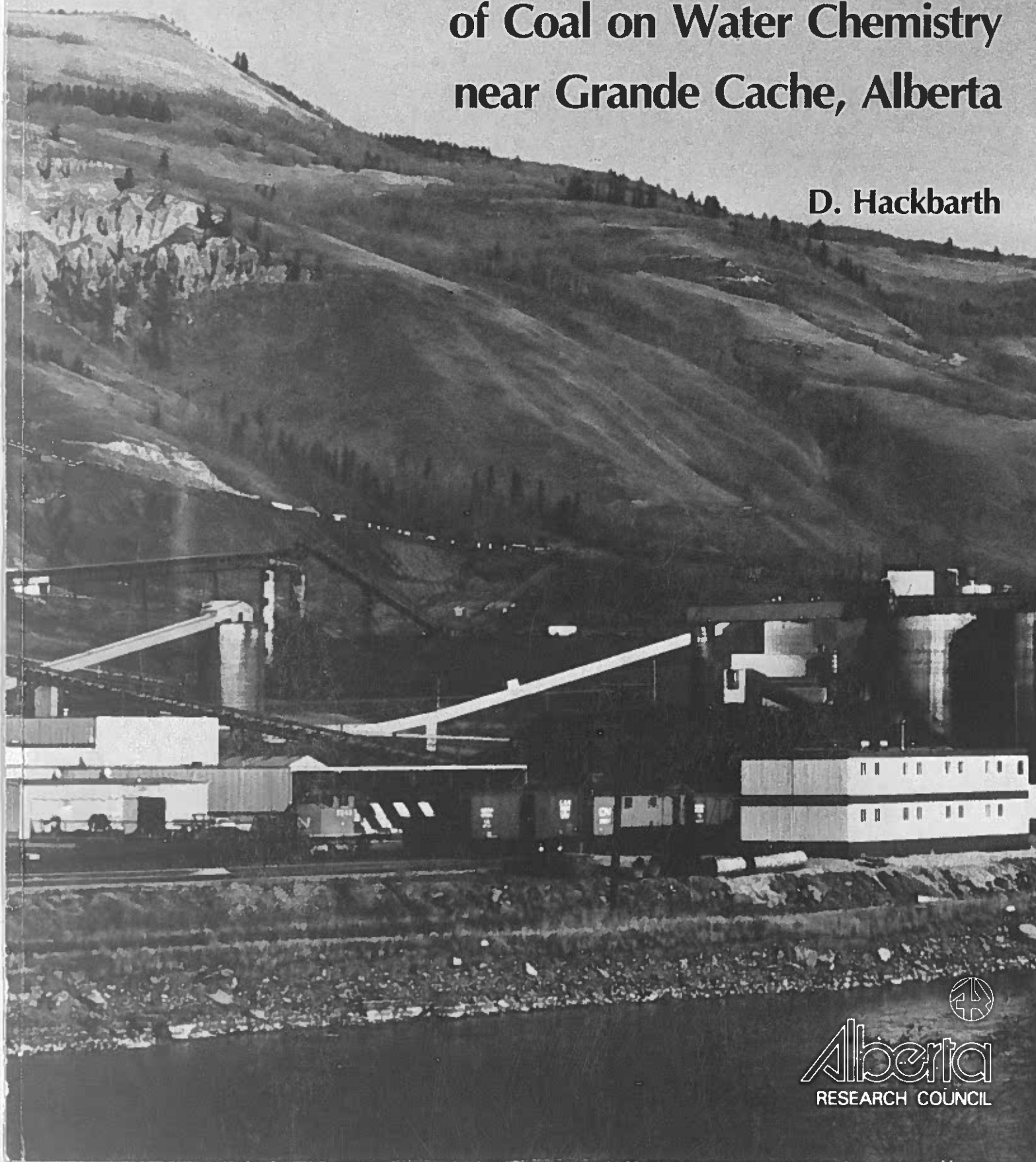


The Effects of Surface Mining of Coal on Water Chemistry near Grande Cache, Alberta

D. Hackbarth



Bulletin 40

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of Coal on Water Chemistry
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ABSTRACT

Streams and springs in and near surface coal mines located on the eastern slopes of the Canadian Rocky Mountains were sampled between 1972 and 1978. Dominant ions in streams unaffected by mining activity characteristically are calcium, magnesium, and bicarbonate. Total dissolved solids concentrations usually range between 125 and 231 mg/L. Sulfate is usually about 20 percent of the anions and has a concentration less than 75 mg/L. Relative amounts of sodium, potassium, chloride, and nitrate are less than 6 percent of the ions. pH ranges between 7.6 and 8.2.

The effects of mining activity on water quality vary in intensity, but follow a consistent pattern. The relative proportions of the various cations do not change, although their concentrations may rise to 4 times those of background values. The concentration of anions also increases, with a shift in the relative proportions from bicarbonate to sulfate and, at the more strongly affected sites, to nitrate. pH is not significantly different from unaffected sites.

Enhanced oxidation of sulfide minerals, which account for less than about 0.07 percent of the loose, unsaturated spoil piles, is probably responsible for the increase in sulfate ions. The hydrogen ion produced during the oxidation of the sulfide minerals is consumed in the dissolution of the abundant carbonate minerals thus releasing calcium and magnesium. Concentrations of nitrate increase from the use of ammonium nitrate for blasting.

The estimated rate of chemical denudation at sites unaffected by mining activity ranges from 4 to 18 mg/sec-ha. The rate at affected sites varies from 4 to 55 mg/sec-ha.

Concentrations of iron, manganese, lead, and copper occasionally exceed drinking water standards regardless of the influence of mining and do not appear to be increased by that activity. Zinc, strontium, and mercury concentrations may increase as a result of mining activity, but the evidence is not conclusive and concentrations are well below drinking water standards.

INTRODUCTION

Surface mining of bituminous coal on the eastern slopes of the Rocky Mountains in Alberta has increased 3300 percent from about 132 000 tonnes in 1968 to about 4 500 000 tonnes in 1977 (Alberta Energy Resources Conservation Board, 1978). During this same period, production from underground mines in the same area increased about 100 percent from 731 000 tonnes to 1 590 000 tonnes. Surface mining of coal, currently favored as a method of production, is expanding rapidly.

Surface mining is expanding so rapidly in this area

that little information exists about the quality of water draining from these mines. Although information is available about the United States (Musser, 1963; Collier and others, 1964; Collier *et al.*, 1971; Grubb and Ryder, 1972; McWhorter *et al.*, n.d.; Minear and Tschantz, 1976; Heohn and Sizemore, 1977; Rowe and McWhorter, 1978), it is difficult to apply to Alberta where the climate is more rigorous and the geological setting is different. The only published Canadian work was that of Root (1976), who investigated a mine near Cadenham, Alberta that had been inactive for 20 years. The previous mining activity seems not to have had an impact on water chemistry.

LOCATION AND HISTORY OF THE PROJECT

McIntyre Mines Ltd. operates surface coal mines in west-central Alberta on the eastern slopes of the Rocky Mountains about 390 km (242 mi) west of Edmonton (Fig. 1). The plant site is about 14.5 km (9 mi) north of Grande Cache. No. 8 and No. 9 mines are 1.6 km (1 mi) and 6.4 km (4 mi) to the northwest of the plant site (Fig. 2).

In 1971 McIntyre Mines Ltd. asked the Alberta Research Council to study certain environmental aspects of surface mining coal at No. 8 Mine, which was about to open. The study was extended in 1973 when No. 9 Mine was about to open. The scope of the study included:

- (1) monitoring the influence of the mining operations on water chemistry in the area;
- (2) making an inventory of soil cover (Macyk, 1973b);
- (3) revegetation research (Macyk, 1972, 1973a, 1974, 1975, 1976, 1977a, 1977b; and Macyk and Steward, 1977).

The study started too late to collect pre-mining data for No. 8 Mine, although there was time to get this information for No. 9 Mine. Table 1 presents a history of these two mines. Figures 2 and 3 identify the location of features mentioned in this report. This report presents the results of the monitoring program for water chemistry, draws conclusions, and predicts future trends.

ACKNOWLEDGMENTS

McIntyre Mines Ltd. initiated the project and was the major source of funds. We thank them for their assistance.

The manuscript was critically reviewed by Mr. R.I.J. Vogwill, Dr. R. Green, and Dr. S.R. Moran of the Alberta Research Council and Mr. R. Wigelsworth of McIntyre Mines Ltd. Dr. L. Jackson of the Geological Survey of Canada also reviewed and commented on the manuscript. F. Tuck edited the report.

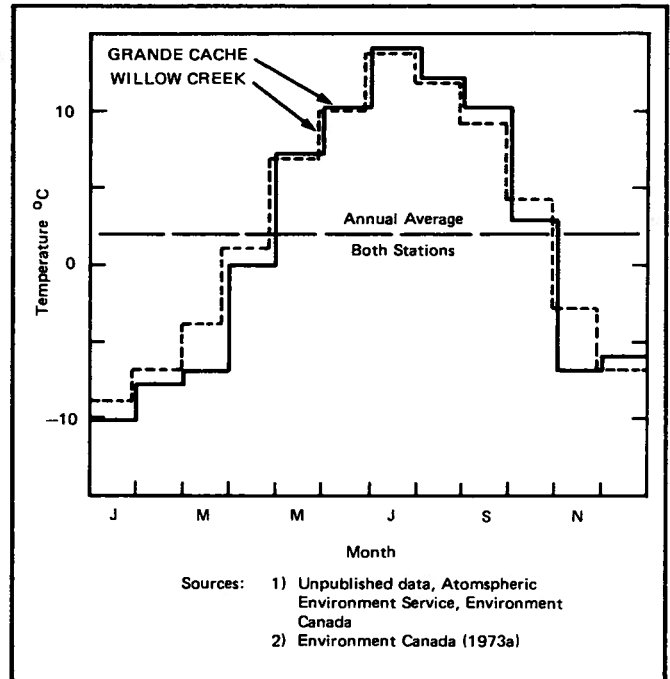


FIGURE 4. Mean monthly temperatures at Grande Cache and Willow Creek, Alberta

PHYSICAL SETTING

PHYSIOGRAPHY

The study area lies in the foothills of the eastern slopes of the Rocky Mountains (Fig. 1). Elevations range from about 915 m (3000 ft) along the Smoky River to 1585 m (5200 ft) and 1677 m (5500 ft) at No. 8 and No. 9 Mines. In the immediate mining area, Sheep Creek is at 1037 m (3400 ft), 610 m (2000 ft) below the mines.

CLIMATE

At Grande Cache, the mean annual temperature for 1973 to 1978 (the available period of record) is 2°C (Fig. 4); January is the coldest month and July the warmest. Average monthly temperatures are above freezing from May through October. The Grande Cache weather station is located at about 1220 m (4000 ft); temperatures at the mine sites will be slightly lower because of their higher elevation.

TABLE 1
Chronological history of No. 8 and No. 9 mines

Event	Date (Month, Year)	Sampling Sites Affected*
<i>Number 8 Mine</i>		
1. Stripping commences	April, 1971	N/A
2. Spoil area 1 starts	April, 1971	Stream 6, Springs 3, 4
3. Spoil area 2 starts		Stream 6, Springs 3, 4
4. Spoil area 3 starts		Stream 4
5. Spoil area 4 starts	October, 1973	Stream 2
6. Seed and fertilize 6 ha in east portion of Phase 1 area	August, 1973	Springs 3, 4, 8 Stream 6
7. Seed and fertilize 14 ha in Phase 1 area and Spoil area 1	May, 1974	Springs 3, 4, 8
8. Seed and fertilize 18 ha in Spoil areas 3 and 4	August, 1974	Streams 2, 4
9. Refertilize areas in numbers 6, 7 and 8 above	May, 1975	Springs 3, 4, 8 Streams 2, 4, 6
10. Seed and fertilize 20 ha in Phase I and II areas	June, 1975	Springs 3, 4, 8 Streams 4, 6
11. Seed and fertilize 49 ha in Phase II area and West Ridge	August, 1975	Springs 3, 4, 8 Streams 2, 4, 6
12. Refertilize 69 ha in numbers 10 and 11 above	May, 1976	Springs 3, 4, 8 Streams 2, 4, 5, 6
13. Start dumping bottom ash into West Ridge pit	February, 1977	Streams 2, 5
14. Refertilize portion of areas in numbers 7, 8, 9 and 11	May, 1977	Springs 3, 4, 8 Streams 2, 4, 5, 6
<i>Number 9 Mine</i>		
1. Road building on north side of Sheep Creek	January, 1973	Stream 9-3
2. Stripping of overburden commences	March, 1974	Streams 9-2, 9-3
3. Logging and brush clearing for M-1 Spoil area	May, 1974	Stream 9-3
4. Spoiling in M-1 Spoil area begins	May, 1974	Stream 9-3

*See figures 2 and 3 for locations of features

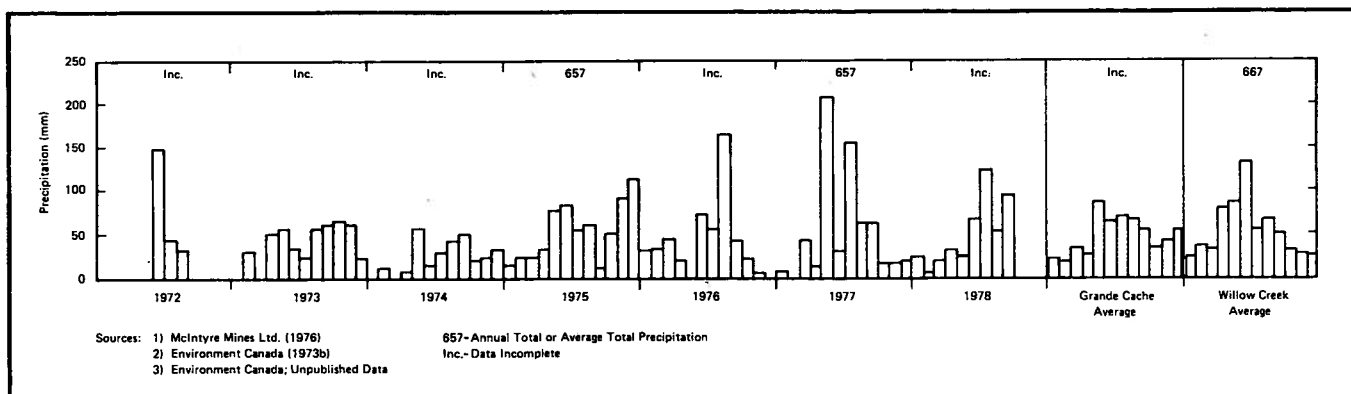


FIGURE 5. Monthly precipitation (1972-1978) at Grande Cache and average precipitation at Willow Creek, Alberta

Mean monthly temperatures at Willow Creek Ranger Station, 83 km (52 mi) southeast of the mine sites, are included in figure 4 for comparison. This station is at about the same elevation in approximately the same physiographic setting as Grande Cache. Temperatures at Grande Cache between 1973 and 1978 were close to long-term averages at Willow Creek Ranger Station.

Total annual precipitation data at Grande Cache for 1972 through 1978 are presented in figure 5. The data for 1972, 1973, 1974, and 1976 are incomplete. Long-term average precipitation values at Willow Creek Ranger Station are also presented. The data from Grande Cache for 1972 to 1978 do not correspond well on a month-by-month basis with the long-term averages at Willow Creek. This discrepancy may exist because the two stations are simply not comparable in precipitation, or because precipitation at Grande Cache was abnormal during the seven years in which data were collected. Even though the data are incomplete, annual precipitation at Grande Cache seems somewhat less than at Willow Creek Ranger Station; it might be expected to be about 600 mm per year. Based on incomplete data collected by McIntyre Mines Ltd., precipitation at the mine sites may exceed that at Grande Cache because of orographic effects.

Aspect is important in the microclimate of the two mine sites. No. 8 Mine has generally north-facing slopes (Fig. 1) and holds snow earlier in the winter and later in the spring; the resulting cooler microclimate promotes spruce growth and the frequent occurrence of quasi-muskeg conditions. No. 9

Mine, in contrast, has mostly south-facing slopes (Plate 1). The snow pack on these slopes develops later in the winter and may be gone up to a month earlier in the spring than the snow at No. 8 Mine. During chinooks or under sunny conditions with moderate winter temperatures, the snow pack may be reduced substantially on south-facing slopes, even in mid-winter. Vegetation on south-facing slopes in the No. 9 Mine area is generally stands of aspen or willow over grass; open grassy meadows are common. These slopes are noticeably drier than the north-facing slopes of No. 8 Mine.

GEOLOGY

Exposed rock units in and near the mines are of early Cretaceous age. The following descriptions of rock units (oldest to youngest) are taken from Irish (1965) and are supplemented by observations made during this study:

Nikanassin Formation — nonmarine; consisting in the upper part of quartzite sandstone and softer, poorly sorted to argillaceous sandstone interbedded with gray shale and black carbonaceous shale. Thickness is about 180 m (590 ft) in this area and exposure consists of a few small outcrops at structural highs along Sheep Creek. This unit is normally not disturbed by mining activity.

Cadomin Formation — a hard, massive conglomerate of nonmarine origin; consisting of chert and quartzite pebbles. Thickness is reported to be 10 to 30 m (33 to 98 ft) in the area. This unit is normally

not disturbed by mining activity as it crops out only at structural highs along Sheep Creek.

Luscar Formation — nonmarine to brackish-water origin; fine-, medium-, and coarse-grained sandstones and argillaceous sandstone with gray to dark gray shale. Bituminous coal seams occurring in the lower portions of this unit are mined in the No. 8 and No. 9 Mines. The thickness of this unit in the area is about 400 m (1312 ft). The unit underlies most of the area shown in figure 1.

Fort St. John Group — dark gray shale and silty shale of marine origin with minor interbedded ironstone. This unit is disturbed by mining of the underlying coal in some places.

The area is structurally complex. The ridge on which No. 9 Mine is located is an anticline that plunges to the northwest. No. 8 Mine is on the same anticline, although at that location topography does not reflect structure. Numerous local faults can be observed.

Mineralogical studies have not been conducted on the Luscar Formation in this area. Chemical analy-

ses of the Luscar Formation have revealed the following features:

- (1) Sandstone and siltstone, which are the bulk of the formation, contain an average of 14 percent carbonate and 0.07 percent total sulfur. The carbonate is assumed to be dominantly in calcite, aragonite, and dolomite with minor amounts in siderite (Mellon, 1967). The sulfur is thought to occur in sulfide minerals and organic compounds.
- (2) Mudstones and claystones, a minor part of the formation, contain an average of 0.6 percent carbonate and 0.06 percent total sulfur. The compounds containing these are assumed to be the same as in the more sandy facies.
- (3) Coal contains less than 0.37 percent total sulfur (McIntyre Mines Ltd., 1973).

