b) fo storage and subsequent application to beneficial uses; c) for substitution and exchange; d) for replacement of depletions; and e) for augmentation. Natural Soda, Inc. shall have the right to fully consume the wate during the first use of the water, or to recaptu and reuse the water until the water is fully consumed. The conditional water rights will b used as a source of augmentation water for th augmentation plan described in the 88CW42 Decree.	Diligence: 97CW191 an 05CW41.
Raven Pump an Pipeline	2.5 cfs, conditional	SW1/4 NW1/4, Section 21, T1S, R98W, 6th P.M. at a point 830 feet from the West Section line an 2130 feet from the North Section line	11/14/1966 and10/30/1998	Pending	98CW315	Industrial, Commercial, Domestic, Irrigation and storage for Augmentation of current and future depletions to Yellow Creek associated with mining operations on the Sodium Leases	Includes various storag locations
Piceance Creek Substution and Exchange	2.21 cfs, conditional	Piceance Creek within a area along Piceance Creek beginning at approximately Section 3 Township 3 South, Rang 96 West of the 6th P.M. and ending at approximately Sections 11 and 12, Township 1 North, Range 97 West o the 6th P.M.	4/5/1988	8/13/1991	88CW420	Fully consumable uses authorized pursuant to the 88CW420 Decree	Diligence: 97CW191 an 05CW41.

Table 5-1. Natural Soda, Inc. White River/Yellow Creek water rights summary of decree information (continued).

NATURAL SODA, INC. WATER RIGHTS
(Continuted)

Name of Structure	Decreed Amount[1]	Decreed Location	Approp. Date[2]	Adjudic. Date[3]	Case Number[4]	Decreed Uses	Remarks
Yellow Creek Substitution anc Exchange	2.21 cfs, conditional	Yellow Creek, including Corral Gulch and Stake Springs Draw, within an area along Yellow Creek beginning at approximately Section 6 Township 2 South, Rang 98 West of the 6th P.M. and ending at approximately Sections 15 and 16, Township 2 North, Range 98 West o the 6th P.M.	4/5/1988	8/13/1991	88CW420	Fully consumable uses authorized pursuant to the 88CW420 Decree	Diligence: 97CW191 an 05CW41.
White River Substitution anc Exchange	2.21 cfs, conditional, but not to exceed a tot of 1600 AF per year	White River downstream of the point of diversion the Wolf Ridge Feeder Pipeline, which is locate on the left bank of the White River whence Corner No. 2 of Tract 46 Section 34, Township 2 North, Range 97 West o the 6th P. M. bears Nortl 77°44' West a distance c 545 feet, the water diverted pursuant to the Wolf Ridge Feeder Pipeline water right will t substituted and exchanged for the water depleted from Piceance Creek and Yellow Creek	4/5/1988	8/13/1991	88CW420	Fully consumable uses authorized pursuant to the 88CW420 Decree	Diligence: 97CW191 an 05CW41.
Augmentation Plan				8/13/1991	88CW420	Augments the stream depletions associated with well pumping for all of the foregoing wells	

[1] cfs = cubic feet of water per second of time; AF = acre feet of water.
[2] Approp. Date = Appropriation Date pursuant to the Court decree.
[3] Adjudic. Date = Adjudication Date of Court decree.
[4] Case Numbers in this column and the Remarks column refer to the District Court in and for Water Division No. 5, except cases with prefix "10CW", which referto the District court in and for Water Division No. 6.

Table 5-1. Natural Soda, Inc. White River/Yellow Creek water rights summary of decree information (continued).

Oil shale development in Colorado has been largely confined to research and pilot-scale operations. Consequently, it is uncertain as to when or how much water will be required for a synfuels industry in the Piceance Creek Basin.

5.2.5. Surface Water Quality

Water quality in the Yellow Creek and Piceance Creek drainages can be classified as mixed bicarbonate type in the upper reaches and sodium bicarbonate type in the lower reaches. Generally, total dissolved solids (TDS) range from 797 mg/l in the Corral Gulch near Rangely, CO to more than 2,700 mg/l at the mouth of Yellow Creek. Figure 5-4 depicts the change in water quality from upstream areas to downstream reaches in the Yellow Creek and Piceance Creek drainages.

Irrigation return flows, evapotranspiration and groundwater discharge from the Uinta and Green River Formations (saline minerals) are the main cause of the water quality degradation in Yellow Creek. However, due to the low acreage irrigated in Yellow Creek, it is believed that irrigation return flows have only a small effect. As is typical, water quality varies substantially with streamflow. During high runoff periods (snowmelt) TDS concentrations are typically at their lowest levels.

The increase in TDS concentration during low flow periods is a good indication that groundwater is discharging into surface streams. As discussed later, groundwater in the Uinta and Green River Formations generally contains high concentrations of sodium, bicarbonate, chloride and fluoride.

Table 5-2 summarizes characteristics of major streams near the sodium lease tracts. A summary of the water quality characteristics of the Piceance Creek below Ryan Gulch and the Yellow Creek near White River drainages for the years 1980-2010 is presented in Table 5-3.

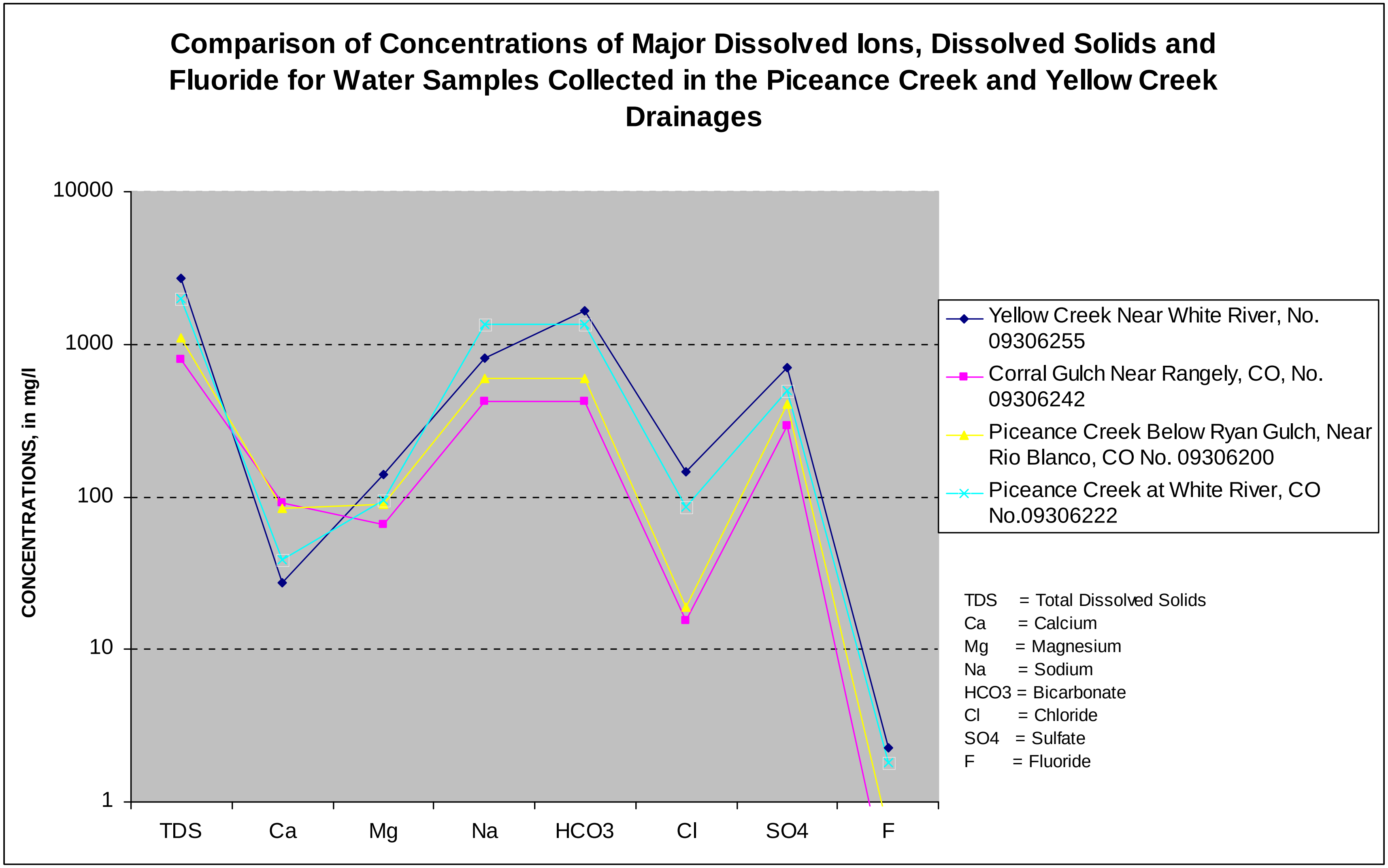

Figure 5-4. Comparison of concentrations of major dissolved ions, dissolved solids and fluoride for water samples collected in the Piceance Creek and Yellow Creek Drainages, July 7-8, 2009.

As shown in Table 5-2, sediment yield daily extremes for the Piceance Creek below Ryan Gulch station within the period of record (1965-2008) vary from less than 1 to 17,300 tons per day (USGS, 2010). The event which produced the maximum instantaneous daily load of 17,300 tons occurred on May 12, 1983 from the Piceance Creek below Ryan Gulch station. The event was most likely the result of a high intensity, localized thunderstorm which occurred in the lower portion of the basin.

During the 2008 water year, suspended sediment discharge ranged from 0.08 tons per day to 959 tons per day for the Piceance Creek at White River station, while the Piceance Creek below Ryan Gulch station ranged from less than 1 ton per day to 207 tons per day.

TABLE 5-2

2008 CHARACTERISTICS OF MAJOR STREAMS
IN THE PICEANCE CREEK BASIN

Characteristics	Corral Gulch near C-a Tract	Yellow Creek near White River
Drainage area (sq. mi.)	31.6	262
Average Annual Discharge (acre-ft.)	931	804
Average Daily Discharge (CFS)	1.28	1.11
Maximum Instantaneous Discharge (CFS)	10	29

Characteristics	Piceance Creek at White River	Piceance Creek Below Ryan Gulch
Drainage area (sq. mi.)	652	506
Average Annual Discharge (acre-ft.)	26,290	20,270
Average Daily Discharge (CFS)	36.2	27.9
Maximum Instantaneous Discharge (CFS)	164	131
Maximum Daily Sediment Discharge (tons/d)	10,100	17,300
Minimum Daily Sediment Discharge (tons/d)	0.08	<1

Table 5-2. Characteristics of major streams in the Piceance Creek Basin.

TABLE 5-3

HISTORICAL SURFACE WATER QUALITY SUMMARY FROM 1980-2010

	Piceance Creek Below Ryan Gulch (USGS 09306200)				Yellow Creek Near White River (USGS 09306255)			
	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
	5/20/80	9/17/80	1/15/81	7/9/81	2/19/80	12/15/80	4/21/81	8/26/81
Discharge (cubic meters per second)	4.3	0.538	0.821	0.088	1.81	E0.074	0.074	E0.025
pH (units)	na	na	8.2	8.1	na	8.5	8.7	8.9
Specific Conductance (uS/cm)	1000	1675	1450	2380	620	2950	3500	3300
Temperature (°C)	10	10.5	0.5	16	5e-006	5e-006	14	29
Dissolved Oxygen (mg/1)	na	9	12.1	5.8	13.6	13.2	9.4	8.3
Hardness, (mg/1)	370	550	460	620	75	470	510	460
Alkalinity, (mg/1)	na	na	na	na	na	na	na	na
Bicarbonate (mg/l)	430	670	600	960	na	na	na	na
Carbonate (mg/l)	na	na	na	na	na	na	na	na
Chloride (mg/1)	8.6	17	13	24	16	94	96	140
Fluoride (mg/1)	0.5	1.2	2	1.2	0.6	2	1.9	1.9
Sulfate (mg/1)	200	410	320	660	110	460	630	500
Boron (ug/1)	140	280	210	430	200	520	620	750
Calcium (mg/1)	69	75	74	66	12	36	22	19
Magnesium (mg/1)	47	86	65	110	11	92	110	99
Sodium (mg/1)	89	200	180	370	130	560	720	670
Potassium (mg/1)	2.6	3.6	0.3	2.8	4.7	5.8	2.7	3.3
Silica as SiO2 (mg/1)	16	19	18	15	7.7	9.2	9.3	5.7
Strontium (ug/1)	1600	3300	2800	340	na	na	na	na

E = Estimated

Source: USGS Colorado Water-Quality Data Repository

Table 5-3. Historical water quality summary for Piceance Creek and Yellow Creek from 1980-2010.

TABLE 5-3

HISTORICAL SURFACE WATER QUALITY SUMMARY FROM 1980-2010

	Piceance Creek Below Ryan Gulch (USGS 09306200)				Yellow Creek Near White River (USGS 09306255)			
	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
	9/23/82	6/9/82	5/27/83	4/7/83	2/22/82	9/22/82	8/10/83	1983
Discharge (cubic meters per second)	0.736	0.269	13.3	0.793	3.54	0.057	0.113	na
pH (units)	8.4	8.2	8.3	8.3	8	8.9	8.4	na
Specific Conductance (uS/cm)	1390	2200	854	1400	460	3200	2640	na
Temperature (°C)	11	13	15	6.5	5e-006	16.5	13	na
Dissolved Oxygen (mg/1)	8.6	9.1	7.8	9.7	10.5	11.6	8	na
Hardness, (mg/1)	470	650	316	500	73	470	522	na
Alkalinity, (mg/1)	na	na	na	na	na	na	na	na
Bicarbonate (mg/l)	na	na	na	na	na	na	na	na
Carbonate (mg/l)	na	na	na	na	na	na	na	na
Chloride (mg/1)	16	21	9.8	21	9.1	120	75	na
Fluoride (mg/1)	1.1	1	0.4	0.7	0.3	0.3	1.6	na
Sulfate (mg/1)	300	490	170	300	75	490	550	na
Boron (ug/1)	210	280	80	160	90	660	500	na
Calcium (mg/1)	72	77	65	84	11	30	51	na
Magnesium (mg/1)	69	110	37	69	11	97	95	na
Sodium (mg/1)	160	270	65	150	89	670	500	na
Potassium (mg/1)	2.4	3.8	2.6	2.4	5	3.2	2.5	na
Silica as SiO2 (mg/1)	16	19	14	16	6.6	9.2	13	na
Strontium (ug/1)	2700	3000	1200	2600	na	na	2900	na

E = Estimated

Source: USGS Colorado Water-Quality Data Repository

Table 5-3. Historical water quality summary for Piceance Creek and Yellow Creek from 1980-2010 (Continued).

TABLE 5-3

HISTORICAL SURFACE WATER QUALITY SUMMARY FROM 1980-2010

	Piceance Creek Below Ryan Gulch (USGS 09306200)				Yellow Creek Near White River (USGS 09306255)			
	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
	5/23/84	1/26/84	5/6/85	2/15/85	1984	1984	5/13/85	1985
Discharge (cubic meters per second)	7.82	1.33	14.1	1.42	na	na	0.671	na
pH (units)	8.3	8.1	8.3	8.4	na	na	8.3	na
Specific Conductance (uS/cm)	966	1250	960	1340	na	na	2520	na
Temperature (°C)	13.5	0	11	0	na	na	12	na
Dissolved Oxygen (mg/1)	8.6	12.5	8.7	11.3	na	na	na	na
Hardness, (mg/1)	375	461	379	485	na	na	830	na
Alkalinity, (mg/1)	na	na	na	na	na	na	na	na
Bicarbonate (mg/l)	na	na	na	na	na	na	na	na
Carbonate (mg/l)	na	na	na	na	na	na	na	na
Chloride (mg/1)	11	12	11	14	na	na	29	na
Fluoride (mg/1)	0.4	0.9	0.4	0.7	na	na	0.5	na
Sulfate (mg/1)	210	300	230	330	na	na	930	na
Boron (ug/1)	80	150	70	150	na	na	270	na
Calcium (mg/1)	77	78	77	81	na	na	100	na
Magnesium (mg/1)	44	64	45	68	na	na	140	na
Sodium (mg/1)	78	130	77	140	na	na	310	na
Potassium (mg/1)	1.9	1.9	2.6	2	na	na	3.4	na
Silica as SiO2 (mg/1)	16	15	15	16	na	na	19	na
Strontium (ug/1)	1300	2500	1300	2600	na	na	3400	na

E = Estimated

Source: USGS Colorado Water-Quality Data Repository

Table 5-3. Historical water quality summary for Piceance Creek and Yellow Creek from 1980-2010 (Continued).

TABLE 5-3

HISTORICAL SURFACE WATER QUALITY SUMMARY FROM 1980-2010

	Piceance Creek Below Ryan Gulch (USGS 09306200)				Yellow Creek Near White River (USGS 09306255)			
	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
	4/23/86	7/21/86	5/4/87	7/10/87	1986	1986	1987	1987
Discharge (cubic meters per second)	6.66	2.32	3.48	0.595	na	na	na	na
pH (units)	8.4	8.3	8.3	8.3	na	na	na	na
Specific Conductance (uS/cm)	1030	1600	1110	1910	na	na	na	na
Temperature (°C)	10.5	17	11.5	15	na	na	na	na
Dissolved Oxygen (mg/1)	10.1	8.2	8.5	8.1	na	na	na	na
Hardness, (mg/1)	406	588	452	631	na	na	na	na
Alkalinity, (mg/1)	na	na	na	na	na	na	na	na
Bicarbonate (mg/l)	na	na	na	na	na	na	na	na
Carbonate (mg/l)	na	na	na	na	na	na	na	na
Chloride (mg/1)	13	16	13	19	na	na	na	na
Fluoride (mg/1)	0.4	0.9	0.4	0.7	na	na	na	na
Sulfate (mg/1)	250	430	280	500	na	na	na	na
Boron (ug/1)	90	200	100	280	na	na	na	na
Calcium (mg/1)	81	92	88	86	na	na	na	na
Magnesium (mg/1)	49	86	56	100	na	na	na	na
Sodium (mg/1)	73	180	88	230	na	na	na	na
Potassium (mg/1)	1.9	3.2	1.9	3.5	na	na	na	na
Silica as SiO2 (mg/1)	15	19	16	17	na	na	na	na
Strontium (ug/1)	1500	3200	1800	3500	na	na	na	na

E = Estimated

Source: USGS Colorado Water-Quality Data Repository

Table 5-3. Historical water quality summary for Piceance Creek and Yellow Creek from 1980-2010 (Continued).

TABLE 5-3

HISTORICAL SURFACE WATER QUALITY SUMMARY FROM 1980-2010

	Piceance Creek Below Ryan Gulch (USGS 09306200)				Yellow Creek Near White River (USGS 09306255)			
	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
	5/11/88	6/29/88	3/14/89	8/8/89	3/15/88	9/2/88	3/6/89	8/31/89
Discharge (cubic meters per second)	0.926	0.3	2.35	0.195	0.312	0.133	0.153	0.068
pH (units)	8.1	8.3	8.2	8.3	na	na	na	8.5
Specific Conductance (uS/cm)	1460	1930	1100	2120	3150	na	3210	3380
Temperature (°C)	14	16.5	2.5	12	4	21	5.5	22
Dissolved Oxygen (mg/1)	12	9.5	10.7	8	11.4	9	10	10.5
Hardness, (mg/1)	551	667	384	584	972	862	973	817
Alkalinity, (mg/1)	na	na	na	na	na	na	na	na
Bicarbonate (mg/l)	na	na	na	na	na	na	na	na
Carbonate (mg/l)	na	na	na	na	na	na	na	na
Chloride (mg/1)	15	19	16	23	53	66	60	78
Fluoride (mg/1)	0.6	0.7	0.5	1.1	0.8	0.9	0.9	1.3
Sulfate (mg/1)	410	520	290	570	1100	1100	1100	1000
Boron (ug/1)	160	250	100	770	420	440	420	530
Calcium (mg/1)	89	84	69	69	90	63	74	45
Magnesium (mg/1)	79	110	51	99	180	170	190	170
Sodium (mg/1)	150	230	110	310	450	500	510	560
Potassium (mg/1)	2.8	3.3	3.1	3.3	3.2	2.5	3.2	3.2
Silica as SiO2 (mg/1)	17	17	12	18	17	13	19	7
Strontium (ug/1)	2900	3700	1700	3600	5500	4000	5200	4100

E = Estimated

Source: USGS Colorado Water-Quality Data Repository

Table 5-3. Historical water quality summary for Piceance Creek and Yellow Creek from 1980-2010 (Continued).

