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CHARACTERIZATION OF OIL SHALE MINE WATERS
CENTRAL PICEANCE BASIN, COLORADO

by

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FORWARD

When energy and material resources are extracted, processed, converted and used, the related pollution impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory-Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report provides data characterizing oil shale mine waters from the central part of the Piceance Basin in western Colorado and assesses the effectivness of retention ponds to treat these waters. The results should assist developers and permit writers in selecting appropriate controls for the handling of excess mine waters.

David G. Stephan, Director
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ABSTRACT

A study was conducted to characterize the oil shale mine waters in the Piceance Basin. The study sites were Federal Prototype Lease Tracts C-a and C-b, located in the central portion of the basin. The objective was to collect water quality data in order to characterize the mine waters and to assess the effectiveness of treatment systems located at these facilities. These treatment systems involve in-series retention ponds. In addition, the effectiveness of a one-pond versus two-pond system was investigated.

The sources of the water routed through the retention ponds were water pumped from the on-site aquifers that were dewatered during mining activities and the water pumped directly from the underground mines. Water samples were taken from both the inflow and outflow points for both the Tract C-a and C-b pond systems and were analyzed for a fairly detailed suite of selected water quality constituents. This suite included total suspended solids (TSS) and total dissolved solids (TDS), pH, the major species of cations and anions, and dissolved trace elements such as selenium, lead, and arsenic. The inflow samples were then compared to the outflow samples to determine changes in water quality and, therefore, the effectiveness of the retention ponds. An additional part to this study was an assessment of the effectiveness of using a flocculent and sulfuric acid for the treatment of excess waters encountered during active mining on Tract C-b. The flocculent was added to reduce the suspended solids concentrations during periods of active mining and the acid was used to reduce the somewhat high pH values.

The water quality changes observed during this study, when comparing the inflow waters to the outflow waters of the respective pond systems, were found to be generally small. Fluccuations in some constituents may have been due to such phenomena as pH changes, aeration, evaporation, and oxidation-reduction changes associated with the transformation of the groundwater from an underground (aquifer) environment to a surface (retention pond) environment. The retention time, as well as inherent laboratory technique variations, may also help explain the small fluctuations.

The overall conclusion with respect to the effectiveness of the retention pond systems in maintaining or improving water quality is that they appear to make negligible difference unless chemicals are added . The addition of the flocculent in the Tract C-b pond system during periods of active mining was very effective in reducing the suspended sediment concentrations. In addition, the sulfuric acid treatment reduced the pH at Tract C-b. Concerning the general water quality, such as the trace elements, cations and anions, and other pertinent constituents, there was not a significant increase or decrease due to the chemical additives. In addition, the effectiveness of the one-pond and two-pond systems are very similar upon comparison.

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CHAPTER 1

INTRODUCTION AND BACKGROUND

PURPOSE AND OBJECTIVE OF STUDY

The objective of this study was to provide a detailed characterization of the mine water and assess the treatment systems used on Federal Prototype Lease Tracts C-a and C-b, located in the Piceance Basin, Colorado. These data were collected to assist other oil shale developers and permit writers in selecting appropriate controls for the handling of excess mine waters. The treatment facilities at both sites consisted of two in-series retention ponds. To characterize these facilities, samples were collected for determining the quality of water derived from mine pumpage and aquifer dewatering activities previous to treatment, as well as the treated water derived from the outflow of the in-series retention ponds. Presently, the treated water is disposed of by reinjection into the groundwater system, utilized for on-site activities, or discharged to surface water systems. The data collection procedures, results, and quality assurance programs are discussed in Chapters 2, 3, and 4, respectively.

LOCATION AND DESCRIPTION OF STUDY AREA

Lease Tracts C-a and C-b are located in the Piceance Basin of Rio Blanco County, Colorado (Figure 1). The climate of the Piceance Basin is considered to be semiarid montane. The average annual precipitation in the central portion of the basin is generally on the order of 12 inches, most of which occurs as snowfall. High summer temperatures coupled with low humidity create a high evaporation rate.

The Piceance Basin is drained by two perennial streams, Yellow Creek and Piceance Creek, both of which are tributary to the White River. The White River flows into the Green River, which is a tributary to the Colorado River. The base flow of Yellow and Piceance Creeks is provided by numerous springs throughout the basin.

The regional stratigraphy of the basin is comprised of the following Eocene units, in ascending order: Wasatch Formation, Green River Formation, and the Uinta Formation. In addition, the Green River Formation is comprised of the following members, in ascending order: Douglas Creek, Garden Gulch, Anvil Points, and Parachute Creek. The oil shale to be mined is located in the Mahogany Zone of the Parachute Creek member. A generalized geologic cross-section through the Piceance Basin is shown in Figure 2.

The area contains two important bedrock aquifer systems: the Upper Aquifer and the Lower Aquifer. The Lower Aquifer occurs in the Parachute Creek Member below the Mahogany Zone. The Upper Aquifer is located in the upper Parachute Creek Member

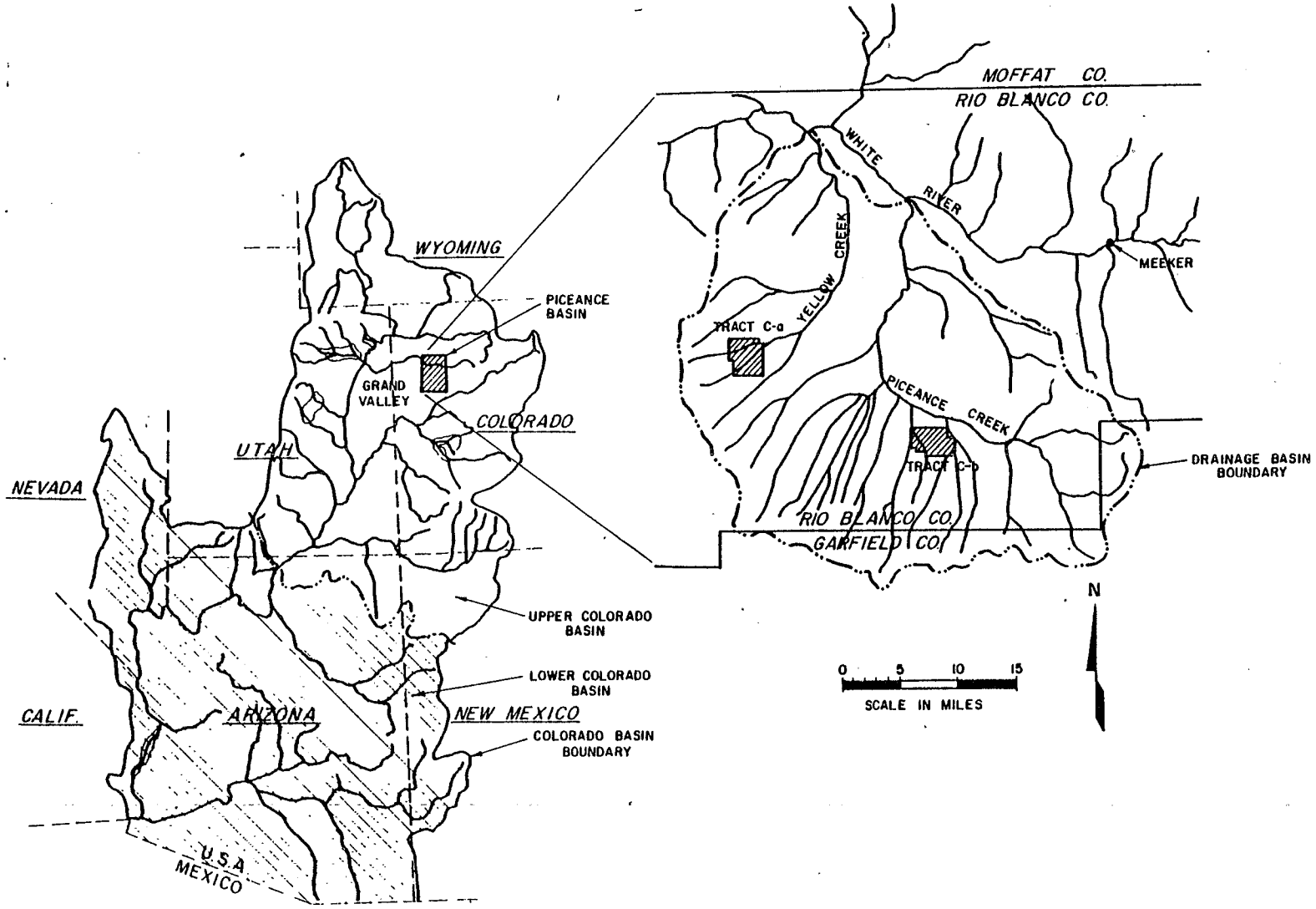

Figure 1: Location of Tracts C-a and C-b Study Area in Piceance Basin (Slawson, 1980)

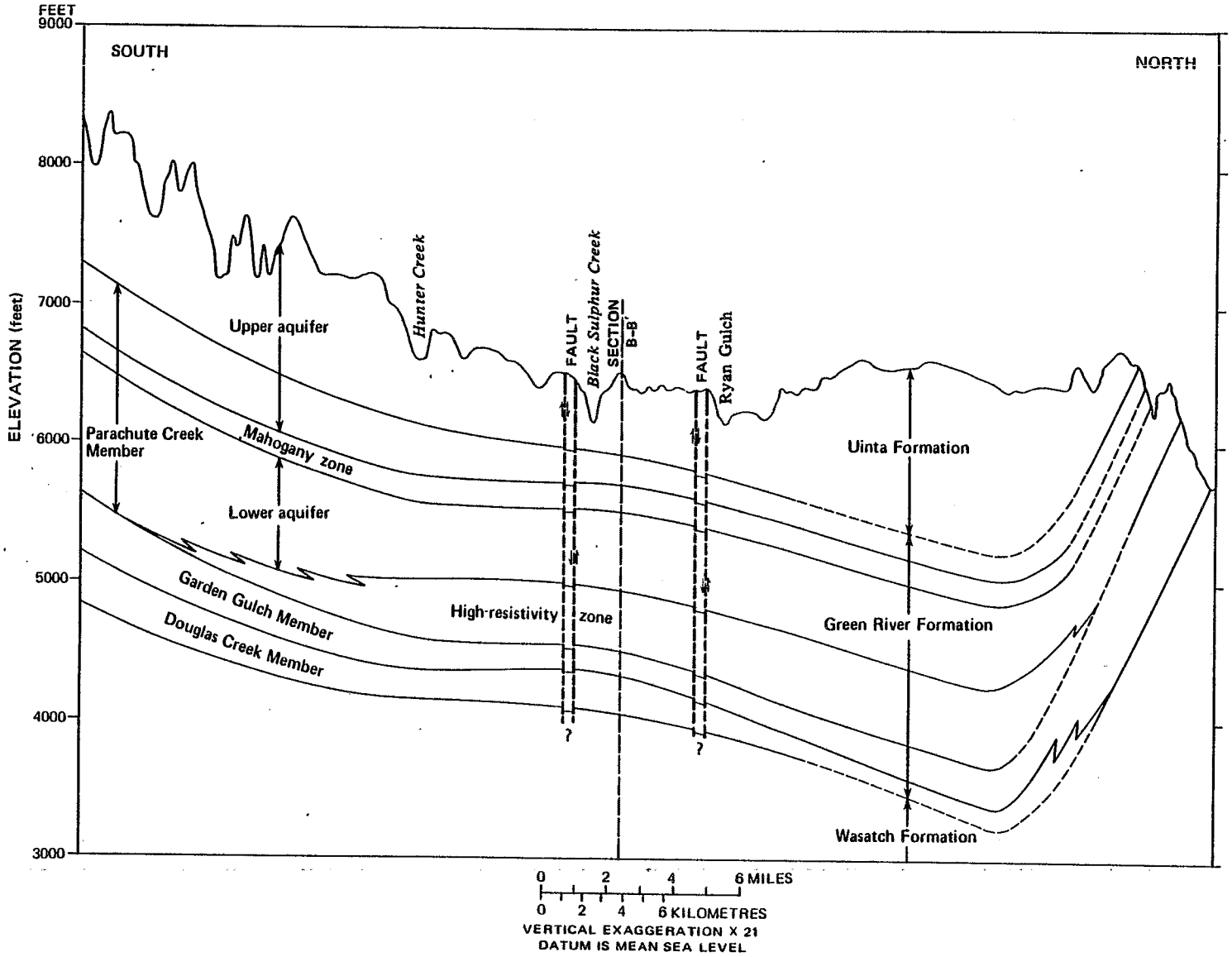

Figure 2: Geologic Cross-Section Through the Piceance Basin Along a North-South Line Between Tracts C-a and C-b (Weeks, et.al., 1974).

and the Uinta Formation above the Mahogany Zone. The Mahogany Zone acts as a leaky aquitard between the Upper and Lower Aquifers.

Recharge for the Upper Aquifer dominately occurs along the rim of the Piceance Basin where the Green River Formation outcrops, although downward infiltration of snow melt probably also contributes. The downward potential difference between the Upper Aquifer and Lower Aquifer indicates that most of the recharge for the Lower Aquifer occurs as leakage through the Mahogany Zone from the Upper Aquifer. The water in both aquifers flows toward the center of the basin and, in some locations, discharges into Piceance and Yellow Creeks.

In regard to water use within the Piceance Basin, there is no extensive use of water from the bedrock aquifers beneath Tracts C-a and C-b. This is probably due to groundwater quality and depth considerations, as well as the availability of surface water sources. In addition, there is rather limited agricultural, livestock, industrial, and municipal development in the area.

The agricultural development which does occur within the basin consists of 5100 acres of irrigated hay and pastureland. The irrigation water for these activities is derived dominately from the Piceance Creek watershed during the months of April and May. In addition to the irrigated acreage in the Piceance Creek watershed, approximately 200 acres of irrigated land are present in the Yellow Creek watershed. This land is irrigated with water derived from Yellow Creek.

The existing water quality within the basin will be discussed separately as Upper Aquifer, Lower Aquifer, and surface water. The major source of baseline water quality data are the Tract C-a and C-b operators due to the environmental monitoring requirements associated with the Federal leases. Additional sources of baseline data, particularly for surface water, includes the Bureau of Land Management (B.L.M.) and the U.S. Geological Survey (U.S.G.S.).

Lower Aquifer

The total dissolved solids (TDS) content for Lower Aquifer water ranges from about 500 milligrams per liter (mg/l) to nearly 40,000 mg/l (Figure 3), with the average 9400 mg/l. Using the classification developed by Robinove, et al. (1958), this water is classified as moderately saline, although it can be briney in some locations. Obviously, these high salinity values render the Lower Aquifer unsuitable for many uses in many locations throughout the basin.

The water is of fairly pure sodium-bicarbonate type, with chloride as the only other major ion. Calcium and magnesium are very low, partly because of the minerals dissolved are sodium salts, dominatly nacholite. Chloride is significant because of

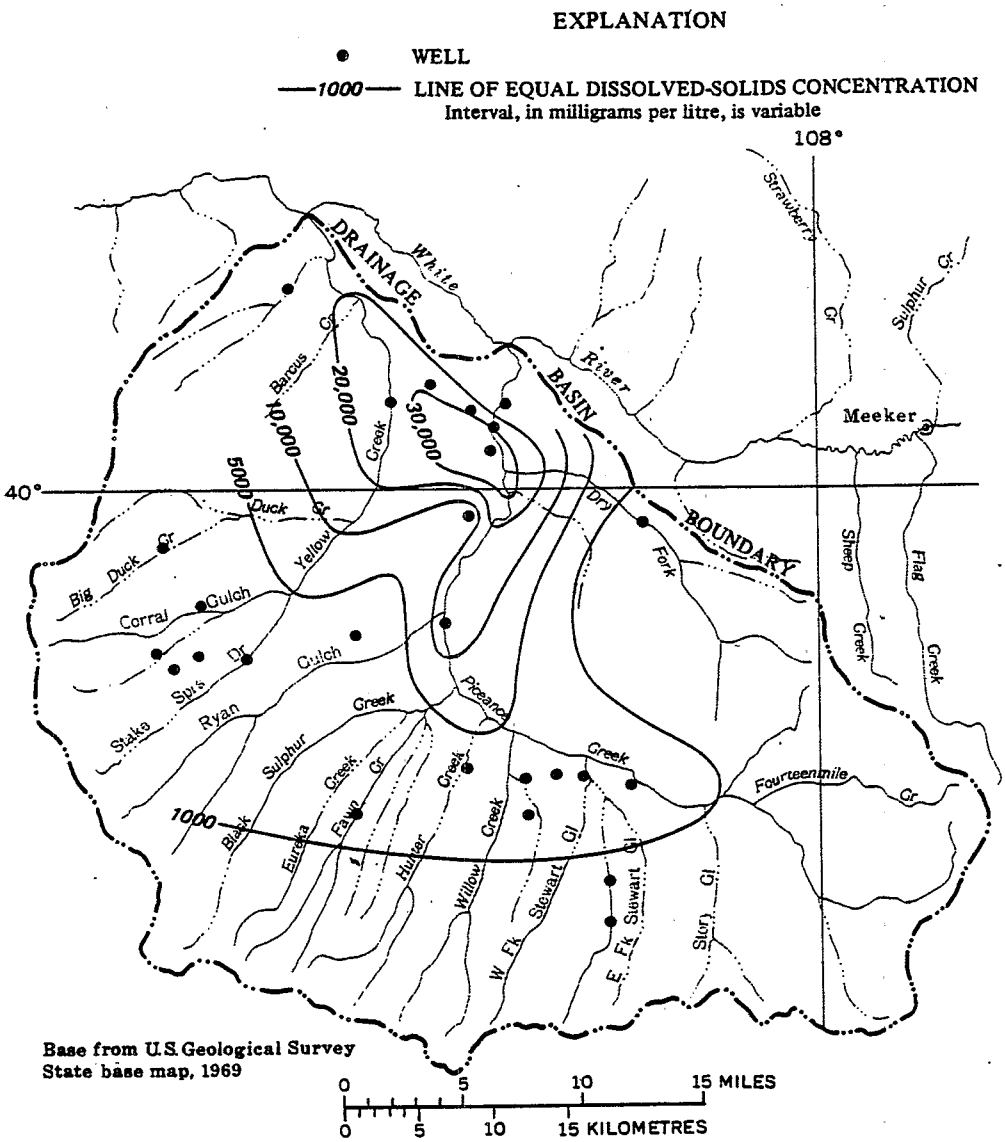

Figure 3. Concentration of dissolved solids in the Lower Aquifer, May-September 1973 (Weeks et al., 1974).

the presence of significant quantities of halite in the aquifer. Trace elements in the aquifer which can attain rather high concentrations include barium, boron, fluoride, and lithium. For instance, even in regions of lower salinity, the fluoride content is over 10 mg/l, with extremes as high as 60 mg/l common. In the high-salinity region, barium concentrations of 13 mg/l, boron concentrations of 120 mg/l, and lithium concentrations of 6 mg/l have been measure. Baseline water quality values for an extensive suite of constituents measured for samples collected from the Lower Aquifer on Tracts C-a and C-b are shown in Tables 1 and 2, respectively. This data has been tabulated to show the minimum, maximum, and mean, as well as the standard deviation for the period of collection. In addition, Figures 4 and 5 are trilinear diagrams for the Upper Aquifer and Lower Aquifer baseline data on Tract C-a and C-b, respectively. These diagrams provide a useful means for characterizing the groundwater quality data.

Upper Aquifer

The Upper Aquifer water quality does not exhibit the extreme salinities or trace element concentrations of the Lower Aquifer. The water quality for the Upper Aquifer in the basin does show an increase in total dissolved solids from 350 mg/l near the recharge areas to over 2000 mg/l in the basin center (Figure 6). However, this increase in TDS is not accompanied by high trace element concentrations. The water is of a similar type to that of the Lower Aquifer, with a sodium-bicarbonate character and moderately chloride. However, unlike the Lower Aquifer, fluoride and other trace elements have very low concentrations. Baseline water quality data for the Upper Aquifer collected on Tracts C-a and C-b are shown in Tables 1 and 3, respectively. This data has been tabulated to show the minimum, maximum, mean, and standard deviation for the period of collection.

Surface Water

As previously mentioned, Yellow and Piceance Creeks are the primary surface waters in Piceance Basin. The location of Tracts C-a and C-b in relation to these creeks are shown in Figure 1. Baseline water quality data for four U.S.G.S. stations located along Piceance Creek and a tributary to Yellow Creek are presented in Table 4. These data represent the October, 1974 to September, 1975, water year. The description of the U.S.G.S. stations are as follows:

U.S.G.S. STATION	LOCATION
09306007	Piceance Creek below Rio Blanco, Colorado; in SE1/4, SE1/4, Sec. 32, T2S, R96W, above Tract C-b.
09306061	Piceance Creek above Hunter Creek, in SE1/4, NE1/2,

TABLE 1: LOWER AND UPPER AQUIFER BASELINE WATER QUALITY DATA ON TRACT C-a (RBOSC, 1977).

	Lower Aquifer					Upper Aquifer				
Constituent*	N	Mean	Max	Min	Standard Deviation	N	Mean	Max	Min	Standard Deviation
pH	58	7.1	10.2	6.0	.49	72	6.78	8.8	6.0	.30
Conductivity	66	1258	3600	520	356	72	1702	2610	460	138
Total Dissolved Solids	67	976	3360	369	293	72	1267	2790	620	86
Alkalinity	80	558	2540	194	324	66	654	2343	295	44.6
Calcium	68	28.2	98.0	4.1	17.4	72	83.5	260	4.9	30.0
Magnesium	68	38.2	130	2.1	15.4	72	59.3	155	3.5	13.6
Sodium	67	284	1320	86	133	72	301.8	1170	120	36.2
Bicarbonate	62	599	2980	170	267	72	744	2760	220	62.0
Carbonate	68	1.25	84	.01	3.05	72	.98	66	.01	3.4
Chloride	68	19.2	96	1.0	14.3	66	16.9	69	1.0	11.4
Nitrate	62	.47	2.0	.1	.40	72	.50	4.5	.1	.53
Sulfate	67	250	600	15	74.9	54	474	900	30	52.8
Fluoride	61	6.35	32	.05	6.02	72	3.0	30	.1	.40

(continued)

TABLE 1 (Continued)

Constituent	Lower Aquifer N	Lower Aquifer Mean	Lower Aquifer Max	Lower Aquifer Min	Lower Aquifer Standard Deviation	Upper Aquifer N	Upper Aquifer Mean	Upper Aquifer Max	Upper Aquifer Min	Upper Aquifer Standard Deviation
Ammonia	63	.35	2.0	.01	.27	60	.37	1.8	.1	.25
Phosphate	68	BDL (<.01)				72	BDL (<.01)			
Boron	68	1.21	20	.01	1.51	72	.75	4.8	.01	.47
Silica	68	10.8	32	.1	5.3	72	32.8	58	6	7.8
Iron	67	3.45	16.2	.05	2.97	72	6.3	18	.05	4.9
Dissolved Organic Carbon	52	11.8	37	3.0	7.21	55	10.2	35	1	5.6
Arsenic	67	BDL (<.01)				72	.01	.04	<.01	.01
Selenium	68	BDL (<.01)				72	BDL (<.01)			
Mercury	68	BDL (<.01)				72	BDL (<.03)			
Aluminum	13	BDL (<.01)				11	BDL (<.1)			
Barium	68	BDL (<1)				72	BDL (<1)			
Cadium	68	BDL (<.01)				72	BDL (<.01)			

BDL: Below detection limits, detection limit stated in parentheses.