MINING OPERATIONS

For this report, *mining activity* is defined as those processes directly associated with coal mining, including:

- (1) overburden blasting, removal, and relocation to spoil areas;

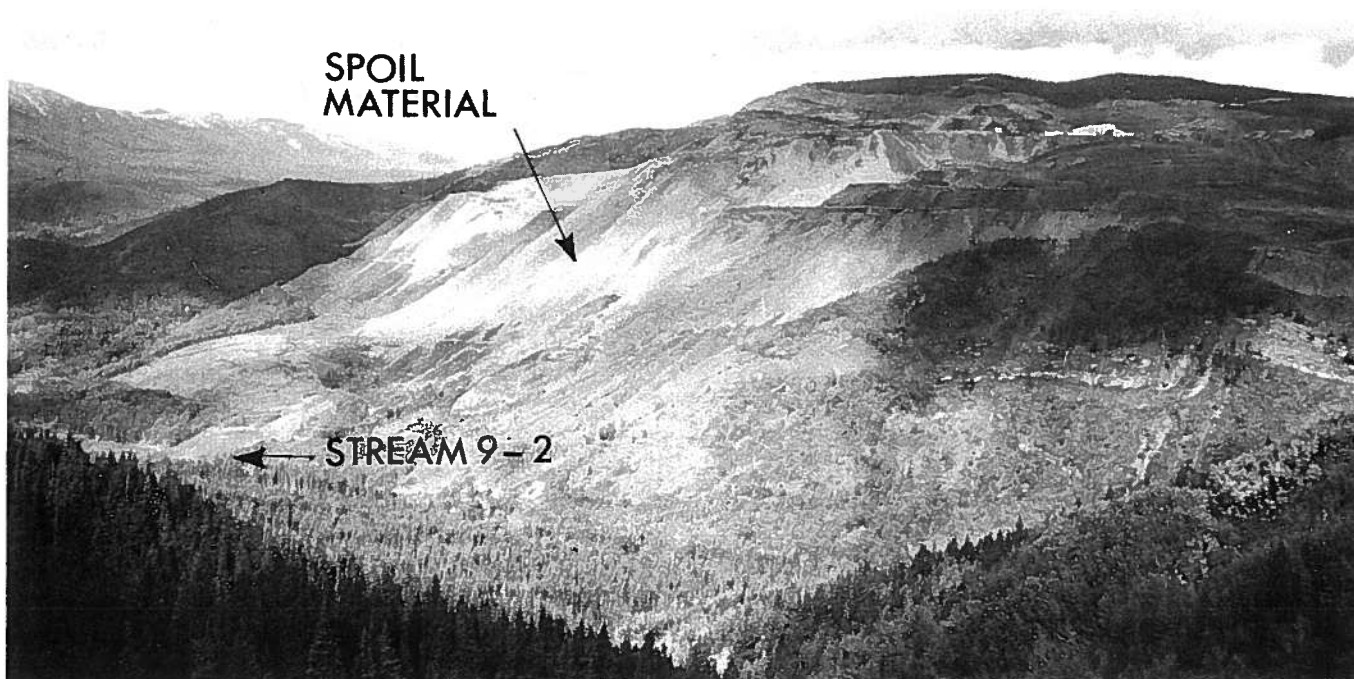


PLATE 1. No. 9 Mine looking northwest from No. 8 Mine



PLATE 2. Stream 2 sampling site. Water sample bottles are 20 cm high

- (2) removal of the coal and associated reject material; and
- (3) storage of materials such as blasting supplies.

These processes are regarded as the major activities influencing the environment of the mine. Exploration activities, such as trail construction and drilling, although environmentally important, are not considered mining activities because, compared to the overall impact of mining, they cause only temporary stresses. Designating a water sampling site as *affected* or *unaffected* by mining activity depends on whether any of these three processes has taken place in the basin upstream of the site.

The coal being mined in No. 9 Mine and that previously mined in No. 8 Mine is low volatile bituminous coal (McIntyre Porcupine Mines Ltd., 1973). Between 1971 and 1975, 4 276 127 tonnes of coal and 11 900 000 m³ (9 080 000 yd³) of overburden and reject were handled in No. 8 Mine. By November 1, 1977, 5 350 312 tonnes of coal had been removed from No. 9 Mine. About 36 600 000 m³ (28 000 000 yd³) of waste material had been removed from No. 9 Mine — mostly to the M-1 Spoil Area (Fig. 2) by November 1, 1977.

The mining operation, although locally referred to as strip mining, is actually pit mining. Casting overburden to one side is not always possible as in contour mining, so this material must be trucked to abandoned pits or selected dumping locations. Waste material is not artificially compacted, so the larger boulders will likely tend to travel to the toe of the dump, creating a subdrain over which smaller material will accumulate as the dump advances. A subdrain was constructed under Spoil Area 4 (Fig. 2) in No. 8 Mine to ensure that poor drainage did not increase hydraulic pressures.

Both the shale and the sandstone of the Luscar Formation are well cemented and when blasted break in fragments 10 cm (3 in) or more in diameter (Plate 2). On the surface these materials break down physically by weathering processes, but the clastic nature of the spoil is preserved. Since physical weathering in the subsurface is negligible, the spoil piles consist of a highly porous and permeable mass of angular fragments mainly of boulder to cobble size, which are subject only to chemical weathering.

Soils of the area, classified (Macyk, 1972, 1973a) as brunisolic and luvisolic, are often 2 m (6.6 ft) deep, although the average is 60 cm (2 ft) (Macyk, 1972).

This soil is stockpiled for use in reclamation. The overburden-moving equipment tends to pick up considerable amounts of bedrock with the soil, because of rapid local changes in the thickness of the soil. The numerous bedrock fragments caught up in this manner make planting and tilling difficult. Revegetation experiments in No. 8 Mine since 1971 (Macyk and Steward, 1977; Macyk, 1976) have resulted in successful revegetation of 110 ha.

HYDROLOGY

Surface water from both No. 8 and No. 9 Mines, except a small area on the south side of No. 8 Mine, drains into Sheep Creek (Fig. 1), which in turn joins the Smoky River about 16 km (10 mi) downstream from the mines. Many streams in the area are intermittent and commonly cease to flow by late summer. The persistence of streamflow appears to be controlled to a large extent by aspect; streams on south- and west-facing slopes tend to dry up more frequently than those on north-facing slopes where spring melt is slower and evapotranspiration rates are lower. Streams commonly infiltrate into the wide gravel terraces along Sheep Creek instead of discharging directly into it.

Estimates of flow at all sampling sites are presented in Appendix 3. These are estimates only; they were taken to allow qualitative approximations of chemical load.

Flow in Sheep Creek was not monitored for this study; however, a temporary monitoring station was established at the Bailey bridge for part of 1975 (McIntyre Mines Ltd., 1976). Maximum and minimum flows of 57 m³/sec were recorded on July 16, 1975 and 5 m³/sec on September 5, 1975 respectively. Although measurements were not taken during the winter, flows of 0.7 to 1.1 m³/sec during the winter were predicted. Because no major tributaries enter Sheep Creek between the Bailey bridge and confluence with Smoky River, it is assumed that the volume of flow does not change significantly between these locations.

Estimates of discharge made during this study (Appendix 3) indicate that the total flow rate at Streams 2, 4, 6, 9-2, and 9-3 (Appendix 1 and Fig. 3) (those affected by mining) was about 0.008 m³/sec on September 9, 1975. Even if flow estimates are low by an order of magnitude, the ratio of dis-

charge in Sheep Creek to that in the tributaries affected by mining activity was 60 to 1, and it is likely to have been much higher, particularly in spring and early summer.

Groundwater is not abundant in either of the two mine areas. Few blast-holes and pits encountered groundwater, and then only in limited amounts. Barnes (1977) indicates a 20-year safe yield of 0.4 to 2 L/sec for this area. This estimate is optimistic, except possibly in the valley of Sheep Creek.

In No. 2 Mine, located underground 600 m below No. 8 Mine, water occurs only in fracture zones in small quantities. Water is occasionally a problem at a mining face when a new fracture or joint is encountered, but these drain quickly. Water must be pumped into No. 2 Mine to suppress the dust.

An outcrop of coal at the portal to Reiff Terrace No. 4 Mine (Fig. 2) has small water seepages coming from the top of the seam. A small amount of water must be pumped from this underground mine. This location is on a north-facing slope, so tends to be somewhat damper than south-facing slopes.

A well 25 m deep was installed by McIntyre Mines Ltd. personnel near the former site of maintenance sheds at No. 8 Mine. Although reports on the performance of this well are not considered reliable, it seems to have produced about 0.2 L/sec, but went dry in the winter. Nearby mining pits, which were deeper than this well, were dry all year. One available chemical analysis of the yellow-colored water from the well indicated a total concentration of dissolved solids of 290 mg/L. The low dissolved solids and organic coloring indicate near-surface water.

It can be concluded that the bedrock under the ridges on which the two mines are located contains very little groundwater and, furthermore, that the groundwater is concentrated in fractures and other permeable zones.

Two piezometer sites were installed below Spoil Area 2 in No. 8 Mine and below M-1 Spoil Area in No. 9 Mine. Data from these sites are unsatisfactory because of difficulties in construction and subsequent land-use conflicts. Influences of mining activity were not observed since the two piezo-

PIEZOMETER NEST WR1

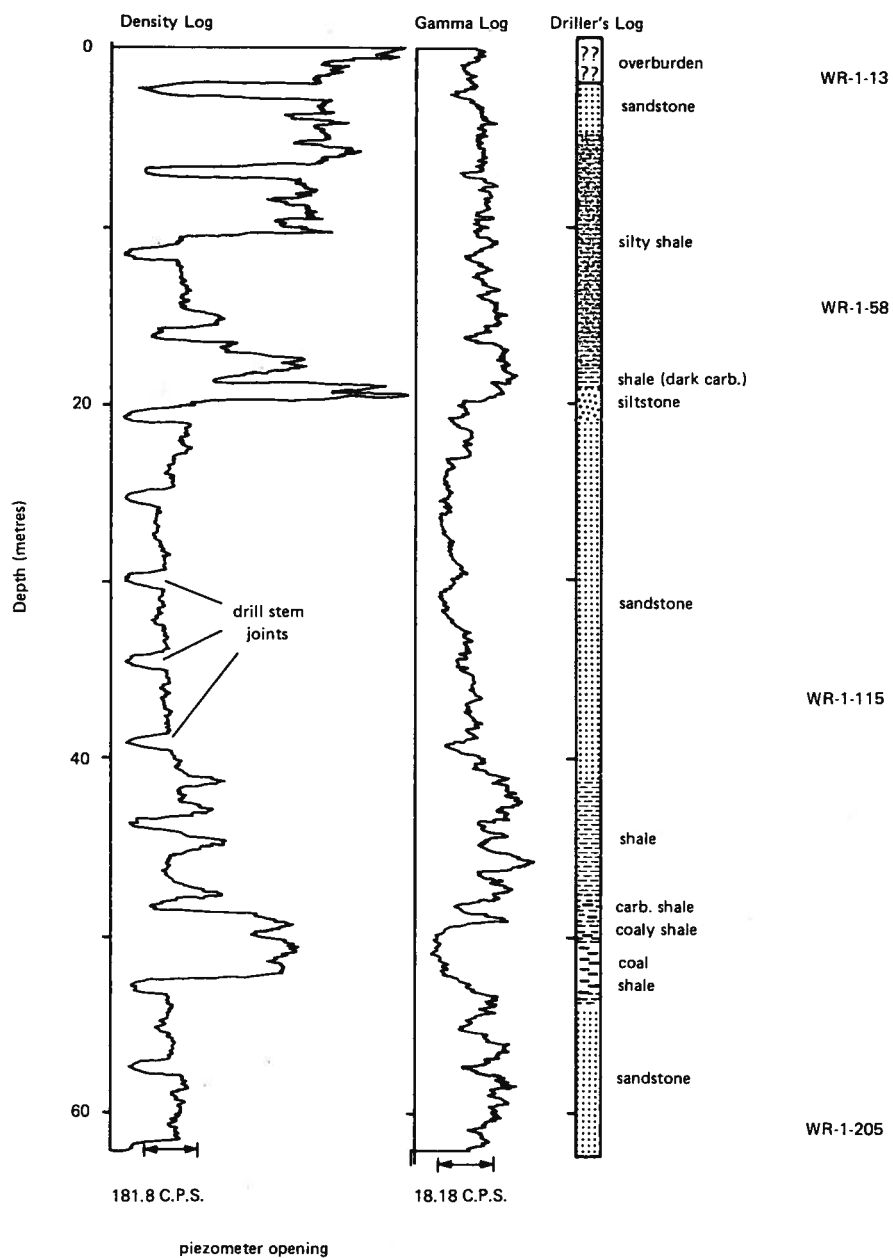


FIGURE 6. Geological and geophysical logs — Piezometer Site WR-1

meter sites below the M-1 Spoil Area were destroyed about one year after installation. One of the two piezometer sites below Spoil Area 2 in No. 8 Mine was destroyed soon after construction; the other (WR-1) has been monitored to provide data on water chemistry and water levels.

Geophysical and geological logs for piezometer site WR-1 are presented in figure 6; relative water levels in each of the four wells are presented in figure 7. The seal between wells WR-1-13 and WR-1-58 was probably broken in 1975 because since that time withdrawal of water from one has caused a drop in the water level of the other. Before 1975, hydraulic heads (Fig. 7) indicated that groundwater was flowing upward from the vicinity of WR-1-58 towards WR-1-13. In 1976 and 1977, there were occasional returns to this pattern; however, the data are not conclusive.

Water levels in WR-1-13 and WR-1-58 have been slightly above those in WR-1-115 (Fig. 7). On several occasions, however, all three wells had virtually the same head or WR-1-115 had a slightly greater head than the two shallower wells. This reversal of gradient might be related to precipitation; the winter of 1975-76 had relatively large accumulations of snow (Fig. 5), and during part of 1977 hydraulic heads in WR-1-115 exceeded those in the

two shallower wells.

The flowing conditions from wells WR-1-13, WR-1-58, and occasionally from WR-1-115 are somewhat unexpected considering their location near, but below, the crest of a relatively narrow 610 m (2000 ft) high ridge. This condition is probably caused by the steep surface slope (about 1:2) combined with a relatively low hydraulic conductivity in the colluvial materials compared to that of the fractured bedrock. This contrast in hydraulic conductivities causes heads to rise in the bedrock. Because of the steepness of the surface topography, the top of a well can easily be below the hydraulic head at its lower end; this condition results in flowing wells.

Water levels in the three shallow piezometers are usually about 15 to 30 m above those in WR-1-205. The difference in depth between WR-1-115 and WR-1-205 is about 27 m, which means that gradients of hydraulic head approach unity. This situation indicates a local zone of high hydraulic conductivity probably in the coal (Fig. 6).

Groundwater is frequently encountered at the contact between the colluvial material and the bedrock during the construction of exploration

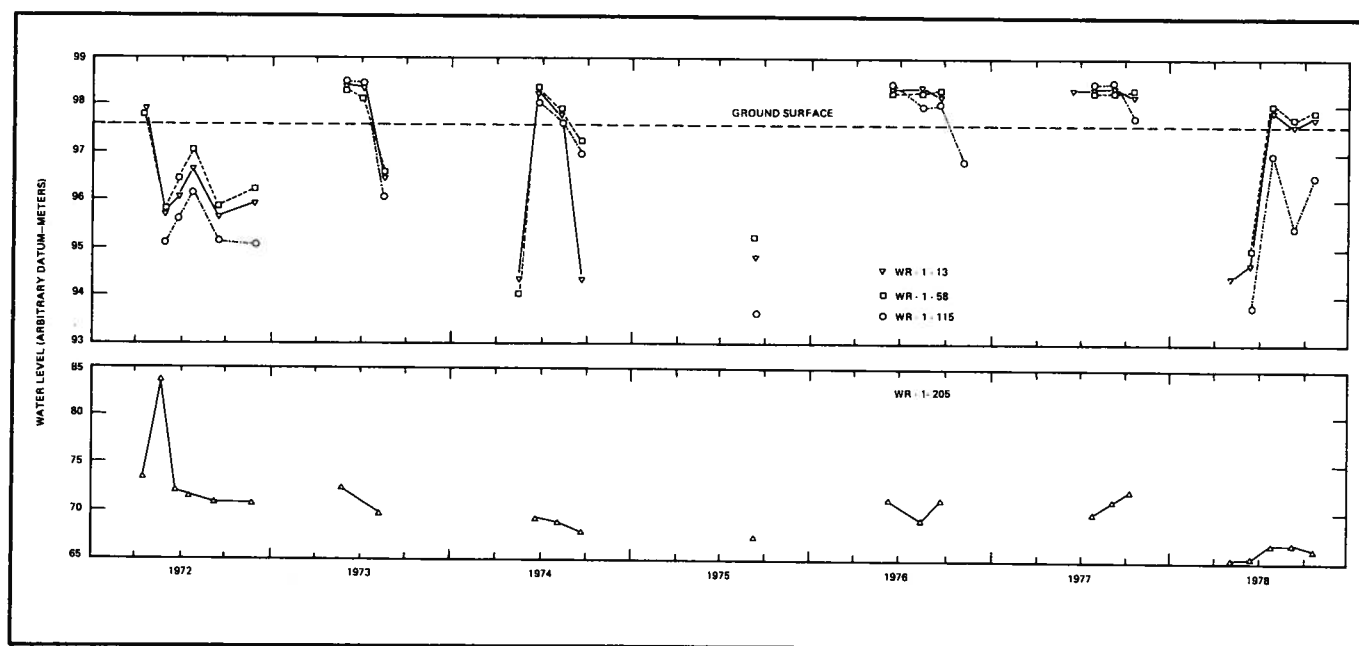


FIGURE 7. Water levels — Piezometer Site WR-1

trails in and near the mine sites. These trails are cut into the slope, so they intersect water moving along this contact. The water flows across the trail and seeps into the colluvium on the other side. Seepages such as these are more common and more persistent on north-facing slopes than on south-facing slopes, which have a drier microclimate.

Natural springs and seepage areas seem to be located where the colluvial cover is thin, possibly over local highs on the bedrock. Water from springs characteristically flows on the surface for several metres and then infiltrates again presumably where the colluvial materials thicken.

Springs and seepage areas are more common on slopes with a northern aspect than on those with a southern aspect. Large springs are not found in the area; the largest spring, Spring 4, had a maximum observed flow of about 4 L/sec. Spring 4 and Spring 8 are the only true springs of any size in or near the mining areas. Spring 3 is a stream emerging from the base of a spoil pile.

Macyk (1977a, 1977b) measured infiltration rates at undisturbed and revegetated sites in No. 8 and No. 9 Mines using a dual-ring infiltrometer. His results show that the sites undisturbed by mining had infiltration rates 2 to 10 times greater than the disturbed and revegetated sites. Macyk also shows that infiltration rates increase with time after revegetation at disturbed sites. The decrease in infiltration rate in the topsoil of disturbed areas is caused by lack of organic material and compaction by heavy equipment. The decrease in infiltration rates might appear to result in decreased groundwater storage in an area disturbed by mining; however, this may not be the case. Where the topsoil is missing either by erosion in drainage channels or where slopes are too steep to permit replacement, the underlying spoil is exposed. The infiltration rate in the large boulders and cobbles of the spoil in these exposed areas is probably many times higher than that in revegetated areas. Thus, even though infiltration rates are low for revegetated sites, the overall rate for the area is important for groundwater conditions. Speculation on this overall effect is premature, since no discernible trends in streamflow have been detected (Appendix 3).

MAJOR ELEMENT CHEMISTRY

SAMPLING PROCEDURE

The procedure adopted for this study was to sample bodies of surface water on a regular basis in order to monitor changes with time. Sites were selected on the basis of permanence (for both natural fluctuations of flow and destruction by mining), accessibility, and location with respect to mining operations. Monitoring took place between April and November of each year at 4- to 6-week intervals.

No. 8 Mine, located on the north side of the ridge (Figs. 1 and 2), has wetter conditions than No. 9 Mine. Five locations for sampling of streams and 12 locations for sampling of springs were initially established in this area. Four sites for streams and three for springs (Fig. 3) eventually became permanent locations. The others were either destroyed by mining or were not considered permanent enough to justify continued monitoring.

No. 9 Mine, located on south-facing slopes, is much drier than No. 8 Mine. Only three sites for sampling of springs were initially established. These sites were soon abandoned as impermanent features. Four sites for sampling streams were established initially and all continue to be monitored. Two more sites were added in 1977.

A description of each sampling site is given in Appendix 1 and locations are shown in figure 3. Chemical constituents and estimates of streamflow are listed in Appendixes 2 and 3. The Alberta Research Council staff analyzed for the major ion chemistry.

Concentrations of dissolved oxygen, measured with a Hach Chemical Company field kit during 1973 and 1974, are presented in Appendix 3. The average concentration of dissolved oxygen in streams affected by mining was 9.7 mg/L (Fig. 8) with a standard deviation of 1.4 mg/L; similar values for unaffected streams (excluding Sheep Creek) were 9.8 mg/L with a standard deviation of 1.0 mg/L. These concentrations are nearly at saturation values (Fig. 8), considering the altitude and probable water temperatures, regardless of whether or not the site is influenced by mining

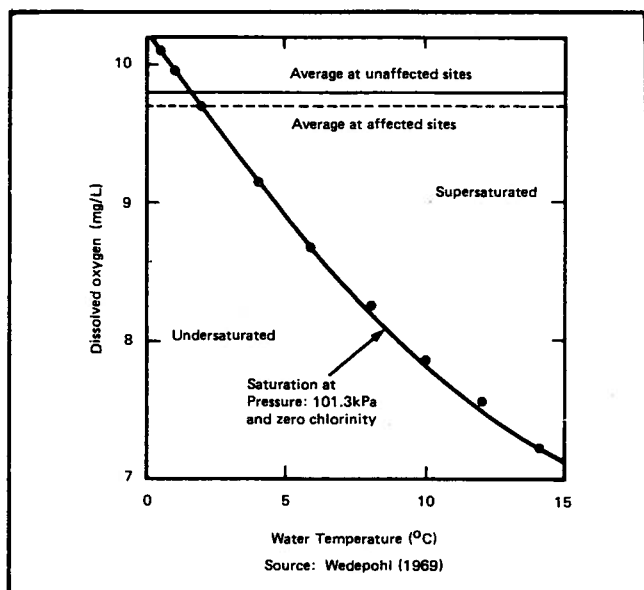


FIGURE 8. Dissolved oxygen concentrations

activity. Monitoring of dissolved oxygen was discontinued in 1975 because it was apparent that oxygen deficiencies would not be a problem in the turbulent, well-aerated mountain streams.