TABLE 5-3

HISTORICAL SURFACE WATER QUALITY SUMMARY FROM 1980-2010

	Piceance Creek Below Ryan Gulch (USGS 09306200)				Yellow Creek Near White River (USGS 09306255)			
	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
	4/4/90	8/1/90	11/6/91	7/18/91	3/21/90	8/30/90	3/29/91	8/30/91
Discharge (cubic meters per second)	0.382	0.13	0.784	0.283	0.13	0.042	0.105	0.037
pH (units)	8.3	8.5	8.2	8.2	8.4	8.5	8.3	8.4
Specific Conductance (uS/cm)	1594	1960	1678	2080	3460	3570	3350	3760
Temperature (°C)	10	21.5	6.5	15	10	20	2	14
Dissolved Oxygen (mg/1)	9.3	9.7	10.1	8	9.9	12.4	11.6	9.8
Hardness, (mg/1)	551	561	554	568	978	757	955	856
Alkalinity, (mg/1)	na	na	na	na	na	na	na	na
Bicarbonate (mg/l)	na	na	na	na	na	na	na	na
Carbonate (mg/l)	na	na	na	na	na	na	na	na
Chloride (mg/1)	17	26	26	26	71	96	76	90
Fluoride (mg/1)	0.4	0.8	0.8	1	0.7	1.4	1.1	2.2
Sulfate (mg/1)	400	470	470	510	1000	950	1300	990
Boron (ug/1)	170	310	200	330	480	560	470	560
Calcium (mg/1)	84	68	87	71	76	37	67	44
Magnesium (mg/1)	82	94	81	94	190	160	190	180
Sodium (mg/1)	160	280	180	290	540	640	560	670
Potassium (mg/1)	2.6	3.3	3.8	3.3	3.4	3.2	3.3	3.1
Silica as SiO2 (mg/1)	15	11	16	13	17	12	14	7.9
Strontium (ug/1)	3400	3200	2900	3300	5300	4600	4800	4400

E = Estimated

Source: USGS Colorado Water-Quality Data Repository

Table 5-3. Historical water quality summary for Piceance Creek and Yellow Creek from 1980-2010 (Continued).

TABLE 5-3

HISTORICAL SURFACE WATER QUALITY SUMMARY FROM 1980-2010

	Piceance Creek Below Ryan Gulch (USGS 09306200)				Yellow Creek Near White River (USGS 09306255)			
	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
	3/5/92	9/16/92	9/1/93	3/25/93	3/3/92	9/17/92	9/29/93	8/31/93
Discharge (cubic meters per second)	0.68	0.159	1.17	0.793	0.085	0.049	0.108	0.083
pH (units)	8.3	8.3	8	8.3	8.4	8.5	8.2	8.3
Specific Conductance (uS/cm)	1448	2180	1500	1500	3570	3826	3010	3010
Temperature (°C)	4.4	16.8	13.6	8.6	7.1	13.2	12	16.9
Dissolved Oxygen (mg/1)	9.9	10	9.32	8.9	10.2	8.26	11.3	8.3
Hardness, (mg/1)	495	665	536	506	928	788	685	665
Alkalinity, (mg/1)	na	na	na	na	na	na	na	na
Bicarbonate (mg/l)	na	na	na	na	na	na	na	na
Carbonate (mg/l)	na	na	na	na	na	na	na	na
Chloride (mg/1)	19	31	16	18	84	110	82	85
Fluoride (mg/1)	0.5	0.6	0.7	0.6	1.1	1.3	1.3	1.5
Sulfate (mg/1)	360	510	380	360	960	840	710	660
Boron (ug/1)	140	330	200	180	450	630	510	500
Calcium (mg/1)	80	83	93	81	73	33	58	50
Magnesium (mg/1)	71	110	73	73	180	170	130	130
Sodium (mg/1)	140	280	150	150	590	700	500	490
Potassium (mg/1)	3.6	3.9	2.7	2.8	3.9	5.2	2.6	2.7
Silica as SiO2 (mg/1)	16	18	18	15	16	4.1	12	13
Strontium (ug/1)	2700	3800	2600	2900	4200	4900	4300	4100

E = Estimated

Source: USGS Colorado Water-Quality Data Repository

Table 5-3. Historical water quality summary for Piceance Creek and Yellow Creek from 1980-2010 (Continued).

TABLE 5-3

HISTORICAL SURFACE WATER QUALITY SUMMARY FROM 1980-2010

	Piceance Creek Below Ryan Gulch (USGS 09306200)				Yellow Creek Near White River (USGS 09306255)			
	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
	3/30/94	9/6/94	5/9/95	3/29/95	3/29/94	11/15/94	3/28/95	8/30/95
Discharge (cubic meters per second)	0.745	0.13	3.57	0.481	0.073	0.036	0.059	0.042
pH (units)	8	8.2	7.3	7.9	7.8	8.3	8.3	8.6
Specific Conductance (uS/cm)	1410	2120	872	1480	3580	3740	3530	3480
Temperature (°C)	3.9	19.5	10.3	3	10.4	0	8.3	26.1
Dissolved Oxygen (mg/1)	10.93	7.71	9.33	10.8	12.26	14.2	12.3	12.1
Hardness, (mg/1)	529	703	271	550	753	796	831	679
Alkalinity, (mg/1)	na	na	na	na	na	na	na	na
Bicarbonate (mg/l)	na	na	na	na	na	na	na	na
Carbonate (mg/l)	na	na	na	na	na	na	na	na
Chloride (mg/1)	15	24	13	16	93	100	99	110
Fluoride (mg/1)	0.6	1	0.5	0.6	1.5	1.7	1.6	1.9
Sulfate (mg/1)	360	550	200	390	850	860	880	700
Boron (ug/1)	150	320	100	160	560	590	590	620
Calcium (mg/1)	90	82	47	87	52	53	50	23
Magnesium (mg/1)	73	120	37	80	150	160	170	150
Sodium (mg/1)	130	290	96	150	610	730	680	680
Potassium (mg/1)	2.2	3.7	3.3	2.3	3.3	3.7	3.5	3.2
Silica as SiO2 (mg/1)	17	18	11	16	16	13	13	9.9
Strontium (ug/1)	2800	3900	1300	3200	4400	4500	5000	3700

E = Estimated

Source: USGS Colorado Water-Quality Data Repository

Table 5-3. Historical water quality summary for Piceance Creek and Yellow Creek from 1980-2010 (Continued).

TABLE 5-3

HISTORICAL SURFACE WATER QUALITY SUMMARY FROM 1980-2010

	Piceance Creek Below Ryan Gulch (USGS 09306200)				Yellow Creek Near White River (USGS 09306255)			
	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
	5/15/96	10/29/96	5/15/97	3/5/97	3/12/96	6/14/96	3/12/97	3/4/97
Discharge (cubic meters per second)	1.05	0.765	2.35	0.538	0.096	0.05	3.62	0.051
pH (units)	7.9	8	7.945	8.2	8.3	8.7	7.896	8.3
Specific Conductance (uS/cm)	1257	1479	1011	1457	2700	3520	495	3300
Temperature (°C)	12	5.5	12	4.6	9	23	3.8	3.6
Dissolved Oxygen (mg/1)	8.65	11.17	9.2	10.5	9.79	na	12	11
Hardness, (mg/1)	440	503	378	508	590	631	93.3	765
Alkalinity, (mg/1)	na	na	na	na	na	na	na	na
Bicarbonate (mg/l)	na	na	na	na	na	na	na	na
Carbonate (mg/l)	na	na	na	na	na	na	na	na
Chloride (mg/1)	14	15	9.17	15	73	110	9.482	85
Fluoride (mg/1)	0.6	0.7	0.451	0.7	1.3	1.9	0.262	1.5
Sulfate (mg/1)	290	370	204.18	380	580	790	84.597	820
Boron (ug/1)	150	174	90.753	156	na	627	97.07	501
Calcium (mg/1)	78	80	71.954	80	55	20	15.52	57
Magnesium (mg/1)	59	73	47.603	74	110	140	13.11	150
Sodium (mg/1)	120	150	83.99	140	460	660	72.75	560
Potassium (mg/1)	2.5	2.5	1.96	2.3	3.8	2.8	4.55	3.2
Silica as SiO2 (mg/1)	14	16	16.97	15	13	4.8	6.24	15
Strontium (ug/1)	2000	2600	1611.3	2900	na	4200	499.92	4700

E = Estimated

Source: USGS Colorado Water-Quality Data Repository

Table 5-3. Historical water quality summary for Piceance Creek and Yellow Creek from 1980-2010 (Continued).

TABLE 5-3

HISTORICAL SURFACE WATER QUALITY SUMMARY FROM 1980-2010

	Piceance Creek Below Ryan Gulch (USGS 09306200)				Yellow Creek Near White River (USGS 09306255)			
	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
	4/30/98	9/3/98	8/11/99	11/8/99	11/12/98	3/24/98	3/10/99	11/9/99
Discharge (cubic meters per second)	9.52	1.24	1.3	0.736	0.312	0.153	0.252	0.184
pH (units)	8.202	7.962	8.302	8.158	8.227	8.34	8.278	8.202
Specific Conductance (uS/cm)	964	1420	1520	1470	2810	3230	3120	2960
Temperature (°C)	6.6	12.1	18.1	7.3	6.9	8.3	9	5.2
Dissolved Oxygen (mg/1)	11.5	8.8	6.7	12.6	9.8	9.24	9.8	12.9
Hardness, (mg/1)	387	528	513	536	886	806	925	916
Alkalinity, (mg/1)	na	na	473.37	426.88	na	na	na	723.75
Bicarbonate (mg/l)	na	na	na	na	na	na	744	na
Carbonate (mg/l)	na	na	na	na	na	na	96	na
Chloride (mg/1)	10.534	14.345	16	15.51	53.692	71.063	53.461	53.24
Fluoride (mg/1)	0.388	0.554	0.601	0.658	0.918	1.256	0.886	0.993
Sulfate (mg/1)	206.77	372.23	376.13	394.57	915.84	864.17	986.51	989.14
Boron (ug/1)	72.939	151.14	172.17	162.32	427.39	467.78	422.61	408.11
Calcium (mg/1)	77.02	83.077	79.514	82.826	75.595	60.438	78.185	72.749
Magnesium (mg/1)	47.01	77.028	75.681	79.076	167.95	157.77	175.78	176.99
Sodium (mg/1)	75.01	141.18	151.52	155.37	444.82	539.72	427.35	420.45
Potassium (mg/1)	2.16	2.14	3.32	2.46	2.98	3.58	2.88	2.86
Silica as SiO2 (mg/1)	15.3	16.09	18.666	15.484	15.283	16	16.674	8.597
Strontium (ug/1)	1330	2824.5	2624.9	3025.5	4643.1	4382	4763.9	4761.8

E = Estimated

Source: USGS Colorado Water-Quality Data Repository

Table 5-3. Historical water quality summary for Piceance Creek and Yellow Creek from 1980-2010 (Continued).

TABLE 5-3

HISTORICAL SURFACE WATER QUALITY SUMMARY FROM 1980-2010

	Piceance Creek Below Ryan Gulch (USGS 09306200)				**Yellow Creek Near White River (USGS 09306255)**			
	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
	4/4/00	8/29/00	11/15/01	8/16/01	4/5/00	11/17/00	3/7/01	8/16/01
Discharge (cubic meters per second)	0.838	0.113	0.466	0.136	0.191	0.088	0.159	0.074
pH (units)	8.17	8.271	8.225	8.458	8.325	8.072	8.33	8.439
Specific Conductance (uS/cm)	1410	2160	1592	1806	3150	3590	3020	3473
Temperature (°C)	10.2	18.6	5.5	21.1	7.7	0	7.6	15.7
Dissolved Oxygen (mg/1)	10.6	9.8	11.8	11.6	11.5	12.4	9.6	9
Hardness, (mg/1)	492	609	600	644	920	918	744	790
Alkalinity, (mg/1)	403.02	732.93	525.63	523.01	765.35	1026.2	862.53	1063.52
Bicarbonate (mg/l)	na	na	na	na	na	na	958	na
Carbonate (mg/l)	na	na	na	24	na	na	30	na
Chloride (mg/1)	14.92	23.37	16.79	19.66	51.6	72.29	55.86	91.37
Fluoride (mg/1)	0.61	1.188	0.653	0.822	0.894	1.326	1.129	1.583
Sulfate (mg/1)	350.8	514.05	421.16	487.62	1025.7	1006.8	808.74	879.28
Boron (ug/1)	132.19	271.57	187.326	235.245	392.68	523.82	429	607.64
Calcium (mg/1)	83.083	70.201	91.8744	82.0744	74.286	66.318	63.48	49.45
Magnesium (mg/1)	68.473	104.33	88.9811	105.493	176.9	181.23	141.09	160.74
Sodium (mg/1)	134.2	248.13	174.098	216.196	451.17	572.12	458.39	610.38
Potassium (mg/1)	2.39	3.45	2.7	3.03	2.7	1.15	3.7	3.4
Silica as SiO2 (mg/1)	13.602	19.273	15.3039	12.0204	17.06	14.355	16.439	15.6836
Strontium (ug/1)	2559.6	3546.2	3278.52	3908.87	4977.7	4899.6	4035	4308.26

E = Estimated

Source: USGS Colorado Water-Quality Data Repository

Table 5-3. Historical water quality summary for Piceance Creek and Yellow Creek from 1980-2010 (Continued).

TABLE 5-3
HISTORICAL SURFACE WATER QUALITY SUMMARY FROM 1980-2010

	Piceance Creek Below Ryan Gulch (USGS 09306200)				Yellow Creek Near White River (USGS 09306255)			
	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
	4/8/02	5/12/02	3/24/03	6/18/03	3/22/02	7/31/02	10/15/03	8/18/03
Discharge (cubic meters per second)	0.404	0.073	0.273	0.099	0.172	0.044	0.074	0.026
pH (units)	8.211	8.264	8.24	8.16	8.366	8.696	na	8.71
Specific Conductance (uS/cm)	1517	2089	1672	1634	2656	3724	3820	3851
Temperature (°C)	7.6	15.7	8.1	19.2	8.2	21.5	3.5	18.6
Dissolved Oxygen (mg/1)	11.7	9.7	9.9	8.4	9.5	8.4	12.4	8.8
Hardness, (mg/1)	553	605	590	562	668	688	824	698
Alkalinity, (mg/1)	444.45	723.09	467.72	466.18	787.64	1292.09	1228.96	1459.57
Bicarbonate (mg/l)	na	na	na	na	817	1452	632	1635
Carbonate (mg/l)	na	na	14.4	na	4.8	na	14.4	72
Chloride (mg/1)	14.28	20.61	17.92	18.75	55.4	109.02	111.53	139.12
Fluoride (mg/1)	0.505	0.87	0.673	0.764	0.965	1.85	1.592	2.136
Sulfate (mg/1)	400.89	495.69	428.88	418.83	725.5	839.11	820.58	643.71
Boron (ug/1)	150.019	266.955	166.52	190.709	381.61	653.955	594.82	644.289
Calcium (mg/1)	89.8009	74.3007	88.9845	74.9706	51.19	22.7169	58.2002	33.2608
Magnesium (mg/1)	78.9024	100.964	88.2568	90.0279	130.14	152.31	163.659	148.387
Sodium (mg/1)	157.53	276.974	181.096	193.457	411.82	745.58	695.628	885.204
Potassium (mg/1)	2.38	3.4	2.61	2.6765	3.51	3.84	4.0122	4.9595
Silica as SiO2 (mg/1)	15.3926	14.7111	14.8434	13.7357	13.6358	7.9007	12.2936	4.4286
Strontium (ug/1)	3223.07	3565.65	3681.2	3172.45	3712.99	3638.13	4411.14	3398.52

E = Estimated

Source: USGS Colorado Water-Quality Data Repository

Table 5-3. Historical water quality summary for Piceance Creek and Yellow Creek from 1980-2010 (Continued).

TABLE 5-3

HISTORICAL SURFACE WATER QUALITY SUMMARY FROM 1980-2010

	Piceance Creek Below Ryan Gulch (USGS 09306200)				Yellow Creek Near White River (USGS 09306255)			
	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
	12/15/04	6/8/04	8/23/05	2/7/05	4/15/04	6/23/04	2/19/05	8/22/05
Discharge (cubic meters per second)	0.531	0.052	0.793	0.396	0.051	0.02	0.06	0.016
pH (units)	8.23	8.22	na	8.29	na	na	na	na
Specific Conductance (uS/cm)	1550	1814	1569	1484	3900	4000	3600	4250
Temperature (°C)	3.1	17.9	13.9	5.4	11.6	17.7	4.2	20.7
Dissolved Oxygen (mg/1)	12.2	10.2	9.9	10.7	10.1	9.2	11.9	8.5
Hardness, (mg/1)	591	646	594	598	891	745	837	640
Alkalinity, (mg/1)	na	486.08	na	na	1188.43	1415.67	na	na
Bicarbonate (mg/l)	na	na	na	na	1350	1404.3	1375.8	E1350
Carbonate (mg/l)	6.3	14.6	8.5	7.3	76.8	110.4	40.4	E70
Chloride (mg/1)	16.537	21.21	17.343	15.586	103.75	130.72	96.105	164.026
Fluoride (mg/1)	0.759	<0.85	0.678	0.696	1.521	1.918	1.537	2.3
Sulfate (mg/1)	378.934	473.64	391.144	377.971	918.58	778.64	767.862	634.009
Boron (ug/1)	141.143	215.191	167.251	178.284	551.4	592.47	565.66	1079.88
Calcium (mg/1)	97.84	82.96	89.94	96.67	52.6	24.3	55.18	25.24
Magnesium (mg/1)	83.43	105.6	88.88	85.72	183	165	168.5	139.1
Sodium (mg/1)	164.7	230.2	160.5	158.8	725	816	643.2	850.8
Potassium (mg/1)	3.003	2.813	2.711	2.56	3.57	4.05	3.006	4.312
Silica as SiO2 (mg/1)	19.27	14.3	12.75	18.29	13.2	2.73	18.07	11.75
Strontium (ug/1)	3051.03	3277.05	3147.97	3026.32	4916.62	3692.38	4713.19	3197.59

E = Estimated

Source: USGS Colorado Water-Quality Data Repository

Table 5-3 Historical water quality summary for Piceance Creek and Yellow Creek from 1980-2010 (Continued).

TABLE 5-3

HISTORICAL SURFACE WATER QUALITY SUMMARY FROM 1980-2010

	Piceance Creek Below Ryan Gulch (USGS 09306200)				**Yellow Creek Near White River (USGS 09306255)**			
	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
	12/13/06	9/12/06	4/17/07	5/30/07	12/14/06	9/13/06	4/18/07	8/22/07
Discharge (cubic meters per second)	0.564	0.204	0.85	0.017	0.033	0.008	0.034	0.011
pH (units)	na	na	na	na	na	na	na	na
Specific Conductance (uS/cm)	1489	1795	1257	2648	3705	4320	3907	3949
Temperature (°C)	0.9	13.3	8.5	14.2	0	22.3	12.7	18.1
Dissolved Oxygen (mg/1)	11	10.3	9.36	10.61	11.74	8.7	9.6	7.82
Hardness, (mg/1)	569	594	478	762	789	611	760	512
Alkalinity, (mg/1)	na	na	na	na	na	na	na	na
Bicarbonate (mg/l)	na	na	na	na	1651.6	1813.9	1596	1731
Carbonate (mg/l)	10.5	15	9.4	13.9	39.4	126	72.3	75.5
Chloride (mg/1)	16.437	21.089	13.742	32.631	118.854	167.528	125.476	155.682
Fluoride (mg/1)	0.649	0.845	0.592	1.355	1.708	2.573	1.769	1.927
Sulfate (mg/1)	383.902	474.371	298.008	630.317	776.173	622.87	839.607	595.177
Boron (ug/1)	173.7	190.86	142.42	343.2	632.8	789.84	769.84	672.7
Calcium (mg/1)	92.5	77.57	81.64	79.55	53.29	19.39	33.31	29.6
Magnesium (mg/1)	81.31	96.37	65.97	135.5	158.1	135.7	162.9	105.7
Sodium (mg/1)	159.3	195.7	128.9	412.1	736.8	873.3	733.2	845.9
Potassium (mg/1)	2.602	3.148	2.485	3.152	3.46	4.223	3.649	5.437
Silica as SiO2 (mg/1)	16.37	11.39	13.69	17.07	15.73	6.825	5.564	11.53
Strontium (ug/1)	3035	3399	2446	4354	4650	3504	4928	2644

E = Estimated

Source: USGS Colorado Water-Quality Data Repository

Table 5-3. Historical water quality summary for Piceance Creek and Yellow Creek from 1980-2010 (Continued).