(Continued)

TABLE 1 (Continued)

Constituent	Lower Aquifer					Upper Aquifer				
	N	Mean	Max	Min	Standard Deviation	N	Mean	Max	Min	Standard Deviation
Chromium	68	.01	.05	.01	.02	71	.01	.02	<.01 (BDL)	
Copper	67	.08	.2	.01	.04	72	.09	.78	<.01 (BDL)	.06
Lead	66	.60	4.6	.01	.55	72	.35	2.5	<.01 (BDL)	.30
Manganese	68	.1	.5	.01	.06	72	.17	.78	<.01 (BDL)	.11
Nickel	68	.02	.9	.00	.05	68	.02	.06	<.01 (BDL)	.01
Zinc	66	.46	5.5	.01	.50	68	.58	5.5	<.01 (BDL)	.72

BDL: Below detection limits, detection limits stated in parentheses.

* Mean, maximum, and minimum values are in milligrams per liter, with the following exceptions: conductivity (micromhos per centimeter); pH (pH units).

TABLE 2: LOWER AQUIFER BASELINE WATER QUALITY DATA COLLECTED ON TRACT C-b (C-b SHALE OIL VENTURE, 1977).

Constituent	Number of observations	CONCENTRATION[a] Min	Max	Mean	Standard deviation	Constituent	Number of observations	Min	Max	Mean	Standard deviation
Conductivity	49	630	45,000	7,240	11,800	Iodine	45	<0.001	3	0.3	0.7
pH	49	8.1	9.3	8.7	0.024	Iron	49	<0.05	8	0.8	1.8
Total dissolved solids	49	356	42,000	6,190	11,600	Lead	47	0.003	0.4	0.03	0.06
Gross alpha radiation	43	0	460	28	83	Lithium	47	1.3	79	10	23
Gross beta radiation	43	0	390	16	60	Magnesium	49	1.5	110	11	21
Total organic carbon	27	1	40	10	11	Manganese	48	0.002	0.6	0.1	0.09
Dissolved organic carbon	21	2	175	23	38	Mercury	44	<0.00003	0.0027	0.000	0.0007
Aluminum	45	0.002	2	0.3	0.4	Molybdenum	42	<0.004	0.2	0.04	0.04
Ammonia	48	0.1	200	17	42	Nickel	30	<0.001	0.06	0.01	0.01
Antimony	24	ND	0.08	---	---	Nitrate	49	<0.02	3.4	0.46	0.77
Arsenic	48	0.001	0.2	0.02	0.03	Phosphate	49	0.01	0.7	<0.9	0.10
Barium	47	0.02	8	0.8	1.7	Potassium	48	1	120	21	36

(continued)

TABLE 2 (Continued)

Constituent	Number of observations	Min	Max	Mean	Standard deviation	Constituent	Number of observations	Min	Max	Mean	Standard deviation
				CONCENTRATION[a]							
Beryllium	18	ND	0.002	---	---	Rubidium	47	0.005	0.9	0.07	0.2
Bicarbonate	49	100	25,000	4,000	6,700	Scandium	47	<0.001	0.01	0.004	0.003
Boron	44	6.05	400	36	100	Selenium	23	<0.001	0.01	0.004	0.004
Bromine	45	0.003	10	0.7	2.1	Silica dioxide	49	2	38	13	7
Cadmium	4	ND	0.1	---	---	Silver	9	ND	0.02	---	---
Calcium	49	2	220	14	34	Sodium	49	140	17,000	2,500	4,700
Carbonate	47	7	2,000	220	490	Strontium	49	0.1	10	1.3	2.1
Cesium	46	<0.001	4	0.2	0.8	Sulfate	49	2	350	63	92
Chloride	49	1	9,800	1,200	2,700	Thorium	1	ND	<0.001	---	---
Chromium	47	0.002	0.2	<0.009	0.004	Titanium	47	0.006	1	0.1	0.2
Cobalt	43	<0.001	0.03	0.006	0.007	Tungsten	13	ND	0.05	---	---
Copper	46	0.003	0.9	0.06	0.14	Uranium	10	ND	0.02	---	---
Fluoride	49	4	48	21	10	Vanadium	47	<0.001	0.1	0.01	0.02
Gallium	37	<0.001	0.06	0.007	0.01	Yttrium	19	<0.001	0.03	---	---
Germanium	15	ND	0.05	---	---	Zinc	45	0.005	4	0.2	0.6
Hydroxide	27	---	<0.1	---	---	Zirconium	36	<0.001	0.9	0.008	0.2

[a]Units are in milligrams per liter, with the following exceptions: conductivity (micromhos per centimeter); pH (ph units); radiation (picocuries liter); ND: not detected.

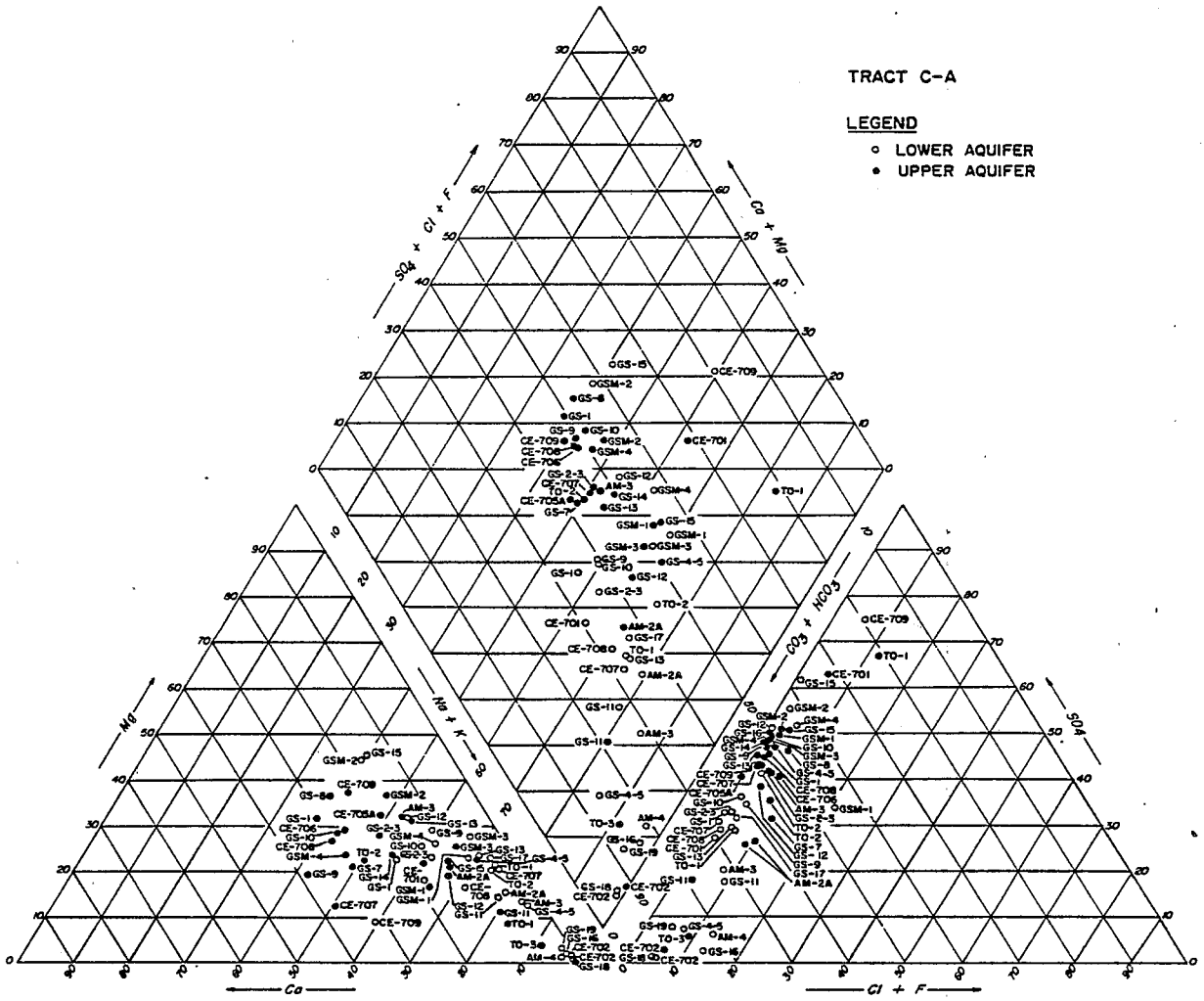

Figure 4. Trilinear diagram of water quality data for Upper and Lower Aquifers, Tract C-a (data from RBOSP, 1977).

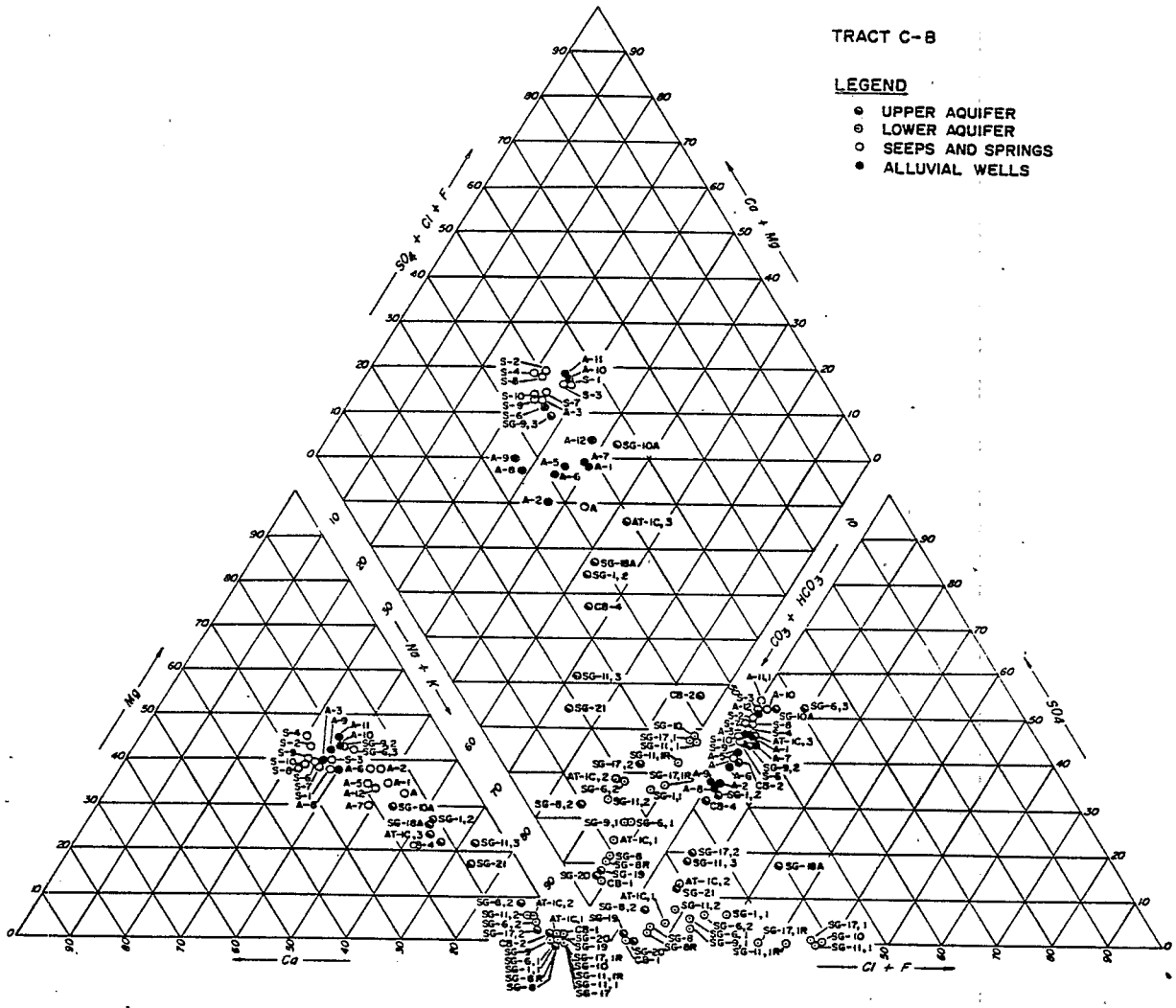

Figure 5. Trilinear diagram presenting groundwater quality data for Tract C-b (data from C-b Shale Oil Venture, 1977).

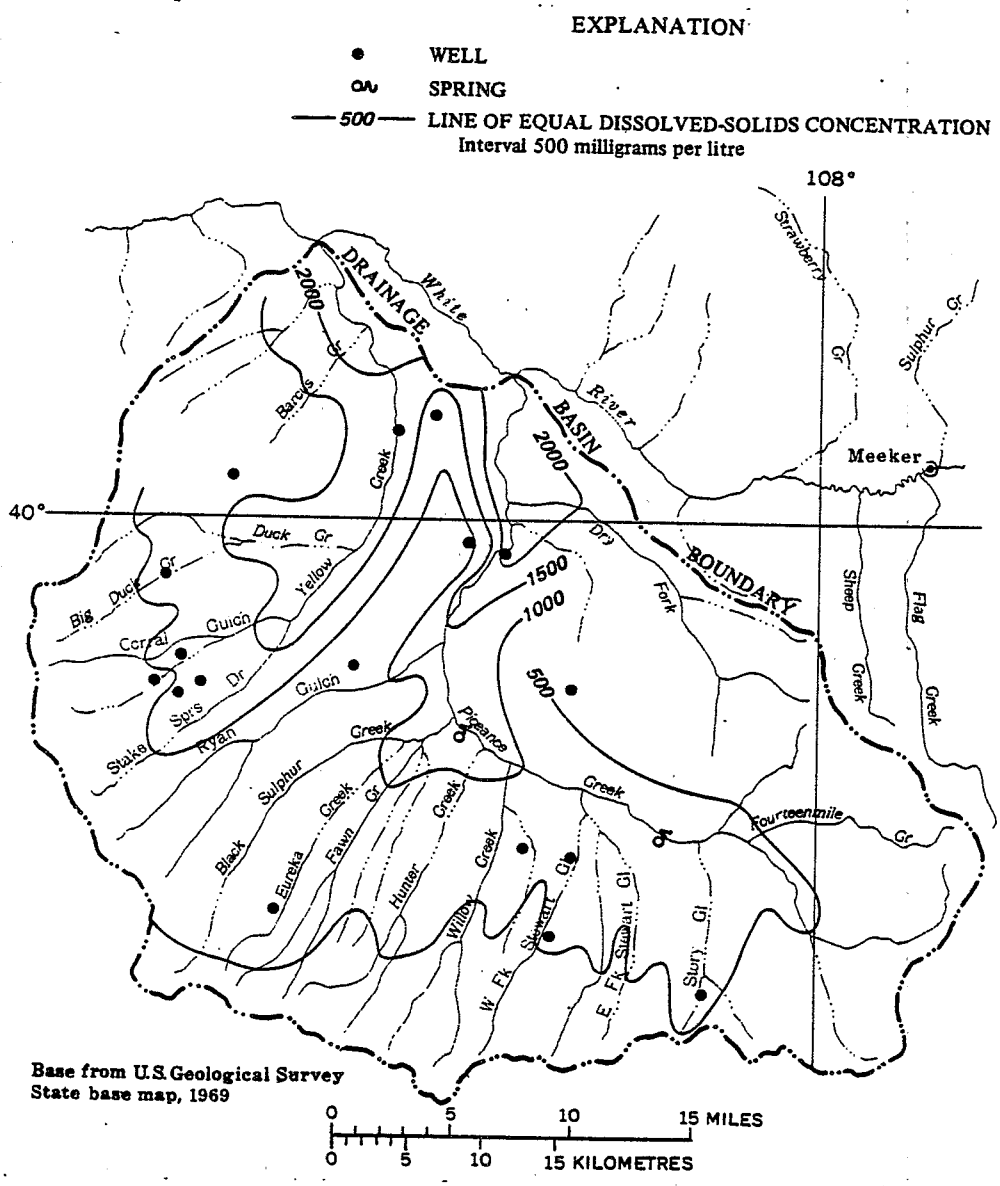

Figure 6. Concentration of dissolved solids in the Upper Aquifer, May-September 1973 (Weeks et al., 1974).

TABLE 3: UPPER AQUIFER BASELINE WATER QUALITY DATA COLLECTED ON TRACT C-b (C-b SHALE OIL VENTURE, 1977)

Constituent	Number of observa-tions	CONCENTRATION[a] Min	Max	Mean	Standard deviation	Constituent	Number of observa-vations	Min	Max	Mean	Standard deviation
Conductivity	52	800	4,200	1,670	700	Iodine	46	<0.001	0.08	0.006	0.01
pH	53	8.1	9.1	8.6	0.24	Iron	53	<0.02	7	0.5	1.2
Total dissolved solids	52	520	3,100	1,100	490	Lead	52	<0.002	0.07	0.01	0.01
Gross alpha radiation	49	0	21	6	5	Lithium	52	---	3.1	---	---
Gross beta radiation	49	0	33	3	8	Magnesium	53	2.2	150	42	40
Total organic carbon	34	1	9	3	2	Manganese	53	0.002	0.6	0.1	0.01
Dissolved organic carbon	---	---	---	---	---	Mercury	49	<0.00003	0.0031	0.0004	0.0008
Aluminum	48	0.003	4	0.3	0.7	Molybdenum	47	0.003	0.1	0.02	0.02
Ammonia	51	0.1	7.9	1.2	1.3	Nickel	50	<0.001	0.02	0.02	0.03
Antimony	11	ND	0.02	---	---	Nitrate	52	0.02	2.9	0.41	0.57
Arsenic	53	<0.001	0.06	0.01	0.01	Phosphate	51	<0.1	0.4	<0.09	0.06
Barium	51	0.009	0.6	0.1	0.1	Potassium	48	1	120	21	36

(continued)

TABLE 3 (Continued)

Constituent	Number of observations	Min	Max	Mean	Standard deviation	Constituent	Number of observations	Min	Max	Mean	Standard deviation
		CONCENTRATION[a]									
Beryllium	14	ND	0.003	---	---	Rubidium	50	<0.002	0.05	0.02	0.01
Bicarbonate	53	340	2,100	790	525	Scandium	51	<0.001	0.009	0.003	0.002
Boron	52	0.01	18	1.4	2.6	Selenium	33	<0.001	0.03	0.006	0.026
Bromine	52	0.003	0.2	0.03	0.04	Silica dioxide	53	4	32	17	6
Cadmium	9	ND	<0.02	---	---	Silver	12	ND	0.05	---	---
Calcium	53	3	120	32	28	Sodium	53	44	1,200	330	248
Carbonate	51	<1	76	21	18	Strontium	51	0.1	17	2.4	2.6
Cesium	40	0.001	0.2	0.01	0.03	Sulfate	53	4	520	220	170
Chloride	53	2	510	26	70	Thorium	4	ND	<0.001	---	---
Chromium	50	0.002	0.3	---	---	Titanium	52	0.003	2	0.1	0.3
Cobalt	43	<0.001	0.01	0.003	0.003	Tungsten	8	ND	0.03	---	---
Copper	52	0.003	3	0.09	0.4	Uranium	13	ND	0.03	---	---
Fluoride	53	0.1	190	10	26	Vanadium	51	<0.001	0.006	0.002	0.001
Gallium	33	<0.001	0.004	---	---	Yttrium	4	ND	0.01	---	---
Germanium	8	ND	0.002	---	---	Zinc	52	0.003	2	0.2	0.4
Hydroxide	33	---	<0.1	---	---	Zirconium	28	<0.001	0.03	0.006	0.009

[a]Units are in milligrams per liter, with the following exceptions: conductivity (micromhos per centimeter); pH (ph units); radiation (picocuries per liter); ND: not detected.

	Sec. 27, T2S, R97W, below Tract C-b.
09306235	Corral Gulch near Rangely, Colorado in SE1/4, NW1/4, Sec.5, T2S, R99W, a tributary to Yellow Creek above Tract C-a.
09306242	Corral Gulch near Rangely, Colorado in SE1/4, NW1/4, Sec. 25, T1S, R99W, a tributary to Yellow Creek below Tract C-a.

The total dissolved solids concentration for Yellow Creek in the area of Tract C-a ranges from 664 to 1140 mg/l, with an average of 735 mg/l upstream from Tract C-a and 851 mg/l downstream from Tract C-a. The major cations of the baseline water quality for Yellow Creek consist of sodium, calcium, and magnesium, whereas the major anion is bicarbonate. There are not any trace elements present which obtain appreciable values. In general, the water quality of Yellow Creek can be characterized as magnesium-calcium-sodium bicarbonate type, very similar to the type found in the Upper Aquifer, which provides base flow to Yellow Creek. In addition, the water quality of Yellow Creek degrades downstream, as indicated by the increase in total dissolved solids.

The baseline water quality for Piceance Creek is very similar to Yellow Creek. Total dissolved solids range in concentration from 502 to 1050 mg/l, with an average of 698 mg/l upstream from Tract C-b and an average of 893 mg/l downstream from Tract C-b. The major cations of Piceance Creek consist of sodium, calcium, and magnesium; whereas the dominant anion is bicarbonate. In regard to trace elements, none are very important. The water quality of Piceance Creek is also very similar to the Upper Aquifer water quality. In addition, there is a general degradation of water quality in a downstream direction, as indicated by the increase in total dissolved solids from an average of 698 mg/l to 893 mg/l.

OVERVIEW OF TRACT C-A AND C-B DEVELOPMENT ACTIVITIES

Kaman Tempo's sampling activities occurred between September, 1981 and March, 1983. The specific dates for each sampling effort were September, 1981; May, June, September, and November, 1982; and January and March, 1983. To better understand and interpret the analytical data, the activities of the operators for Tracts C-b and C-a will be discussed below.