DATA PRESENTATION

Hydrochemistry is discussed in terms of:

- (1) changes in absolute concentrations of calcium, magnesium, bicarbonate, sulfate, nitrate, and total dissolved solids. General trends are shown as smoothed curves connecting annual averages of any of these 6 parameters. Sodium, potassium, and chloride concentrations, although increased slightly by mining activity, remain insignificant so are not presented;
- (2) relative abundances, as expressed by percent of milliequivalents per litre (meq/L), based on either total cations or total anions and referred to simply as "percent."

Changes in concentration with time will be discussed using average annual values of selected constituents in order to avoid minor fluctuations caused by short-term phenomena such as precipitation. Comparisons are made with background values in streams not affected by mining activity. By these means, long-term trends will become evident and changes in chemistry caused by pre-

cipitation may be normalized to some extent.

Averages are presented only where two or more analyses are available for a particular year. An average is not presented for 1975 because only one set of samples was collected (see Appendix 2). Some streams or springs cease to flow during dry years or during part of each year. These sites may have only one analysis available in any particular year, so an average was not calculated.

The method used averages the available analyses. A more rigorous method of analysis would be to present discharge-weighted values; however, the available discharge information (Appendix 3) is too imprecise to allow this. Thus, the overall impact of Spring 8, which will be shown later to have high concentrations of nitrate, may be less than Stream 9-3 because the flow in it is much greater than in Spring 8 (Appendix 3). Accordingly, this section deals with the observed changes in water chemistry resulting from mining activity; it does not relate them to loadings of dissolved material in Sheep Creek or its tributaries. The discussion documents the changes in water chemistry rather than the loading of downstream water bodies by these changes.

BACKGROUND WATER CHEMISTRY

The five sampling sites selected on streams adjacent to, but unaffected by, mining activity are Sheep Creek at the Bailey bridge and Streams 1, 9-1, 9-1A, and 9-4 (Fig. 3; Appendixes 1, 2, 3). Under natural circumstances, the relative abundance (Fig. 9) and the absolute concentrations of major cations (Table 2) in water from these sites are restricted to a narrow range of values. Calcium ranges from about 55 to 65 percent (25 to 45 mg/L), magnesium from about 20 to 40 percent (7.4 to 15 mg/L), and sodium (5 to 12.8 mg/L) and potassium (0 to 2 mg/L) from 0 to 15 percent.

Anion chemistry shows a wider distribution (Fig. 9; Table 2) than that for cations. Bicarbonate (carbonate is virtually never present) ranges between 55 and 95 percent (112 to 186 mg/L) and usually between 80 and 95 percent. Sulfate commonly ranges from 0 to 45 percent (7 to 49 mg/L) and frequently falls between 0 to 20 percent. Nitrate (0 to 2.6 mg/L) and chloride (0 to 5.2 mg/L) together seldom exceed 5 percent of the anions.

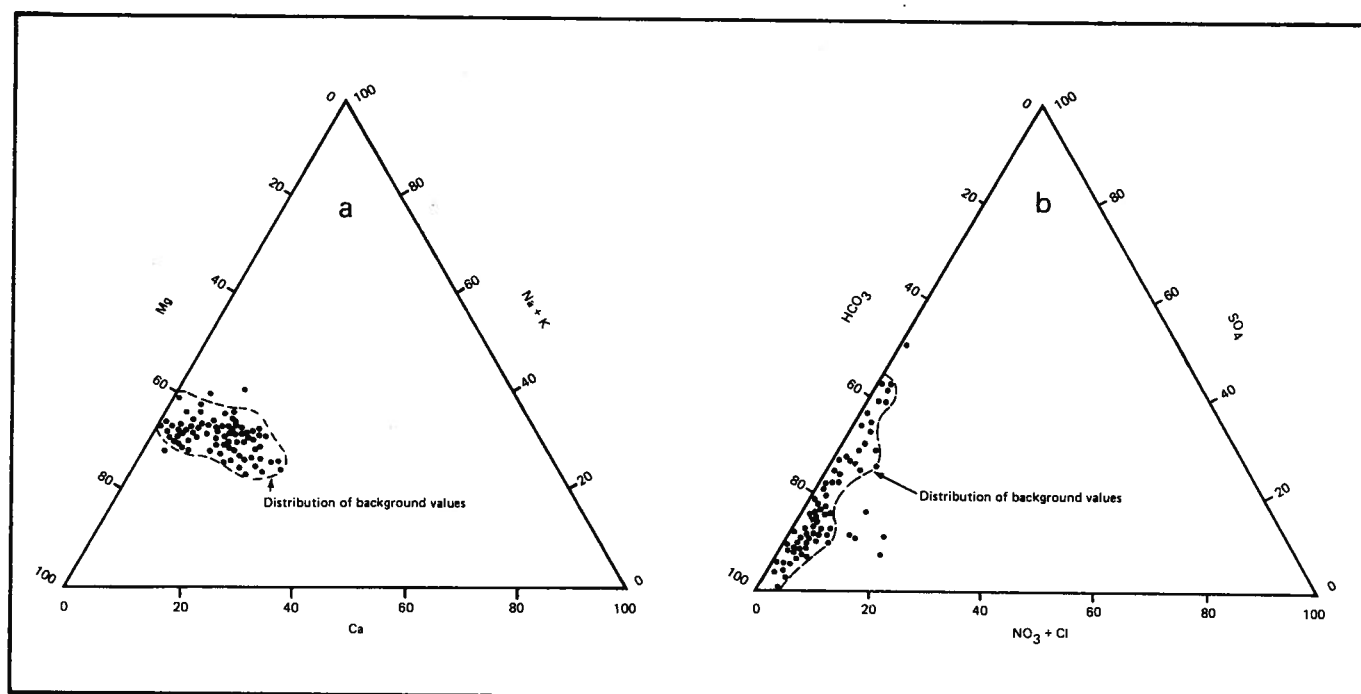


FIGURE 9. Background water chemistry: (a) Cation hydrochemistry, (b) Anion hydrochemistry

The distribution of total dissolved solids concentration (Table 2) for the background sites is narrow, ranging between 125 and 231 mg/L. The average for all five sites is 178 mg/L. Statistical tests of the means and variances of the distributions of total dissolved solids concentrations at each of the five sites indicates they are the same at the 95 percent confidence limit.

These streams, which are not fed by surface water bodies, yet continue to flow during extended dry periods, must be fed substantially by groundwater. The relatively low concentrations of total dissolved solids in water from springs suggest that groundwater is in the subsurface for a short time and that substantial volumes may be released from storage in muskegs.

TABLE 2.
Average and standard deviation of concentrations of chemical constituents
at background sites.

Constituent	Mean (mg/L)	Standard Deviation (mg/L)	EPM (%)	Standard Deviation (EPM%)
Total dissolved solids	178	53	—	—
Calcium (Ca++)	35	10	58	4
Magnesium (Mg++)	11.7	3.3	31	4
Sodium (Na+)	7.9	4.9	9	6
Potassium (K+)	0.8	1.2	—	—
Bicarbonate (HCO ₃ ⁻)	149	37	79	5
Sulfate (SO ₄ ⁻)	28	21	19	11
Chloride (Cl ⁻)	2.6	2.6	2.7	2.8
Nitrate (NO ₃ ⁻)	1.1	1.5	0.7	1.2
pH	8.0	0.4	—	—

TABLE 3
Legend for Figures 10 to 18

- △ Average background concentration on sampling date.
- Concentration of indicated parameter on sampling date.
- Average concentration of indicated parameter for the year.
- 7 Relative anion hydrochemistry; number indicates year of 1970's in which samples were taken.
- ~600~ Total dissolved solids concentration.

Calcium, magnesium, and bicarbonate, which dominate the background water chemistry, reflect weathering of the local rocks of the Luscar Formation. The molar concentration of calcium plus magnesium is nearly equal to that for bicarbonate in all background samples, indicating that the dominant sources of these three ions are calcite and dolomite. Sulfate concentrations, although low, are independent of calcium at background sites, indicating that the source of that ion is probably not gypsum. The oxidation of sulfide minerals is probably the source of the background concentrations of sulfate.

The combination of stable concentrations of total dissolved solids and cation composition implies that the weathering processes that bring these cations into solution are reasonably constant, both in time and in space. The variation noted in the background anion chemistry (Fig. 9; Table 2) is accounted for mostly by differences among the five sites. One site tends to produce most of the higher sulfate percentages (Stream 1) and the other four tend to have the lower values. Anion chemistry is fairly constant with time.

These sites are assumed to represent the chemistry of water of streams in the mining area had mining not taken place; significant differences of means or distributions represent changes caused by mining activity. Average background concentrations of selected ions for each sampling date are presented in figures 10 through 18; table 3 is the legend for these figures. The average background chemistry indicates no identifiable trends.

Background water chemistry of the area (Table 2) can be regarded as excellent relative to criteria for drinking water (Table 4). Concentrations of all constituents are well below acceptable levels.

EFFECTS OF MINING

Except for an increase in the range of values, all cations remain at the same relative concentration

TABLE 4
Drinking water criteria - major constituents

Parameter ¹	Acceptable (mg/L)	Maximum Permissible (mg/L)	Reference
Total dissolved solids	500	1000	1
Calcium (Ca ⁺⁺)	200	—	1
Magnesium (Mg ⁺⁺)	50	150	1
Sodium (Na ⁺)	—	300	2
Potassium (K ⁺)	—	2000	2
Carbonate plus Bicarbonate (HCO ₃ ⁻)	—	625	1
Sulfate (SO ₄ ⁼)	250	500	1
Chloride (Cl ⁻)	250	250	1
Nitrate (NO ₃ ⁼)	45	45	1

¹Parameter is expressed as the compound in parenthesis.

²Commonly known as alkalinity when expressed as calcium carbonate (CaCO₃) for which the maximum permissible level is 500 mg/L.

- References:
1. Canada Department of National Health and Welfare (1969).
 2. McKee and Wolf (1971).