TABLE 5-3

HISTORICAL SURFACE WATER QUALITY SUMMARY FROM 1980-2010

	Piceance Creek Below Ryan Gulch (USGS 09306200)				**Yellow Creek Near White River (USGS 09306255)**			
	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
	5/13/08	3/27/08	5/5/09	12/21/09	3/26/08	8/21/08	5/6/09	12/22/09
Discharge (cubic meters per second)	3.31	0.68	0.68	0.521	0.051	0.024	0.034	0.033
pH (units)	na	na	na	na	na	na	na	na
Specific Conductance (uS/cm)	943	1457	1321	1453	3832	3821	3744	3754
Temperature (°C)	7.1	10.2	10.5	0	8.9	19.4	16.5	0
Dissolved Oxygen (mg/1)	9.7	9.94	8.66	10.8	10.31	11.5	11	11.3
Hardness, (mg/1)	372	541	520	554	767	546	683	685
Alkalinity, (mg/1)	na	na	na	na	na	na	na	1757.9
Bicarbonate (mg/l)	na	na	na	na	1541	1624	1508	28.3
Carbonate (mg/l)	5.9	10.1	9.5	10	60.4	58.9	70.3	132.624
Chloride (mg/1)	9.343	16.605	13.71	16.468	114.332	146.736	120.131	2.147
Fluoride (mg/1)	0.46	0.611	0.564	0.676	1.661	2.053	1.761	650.183
Sulfate (mg/1)	194.793	359.213	317.785	373.459	862.468	573.6	768.831	585.2
Boron (ug/1)	83.5	143.7	124.9	166.14	492.6	635.6	750.8	51.79
Calcium (mg/1)	71.88	88.42	85.44	91.55	50.47	24.46	27.12	133.8
Magnesium (mg/1)	46.45	76.96	73.56	78.03	154.3	116.7	148.3	712.8
Sodium (mg/1)	86.5	151.3	126	140.4	727.9	734.1	697.4	3.337
Potassium (mg/1)	2.301	2.874	2.066	2.377	4.066	3.376	3.287	17.72
Silica as SiO2 (mg/1)	14.3	13.49	15.69	17.79	10.79	8.373	4.581	4300
Strontium (ug/1)	1365	2592.9	2850	3135	4410	3698	4353	na

E = Estimated

Source: USGS Colorado Water-Quality Data Repository

Table 5-3. Historical water quality summary for Piceance Creek and Yellow Creek from 1980-2010 (Continued).

5.3. GROUNDWATER

5.3.1. Regional Setting

The principal water-bearing zones are located in the Uinta and Green River Formations and in the alluvium of stream valley bottoms. The principal aquifer system consists of a minor perched aquifer and three major aquifers. These are known as the Perched Aquifer, A-groove Aquifer, B-groove Aquifer, and Dissolution Surface Aquifer, respectively. Historically, the Perched Aquifer and A-groove Aquifer were grouped into what was known as the "Upper Aquifer," while the B-groove and Dissolution Surface Aquifers were grouped into what was known as the "Lower Aquifer." The A-groove and B-groove Aquifers are separated by a leaky semi-confining oil shale-rich layer called the Mahogany Zone (R-7 Zone) (Daub et al, 1985). Similarly, the B-groove and Dissolution Surface Aquifers are separated by a leaky semi-confining oil shale-rich layer called the R-6 zone. A cross-sectional profile of the water-bearing zones is presented in Figure 5-5.

Recharge to the aquifer system occurs principally from snowmelt during the spring. Weeks et al, (1974) suggested that recharge to the aquifer system is probably most effective in the areas of the basin above 7,000 feet elevation, where about 65 percent of the total volume of November to March precipitation occurs. During the summer months, most rainfall is lost as direct runoff or goes to meet the soil moisture deficiency and is subsequently evapotranspired.

During spring snowmelt, water is released slowly, especially on the north facing slopes, allowing ample opportunity for the melt to infiltrate the soil, increase soil moisture content to field capacity and percolate into the saturated zone.

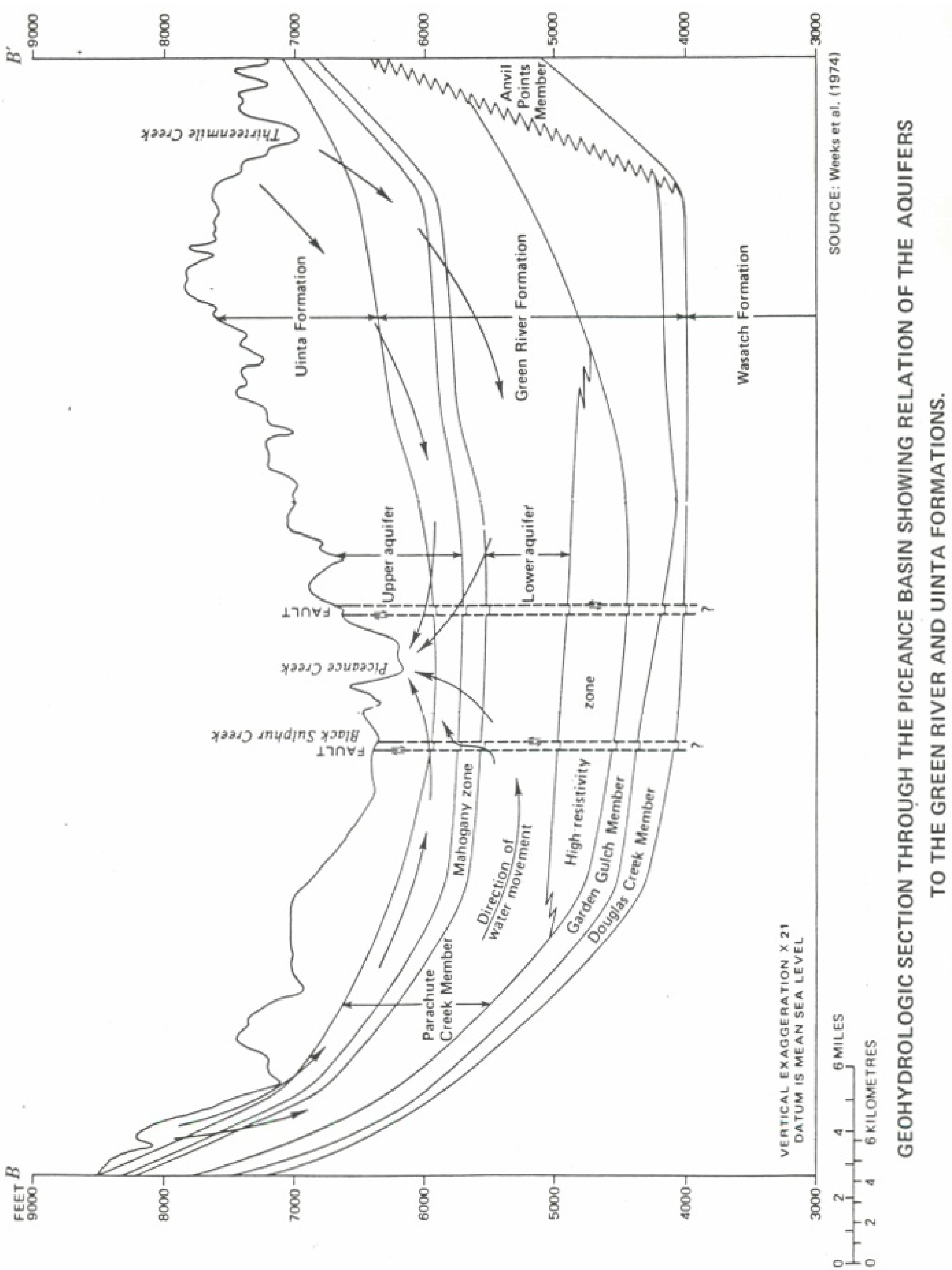

Figure 5-5. West–east geohydrologic section through the Piceance Creek Basin, showing the location of the historic Aquifers with respect to the Green River and Uinta Formations.

In the recharge areas, water from the A-groove Aquifer moves downward through the Mahogany Zone to recharge the B-groove Aquifer. A minor amount of water moves downward through the R-6 zone to recharge the Dissolution Surface Aquifer. Generally groundwater in the A-groove and B-groove Aquifers flows from the recharge areas at the basin margins toward the north-central part of the basin.

In discharge areas, water moves upward from the B-groove and Dissolution Surface Aquifers through the R-6 and Mahogany Zones to the A-groove Aquifer. Water is discharged from the A-groove Aquifer to the alluvium through valley floors and by springs along the valley walls. Groundwater flows through the alluvium to the streams and is lost from the basin by evapotranspiration and discharge to Piceance Creek and Yellow Creek.

5.3.2. Aquifer Systems

5.3.2.1. Alluvial Aquifers

The alluvial aquifers are limited to the valley bottoms along the major creeks. Although not continuous throughout the basin, the alluvial deposits can provide significant sources of groundwater particularly in major stream valleys. Generally, the aquifers are less than 0.5 mile in width and the alluvium less than 140 feet thick. Saturated thickness of the alluvium in Yellow Creek has been reported to be up to 100 feet.

The degree of saturation within the alluvium is highly variable and dependent on seasonal recharge from precipitation, snowmelt runoff, and discharge from underlying bedrock aquifers. Generally, the alluvial aquifer is under unconfined conditions. However, locally semi-confined conditions could exist depending on the occurrence of clay beds.

Groundwater movement generally parallels the direction of streamflow in the alluvial valleys. Discharge from the alluvial system occurs in springs along valley bottoms, from withdrawals for domestic and irrigation usage, and predominantly directly to streams during low flow periods (November through February) where streamflow is almost wholly derived from groundwater discharge.

The only alluvial deposits which can provide significant sources of groundwater in or adjacent to the sodium lease tracts are those found in the Yellow Creek drainage. The other intermittent water courses and their associated alluvium on the sodium leases do not maintain any significant perennial alluvial groundwater.

5.3.2.2. Bedrock Aquifers

In the area of the NSI Sodium Lease, the bedrock aquifer system is comprised of three major systems, the A-groove, B-groove, and Dissolution Surface Aquifers. Additionally, a Perched Aquifer exists in the upper Uinta Formation. The following discussion incorporates both historic and more recently obtained aquifer information.

Figure 5-6 shows the locations and designations of the various wells and drill holes in the vicinity of the sodium lease, including those presented in Figure 5-7. Figure 5-7 presents a cross-section of the historic Upper and Lower Aquifers beneath the sodium lease.

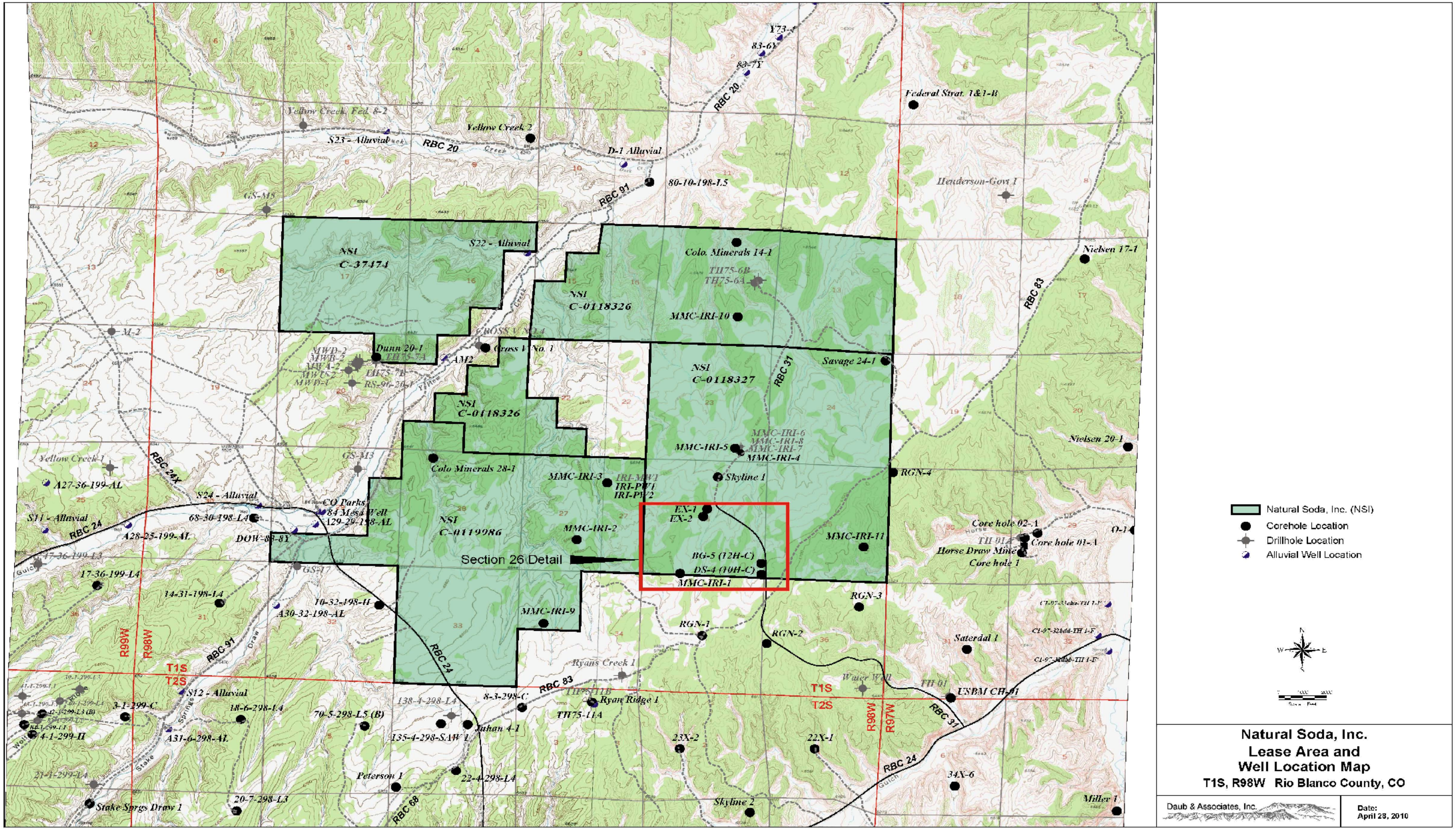

Figure 5-6. Lease Area and Well Location Map.

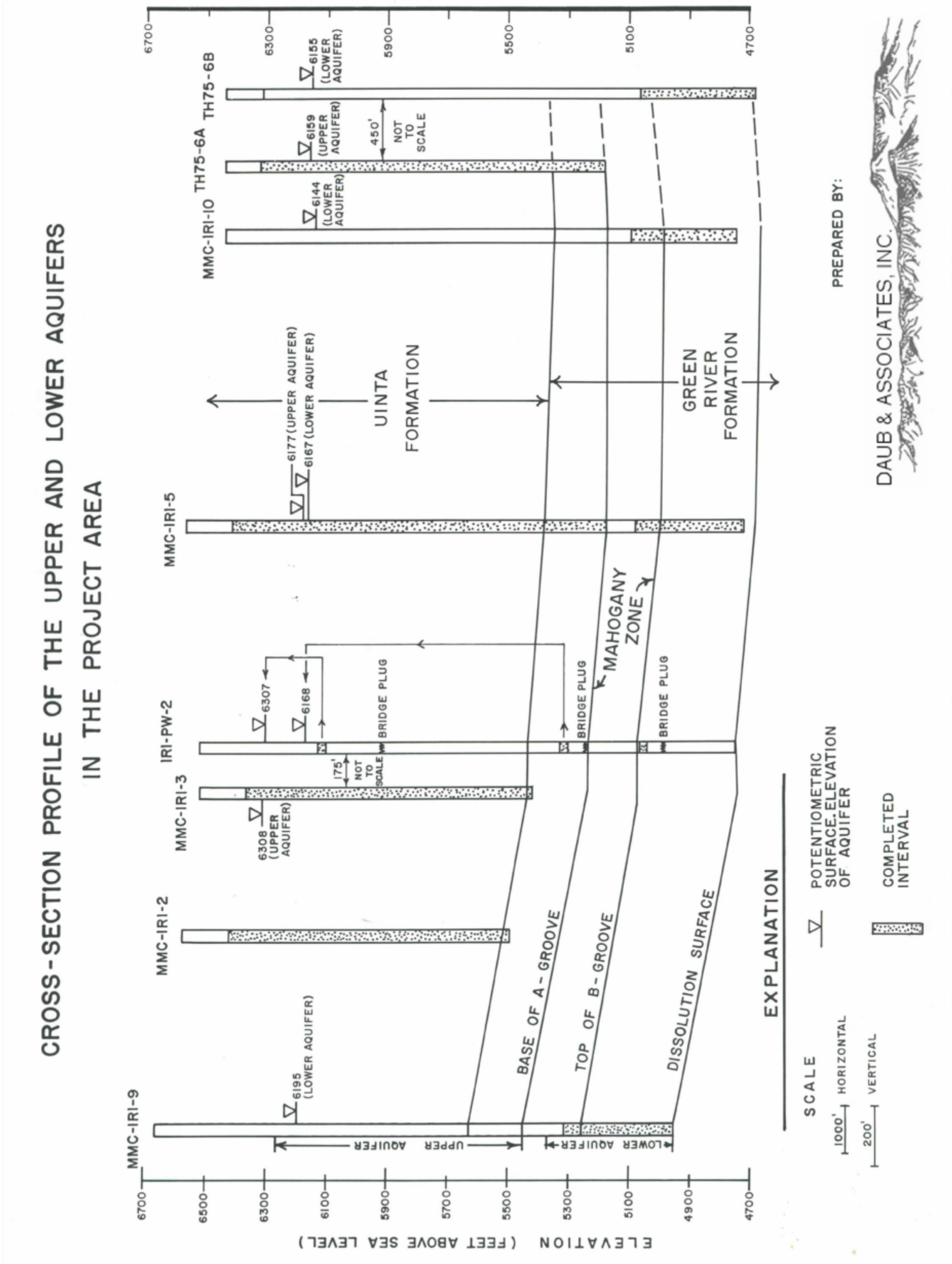

Figure 5-7. Cross Section of the historic Upper and Lower Aquifers.

Perched Aquifer

The Perched Aquifer is an aquifer locally present in the lease area due to the presence of the Thirteenmile Creek tongue of the Green River Formation within the permeable sandstones of the Uinta Formation. The Thirteenmile Creek tongue consists of largely impermeable oil shale units, and groundwater is encountered in the Uinta Formation sandstones that immediately overlie the Thirteenmile Creek tongue.

Near core hole MMC-IRI-3, on the NSI lease, groundwater in the Perched Aquifer is first encountered at the contact between the top of the Thirteenmile Creek tongue of the Green River Formation with the overlying Uinta Formation, occurring approximately 400 feet below the ground surface.

A-groove Aquifer

The A-groove Aquifer consists of fractured lean oil shale and marlstone of the Parachute Creek Member located immediately above the Mahogany Zone. The permeability of the aquifer is due to primary matrix porosity and secondary fracture porosity. The A-groove Aquifer is encountered at approximately 1,197 to 1,390 feet below ground surface (depending on location in and around the lease area) in the Parachute Creek Member of the Green River Formation just above the Mahogany Zone. It is generally between 15 and 20 feet thick.

The transmissivity of the historic Upper Aquifer ranged from 8 to 1,000 square feet per day in the Piceance Basin (Weeks et al, 1974). Aquifer tests conducted at the Horse Draw Mine in the 01-A and 02-A core holes by the U.S. Geological Survey indicated transmissivity of 2,600 square feet per day (Dale and Weeks, 1978). Their analysis indicated that the data obtained from the testing was typical of a well completed in a vertically fractured porous medium or in a fracture zone. Aquifer tests conducted on the Multi Mineral Corporation Maxi Pad in 1981 found transmissivity values of the historic Upper Aquifer ranging between 530 and 760 square feet per day.