Tract C-b

The principal activities associated with the development of Tract C-b during the sampling project were the continuation and

TABLE 4: SURFACE WATER BASELINE WATER QUALITY DATA FOR WATER YEAR 1975 (USGS, 1977)

	09306007				09306061				0906235				0930642			
Constituent[1]	N	Mean	Max	Min	N	Mean	Max	Min	N	Mean	Max	Min	N	Mean	Max	Min
Discharge (cfs)	26	12.6	84	2.1	22	16.2	35	4.0	13	.22	.49	.02	19	.81	3.1	.32
Silica	27	15	18	12	27	17.0	20	13	18	20.8	23	18	25	20.4	23	13
Iron	28	.07	.39	0	27	.04	.46	<.02	19	.04	.1	.01	25	.035	.14	.01
Manganese	27	.01	.23	.001	27	.06	.17	0	19	.006	.05	0	25	.023	.07	0
Calcium	28	68.9	79	54	27	78.7	87	59	19	83	93	68	25	82.3	92	55
Magnesium	28	46.2	56	34	27	65.9	82	56	19	55.8	67	50	25	62.0	71	52
Sodium	28	115.4	150	75	27	148	180	100	19	86	120	75	29	113	300	94
Potassium	28	3.7	19	2.4	27	3.7	5.0	1.2	19	1.3	1.6	.6	25	1.54	2.3	.8
Bicarbonate	28	523	602	390	27	572	678	517	19	394	513	355	25	527	901	426
Carbonate	28	1.5	32	0	27	1.5	39	0	19	0	0	0	25	0	0	0
Alkalinity	28	432	494	320	27	472	544	377	19	323	421	291	25	432	668	349
Sulfate	28	161	190	110	27	239	330	170	19	278	310	240	25	280	320	200
Chloride	28	15.5	24	9.0	27	13.5	16	11	19	7.7	9.5	5.9	25	10.2	15	8.1
Nitrate	20	.33	.83	.09	20	.39	.79	.08	13	.86	1.5	.27	20	.33	.68	.25
Fluoride	28	.98	1.3	.3	27	.6	.9	.5	19	.24	.3	0	25	.93	6.9	.3

(Continued)

TABLE 4 (Continued)

Constituent[1]	09306007				09306061				0906235				0930642			
	N	Mean	Max	Min	N	Mean	Max	Min	N	Mean	Max	Min	N	Mean	Max	Min
Ammonia	20	.04	.13	0	20	.02	.09	0	13	.02	.09	0	19	.05	.27	0
Phosphorus	20	.12	.48	0	20	.14	.57	.01	13	.16	1.3	.01	19	.16	.6	0
Orthophosphorus	20	.04	.11	.01	27	.03	.08	0	13	.05	.45	.01	25	.028	.09	0
Total Disv'd Solid	27	698	762	502	27	893	1050	639	18	735	874	664	25	851	1140	691
Conductivity (umhos/cm)	28	1099	1410	825	27	1324	1560	950	19	1078	1200	900	25	1259	1720	1000
pH (units)	24	8.3	8.7	7.8	26	8.3	9.2	7.5	19	8.16	8.5	7.3	25	7.94	8.9	7.1
Temperature (°C)	28	8.7	22	0	27	9.1	21.1	0	19	13.5	26.5	2.0	25	11.2	19.0	6.0
Dissolved oxygen	24	9.9	13	6.9	24	9.7	16.0	6.4	15	8.5	10.2	5.6	22	8.7	13	4.8
Aluminum (µg/l)	4	155	450	20	3	33	60	10	2	37.5	40	35	3	30	40	20
Arsenic (µg/l)	27	2.1	5	0	27	2.1	5	0	19	4.7	9	1	25	4.9	9	1
Barium (µg/l)	27	60	200	0	27	17.7	110	0	19	25.1	200	0	25	26.4	100	0
Beryllium (µg/l)	4	BDL[2] (<1)			4	BDL (<2)			1	BDL (<1)				BDL (<2)		
Boron (µg/l)	27	194	290	110	27	183	270	120	19	95	130	60	25	170	670	80
Cadmium (µg/l)	26	<1	1	0	26	<1	5	0	19	BDL (<1)				BDL (<1)		
Chromium (µg/l)	19	5.2	90	0	19	3.2	40	0	13	1.5	10	0	19	4.2	50	0
Cobalt (µg/l)	4	BDL (<5)		3		BDL (<6)			2	BDL (<2)			1	12	12	.2

(Continued)

TABLE 4 (Continued)

Constituent[1]	09306007				09306061				0906235				0930642			
	N	Mean	Max	Min	N	Mean	Max	Min	N	Mean	Max	Min	N	Mean	Max	Min
Copper (µg/l)	26	2.1	8	0	27	2.2	10	0	19	2.4	8	0	25	2.7	13	0
Lead (µg/l)	26	1.6	7	0	27	1.6	10	0	18	1.3	6	0	25	2.0	8	0
Lithium (µg/l)	26	9.9	20	0	27	7.8	20	0	19	13.7	20	0	25	11.4	30	0
Mercury (µg/l)	26	BDL (<.1)			27	BDL (<.1)			19	.13	1.2	0	25	BDL (<.1)		0
Molybdenum (µg/l)	4	10.4	16	6	3	9.7	14	5	2	45	46	45	3	37.3	56	26
Nickel (µg/l)	4	BDL (<3)			3	BDL (<3)			2	BDL (<5)						
Selenium (µg/l)	27	1.0	2.0	0	27	1	2	1	19	3.9	6	3	25	2.6	5	1
Silver (µg/l)	4	BDL (<1)			3	BDL (<1)			2	BDL (<1)			3	BDL (<1)		
Strontium (µg/l)	4	1603	2300	810	3	1667	2400	1200	1	1300	1300	1300	3	1667	2000	1400
Titanium (µg/l)	4	6.3	25	0	3	BDL (6)			1	1200	1200	200	1	2000	2000	1400
Vanadium (µg/l)	4	BDL (<3)			3	2.0	6	<3 (BDL)	2	3.5	7	0	3	3.7	4	3
Zinc (µg/l)	26	16.5	60	8	27	15.4	40	0	19	18.7	110	0	25	18.3	100	4

[1] In miligrams per liter, unless otherwise indicated

[2] BDL: Below detection limits, detection limit stated in parenthesis

completion of three major shafts. In addition, the water management program to treat and dispose of waters associated with the mine dewatering activities was expanded. This program consists of pumping the excess mine water derived from the dewatering of two of the shafts into two retention ponds (i.e., Ponds A and B) which are in-series. The retention ponds outflow water is then discharged to Piceance Creek, reinjected into the groundwater system, or utilized for on-site sprinkler irrigation. These activities did not vary over the duration of the sampling project.

The mining activities associated with the development of Tract C-b were rather sporatic during the project. For instance, mining activities were not very active during the first half of 1982, and virtually non-existent after September, 1982. However, activities were fairly brisk during 1981.

Tract C-a

At the end of 1981, Rio Blanco Oil Shale Company (RBOSC) nearly completed the 4-1/2 year development program designed to determine the technical, economical, and environmental viability of the modified in-situ (MIS) recovery process. This program resulted in the ignition of Retort 1 on June, 1981. Retort 1 burned through December of 1981, at which time it was shut-in and is presently cooling down. Due to the retort activities, aquifer and surface water quality data collected after June of 1981, are not considered to represent baseline conditions (RBOSC, 1983).

The next phase of development was intended to determine the viability of Lurgi surface retorting activities. This demonstration was temporarily suspended on August 1, 1982.

The dewatering operations during the initial sampling effort (September, 1981) consisted of two upgradient dewatering wells and mine sumps. In November of 1981, the use of the dewatering wells was discontinued, although pumping from the mine sumps continued to dewater the mine. The water from the dewatering operations is treated by two retention ponds which are in-series. The treated water is then reinjected into the Upper Aquifer. There are no surface discharges. In addition, water derived from the Retort 1 burn is pumped to another treatment system consisting of non-discharging evaporation ponds and, therefore, was not sampled during this project.

CHAPTER 2

STUDY APPROACH

CONSTITUENTS SELECTED FOR ANALYSIS

To best characterize the water derived from the mine and dewatering activities, as well as the treated water, a fairly extensive suite of constituents was selected for analysis. Many of these constituents have also been identified as potential pollutants from studies conducted on the chemical characterization of simulated and observed in-situ oil shale process water (e.g., Fox et al., 1978; Slawson, 1979; Pfeffer, 1974; Stuber and Leenheer, 1978; LBL, 1978).

The constituents selected for analysis during this study are shown in Table 5. In addition, the methods of analysis for each constituent are also shown in Table 5. This suite of constituents was divided into a comprehensive group and an abbreviated group. Analysis for the abbreviated group was conducted during the months of September, 1981; September, 1982; and November, 1982. Analysis for the comprehensive group of constituents, which also included analysis for the abbreviated group, was conducted during the months of May, 1982; July, 1982; January, 1983; and March, 1983. The analytical and field data collected during this study for Tract C-a and C-b are presented in Appendices A and B, respectively.

SAMPLE COLLECTION POINTS

An overview of the development activities on both Tracts C-a and C-b was previously discussed in Chapter 1. This section identifies the sample collection points on each tract, as well as discusses the mine dewatering and water treatment activities.

Tract C-a

The water from the mine on Tract C-a is pumped from levels within the mine and the mine shaft to the Jeffrey Pond, which is the primary retention pond. After preliminary treatment in the Jeffrey Pond, the water is discharged to the West Retention Pond for secondary treatment. The West Retention Pond is in-series with the Jeffrey Pond. The treated water derived from the West Retention Pond is then reinjected into the Upper Aquifer.

The sampling points on Tract C-a consisted of three locations: (1) the mine outflow into the Jeffrey Pond, (2) the Jeffrey Pond outflow into the West Retention Pond, and (3) the West Retention Pond outflow. This approach allowed the evaluation of the total treatment system. For example, sampling both the inflow and outflow of the primary retention pond (i.e., Jeffrey Pond) provides an indication of the effectiveness of a single retention pond. In addition, sampling the outflow of the secondary pond (i.e., West Retention Pond) demonstrates the effectiveness of the treatment system as a whole.

TABLE 5

LIST OF CONSTITUENTS/METHODS[1] SELECTED FOR CHEMICAL ANALYSIS

Abbreviated Analysis

CONSTITUENT	Method	CONSTITUENT	Method
pH	Field	Barium	208.1
Temperature	Field	Beryllium	210.1
Conductivity	Field	Cadmium[2]	301A.III
Dissolved Oxygen	Field	Chromium[2]	301A.III
Ammonia	350.3	Cobalt[2]	219.1
Arsenic[2]	301A.VII	Copper[2]	301A.II
Bicarbonate	310.1	Cyanide	355.2
Boron	212.3	Fractionated DOC	USGS Report[4]
Carbonate	310.1		
Calcium[2]	301A.II	Lead[2]	301A.II
Chloride	325.3	Lithium	AA[8]
Fluoride	340.2	Manganese	243.1
Iron[2]	301A.II	Nickel[2]	301A.II
Magnesium	242.1	Orthophosphorus	365.1
Mercury	245.1	Phenols	420.2
Molybdenum	246.1	Phosphorus	365.4
Nitrate	352.1	Silver[2]	301A.II
Nitrogen	351.1	Strontium	EPA Report[5]
Potassium	258.1	Sulfide	376.1
Selenium	270.3	Thallium	279.2
Silica	370.1	Thiosulfate	NSM[9]
Silver	272.1	Tin	282.1
Sodium	---[3]	Titanium	283.1
Sulfate	375.3	Tubidity	180.1
Vanadium	---[3]	Uranium	EPA Report[6]
Dissolved Organic Carbon	---[7]	Zinc	301A.II
Total Dissolved Solids	160.1		
Total Volatile Solids	160.4		
Total Suspended Solids	160.2		
Total Solids	160.3		
Settleable Matter	160.5		

(continued)

TABLE 5

(continued)

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[1] All methods are from U.S. EPA, 1979. Methods of Chemical Analysis of Water and Wastes, EPA-600/4-79-620; unless otherwise denoted.

[2] Methods from American Public Health Association, 1976. Standard Methods for the Examination of Water and Waste Water. 14th Ed.

[3] Method from U.S. EPA, The Inductively Coupled Plasma Optical Emission Spectrometric Method (Method 200.7).

[4] Analyzed according to method stated in: U.S. Geolog. Survey, 1979. Analytical Method for Dissolved Organic Carbon Fractionation. USGS/WRI-79-4.

[5] Analyzed according to method stated in: U.S. Environmental Protection Agency, 1975. Interim Radiochemical Methodology for Drinking Water. EPA-600/7-760-093.

[6] Analyzed according to method stated in: U.S. Environmental Protection Agency, 1979. Radiometric Method for the Determination of Uranium in Water. EPA-600/7-79-093.

[7] Analyzed on a Coulmetric Carbon Analyzer.

[8] Analyzed with Atomic Absorption.

[9] No standard method.

Tract C-b

As with the treatment facilities on Tract C-a, the Tract C-b facilities consist of two retention ponds which are in-series. The water from the mine production and service shafts dewatering operations are pumped into the primary retention pond (i.e., Pond A). After retention in Pond A, the water is treated with sulfuric acid and a magnifloc cationic flocculent to lower the pH and settle the suspended solids, respectively. This water then flows into Pond B via gravity for additional retention. The acid and flocculent treatment was discontinued in September, 1982, when the mining activities terminated. After this date, chemicals were not used in the treatment. The treated waters were then subject to one of the following modes of disposal: (1) discharge to Piceance Creek, (2) on-site sprinkler irrigation, or (3) reinjection into the Upper Aquifer.

The sampling points on Tracts C-b consisted of two locations: (1) the inflow into Pond A, which is water derived from the dewatering of the shafts previous to treatment and (2) the treated water discharge from Pond B. The discharge from Pond A was not sampled since the effectiveness of treatment with a single pond was evaluated on Tract C-a. By sampling the inflow and outflow of the entire treatment system on Tract C-b, comprehensive analytical data for the effectiveness of the treatment system as a whole were collected.

SAMPLING AND ANALYTICAL PROCEDURES

Grab samples were collected in the field from the discharging water at the various sample collection points previously discussed. Immediately upon sample collection, the following constituents were measured in the field with portable instruments: pH, specific conductance, dissolved oxygen, and temperature. Samples which were sent to the laboratory for analysis and required filtering were also filtered in the field through a standard .45 micron (µm) membrane filter with a Skougstand filter apparatus. A Gilman stainless steel filtering apparatus was used to filter dissolved organic carbon samples through a .45 µm silver membrane filter. After filtration, the samples were preserved and cooled with ice according to U.S. EPA (1979a) recommended procedures and placed in ice chest for shipment. The samples were shipped via commercial bus to both the Colorado State University (CSU) laboratory in Fort Collins, Colorado and CORE laboratories in Denver, Colorado. Every shipment during the course of the study was received within 24 hours by the laboratories, except for the samples collected July 20, 1982, which did not arrive at the CSU laboratory until 36 hours after collection.

The analytical laboratories performed the analyses of the selected constituents in Table 5. These constituents were analyzed according to the methods presented in Table 5. The quality assurance program for the analytical laboratories, as

well as the field sampling, is presented in Chapter 4. It should be noted that values for ammonia and nitrate reflect abrupt changes that are not characteristic of historical trends. Therefore, the data on ammonia and nitrate are suspect.

CHAPTER 3

DATA DISCUSSION

The results of the sampling program are discussed in this chapter. The effects of changes in operational procedures on the water quality trends at each sampling point are also discussed. The data for each tract is discussed separately under each section below.

WATER QUALITY DATA FOR TRACT C-A and C-B

Tract C-a

As previously discussed in Chapter 2, there were three sampling points on Tract C-a. These included the mine inflow into the primary retention pond (i.e., Jeffrey Pond), the inflow to the secondary retention pond (i.e., West Retention Pond) from the primary retention pond, and the outflow of the secondary retention pond. The data collected during this sampling effort are shown in Appendix A. In addition, the following statistics have been summarized on the major constituents and are presented in Table 6: number of samples, mean, high, low, and standard deviation. In addition to the data presented in Table 6, trilinear diagrams were prepared to characterize the water quality at each sampling point over the duration of the project. The trilinear diagrams for the Jeffrey Pond inflow, West Retention Pond inflow, and West Retention Pond outflow are shown in Figures 7, 8, and 9, respectively.

Inspection of the trilinear diagrams for all three of the sampling points indicates that the quality can be classified as a non-dominant type water. The major cations and anions consist of: magnesium, sodium, sulfate, and bicarbonate. The percentages of total anion or cation concentration for each constituent at each sampling point over the duration of the project were:

Sampling Point	Magnesium	Sodium	Bicarbonate	Sulfate
Jeffrey Pond Inflow	39.0%	49.4%	50.9%	46.7%
West Retention Pond Inflow	39.4%	48.6%	50.4%	47.0%
West Retention Pond Outflow	39.2%	48.7%	50.5%	46.8%

The operational procedures on Tract C-a did change during the course of the study. In November of 1981, the Upper Aquifer dewatering system was discontinued. Previous to this period, dewatering wells GS-D6U and GS-D8U were used for this activity. The water derived from these wells was discharged into the Jeffrey Pond. In addition, the water from the mine sumps was also discharged into the Jeffrey Pond. This composite water was then treated in the two ponds and reinjected into the Upper

TABLE 6. TRACT C-a WATER QUALITY DATA.

CONSTITUENT*	INFLOW TO JEFFREY POND NUMBER	MEAN	HIGH	LOW	STND. DEV.	WEST RETENTION POND INFLOW NUMBER	MEAN	HIGH	LOW	STND. DEV.	WEST RETENTION POND OUTFLOW NUMBER	MEAN	HIGH	LOW	STND. DEV.
AMMONIA	6	.30	.47	.11	.12	6	.22	.32	.10	.09	6	.24	.42	.16	.11
ARSENIC	7	BDL	(<.003)			7	BDL	(<0.003)			7		BDL	(<.003)	
BICARBONATE	7	555	599	527	25.3	7	535	548	523	9.8	7	517	558	368	67
BORON	6	.21	.41	.12	.10	6	.34	.80	.15	.26	7	.33	.9	.16	.29
CARBONATE	7	6.33	9.09	1.0	2.85	7	7.09	11.4	1.08	3.43	7	7.5	10.4	<1	2.2
CALCIUM	7	38.8	48.7	32.6	7.3	7	41.0	63.5	31.0	11.8	7	41.4	62	32	10.8
CHLORIDE	7	8.06	8.52	7.74	.30	7	8.4	9.47	7.58	.67	7	7.96	9.47	5.73	1.13
CONDUCTIVITY (μ mhos/cm)	7	1,590	2,250	1,400	308	7	1,434	1,510	1,390	53	7	1,409	1,475	1,320	49
DISSOLVED ORGANIC CARBON	7	3.5	4.7	<2	1.1	7	3.5	4	3	.46	7	3.3	3.8	2.0	.8
DISSOLVED OXYGEN	7	4.0	6.8	3.0	1.3	7	6.7	8.5	5.9	1.0	7	5.8	8.0	3.9	1.4
FLUORIDE	7	1.35	1.71	1.1	.21	7	1.34	1.7	1.2	.18	7	1.24	1.32	1.11	.07
IRON	7	.19	1.0	<.01	.36	7	.18	.59	.03	.20	7	.29	.64	<.01	.23
MAGNESIUM	7	80.1	95.0	72.8	8.0	7	82	98.9	74.1	8.2	7	82.3	100.9	73.1	9.1
MOLYBDENUM	7	.06	.11	<.03	.02	7	.16	.3	<.03	.18	7	.23	.24	<.01	.01
NITRATE	7	.53	2.02	<.1	.83	7	1.83	8.59	0.1	3.78	5	.39	.77	.05	.28
POTASSIUM	7	.62	1.26	.14	.36	7	.76	1.24	.36	.33	7	.84	1.49	.36	.43
RESIDUES															
-TOTAL DISSOLVED	7	994	1,152	614	175	7	1,134	1,446	988	164	7	1,177	1,392	980	177
-TOTAL SUSPENDED	7	BDL	(<4)			7	6.3	10	<4	2.6	7	BDL	(<4)		
-TOTAL SOLIDS	7	1,071	1,208	992	69	7	1,153	1,446	1,016	160	7	1,185	1,395	1,007	170
-TOTAL VOLATILE	6	197	226	148	31	6	198	252	74	65	6	187	225	86	55
-SETTLEABLE MATTER	7	BDL	(<.1)			7	BDL	(<.1)			7	BDL	(<.1)		
TEMPERATURE (°C)	7	14.3	19	11	2.7	7	14.5	23	10	4.7	7	13.9	20	9.5	3.9
SELENIUM	7	BDL	(<.01)			7	BDL	(<.01)			7	BDL	(<.01)		
SILICA	6	13.9	23	11	4.5	6	13.2	22	10.9	4.4	5	11.6	12.8	11.0	.7
SODIUM	7	191	200	174	8.2	7	190	198	170	9.7	7	192	198	177	7.3
SULFATE	7	402	430	343	31	7	342	441	345	137	7	377	449	302	48
VANADIUM	4	BDL		(<.005)		4		BDL	(<.005)		4		BDL	(<.005)	
ACIDITY	7	5.1	9.45	3.13	2.13	7	3.56	4.99	2.52	1.13	6	3.57	4.96	2.33	1.12
ALKALINITY	7	469	506	445	20	7	456	474	442	11	7	439	470	311	57
pH (Units)	7	7.7	9.2	7.17	.77	7	7.6	9.0	7.0	.7	7	7.6	8.9	6.9	.6

*In mg/ℓ, unless otherwise indicated.
BDL = Below Detection Limits, with detection limits in parenthesis.