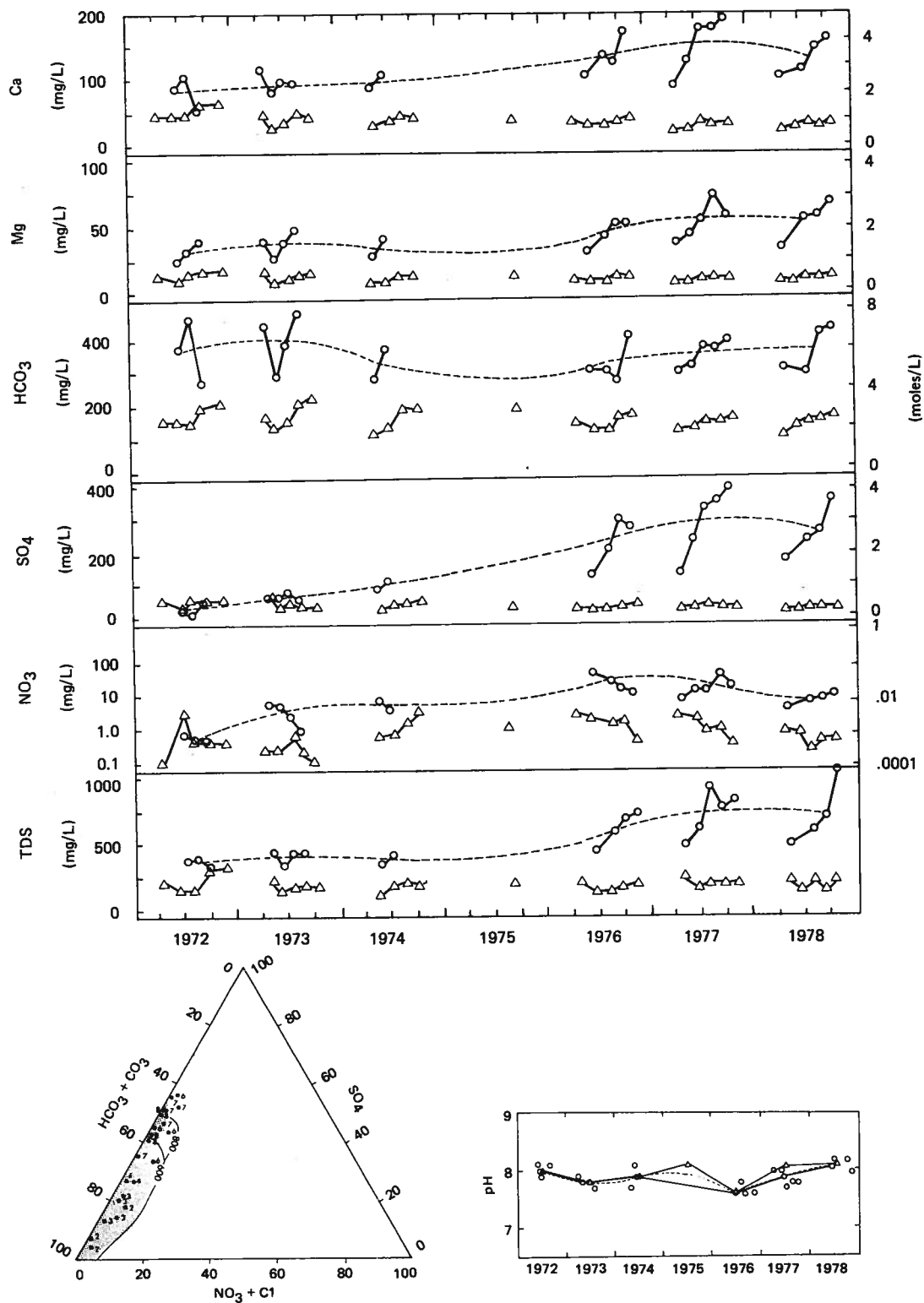


FIGURE 10. Water chemistry — Spring 3, 1972-1978

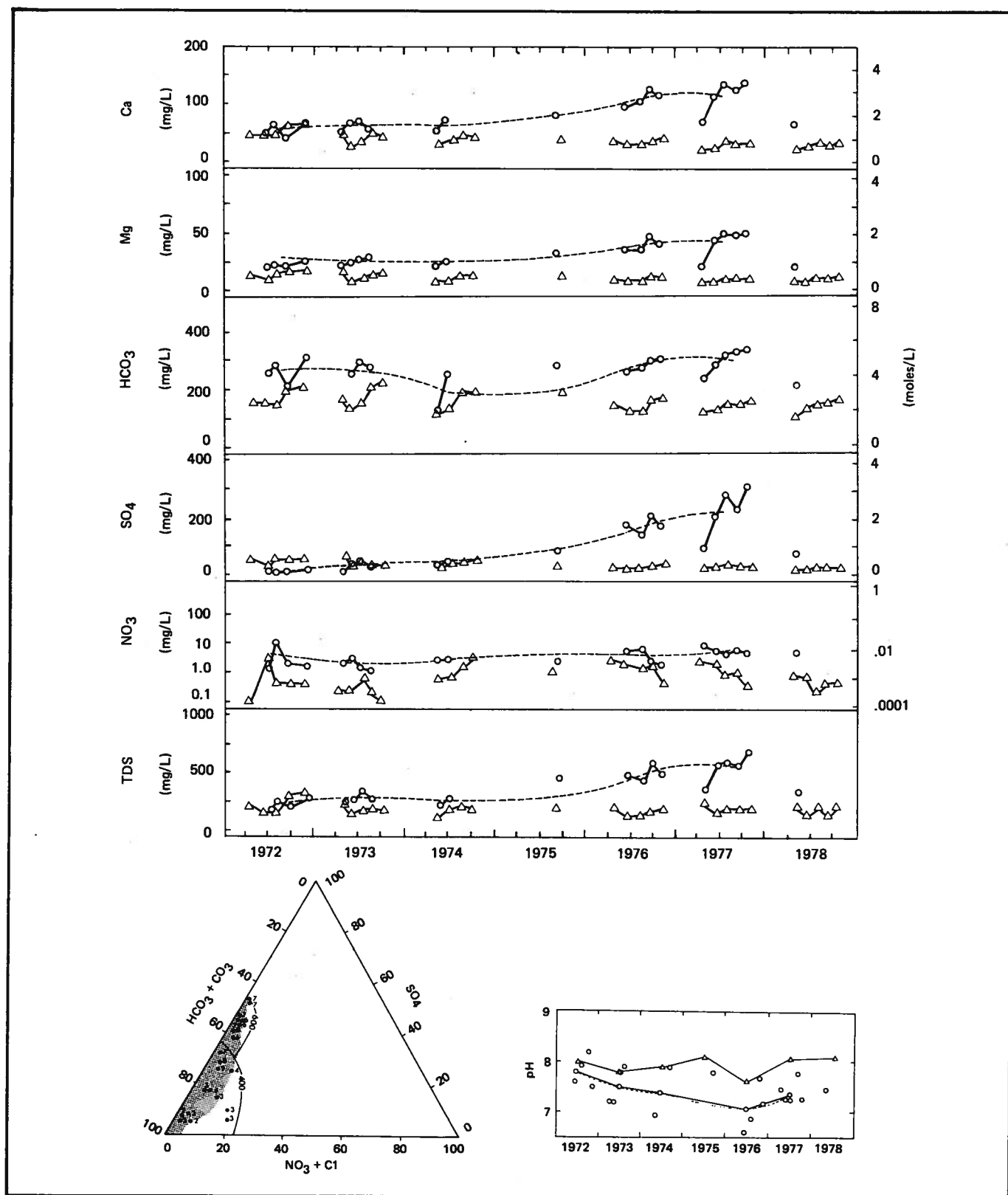


FIGURE 11. Water chemistry — Spring 4, 1972-1978

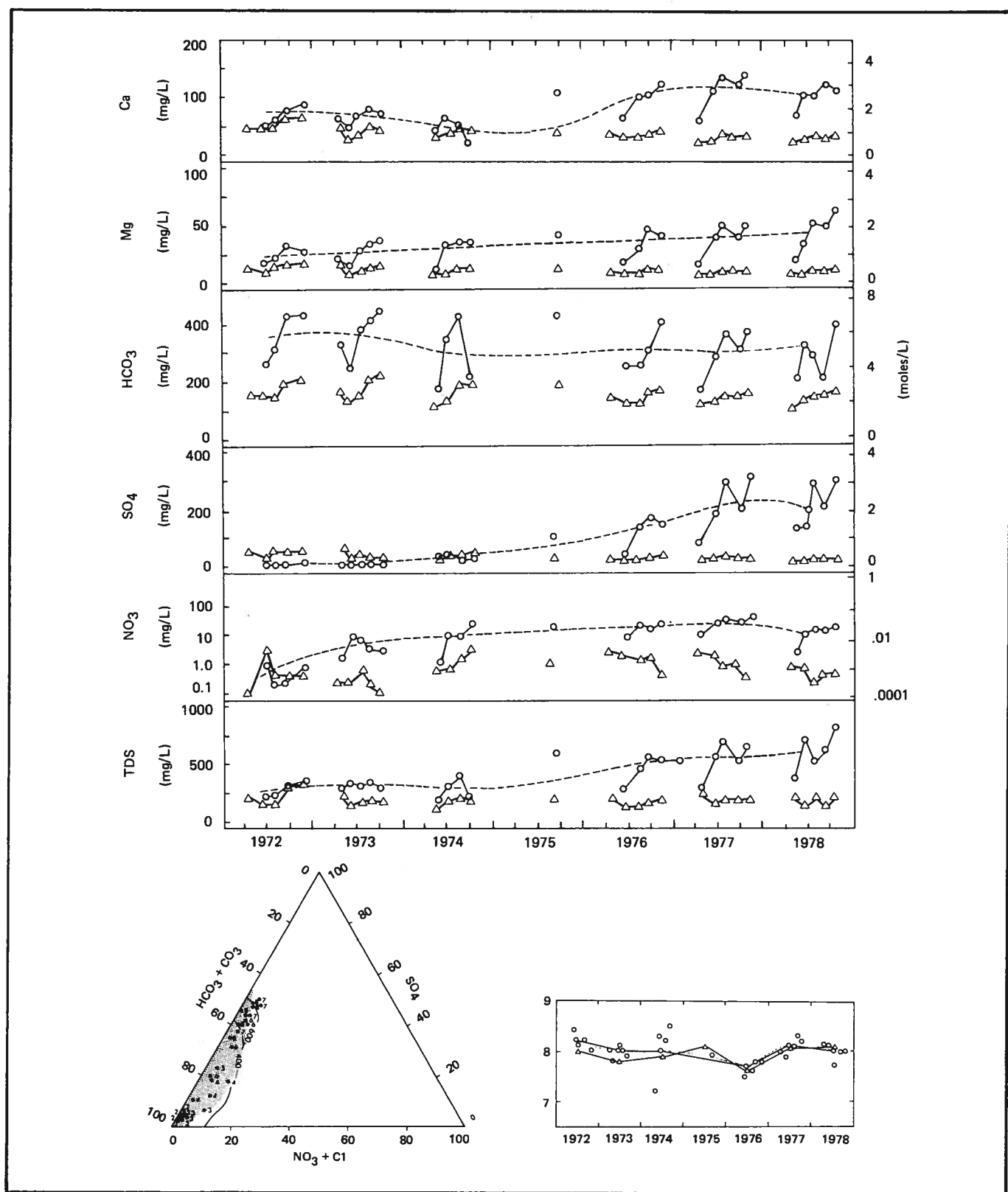


FIGURE 12. Water chemistry — Stream 2, 1972-1978

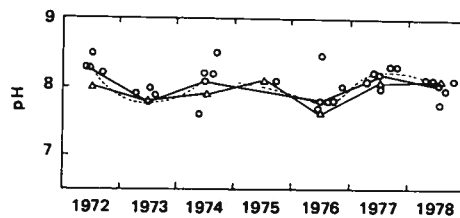
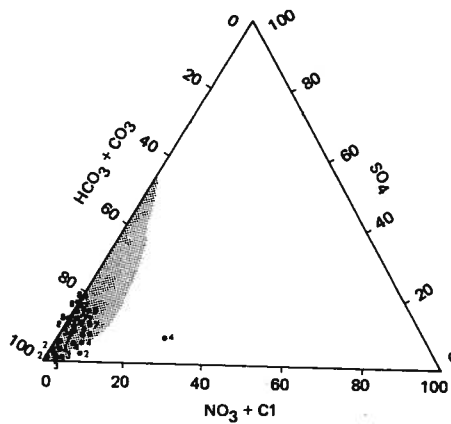
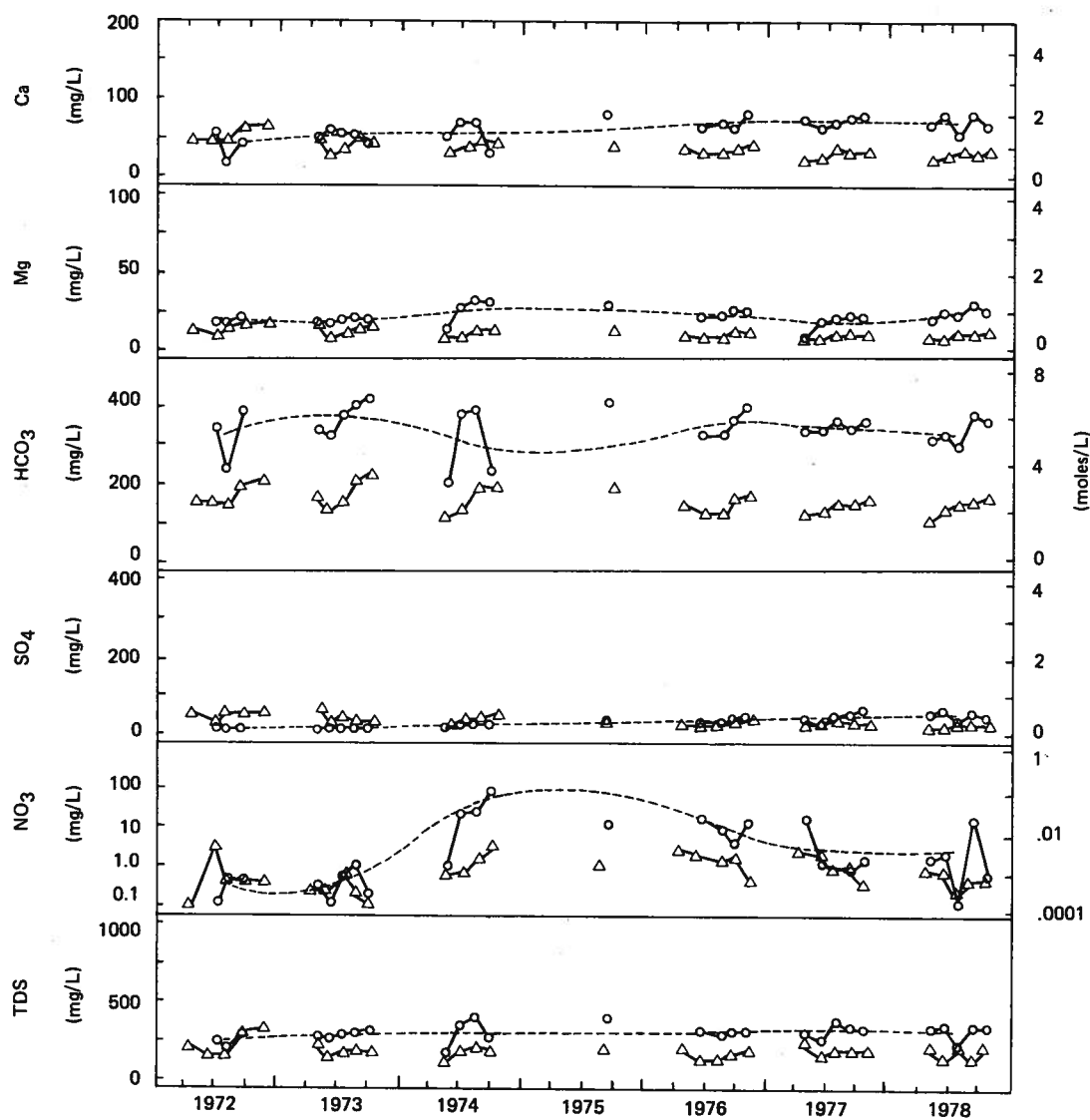


FIGURE 13. Water chemistry — Stream 4, 1973-1978

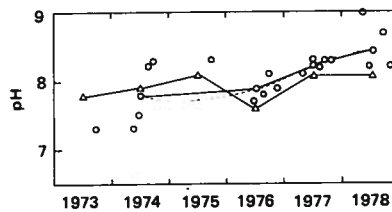
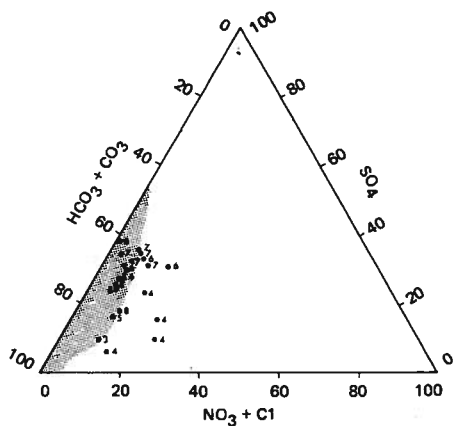
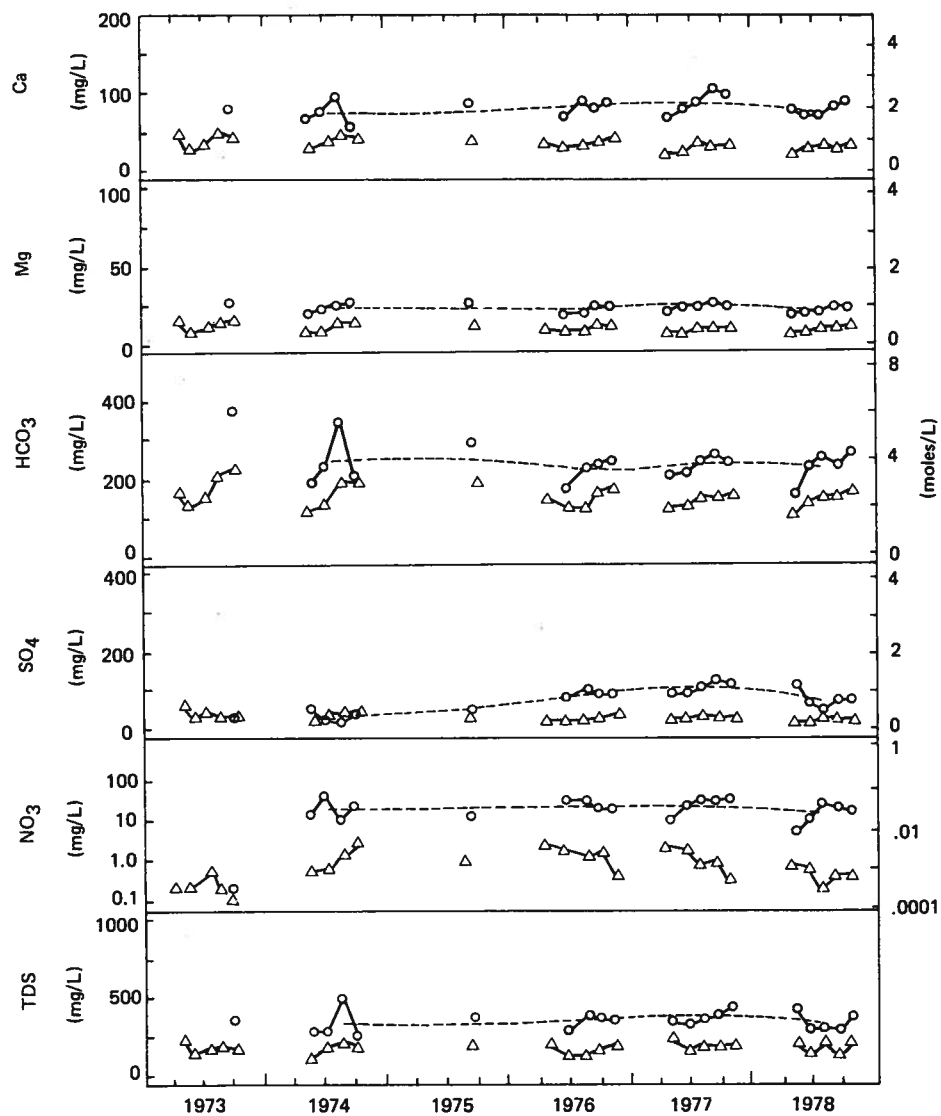


FIGURE 14. Water chemistry — Stream 6, 1973-1978

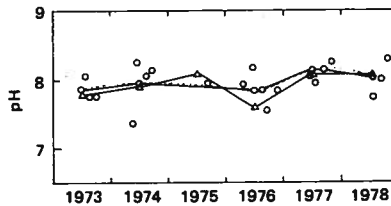
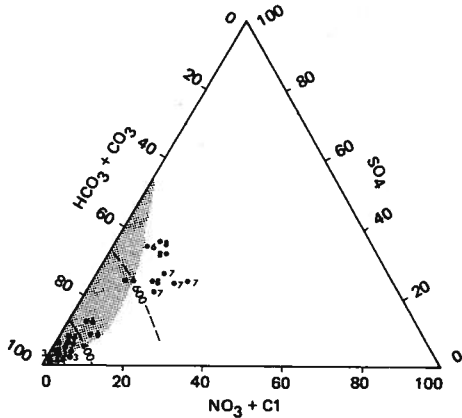
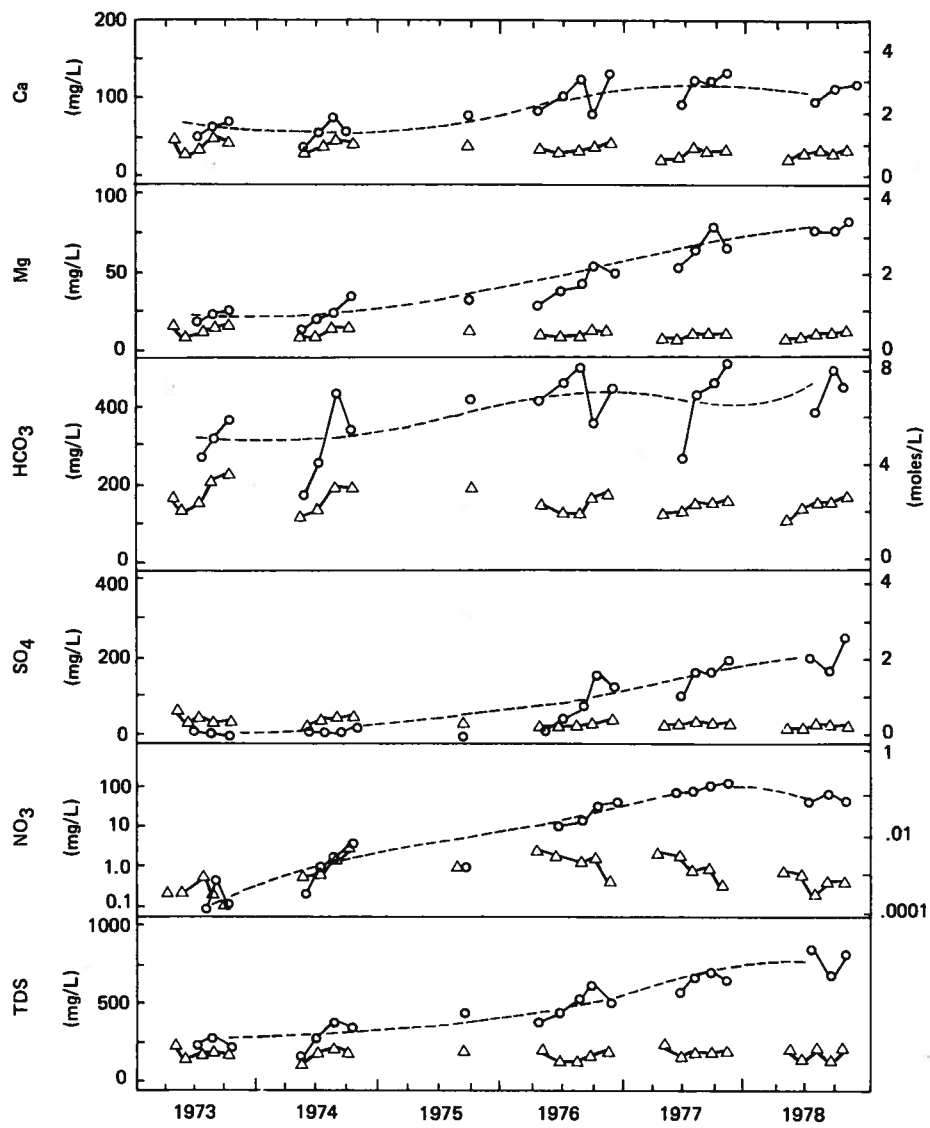


FIGURE 15. Water chemistry — Stream 9-2, 1973-1978

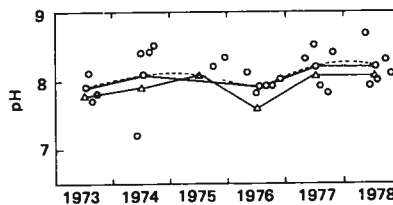
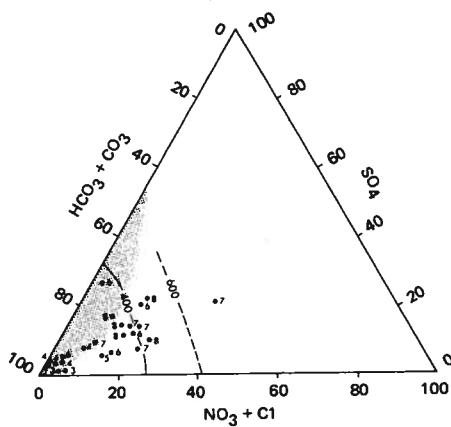
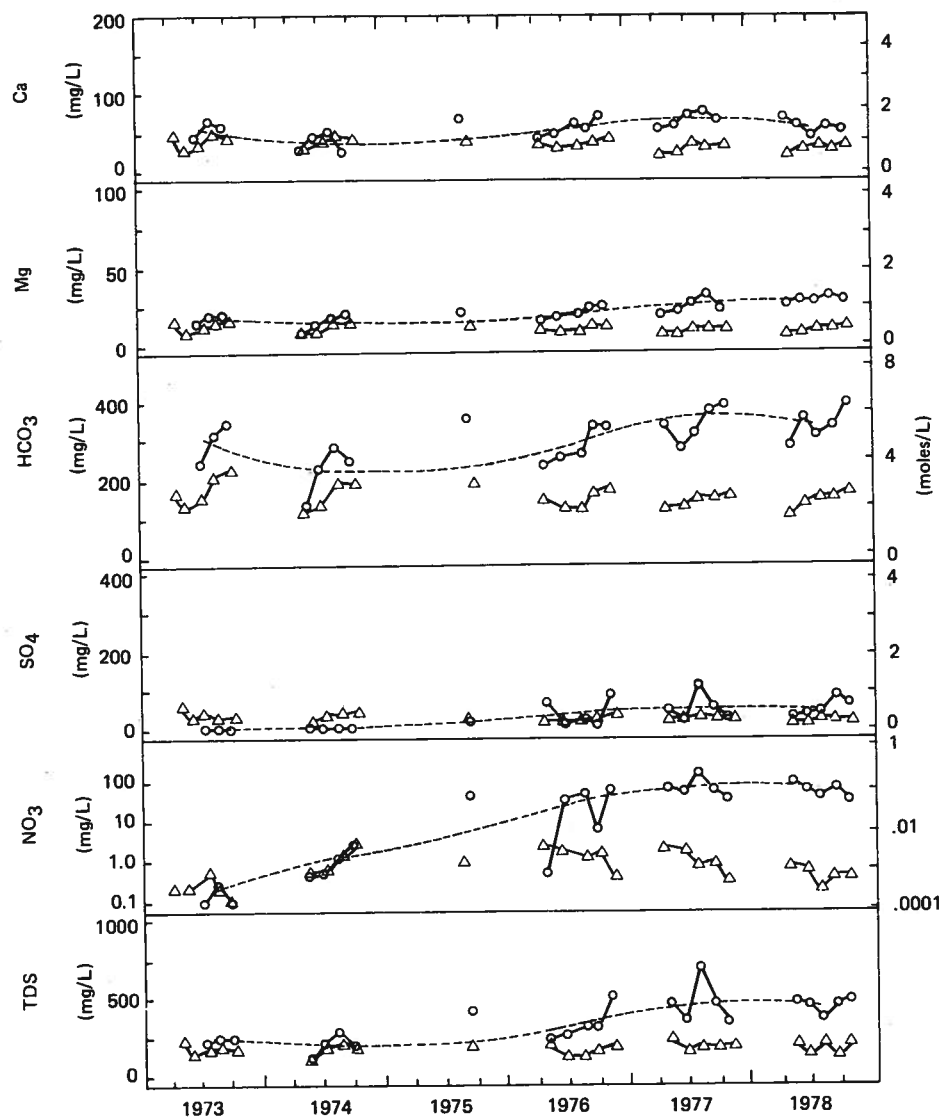