B-Groove Aquifer

The B-groove Aquifer consists of lean fractured oil shale and marlstone of the Parachute Creek Member underlying the Mahogany Zone. The B-groove Aquifer occurs approximately 1,387 to 1,564 feet below ground surface in the area of NSI operations (see Figure 5-7). It is generally between 18 and 25 feet thick.

The transmissivity of the historic Lower Aquifer varies considerably throughout the Piceance Basin. Weeks et al, (1974) reported values as high as 1,940 square feet per day and Coffin et al, (1971) reported values as high as 2,700 square feet per day. Generally, the historic Lower Aquifer is more fully developed in the north-central part of the basin and transmissivity is greatest there. Dale and Weeks (1978) performed a pump test of the Lower Aquifer on the U.S. Bureau of Mines Horse Draw Underground Oil Shale Research Facility site. Although the test was very short, they estimated a transmissivity of 210 square feet per day. Aquifer tests conducted on the Multi Mineral Corporation Maxi Pad in 1981 found transmissivity values of the historic Lower Aquifer ranging between 260 and 380 square feet per day.

Dissolution Surface Aquifer

The Dissolution Surface Aquifer is present between 20 and 50 feet immediately above the top of the Saline Zone. In the vicinity of the NSI lease, the Dissolution Surface Aquifer is found in the lean, fractured, brecciated, and rubblized oil shales and marlstones of the upper L-5 stratigraphic zone. Due to the proximity of the Dissolution Surface, solution features such as vugs, voids and pits are common characteristics of the matrix material. The Dissolution Surface Aquifer occurs approximately 1,660 to 1,840 feet below the ground surface in the area of NSI operations.

5.3.2.3. Aquifer Testing on the Sodium Lease Tracts

<u>1981 Hydrologic Test Program</u>

During the summer of 1981, the U.S. Geological Survey, in conjunction with Multi Mineral Corporation conducted aquifer testing of the historic Upper and Lower Aquifer systems at a site on Sodium Lease C-0118327 in the Piceance Creek Basin, Colorado (Figure 5-8). The study included the collection of time-drawdown data from a pump test in the historic Upper and Lower Aquifers. The Lower Aquifer test was conducted in July 1981. Five wells were utilized, with one located centrally as the pumping well and the other four wells at varying distances and directions from the pumped well (Figure 5-9).

The pumping well, MMC-IRI-8, was pumped at approximately 60 gallons per minute (gpm) over a time period of 10,000 minutes. Dual completion wells MMC-IRI-4, -5, -6 and -7 served as observation wells to measure the groundwater level drawdown during the test. The Upper Aquifer was pump tested in November 1981, again using the recompleted well MMC-IRI-8 as the pumping well. The test involved a discharge of approximately 20 gpm over a period of 2,000 minutes. Dual completion wells MMC-IRI-4, -5, -6 and -7 served as observation wells to measure the groundwater drawdown during the test.

Weston (1984) analyzed the 1981 aquifer test data and observed that 3 of the 4 observation wells appeared to have been closely approaching or reached steady-state conditions. Weston showed that a recharge boundary was encountered during the test which signifies leakage through fractures (in the Mahogany Zone) between the Upper and Lower Aquifers. Weston utilized the Hantush-Jacob Method (Lohman, 1972) for non-steady flow in an infinite leaky confined aquifer. This method assumes that storage in the Mahogany Zone would be negligible due to the porosity being comprised of fractures. The data are presented and analyzed in Appendix 5A.

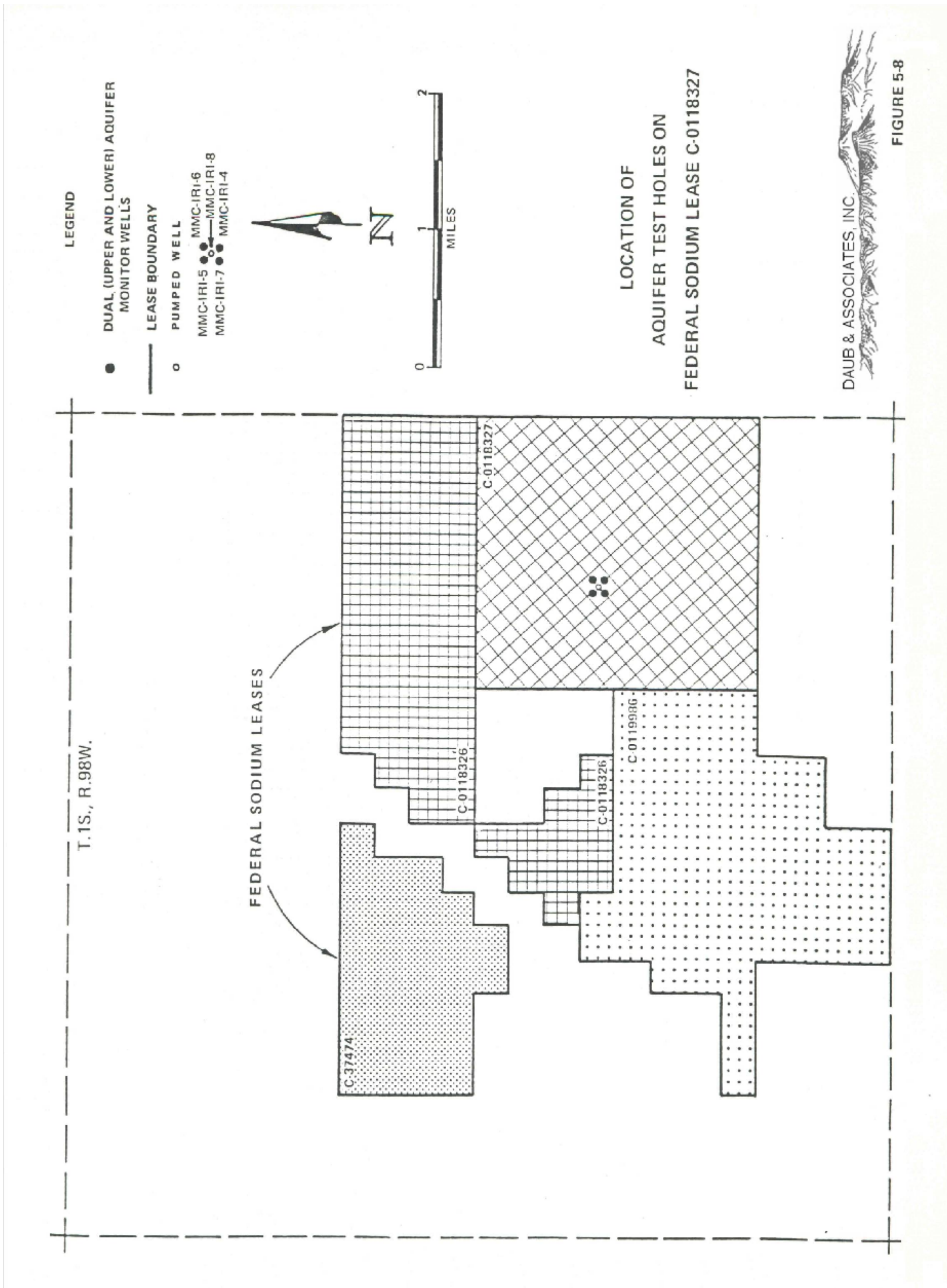

Figure 5-8. Location of aquifer test holes on Federal Sodium Lease C-0118327.

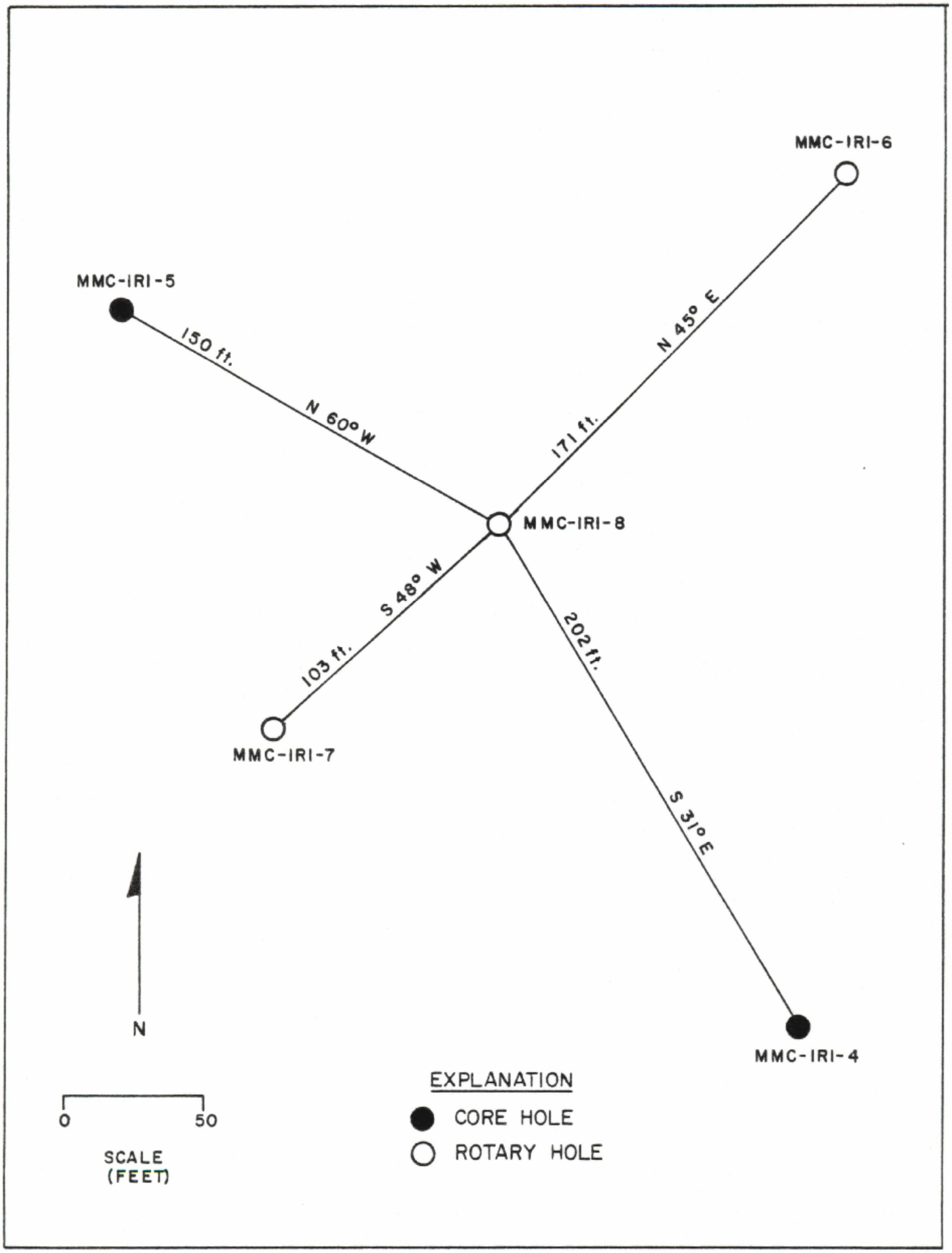

Figure 5-9. Detail of well field (Maxi Pad) showing distance and bearing of observation wells from the pump well (MMC-IRI-8).

The analysis of the data indicated that the average transmissivity of the Lower aquifer was 320 square feet per day with a storage coefficient of 1.13 x 10^{-4}. Vertical hydraulic conductivity of the Mahogany Zone at the test site was on the order of 10^{-4} to 10^{-3} feet per day. The calculated permeabilities of the Mahogany Zone are relatively small, however the analyses did indicate water can move through the zone with sufficient hydraulic head. Daub, et al, 1985 provided additional data and support that the Mahogany Zone acts as a Leaky Semi-Confining Layer.

Robson and Saulnier (1981) indicated that fracture permeability joints and minor faults may occur at depth in a pattern analogous to that indicated at the surface. Working from data collected by Weeks et al, (1974) and others, they indicated in their report that vertical hydraulic conductivity ranged from 7 x 10^{-4} to 6 x 10^{-3} feet per day for the Mahogany Zone in the vicinity of the sodium lease tracts.

Taylor (1981) used a heat-flow technique to estimate vertical hydraulic conductivity of the Mahogany Zone. Utilizing data reported by Welder and Saulnier (1978), he estimated a vertical hydraulic conductivity for a site near the sodium lease tracts (Section 3, T2S, R98W) of 7.8 x 10^{-4} feet per day.

Weston (1984) used the Theis curve-matching method to analyze the data collected on the Upper aquifer. The analysis showed that the transmissivity of the Upper aquifer averaged 675 square feet per day with a storage coefficient of 2.6 x 10^{-4}. These values are similar to those values obtained elsewhere in the basin.

1984 Test Program

During August 1984, IRI conducted tests on Sodium Lease C-0119986 to determine vertical variations within the Upper and Lower aquifers. Production well IRI-PW-2 (in Section 27) was used as the test hole to conduct the investigations.

The test well IRI-PW-2 is a completed production well with approximately 5-1/2" steel casing extending from the surface to the Boies Bed. The well was plugged to approximately 1,540 feet depth, which is approximately the middle of the R-6 zone.

The casing was perforated from 1,460 to 1,480 feet depth, which incorporates the B-groove (below the Mahogany Zone). The zone was pumped (air lift) for several hours and samples were collected using a nitrogen lift sampler. The well was then plugged at 1,280 feet and perforations made between the depths of 1,200 to 1,220 feet, in the R-8 zone of the Upper aquifer. The well was pumped and sampled and after stabilizing, water level readings indicated a static water level elevation of 6,170 feet as compared to a water level elevation taken in an adjacent monitoring well (IRI-MW-1) in the Lower aquifer of 6,169 feet. The hole was then plugged at 600 feet and the well perforated at 395 to 415 feet below ground surface. These perforations straddled the upper contact of the Thirteenmile Creek tongue within the Uinta Formation. This zone had been previously identified as the first point groundwater was encountered during drilling of well IRI-PW-2 (Daub, 1984). Static water level elevation of the Upper aquifer in this zone was 6,310 feet. This corresponded closely with well MMC-IRI-3 which was completed in the upper part of the Upper aquifer and had a static groundwater level elevation of 6,308 feet taken during the same period. This zone was also pumped and sampled. Water quality results are discussed in Section 5.3.3.2.

Potentiometric surface differences between the base of the Upper aquifer and the Lower aquifer at this site was only at 1.0 feet. The relatively minor difference suggests that communication between the aquifers is probably well established at the IRI-PW-2 location. In the area of MMC-IRI-4, -5, -6 and -7, the potentiometric surface between the aquifers is approximately 10 feet, which suggests that the variations in potentiometric surfaces is characteristic of the area. Even at the latter location with a difference of 10 feet, leakage between the aquifers is believed to be occurring (Daub et al, 1985).

The general consensus for the regional groundwater system in the Piceance Creek Basin is that the historical Upper and Lower Aquifers appear to be partially connected hydraulically in some areas more than others. The degree to which they are connected depends on the amount and extent of fracturing in the intervening zone and the thickness and continuity of rich oil shale beds which act as impermeable layers. The "Upper Aquifer" in Tract C-a is different from the standard accepted configuration of the historic Upper Aquifer as it exists elsewhere in the Piceance Creek Basin. The "Upper Aquifer" system (Gulf 1976) was found to be variably located above and below, as well as within the Mahogany Zone. This communication through the Mahogany Zone was caused by extensive joints, faults and/or fracture systems. Campbell's (1977) geophysical work has also indicated vertical fracture systems which are responsible for vertical hydraulic communication.

A similar type of communication potential exists for a portion of Lease C-0119986, with a likely influence into Lease C-0118327 (Figure 5-8). The Dudley Bluffs Graben (Cole, 1983) approaches the Lease from the southeast. A fracture system is indicated to traverse Lease C-0119986 and extend into Yellow Creek. Geophysical work by Campbell (1977) has indicated a graben structure that is located at depth in the vicinity of Stake Springs Draw and Corral Gulch. This graben structure is on strike with the Dudley Bluffs Graben mapped by Donnell (1961) and Eckert (1982). Although no surface expression of the Dudley Bluffs Graben exists on the Lease tracts, there is evidence for this structure to exist in the subsurface. Geophysical (vibroseis) data was run in a 1974 and 1975 transverse near the strike of the Dudley Bluffs Graben, along the Yellow Creek Jeep Trail. These seismic data indicated a significant near surface anomaly where the seismic line crosses the Dudley Bluffs Graben (Daub, 1984). This anomaly appears to be a near surface normal fault with approximately 100 feet of throw. These data are subject to interpretation and without further reprocessing of the seismic data; no definitive conclusions can be reached. However, an anomaly does exist at this location. Eckert (1982) has mapped the Dudley Bluffs Graben and states that there are two lines of evidence which suggest that the Dudley Bluffs Graben extends into the Yellow Creek area.

The first is that there is a significant red area on the Landsat false color composite photo in Yellow Creek which aligns with the strike of the graben. This red area is indication of a higher permeability than the surrounding area. This may be an area where the connection between the historic Upper and Lower Aquifers exist (Eckert, 1982). The second line of evidence is Campbell's (1977) geophysical work.

Geophysical work and mapping confirms the presence of fractures in Yellow Creek near the confluence of Corral Gulch and Stake Springs Draw.

The Dudley Bluffs Graben may act as a large vertical hydraulic conduit which provides communication between the two aquifers, similar to the Black Sulphur Creek Fault.

Core holes MMC-IRI-2 and MMC-IRI-9 straddle the projection of the Dudley Bluffs Graben on the north and south side, respectively. These two core holes consumed an inordinate amount of fluid during drilling as compared to the other core holes on the Lease. While drilling core hole MMC-IRI-2, drilling circulation was lost at a depth of 200 feet and was never regained. A total of 157,800 gallons of mud and lost circulation material were used to complete the hole. Core hole MMC-IRI-9 consumed 199,650 gallons of mud. This drilling fluid consumption rate indicates the presence of a shear or fault zone at depth of quite substantial size, presumably influenced by the Dudley Bluffs Graben (Daub, 1984).

An inordinate water discharge occurred when USBM-Core Hole-01 was drilled about one quarter mile north of the Dudley Bluffs Graben. This well was abandoned due to the highly fractured and faulted nature of the core as well as the large quantities of water which were produced. At this location water production during drilling increased substantially with depth while the Mahogany Zone was being penetrated. The same was also the case for USMB-Core Hole-01-A (Dale and Weeks 1977).

5.3.3. Groundwater Quality

Baseline groundwater quality information on the groundwater system in the Piceance Creek Basin has been collected by the USGS, Natural Soda, Inc., Multi Mineral Corporation, Gulf Oil and Standard Oil Company (Indiana), Industrial Resources, Inc., Shell Oil Company, and others. The following discussion presents available data to describe the existing groundwater quality both regionally and site-specifically.

5.3.3.1. Regional Groundwater Quality

The chemical quality of groundwater in the Piceance Creek Basin varies both within and among the aquifers. Weeks et al, (1974) indicated that generally the groundwater in the alluvial and historic Upper and Lower Aquifers does not meet the drinking water standards recommended by the Colorado Department of Public Health and Environment (CDPHE), although it is frequently used for stock watering and supplies some ranches.

The water in the alluvium is classified as a sodium bicarbonate type. Concentrations of major ions indicate that the alluvial groundwater is similar in chemistry to that found in the Upper Aquifer. Concentrations of dissolved solids range from 470 to 6,720 mg/l and average 1,750 mg/l (Weeks et al, 1974). Generally, concentrations of dissolved solids increases in the downstream direction, with an increase in sodium and bicarbonate from recharge areas to the discharge areas. The increase is believed to reflect influences from irrigation-return flows, contributions from bedrock groundwater discharging to the alluvium, and concentration by evapotranspiration.

In general, water in the Upper Aquifer is of better quality than the Lower Aquifer. Water in the Upper Aquifer can be classified as a sodium bicarbonate type with a TDS concentration ranging from 400 to 2,000 mg/l (Weeks et al, 1974). Calcium, magnesium and sulfate concentrations in the Upper Aquifer are greater than in the Lower Aquifer.

The Lower Aquifer can likewise be classified as sodium bicarbonate type, with higher TDS concentrations ranging from 500 to 40,000 mg/l. The very high TDS concentrations are located near the top of the Saline Zone, i.e., the Dissolution Surface (Coffin et al, 1971). Throughout the Basin, the Lower Aquifer has characteristically exhibited a much higher concentration of fluoride than the Upper Aquifer. Wells sampled in the Lower Aquifer on Tracts C-a and C-b for the period 1974-1976 had average fluoride values of 14.7 and 21.0 mg/l, respectively.