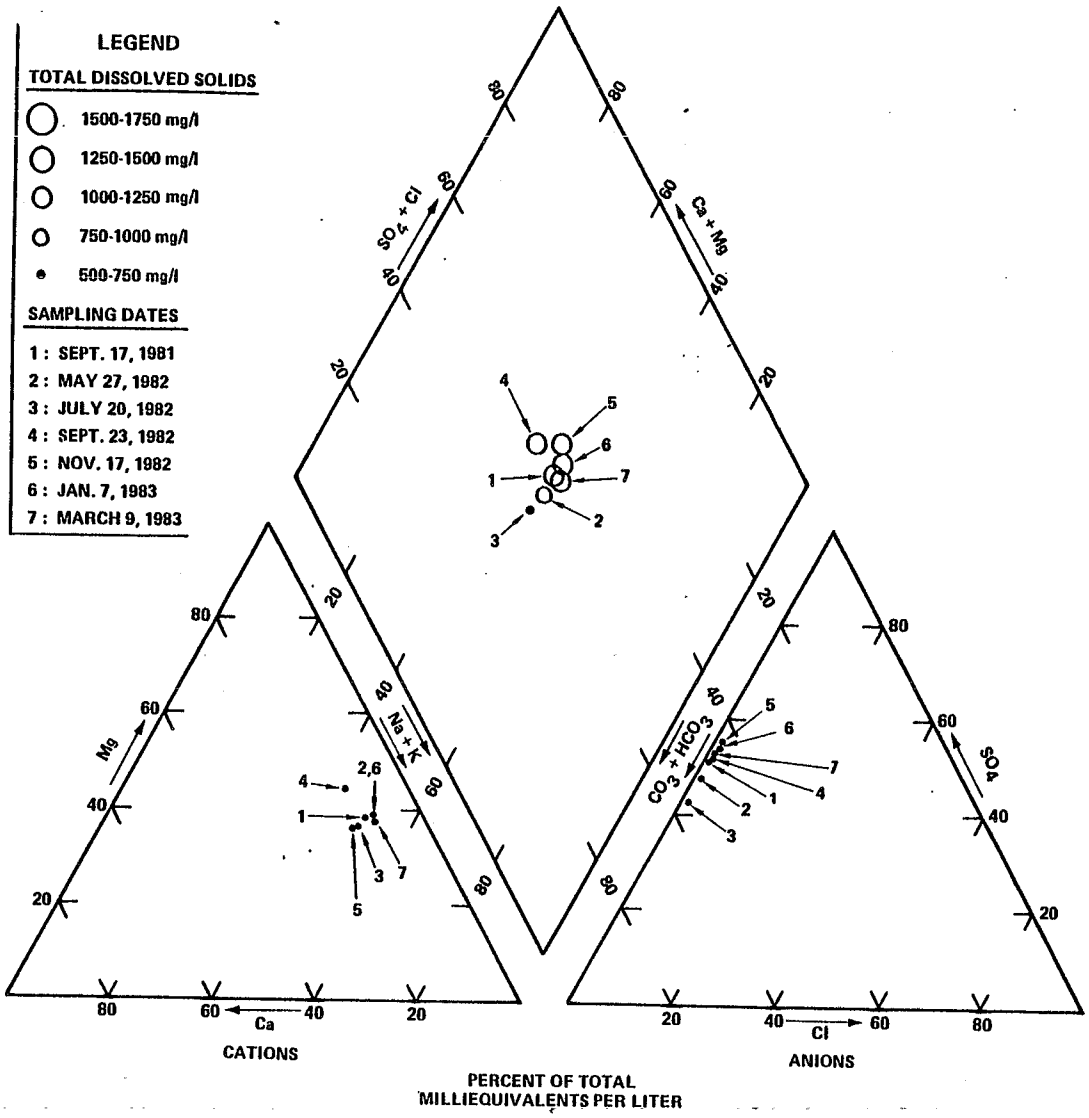

FIGURE 7: Trilinear Diagram for the Jeffrey Pond Inflow, Tract C-a.

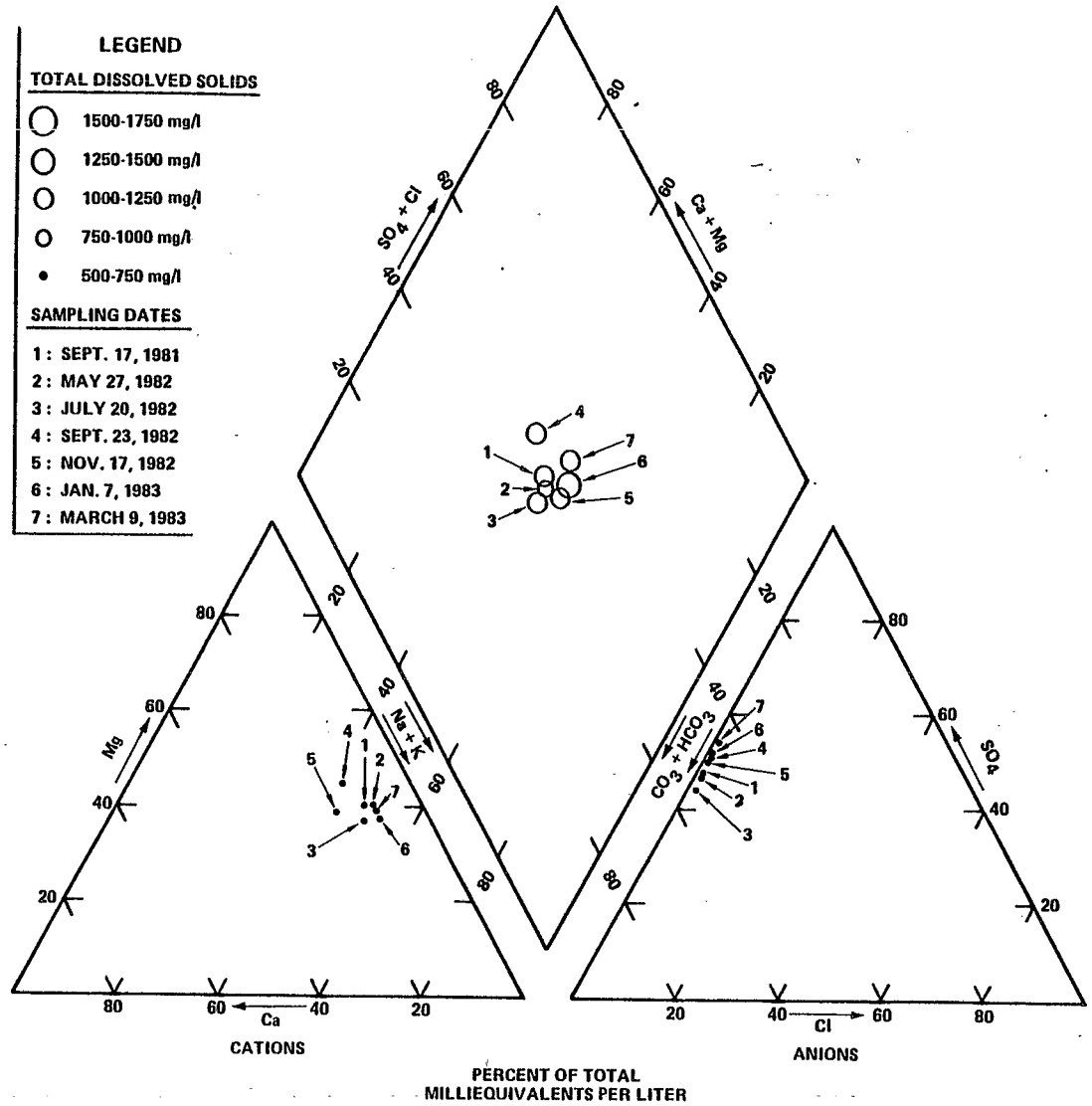

FIGURE 8: Trilinear Diagram for West Retention Pond Inflow, Tract C-a.

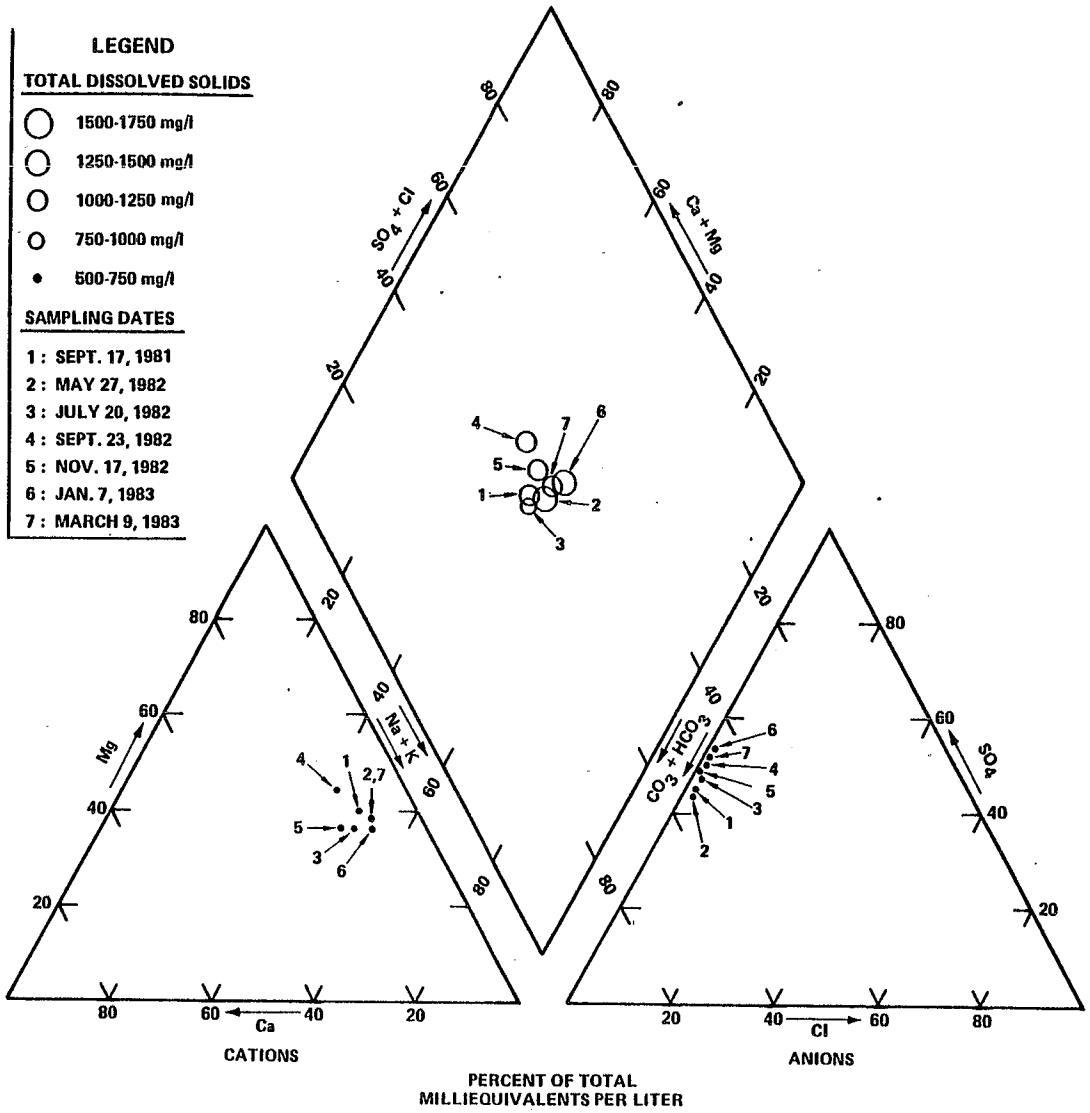

FIGURE 9: Trilinear Diagram for West Retention Pond Outflow, Tract C-a

Aquifer. After the discontinuation of the dewatering wells in November of 1981, the dewatering of the mine via sumps continued throughout the duration of the project.

In regard to water quality trends at each sampling point, none were observed over the course of the study. In fact, inspection of the trilinear diagrams for each sampling point (i.e., Figures 7, 8, and 9) indicates that the analytical data are very consistent. The analytical data for all of the sampling dates are very similar for each sampling point, and consequently, result in very good grouping of points on the trilinear diagram. In addition, a variation in the water quality was not observed after the discontinuation of the dewatering program. This indicates that the quality of water derived from the mine sumps is very similar to the quality of water derived from the once operating Upper Aquifer dewatering program. Comparison of the trilinear diagrams for the data collected during this study correlates quite nicely with the Upper Aquifer data presented in Figure 4, a trilinear diagram of the water quality baseline data for the Upper and Lower Aquifers on Tract C-a. Therefore, it is reasonable to assume that water derived from the dewatering activities on Tract C-a is predominately from the Upper Aquifer.

The changes in water quality between the three sampling points is somewhat variable. A comparison between the untreated water flowing into Jeffrey Pond with the treated water flowing out of the West Retention Pond shows an increase in concentration of many constituents. For example, the mean values of the following constituents show slight increases when the data collected for the Jeffrey Pond inflow is compared with the data of the West Retention Pond outflow (see Table 6): boron, carbonate, calcium, dissolved oxygen, iron, magnesium, molybdenum, potassium, total solids, and total dissolved solids. None of these increases are very significant and can probably be related to pH changes, aeration, evaporation, and reduction - oxidation changes associated with the transformation of the groundwater from an underground environment to a surface environment, as well as the associated retention time in the ponds. In addition, some of the changes may be attributable to laboratory variations.

Groundwater quality data for Tract C-a are available for both the Upper and Lower Aquifers. These data, as well as the data collected during this study to characterize the treatment system, are presented in Table 7. In addition, corresponding Federal Drinking Water Quality Standards are also included in Table 7. It should be noted that this comparison is not meant to imply that the discharges from the treatment system should meet these standards, these are only included for reference purposes.

Comparison of the water quality data collected from the outflow of the West Retention Pond with the baseline groundwater quality, data indicates that several constituents exceed baseline conditions upon discharge from the West Retention Pond. Specific water quality constituents in which the mean values exceed the

TABLE 7. COMPARISON OF TRACT C-a GROUNDWATER BASELINE DATA AND FEDERAL DRINKING WATER STANDARDS WITH HOLDING POND DATA COLLECTED DURING THIS STUDY

CONSTITUENT*	BASELINE DATA (TRACT C-a)[6] GROUNDWATER UPPER AQUIFER		GROUNDWATER LOWER AQUIFER		TRACT C-a DATA INFLOW TO JEFFERY POND		WEST RETENTION POND INFLOW		WEST RETENTION POND OUTFLOW		FEDERAL DRINKING WATER QUALITY STANDARDS[1]	
	MEAN VALUE	HIGH VALUE	MEAN VALUE	HIGH VALUE	MEAN VALUE	HIGH VALUE	MEAN VALUE	HIGH VALUE	MEAN VALUE	HIGH VALUE	PRIMARY[2] (40CFR PART 141)	SECONDARY[3] (40CFR PART 143)
AMMONIA	0.37	1.8	0.35	2.0	0.30	0.47	0.22	0.32	0.24	0.42		
ARSENIC	0.01	0.04	BDL[1]	<0.01	BDL	<0.003	BDL	<0.003	BDL	<0.003	.05	
BICARBONATE	744	2,760	599	2,980	555	599	535	548	517	558		
BORON	0.75	4.8	1.21	20.0	0.21	0.41	0.34	0.80	0.33	0.90		
CARBONATE	0.98	66	1.25	84	6.33	9.09	7.09	11.4	7.5	10.4		
CALCIUM	83.5	260	28.2	98.0	38.8	48.7	41.0	63.5	41.4	62		
CHLORIDE	16.9	69	19.2	96	8.06	8.52	8.4	9.47	7.96	9.47		250
CONDUCTIVITY (μ mhos/cm)	1,702	2,610	1,258	3,600	1,590	2,250	1,434	1,510	1,409	1,475		
DISSOLVED ORGANIC CARBON	10.2	35	11.8	37	3.5	250 4.7	3.5	4	3.3	3.8		
DISSOLVED OXYGEN	-	-	-	-	4.0	6.8	.05	8.5	5.8	8.0		
FLUORIDE	0.37	1.8	6.35	32	1.35	1.71	1.34	1.7	1.24	1.32	2.0 - 2.2[5]	
IRON	6.3	18.0	3.45	16.2	0.19	1.0	0.18	0.59	0.29	0.64	0.3	
MAGNESIUM	59.3	155	38.2	130	80.1	95.0	82.0	98.9	82.3	100.9		
MOLYBDENUM	-	-	-	-	0.06	0.107	0.16	0.3	0.23	0.24		
NITRATE	0.50	4.5	0.47	2.0	0.53	2.02	1.83	8.59	0.39	0.77	10	
POTASSIUM	-	-	-	-	0.62	1.26	0.76	1.24	0.84	1.49		
RESIDUES												
-TOTAL DISSOLVED	1,267	2,790	976	3,360	994	1,152	1,134	1,446	1,177	1,392		
-TOTAL SUSPENDED	-	-	-	-	BDL	<4	6.3	10	BDL	<4		
-TOTAL SOLIDS	-	-	-	-	1,071	1,208	1,153	1,446	1,185	1,395		
-TOTAL VOLATILE	-	-	-	-	197	226	198	252	187	225		
-SEATTLEABLE MATTER	-	-	-	-	BDL	<0.1	BDL	<0.1	BDL	<0.1	0.01	
TEMPERATURE (°C)	-	-	-	-	14.3	19	14.5	23	13.9	20		
SELENIUM	BDL	<0.01	BDL	<0.01	BDL	<0.01	BDL	<0.01	BDL	<0.01		
SILICA	32.8	58	10.8	32	13.9	23	13.2	22	11.6	12.8		
SODIUM	301.8	1,170	284	1,320	191	200	190	198	192	198		
SULFATE	474	900	250	600	402	430	342	441	377	449		250
VANADIUM	-	-	-	-	BDL	<0.005	BDL	<0.005	BDL	<0.005		
ACIDITY	-	-	-	-	5.1	9.45	3.86	4.99	3.57	4.96		
ALKALINITY	654	2,343	558	2,540	469	506	456	474	439	470		
pH (Units)	6.78	8.8	7.1	10.2	7.7	9.2	7.6	9.0	7.6	8.9		6.5 - 8.5

*Values in mg/l unless otherwise indicated.

1. Provided as a reference point. Not intended to imply that discharge should meet Drinking Water Standards.
2. Federally Enforceable - Federal Register - EPA Water Programs, Wednesday, December 24, 1975 (Vol. 40, No. 248).
3. Not Federally Enforceable - Federal Register - EPA Water Programs, Thursday, July 19, 1979 (Vol. 44, No. 140).
4. BDL = Below Detection Limit
5. Dependent on Temperature (Average of maximum daily air temperatures).
6. Source: Rio Blanco Oil Shale Company, 1977.

mean values for baseline conditions in some or all instances include carbonate, flouride, magnesium, and pH. However, it is evident from reviewing Table 7, that these increases over baseline conditions are minimal and, consequently, do not constitute significant increases.

Tract C-b

There were two sampling points on Tract C-b. These points consisted of (1) The inflow to the primary retention pond (i.e., Pond A) and (2) The outflow of the secondary retention pond (i.e., Pond B). The data collected on Tract C-b during the sampling period are presented in Appendix B.

In addition, the following statistics have been summarized for the major constituents and are presented in Table 8: number of samples, mean, high, low, and standard deviation. In order to characterize the water quality, trilinear diagrams were prepared for both the inflow to Pond A and the outflow of Pond B. These diagrams are presented in Figures 10 and 11, respectively.

The trilinear diagrams presented in Figures 10 and 11, indicate that the dominant cation and anion present in the water sodium and bicarbonate, respectively. The average percentages of total anion or cation concentration for each constituent at each sampling point over the duration of the project were:

Sampling Point	Sodium	Bicarbonate
Pond A Inflow	96.8%	90.3%
Pond B Outflow	96.9%	88.3%

Therefore, the water of the Tract C-b system is classified as a sodium-bicarbonate type.

In regard to water quality trends at each sampling point, none were observed during the sampling program (Table 8). The sampling dates plotted on the trilinear diagrams (Figures 10 and 11) for the sampling points show a very good grouping of data points. However, a small deviation is noted for Sample 1, which represents the sample collected during acid and flocculent treatment. In general, the remaining data points indicate that there is very little variability in the water quality. In regard to Tract C-b operational procedures, the dewatering of the production and service shafts continued throughout the sampling period without variation.

The trilinear diagrams for the data collected on Tract C-b during this sampling program correlates fairly well with the Lower Aquifer data presented in Figure 5, a trilinear diagram of the baseline water quality data for the Upper and Lower Aquifers on Tract C-b. This indicates the water from the dewatering activities is primarily derived from Lower Aquifer sources. However, the stratigraphic interval from which the dewatering occurs is located in the zone designated as Upper Aquifer. One explanation for this discrepancy may be that the dewatering

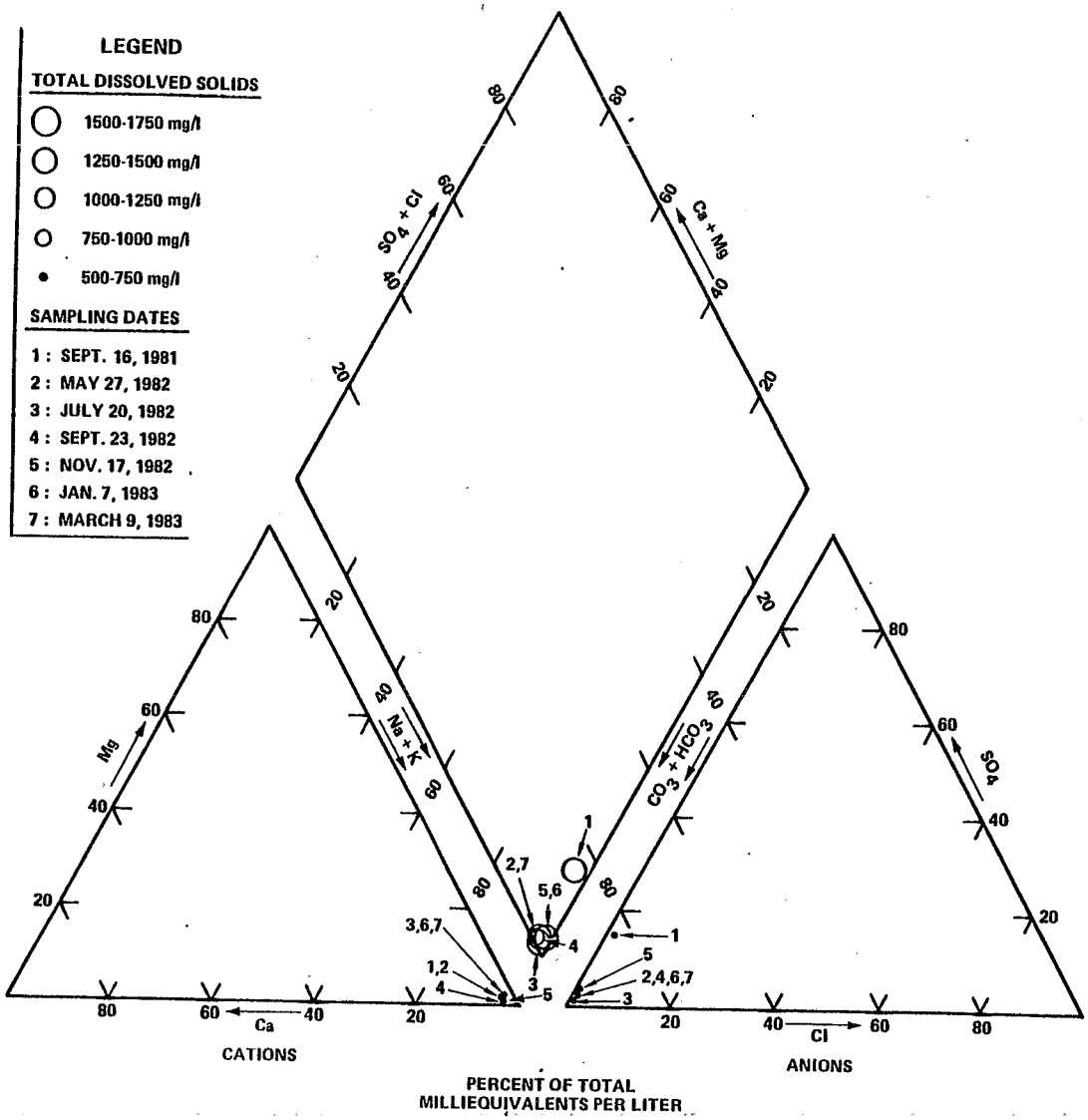

FIGURE 10: Trilinear Diagram for the Pond A Inflow, Tract C-b (Sept. 16, 1981 sample date represents flocculent and acid treatment).