FIGURE 16. Water chemistry — Stream 9-3, 1973-1978

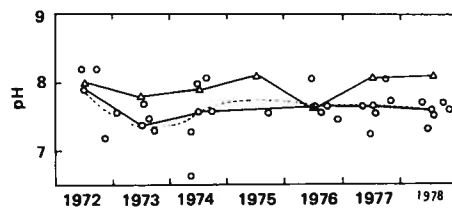
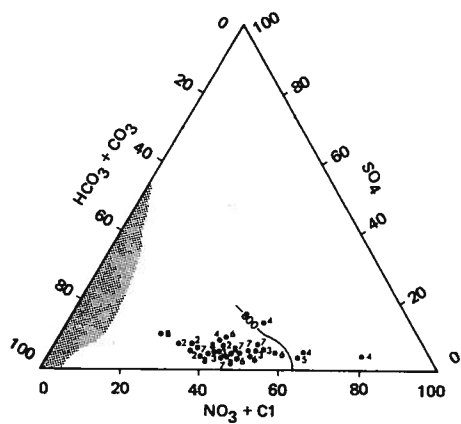
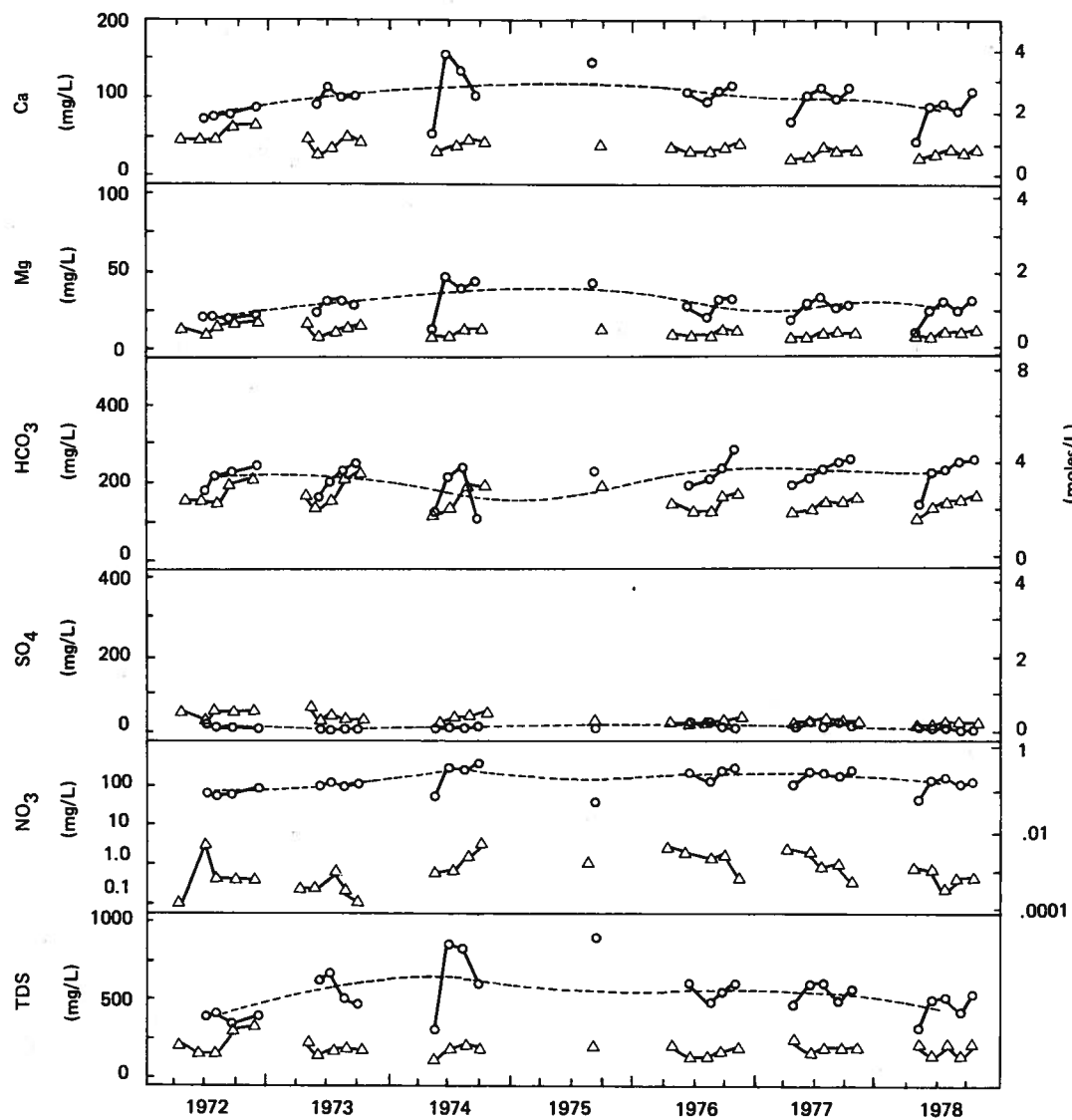


FIGURE 17. Water chemistry — Spring 8, 1972-1978

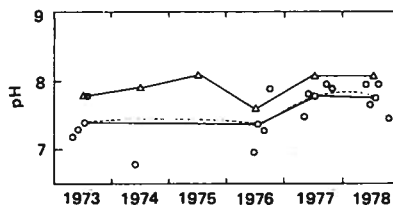
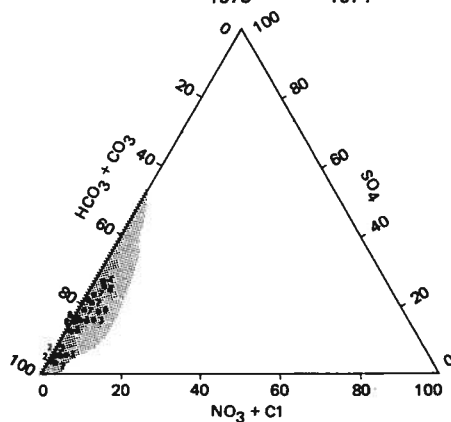
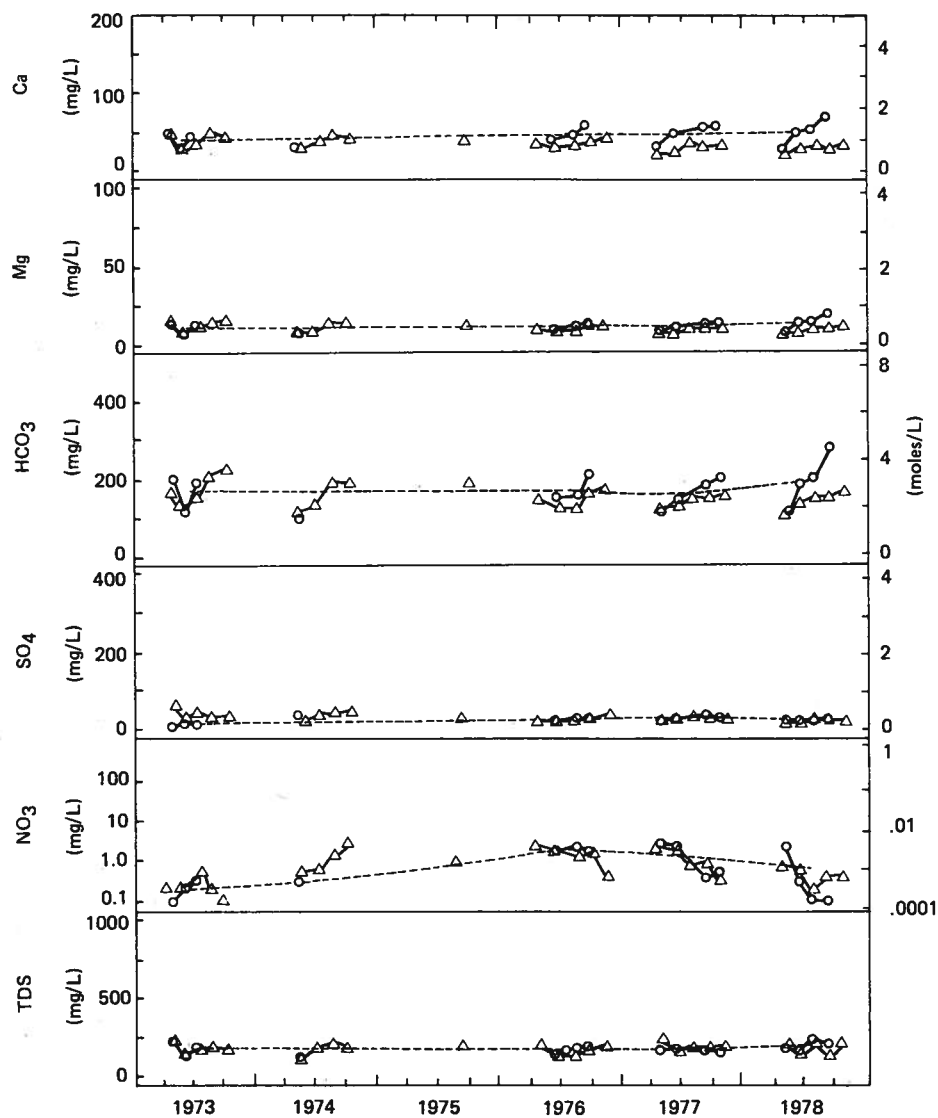


FIGURE 18. Water chemistry — Stream 5, 1973-1978

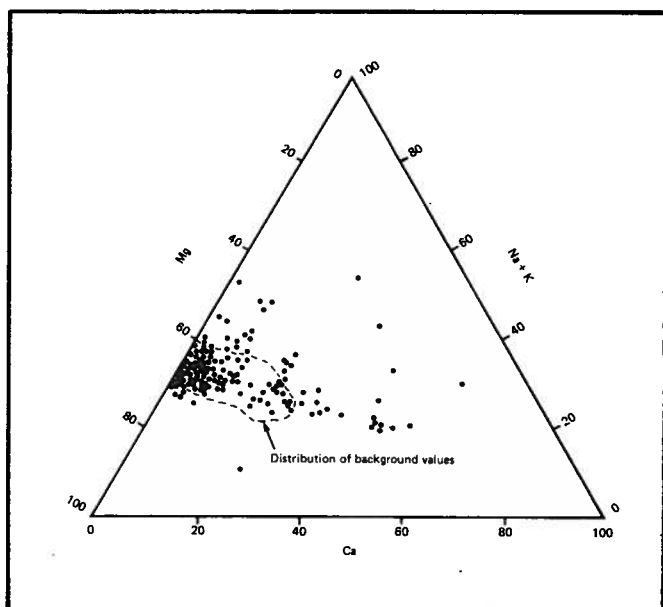


FIGURE 19. Cation hydrochemistry — sites affected by mining activity

(Fig. 19) regardless of whether or not a site is affected by mining. Certain anions, notably sulfate and nitrate, have changed in relative concentrations as a result of mining activity.

The effects of mining activity on hydrochemistry vary in intensity but follow a consistent pattern. The variation in intensity or magnitude of impact is caused by the relative areas of watershed disturbed by mining compared to the total basin size. Sites with a large proportion of their drainage basin in the natural state show only minor impact on water quality (Fig. 13, 14, and 18), while those with a large proportion mined experience a greater change (Fig. 10, 11, 12, 15, 16, and 17).

Regardless of the intensity of the change in hydrochemistry, the total dissolved solids tend to increase. This change took place gradually in the two years after mining activity ceased at No. 8 Mine (Figs. 10 to 14, 17, and 18). Total dissolved solids seem to have peaked in 1977 at Springs 3 and 4 and Stream 6 (Figs. 10, 11, and 14) in No. 8 Mine. Concentrations of dissolved solids continued to increase, however, through 1978 at Stream 2 (Fig. 12). Concentrations of total dissolved solids do not appear to have stabilized at Streams 9-2 and 9-3 (Figs. 15 and 16) in No. 9 Mine, probably because mining activity continued to take place in the drainage basins of these two streams.

The change in water chemistry involves more than an increase in total dissolved solids: the hydrochemistry changed as well. Calcium and magnesium increase in concentration (Figs. 10, 11, 12, 13, 15, and 16) but remain in the same relative proportions as at unaffected sites (Figs. 9 and 19).

Anion hydrochemistry shows a change in constituents that does not take place in the cations. Bicarbonate concentrations increase rapidly to about double the background values and subsequently remain relatively constant. Sulfate concentrations rise slowly after mining begins; in 1978, the sulfate level had reached an annual average in excess of 200 mg/L at some sites (Figs. 10, 11, 12, and 15). Nitrate concentrations increase quite rapidly in response to the initiation of mining activity and range from 10 to 100 mg/L.

The net result of the changes in anion concentration is a shift in the relative chemistry away from bicarbonate dominance in favor of sulfate (Figs. 10, 11, and 12) and, to some extent, of nitrate (Figs. 14, 16, and 17). These changes are very regular, both in time and in total dissolved solids (Figs. 10 to 17). The general decline in concentration of either sulfate, nitrate, or both these ions after 1977 is reflected in the relative chemistry by a shift back towards bicarbonate from the previous general trend towards sulfate and nitrate.

The general trend of increasing dissolved material may have peaked in 1977 in No. 8 Mine (mining had stopped in No. 8 Mine in 1975), because all sites (Figs. 10 to 14) showed a decrease in the average concentration of one or more ions between 1977 and 1978. Such a trend is not evident in No. 9 Mine (Figs. 15 and 16), which was still being mined in 1978.

Acidic conditions are not developing as a result of mining activity. Spring 3, Streams 2, 9-2, and 9-3 (Figs. 10, 12, 15, and 16) are most strongly influenced by mining activity, yet pH values remain stable and at background values. Compared to background values, Springs 4 and 8 and Stream 5 (Figs. 11, 17, and 18) show a trend towards lower pH. These three sites were sampled just as the water emerges from under the muskeg/soil cover and the low values could be the result of carbon dioxide gas introduced into the water by plant roots.

In addition to increased concentrations, mining activity changes the chemical hydrography from relatively constant concentrations to large annual variations. Sites affected by mining (Figs. 10 to 17) show a much wider annual variation of concentration of major ions than the average background values. Minear and Tschantz (1976) noted a similar variation in Kentucky, where concentrations were generally lower in the spring and rose through the summer and fall. This variation suggests that dilution from snow melt and spring rains may play a more important role at sites affected by mining than at the unaffected sites. The relatively constant average concentrations at background sites probably reflect a constant supply of water to these streams from muskegs, interflow, and shallow groundwater. Muskeg probably contributes the bulk of the water volume. At sites affected by mining, the muskeg may be largely removed leaving interflow, shallow groundwater, and seepage through spoil piles as the main contributors to streamflow. Without the modifying effect of relatively constant water quality and the large storage capacity of muskeg, the water quality at sites affected by mining shows more annual variation than at unaffected sites.

The changes in relative hydrochemistry observed during the seven years of sampling can be summarized as follows.

The relative anion hydrochemistry systematically shifts over time from bicarbonate dominance towards sulfate; nitrate also tends to increase. Total dissolved solids also systematically increase both with time and with changes in the relative anion hydrochemistry. The change in sulfate may peak at about 30 to 50 percent with concentrations of about 200 mg/L. Both in relative and absolute terms, nitrate appears to reach a maximum and then to decline slowly over time. No changes in the relative cation hydrochemistry are observed, although absolute concentrations increase.

CHANGES IN WATER CHEMISTRY WITHIN SPOILS

Streams 2 and 5 are located above and below Spoil Area 4, (Figs. 2 and 3). Stream 2 contains water flowing past the Stream 5 site and discharge from springs buried under Spoil Area 4. Comparing

waters at these two sites indicates that the quality of the water changes as it passes through a spoil pile.

From the beginning of sampling in 1973 until mid-1976, samples from Stream 5 (Fig. 18) were very similar to background values. The water was a calcium-magnesium bicarbonate type with total dissolved solids concentrations less than 200 mg/L. In 1976 and 1977, the amount of sulfate compared to bicarbonate increased. This change probably reflects mining activities in the West Ridge area (Fig. 2). A large proportion of the drainage area for this site remains undisturbed by mining. The influence of the West Ridge area is probably minor.

Water passing through the spoil at Spoil Area 4 (Figs. 12 and 18) increases in total dissolved solids concentration from background values of about 180 mg/L to about 600 mg/L. The anion composition also changes from 20 percent to about 50 percent sulfate. These changes take place over a flowpath of 300 m along the base of the spoil. The water probably travels this distance in less than one day due to the very coarse nature of the subdrain installed at the base of the spoil. Rates of weathering in the spoil pile may be concluded to be high in order to provide this amount of dissolved material continuously.

GROUNDWATER CHEMISTRY

The effect of mining on groundwater chemistry in the area is reflected to a great extent by the chemistry of streams and springs. Some groundwater data do exist for water samples taken from the piezometers.

The two piezometer nest sites below the M-1 Spoil Area were available for monitoring for about one year. Water samples from the piezometers at depths of about 30 m were of the calcium-magnesium bicarbonate type and are similar to background chemical types of the area. Both piezometer sites were destroyed during initial construction of the M-1 Spoil Area, hence the influence of mining activity could not be observed.

The three upper piezometers at WR-1 (Fig. 6) contain water of the calcium-magnesium bicarbonate type (Fig. 20), while sodium is the dominant cation

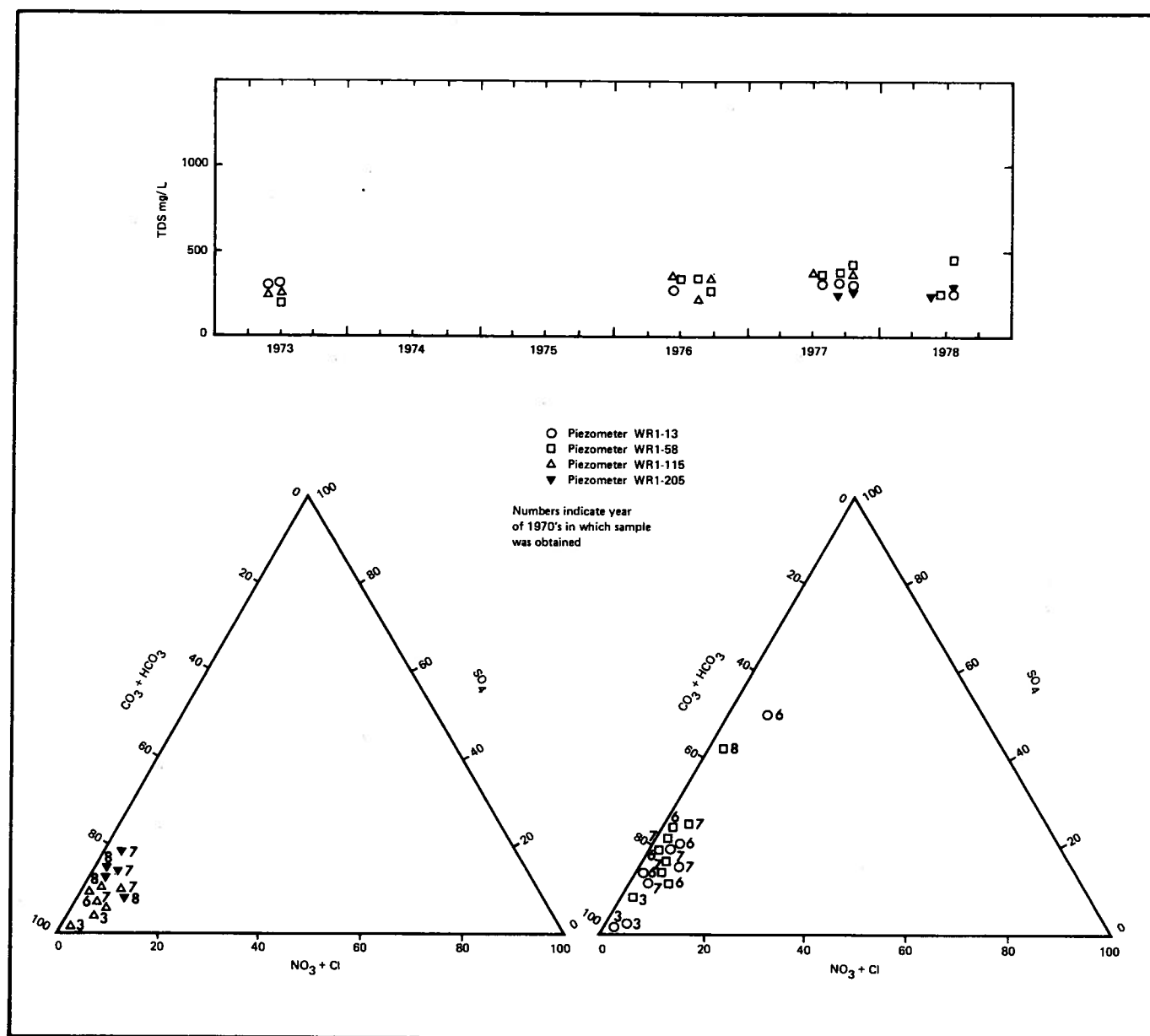


FIGURE 20. Water chemistry — Piezometer Site WR-1

in the five samples from WR-1-205. The significance of this difference in chemical composition is unclear.

Concentrations of calcium, magnesium, and sulfate have increased in the three shallow wells at piezometer site WR-1 (Fig. 20). Calcium and magnesium constitute over 85 percent of the cations in all samples. The trend towards increased sulfate noted at surface-water sampling sites influenced by mining activity (Figs. 10 through 18) is also taking place in

the groundwater, but to a lesser extent. The relative and absolute chemistry of water in the 62 m deep piezometer has not changed with time, which suggests that the effects of mining do not extend to that depth. The concentration of total dissolved solids in the three shallow wells has increased from about 250 mg/L in 1973 to over 400 mg/L in 1978.