It has been reported by Weeks et al, (1974) that some concentrations of trace materials found within the Lower Aquifer are great enough to be of environmental concern. Barium, boron and lithium are consistently found in high concentrations in the northern part of the Basin. They indicated that concentrations of barium occasionally exceeded drinking water standards.

5.3.3.2. Site-Specific Groundwater Quality

For more than 17 years Natural Soda, Inc. has tested and established a credible baseline for groundwater quality information on four aquifer systems in the Piceance Creek Basin. The Perched, A-groove, B-groove, and Dissolution Surface Aquifers are continually monitored by way of a comprehensive ground water monitor network of wells located throughout the project area. The monitoring wells are established both outside the direct area of influence of well field operations as well as within the well field. Tables 5-4, 5-5, 5-6, and 5-7 display the average water quality values for major analytes tested from the Perched, A-groove, B-groove, and Dissolution Surface Aquifer monitor wells, respectively, between the years 2000 and 2010.

Well	Total Alkalinity as CaCO3	Bicarbonate as CaCO3	Carbonate as CaCO3	Chloride	Conductivity, Lab	Fluoride	pH, lab	Sulfate	Total Dissolved Solids	Boron, dissolved	Calcium, dissolved	Magnesium, dissolved	Potassium, dissolved	Silica, dissolved	Sodium, dissolved	Location
	mg/l	mg/l	mg/l	mg/l	umhos/cm	mg/l	pH units	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	
MMC-IRI-1	268.276	162.310	109.750	30.203	719.000	6.169	9.407	79.418	534.483	0.159	6.618	3.661	3.746	37.521	166.552	Updgradient
89-3	226.788	212.273	14.545	14.136	704.273	0.375	8.455	118.524	453.455	0.061	11.773	13.270	0.915	18.839	133.788	Downgradient
MMC-IRI-5	252.125	221.000	33.200	11.775	949.188	0.194	8.594	215.563	649.250	0.068	11.700	5.138	2.194	14.019	207.938	Downgradient
MMC-IRI-8	256.250	91.333	154.750	84.642	934.083	1.258	9.817	61.367	594.167	0.097	2.258	0.000	4.542	26.983	191.417	Downgradient
Average	250.860	171.729	78.061	35.189	826.636	1.999	9.068	118.718	557.838	0.096	8.087	5.517	2.849	24.341	174.923	

Table 5-4. Average values for major analytes in Perched Aquifer monitoring wells between the years 2000-1010.

Well	Total Alkalinity as CaCO3	Bicarbonate as CaCO3	Carbonate as CaCO3	Chloride	Conductivity, Lab	Fluoride	pH, lab	Sulfate	Total Dissolved Solids	Boron, dissolved	Calcium, dissolved	Magnesium, dissolved	Potassium, dissolved	Silica, dissolved	Sodium, dissolved	Location
	mg/l	mg/l	mg/l	mg/l	umhos/cm	mg/l	pH units	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	
90-4	907.821	828.923	78.667	2498.718	8420.769	13.054	8.785	4.818	5090.769	0.311	10.760	13.725	2.635	14.858	1933.500	Upgradient
90-1	632.606	595.061	37.727	156.555	1804.848	11.758	8.406	86.079	1098.030	0.374	4.830	5.458	0.545	13.400	430.091	Well Field
89-2	638.432	547.811	90.649	18.578	1291.622	20.592	8.905	20.442	861.135	0.399	1.232	0.926	1.584	11.884	368.105	Downgradient
MMC-IRI-4	275.563	201.375	79.563	211.375	1238.750	5.931	9.269	15.819	722.625	0.199	4.475	0.631	2.031	11.031	284.625	Downgradient
Average	613.605	543.292	71.651	721.306	3188.997	12.834	8.841	31.789	1943.140	0.321	5.324	5.185	1.699	12.793	754.080	

Table 5-5. Average values for major analytes in A-groove Aquifer monitoring wells between the years 2000-2010.

Well	Total Alkalinity as CaCO3	Bicarbonate as CaCO3	Carbonate as CaCO3	Chloride	Conductivity, Lab	Fluoride	pH, lab	Sulfate	Total Dissolved Solids	Boron, dissolved	Calcium, dissolved	Magnesium, dissolved	Potassium, dissolved	Silica, dissolved	Sodium, dissolved	Location
	mg/l	mg/l	mg/l	mg/l	umhos/cm	mg/l	pH units	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	
BG-1	766.833	644.727	122.439	23.251	1455.106	23.223	8.835	4.454	959.136	0.818	2.100	1.406	2.965	10.883	384.015	Upgradient
90-3	868.256	791.333	76.769	22.156	2992.179	21.821	8.667	6.897	1032.795	0.695	2.279	2.141	1.567	22.164	413.462	Upgradient
BG-4	772.035	699.894	80.294	14.568	1468.214	22.119	8.655	2.559	923.282	0.710	2.876	1.654	2.125	14.145	370.847	Well Field
BG-5	741.556	521.111	220.333	382.111	2811.111	11.156	9.433	59.444	1586.667	0.522	3.478	4.600	3.278	1.600	587.111	Well Field
89-1	705.895	619.053	86.763	12.466	1376.579	23.568	8.845	2.290	873.079	0.624	1.871	1.095	1.405	17.850	351.684	Downgradient
MMC-IRI-6	666.938	591.813	73.875	38.819	1426.250	21.869	8.869	9.375	885.313	0.482	1.663	0.763	1.281	16.394	356.438	Downgradient
Average	753.585	644.655	110.079	82.229	1921.573	20.626	8.884	14.170	1043.379	0.642	2.378	1.943	2.103	13.839	410.593	

Table 5-6. Average values for major analytes in B-groove Aquifer monitoring wells between the years 2000-2010.

Well	Total Alkalinity as CaCO3	Bicarbonate as CaCO3	Carbonate as CaCO3	Chloride	Conductivity, Lab	Fluoride	pH, lab	Sulfate	Total Dissolved Solids	Boron, dissolved	Calcium, dissolved	Magnesium, dissolved	Potassium, dissolved	Silica, dissolved	Sodium, dissolved	Location
	mg/l	mg/l	mg/l	mg/l	umhos/cm	mg/l	pH units	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	
DS-2	46300.000	43766.711	2253.737	805.105	48000.395	49.011	8.309	136.459	49613.158	25.200	4.000	0.000	29.000	32.000	16200.000	Upgradient
90-2	34767.778	25399.222	8971.194	4978.222	43985.278	82.200	8.744	240.591	50102.944	38.964	1.292	0.524	64.389	31.564	19945.222	Upgradient
DS-4	18733.333	17100.000	1633.333	3326.667	32633.333	47.200	8.650	25.000	21500.000	11.633	6.833	1.000	40.500	26.667	10001.667	Well Field
DS-3	31618.750	28070.625	3249.000	4881.013	45997.468	54.786	8.515	87.790	42001.250	13.325	1.453	0.239	27.863	27.924	16976.500	Well Field
4A-1V	9110.000	5653.333	3456.667	978.333	15833.333	19.933	9.367	40.667	12700.000	8.160	2.067	4.400	15.900	11.100	4796.667	Well Field
EX-2	50473.333	33490.909	16724.545	2760.152	49760.000	84.548	9.070	568.667	65151.212	18.214	0.621	0.061	60.097	27.479	24493.424	Downgradient
MMC-IRI-7	13028.750	11431.875	1682.133	511.063	18318.750	28.781	8.713	208.571	15337.500	3.446	8.163	4.294	13.169	21.375	6085.625	Downgradient
Average	28105.972	23997.978	3912.786	2993.868	36361.223	52.351	8.767	186.821	36629.438	16.992	3.490	1.502	35.845	25.444	14071.301	

Table 5-7. Average values for major analytes in Dissolution Surface Aquifer monitoring wells between the years 2000-2010.

In general, most analyte concentrations are greatest in the Dissolution Surface Aquifer (by at least an order of magnitude), and least in the Perched Aquifer, with gradational analyte values found in the A and B-groove Aquifers. Magnesium is a notable exception to this trend, however, as it is found to be in lowest concentrations in the Dissolution Aquifer monitor wells and greatest in Perched Aquifer monitor wells. The A-groove and B-groove Aquifers can be differentiated by specific analytes , including chloride (A-groove is generally an order of magnitude greater than the B-groove), fluoride (B-groove concentrations are generally nearly twice as great as found in the A-groove), sulfate (A-groove concentrations are generally at least twice as great as found in the B-groove), and boron (B-groove concentrations are generally twice as great as found in the A-groove).

The monitoring of the project area is described in a Comprehensive Monitoring Plan (Daub, 2010) that has been designed to enable detection and/or evaluation of hydrologic impacts through the use of these monitoring wells. The Comprehensive Monitoring Plan states that the project will continue operations if site-specific monitoring results do not indicate significant negative impacts and has been submitted to the BLM and EPA.

In 1995 the operation incurred a variance in the A-groove Aquifer water quality in the 90-1 well, directly above the mining zone. Up to that time, the established solution mining technology was to inject barren brine into the cavity under pressure, thereby forcing saturated brine to surface for processing. An anomaly in the pressurized cavity allowed mining fluid to infiltrate a portion of the A-groove Aquifer directly above the mining zone. This variance was corrected by developing the current mining technology of installing submersible downhole pumps in the recovery wells and maintaining mining cavity pressures in equilibrium with the Dissolution Surface. The localized reduction of water quality in the A-Groove Aquifer was remediated by utilizing the 90-1 well as a water supply well for the Processing Plant, thereby consuming this lower quality fluid. The 90-1 well parameters are approaching baseline conditions, and no impacts from this variance were seen up-dip or down-dip from this well.

A number of samples are collected for groundwater quality in the Perched, A-groove, B-groove and Dissolution Surface Aquifers as part of an ongoing monitoring program conducted by Natural Soda, Inc. Data collected from each of the four aquifers between July 29, 2009 and October 7, 2009 is discussed below to provide a general overview of the water quality within the project area. The empirical data for these samples are presented in Figure 5-10. Groundwater quality data were collected on August 19, 2009 for the Perched Aquifer. The Perched Aquifer, sampled within the Uinta Formation, was found to be a sodium bicarbonate type. The aquifer yielded water having a total dissolved solids concentration of 422 mg/l. Groundwater in the A-Groove Aquifer collected on July 29, 2009 was found to be a sodium bicarbonate type water high in fluoride. The aquifer had a total dissolved solids concentration of 5,090 mg/l. Distinct differences were noted in the water quality between the Perched Aquifer and A-groove Aquifer. With the exception of sulfate, all anions were substantially higher in the A-groove Aquifer than the Perched Aquifer. Sulfate was found to be 40 mg/l in the Perched Aquifer and 10 mg/l in the A-Groove Aquifer. Fluoride was found at 0.3 mg/l in the Perched Aquifer, while it was found at 11.7 mg/l in the A-Groove Aquifer.

Additionally, sodium concentrations were an order of magnitude greater in the A-groove Aquifer (1,770 mg/l) than in the Perched Aquifer (131 mg/l), and chloride concentrations were two orders of magnitude greater in the A-Groove Aquifer (2,710 mg/l) than in the Perched Aquifer (23 mg/l). It should be noted that the A-groove Aquifer monitoring well sampled from in this sampling event (90-4) is atypical of most A-groove monitoring wells, in that analyte concentrations tend to be closer to the average of those found in B-groove and Dissolution Surface Aquifer monitoring wells. The cause of such concentrations as are found in the 90-4 is unknown at this time but are under investigation at the time of this update.

Groundwater quality data for the B-groove Aquifer was collected on October 7, 2009. The results of the analysis indicated that the B-groove Aquifer contains sodium bicarbonate type water high in fluoride. The aquifer had a total dissolved solids concentration of 1,420 mg/l. Groundwater in the Dissolution Surface Aquifer collected on July 30, 2009 contained a sodium bicarbonate type of water very high in fluoride. Total dissolved solids were found to be at a concentration of 33,300 mg/l. In both aquifers, bicarbonate was the dominant ion, being two orders of magnitude greater in the Dissolution Surface Aquifer (22,700 mg/l) than in the B-groove Aquifer (493 mg/l). Sodium was the second most dominant ion, again two orders of magnitude greater in the Dissolution Surface Aquifer (13,000 mg/l) than in the B-groove Aquifer (538 mg/l). Chloride concentrations were found to be 270 mg/l in the B-groove Aquifer and 3,940 mg/l in the Dissolution Surface Aquifer, respectively. Fluoride concentration was five times higher in the Dissolution Surface Aquifer (54 mg/l) than in the B-groove Aquifer (11 mg/l).

As shown in Figure 5-10, TDS is substantially higher in the Dissolution Surface Aquifer than that measured in the B-groove Aquifer. The difference indicates that water quality deteriorates with depth as the Dissolution Surface is approached and shows that a density separation is maintained.

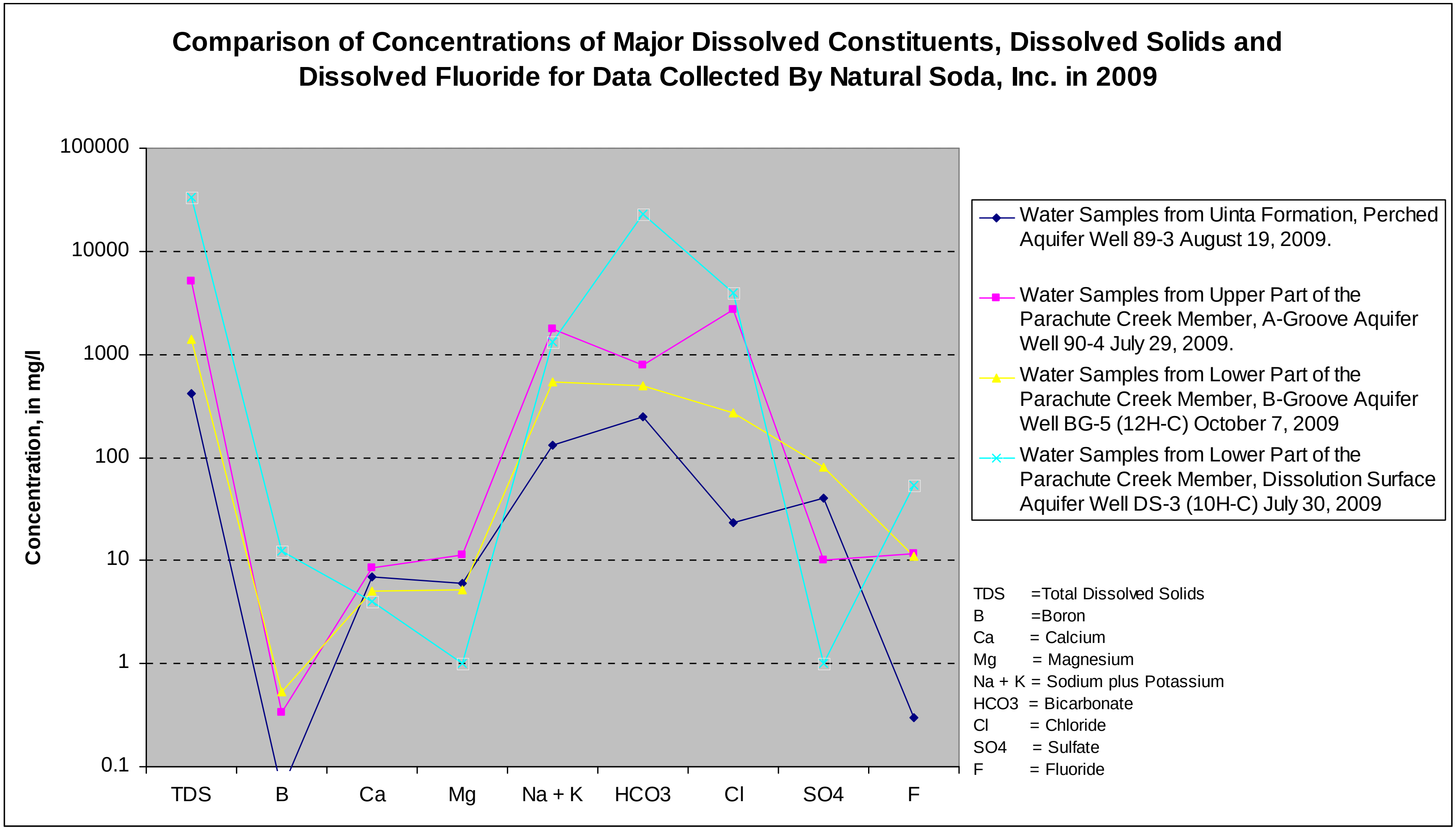

Figure 5-10. Comparison of concentrations of major dissolved constituents, dissolved solids and dissolved fluoride for data collected by Natural Soda, Inc in 2009.

5.4. SUPPORTING DATA AND INFORMATION

5.4.1. References Cited

Alley, W.A., 1982. Relative importance of groundwater and surface water supplies to oil shale development, Piceance Basin, Colorado. U.S. Geological Survey Open-File Report 82-340.

Ashland Oil Inc. and Shell Oil Co. 1976. Final environmental baseline report.

Bureau of Land Management, 1987. Final Environmental Impact Statement: Wolf Ridge Corporation Mine Plan for a Nahcolite Solution Mine. White River Resource Area, Craig District, Colorado.

Campbell, D.L, 1977. Electrical soundings near Yellow Creek, Rio Blanco County, Colorado. U.S. Geological Survey Journal Research, V. 5, p. 193-205.

Cliffs Engineering, Inc. 1983. Hydrological summary. Industrial, Resources, Inc. Sodium Minerals Project.

Coffin, D.L, Welder, F.A., and Glanzman, R.K. 1971. Geohydrology of the Piceance Creek structural basin between the White and Colorado Rivers, northwestern Colorado. U.S. Geological Survey Hydrology Inc. Atlas HA-370.

Dale, R.H. and Weeks, J.B., 1977. Hydrologic analysis of the U.S. Bureau of Mines' prototype mine site, Piceance Creek Basin, Rio Blanco County, Colorado: USGS Water-Resources Investigations.

Daub, G.J., 1984. Engineering and completion report for Industrial Resources Incorporated, rotary/core Holes IRI-PW-1, IRI-PW-2, IRI-MW-1. Prepared by G.J. Daub of Daub & Associates, Grand Junction, Colorado.

Daub, G.J., 2010. Comprehensive Monitoring Plan. Prepared by G.J. Daub of Daub & Associates, Grand Junction, Colorado.

Daub, G.J., Weston, L. K. and Rosar, E. C., 1985, Detailed Lithologic, Rock Quality and Hydrologic Data from Four Drill Holes in the Central Piceance Creek Basin, Rio Blanco County, Colorado: Colo Sch. Mines 18th Oil Shale Symposium Proceedings, p. 21-46.

Donnell, J.R., 1961. Tertiary geology and oil shale resources of the Piceance Creek Basin between the Colorado and White Rivers, northwestern Colorado: U.S. Geological Survey Bulletin 1082-L, p. 835-887.

Eckert, A.D., 1982. The geology and seismology of the Dudley Gulch Graben and related faults, Piceance Creek Basin, northwestern Colorado (MS Thesis): Boulder, University of Colorado, 139 p.

Ege, J.R., G.H. Leavesley, S.G. Steele and J.B. Weeks, 1978. Site evaluation for U.S. Bureau of Mines Experimental Oil Shale Mine, Piceance Creek Basin, Rio Blanco County, Colorado. U.S. Geological Survey Open-File Report 78-390.

MacDonnell, Lawrence J., 2009. Water on the Rocks: Oil Shale Water Rights in Colorado. Western Resource Advocates, Boulder, Colorado.

Multi Mineral Corporation, Engineering Completion Reports, 1980-1981.

Robson, S.G. and G.J. Saulnier Jr., 1981. Hydrogeochemistry and simulated solute transport, Piceance Basin, northwestern Colorado. U.S. Geological Survey Professional Paper 1196.

Simpson, D., 1984. Personal Communication Colorado Department of Health, Denver, Colorado.

Slawson Jr., G.C., 1980. Monitoring groundwater quality: The impact of oil shale retorting. Environmental Monitoring Systems Laboratory, Office of Research Development, U.S. Environmental Protection Agency, Las Vegas, Nevada.

Taylor, O.J., 1982. Three dimensional mathematical model for simulating the hydrologic system in the Piceance Basin, Colorado. U.S. Geological Survey Water-Resources Investigations Open-File Report 82-637.