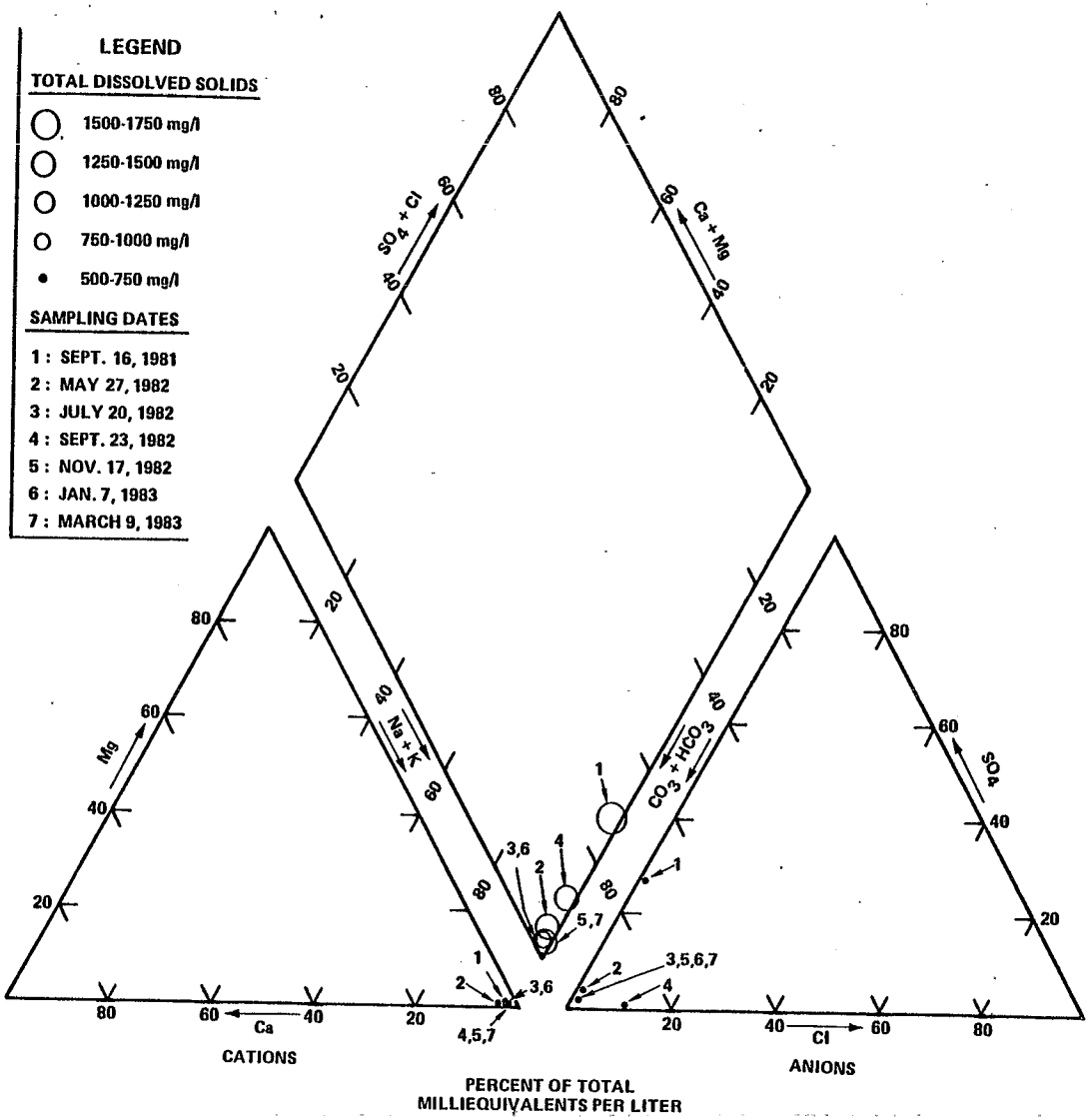

FIGURE 11: Trilinear Diagram for the Pond B Outflow, Tract C-b (Sept. 16, 1981 sample date represents flocculent and acid treatment).

TABLE 8. TRACT C-b HOLDING POND QUALITY DATA COLLECTED DURING THIS STUDY

CONSTITUENT*	SULFURIC ACID AND FLOCCULENT		NO CHEMICAL TREATMENT									
	INFLOW TO POND A	OUTFLOW FROM POND B	INFLOW TO POND A					OUTFLOW FROM POND B				
			NUMBER	MEAN	HIGH	LOW	STND. DEV.	NUMBER	MEAN	HIGH	LOW	STND. DEV.
AMMONIA	.90	1.33	5	.37	.688	.21	.19	5	.33	.372	.28	.03
ARSENIC	<.01	<.01	6	BDL	.003			6	BDL	(<.003)		
BICARBONATE	1,135	1,069	6	1,217	1,350	896	167	6	1,294	1,359	1,210	53
BORON	.86	.79	6	.77	.87	.74	.05	5	78	99	165	.13
CARBONATE	10.8	<1.0	6	38.7	53.3	24.1	11.7	6	44.9	63.2	25.9	12.3
CALCIUM	7.30	6.50	6	5.75	7.00	4.78	.74	6	6.32	10.0	4.78	1.9
CHLORIDE	8.34	8.12	6	7.10	8.14	5.79	.81	6	6.97	8.14	6.09	.77
CONDUCTIVITIY (μ mhos/cm)	2,275	2,200	6	2,113	2,620	1,620	325	6	2,150	2,500	2,000	179
DISSOLVED ORGANIC CARBON	4.7	3.9	6	3.8	5.0	<2	1.1	6	3.9	6.0	2.0	1.4
DISSOLVED OXYGEN	4.0	9.0	6	4.7	5.7	4.0	.7	6	5.3	7.0	4.3	1.1
FLUORIDE	15.3	15.3	6	17.5	19.8	11.1	3.3	6	17.7	19.7	12.2	2.8
IRON	.08	.05	6	.09	.21	<.01	.08	6	.14	.31	<.01	.12
MAGNESIUM	4.40	4.60	6	4.50	5.38	3.80	.60	6	4.52	5.7	3.94	.65
MOLYBDENUM	<.1	<.1	6	.38	.88	<.03	.43	6	.33	.80	<.03	.41
NITRATE	1.2	1.5	6	2.95	4.12	1.20	1.35	6	5.72	5.8	<1.0	4.5
POTASSIUM	4.3	4.1	6	2.54	4.67	1.65	1.13	6	2.63	5.7	3.94	1.21
RESIDUES												
-TOTAL DISSOLVED	1,354	1,517	6	1,269	1,380	912	179	6	1,347	1,398	1,206	71
-TOTAL SUSPENDED	565	6	5	7.0	8.0	<4	1.4	6	5	5.0	<4	
-TOTAL SOLIDS	1,919	1,523	6	1,300	1,424	958	173	6	1,381	1,439	1,342	36
-TOTAL VOLATILE	320	297	5	141	194	88	42	5	153	244	96	59
-SETTLEABLE MATTER	4.5	<.1	6	<.1	<.1	<.1		6	BDL	(<.1)		
TEMPERATURE (°C)	13.0	15.5	6	19.3	23.5	16	3.3	6	17.5	23	12	4.8
SELENIUM	<0.1	<.01	6	BDL	(<.002)			6	BDL	(<.01		
SILICA	23	35	5	6.88	7.30	6.12	.49	5	6.5	7.5	5.6	.73
SODIUM	540	540	6	520	578	391	66	6	549	578	522	18
SULFATE	176	311	6	15.9	22.6	10.9	3.97	6	20.0	50.3	6.0	15.4
VANADIUM	<.5	<.5	3	BDL	(<.005)			3	BDL	(<.005)		
ACIDITY	<5	<5	6	3.93	5.30	2.63	1.08	6	3.93	6.2	2.6	1.30
ALKALINITY	1,147	926	6	1,061	1,160	775	147	6	1,135	1,190	1,070	44
pH (Units)	9.2	7.8	6	8.3	8.8	8.0	.3	6	8.5	9.2	8.2	.4

*In mg/l, unless otherwise indicated.
BLD: Below Detection Limits, with detection limits in parenthesis.

activities have reversed the gradient between the Upper and Lower Aquifers to such an extent that the Lower Aquifer is recharging the Upper Aquifer through the semi-permeable Mahogany zone.

A comparison of the inflow and the outflow of the Tract C-b treatment system indicated no significant changes except for reductions in total suspended solids and pH when flocculent and sulfuric acid were added. (see Table 8). This relationship is true for the samples collected during the period of chemical treatment (i.e., flocculent and sulfuric acid) and the periods without chemical treatment. Once again, this aspect is probably due to the exposure of the groundwaters to atmospheric conditions. The fact that many of the constituents increased slightly after residence in the retention ponds indicates that this type of treatment method may not be totally effective for groundwaters.

Baseline water quality information is also available for Tract C-b. These data include locations above and below Tract C-b on Piceance Creek, as well as groundwater data for both the Upper and Lower Aquifers. This information is included in Table 9. In addition, both the quality data for the treatment system on Tract C-b collected during this study and the Federal Drinking Water Standards are also included in Table 9.

An inspection of Table 9 indicates that the mean values for some constituents in the discharge from Pond B exceeded, in some cases, the mean values in the Upper Aquifer baseline groundwater quality concentrations. These constituents include bicarbonate, carbonate, conductivity, flouride, molybdenum, (except during sulferic acid and flocculent treatment) nitrate, potassium, TDS, and sodium. However, these increases were fairly minimal and, therefore, not large enough to insinuate significant degradation in the quality of groundwater derived from Tract C-b.

The mean values of the following constituents upon discharge from Pond B exceeded baseline conditions for the mean values along Piceance Creek at the site below Tract C-b (see Table 9): ammonia, bicarbonate, boron, carbonate, conductivity, dissolved oxygen (lower concentration), TDS, temperature, sodium, alkalinity, and pH. One obvious reason for the elevated values of the above constituents relative to the baseline conditions of Piceance Creek is the fact that the water discharged from Pond B is derived entirely from the groundwater system, which is of poorer quality than Piceance Creek.

TABLE 9. COMPARISON OF TRACT C-b GROUNDWATER AND SURFACE WATER BASELINE DATA AND FEDERAL DRINKING WATER STANDARDS WITH HOLDING POND DATA COLLECTED DURING THIS STUDY

	BASELINE DATA - (TRACT C-b)								TRACT C-b HOLDING POND DATA							
	GROUNDWATER[6]				SURFACE WATER[7]				NO CHEMICAL TREATMENT				SULFURIC ACID AND FLOCCULENT			
	UPPER AQUIFER		LOWER AQUIFER		PICEANCE CREEK ABOVE TRACT C-b		PICEANCE CREEK BELOW TRACT C-b		INFLOW TO POND A		OUTFLOW FROM POND B		INFLOW TO POND A	OUTFLOW FROM POND B	FEDERAL DRINKING WATER QUALITY STANDARDS[1]	
CONSTITUENTS*	MEAN VALUE	HIGH VALUE	MEAN VALUE	HIGH VALUE	MEAN VALUE	HIGH VALUE	MEAN VALUE	HIGH VALUE	MEAN VALUE	HIGH VALUE	MEAN VALUE	HIGH VALUE			PRIMARY[2] (40CFR PART 141)	SECONDARY[3] (40CFR PART 143)
AMMONIA	7.9	1.2	17	200	0.04	0.13	0.02	0.09	0.37	0.69	0.33	0.372	.90	1.33		
ARSENIC	0.01	0.06	0.02	0.02	2.1	5.0	2.1	5.0	BDL[4]	<0.003	BDL	<0.003	<.01	<.01	.05	
BICARBONATE	790	2,100	4,000	25,000	523	602	572	678	1,217	1,350	1,294	1,359	1,135	1,069		
BORON	1.4	18	36	400	0.194	0.29	0.183	0.270	.77	0.87	.78	0.99	.86	.79		
CARBONATE	21	76	220	2,000	1.5	32	1.5	39	38.7	53.3	44.9	63.2	10.8	<1.0		
CALCIUM	32	120	14	220	68.9	79	78.7	87	5.75	7.00	6.32	10.0	7.30	6.50		
CHLORIDE	26	510	1,200	9,800	15,5	24	13.5	16	7.10	8.14	6.97	8.14	8.34	8.12		250
CONDUCTIVITY (μ mhos/cm)	1,670	4,200	7,240	45,000	1,099	1,410	1,324	1,560	2,113	2,500	2,150	2,500	2,275	2,200		
DISSOLVED ORGANIC CARBON	-	-	23	175	-	-	-	-	3.8	5.0	3.9	6.0	4.7	3.9		
DISSOLVED OXYGEN	-	-	-	-	9.9	13	9.7	16.0	4.7	5.7	5.3	7.0	4.0	9.0		
FLUORIDE	10	190	21	48	0.98	1.3	0.6	0.9	17.5	19.8	17.7	19.7	15.3	15.3	2.0-2.2[5]	
IRON	0.5	7	0.8	8.0	0.07	0.39	0.04	0.46	.09	0.21	.14	0.311	.08	.05	0.3	
MAGNESIUM	42	150	11	110	46.2	56	65.9	82.0	4.50	5.38	4.52	5.7	4.40	4.60		
MOLYBDENUM	0.02	0.1	0.04	0.2	0.0104	0.016	0.0097	0.014	.38	0.883	.33	0.80	<.1	<.1		
NITRATE	0.41	2.9	0.46	3.4	0.33	0.83	0.39	0.79	2.95	4.12	5.72	5.8	1.2	1.5	10	
POTASSIUM	2.2	11	21	120	3.7	19	3.7	5.0	2.54	4.67	2.63	5.7	4.3	4.1		
RESIDUES																
-TOTAL DISSOLVED	1,100	3,100	6,190	42,000	698	762	893	1,050	1,269	1,380	1,347	1,398	1,354	1,517		
-TOTAL SUSPENDED	-	-	-	-	-	-	-	-	7.0	8.0	5.0	5.0	565	6		
-TOTAL SOLIDS	-	-	-	-	-	-	-	-	1,300	1,424	1,381	1,439	1,919	1,523		
-TOTAL VOLATILE	-	-	-	-	-	-	-	-	141	194	153	244	320	297		
-SETTLEABLE MATTER	-	-	-	-	-	-	-	-	<.1	<.1	BDL	<0.1	4.5	<.1		
-TEMPERATURE(°C)	-	-	-	-	8.7	22	9.1	21.1	19.3	23.5	17.5	23.0	13.0	15.5		
SELENIUM	0.006	0.03	0.004	0.02	0.001	0.002	0.001	0.002	BDL	<0.002	BDL	<0.01	<.01	<.01	0.01	
SILICA	17	32	13	38	15	18	17	20	6.88	7.30	6.5	7.5	23	35		
SODIUM	330	1,200	2,500	17,000	115.4	150	148	180	520	578	549	578	540	540		
SULFATE	220	520	63	350	161	190	239	330	15.9	22.6	20.0	50.3	176	311		250
VANADIUM	0.002	0.006	0.01	0.1	BDL	<0.003	0.002	0.006	BDL	<0.005	BDL	<0.005	<.5	<.5		
ACIDITY	-	-	-	-	-	-	-	-	3.93	5.3	3.93	6.2	<5	<5		
ALKALINITY	-	-	-	-	432	494	472	544	1,061	1,160	1,135	1,190	1,147	926		
pH (Units)	8.6	9.1	8.7	9.3	8.3	8.7	8.3	9.2	8.3	8.8	8.5	9.2	9.2	7.8		6.5 - 8.5

*Values in mg/l except as noted.

1. Provided as a reference point. Not intended to imply that discharge should meet Drinking Water Standards.
2. Federally Enforceable - Federal Register - EPA Water Programs, Wednesday, December 24, 1975 (Vol. 40, No. 248).
3. Not Federally Enforceable - Federal Register - EPA Water Programs, Thursday, July 19, 1979 (Vol. 44, No. 140).
4. BDL = Below Detection Limit
5. Dependent on Temperature (Average of maximum daily air temperatures).
6. Source: C-b Shale Oil Venture, 1977.
7. Source: USGS, 1977.

CONCLUSIONS

This discussion is divided into two sections. The first section addresses the effectiveness, of a one-pond or two-pond system without chemical treatment (i.e., flocculent and sulfuric acid). The second section presents conclusions concerning the effectiveness of adding a flocculent to decrease total suspended solids concentrations and adding sulfuric acid to decrease the pH in the treatment system. It should be noted that the discussions of the respective pond systems with respect to water quality data and the resultant changes are presented using mean values of respective water quality constituents.

Effectiveness of System Without Chemical Treatment

The one-pond system addressed here consisted of the West Retention Pond on Tract C-a. With respect to Jeffrey Pond, it was not included as part of the assessment due to its extremely small size and corresponding short retention time. It was felt that even though the water passed through Jeffrey Pond before it entered the West Retention Pond, the holding time was so small that effects on water quality were believed to be negligible compared to the West Retention Pond.

The overall quality remained essentially unchanged as the water passes through the West Retention Pond. The decrease in total suspended solids concentrations from 6.3 mg/l to below detection limits is not significant.

The two-pond system assessed during this study is located on Tract C-b and consisted of the primary retention pond (Pond A) and the secondary retention pond (Pond B), which are in-series. Samples were collected for the inflow to Pond A and the outflow from Pond B on six occassions. In addition, one sample was collected when flocculent and sulfuric acid were added, as discussed below. Similar to the one-pond system, fluctuations for most of the water quality constituents were insignificantly small (less than 10%). Total suspended solids concentrations remained unchanged (less than 10 mg/l). Concentrations of other constituents varied slightly but not significantly. In summary, the general water quality did not improve nor was it degraded, after treatment in the two ponds (without chemical treatment).

Treatment with Flocculent and Sulfuric Acid

A magnifloc cationic flocculent designed to precipitate out suspended solids concentrations was added to the two-pond system on Tract C-b. This was done at a time when mining activities were occurring and large increases in total suspended solids were expected to be observed in the two ponds.

Water quality samples were taken on September 16, 1981 at the inflow to Pond A and the outflow from Pond B to assess the effectiveness of the flocculent. The concentration of suspended

solids at the inflow to the system was found to be 565 mg/l, with the concentration reduced to 6.0 mg/l at the outflow of the system. These data clearly indicate the effectiveness of the flocculent, as the suspended solids concentration was reduced by about 99%. At the same time, the silica concentration increased (from 23 mg/l to 35 mg/l) and the total dissolved solids concentration increased (from 1,354 mg/l to 1,517 mg/l). However, these increases did not significantly degrade the water quality.

At the same time as the flocculent was added (during mining activities), sulfuric acid was also added in order to reduce the pH of the water before it was discharged from the two-pond system. The water sampled at the inflow point had a pH of 9.2, compared to a value of 7.8 at the outflow point, which reflects the addition of sulfuric acid. At the same time, alkalinity was reduced from 1147 mg/l to 926 mg/l (a decrease of 19%), while acidity remained stable at <5 mg/l. The one apparent effect of adding sulferic acid was an increase in sulfate from 186 mg/l to 311 mg/l (an increase of 77%). However, this increase in sulfate did not seriously degrade the water quality.

The overall conclusion regarding the effectiveness of the one- and two-pond systems is the same. The water quality constituents analyzed for in this study were not appreciably affected by the respective pond systems. With respect to the addition of flocculent and sulfuric acid, both additives appear to adequately treat specific constituents. The flocculent was very effective in reducing suspended solids concentrations and the sulfuric acid reduced the pH. These changes occurred without significant degradations of the general water quality.

CHAPTER 4

QUALITY ASSURANCE PROGRAMS

FIELD SAMPLING PROGRAM QUALITY CONTROL

Grab samples were collected in 5-gallon carboys at each of the sampling points. Previous to sample collection, the carboys were thoroughly rinsed with a deionized water to prevent cross-contamination. In addition, samples were collected as close to the discharge point as possible in an effort to obtain representative samples. Immediately upon sample collection, the following constituents were measured with portable instruments: pH, temperature, dissolved oxygen, and specific conductance. In order to obtain accurate measurements the samples were analyzed for a period of at least 20 minutes, which allowed the instruments to equilibrate. In addition, all of the instruments were calibrated previous to sample measurement. The instruments were thoroughly cleaned with deionized water after each sample.

Samples which required filtering were filtered with high purity nitrogen in a Skougstad-type filter apparatus. This apparatus is composed of a polyethylene material and can be pressurized to force the sample through a 0.45 micron filter into the sample container. The dissolved organic carbon samples were filtered with a stainless steel apparatus through a 0.45 micron silver membrane filter to prevent the introduction of organics. Previous to the introduction of another sample into the filtering units, the units were disassembled and thoroughly decontaminated with deionized water. In addition, a new filter was installed into each unit previous to the filtration of another sample.

Following filtration, preservatives were added to the sample, if necessary. In addition, the samples were placed in ice chests and cooled to 4 degrees Celsius with ice. The U.S. EPA (1979a) recommended procedures were utilized for sample preservation. In addition, the U.S. EPA recommended sample volume requirements, containers, and holding times were used as guidelines during this study. All of these aspects are shown in Table 10.

Samples were shipped from Rifle, Colorado to the Colorado State University laboratory in Fort Collins and Core laboratories in Denver. Commercial buslines were used for these sample shipments due to the overnight services provided by these buslines. This arrangement worked very well throughout the duration of the project and, in every case except one, the samples were received by the laboratory within 18 hours of the sampling effort. The exception was during the July 20, 1982, sampling effort in which the samples were not received by the Colorado State University laboratory until 36 hours after the samples were collected.