The quality of groundwater to a depth of 30 m has been influenced by mining activity in the same manner as has surface-water quality. Increases in cal-

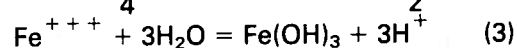
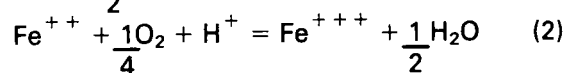
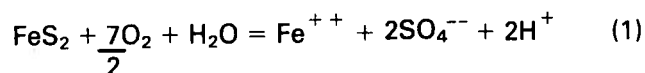
cium, magnesium, and sulfate concentrations have contributed to the rise in total dissolved solids, while nitrate concentrations remain at background values.

CAUSES OF CHANGES IN WATER CHEMISTRY

Rates of chemical weathering of the bedrock (basically the Luscar Formation) have increased substantially as a result of mining activity. Two factors contribute to this:

- (1) The movement of water in bedrock under undisturbed conditions is probably limited to fractures and joints rather than as intergranular flow. Blasting, excavating, and dumping this material increases its porosity by about 20 to 30 percent (R. Wigelsworth, McIntyre Mines Ltd., personal communication). The spoil material, largely cobble and larger-sized fragments (Plate 2), but also containing appreciable amounts of smaller-sized particles, has more rock surface available for chemical weathering than the undisturbed bedrock. A similar theory was expressed by Minear and Tschantz (1976). Reject material from within the coal, which is also placed in the spoil piles, is exposed to chemical weathering to a much greater extent than before mining.
- (2) Oxidation processes, which were restricted because of the saturated conditions in the in-place bedrock, accelerate in the porous, unsaturated spoil. Alternating periods of dryness and wetness allow for the repeated production and removal of oxidation products by infiltrating water passing readily through the spoil material.

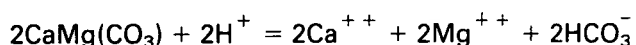
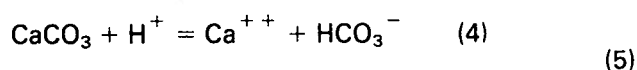
The increase in sulfate ion concentration is caused by increased rates of oxidation of sulfide minerals in the spoil as exemplified by the following reactions involving pyrite (Stumm and Morgan, 1970):



The ferric ion, produced because of the highly oxidizing conditions (2), probably precipitates out of solution as ferric hydroxide (3). This compound

is observed in the area, although much of it probably washes away during periods of high runoff. Increases in concentration of iron are not observed at sites influenced by mining due to the filtering of water samples.

The hydrogen ion, produced during the oxidation of sulfide minerals (1) and in the subsequent hydrolysis (3) of the ferric ion, increases the weathering rate of the abundant carbonate minerals in the spoil according to the following reactions (Hem, 1970):



Since these minerals probably contributed most of the dissolved cations in the natural situation, an increased rate of weathering does not change the relative abundance of calcium and magnesium (Fig. 19), but only increases their concentration.

Equations (1) through (5) indicate that the production of 1 mole of sulfate should produce 2 moles of calcium plus magnesium either from dolomite (5), aragonite (4), or calcite (4) regardless of their relative amounts, if the dolomite is assumed to have equal proportions of calcium and magnesium.

The relationship of the molar concentrations of calcium plus magnesium to sulfate, both at background sites and at all sites affected by mining, shows a linear trend (Fig. 21), which has a slope of 0.86 moles of sulfate per 2 moles of calcium plus magnesium. This result suggests that the processes hypothesized above are correct.

Although sulfate concentrations in the natural state are generally less than 0.5 moles/L (Fig. 10; Table 2), they can range as high as 3.5 moles/L (Fig. 10) at sites influenced by mining activity. The stability of sulfate concentrations under natural conditions reflects a steady-state condition between the rate of production of that ion from sulfide minerals and its removal and transport to streams by subsurface water. Mining disturbs the natural sulfate equilibrium by increasing the rate of oxidation of sulfide minerals. Molar concentrations of sulfate and calcium at sites affected by mining tend to increase at a one-to-one rate. The rate is

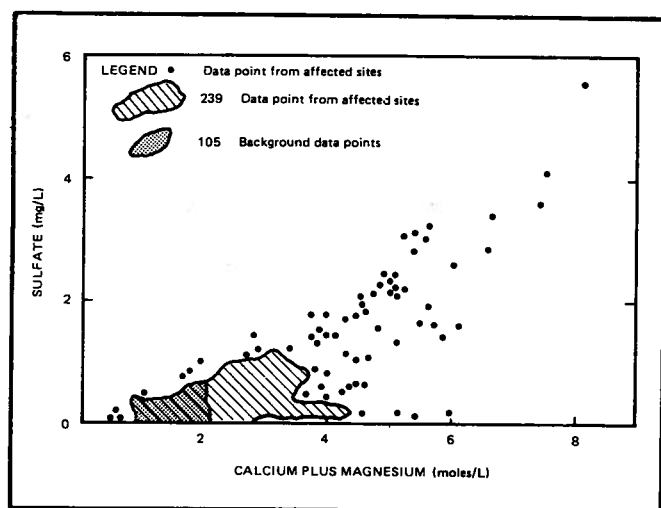


FIGURE 21. Relationship of molar concentrations of calcium plus magnesium to sulfate

similar to that for the dissolution of gypsum, suggesting that gypsum may be an intermediate mineral in the weathering process within the spoil piles.

The concentration of bicarbonate, which is produced from the enhanced solution of dolomite, aragonite, calcite, and from the dissolution of carbon dioxide gas in water, is controlled to some extent by the ambient partial pressure of carbon dioxide. This pressure is high in the subsurface due to respiration and decay processes in the soil and to oxidation of coal in the spoil. The partial pressure of carbon dioxide in surface streams is much lower than in the spoil, so water recently discharged from the subsurface tends to exsolve carbon dioxide, thus reducing the bicarbonate concentration. Bicarbonate is not a conservative parameter in the system. Concentration of bicarbonate in surface water may be largely a function of the location of these sampling sites with respect to points of groundwater discharge, which may account for the lack of a parallel increase of bicarbonate with calcium and magnesium.

Ammonium nitrate, used for blasting by the mining company, is included in the spoil from spills or as nitrous oxide residue produced by the blasting. These sources account for the increase in nitrate over background conditions. Under natural conditions, nitrate is an insignificant anion both in relative (Fig. 9) and in absolute terms (Table 2). Virtually all the nitrate in streams affected by

mining activity is from blasting materials. All sampling sites show some increase in nitrate as a result of mining activity. Concentrations, which vary between sites and at individual sites with time, usually ranged between 10 and 100 mg/L over the seven years of monitoring (Figs. 10 to 18). Spring 8, located just downslope from a storage area for blasting supplies, had nitrate concentrations that occasionally exceeded 400 mg/L (Fig. 17); nitrate was about 50 percent of the anions at these times. The storage area was removed in 1975 when No. 8 Mine closed and, since then the water chemistry at Spring 8 has shown a consistent shift towards natural conditions. Nitrate concentrations are decreasing as precipitation leaches the residual ammonium nitrate from the storage area.

Systematic changes in pH did not take place during this study (Figs. 10 through 18). Statistical tests of means and variances of pH values indicated no differences in the distributions at affected or unaffected sites at the 95 percent confidence limit. Both background sites and sites affected by mining have pH values of about 8.0. Similar observations were made by McWhorter *et al.* (n.d.) for an area in Colorado and by Minear and Tschantz (1976) in Kentucky. The stability of pH differentiates the effects of mining in the Alberta foothills from those in parts of the eastern United States where acid mine-drainage is common (Musser, 1963; Collier and others, 1964; Collier *et al.*, 1971; Grubb and Ryder, 1972; Heohn and Sizemore, 1977).

With the exception of the changes in nitrate concentrations, the trends in water chemistry noted in this section were also observed in Kentucky (Minear and Tschantz, 1976) and Colorado (McWhorter *et al.*, n.d.). The buffering capacity [equations (4) and (5) above] of the natural system in the Alberta foothills is sufficient to prevent a decline in pH, as it was in the study areas of Kentucky and Colorado. Carbonate minerals could probably not be totally consumed [equations (4) and (5) above] as a result of hydrogen ion production [equations (1), (2), and (3) above] because carbonate is 100 times more abundant on a molar basis in the spoil than is total sulfur and only two moles of carbonate will be consumed for every mole of sulfide oxidized. Thus, the processes observed elsewhere can be applied to the Alberta foothills context when due consideration is made for geological differences.

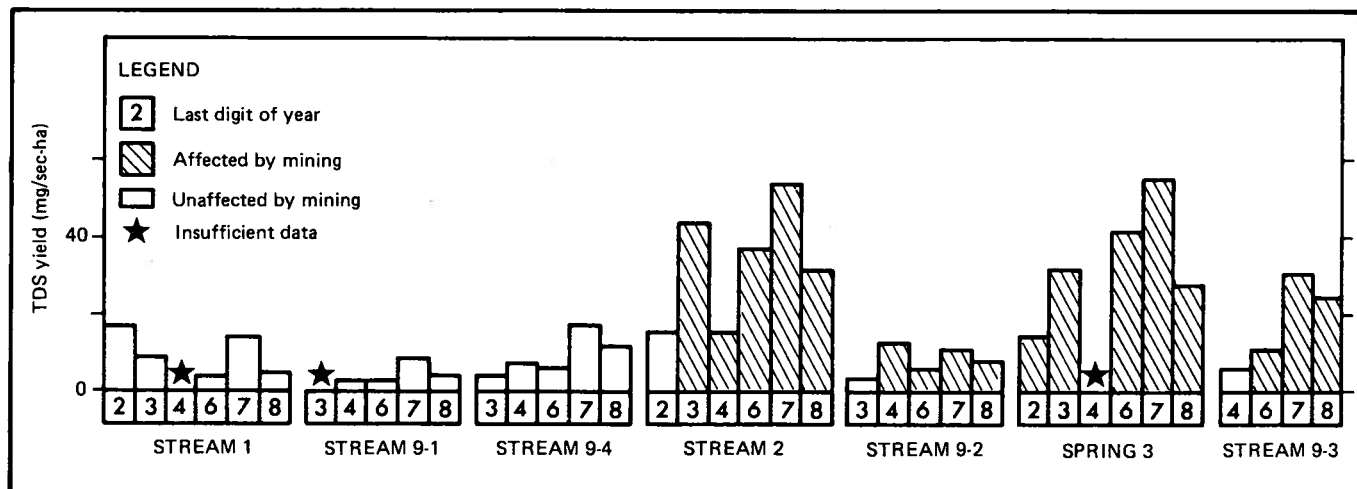


FIGURE 22. Total dissolved solids yield

TOTAL DISSOLVED SOLIDS YIELD

Calculations of the total dissolved solids yield per unit area of drainage basin for mined and unmined areas (Fig. 22) were made using averages of both streamflow and concentration of total dissolved solids for three or more data points each year. These numbers must be used solely as guidelines, since estimates of discharge and only 3 to 6 samples a year were used in the calculations. A relative comparison may more reasonably represent conditions than the actual yield values presented. If the lowest runoff value is taken as unity (Stream 9-1, 1974), runoff from unaffected areas varies from about 1 to 5. Runoff from areas affected by mining varied from about 2, during the early stages of No. 9 Mine in 1974, to 16, in 1974 at Stream 2 and Spring 3.

Areas unaffected by mining have yields of total dissolved solids between 3.5 and 18.5 mg/sec-ha (Fig. 22). Judson and Ritter (1964) give values of 7 mg/sec-ha and 18 mg/sec-ha for yields of total dissolved solids in the basins of the Colorado and Columbia Rivers. Streams in the Marmot Creek Research Basin (Environment Canada, 1974, 1975) have yields of total dissolved solids of 20 to 26 mg/sec-ha, based on period-of-record averages of both discharge and total dissolved solids. Miller and Drever (1977) found 6 mg/sec-ha for a portion of the Shoshone River in an unmined area of Wyoming. Rowe and McWhorter (1978) found 24 to 27 mg/

sec-ha in unmined areas in a mountainous part of Colorado.

Yields of dissolved solids vary between 3.7 and 55 mg/sec-ha for areas affected by mining. Data from McWhorter *et al.* (n.d.) and Rowe and McWhorter (1978) for three areas in northwestern Colorado note yield values between 51 and 169 mg/sec-ha, 40 years after mining ceased. Thus, the approximate values obtained by using average concentrations of total dissolved solids and streamflow give yields which agree with those obtained by more rigorous techniques.

Sites affected by mining (Fig. 22) show a peak in yields of total dissolved solids yield in 1977 followed by a decline. Stream 2 and Spring 3, because of their similar physical setting, have similar yields of total dissolved solids on a year-by-year basis. Yields at Stream 9-2 and 9-3, although much lower than at Stream 2 or Spring 3, also peaked and declined in 1977 and 1978. The three background sites also exhibited a similar decline between 1977 and 1978, probably as a result of natural phenomenon. One possible explanation is that precipitation during the spring and summer of 1977 was unusually high (Fig. 5) and could have caused an abnormal flushing of accumulated weathering products during that year. The return to lower precipitation during the spring and summer of 1978 subsequently caused less flushing and a lower yield of total dissolved solids, compared to 1977, both in mined and in unmined areas.

INFLUENCE OF MINING ON SHEEP CREEK

A statistical comparison of various chemical parameters for Sheep Creek at the Bailey bridge and at Smoky River (Table 5) shows a 95 percent confidence, except for nitrate, that the means and variances of these chemical constituents are not different at the two sites. If the chemistry of water passing these two sites cannot be demonstrated to be significantly different, the influence of mining activities on Sheep Creek must be negligible.

Although the variance of nitrate concentrations is demonstrably different in Sheep Creek at the Bailey bridge and at Smoky River (Table 5), average values of nitrate concentration for these two sites are not different at the 95 percent confidence limit. In other words, the evidence does not suggest that the averages are from different sample populations. Again, statistical tests indicate that mining is not adversely affecting the water chemistry of Sheep Creek.

Sulfate, which has been demonstrated to be a major ion in drainage from the mining area, has the same average concentration (Table 5) at both the Bailey bridge and Smoky River. Standard devia-

tions are nearly equal at both sites and a high correlation coefficient exists, which also supports the conclusion that Sheep Creek is unaffected by mining.

Statistics notwithstanding, on a yearly basis, the average concentration of total dissolved solids in Sheep Creek at Smoky River exceeds that at the Bailey bridge (Fig. 23a) by 8 to 17 mg/L, except in 1972 when the reverse was true. A portion of this increase might be attributed to mining activity. Some increase in concentrations of total dissolved solids can, however, be attributed to the fact that concentrations of total dissolved solids in Streams 1, 9-1, and 9-4 (Fig. 23b) exceed those of Sheep Creek at the Bailey bridge on about 70 percent of the sample-days between 1972 and 1978. Thus, some of the increase in concentrations of total dissolved solids in Sheep Creek between the Bailey bridge and Smoky River comes from the tributaries which, under natural conditions, contain slightly higher chemical concentrations than does Sheep Creek.

Average values of pH decrease slightly in Sheep Creek between the Bailey bridge and Smoky River (Table 5). The magnitude of the change is not demonstrably significant and could be due to

TABLE 5
Statistics of chemical analysis of Sheep Creek at Bailey Bridge
and Smoky river (1972 to 1978)

Constituent	Bailey Bridge		Smokey River		T test ²	F test ³	Correlation Coefficient ⁴
	Mean	Standard Deviation ¹	Mean	Standard Deviation ¹			
Total dissolved solids	188	56	183	63	x	x	0.73
Calcium	42.3	11.4	41.8	11.6	x	x	0.81
Magnesium	13.0	3.3	13.0	3.4	x	x	0.74
Sodium	5.0	3.0	3.8	2.7	x	x	0.71
Potassium	0.6	0.5	0.5	0.4	x	x	0.57
Bicarbonate	160	31	157	30	x	x	0.79
Sulfate	33.1	14.3	32.5	16	x	x	0.82
Chloride	3.2	2.3	2.6	1.9	x	x	0.67
Nitrate	0.6	0.7	0.9	1.3	x	○	0.46
pH	8.1	0.3	8.0	0.3	x	x	0.49

All values are in mg/L except for pH.

¹Standard deviation (mg/L)

²Students' T test that the means of two populations are not different; "x" indicates 95 percent confidence.

³F test that variances of two populations are not different; "x" indicates 95 percent confidence; "○" indicates rejection.

⁴Correlation coefficient of linear regression.

natural changes in the carbonate equilibrium caused, for example, by temperature or turbulence.

In summary, the chemistry of the water in Sheep Creek undergoes insignificant changes as it passes through the mining area. This lack of significant change in sulfate and nitrate concentrations downstream supports the conclusion that the impact of mining activity on water chemistry is minor and unmeasurable with the techniques employed.

MINOR CONSTITUENT CHEMISTRY

In 1976 and 1977, the water samples taken for minor constituent analysis were passed through 0.45 micron filter paper in the field and subsequently acidified. Before 1976, all samples taken for minor element analysis were only decanted and acidified. This latter procedure might allow small particles suspended in the sample to be leached by the acid, giving falsely high concentrations of certain ions. Under these conditions, the results of analyses for all minor constituents before 1976 should be regarded only as indications of dissolved concentrations and not as absolute values. Iron and manganese for instance, which are common elements in clay minerals, have generally higher concentrations at most sampling sites during the years 1972 to 1974 than in 1976 and 1977 (Figs. 24 through 30). Filtering out the suspended clay particles from the samples after 1976 probably reduced concentration of these two elements.

Iron and manganese (Figs. 24 and 25) are usually above acceptable limits for drinking water (Table 6) and are frequently above maximum permissible values regardless of whether or not a site is influenced by mining. This situation was anticipated as the weathering of sulfide and clay minerals is known to produce iron and manganese.

Manganese frequently exceeds background averages, while iron is commonly near or below background values. Current results do not indicate a tendency for either of these ions to increase in concentration with time.