United States Geological Society (USGS). Colorado Water Science Center. 2010, http://co.water.usgs.gov/. Accessed 4-7-2010.

U.S. Geological Survey, 1983. Water resources data report Colorado water year 1982, Volume 3. Dolores River Basin, Green River Basin, and San Juan River Basin. U.S. Geological Survey Water-Data Report CO-82-3.

U.S. Water Resources Council, 1981. Synthetic fuel development in the upper Colorado region: Technical Report, Section 13 Water Assessment Report.

Weeks, J.B. and R.H. Dale, 1978. Hydrologic analysis of the Bureau of Mines Underground Oil Shale Research Facility Site, Piceance Creek Basin, Rio Blanco County, Colorado. U.S. Geological Survey Water Resources Investigations 78-28.

Weeks, J.B., G.H. Leavesley, F.A. Welds, and G.J. Saulnier Jr., 1974. Simulated effects of oil shale development on the Piceance Basin, Colorado. U.S. Geological Survey Professional Paper 908.

Welder, F.A. and G.J. Saulnier, Jr., 1973. Geohydrologic data from 24 test holes drilled in the Piceance Basin, Rio Blanco County, Colorado, 1976-76. U.S. Geological Survey Open-File Report 78-734.

Weston, L.K., 1984. Hydrogeologic reconnaissance of Federal Sodium Lease C-0118326, Piceance Basin, Colorado. Prepared for Industrial Resources, Inc., Lakewood, Colorado.

DAUB & ASSOCIATES, INC.

1985 ½ SOUTH BROADWAY
GRAND JUNCTION, CO 81507-9649
(970) 254-1224
FAX (970) 242-8438
email: gjdaub@daubandassociates.com
www.daubandassociates.com

2010 Mine Plan
Volume 4, Section 5A
Appendix

Prepared for:

Natural Soda, Inc.
Piceance Creek Basin
Rio Blanco County, Colorado

Prepared by:

Daub & Associates, Inc.
Grand Junction, Colorado

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF PLATES

LIST OF TABLES

APPENDIX 5A

ANALYSIS OF AQUIFER TEST DATA COLLECTED DURING SUMMER OF 1981 ON FEDERAL SODIUM LEASE C-0118327 PICEANCE CREEK BASIN, COLORADO

INTRODUCTION

During the summer of 1981, the U.S. Geological Survey, in conjunction with Multi Mineral Corporation, conducted pump-out tests of the Upper and Lower aquifer systems at a site within the bounds of Federal Sodium Lease C-0118327 in Piceance Creek Basin, Colorado (Figure 5A-1).

This report presents a detailed analysis of the aquifer test data, and addresses the aspect of leakage between the Upper and Lower aquifer systems.

BACKGROUND

Figure 5A-2 shows the stratigraphic definition of the aquifer systems beneath the Lease area. This report does not address the alluvial aquifer system, but rather the two major bedrock aquifers known as the Upper and Lower aquifers.

The Upper aquifer includes the Uinta Formation and the upper part of the Parachute Creek Member of the Green River Formation down to the base of the A-groove. The Mahogany Zone acts as a semi-confining layer between the Upper and Lower aquifer systems (Weeks and others, 1974). The Lower aquifer lies entirely within the Parachute Creek Member of the Green River Formation, and is synonymous with the Leached Zone (top of the B-groove to the Dissolution Surface). Below the Dissolution Surface, unsaturated saline minerals are present along with the beds of rich oil shale. The Saline Zone acts as a lower confining bed to the Lower aquifer system.

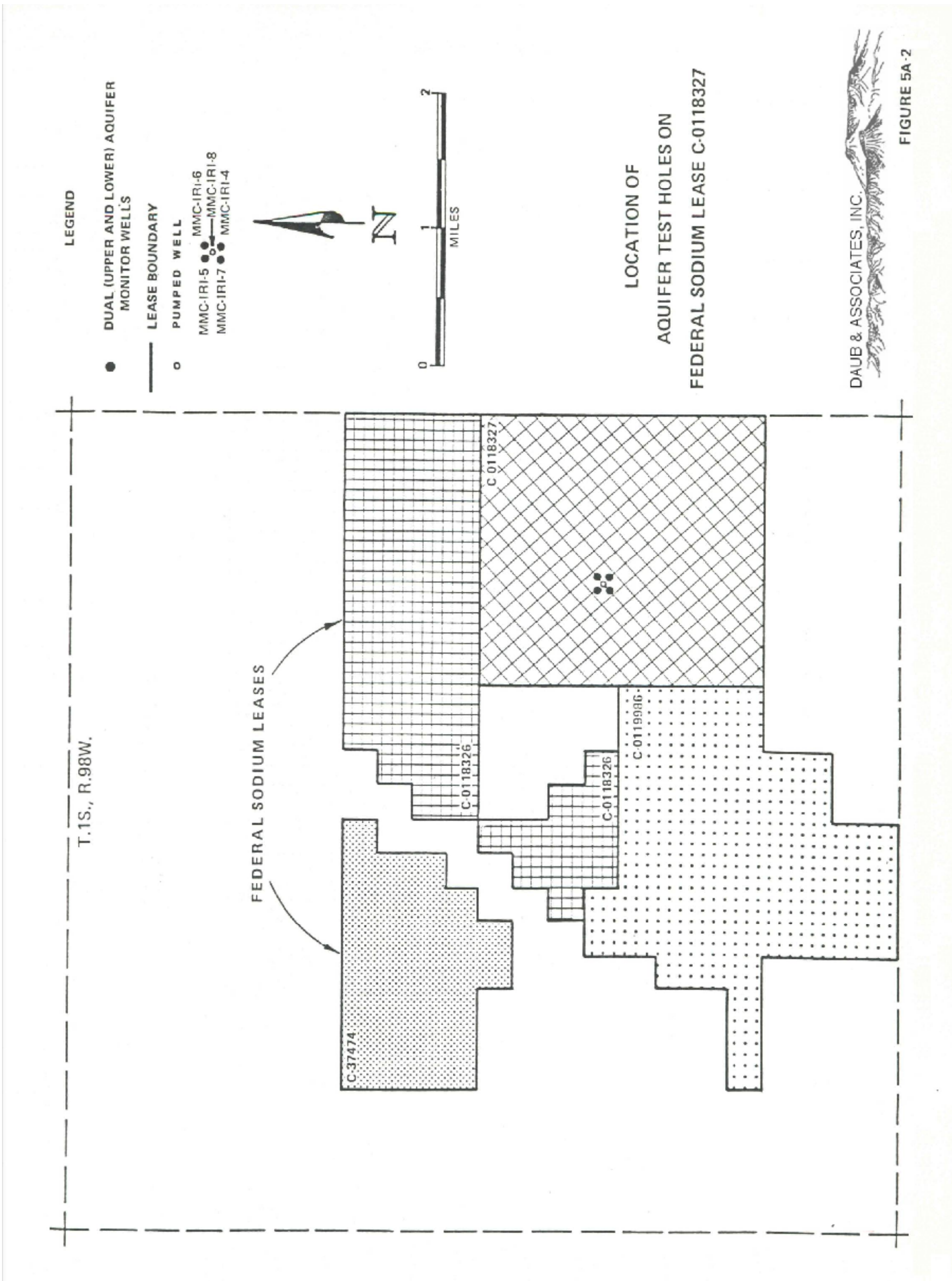

Figure 5A-1. Location of Aquifer Test Holes on Federal Sodium Lease C-0118327.

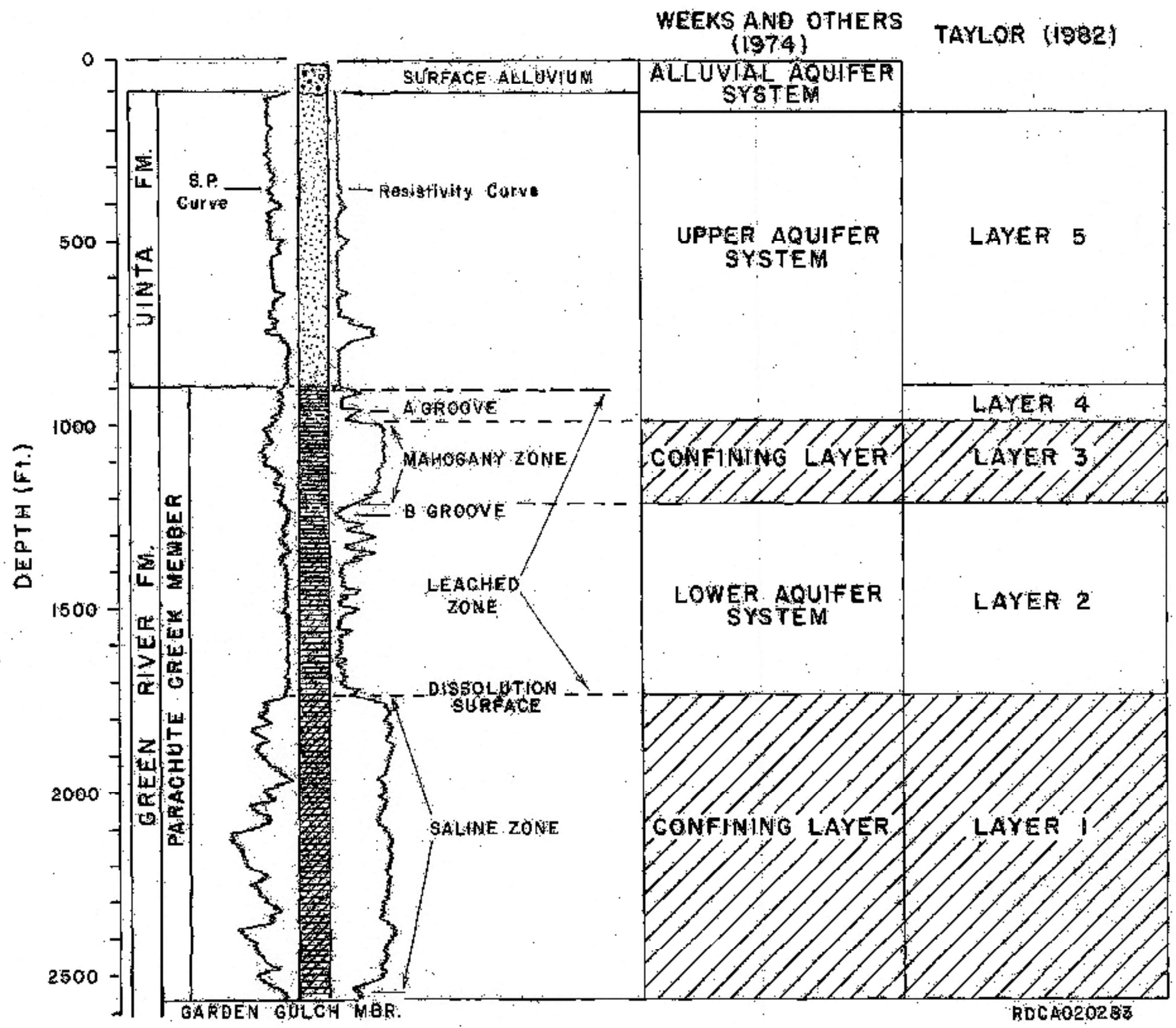

Figure 5A-2. Stratigraphic Definition of Aquifer Systems in the Vicinity of Federal Sodium Lease C-0118326. (adapted from Cole, 1983).

Porosity and permeability of the Upper and Lower aquifers are of secondary nature. In the Upper aquifer, the lean oil shales of the Parachute Creek Member of the Green River Formation, and the marlstones, siltstones and sandstones of the Uinta Formation are fractured and offer paths for water flow and storage. Primary porosity of the siltstones and sandstones of the Uinta Formation is very low due to cementation by precipitation of minerals from percolating waters (Weeks and others, 1974, p. 28). Transmissivity of the Upper aquifer ranges from 8 to 1,000 square feet per day, and the storage coefficient is on the order of 10^{-3} (Weeks and others, 1974). On prototype oil shale lease Tract C-b, transmissivities range from 128 to 223 square feet per day and storage coefficients range from about 7×10^{-5} to 2×10^{-3} (Ashland Oil Inc. and Shell Oil Co., 1976).

The Mahogany Zone aquitard separates the Upper and Lower aquifer systems. The Mahogany Bed, however, is probably the principal confining layer. Even though the rich oil shale composing the Mahogany Zone is quite impermeable, the presence of fractures permits the vertical exchange of water between the two aquifer systems. Weeks and others (1974) report that the vertical hydraulic conductivity of the Mahogany Zone has not been adequately determined, but may be as high as 0.37 feet per day.

The secondary porosity and permeability of the Lower aquifer have been enhanced by the removal of soluble minerals, principally nahcolite, by percolating groundwaters. Secondary features include fractures, vugs, pits, solution cavities, and collapse breccias. Weeks and others (1974) state that transmissivity of the Lower aquifer may be as high as 2,700 square feet per day and the storage coefficient is on the order of 10^{-4}. Data from Tract C-b shows transmissivities of the Lower aquifer ranging from about 15 to 92 square feet per day and storage coefficients ranging from about 1×10^{-5} to 5×10^{-4} (Ashland oil Inc. and Shell Oil Co., 1976).

Both the Upper and Lower aquifers beneath the Sodium Lease were pump tested during the summer of 1981 by USGS personnel. The well field used during testing consisted of three air-rotary drilled holes (MMC-IRI-6, -7 and -8) and two core holes (MMC-IRI-4 and -5) (Figure 5A-3). MMC-IRI-8 was used as the pumped well and the remaining holes, MMC-IRI-4, -5, -6 and -7, were used as observation wells. The observation wells were completed in such a manner as to allow for simultaneous monitoring of both aquifers during testing. For details of drilling, well completion and sequence of events during testing, the reader is referred to a hydrogeologic reconnaissance report prepared for industrial Resources, Inc., by Weston (1984).

LOWER AQUIFER TEST

In July 1981, the USGS pump tested the Lower aquifer. The test was run for 10,000 minutes (approximately 7 days), and the discharge was held constant at 18 gallons per minute. Both Upper and Lower aquifer piezometers were monitored throughout the test. Time-drawdown data for each of the observation wells are located in Tables 5A-3, -4, -5 and -6.

Figures 1, 4, 6 and 8 (located on Plate 5A-1) are the semi logarithmic plots of the data for each of the observation wells. Note that Figures 1 and 8 show considerable scatter in the data points. This was due to malfunctioning water-level probes and constant change from one water-level measuring device to another. Each grouping of erratic data points, however, appear to fall near straight-line segments that have the same slope as the main body of the curve, suggesting that constant errors have been introduced in each case. Correction factors were applied to each grouping of erratic data points so that a continuous curve could be plotted (Figures 2 and 9, Plate 5A-1). This was necessary to facilitate the interpretation of full logarithmic plots (type-curve analysis) discussed below. Table 5A-1 contains a summary of transmissivity and storativity values of the Lower aquifer using the straight-line approach. Transmissivity averages 320 feet per day, and the storage coefficient averages 1.2×10^{-4}.

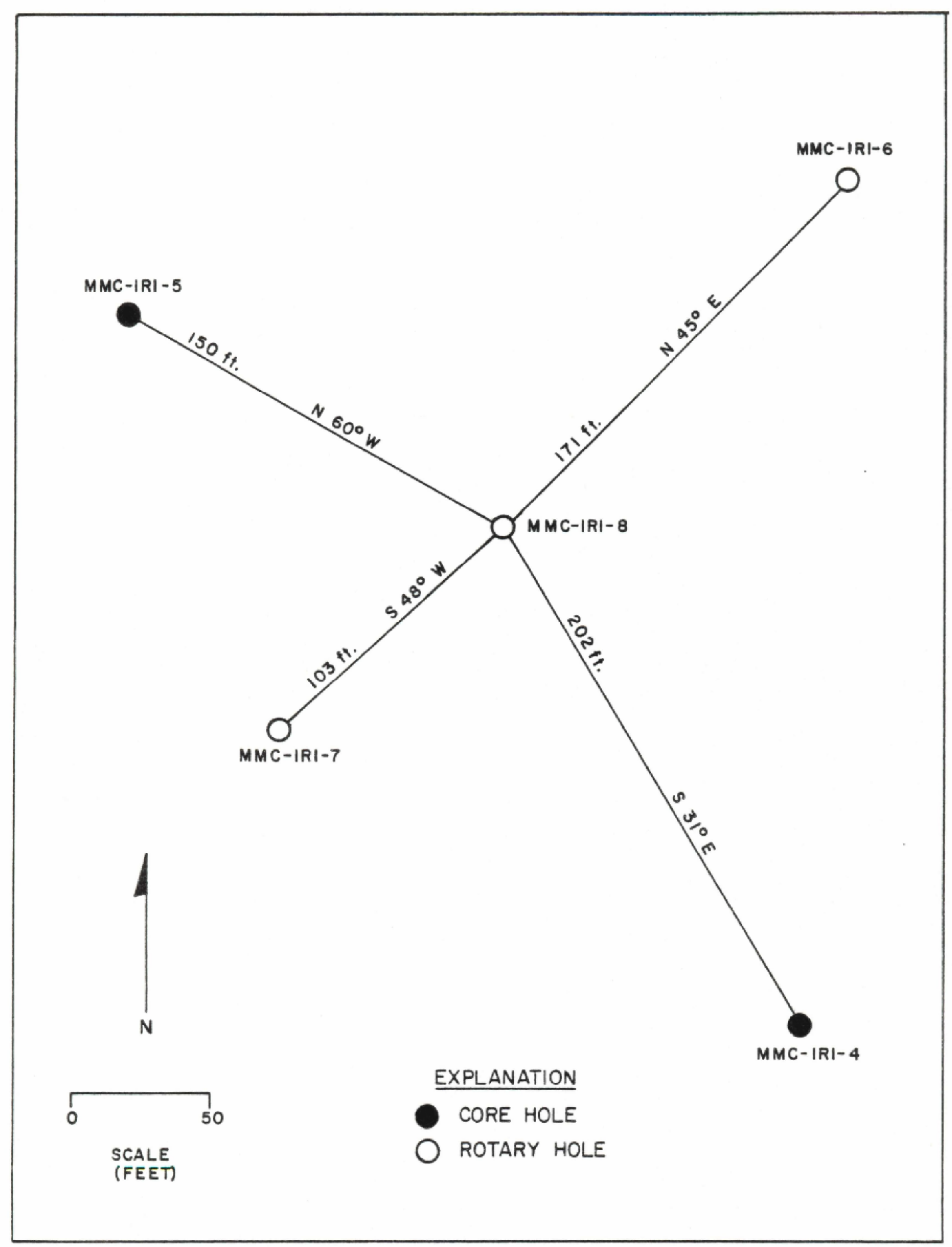

Figure 5A-3. Detail of Well Field Showing Distance and Bearing of Observation Wells from the Pump Well (MMC-IRI-8).

TABLE 5A-1

Summary of Lower aquifer properties calculated by the Jacob straight-line method and the Hantush-Jacob leaky aquifer method.

METHOD	PARAMETER	OBSERVATION WELL MMC-IRI-4	MMC-IRI-5	MMC-IRI-6	MMC-IRI-7
Jacob's	Transmissivity (ft^2/day)	380	280	260	360
	Storage Coefficient	3.0×10^{4}	2.0×10^{5}	8.6×10^{5}	6.3×10^{5}
Hantush-Jacob	Transmissivity (ft^2/day)	380	290	270	340
	Storage Coefficient	2.9×10^{4}	1.4×10^{5}	8.0×10^{5}	6.8×10^{5}
	Leakance (day^{-1})	---	$1\ 3 \times 10^{6}$	1.5×10^{5}	1.3×10^{5}
	Vertical Hydraulic Conduc:Livi (ft/day)	---	2.2×10^{4}	2.5×10^{3}	2.2×10^{3}

Table 5A-1. Summary of Lower aquifer Properties Calculated by the Jacob Straight Line Method and the Hantush-Jacob Leaky Aquifer Method.

TABLE 5A-2

Summary of Upper aquifer properties calculated by the Jacob straight-line method and the Theis type-curve method.

METHOD	PARAMETER	OBSERVATION WELL MMC-IRI-4	MMC-IRI-5	MMC-IRI-6	MMC-IRI-7
Jacob's	Transmissivity (ft^2/day)	760	640	620	650
	Storage Coefficient	2.1×10^4	4.4×10^4	2.2×10^4	1.4×10^4
Theis	Transmissivity (ft^2/day)	770	660	610	660
	Storage Coefficient	2.2×10^4	3.9×10^4	2.6×10^4	1.6×10^4

Table 5A-2. Summary of Upper Aquifer Properties Calculated by the Jacob Straight-Line method and the Theis Type-Curve Method.