TABLE 10
U.S. EPA RECOMMENDED SAMPLE PRESERVATIVES, VOLUME REQUIREMENTS, CONTAINERS, AND HOLDING TIMES (U.S. EPA. 1979)1

Constituent	Req. (ml)	Container[2]	Preservative	Holding Time[3]
RESIDUE				
Filterable	100	P, G	Cool, 4°C	7 Days
Non-Filterable	100	P, G	Cool, 4°C	7 Days
Total	100	P, G	Cool, 4°C	7 Days
Volatile	100	P, G	Cool, 4°C	7 Days
Settleable Matter	1000	P, G	None Req.	24 Hrs.
Turbidity	100	P, G	Cool, 4°	7 Days
METALS				
Dissolved	200	P, G	HNO_3 to pH<2	6 Mos.(4)
Suspended	200		Cool, 4°C	6 Mos.(4)
Total	100	P, G	HNO_3 to pH<2	6 Mos.(4)
Mercury Dissolved	100	P, G	HNO^3 to pH<2	38 Days (Glass) 13 Days (Hard Plastic)
Total	100	P, G	HNO_3 to pH<2	38 Days (Glass) 13 Days (Hard Plastic)

(continued)

TABLE 10
(Continued)

Constituent	Vol. Req. (ml)	Container[2]	Preservative	Holding Time[3]
INORGANICS, Non-Metallic				
Acidity	100	P, G	None Req.	24 Hrs.
Alkalinity	100	P, G	Cool, 4°C	24 Hrs.
Bromide	100	P, G	Cool, 4°C	24 Hrs.
Chloride	50	P, G	None Req.	7 Days
Cyanides	500	P, G	Cool, 4°C NaOH to pH 12	24 Hrs.
Fluoride	300	P, G	None Req.	7 Days
Nitrogen Ammonia	400	P, G	Cool, 4°C H_2SO_4 to pH<2	24 Hrs.
Nitrate	100	P, G	Cool, 4°C	24 Hrs.
Phosphorus Ortho-phosphate, Dissolved	50	P, G	Cool, 4°C	24 Hrs.
Total	50	P, G	Cool, 4°C H_2SO_4 to pH<2	24 Hrs.[6]
Silica	50	P only	Cool, 4°C	7 Days
Sulfate	50	P, G	Cool, 4°C	7 Days
Sulfide	500	P, G	2 ml. zinc acetate	24 Hrs.
Organic carbon	25	P, G	Cool, 4°C H_2SO_4 or HCl to pH<2	24 Hrs.

(continued)

TABLE 10

(continued)

1. More specific instructions for preservation and sampling are found with each procedure as detailed in this manual. A general discussion on sampling water and industrial wastewater may be found in ASTM, Part 31, p. 72-82 (1976) Method D-3370.

2. Plastic (P) or Glass (G). For metals, polyethylene with a polypropylene cap (no liner) is preferred.

3. It should be pointed out that holding times listed above are recommended for properly preserved samples based on currently available data. It is recognized that for some sample types, extension of these times may be possible while for other types, these times may be too long. Where shipping regulations present the use of the proper preservation technique or the holding time is is exceeded, such as the case of a 24-hour composite, the final reported data for these samples should indicate the specific variance.

4. Where HNO_3 cannot be used because of shipping restrictions, the sample may be initially preserved by icing and immediately shipped to the laboratory. Upon receipt in the laboratory, the sample must be acidified to a pH<2 with HNO_3 (normally 3 ml. 1:1 HNO_3/liter is sufficient). At the time of analysis, the sample container should be thoroughly rinsed with 1:1 HNO_3 and the washings added to the sample (volume correction may be required).

5. Data obtained from National Enforcement Investigations Center-Denver, Colorado, support a four-week holding time for this parameter in Sewerage Systems. (SIC 4952).

LABORATORIES QUALITY ASSURANCE PROGRAMS

Two laboratories were utilized during this sampling project. They consisted of the University of Colorado laboratory and CORE laboratories. The quality assurance programs for each will be individually discussed below.

CORE Laboratories

I. Instrument Quality Control
   A. Calibrations and Standardizations
      (1) Instruments are checked daily for temperature consistency, weighing accuracy, etc. prior to sample introduction to assure proper operation.
      (2) Detection limits and linear working range data are verified by using sample blanks, standards, standard additions, sample spiking, etc.
   B. Service
      Instruments receive periodic servicing to assure proper functioning within specifications. Special care is taken to insure precise and accurate operation of all analytical balances, being the initial source of laboratory accuracy. Files are maintained on all major analytical instruments to document servicing.

II. Laboratory Supplies and Reagents
   A. Water
      (1) Tap water - used as a preliminary wash for glassware daily.
      (2) Deionized water - obtained by passing through Cation-Anion ion exchange columns. This water meets all specifications set forth by the U.S. Environmental Protection Agency.
   B. Reagents - all A.C.S./analytical grade
   C. Solvents - all A.C.S./analytical grade
   D. Volumetric Glassware - all glassware used for this purpose meets Class A requirements as set forth by the National Bureau of Standards. This glassware includes volumetric flasks and pipets which are always used for standard preparation and measurement of sample volumes, as well as for other purposes.

III. Internal Quality Control/Precision and Accuracy

To assure that data be both precise and accurate, duplicate samples, spiked samples, and internal unknowns are run on a routine basis within the Aurora

Lab, as well as within the entire CORE laboratories network for comparative purposes.

In addition, the data base is evaluated on CORE's computer system prior to report finalization for statistically known correlations. These correlations include sodium conductivity, anion/cation balances, cation/anion sums, total dissolved solids, maximum oil and grease, maximum BOD, and nitrogen relationships.

Ultimately, a data base which has had individual data point pairs compared against themselves, individual sample inter-relationships compared against themselves and sample interrelationships compared against other samples within the same area or project will be provided.

This detailed procedure performed on a continuing basis results in water quality data that is both precise and accurate.

IV. Sample Tracking

Sample bottles with the appropriate preservatives added are supplied by the laboratory for use in the field. Records are maintained which indicate bottle groupings, client name, client location, and total bottles shipped. This information is then cross-referenced upon sample receipt.

V. Analysis Reporting

Raw data is handled a single time when entered into the in-house PDP-11 computer for calculation, storage, and reporting. The data base analyses previously mentioned is then performed and appropriate analyses are re-checked and re-entered into the computer. Subsequent data manipulation, i.e., additional reports, transfer of data base to client computers, storage, etc. are handled electronically to insure integrity of the data.

Colorado State University

Colorado State University laboratory has a quality control program in the following areas: sample preservation, sample analysis, and data handling. These programs are performed according to the criteria of the U.S. EPA (1979b). Each of these items are discussed further below.

The sample analysis quality control involves the use of blanks and duplicates. For example, both a blank and duplicate sample are analyzed per sample set. In addition, a standard curve consisting of four or more values is established and compared to the analytical results. The sample

analysis quality control also involves analyzing the U.S. EPA Reference Standard and biannual participation in the U.S. EPA performance study.

In regard to the data handling, records are kept of the correlation coefficient, slope, and the intercept of the standard curve. These records are used to insure linearity and acceptability of standards. In addition, quality control charts are kept to provide criteria for accepting data.

Kaman Tempo Quality Control

Kaman Tempo also performed internal quality control measures for the data received by the laboratories. These measures consisted of calculating the cation-anion balance for the data set and the evaluation of general water quality trends at each sampling point. The ions utilized for the cation/anion balance calculation consisted of calcium, magnesium, sodium, potassium, carbonate, bicarbonate, sulfate, and chloride. The data was considered to be fairly accurate if the difference between the cations and anions did not exceed ten percent.

These quality control measures resulted in identifying some potential problems with the analytical data received from the Colorado State University laboratory. For instance, some data sets had a cation-anion balance off by as much as 45 percent. However, by the time the data was received, many of the constituents were beyond the recommended holding periods and, therefore, a reanalysis would probably not have resulted in more accurate data.

An additional problem associated with the Colorado State University data were the analytical results for some fairly volatile constituents. For example, ammonia and nitrate are very inconsistent and, in some cases, reflect very abrupt increases which are not characteristic with historic trends.

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APPENDIX A

ANALYTICAL AND FIELD DATA FOR THE SAMPLING SITES ON TRACT C-a

TABLE A-1: ANALYTICAL AND FIELD DATA FOR THE MINE INFLOW TO JEFFREY POND

Constituents*	Sampling Date 9/17/81	5/27/82	7/20/82	9/23/82	11/17/82	1/7/83	3/9/83
ABBREVIATED MONITORING							
Ammonia (NH_3-N)	0.11	.28	.467	.333		.354	.253
Arsenic	<0.01	<0.005	<.003	.003	<.005	<.005	<.005
Bicarbonate	532	548	577	527	599	554	548
Carbonate	<1	5.1	6.06	7.59	9.09	9.44	3.02
Calcium	36	32	44.1	46.3	48.7	32.6	31.9
Chloride	8.34	7.9	8.23	8.52	7.74	7.89	7.89
Fluoride	1.71	1.1	1.51	1.4	1.2	1.32	1.21
Iron	0.06	.017	.15	1.00	<.01	.085	<.01
Magnesium	83	78.9	77.1	95	77.5	76.2	72.8
Mercury (μg/l)	<0.3	<.001	<.001	<.001		.001	<.001
Molybdenum	<0.1	<0.05	<.05	<.03	.052	<.03	.107
Nitrate (NO_3-N)	<0.1	.09	<1.0	<1.0	.245	.231	2.02
Potassium	0.35	.8	.531	1.26	.666	.615	.136
Selenium	<0.01	<.02	<.002	<.002	<.002	<.01	<.01
Silica	23	11	12.3		12.7	12.1	12.0
Sodium	200	190	191	174	193	195	195
Sulfate	430	388	343	438	414	400	400
Vanadium	<0.5			<0.1		<.005	<.005
Acidity (As $CaCO_3$)	<5	5.6	5.25	3.51	3.79	3.13	9.45
Alkalinity (As $CaCO_3$)	469	458	483	445	506	470	454

*In mg/l, unless otherwise indicated.

TABLE A-1 (Continued)

Constituents*	Sampling Date 9/17/81	5/27/82	7/20/82	9/23/82	11/17/82	1/7/83	3/9/83
Conductivity (field, μmhos/cm)	2250	1400	1500	1670	1520	1440	1350
DOC	3.1	4.7	<3	4.0	5.0	2.8	<2
pH (field, units)	9.2	8.35	8.92	7.17	8.6	7.5	7.65
Dissolved Oxygen (field, ppm)	3	3.2	6.8	3.9	3.5	3.0	4.6
Boron	0.41	.21	.12	<3.0	.15	.169	.175
Fractionated DOC							
-Hydrophobics (Total)	1.5	3.6		1.7		1.0	
-Bases	0.2	0.0		0.1		0.0	
-Acids	1.1	0.2		1.1		0.9	
-Neutral	0.2	3.4		0.5		0.1	
-Hydrophilics (Total)	2.4	1.1		2.3		1.8	
-Bases	0.7	0.0		0.1		0.5	
-Acids	1.6	1.1		1.4		1.2	
-Neutrals	0.1	0.0		0.8		0.1	
Residues							
-TDS	1033	992	614	1152	1070	1080	1020
-TSS	<4	<4	< 4	<4	<4	<4	4
-Total Solids	1036	992	1074	1208	1082	1080	1024
-Total Volatile	226		223	216	188	148	178
-Settleable Matter	<0.1	<1	<.1	<0.1	<0.1	<.1	<.1
Temperature (field, °C)	14	15	19	16	13	11	12

*In mg/l, unless otherwise indicated.

TABLE A-1 (Continued)

Constituents*	Sampling Date 9/17/81	5/27/82	7/20/82	9/23/82	11/17/82	1/7/83	3/9/83
COMPREHENSIVE MONITORING*							
Aluminum		<.02	.29	<1.0	<.02	.173	.073
Barium		.083	<1.0	<1.0	.069		.07
Beryllium		<.0005	<.0005	<.01		.887	<.0005
Cadmium		<.001	.005	.005	<.004	<.004	<.004
Chromium		<.005	<.005	<.02		<.05	<.05
Cobalt		<.005	<.005	<.05		<.05	<.05
Copper		<.001	<.001	<.005		<.005	<.005
Cyanide		<0.005	<0.005			<.1	<.1
Lead		<.01	<.01	<.01		<.025	<.025
Lithium		.09	.077	.079		.085	.079
Manganese		<.002	<.002	.042	1.5	.007	<.005
Nickel		<.005	<.001	<.05	.01	<.01	<.01
Phenols		<0.005	<.005			<.05	
Phosphorus							
-Ortho		.05	<.4			<.01	<.01
-Total		.5	<.05	<.4	.094	.178	.193
Silver		<.001	<.001	<.001		<.01	<.01
Strontium		8.4	6.8	9.26	6.83	8.1	7.23
Sulfide		<0.1	0.1			.06	
Thallium		<.005				.01	.004
Thiosulfate		<5	<0.05			<.5	
Tin		<.05	<0.01				

*In mg/l, unless otherwise indicated.

TABLE A-1 (Continued)

Constituents*	Sampling Date 9/17/81	5/27/82	7/20/82	9/23/82	11/17/82	1/7/83	3/9/83
Titanium		<0.5	<.05				
Zinc		.005	.007	.122		.075	.033
Turbidity		.6	4.5	7.5			
Uranium-234 (pci/l)		1.3 ± 1.1		0.3 ± .3			
Uranium-235 (pci/l)		.2 ± 0.5		0.0 ± .2			
Uranium-238 (pci/l)		0.9 ± 1.0		0.3 ± .3			

*In mg/l, unless otherwise indicated.

TABLE A-2: ANALYTICAL AND FIELD DATA FOR THE JEFFREY POND DISCHARGE INTO THE WEST RETENTION POND.

	Sampling Date						
Constituents*	9/17/81	5/27/82	7/20/82	9/23/82	11/17/82	1/7/83	3/9/83
ABBREVIATED MONITORING							
Ammonia (NH_3-N)	0.10	.11	.317	.238		.306	.243
Arsenic	<0.01	<.005	.003	<.003	<.005	<.005	<.005
Bicarbonate	531	540	546	523	525	533	548
Carbonate	1.08	5.7	11.4	8.01	10.5	7.21	5.76
Calcium	37	31	44.1	47.5	63.5	32.4	31.7
Chloride	9.47	8.1	7.90	8.94	8.67	7.58	8.14
Fluoride	1.70	1.2	1.22	1.43	1.28	1.21	1.31
Iron	0.05	.026	.049	.59	.282	.164	.124
Magnesium	83	79.4	78.1	98.9	84	74.1	76.5
Mercury (μg/l)	<0.3	<.001	<.001	<.001		<.001	<.001
Molybdenum	<0.1	<0.05	<.05	<.03	.038	<.03	.3
Nitrate (NO_3-N)	0.1	.008	<1.0	<1.0	.245	.219	8.59
Potassium	0.36	.9	.369	1.24	.817	.636	1.02
Selenium	<0.01	<.02	<.002	<.003	<.002	<.01	<.01
Silica	22	11	10.9		12.7	11.9	10.9
Sodium	190	187	197	170	196	198	192
Sulfate	382	392	345	427	441	412	364
Vanadium	<0.5			<0.1		<.005	<.005
Acidity (As $CaCO_3$)	<5	4.9	2.52	3.28	2.53	3.78	4.99
Alkalinity (As $CaCO_3$)	474	452	467	442	448	449	459

*In mg/l, unless otherwise indicated.

TABLE A-2 (Continued)

Constituents*	Sampling Date 9/17/81	5/27/82	7/20/82	9/23/82	11/17/82	1/7/83	3/9/83
Conductivity (field, μmhos/cm)	1425	1400	1400	1510	1400	1390	1510
DOC	3.9	3.2	<3	4.0	4.0	3.6	3
pH (field, units)	8.2	8.35	8.96	7.0	8.7	7.8	7.45
Dissolved Oxygen (field, ppm)	7.0	7.4	8.5	6.2	5.9	5.9	6.2
Boron	.39	.22	.8	<3.0	.15		.183
Fractionated DOC							
-Hydrophobics (Total)	1.5	2.4		1.8		1.5	
-Bases	0.2	0.0		0.1		0.0	
-Acids	1.1	0.9		1.2		1.2	
-Neutral	0.2	1.5		0.6		0.3	
-Hydrophilics (Total)	2.4	1.3		2.2		2.1	
-Bases	0.7	0.2		0.0		1.1	
-Acids	1.6	1.1		1.5		0.7	
-Neutrals	0.1	0.0		0.7		0.3	
Residues							
-TDS	1053	988	1018	1188	1220	1446	1023
-TSS	<4	4	6	10	<4	<4	5
-Total Solids	1054	1016	1061	1244	1228	1446	1028
-Total Volatile	214	N/M	235	230	252	74	184
-Settleable Matter	<0.1	<1	.3	<0.1	<0.1	<.1	<.1
Temperature (field, °C)	15.5	16	23	16	10	10	11

*In mg/l, unless otherwise indicated.

TABLE A-2 (Continued)

Constituents*	Sampling Date 9/17/81	5/27/82	7/20/82	9/23/82	11/17/82	1/7/83	3/9/83
COMPREHENSIVE MONITORING*							
Aluminum		<.02	.06	<1.0	.042	.175	.242
Barium		.081	1.05	<1.0		.074	.069
Beryllium		<.0005	<.005	<.01		.493	<.0005
Cadmium		<.001	.005	.005	<.004	<.004	<.004
Chromium		<.005	<.005	.024		<.05	<.05
Cobalt		<.005	<.005	<.05		<.05	<.05
Copper		<.001	<.001	<.005		<.005	<.005
Cyanide		<0.005		<0.5		<.1	<.1
Lead		<.01	<.01	<.01		<.025	<.025
Lithium		.091	.077	.074		.085	.085
Manganese		<.002	<.002	.042	.056	.007	<.005
Nickel		<.005	<.001	<.05	.01	<.01	<.01
Phenols		<.005		<.05		<.05	
Phosphorus							
-Ortho		<.01	<.4	<.4		<.01	.257
-Total		.4	<.05		.141	.144	.299
Silver		<.001	<.001	<.001		<.01	<.01
Strontium		8.2	8.5	9.19	7.16	8.31	7.24
Sulfide		<.1		<.1		.06	
Thallium		<.005				.012	.004
Thiosulfate		5		<.05		<.05	
Tin		<.05		<0.01			

*In mg/l, unless otherwise indicated.

TABLE A-2 (Continued)

Constituents*	Sampling Date 9/17/81	5/27/82	7/20/82	9/23/82	11/17/82	1/7/83	3/9/83
Titanium		<.5		<.05			
Zinc		.009	.032	.077		.062	.026
Turbidity		1.4	3.2	4.9			
Uranium-234 (pci/l)		.1 ± .4		0.4 ± 0.4			
Uranium-235 (pci/l)		0 ± .1		0.0 ± 0.1			
Uranium-238 (pci/l)		1.4 ± 1.5		0.3 ± 0.3			

*In mg/l, unless otherwise indicated.

TABLE A-3: ANALYTICAL AND FIELD DATA FOR THE WEST RETENTION POND DISCHARGE.

	Sampling Date						
Constituents*	9/17/81	5/27/82	7/20/82	9/23/82	11/17/82	1/7/83	3/9/83
ABBREVIATED MONITORING							
Ammonia (NH_3-N)	0.22	.16	.424	.163		.317	.185
Arsenic	<0.01	<.005	<.003	<.003	<.005	<.005	<.005
Bicarbonate	535	541	558	368	524	553	541
Carbonate	<1	6.8	5.99	5.58	10.4	10.1	6.09
Calcium	37	32	44.5	47.5	62	34.6	32.4
Chloride	9.47	8.0	7.8	5.73	8.56	8.02	8.14
Fluoride	1.25	1.2	1.2	1.11	1.26	1.32	1.31
Iron	0.26	.018	.069	.283	.44	.644	<.01
Magnesium	83	77.4	77.5	100.9	84.6	73.1	78.7
Mercury (µg/l)	<0.3	<.001	<.001	<.001		<.001	<.002
Molybdenum	<0.1	<.05	<.05	<.03	.24	<.03	.232
Nitrate (NO_3-N)	0.2	.05	<1.0	<1.0	.769	.516	.407
Potassium	0.36	.7	.466	1.34	.858	.632	1.49
Selenium	<0.01	<.02	<.002	<.002	<.002	<.01	<.01
Silica	20	11	11.6		12.8	11.7	11.1
Sodium	190	194	194	177	195	198	198
Sulfate	348	391	350	302	449	398	402
Vanadium	<0.5			<0.1		<.005	<.005
Acidity (As $CaCO_3$)	<5	4.1	4.96	2.33	2.53	2.92	4.6
Alkalinity (As $CaCO_3$)	469	455	467	311	447	470	454

*In mg/l, unless otherwise indicated.

TABLE A-3 (Continued)

Constituents*	Sampling Date 9/17/81	5/27/82	7/20/82	9/23/82	11/17/82	1/7/83	3/9/83
Conductivity (field, µmhos/cm)	1475	1400	1400	1400	1420	1450	1320
DOC	3.3	3.7	3	3.8	3	4.6	2
pH (field, units)	8.1	8.4	8.9	6.9	7.9	8.1	7.6
Dissolved Oxygen (field, ppm)	8.0	6.6	6.4	3.9	4.2	5.8	5.6
Boron	.37	.21	.9	<3	.16	.175	.173
Fractionated DOC							
-Hydrophobics (Total)	1.6	2.0		1.5		1.6	
-Bases	0.0	0.0		0.0		0.0	
-Acids	1.1	0.9		1.0		1.0	
-Neutral	0.5	1.1		0.5		0.6	
-Hydrophilics (Total)	1.7	1.2		2.3		2.0	
-Bases	0.2	0.1		0.1		0.6	
-Acids	1.4	1.1		1.7		1.1	
-Neutrals	0.1	0.0		0.5		0.2	
Residues							
-TDS	1003	1390	980	1198	1250	1392	1028
-TSS	4	<4	<4	<4	<4	<4	<4
-Total Solids	1007	1395	1023	1193	1254	1392	1028
-Total Volatile	205		225	207	236	86	162
-Settleable Matter	<0.1	<1	<1	<.1	<0.1	<.1	<.1
Temperature (field, °C)	15	16	20	16	10	9.5	11

*In mg/l, unless otherwise indicated.

TABLE A-3 (Continued)

Constituents*	Sampling Date 9/17/81	5/27/82	7/20/82	9/23/82	11/17/82	1/7/83	3/9/83
COMPREHENSIVE MONITORING*							
Aluminum		.04	.27	<1.0	.089	.158	.115
Barium		.082	1.05	<1.0		.075	.07
Beryllium		<.0005	<.0005	<.01		1.103	.946
Cadmium		<.001	<.005	.005	<.004	<.004	<.004
Chromium		<.005	<.005	.024		<.05	<.05
Cobalt		<.005	<.005	<.05		<.05	<.05
Copper		<.001	<.001	<.005		.021	<.005
Cyanide		<0.005		<0.5		<.1	8.72
Lead		<.01	<.01	<.01		.025	.025
Lithium		.09	.077	.079		.085	.079
Manganese		<.002	<.002	.042	.063	.022	<.005
Nickel		<.005	<.001	<.05	.01	<.01	<.01
Phenols		<.005		<.05		<.05	
Phosphorus							
-Ortho		<.01	<.4	<.4		<.01	<.01
-Total		.4	<.05		.087	.166	.379
Silver		<.001	<.001	<.001		<.01	<.01
Strontium		8.4	7.2	9.19	7.49	8.1	7.14
Sulfide		<.1		<.1		.06	
Thallium		<.005				.011	.005
Thiosulfate		<5		<.05		<.05	
Tin		<.05		<0.01			

*In mg/l, unless otherwise indicated.