Iron produced during the weathering of sulfide minerals would be expected to precipitate from solution as hydroxide due to the abundance of oxygen and high pH of the surface streams. Iron is probably present in the suspended load carried by

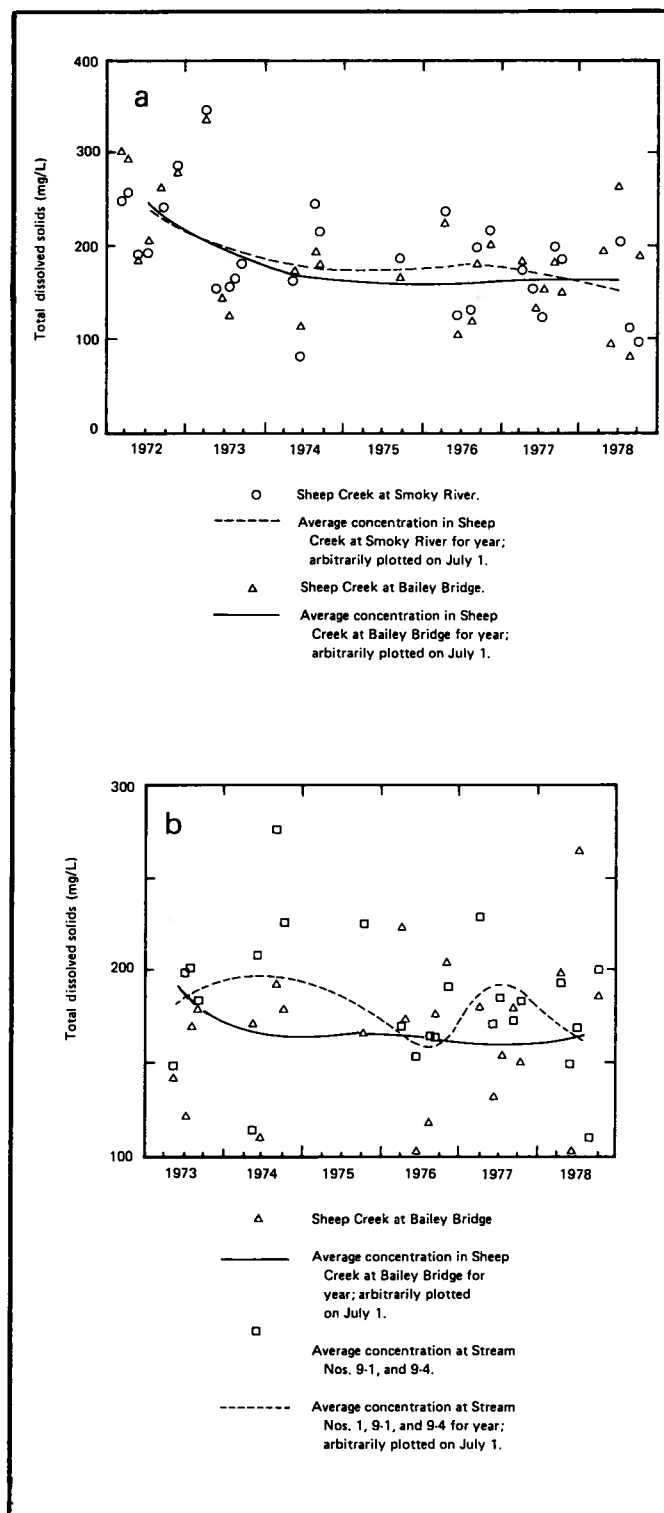


FIGURE 23. Total dissolved solids concentrations: (a) in Sheep Creek at the Bailey bridge and at Smoky River, B) at Streams 1, 9-1, 9-4, and Sheep Creek at Bailey bridge

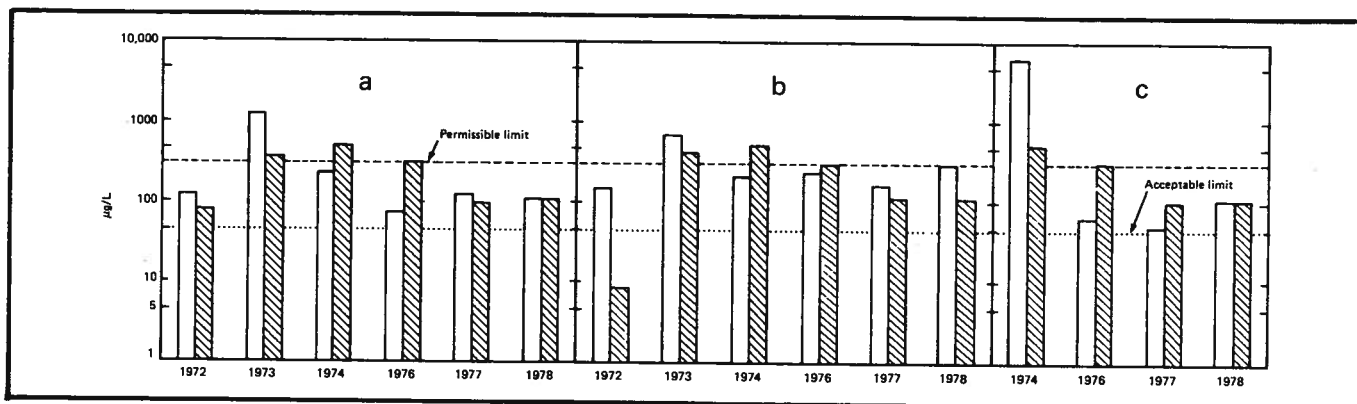


FIGURE 24. Average annual iron concentrations: (a) Stream 2, (b) Spring 3, and (c) Stream 9-2 (see figure 29 for legend)

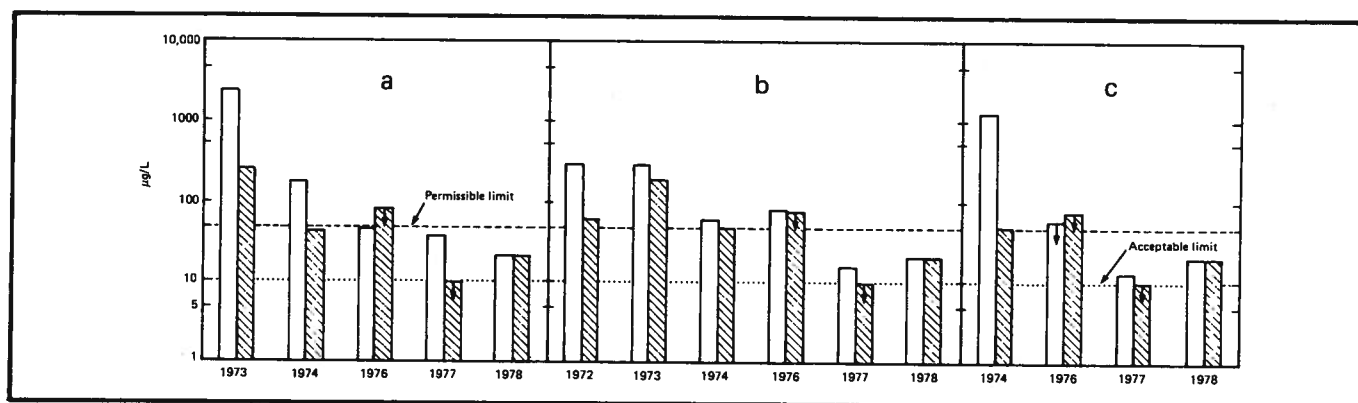


FIGURE 25. Average annual manganese concentrations: (a) Stream 2, (b) Spring 3, and (c) Stream 9-2 (see figure 29 for legend)

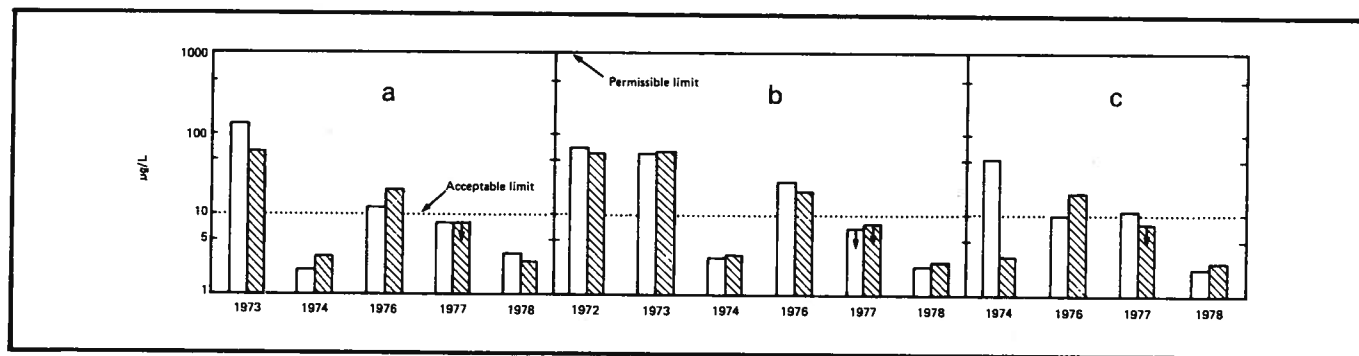


FIGURE 26. Average annual copper concentrations: (a) Stream 2, (b) Spring 3, and (c) Stream 9-2 (see figure 29 for legend)

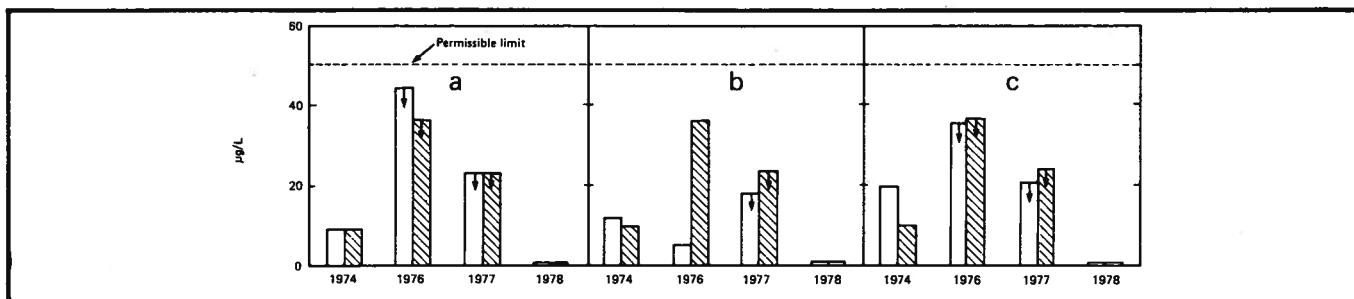


FIGURE 27. Average annual lead concentrations: (a) Stream 2, (b) Spring 3, and (c) Stream 9-2 (see figure 29 for legend)

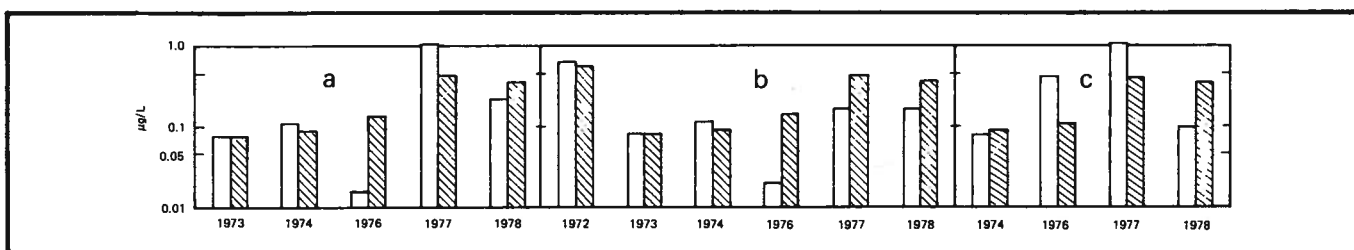


FIGURE 28. Average annual zinc concentrations: (a) Stream 2, (b) Spring 3, and (c) Stream 9-2 (see figure 29 for legend)

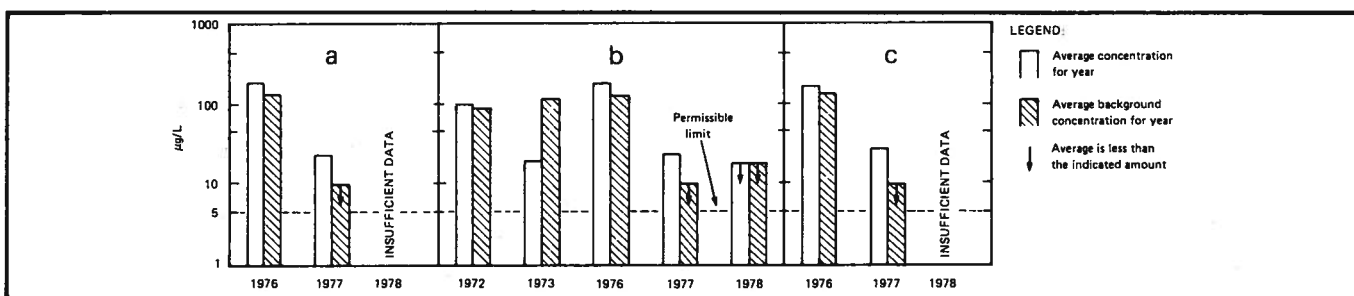


FIGURE 29. Average annual mercury concentrations: (a) Stream 2, (b) Spring 3, and (c) Stream 9-2 (see figure 29 for legend)

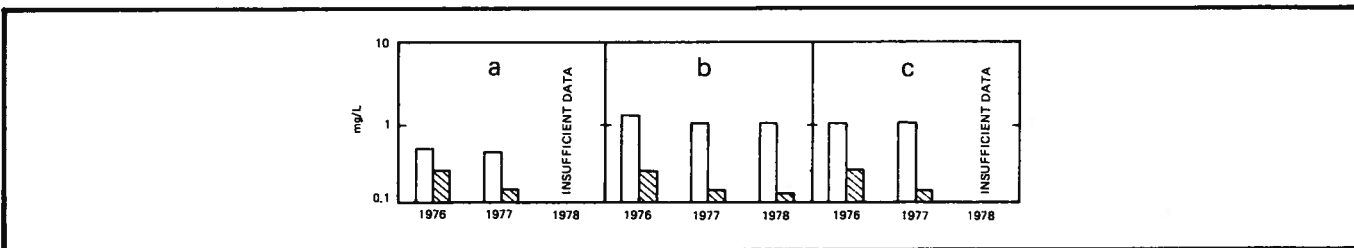


FIGURE 30. Average annual strontium concentrations: (a) Stream 2, (b) Spring 3, and (c) Stream 9-2 (see figure 29 for legend)

TABLE 6
Drinking water criteria - minor constituents

Element or Parameter	Acceptable (µg/l)	Maximum Permissible (µg/l)	Reference
Aluminum (Al)	—	A	2
Arsenic (As)	10	50	1
Barium (Ba)	1000	1000	1
Beryllium (Be)	—	B	2
Boron (B)	5000	5000	1
Cadmium (Cd)	10	10	1
Chromium (Cr)	50	50	1
Cobalt (Co)	—	B	2
Copper (Cu)	10	1000	1
Europium (Eu)	—	C	1, 2
Gold (Au)	—	A	2
Iron (Fe)	50	300	1
Lead (Pb)	50	50	1
Manganese (Mn)	10	50	1
Mercury (Hg)	—	5	2
Molybdenum (Mo)	—	B	2
Nickel (Ni)	—	1000	1
Phosphorus (P)	60	60	1
Selenium (Se)	10	10	1
Silica (SiO ₂)	—	A	2
Silver (Ag)	—	50	1
Strontium (Sr)	—	A	2
Tellurium (Ti)	—	C	1, 2
Tin (Sn)	—	A	2
Titanium (Ti)	—	A	2
Tungsten (W)	—	A	2
Uranium (U)	—	1000	2
Vanadium (V)	—	B	2
Zinc (Zn)	1000	5000	1

A - Not a contaminant in water because of either lack of solubility or physiological considerations.

B - Limit not established.

C - Not mentioned in references.

References: 1. Canada Department of National Health and Welfare (1969).
2. McKee and Wolf (1971).

streams leaving the mining area. A decanting or filtering process removes the iron from the water samples, so only minor amounts are detected.

The manganese ion, produced by the weathering of clay minerals, is more soluble than the iron (Hem, 1970) at the existing pH and Eh conditions and shows a tendency to increase over background

values. Hem (1970) states that elevated levels of manganese are typical of streams receiving acid mine-drainage. McWhorter *et al.* (n.d.) noted somewhat increased levels of manganese in streams draining coal mines in Colorado, even though pH values remained stable. Manganese levels apparently increase regardless of whether or not the area produces acid mine-drainage.

Neither manganese nor iron represent a physiological danger to animals; the limits (Table 6) are based on esthetic considerations (McKee and Wolf, 1971). This fact, when coupled with the fact that naturally occurring background concentrations commonly exceed drinking water standards, means that there is little need for concern about concentrations of these two elements in water from the mining area.

The analyses of minor elements (Appendix 2) show that copper and lead concentrations occasionally exceed standards for drinking water (Table 6) at both affected and unaffected sites. Concentrations of lead and copper (Figs. 26 and 27) are not increased by mining activity because background averages and annual averages at the three sites are usually similar and occasionally exceed acceptable standards for drinking water. The sources of lead and copper are probably sulfide minerals originally deposited in association with the pyrite. Apparently, release of these metals by weathering is not increased by mining activities over normal rates for this area.

Concentrations of zinc (Fig. 28) apparently increase somewhat over background averages due to mining activity. No increases in background levels with time are observed; in fact, concentrations in background streams and at Streams 2 and 9-2 and Spring 3 decreased from 1976 and 1977. The source of the zinc is sedimentary sulfides containing zinc, as is the case for most other metals mentioned above.

Concentrations of mercury are well below the maximum permissible value of $5 \mu\text{g/L}$ (Fig. 29). Average annual concentrations of mercury have exceeded values at Streams 2, 9-2, and Spring 3 in six of the twelve sample years between 1972 and 1977 for which averages could be calculated. Increases in annual average concentration took place in 1974, 1976, and 1977 at Stream 9-2. The pattern is not repeated at Stream 2 and Spring 3 and background values also increased over that same time period. Whether mining has caused increases is a matter of speculation.

Strontium concentrations appear to rise (Fig. 30) about four to six times above average background values as a result of mining activity. Average background values were 0.25 to 0.15 mg/L in 1976

and 1977, while concentrations were as high as 1 mg/L at Streams 2 and 9-2 (Figs. 30a and 30c) during those same years. This increase was probably due to the advanced weathering of aragonite in which strontium can replace calcium. Standards for non-radioactive strontium in drinking water (Table 6) have not been established and the only impact of the increase would be to contribute to greater hardness in the water.

Chromium, another metal of environmental interest, remains at very low concentrations in all streams and springs of the area (Appendix 2).

Concentrations of phosphorus (Appendix 2) occasionally exceed the maximum permissible standard of $60 \mu\text{g/L}$ for drinking water. In this case, the detection limits (Table 6) exceed the standard for drinking water; however, concentrations as high as $1430 \mu\text{g/L}$ have been observed (Spring 3, November 3, 1976). High concentrations of phosphorus usually occur at sites affected by mining activity and might be related to fertilization for revegetation (Table 1). On September 31, 1976, Stream 9-1 had a concentration of $1000 \mu\text{g/L}$; the source of this high level of phosphorus is as yet unexplained.

Figure 31 presents annual averages of selected minor constituents in Sheep Creek. Average annual values of iron, lead, manganese, and copper commonly exceeded acceptable standards for drinking water (Table 6) both above (the Bailey bridge) and below (Smoky River) the mines. When examined on this basis, iron, copper, lead, mercury, zinc, and strontium tend to increase between the Bailey bridge and the Smoky River. Whether this represents natural increases or is caused by mining cannot be determined from the data. Considered over the seven years of sampling, however, the statistical difference (95 percent confidence) is insignificant, as indicated by means and variance tests, in the distribution of strontium, manganese, copper, lead, zinc, and mercury between water passing the Bailey bridge and reaching the Smoky River. Iron concentrations between these two sites were the same at 95 percent confidence when means were tested. A test of the variances, however, did not achieve a similar confidence limit. The situation with these metals in Sheep Creek is the same as that discussed previously with respect to the major constituents.

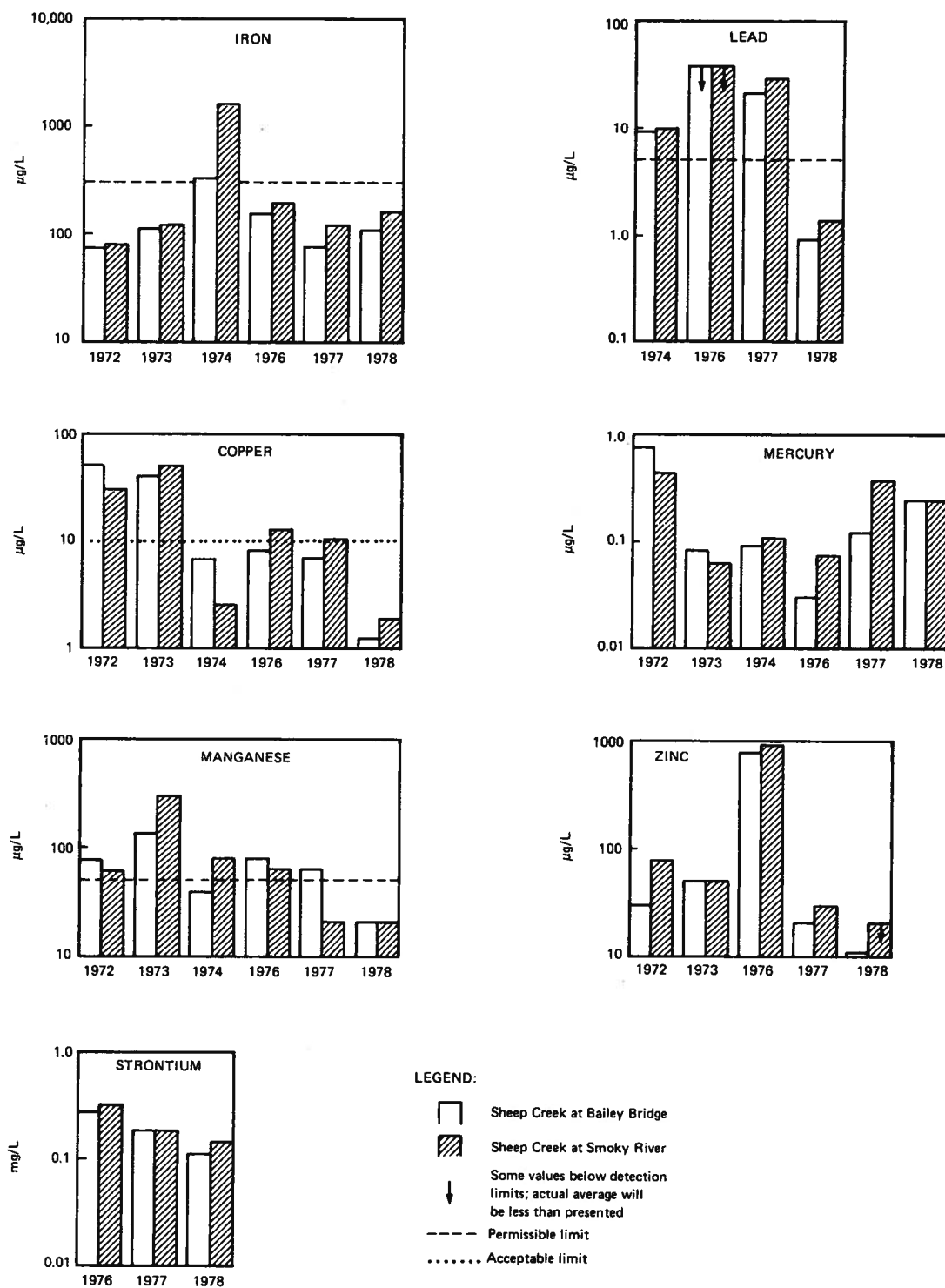


FIGURE 31. Average annual concentrations of minor constituents in Sheep Creek at the Bailey bridge and at Smoky lake

Mining activity in general has had little impact on the minor element chemistry of streams and springs. Iron, manganese, and lead exceed standards for drinking water on various occasions in both affected and unaffected streams. Temporal trends in the concentration of minor constituents were not seen, even though such changes might be expected given the changes in major ion chemistry. This conclusion is based on only three years (1976 to 1978) of analyses of water samples collected with good techniques for preservation of minor constituents (see Appendix 2). Further sampling is necessary to validate the conclusions.