TABLE 5A-3

Time-drawdown data for observation well MMC-IRI-4 during Lower aquifer test.

TIME (minutes)	MEASURED DRAWDOWN (feet)	CORRECTION (feet)	CORRECTED DRAWDOWN (feet)
1	0	-	0
2	-0.02	-	-0.02
3	-0.05	-	-0.05
4	-0.05	-	-0.05
5	-0.09	-	-0.09
6	-0.02	-	-0.02
7	-0.03	-	-0.03
8	-0.01	-	-0.01
9	0.03	-	0.03
10	0.06	-	0.06
15	0.23	-	0.23
20	0.33	-	0.33
30	0.55	-	0.55
40	0.68	-	0.68
50	0.62	-	0.62
60	0.60	-	0.60
71	0.96	-	0.96
80	0.95	-	0.95
90	1.07	-	1.07
100	1.13	-	1.13
150	1.43	-	1.43
200	1.72	-	1.72
302	3.18	-1.14	2.04
403	3.23	-1.14	2.09
503	3.61	-1.14	2.47
603	3.23	-1.14	2.09
704	3.76	-1.14	2.62
803	3.70	-1.14	2.56
908	4.40	-1.64	2.76
1005	4.44	-1.64	2.80
1105	4.93	-2.04	2.89
1205	4.96	-2.04	2.92
1308	4.49	-1.64	2.85
1415	5.08	-2.04	3.04
1620	2.16	0.82	2.98
1700	2.41	0.82	3.23
1810	2.26	0.82	3.08
1900	2.27	0.82	3.09
2010	2.43	0.82	3.25
2210	2.53	0.82	3.35
2400	2.84	0.82	3.66
2630	2.85	0.82	3.67
2810	2.47	0.82	3.29
3025	2.75	0.82	3.29
3570	2.85	0.82	3.57
3990	3.09	0.82	3.67
4500	2.98	-	3.91
5030	3.16	-	2.98
5505	2.95	-	3.16
5980	2.93	-	2.95
6200	2.83	-	2.93
7000	2.83	-	2.83
7500	3.95	-	2.83
8468	4.24	-	3.95
9000	4.20	-	4.24
9505	4.24	-	4.20
10002	4.37	-	4.24

Table 5A-3. Time-Drawdown Data for Observation Well MMC-IRI-4 During Lower Aquifer Test.

TABLE 5A-4

Time-drawdown data for observation well MMC-IRI-5 during Lower aquifer test.

TIME (minutes)	MEASURED DRAWDOWN (feet)	TIME (minutes)	MEASURED DRAWDOWN (feet)
1	0.25	603	6.34
2	0.76	703	6.53
3	1.28	805	6.48
4	1.67	909	6.58
5	1.93	1003	6.38
6	2.11	1103	6.39
7	2.18	1203	6.83
8	2.26	1316	6.86
9	2.36	1403	6.88
10	2.44	1510	6.90
15	2.75	1604	6.90
20	2.96	1702	6.92
30	3.36	2425	7.16
40	3.65	2760	7.42
50	3.86	3033	7.40
60	4.13	3600	7.61
70	4.23	4000	7.63
80	4.40	4517	7.91
90	4.49	4915	7.98
100	4.61	5520	8.22
150	5.04	5990	7.93
200	5.27	6208	7.93
304	5.74	7025	7.92
402	5.93	7500	7.94
504	6.29	8475	8.03
		9007	7.95
		9505	8.20
		10002	7.95

Table 5A-4. Time Drawdown Data for Observation Well MMC-IRI-5 During Lower Aquifer Test.

TABLE 5A-5

Time-drawdown data for observation well MMC-IRI-6 during Lower aquifer test.

TIME (minutes)	MEASURED DRAWDOWN (feet)	TIME (minutes)	MEASURED DRAWDOWN (feet)
1	0	700	4.81
2	0.09	800	4.85
3	0.21	900	4.95
4	0.32	1000	5.06
5	0.47	1100	5.09
6	0.57	1200	5.20
7	0.68	1312	5.28
8	0.72	1402	5.25
9	0.80	1507	5.32
10	0.84	1607	5.29
15	1.12	1705	5.29
20	1.34	2410	5.47
30	1.64	2765	5.79
40	1.95	3029	5.78
50	2.15	3595	5.88
60	2.36	4005	6.01
70	2.52	4513	6.23
80	2.61	4913	6.34
90	2.77	5515	6.50
100	2.90	5985	6.34
150	3.33	6205	6.32
200	3.61	7020	6.40
300	4.13	7495	6.42
400	4.26	8472	6.54
500	4.62	9005	6.43
600	4.67	9500	6.52
		10000	6.49

Table 5A-5. Time-Drawdown Data for Observation Well MMC-IRI-6 During Lower Aquifer Test.

TABLE 5A-6

Time-drawdown data for observation well MMC-IRI-7 during Lower aquifer test.

TIME (minutes)	MEASURED DRAWDOWN (feet)	CORRECTION (feet)	CORRECTED DRAWDOWN (feet)
4	1.13	-	1.13
5	1.19	-	1.19
6	1.30	-	1.30
7	1.38	-	1.38
8	1.49	-	1.49
9	1.53	-	1.53
10	1.61	-	1.61
15	1.86	-	1.86
20	3.27	-1.16	2.11
30	3.57	-1.16	2.41
40	3.77	-1.16	2.61
50	3.94	-1.16	2.78
60	4.12	-1.16	2.96
70	4.22	-1.16	3.06
80	4.31	-1.16	3.15
90	4.39	-1.16	3.23
100	4.48	-1.16	3.32
150	4.87	-1.16	3.71
200	5.30	-1.16	4.14
300	5.52	-1.16	4.36
400	5.72	-1.16	4.56
500	4.57	-	4.57
600	4.77	-	4.77
700	4.36	-	4.86
800	4.89	-	4.89
905	5.02	-	5.02
1000	5.07	-	5.07
1100	5.1	-	5.10
1203	6.77	-1.16	5.61
1301	6.61	-1.16	5.45
1390	6.53	-1.16	5.37
1400	5.58	-1.16	5.42
1500	6.60	-1.16	5.44
1600	6.59	-1.16	5.43
1700	6.59	-1.16	5.43
1705	5.29	-	5.29
1804	5.30	-	5.30
1910	5.34	-	5.34
2035	5.26	-	5.26
2200	5.34	-	5.34
2410	5.38	-	5.38
2603	5.60	-	5.60
2620	5.63	-	5.63
2820	5.80	-	5.80
3000	5.76	-	5.76
3010	5.76	-	5.76
3015	7.05	-	7.05
3590	5.82	-	5.82
3985	5.92	-	5.92
4500	6.21	-	6.21
4900	6.25	-	6.25
5515	6.52	-	6.52
5975	6.310	-	6.31
7020	6.37	-	6.37
7260	5.81	0.59	6.40
7495	5.73	0.59	6.32
7515	6.37	-	6.37
8465	5.81	0.59	6.40
9000	5.75	0.59	6.34
9500	5.83	0.59	6.42
10000	5.75	0.59	6.34

Table 5A-6. Time-Drawdown Data for Observation Well MMC-IRI-7 During Lower Aquifer Test.

TABLE 5A-7

Time-drawdown Data for Observation Well MMC-IRI-4 During Upper Aquifer Test

TIME (minutes)	MEASURED DRAWDOWN (feet)
1	0
2	0.10
3	0.25
4	0.30
5	0.45
6	0.50
8	0.65
10	0.90
12	0.95
15	1.20
20	1.35
25	1.57
30	1.82
40	2.18
60	2.56
80	2.88
100	3.19
120	3.41
150	3.69
210	4.29
300	4.58
420	5.05
690	5.65
1025	6.15
1180	6.16

Table 5A-7. Time-Drawdown Data for Observation Well MMC-IRI-4 During Upper Aquifer Test.

TABLE 5A-8

Time-drawdown Data for Observation Well MMC-IRI-5 During Upper Aquifer Test

TIME (minutes)	MEASURED DRAWDOWN (feet)
1	0.22
2	0.22
3	0.32
4	0.35
5	0.36
6	0.41
8	0.67
10	0.80
12	0.99
15	1.13
20	1.57
25	1.74
30	1.94
40	2.19
60	2.57
80	3.12
100	3.24
120	3.52
150	3.74
200	4.37
305	4.79
400	5.33
670	5.89
1015	6.54
1187	6.83

Table 5A-8. Time Drawdown Data for Observation Well MMC-IRI-5 During Upper Aquifer Test.

TABLE 5A-9

Time-drawdown Data for Observation Well MMC-IRI-6 During Upper Aquifer Test

TIME (minutes)	MEASURED DRAWDOWN (feet)
1	0.03
2	0.10
3	0.20
4	0.29
5	0.43
6	0.52
8	0.71
10	0.91
12	1.11
15	1.34
20	1.67
25	1.93
32	2.29
40	2.63
50	2.96
60	3.23
80	3.67
100	4.06
120	4.32
150	4.69
195	5.17
290	5.47
415	6.14
690	6.98
1035	7.42
1180	7.58
1275	7.71

Table 5A-9. Time-Drawdown Data for Observation Well MMC-IRI-6 During Upper Aquifer Test.

TABLE 5A-10

Time-drawdown Data for Observation Well MMC-IRI-7 During Upper Aquifer Test

TIME (minutes)	MEASURED DRAWDOWN (feet)
1	0.3
2	0.95
3	1.54
4	1.75
5	1.90
6	2.25
8	2.48
10	2.55
12	3.00
15	3.30
20	3.65
25	3.96
30	4.30
40	4.63
50	4.90
60	5.17
70	5.58
100	5.93
120	6.22
150	6.58
205	7.05
303	7.53
395	7.78
675	8.48
1020	9.30
1185	9.30
1196	9.28

Table 5A-10. Time-Drawdown Data for Observation Well MMC-IRI-7 During Upper Aquifer Test.

TABLE 5A-11

Chemical analyses of water samples taken During Pump-out test of Upper aquifer

Sample	Date	Time Since Pumping Began	Field Temperature (°C)	Dissolved Oxygen (field) (mg/l)	Specific Conductance (field) (umhos/cm)	Total Dissolved Solids (mg/l)
UA-1	11-11-81	2.5 hrs.	14.5	8.9	830	550
UA-2	11-12-81	21.0 hrs.	15.5	8.9	870	560

Sample	pH (field)	Total Alkalinity (mg/l as CaCO3)	Tootal Suspended Solids (mg/l)	Fluoride (mg/l)	Sulfide as H2S (mg/l)	Boron (mg/l)
UA-1	8.6	485	24.0	1.40	<1	0.1
UA-2	8.6	538	0.10	3.04	<1	0.2

Sample	Chloride (mg/1)	Sulfate (mg/1)	Aluminum (mg/1)	Chromium (mg/1)	Copper (mg/1)	Iron (mg/1)
UA-1	40.1	200	<0.1	<0.05	<0.01	<1
UA-2	55.8	195	<0.1	<0.05	<0.01	<1

Sample	Lead (mg/1)	Manganese (mg/1)	Mercury (mg/1)	Molybdenum (mg/1)	Nickel (mg/1)	Phenols (mg/1)
UA-1	<0.1	<0.01	<0.1	<0.1	<0.1	<0.05
UA-2	<0.1	<0.01	<0.1	<0.1	<0.1	<0.05

Sample	Selenium (mg/l)	Silver (mg/l)	Thallium (mg/l)	Uranium (mg/l)	Zinc (mg/l)	Ammonia (mg/l)
UA-1	<0.5	<0.05	<0.1	<1	<0.05	0.10
UA-2	<0.5	<0.05	<0.1	<1	<0.05	0.47

Sample	Nitrite (mg/l)	Nitrate (mg/l)	Arsenic (mg/l)	Barium (mg/l)	Beryllium (mg/l)	Cadium (mg/l)
UA-1	0.03	<0.01	<0.5	<0.05	<0.01	<0.05
UA-2	0.04	<0.01	<0.5	<0.05	<0.01	<0.05

Sample	Antimony (mg/l)	Free Cyanide (mg/l)	Total Cyanide (mg/l)	Sodium (mg/l)	Chemical Oxygen Demand (mg/l)	Calcium (mg/l)
UA-1	<0.01	<0.05	<0.05	180	<5	7.8
UA-2	<0.01	<0.05	<0.05	190	<5	7.0

Sample	Mangnesium (mg/l)	Strontium (mg/l)	Hardness (mg/l)	Gross Alpha (pCi/l)	Gross Beta (pCi/l)	Radium 226 (pCi/l)
UA-1	6.8	5.9	66.8	0.0±2.8	6.8±5.9	0.6±0.3
UA-2	5.9	5.7	41.7	4.9±2.3	0.0±4.3	0.3±0.3

Sample	Randium 228 (pCi/1)	Fecal Coliform
UA-1	0.5±1.4	<1
UA-2	0.0±5.2	10

Table 5A-11. Chemical Analysis of Water Samples Taken During Pump-Out Test of Upper Aquifer.

TABLE 5A-12

Chemical analyses of water samples taken during pump-out test of Lcmer aquifer.

Sample	Date	Time Since Pumping Bega	Field Temperatur (°C)	Dissolved Oxygen (fiel (mg/l)	Apecific Conductanc (field) (umhos/cm	Total Dissolved Solids (mg/	pH	Total Alkalinity (mg/l as CaCO3)
LA-1	7-9-81	40 min.	14.3	-	1700	920	8.2	820
LA-lA	7-14-81	3 hr. 25 min.	16.0	-	1680	980	8.3	780
LA-2A	7-15-81	24 hr. 30 min.	18.0	-	1800	1020	8.3	760
LA-3A	7-16-81	47 hr. 3 min.	18.0	-	1800	1030	8.4	770
LA-4A	7-17-81	70 hr. 30 min.	19.0	0.9	1900	1040	8.4	780
LA-5A	7-18-81	95 hr. 8 min.	18.5	0.75	1800	1040	8.3	785
LA-6A	7-19-81	124 hr. 50 min.	18.5	8.3	1850	1030	8.2	780
LA-7A	7-20-81	142 hr.	20.0	1.6	1900	1030	8.1	800
LA-8A	7-21-81	166 hr. 40 min.	18.3	1.4	1900	1040	8.1	800

Table 5A-12. Chemical Analysis of Water Samples Taken During Pump-Out Test of Lower Aquifer.

TABLE 5A-12
continued

Chemical analyses of water samples taken during
Pump-out test of Lower aquifer (continued).

Sample	Total Suspended Solids (mg/	Fluoride (mg/l)	Sulfide as H (mg/l)	Boron (mg/l)	Chloride (mg/l)	Sulfate (mg/l)	Aluminum (mg/l)	Chromium (mg/l)
LA-1	490	20.9	<1	0.55	67	17	2	<0.05
LS-1A	120	21.0	<1	0.60	108	7	<0.1	<0.05
LA-2A	2	17.5	<1	0.60	174	4	<0.1	<0.05
LA-3A	<1	21.7	<1	0.45	149	3	<0.1	<0.05
LA-4A	<1	21.7	<1	0.60	179	1	<0.1	<0.05
LA-5A	1	17.3	<1	0.60	192	2	<0.1	<0.05
LA-6A	<1	21.7	<1	0.63	189	<1	<0.1	<0.05
LA-7A	<1	22.4	<1	0.60	196	<1	<0.1	<0.05
LA-8A	<1	21.8	<1	0.60	188	<1	<0.1	<0.05

Table 5A-12. Chemical Analysis of Water Samples Taken During Pump-Out Test of Lower Aquifer (Continued)..

TABLE 5A-12
continued

Chemical analyses of water samples taken during
pump-out test of Lower aquifer (continued).

Sample	Copper (mg/l)	Iron (mg/l)	Lead (mg/l)	Manganese (mg/l)	Mercury (mg/l)	Nickel (mg/l)	Selenium (mg/l)	Silver (mg/l)
LA-1	<0.01	<2	<0.1	0.05	<0.1	<0.1	<0.5	<0.05
LA-1A	<0.01	<2	<0.1	0.02	<0.1	<0.1	<0.5	<0.05
LA-2A	<0.01	<2	<0.1	<0.01	<0.1	<0.1	<0.5	<0.05
LA-3A	<0.01	<2	<0.1	<0.01	<0.1	<0.1	<0.5	<0.05
LA-4A	<0.01	<2	<0.1	<0.01	<0.1	<0.1	<0.5	<0.05
LA-5A	<0.01	<2	<0.1	<0.01	<0.1	<0.1	<0.5	<0.05
LA-6A	<0.01	<2	<0.1	<0.01	<0.1	<0.1	<0.5	<0.05
LA-7A	<0.01	<2	<0.1	<0.01	<0.1	<0.1	<0.5	<0.05
LA-8A	<0.01	<2	<0.1	<0.01	<0.1	<0.1	<0.5	<0.05

Table 5A-12. Chemical Analysis of Water Samples Taken During Pump-Out Test of Lower Aquifer (Continued).

TABLE 5A-12
(continued)

Chemical analyses of water samples taken during pump-out test of Lower aquifer (continued).

Sample	Zinc (mg/l)	Arseni (mg/l	Bariur (mg/l	Cadmiu (mg/l	Sodiur (mg/l	Calciu (mg/l	Magnes m (mg	Strontiu (mg/l	Hardne (mg/l)
LA-1	<0.05	<0.5	0.30	<0.05	410	5.2	3.1	0.80	28
LA-1A	<0.05	<0.5	0.30	<0.05	410	3.6	2.3	0.80	19
LA-2A	<0.05	<0.5	0.40	<0.05	440	2.9	2.0	0.80	16
LA-3A	<0.05	<0.5	0.45	<0.05	430	3.0	2.2	0.85	18
LA-4A	<0.05	<0.5	0.45	<0.05	450	3.1	2.2	0.85	18
LA-5A	<0.05	<0.5	0.45	<0.05	440	3.0	2.2	0.85	18
LA-6A	<0.05	<0.5	0.45	<0.05	440	2.9	2.1	0.85	17
LA-7A	<0.05	<0.5	0.45	<0.05	450	3.0	2.1	0.85	17
LA-8A	<0.05	<0.5	0.45	<0.05	450	3.0	2.1	0.85	17

*Calculated using Ca, Mg, Sr, Fe, Al, Zn, Mn

Table 5A-12. Chemical Analysis of Water Samples Taken During Pump-Out Test of Lower Aquifer (Continued).

Close inspection of Figures 4, 6 and 9 (Plate 5A-1) show that late in the test, observation wells MMC-IRI-5, -6 and -7 were beginning to show steady-state conditions. Steady-state (constant drawdown) occurs when the cone of depression expands to a point where a recharge boundary is encountered. A stable cone of depression develops when the rate of recharge becomes equal to the rate of pumping. Many types of recharge boundaries can bring about steady-state conditions including leakage from adjacent aquifers.

The likelihood of leakage across the Mahogany Zone from the Upper to the Lower aquifer has been discussed by Weeks and others (1974). Furthermore, leakage values obtained from Upper and Lower aquifer pumping tests conducted on Tract C-b have been reported (Ashland Oil Inc. and Shell Oil Co., 1976). A study of the geology at the Sodium Lease test site indicates that conditions necessary for leakage to occur through the Mahogany Zone are present. Extensive fracture data compiled by Weston and Daub (see Daub, 1984) indicates that fractures are prolific in both aquifer systems, and are also present throughout the Mahogany Zone aquitard. With the possibility of leakage in mind, the time-drawdown data from the Lower aquifer test were analyzed using the Hantush-Jacob (1955) method for leaky confined aquifers with no storage in the confining bed (see Lohman, 1972).

The time-drawdown data for the four observation wells MMC-IRI-4, -5, -6 and -7 were plotted on a full logarithmic scale (Figures 3, 5, 7 and 10, Plate 5A-1) and compared with the Theis type curve (non-leaky). As can be seen, data from well MMC-IRI-4 follows the type curve closely, but the data from the other three wells deviates below the type curve late in the test. The data plots showing the deviations from the non-leaky (Theis) curve were superimposed on type curves developed for leaky aquifers (Lohman, 1972). No difficulty was encountered in matching the time-drawdown curves with appropriate leaky-aquifer curves. Figures 5, 7 and 10 (Plate 5A-1) show the traces of both the Theis non-leaky type curve (solid) and the appropriate leaky curve (dashed).