TABLE A-3 (Continued)

Constituents*	Sampling Date						
	9/17/81	5/27/82	7/20/82	9/23/82	11/17/82	1/7/83	3/9/83
Titanium		<.5		<.05			
Zinc		.006	.007	.068		.08	.013
Turbidity		1.2	1.7	5.2			
Uranium-234 (pci/l)		.5 ± .9		0.2 ± 0.2			
Uranium-235 (pci/l)		0 ± .1		0.0 ± 0.1			
Uranium-238 (pci/l)		.5 ± .9		0.3 ± 0.3			

*In mg/l, unless otherwise indicated.

APPENDIX B

ANALYTICAL AND FIELD DATA FOR THE SAMPLING SITES ON TRACT C-b

TABLE B-1: ANALYTICAL AND FIELD DATA FOR THE MINE DISCHARGE TO POND A.

Constituents*	Sampling Date 9/16/81	5/27/82	7/20/82	9/23/82	11/17/82	1/7/83	3/9/83
ABBREVIATED MONITORING							
Ammonia (NH_3-N)	.90	.24	.688	.208		.342	.396
Arsenic	<.01	<.005	<.003	.003	<.005	<.005	<.005
Bicarbonate	1135	1245	1300	896	1190	-1320	1350
Carbonate	10.8	28.6	46.1	24.1	53.3	46.9	33.2
Calcium	7.30	7.0	4.78	5.5	6.08	5.62	5.52
Chloride	8.34	7.2	6.61	5.79	7.47	7.4	8.14
Fluoride	15.3	19.2	19.8	17.0	11.1	18.9	19.04
Iron	.08	.063	.210	<.1	<.01	.079	.026
Magnesium	4.40	4.0	5.38	4.31	5.0	4.52	3.8
Mercury (μg/l)	<.3	<.001	<.001	<.001		<.001	<.001
Molybdenum	<.1	<.05	.14	<.03	.125	<.03	.883
Nitrate (NO_3-N)	1.2	4.0	1.2	1.34	3.12	4.12	3.91
Potassium	4.3	2.9	2.29	1.81	1.65	1.92	4.67
Selenium	<.01	.02	<.002	<.002	<.002	<.01	<.01
Silica	23	6.7	7.3		7.23	7.06	6.12
Sodium	540	530	578	391	525	551	545
Sulfate	176	16.8	13.6	10.9	22.6	14.6	17
Vanadium	<.5			<.1		<.005	<.005
Acidity (As $CaCO_3$)	< 5	5.2	3.57	3.24	2.63	3.63	5.3
Alkalinity (As $CaCO_3$)	1147	1068	1140	775	1065	1160	1160

*In mg/l, unless otherwise indicated.

TABLE B-1 (Continued)

Constituents*	Sampling Date 9/16/81	5/27/82	7/20/82	9/23/82	11/17/82	1/7/83	3/9/83
Conductivity (field, µmhos/cm)	2275	2430	2500	1620	1925	2100	2100
DOC	4.7	3.0	<3	2.8	5	4.3	<2
pH (field, units)	9.2	8.4	8.8	8.6	8.2	8	8.3
Dissolved Oxygen (field, ppm)	4.0	4.3	5.7	5.4	4.3	4.6	4.0
Boron	.86	.87	.77	<3	.756	.739	.738
Fractionated DOC							
-Hydrophobics (Total)	3.9	2.2		1.8		2.3	
-Bases	0.2	0.0		0.1		0.1	
-Acids	0.9	0.8		0.6		1.0	
-Neutral	2.8	1.3		1.2		1.2	
-Hydrophilics (Total)	0.8	0.8		0.9		2.0	
-Bases	0.2	0.1		0.0		0.9	
-Acids	0.3	0.4		0.6		0.6	
-Neutrals	0.3	0.3		0.3		0.5	
Residues							
-TDS	1354	1280	1312	912	1361	1380	1366
-TSS	565	8	<4	<4	<4	<4	6
-Total Solids	1919	1296	1424	958	1372	1380	1372
-Total Volatile	320		194	117	88	172	136
-Settleable Matter (ml/l)	4.5	<1	<.1	<.1	<.1	<.1	<.1
Temperature (field, °C)	13	21	23.5	22	16	16	17

*In mg/l, unless otherwise indicated.

TABLE B-1 (Continued)

Constituents*	Sampling Date 9/16/81	5/27/82	7/20/82	9/23/82	11/17/82	1/7/83	3/9/83
COMPREHENSIVE MONITORING*							
Aluminum		.1	.31	<1	.036	.181	.414
Barium		.92	1.05	1.05		.742	.751
Beryllium		<.0005	<.0005	<.01		.647	4.24
Cadmium		<.001	.016	<.005	.004	<.004	<.004
Chromium		<.005	<.005	<.02		<.05	<.05
Cobalt		<.005	<.005	<.05		<.05	<.05
Copper		<.001	.001	<.005		.119	<.005
Cyanide		<.005		<.05		<.1	<.1
Lead		<.01	<.01	<.01		.025	<.025
Lithium		.043	.028	.062		.04	.037
Manganese		<.002	.063	.004	.65	.007	<.005
Nickel		<.005	<.001	<.05	.01	<.01	<.01
Phenols		<.005		<.05		<.5	
-Ortho		<.01	<.4	<.4	<.01		.212
-Total		.8	.34		.043	.244	1.08
Silver		<.001	.001	<.001		<.01	<.01
Strontium		2.0	1.1	1.73	1.15	1.31	1.84
Sulfide		<.1		< .1		.06	
Thallium		<.005				.026	.023
Thiosulfate		< 5		<.05		<.05	
Tin		<.05		<.01			

*In mg/l, unless otherwise indicated.

TABLE B-1 (Continued)

Constituents*	Sampling Date 9/16/81	5/27/82	7/20/82	9/23/82	11/17/82	1/7/83	3/9/83
Titanium		<.5		<.5			
Zinc		.007	.007	.001		.02	.004
Turbidity (NTU)		2.8	.8	1.9			
Uranium-234 (pci/l)		1.6 ± 1.4		0.0 ± .2			
Uranium-235 (pci/l)		0.0 ± .1		0.0 ± .3			
Uranium-238 (pci/l)		2.3 ± 1.9		0.4 ± .5			

*In mg/l, unless otherwise indicated.

TABLE B-2: ANALYTICAL AND FIELD DATA FOR THE DISCHARGE OF POND B.

Constituents*	Sampling Date 9/16/81	5/28/82	7/20/82	9/23/82	11/17/82	1/7/83	3/9/83
ABBREVIATED MONITORING							
Ammonia (NH_3-N)	1.33	.28	.326	.346		.342	.372
Arsenic	<.01	<.005	<.003	.004	<.005	<.005	<.005
Bicarbonate	1069	1295	1210	1359	1274	1287	1340
Carbonate	<1.0	25.9	48.2	45.7	47.5	63.2	38.6
Calcium	6.50	10	4.78	5.99	5.67	5.43	6.04
Chloride	8.12	7.2	6.09	6.13	7.25	6.98	8.14
Fluoride	15.10	19.7	18.2	18.7	12.2	18.1	19.23
Iron	.05	.048	.311	<.1	<.01	.126	.065
Magnesium	4.60	5.7	4.64	4.07	3.94	4.61	4.13
Mercury (mg/l)	<.3	<.001	<.001	<.001		.002	.002
Molybdenum	<.1	<.05	.11	<.03	.063	<.03	.804
Nitrate (NO_3-N)	1.5	2.45	< 1.0	< 1.0	5.82	2.5	12.1
Potassium	4.1	2.7	2.2	2.56	1.66	1.7	4.94
Selenium	<.01	<.02	<.002	<.002	<.002	<.01	<.01
Silica	35	6.6	7.5		5.61	6.75	5.98
Sodium	540	550	541	578	522	555	545
Sulfate	311	50.3	16.2	5.98	14.4	15.7	17.5
Vanadium	<.5		<.1			<.005	<.005
Acidity (As $CaCO_3$)	<5	6.2	2.97	3.94	3.36	2.6	4.5
Alkalinity (As $CaCO_3$)	926	1104	1070	1190	1124	1160	1160

*In mg/l, unless otherwise indicated.

TABLE B-2 (Continued)

Constituents*	Sampling Date 9/16/81	5/28/82	7/20/82	9/23/82	11/17/82	1/7/83	3/9/83
Conductivity (field, µmhos/cm)	2200	2000	2100	2500	2150	2100	2050
DOC	3.9	3.7	<3	3.6	2	4.2	6
pH (field, units)	7.8	8.6	9.2	8.5	9.0	8.2	8.3
Dissolved Oxygen (field, ppm)	9	7.0	6.3	4.3	4.5	4.7	5.1
Boron	.79	.990	.83	<3	.648	.718	.736
Fractionated DOC							
-Hydrophobics (Total)	2.1	3.0		2.3		3.0	
-Bases	0.3	0.1		0.1		0.1	
-Acids	1.7	1.1		1.2		1.1	
-Neutral	0.2	1.8		1.0		1.9	
-Hydrophilics (Total)	1.5	0.7		1.3		1.2	
-Bases	0.1	0.2		0.1		0.5	
-Acids	1.0	0.3		0.6		0.0	
-Neutrals	0.3	0.3		0.7		0.7	
Residues							
-TDS	1517	1390	1206	1380	1354	1398	1352
-TSS	6	<4	<4	5	<4	<4	<4
-Total Solids	1523	1395	1342	1439	1358	1398	1356
-Total Volatile	297	N/M	244	125	120	180	96
-Settleable Matter	<.1	<1	<.1	<.1	<.1	<.1	<.1
Temperature (field, °C)	15.5	20	23	22	15	13	12

*In mg/l, unless otherwise indicated.

TABLE B-2 (Continued)

Constituents*	Sampling Date 9/16/81	5/28/82	7/20/82	9/23/82	11/17/82	1/7/83	3/9/83
COMPREHENSIVE MONITORING*							
Aluminum		.2	.3	<1	<.02	.235	.586
Barium		.83	1.34	1.34		.735	.748
Beryllium		<.0005	<.0005	<.01		.166	6.35
Cadmium		<.001	<.005	.008	<.004	<.004	<.004
Chromium		<.005	<.005	<.02		<.05	<.05
Cobalt		<.005	<.005	<.05		<.05	<.05
Copper		.002	<.001	<.005		<.005	<.005
Cyanide		<.005		<.05		<.1	1.06
Lead		<.01	.04	<.01		<.025	<.025
Lithium		.042	.028	.056		.043	.037
Manganese		<.002	.012	.004	1.47	<.005	<.005
Nickel		<.005	<.001	<.05	.01	<.01	<.01
Phenols		<.005		<.05		<.05	
Phosphorus							
-Ortho		<.01	<.4	<.4		<.01	.166
-Total		1.0	<.05		.224	.202	1.03
Silver		<.001	<.001	<.001		<.01	<.01
Strontium		1.8	1.0	1.73	.977	1.29	1.76
Sulfide		<.1		<.1		.06	
Thallium		<.005				.033	.026
Thiosulfate		<5		<.05		<.5	
Tin		<.05		<.01			

*In mg/l, unless otherwise indicated.

TABLE B-2 (Continued)

Constituents*	Sampling Date						
	9/16/81	5/28/82	7/20/82	9/23/82	11/17/82	1/7/83	3/9/83
Titanium		<.05		<.5			
Zinc		.008	.013	.007		.02	.007
Turbidity		1.2	1.9	1.2			
Uranium-234 (pci/l)		.5 ± .9		0.0 ± .2			
Uranium-235 (pci/l)		0.0 ± .1		0.0 ± .2			
Uranium-238 (pci/l)		.5 ± .9		0.1 ± .2			

*In mg/l, unless otherwise indicated.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Characterization of Oil Shale Mine Waters, Central Piceance Basin, Colorado		5. REPORT DATE March, '84 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) K. E. Kelly J. D. Dedrick		8. PERFORMING ORGANIZATION REPORT NO.
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15. SUPPLEMENTARY NOTES

16. ABSTRACT

A study was conducted to characterize the oil shale mine waters in the Piceance Basin. The study sites were Federal Prototype Lease Tracts C-a and C-b, located in the central portion of the basin. The objective was to collect water quality data in order to characterize the mine waters and to assess the effectiveness of treatment systems located at these facilities. These treatment systems involve in-series retention ponds.

The overall conclusion with respect to the effectiveness of the retention pond systems in maintaining or improving water quality is that they appear to make negligible difference unless chemicals are added. The addition of the flocculent during periods of active mining was very effective in reducing the suspended sediment concentrations. In addition, sulfuric acid treatment reduced the pH.

Concerning the general water quality, such as the trace elements, cations and anions, and other pertinent constituents, there was not a significant increase or decrease due to the chemical additives. In addition, the effectiveness of the one-pond and two-pond systems are very similiar.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Synthetic Fuels Oil Shale Minewaters Wastewater treatment	Colorado Mining Piceance	68D 05C

18. DISTRIBUTION STATEMENT Release unlimited	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
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PROJECT SUMMARY

CHARACTERIZATION OF OIL SHALE MINE WATERS CENTRAL PICEANCE BASIN, COLORADO

by
KEVIN E. KELLY AND JIM D. DEDERICK

A study was conducted to characterize the oil shale mine waters in the Piceance Basin. The study sites were the Federal Prototype Lease Tracts C-a and C-b, located in the central portion of the basin. The objective was to collect water quality data in order to characterize the mine waters and to assess the effectiveness of the treatment systems located at these facilities. These treatment systems involve in-series retention ponds. Additionally, the effectiveness of a one-pond versus two-pond system was investigated.

The sources of the water routed through the retention ponds were water pumped from the on-site aquifers that were dewatered during mining activities and the water pumped directly from the underground mines. Water samples were taken from both the inflow and outflow points for both the Tract C-a and C-b pond systems and were analyzed for a fairly detailed suite of selected water quality parameters. This suite included total suspended solids (TSS) and total dissolved solids (TDS), pH, the major species of cations and anions, and dissolved trace elements such as selenium, lead, and arsenic. The inflow samples were then compared to the outflow samples to determine changes in water quality and, therefore, the effectiveness of the retention ponds. An additional part to this study was the assessment of the

effectiveness of using a flocculent and sulfuric acid for the treatment of excess waters encountered during active mining on Tract C-b. The flocculent was added to reduce the suspended solids concentrations and the acid was used to reduce the somewhat high pH values.

The water quality changes observed during this study, when comparing the inflow waters to the outflow waters of the respective pond systems, were found to be generally small. Fluctuations may have been due to such phenomena as pH changes, aeration, evaporation, and oxidation-reduction changes associated with the transformation of the groundwater from an underground (aquifer) environment to a surface (retention pond) environment. The retention time, as well as inherent laboratory technique variations, may also help explain the small fluctuations.

The overall conclusion with respect to the effectiveness of the retention pond systems in maintaining or improving water quality is that they appear to make no significant difference unless chemicals are added. The addition of the flocculent in the Tract C-b pond system was effective in reducing the suspended sediment concentrations. In addition, the sulfuric acid treatment effectively reduced the pH values. Concerning the general water quality, such as the trace elements, cations and anions, and other pertinent parameters, there was no noticeable increase or decrease.

INTRODUCTION

The objective of this study was to provide a detailed characterization of the mine waters and treatment systems used on Federal Prototype Lease Tracts C-a and C-b, located in the Piceance Basin, Colorado (Figure 1). These data were collected to assist other oil shale developers and permit writers in selecting appropriate controls for the handling of excess mine waters.

The treatment facilities for the excess mine waters at both sites consisted of two in-series retention ponds. To characterize these facilities, samples were collected for determining the chemistry of water derived from mine pumpage and aquifer dewatering activities previous to treatment. In addition, samples were derived from the outflow of the in-series retention ponds to characterize the treatment. Presently, the treated water is disposed of by reinjection into the groundwater system, is utilized for on-site activities, or is discharged to surface water systems. The approach, data collection procedures, and results are discussed below.

APPROACH

The procedures utilized for obtaining these data involved collecting grab samples of five sampling points. On Tract C-a, the sample collection included sampling the mine water inflow into the primary retention pond (Jeffrey Pond), the outflow of the primary retention pond into the secondary retention pond

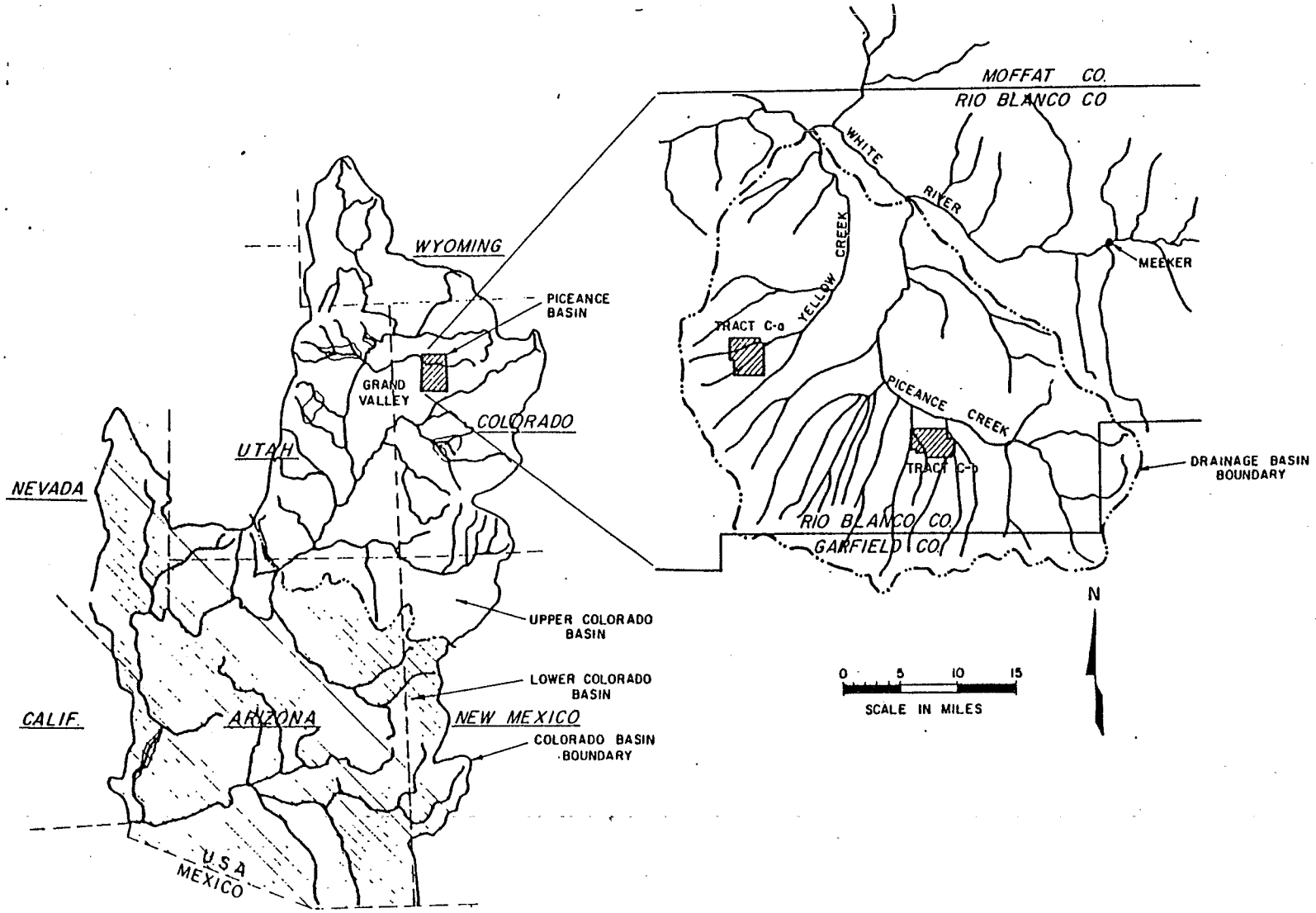

Figure 1: Location of Tracts C-a and C-b Study Area in Piceance Basin (Slawson, 1980)

(West Retention Pond), and the discharge from the secondary pond previous to disposal. It was felt that Jeffrey Pond was fairly inconsequential with respect to the total treatment system due to the very short residence time of the mine waters in this pond. Therefore, the above described sampling scheme would adequately assess the effectiveness of treating the excess mine waters with a one-pond system, namely the West Retention Pond.

In regard to Tract C-b, samples of untreated mine water were collected at the inflow point of the primary retention pond (Pond A). In addition, samples of the treated water were collected from the discharge of the secondary retention pond (Pond B), which is in-series with Pond A. During periods of active mining on Tract C-b, sulfuric acid and a magnifloc cationic flocculent were added to the ponds in order to treat the pH and total suspended solids (TSS), respectively. This sampling strategy assessed the effectiveness of treatment consisting of two ponds which are in series. In addition, the sampling program allowed for an evaluation of chemical treatment (i.e., flocculent and sulfuric acid).

The following constituents were measured in the field immediately upon sample withdrawal: pH, temperature, conductivity, and dissolved oxygen. The samples were then filtered (if necessary) and preserved according to the U.S. EPA (1979) recommended procedures. The samples were then shipped to the laboratories located at the Colorado State University in Fort Collins, Colorado, and Core Laboratories in Denver, Colorado. In

most cases, the U.S. EPA (1979) recommended holding times were observed. The holding times for a few constituents of the samples collected on July, 1982 were exceeded. However, the analytical results were generally in agreement with those for other sampling periods. Exceptions to this include nitrate and ammonia, which were higher in concentration than historic trends. Seven samples were collected at each sample collection point between September, 1981 and March, 1983.

A fairly detailed suite of constituents was selected for analysis during this study. This suite of constituents involved two groups, an abbreviated group and a comprehensive group (Table 1). Analysis for the abbreviated group of constituents was conducted during the months of September, 1981; September, 1982; and November, 1982. Analysis for the comprehensive group of constituents, which included the abbreviated group, was conducted during the months of May, 1982; July, 1982; January, 1983; and March, 1983. These constituents were selected after a review of the baseline water quality data collected by the Tract C-a and C-b operators, as well as the chemical characterization studies of simulated and observed in-situ oil shale process waters conducted by various researchers (e.g., Fox et al., 1978; Slawson, 1979; Pfeffer, 1974, Stuber and Leenheer, 1978; LBL, 1978).

DATA DISCUSSION

The analytical results for the data collected during this study on Tracts C-a and C-b are presented in Tables 2 and 3, respectively. In order to provide a perspective for evaluating

TABLE 1
LIST OF PARAMETERS FOR ABBREVIATED
AND COMPREHENSIVE ANALYSIS

ABBREVIATED

- Acidity
- Alkalinity
- Ammonia
- Arsenic
- Bicarbonate
- Boron
- Carbonate
- Calcium
- Chloride
- Conductivity
- Dissolved Organic Carbon (DOC)
- Dissolved Oxygen
- Fluoride
- Iron
- Magnesium
- Mercury
- Molybdenum
- Nitrate
- pH
- Potassium
- Residues (Total, total dissolved, total, suspended, settleable, and volatile)
- Silica
- Sodium
- Sulfate
- Temperature

COMPREHENSIVE

- Aluminum
- Barium
- Beryllium
- Cadmium
- Chromium
- Cobalt
- Copper
- Cyanide
- Fractionated DOC
- Lead
- Lithium
- Manganese
- Nickel
- Phosphorus (total and ortho)
- Silver
- Strontium
- Sulfide
- Thallium
- Thiosulfate
- Tin
- Titanium
- Turbidity
- Uranium (234, 235, 238)
- Vanadium
- Zinc

NOTE: Comprehensive list includes all parameters in the abbreviated list.