Calculations were then made for transmissivity, storativity, leakage and vertical hydraulic conductivity of the Mahogany Zone. The values of these parameters are summarized on Table 5A-1. As expected, the values of transmissivity and storage coefficients agree well with the Jacob's approximation. The difference between the two approaches is that leakage and vertical hydraulic conductivity of the Mahogany Zone can be determined with the Hantush-Jacob method. From this analysis, leakage appears to be on the order of 10^{-6} to 10^{-5} day^{-1}. These values agree well with leakage calculated from pump test data collected on Tract C-b, which ranged on the order of 10^{-7} to 10^{-5} day^{-1} (Ashland Oil Inc. and Shell Oil Co., 1976). The leakage values were multiplied by the average thickness for the Mahogany Zone at the test site (171 feet) to determine the vertical hydraulic conductivity of the Mahogany Zone. Hydraulic conductivity of the Mahogany Zone at the test site is on the order of 10^{-4} to 10^{-3} feet per day. As a comparison, vertical hydraulic conductivities of thin, rich oil-shale zones were determined by small scale pump tests performed on Tract C-b and ranged on the order of 10^{-6} to 10^{-3} feet per day (Ashland Oil Inc. and Shell Oil Co., 1976).

The calculated permeabilities of the Mahogany Zone are small as expected, but do indicate that water can move through the system with sufficient hydraulic head. At the test site, the potentiometric surface of the upper aquifer is about 10-15 feet higher than the potentiometric surface of the Lower aquifer. Any exchange of water, under natural conditions, between the two aquifers would be downward from the Upper to the Lower aquifer. During pump testing, water levels in the Upper aquifer did not change; however, this does not preclude leakage from occurring. In fact, one of the assumptions inherent in the mathematical analysis is that the head in the aquifer supplying leakage is constant. Obviously, this assumption may not always be met when the aquifer supplying leakage is artesian, but if the transmissivity of the supplying aquifer is reasonably large and leakage is quite low, little if any change in head in the supplying aquifer would be noted.

The cone of depression created during Lower aquifer testing has an elliptical shape trending in a northwest-southeast direction (Figure 5A-4). This trend is based on measured drawdowns in all of the wells at 10,000 minutes. Similar trends have been reported during Lower aquifer testing done on Tracts C-a and C-b (Gulf Oil Corp. and Standard Oil Co., 1977; Ashland Oil Inc. and Shell Oil Co., 1976), and is thought to be a manifestation of major fracture orientations in the Basin (Taylor, 1982, p. 7 & 8). A detailed mathematical analysis for aquifer anisotropy (Papadopulos, 1965) was performed, but meaningful results were not obtained. It is thought that the well field geometry does not meet the requirements for mathematical analysis.

UPPER AQUIFER TEST

The Upper aquifer was tested by USGS personnel in November of 1981. The test was run for approximately one day (1,200 minutes), and the discharge was held constant at 60 gallons per minute. Both Upper and Lower aquifer piezometers were monitored throughout the test. Time-drawdown data for each of the observation wells are located in Tables 5A-7, -8, -9 and -10.

The data were plotted on a full logarithmic scale (Figures 2, 4, 6 and 8, Plate 5A-2) and analyzed by the Jacob's straight-line method and the Theis curve matching method. The transmissivity and storativities thus computed are summarized on Table 5A-2.

Inspection of the data curves indicates that geohydrologic boundaries were not encountered during this test. This is, no doubt, due to the fact that the test was not run long enough. A leaky aquifer analysis, therefore, could not be performed for the Upper aquifer.

The cone of depression created during Upper aquifer testing is, like the Lower aquifer cone, elliptical in shape but trends in a northeast-southwest direction (Figure 5A-5). A similar finding was reported during Upper aquifer testing on Tract C-b (Ashland Oil Inc. and Shell Oil Co., 1976). A study of photolineations on the Sodium Lease indicated a major northeast trend of surface fractures (Figure 5A-6). It is postulated that this fracture trend is influencing the Upper aquifer cone of depression at the test site. It is of further interest to note that the major northeast fracture trend shown on Figure 5A-6 is almost orthogonal to the major northwest fracture trend discussed by Taylor (1982, p. 7 & 8).

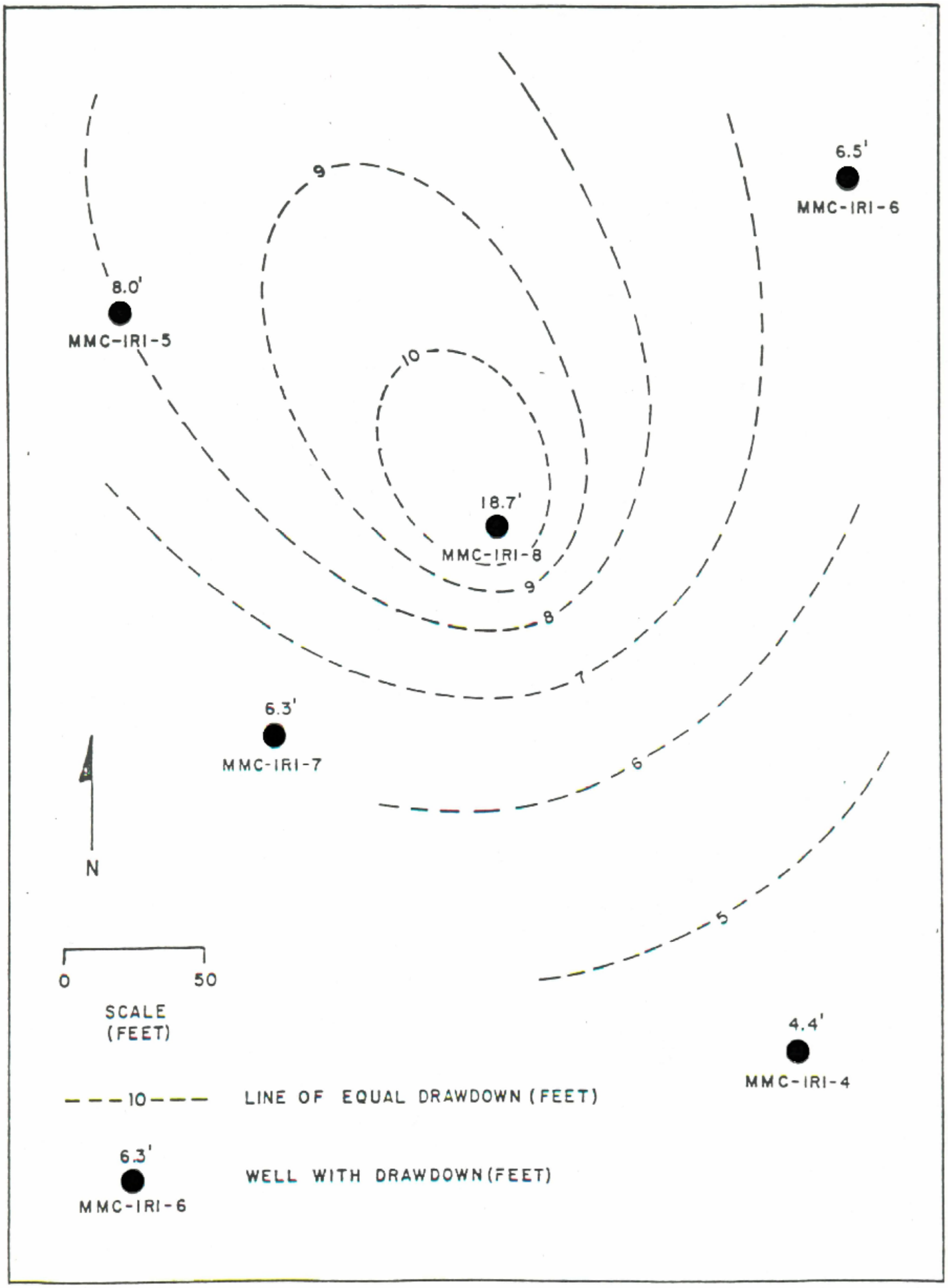

Figure 5A-4. Lower Aquifer Cone of Depression at 10,000 min.

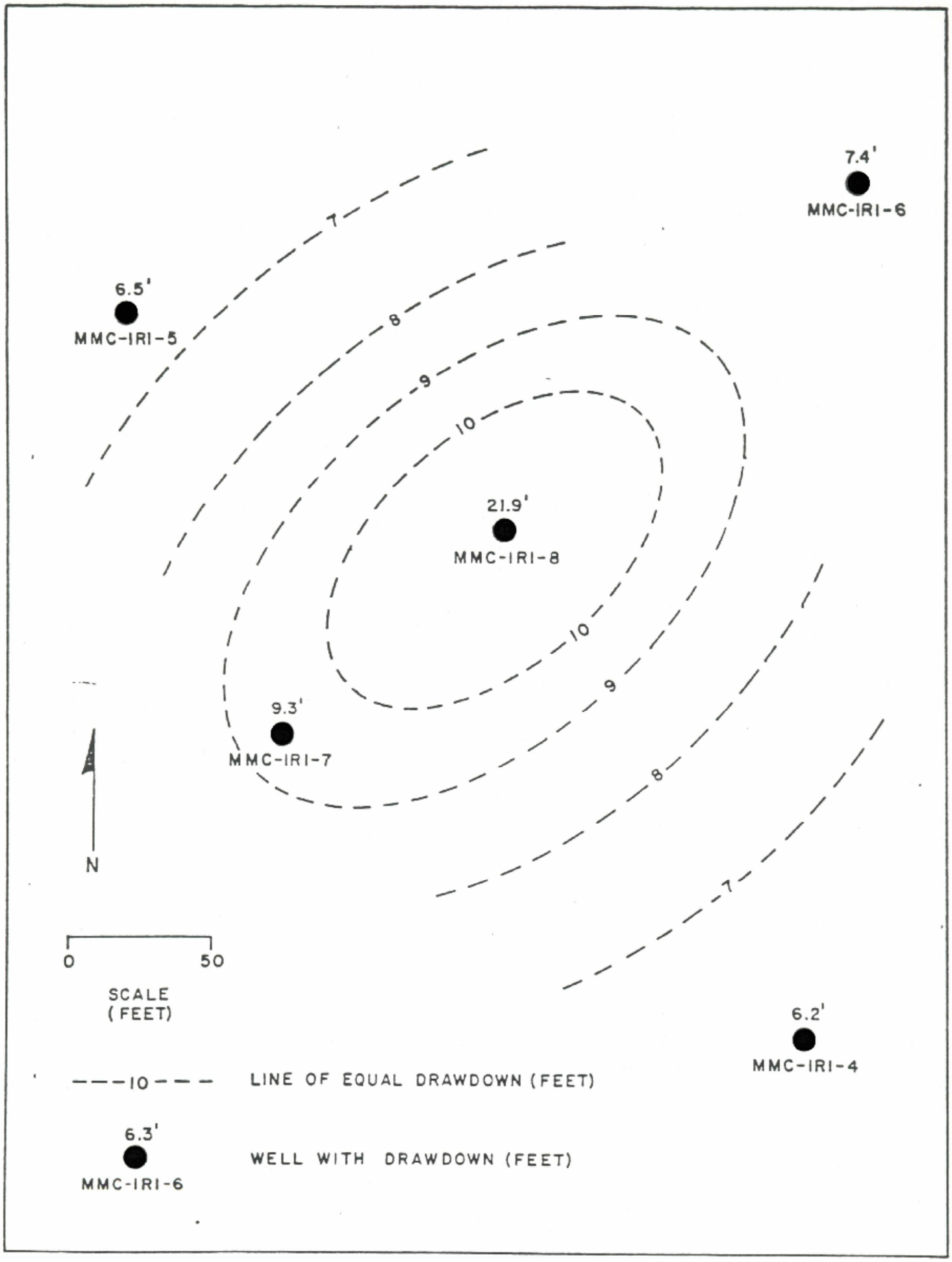

Figure 5A-5. Upper Aquifer Cone of Depression at 1,000 min.

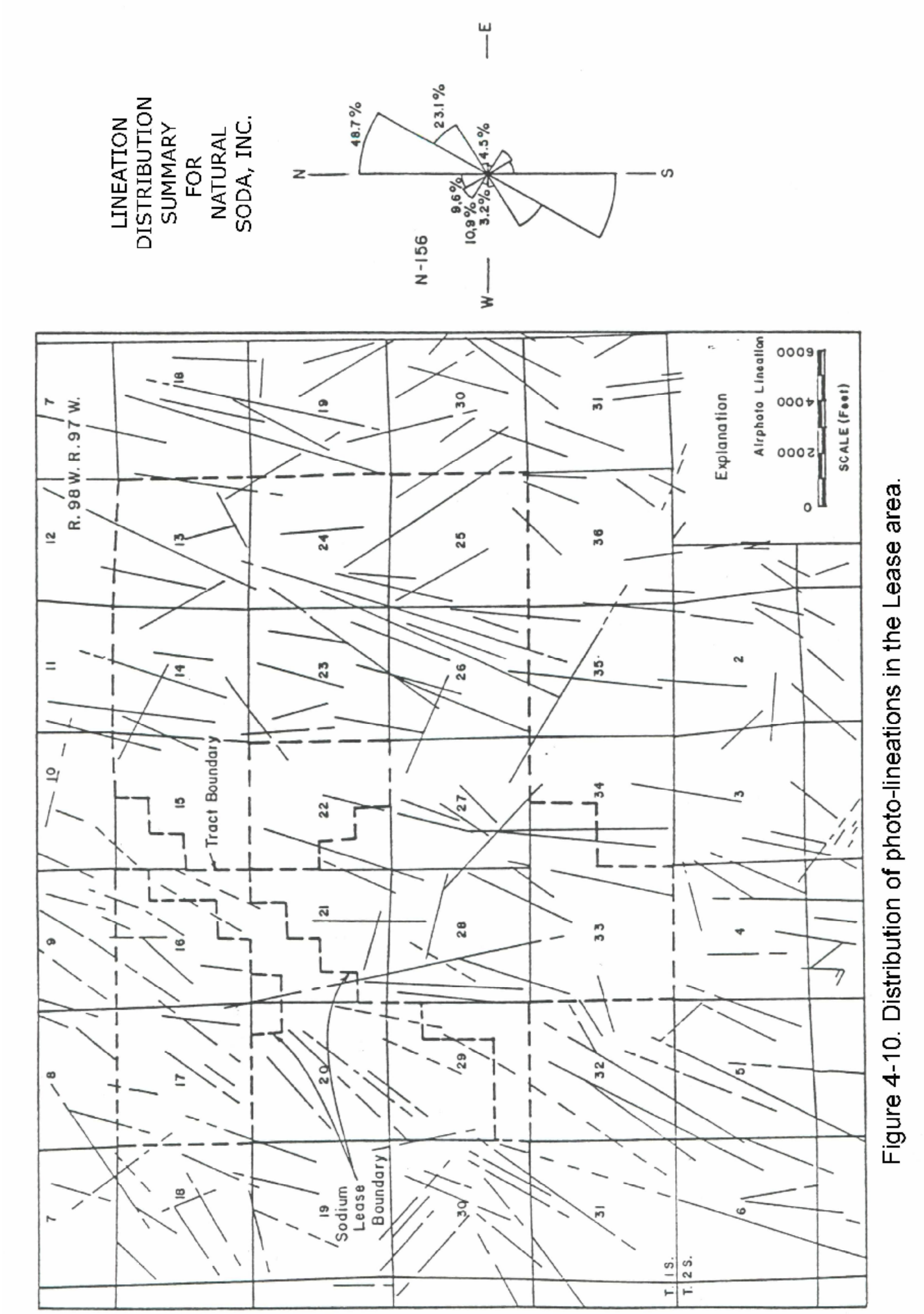

Figure 5A-6. Distribution of Photo-Lineations in the Lease Area.

CONCLUSIONS AND RECOMMENDATIONS

The time-drawdown data from the Lower aquifer test were analyzed by the Hantush-Jacob method for leaky artesian aquifers with no storage in the confining layer. The leaky aquifer analysis was instrumental in explaining the deviation of the data points towards steady-state conditions, and yielded values of leakage and vertical hydraulic conductivity of the semi-confining Mahogany Zone. The calculated vertical hydraulic conductivity of the Mahogany Zone is low, as expected, but does offer the potential for downward leakage of water from the Upper to the Lower aquifer system. The concept of the Mahogany Zone acting as a leaky confining layer between the Upper and Lower aquifer systems is supported in the literature and by other workers in the Piceance Creek Basin. The values of leakage and vertical hydraulic conductivity determined in this study agree well with other published values.

Detailed analyses of fracture data collected during core drilling activities on the Sodium Lease lend considerable geologic support to leaky aquifer conditions at the test site. The presence of fractures throughout both aquifer systems is pronounced. The Mahogany Zone is also fractured to the extent that leakage could take place to some degree.

Analysis of Upper aquifer test data yielded only values of transmissivity and storativity. The test was not run nearly long enough to encounter geohydrologic boundaries. Leaky aquifer analysis, therefore, did not apply. Transmissivity and. storativity obtained by the Theis type-curve analysis agree well with published values.

Transmissivity of the Upper aquifer at the test site is about twice that of the Lower aquifer. Storage coefficients of both aquifers indicate that they are both artesian aquifers.

Both aquifer tests show that directional variations in transmissivity (anisotropy) exist at the test site. This is inferred from the general shape of the cones of depression, but could not be verified through mathematical analysis. The geometry of the well field probably does not meet the requirements for mathematical analysis. The cone of depression developed during Lower aquifer testing trends northwest-southeast while that of the Upper aquifer trends northeast-southwest. Both cases can be explained by major fracture trends in the basin.

REFERENCES CITED

Ashland Oil Inc., and Shell Oil Co., 1976. Detailed Development Plan Report, Tract C-b (submitted to Area Oil-Shale Office, USGS, Grand Junction, Colorado).

Cole, Rex D., 1983. Geologic Framework of Federal Sodium Lease C-0118326, Piceance Creek Basin, Colorado: Consultant's Report prepared for Industrial Resources, Inc., Lakewood, Colorado, 157p.

Cooper, H.H., Jr. and C.E. Jacob, 1946. A Generalized Graphical Method for Evaluating Formation Constants and Summarizing Well Field History: Transactions, American Geophysical Union, v. 27, p. 526-534.

Daub, G.J., 1984. Lithology and Rock Quality Data for Seven Core Holes on Federal Sodium Lease C-0118326, Piceance Creek Basin, Colorado: Consultants report prepared for Industrial Resources, Inc., Lakewood, Colorado by Daub and Associates, Grand Junction, Colorado.

Gulf Oil Corp. and Standard Oil Co. of Indiana, 1976. Rio Blanco Oil Shale Project Detailed Development Plan Report, Tract C-a (submitted to Area Oil Shale Office, USGS, Grand Junction, Colorado).

Hantush, M.S. and C.E. Jacob, 1955. Nonsteady Radial Flow in an Infinite Leaky Aquifer: Transactions, American Geophysical Union, v. 36, no. 1, p. 95-100.

Lohman, S.W., 1972. Groundwater Hydraulics: USGS Professional Paper 708, 70 p.

Multi Mineral Corporation, March 1982. Expression of Leasing Interest in Oil Shale in Piceance Creek Basin, Colorado.

Papadopulos, Istavros S., 1965. Nonsteady Flow to a Well in an Infinite Anisotropic Aquifer: International Association of Scientific Hydrology, Symposium of Dubrovnik, p. 21-31.

Taylor, O. James, 1982. Three-Dimensional Mathematical Model for Simulating the Hydrologic System in the Piceance Basin, Colorado: USGS Water Resources Investigations Open-File Report 82-637, 35 p.

Weeks, John B., George H. Leavesley, Frank A. Welder, and George J. Saulnier, Jr., 1974. Simulated Effects of Oil Shale Development on the Hydrology of Piceance Basin, Colorado: USGS Professional Paper 908, 83 p.

Weston, L.K., 1984. Hydrogeologic Reconnaissance of Federal Sodium Lease C-0118326, Piceance Creek Basin, Colorado: Consultant's Report Prepared for Industrial Resources, inc., Lakewood, Colorado, 64 p.

Plate 5A-1. Drawdown versus Time Plots for the Lower Aquifer.

Plate 5A-2. Drawdown versus Time Plots for the Upper Aquifer.