TABLE 2 TRACT C-a WATER QUALITY DATA.

	INFLOW TO JEFFREY POND					WEST RETENTION POND INFLOW					WEST RETENTION POND OUTFLOW				
CONSTITUENT*	NUMBER	MEAN	HIGH	LOW	STND. DEV.	NUMBER	MEAN	HIGH	LOW	STND. DEV.	NUMBER	MEAN	HIGH	LOW	STND. DEV.
AMMONIA	6	.30	.47	.11	.12	6	.22	.32	.10	.09	6	.24	.42	.16	.11
ARSENIC	7	BDL	(<.003)			7	BDL	(<0.003)			7		BDL	(<.003)	
BICARBONATE	7	555	599	527	25.3	7	535	548	523	9.8	7	517	558	368	67
BORON	6	.21	.41	.12	.10	6	.34	.80	.15	.26	7	.33	.9	.16	.29
CARBONATE	7	6.33	9.09	1.0	2.85	7	7.09	11.4	1.08	3.43	7	7.5	10.4	<1	2.2
CALCIUM	7	38.8	48.7	32.6	7.3	7	41.0	63.5	31.0	11.8	7	41.4	62	32	10.8
CHLORIDE	7	8.06	8.52	7.74	.30	7	8.4	9.47	7.58	.67	7	7.96	9.47	5.73	1.13
CONDUCTIVITY (μ mhos/cm)	7	1,590	2,250	1,400	308	7	1,434	1,510	1,390	53	7	1,409	1,475	1,320	49
DISSOLVED ORGANIC CARBON	7	3.5	4.7	<2	1.1	7	3.5	4	3	.46	7	3.3	3.8	2.0	.8
DISSOLVED OXYGEN	7	4.0	6.8	3.0	1.3	7	6.7	8.5	5.9	1.0	7	5.8	8.0	3.9	1.4
FLUORIDE	7	1.35	1.71	1.1	.21	7	1.34	1.7	1.2	.18	7	1.24	1.32	1.11	.07
IRON	7	.19	1.0	<.01	.36	7	.18	.59	.03	.20	7	.29	.64	<.01	.23
MAGNESIUM	7	80.1	95.0	72.8	8.0	7	82	98.9	74.1	8.2	7	82.3	100.9	73.1	9.1
MOLYBDENUM	7	.06	.11	<.03	.02	7	.16	.3	<.03	.18	7	.23	.24	<.01	.01
NITRATE	7	.53	2.02	<.1	.83	7	1.83	8.59	0.1	3.78	5	.39	.77	.05	.28
POTASSIUM	7	.62	1.26	.14	.36	7	.76	1.24	.36	.33	7	.84	1.49	.36	.43
RESIDUES															
-TOTAL DISSOLVED	7	994	1,152	614	175	7	1,134	1,446	988	164	7	1,177	1,392	980	177
-TOTAL SUSPENDED	7	BDL	(<4)			7	6.3	10	<4	2.6	7	BDL	(<4)		
-TOTAL SOLIDS	7	1,071	1,208	992	69	7	1,153	1,446	1,016	160	7	1,185	1,395	1,007	170
-TOTAL VOLATILE	6	197	226	148	31	6	198	252	74	65	6	187	225	86	55
-SETTLEABLE MATTER	7	BDL	(<.1)			7	BDL	(<.1)			7	BDL	(<.1)		
TEMPERATURE (°C)	7	14.3	19	11	2.7	7	14.5	23	10	4.7	7	13.9	20	9.5	3.9
SELENIUM	7	BDL	(<.01)			7	BDL	(<.01)			7	BDL	(<.01)		
SILICA	6	13.9	23	11	4.5	6	13.2	22	10.9	4.4	5	11.6	12.8	11.0	.7
SODIUM	7	191	200	174	8.2	7	190	198	170	9.7	7	192	198	177	7.3
SULFATE	7	402	430	343	31	7	342	441	345	137	7	377	449	302	48
VANADIUM	4	BDL		(<.005)		4		BDL	(<.005)		4		BDL	(<.005)	
ACIDITY	7	5.1	9.45	3.13	2.13	7	3.56	4.99	2.52	1.13	6	3.57	4.96	2.33	1.12
ALKALINITY	7	469	506	445	20	7	456	474	442	11	7	439	470	311	57
pH (Units)	7	7.7	9.2	7.17	.77	7	7.6	9.0	7.0	.7	7	7.6	8.9	6.9	.6

*In mg/ℓ, unless otherwise indicated.
BDL = Below Detection Limits, with detection limits in parenthesis.

TABLE 3. TRACT C-b HOLDING POND QUALITY DATA COLLECTED DURING THIS STUDY

CONSTITUENT*	SULFURIC ACID AND FLOCCULENT		NO CHEMICAL TREATMENT									
	INFLOW TO POND A	OUTFLOW FROM POND B	INFLOW TO POND A					OUTFLOW FROM POND B				
			NUMBER	MEAN	HIGH	LOW	STND. DEV.	NUMBER	MEAN	HIGH	LOW	STND. DEV.
AMMONIA	.90	1.33	5	.37	.688	.21	.19	5	.33	.372	.28	.03
ARSENIC	<.01	<.01	6	BDL	.003			6	BDL	(<.003)		
BICARBONATE	1,135	1,069	6	1,217	1,350	896	167	6	1,294	1,359	1,210	53
BORON	.86	.79	6	.77	.87	.74	.05	5	78	99	165	.13
CARBONATE	10.8	<1.0	6	38.7	53.3	24.1	11.7	6	44.9	63.2	25.9	12.3
CALCIUM	7.30	6.50	6	5.75	7.00	4.78	.74	6	6.32	10.0	4.78	1.9
CHLORIDE	8.34	8.12	6	7.10	8.14	5.79	.81	6	6.97	8.14	6.09	.77
CONDUCTIVITIY	2,275	2,200										
(μ mhos/cm)			6	2,113	2,620	1,620	325	6	2,150	2,500	2,000	179
DISSOLVED	4.7	3.9										
ORGANIC CARBON			6	3.8	5.0	<2	1.1	6	3.9	6.0	2.0	1.4
DISSOLVED OXYGEN	4.0	9.0	6	4.7	5.7	4.0	.7	6	5.3	7.0	4.3	1.1
FLUORIDE	15.3	15.3	6	17.5	19.8	11.1	3.3	6	17.7	19.7	12.2	2.8
IRON	.08	.05	6	.09	.21	<.01	.08	6	.14	.31	<.01	.12
MAGNESIUM	4.40	4.60	6	4.50	5.38	3.80	.60	6	4.52	5.7	3.94	.65
MOLYBDENUM	<.1	<.1	6	.38	.88	<.03	.43	6	.33	.80	<.03	.41
NITRATE	1.2	1.5	6	2.95	4.12	1.20	1.35	6	5.72	5.8	<1.0	4.5
POTASSIUM	4.3	4.1	6	2.54	4.67	1.65	1.13	6	2.63	5.7	3.94	1.21
RESIDUES												
-TOTAL DISSOLVED	1,354	1,517	6	1,269	1,380	912	179	6	1,347	1,398	1,206	71
-TOTAL SUSPENDED	565	6	5	7.0	8.0	<4	1.4	6	5	5.0	<4	
-TOTAL SOLIDS	1,919	1,523	6	1,300	1,424	958	173	6	1,381	1,439	1,342	36
-TOTAL VOLATILE	320	297	5	141	194	88	42	5	153	244	96	59
-SETTLEABLE MATTER	4.5	<.1	6	<.1	<.1	<.1		6	BDL	(<.1)		
TEMPERATURE (°C)	13.0	15.5	6	19.3	23.5	16	3.3	6	17.5	23	12	4.8
SELENIUM	<0.1	<.01	6	BDL	(<.002)			6	BDL	(<.01		
SILICA	23	35	5	6.88	7.30	6.12	.49	5	6.5	7.5	5.6	.73
SODIUM	540	540	6	520	578	391	66	6	549	578	522	18
SULFATE	176	311	6	15.9	22.6	10.9	3.97	6	20.0	50.3	6.0	15.4
VANADIUM	<.5	<.5	3	BDL	(<.005)			3	BDL	(<.005)		
ACIDITY	<5	<5	6	3.93	5.30	2.63	1.08	6	3.93	6.2	2.6	1.30
ALKALINITY	1,147	926	6	1,061	1,160	775	147	6	1,135	1,190	1,070	44
pH (Units)	9.2	7.8	6	8.3	8.8	8.0	.3	6	8.5	9.2	8.2	.4

*In mg/l, unless otherwise indicated.
BLD: Below Detection Limits, with detection limits in parenthesis.

the mine water data, the analytical results were compared to groundwater and surface water baseline data, as well as Federal Drinking Water Standards. This comparison is not meant to imply that the discharges should meet these standards. The comparisons for the Tract C-a and C-b data are presented in Tables 4 and 5, respectively.

The Tract C-a system involved treating the water in a one-pond system and reinjecting all of the treated water back into the groundwater system. Concerning the effectiveness of the treatment of the mine waters, the following constituents were found to generally exceed baseline groundwater conditions: carbonate, calcium, conductivity, fluoride, magnesium, nitrate, TDS, sulfate, and pH. However, the increase in these constituents above groundwater baseline conditions were small.

The following constituents exceeded the Federal Drinking Water Quality Standards in the discharge from the Tract C-a system: iron, TDS, sulfate, and pH. However, these constituents also exceeded standards in the groundwater analyzed to determine baseline water quality conditions. Therefore, this aspect may not be a problem if the water is reinjected.

In regard to the Tract C-b in-series two pond treatment system, the following constituents in the discharge exceeded baseline groundwater quality concentrations: bicarbonate, carbonate, conductivity, fluoride, molybdenum, nitrate, potassium, TDS, silica, sodium, and pH. However, none of the increases were very great. In addition, during periods of active

TABLE 4. COMPARISON OF TRACT C-a GROUNDWATER BASELINE DATA AND FEDERAL DRINKING WATER STANDARDS WITH HOLDING POND DATA COLLECTED DURING THIS STUDY

CONSTITUENT*	BASELINE DATA (TRACT C-a)[6] GROUNDWATER UPPER AQUIFER MEAN VALUE	UPPER AQUIFER HIGH VALUE	LOWER AQUIFER MEAN VALUE	LOWER AQUIFER HIGH VALUE	TRACT C-a DATA INFLOW TO JEFFERY POND MEAN VALUE	INFLOW HIGH VALUE	WEST RETENTION POND INFLOW MEAN VALUE	WEST RETENTION POND INFLOW HIGH VALUE	WEST RETENTION POND OUTFLOW MEAN VALUE	WEST RETENTION POND OUTFLOW HIGH VALUE	FEDERAL DRINKING WATER QUALITY STANDARDS[1] PRIMARY[2] (40CFR PART 141)	SECONDARY[3] (40CFR PART 143)
AMMONIA	0.37	1.8	0.35	2.0	0.30	0.47	0.22	0.32	0.24	0.42		
ARSENIC	0.01	0.04	BDL[1]	<0.01	BDL	<0.003	BDL	<0.003	BDL	<0.003	.05	
BICARBONATE	744	2,760	599	2,980	555	599	535	548	517	558		
BORON	0.75	4.8	1.21	20.0	0.21	0.41	0.34	0.80	0.33	0.90		
CARBONATE	0.98	66	1.25	84	6.33	9.09	7.09	11.4	7.5	10.4		
CALCIUM	83.5	260	28.2	98.0	38.8	48.7	41.0	63.5	41.4	62		
CHLORIDE	16.9	69	19.2	96	8.06	8.52	8.4	9.47	7.96	9.47		250
CONDUCTIVITY (μ mhos/cm)	1,702	2,610	1,258	3,600	1,590	2,250	1,434	1,510	1,409	1,475		
DISSOLVED ORGANIC CARBON	10.2	35	11.8	37	3.5	250 4.7	3.5	4	3.3	3.8		
DISSOLVED OXYGEN	-	-	-	-	4.0	6.8	.05	8.5	5.8	8.0		
FLUORIDE	0.37	1.8	6.35	32	1.35	1.71	1.34	1.7	1.24	1.32	2.0 - 2.2[5]	
IRON	6.3	18.0	3.45	16.2	0.19	1.0	0.18	0.59	0.29	0.64	0.3	
MAGNESIUM	59.3	155	38.2	130	80.1	95.0	82.0	98.9	82.3	100.9		
MOLYBDENUM	-	-	-	-	0.06	0.107	0.16	0.3	0.23	0.24		
NITRATE	0.50	4.5	0.47	2.0	0.53	2.02	1.83	8.59	0.39	0.77	10	
POTASSIUM	-	-	-	-	0.62	1.26	0.76	1.24	0.84	1.49		
RESIDUES												
-TOTAL DISSOLVED	1,267	2,790	976	3,360	994	1,152	1,134	1,446	1,177	1,392		
-TOTAL SUSPENDED	-	-	-	-	BDL	<4	6.3	10	BDL	<4		
-TOTAL SOLIDS	-	-	-	-	1,071	1,208	1,153	1,446	1,185	1,395		
-TOTAL VOLATILE	-	-	-	-	197	226	198	252	187	225		
-SEATTLEABLE MATTER	-	-	-	-	BDL	<0.1	BDL	<0.1	BDL	<0.1	0.01	
TEMPERATURE (°C)	-	-	-	-	14.3	19	14.5	23	13.9	20		
SELENIUM	BDL	<0.01	BDL	<0.01	BDL	<0.01	BDL	<0.01	BDL	<0.01		
SILICA	32.8	58	10.8	32	13.9	23	13.2	22	11.6	12.8		
SODIUM	301.8	1,170	284	1,320	191	200	190	198	192	198		
SULFATE	474	900	250	600	402	430	342	441	377	449		250
VANADIUM	-	-	-	-	BDL	<0.005	BDL	<0.005	BDL	<0.005		
ACIDITY	-	-	-	-	5.1	9.45	3.86	4.99	3.57	4.96		
ALKALINITY	654	2,343	558	2,540	469	506	456	474	439	470		
pH (Units)	6.78	8.8	7.1	10.2	7.7	9.2	7.6	9.0	7.6	8.9		6.5 - 8.5

*Values in mg/l unless otherwise indicated.

1. Provided as a reference point. Not intended to imply that discharge should meet Drinking Water Standards.
2. Federally Enforceable - Federal Register - EPA Water Programs, Wednesday, December 24, 1975 (Vol. 40, No. 248).
3. Not Federally Enforceable - Federal Register - EPA Water Programs, Thursday, July 19, 1979 (Vol. 44, No. 140).
4. BDL = Below Detection Limit
5. Dependent on Temperature (Average of maximum daily air temperatures).
6. Source: Rio Blanco Oil Shale Company, 1977.

TABLE 5. COMPARISON OF TRACT C-b GROUNDWATER AND SURFACE WATER BASELINE DATA AND FEDERAL DRINKING WATER STANDARDS WITH HOLDING POND DATA COLLECTED DURING THIS STUDY

	BASELINE DATA - (TRACT C-b)								TRACT C-b HOLDING POND DATA							
	GROUNDWATER[6]				SURFACE WATER[7]				NO CHEMICAL TREATMENT				SULFURIC ACID AND FLOCCULENT		FEDERAL DRINKING WATER QUALITY STANDARDS[1]	
	UPPER AQUIFER		LOWER AQUIFER		PICEANCE CREEK ABOVE TRACT C-b		PICEANCE CREEK BELOW TRACT C-b		INFLOW TO POND A		OUTFLOW FROM POND B		INFLOW TO POND A	OUTFLOW FROM POND B		
CONSTITUENTS*	MEAN VALUE	HIGH VALUE	MEAN VALUE	HIGH VALUE	MEAN VALUE	HIGH VALUE	MEAN VALUE	HIGH VALUE	MEAN VALUE	HIGH VALUE	MEAN VALUE	HIGH VALUE			PRIMARY[2] (40CFR PART 141)	SECONDARY[3] (40CFR PART 143)
AMMONIA	7.9	1.2	17	200	0.04	0.13	0.02	0.09	0.37	0.69	0.33	0.372	.90	1.33		
ARSENIC	0.01	0.06	0.02	0.02	2.1	5.0	2.1	5.0	BDL[1]	<0.003	BDL	<0.003	<.01	<.01	.05	
BICARBONATE	790	2,100	4,000	25,000	523	602	572	678	1,217	1,350	1,294	1,359	1,135	1,069		
BORON	1.4	18	36	400	0.194	0.29	0.183	0.270	.77	0.87	.78	0.99	.86	.79		
CARBONATE	21	76	220	2,000	1.5	32	1.5	39	38.7	53.3	44.9	63.2	10.8	<1.0		
CALCIUM	32	120	14	220	68.9	79	78.7	87	5.75	7.00	6.32	10.0	7.30	6.50		
CHLORIDE	26	510	1,200	9,800	15.5	24	13.5	16	7.10	8.14	6.97	8.14	8.34	8.12		250
CONDUCTIVITY (µ mhos/cm)	1,670	4,200	7,240	45,000	1,099	1,410	1,324	1,560	2,113	2,500	2,150	2,500	2,275	2,200		
DISSOLVED ORGANIC CARBON	-	-	23	175	-	-	-	-	3.8	5.0	3.9	6.0	4.7	3.9		
DISSOLVED OXYGEN	-	-	-	-	9.9	13	9.7	16.0	4.7	5.7	5.3	7.0	4.0	9.0		
FLUORIDE	10	190	21	48	0.98	1.3	0.6	0.9	17.5	19.8	17.7	19.7	15.3	15.3	2.0-2.2[5]	
IRON	0.5	7	0.8	8.0	0.07	0.39	0.04	0.46	.09	0.21	.14	0.311	.08	.05	0.3	
MAGNESIUM	42	150	11	110	46.2	56	65.9	82.0	4.50	5.38	4.52	5.7	4.40	4.60		
MOLYBDENUM	0.02	0.1	0.04	0.2	0.0104	0.016	0.0097	0.014	.38	0.883	.33	0.80	<.1	<.1		
NITRATE	0.41	2.9	0.46	3.4	0.33	0.83	0.39	0.79	2.95	4.12	5.72	5.8	1.2	1.5	10	
POTASSIUM	2.2	11	21	120	3.7	19	3.7	5.0	2.54	4.67	2.63	5.7	4.3	4.1		
RESIDUES																
-TOTAL DISSOLVED	1,100	3,100	6,190	42,000	698	762	893	1,050	1,269	1,380	1,347	1,398	1,354	1,517		
-TOTAL SUSPENDED	-	-	-	-	-	-	-	-	7.0	8.0	5.0	5.0	565	6		
-TOTAL SOLIDS	-	-	-	-	-	-	-	-	1,300	1,424	1,381	1,439	1,919	1,523		
-TOTAL VOLATILE	-	-	-	-	-	-	-	-	141	194	153	244	320	297		
-SETTLEABLE MATTER	-	-	-	-	-	-	-	-	<.1	<.1	BDL	<0.1	4.5	<.1		
-TEMPERATURE(°C)	-	-	-	-	8.7	22	9.1	21.1	19.3	23.5	17.5	23.0	13.0	15.5		
SELENIUM	0.006	0.03	0.004	0.02	0.001	0.002	0.001	0.002	BDL	<0.002	BDL	<0.01	<.01	<.01	0.01	
SILICA	17	32	13	38	15	18	17	20	6.88	7.30	6.5	7.5	23	35		
SODIUM	330	1,200	2,500	17,000	115.4	150	148	180	520	578	549	578	540	540		
SULFATE	220	520	63	350	161	190	239	330	15.9	22.6	20.0	50.3	176	311		250
VANADIUM	0.002	0.006	0.01	0.1	BDL	<0.003	0.002	0.006	BDL	<0.005	BDL	<0.005	<.5	<.5		
ACIDITY	-	-	-	-	-	-	-	-	3.93	5.3	3.93	6.2	<5	<5		
ALKALINITY	-	-	-	-	432	494	472	544	1,061	1,160	1,135	1,190	1,147	926		
pH (Units)	8.6	9.1	8.7	9.3	8.3	8.7	8.3	9.2	8.3	8.8	8.5	9.2	9.2	7.8		6.5 - 8.5

*Values in mg/l except as noted.

1. Provided as a reference point. Not intended to imply that discharge should meet Drinking Water Standards.
2. Federally Enforceable - Federal Register - EPA Water Programs, Wednesday, December 24, 1975 (Vol. 40, No. 248).
3. Not Federally Enforceable - Federal Register - EPA Water Programs, Thursday, July 19, 1979 (Vol. 44, No. 140).
4. BDL = Below Detection Limit
5. Dependent on Temperature (Average of maximum daily air temperatures).
6. Source: C-b Shale Oil Venture, 1977.
7. Source: USGS, 1977.

mining on Tract C-b, flocculent and sulfuric acid were added to the system to settle suspended solids and lower the pH, previous to the discharge to Piceance Creek. This treatment was effective and should be utilized if suspended solids and pH are areas of concern.

The quality of the discharge from Tract C-b also exceeded many constituents in the Federal Drinking Water Standards, as well as the baseline water quality data for Piceance Creek. For example, iron, TDS, and sulfate exceed the Drinking Water Standards. In addition, ammonia, bicarbonate, boron, carbonate, conductivity, fluoride, iron, molybdenum, nitrate, potassium, TDS, temperature, silica, sodium, alkalinity, and pH all exceeded the baseline water quality conditions of Piceance Creek. However, all of these constituents were within reasonable agreement with baseline groundwater quality, which is considered poor. Furthermore, the water discharged to Piceance Creek appears to be adequate for livestock and irrigation use.

The water quality changes observed in the data when comparing inflow and outflow of the treatment systems were generally insignificant. These changes can probably be related to pH changes, aeration, evaporation, and reduction-oxidation changes associated with the transformation of the groundwater from an underground environment to a surface environment, as well as the associated retention time in the ponds. In addition, some of the variations may be attributable to laboratory procedures.

CONCLUSION

The effectiveness of the treatment systems with respect to improving water quality without use of chemicals appeared to be negligible. For the one-pond treatment system on Tract C-a, the overall quality, with the exception of total suspended solids, remained essentially unchanged during treatment. The slight decrease in total suspended solids concentrations from 6.3 mg/l to below detection limits is not significant. The two-pond treatment system on Tract C-b is very similar in results to the one-pond system on Tract C-a. The general water quality did not improve or degrade after treatment. However, the addition of a flocculent and sulfuric acid was effective in reducing total suspended solids by nearly 99% and adjusting pH to desired value.