SUMMARY

1. No. 8 Mine, on the north side of a 600 m (2000 ft) high ridge that trends east-west, has wetter conditions than the nearby No. 9 Mine, which is located on south-facing slopes and has similar relief. Snow begins to accumulate earlier in the fall and remains later in the spring at No. 8 Mine than at No. 9 Mine. Aspen and grass dominate the vegetation of the south slopes of No. 9 Mine; spruce and muskeg are frequently found in No. 8 Mine. These differences in vegetation reflect the differences in moisture of the two microclimates.
2. Coal was mined in No. 8 Mine from 1971 to 1975 from the Cretaceous Luscar Formation. Coal mining began in No. 9 Mine in 1974 and continued through 1978. The coal is low-volatile bituminous grade with an average sulfur content of 0.35 percent. Total sulfur in the Luscar Formation, exclusive of the coal, constitutes less than 0.07 percent.
3. Most overburden and other spoil materials placed in abandoned pits and in designated areas consist of well-indurated sandstones and shales and partings from within the coal beds. The degree of induration of the overburden causes the spoil materials to range in size mostly from cobbles to boulders. Water drains readily through the spoil piles and unsaturated conditions are thought to exist, except near the base.
4. Most groundwater is thought to move at or near the contact between the bedrock and the overlying colluvium. Fractures conduct relatively small volumes of groundwater in the bedrock. Springs and seeps occur more often on the north-facing slopes of No. 8 Mine than on the south-facing slopes of No. 9 Mine. Activities such as road building, rather than natural causes, often cause springs and seeps.
5. Streams unaffected by mining activity characteristically have water of the calcium-magnesium bicarbonate type with total dissolved solids concentrations between 125 and 231 mg/L. Nitrate is usually less than 1.9 percent of the anions and sulfate less than 30 percent. From 1972 to 1978, pH values were usually between 7.6 and 8.2.
6. Mining activity can cause concentrations of total dissolved solids in streams draining from the area to increase to four times the background values. The relative amounts of cations remain unchanged from assumed original conditions, although absolute concentrations increased.

Mining activity has changed anion chemistry. The absolute concentrations of anions increase and the relative proportion of sulfate ions present progressively increases. Increases in nitrate concentrations also occasionally exceed the changes in the relative amount of sulfate. The source of the nitrate is thought to be ammonium nitrate used for blasting.

Enhanced rates of oxidation of sulfide minerals in the spoil, compared to background rates, may increase sulfate concentrations. Oxidation of sulfides does not lower pH in streams affected by mining activity, when compared to background values, for two reasons:

- (a) spoil material contains about 14 percent carbonate and only about 0.07 percent total sulfur;
- (b) the absence of an active soil layer causes lower dissolved carbon dioxide concentrations relative to unmined areas, which in turn act to increase the pH.

The chemical controls on drainage from coal mines in Alberta foothills are the same as those outlined for other areas by other work-

ers. The geological characteristics of the area control the extent to which these chemical reactions affect the water draining from the mine.

7. Mining activity increased the dissolved solids yield 2 to 16 times. Areas affected by mining yield between 3.7 and 55 mg/sec-ha, while those unaffected by mining yield between 3.5 and 18.5 mg/sec-ha on an annual basis.
8. Iron and manganese concentrations commonly exceed drinking water standards in streams both affected and unaffected by mining. Copper and lead concentrations occasionally exceed limits for acceptable drinking water;

these levels appear to be unaffected by mining activity, however, and would likely exceed drinking water criteria in any event. Mining activity appears to enhance concentrations of zinc, strontium, and mercury. Background levels of mercury also showed an increase during the study. Concentrations of zinc and mercury meet standards for drinking water.

9. A definite influence of mining activity on the water chemistry of Sheep Creek is statistically undemonstrable. Very slight changes in water chemistry could be attributed to natural differences, to mining, or could be dismissed as statistically insignificant.

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APPENDIX 1

DESCRIPTION OF SAMPLING SITES

Sheep Creek at the Bailey bridge (not on figure 3): This sampling location is at the bridge over Sheep Creek on the Beaverdam Road (Sec 13, Tp 58, R 9, W 6th Mer) about 7 km (5 mi) upstream from the mines. The site is representative of background chemistry in Sheep Creek as it is located above all mining activity.

Sheep Creek at Smoky River (not on figure 3): This site is just upstream from the Alberta Resources Railway bridge at the confluence of Sheep Creek with the Smoky River (Sec 5, Tp 59, R 7, W 6th Mer) about 16 km (10 mi) downstream from the mines. The site should be considered as reflecting the full impact of all of the surface mining activities of McIntyre Mines Ltd. on Sheep Creek.

Stream 0-1 (not on figure 3): This site (Sec 4, Tp 58, R 6, W 6th Mer) is about 0.5 km (½ mi) southwest of the Bailey bridge alongside Beaverdam Road. The purpose of this site is to observe background chemistry in a stream on a north-facing slope.

Stream 1: The site (Sec 5, Tp 58, R 8, W 6th Mer) is along the main road 4.4 km (2 mi) towards Grande Cache from the mine offices. The site can be considered as representative of the natural quality of small streams leaving the general area of the mines. Flow in this stream frequently ceases in late summer. The drainage area above the sampling site is about 111 ha.

Stream 2: This sampling location (Sec 17, Tp 58, R 8, W 6th Mer) is just below Spoil Area 4. It is intended to monitor water chemistry immediately upon discharge from the base of the spoil. Much of the flow at this site is sustained by springs and seeps that occurred in this valley before the spoil area was established. The drainage area contributing to flow at this site is about 40 ha. Technically, this site should be called a "spring," as can be seen on Plate 2. However, sampling originally started at this site before the placement of Spoil Area 4, at

which time the site actually was a surface stream.

Stream 4: This site is located (Sec 20, Tp 58, R 8, W 6th Mer) just to the west of the portal to the underground mine at Reiff Terrace. Its drainage area includes a small portion of the center part of No. 8 Mine.

Stream 5: This site is located (Sec 17, Tp 58, R 8, W 6th Mer) just south of Spoil Area 4. A comparison of water chemistry at this site with that at Stream 2 allows assessment of the degree of change in chemical composition of water as it passes through the spoil.

Stream 6: This site is located (Sec 17, Tp 58, R 8, W 6th Mer) along the upper access road to Reiff Terrace. The drainage area of the site includes Springs 3, 4, and 8. Much of the initial portion of the No. 8 Mine drains through this location. No pre-mining data are available as mining was well underway in the drainage basin when sampling began in 1974.

Spring 3: This spring is located at the foot of one of the older spoil areas (Sec 17, Tp 58, R 8, W 6th Mer) in No. 8 Mine. It is similar in nature to Stream 2 in that it represents water discharging directly from a spoil area. The drainage area for this spring is about 27 ha.

Spring 4: This site is located (Sec 17, Tp 58, R 8, W 6th Mer) about 200 m downslope from Spring 3. This is a true spring in the sense that it would be present regardless of whether or not mining had taken place. The catchment area for this spring is presumably the central portion of No. 8 Mine.

Spring 8: This site is located (Sec 16, Tp 58, R 8, W 6th Mer) on an exploration trail just downslope from the explosive storage site for No. 8 Mine. Many small springs emerge in the immediate vicinity of the site, flow downslope for several metres and then infiltrate into the ground again. No mining or spoiling of over-

See figure 3 for locations.

burden has taken place in the catchment area of this spring.

Stream 9-1: This site is located (Sec 13, Tp 58, R 9, W 6th Mer) along the north side of Sheep Creek and west of any influence of mining activity. It represents background chemistry of water draining near No. 9 Mine. The drainage area above this site is about 1212 ha.

Stream 9-1A: This site is located (Sec 23, Tp 58, R 9, W 6th Mer) about 4.8 km north of the Bailey bridge along the Beaverdam Road. It is on the same watercourse as Stream 9-1. The purpose of this site is to establish background chemistry as the current mining plan calls for the placement of a spoil area in this valley between this location and Stream 9-1.

Stream 9-2: This site is located (Sec 24, Tp 58, R 9, W 6th Mer) just upstream from a small settling pond on the north bank of Sheep Creek. This pond is just east of the much larger M-2

Settling Pond. This site has been influenced by the construction of the M-1 Spoil Area. The drainage area above this site is about 181 ha.

Stream 9-3: This sampling location (Sec 20, Tp 58, R 9, W 6th Mer) is just northwest of the bridge over Sheep Creek on the No. 9 Mine haul road. Major mining activity began in 1974 in the basin above this site. The catchment area above this site is about 377 ha.

Stream 9-4: This site is located (Sec 29, Tp 58, R 8, W 6th Mer) northeast of any mining activity. The stream was selected because plans for the extension of the No. 9 Mine call for a large spoil area in the valley above this site. Water chemistry at this location currently represents background values. The drainage area above this site is about 458 ha.

Stream 9-6: This site is located (Sec 13, Tp 58, R 9, W 6th Mer) at the northwest corner of the M-2 Settling Pond. A major spoil area will be placed upstream of this site.

APPENDIX 2

CHEMICAL ANALYSES OF WATER SAMPLES

This appendix contains the results of chemical analyses performed on samples obtained from the sampling sites described in Appendix 1 and whose locations are shown on figure 3. Analysis for major ions was done at an Alberta Research Council laboratory during the entire period of this study.

Calcium and magnesium appear twice under major constituents in the tables of this appendix. The columns labelled "Ca" and "Mg" present the concentrations in the samples without any form of preservation. The columns labelled "Ca(1)" and "Mg(1)" present the concentrations in samples filtered and acidified to a pH of about three. Any precipitation of calcium or magnesium due to temperature changes should be inhibited at this low pH.

All samples intended for minor constituent analysis and obtained during 1976, 1977, or 1978 were passed through 0.45 micron filters and subsequently acidified to a pH of about three. Before 1976 water samples were decanted to remove

suspended material and then acidified to a pH of about three; filtering was not done.

Minor constituents were analyzed at three different laboratories during the course of the study. These laboratories were:

- (1) Alberta Research Council, Edmonton, Alberta;
- (2) Barringer Research Ltd., Rexdale, Ontario; and
- (3) Chemical and Geological Laboratories Ltd., Edmonton, Alberta.

The minimum detectable limits for the latter two laboratories are presented in Table 7. All analyses of September and October 1977 and September and November 1976 except mercury and silica were done with a Multi-element Radio Frequency Induction Coupled Plasma Emission Spectrometer (RFICP) at one of the two commercial laboratories mentioned above. All mercury and silica analyses as well as analyses on dates other than the four mentioned above were done at the Alberta Research Council laboratory on atomic absorption

Table 7. Minimum Detection Limits

Element or Parameter	Minimum detection limits (by date of sample)	
	µg/L (9/77 and 10/77)	µg/L (9/76 and 10/76)
Aluminum (Al)	100	200
Arsenic (As)	—	38*
Barium (Ba)	5	200
Beryllium (Be)	5	1
Boron (B)	5	0.3
Cadmium (Cd)	10*	2
Chromium (Cr)	20	6
Cobalt (Co)	10	10
Copper (Cu)	5	0.4
Europium (Eu)	—	15
Gold (Au)	—	3
Iron (Fe)	20	12
Lead (Pb)	30	88*
Manganese (Mn)	5	1
Molybdenum (Mo)	50	6
Nickel (Ni)	30	10
Phosphorous	100*	110*
Selenium (Se)	—	60*
Silver (Ag)	20	2
Strontium (Sr)	0.005 mg/L	0.001 mg/L
Tellurium (Te)	50	65
Tin (Sn)	20	45
Titanium (Ti)	10	0.9
Tungsten (W)	—	2
Uranium (U)	—	65
Vanadium (V)	10	0.8
Zinc (Zn)	10	2

*Detection limit exceeds acceptable value for drinking water criteria - Table 6.

equipment. In 1978, analysis for iron, mercury, and the remainder by RFICP. Methods of analysis are shown in Table 8.

Table 8. Methods of Analysis at Chemical Laboratory of Alberta Research Council

Parameter	Method
Aluminum	Atomic absorption (flame) with extraction
Chromium	Diphenylcarboxide method
Copper	Atomic absorption (flameless)
Lead	Atomic absorption (flameless)
Manganese	Atomic absorption (flame)
Mercury	Atomic absorption (cold vapor)
Selenium	3,3' - diaminobenzidine extraction
Silica	Colorimetric
Zinc	Zincon method

manganese, copper, lead, and aluminum were done at the Alberta Research Council laboratory

The RFICP analyses of 1976, 1977, and 1978 reported nickel, cadmium, cobalt, and silver as below detectable limits (Table 7) for those years; consequently they do not appear in the listings. The elements arsenic, europium, gold, selenium, tungsten, and uranium were reported in 1976 to be below detection limits; they were not analyzed for at all in 1977 and 1978.

The units of concentration for ions presented in the following tables of this appendix are as follows:

- (1) mg/L: TDS, Ca, Mg, Na, K, CO₃, HCO₃, SO₄, NO₃, Ca(1), Mg(1), Si, Sr;
- (2) µg/L: Al, As, Ba, Be, B, Cr, Cu, Fe, Hg, Mn, Mo, P, Pb, Se, Te, Ti, V, Zn;
- (3) pH is in conventional units.

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SHEEP CK. @ BAILEY BRIDGE

DATE	TDS	Ca	Mg	Na	K	CO3	HCO3	SO4	Cl	NO3	Ca(1)	Mg(1)	pH
DD MM YY													
26 3 72	302	58.0	19.5	6.3	0.0	0.0	187	61.0	3	0.2			8.0
18 4 72	292	58.0	19.0	7.5	0.0	0.0	209	62.0	1	0.0			8.1
29 5 72	190	21.5	7.8	1.3	0.4	0.0	99	8.0	5	6.5			7.5
24 7 72	158	37.8	10.8	2.5	0.8	0.0	143	21.9	6	0.4			8.0
12 9 72	264	63.0	16.0	3.8	0.8	0.0	195	51.0	4	0.4			8.2
29 11 72	280	62.0	17.0	5.0	0.8	0.0	215	53.0	4	0.4			7.9
25 4 73	334	63.0	20.5	6.3	0.4	0.0	200	69.0	6	0.1			7.6
29 5 73	142	30.0	9.3	2.5	0.4	0.0	128	15.7	4	0.3			7.5
3 7 73	122	30.1	9.6	2.0	0.8	0.0	124	21.2	2	0.9			7.9
15 8 73	170	54.0	14.6	6.3	1.3	0.0	168	50.2	6	0.2			7.8
24 9 73	180	46.5	14.8	5.0	1.3	0.0	173	42.3	2	0.1			8.1
14 5 74	172	40.7	12.4	3.0	0.0	0.0	161	25.0	2	0.3			7.1
25 6 74	112	27.0	8.0	1.3	0.4	0.0	110	17.1	0	0.7			8.1
12 8 74	192	40.9	13.3	0.0	0.0	0.0	146	35.5	0	1.4			8.2
24 9 74	180	43.9	16.5	12.5	1.1	0.0	159	47.0	6	1.7			8.2
9 9 75	166	46.0	13.9	0.0	0.4	0.0	171	36.8	2	1.7	41.0	13.9	7.9
27 4 76	222	44.0	15.3	8.0	1.3	0.0	183	40.0	6	0.0	50.0	14.8	8.2
15 6 76	100	29.0	9.3	0.0	0.8	0.0	120	16.1	2	0.8	31.0	9.1	8.1
17 8 76	118	35.0	10.7	5.0	0.8	0.0	127	18.6	2	1.0	34.5	10.8	7.6
20 9 76	176	40.0	15.9	3.8	0.0	0.0	168	28.3	2	4.0			7.9
2 11 76	204	53.0	14.7	5.0	0.8	0.0	183	42.9	2	0.2			7.8
26 4 77	180	31.6	10.9	3.8	0.8	0.0	139	28.0	2	0.9	23.0	15.0	8.2
14 6 77	132	28.0	9.3	2.5	0.0	0.0	124	17.7	1	1.2	21.0	8.8	8.0
26 7 77	158	38.0	11.2	3.8	0.8	0.0	139	25.0	2	0.1	34.0	97.0	8.2
7 9 77	150	43.0	12.9	1.3	0.0	0.0	156	31.8	0	1.1	34.0	14.0	8.1
18 10 77	180	44.0	13.4	2.5	0.0	0.0	173	34.6	0	0.0	43.0		8.3
2 5 78	196	28.0	9.0	3.8	0.4	0.0	134	14.5	2	0.5	25.0	9.8	8.3
13 6 78	96	31.0	9.1	3.8	0.8	0.0	127	14.5	2	0.4	28.0	8.8	8.2
25 7 78	266	51.0	14.0	2.5	0.0	0.0	171	31.8	2	0.0	32.0	12.9	8.6
7 9 78	80	36.0	12.6	2.5	0.0	0.0	163	19.5	2	0.4	35.0	12.1	7.8
17 10 78	188	41.2	13.1	2.5	0.6	0.0	163	26.9	2	0.6	36.0	11.5	8.2

MINOR CONSTITUENTS
SHEEP CK. @ BAILEY BRIDGE

DATE	Al	As	Ba	Be	B	Cr	Cu	Fe	Hg	Mn	Mo	P	Pb	Se	Si	Sn	Sr	Te	Ti	V	Zn
DD MM YY																					
26 3 72	130							50	0.46	80				30							90
18 4 72	50							80	0.54	50				0							60
29 5 72	690							110	1.10	90				10							140
24 7 72								50													
12 9 72								50													
29 11 72								110													
25 4 73	80						40	90	0.08	130					4.15						70
29 5 73								90													
3 7 73																					
15 8 73	70						40	140	0.07	160											30
24 9 73																					
14 5 74	380						1	380	0.09	90			10.2								
25 6 74	570						1	790	0.09	40			11.2								
12 8 74	100						2	20	0.07	20					3.70						
24 9 74	130						22	110	0.10	10			5.4		1.20						
9 9 75	100						0	200	0.21	500			10.0		3.30						
27 4 76	20						0	200	0.06	100			0.0		2.60						
15 6 76	60						0	100	0.04	100			0.0		2.90						
17 8 76	120						0	100	0.00	200			0.0		2.70						
20 9 76	200	38	200	1	26	6	25	223		7	6	110	88.0	60	3.50	45	0.24	65	1	1	120
2 11 76	2	38	200	1	10	6	13	110		5	6	110	88.0	60	3.50	45	0.32	65	1	1	55
26 4 77															3.60						
14 6 77							9	0	0.11	0			5.0		2.30						
26 7 77							5	0	0.27	0			4.5		2.60						
7 9 77	100		119	5	9	23	7	67	0.08	17	50	100	39.0		3.50	23	0.18	50	10	10	33
18 10 77	100		127	5	9	20	5	79	0.00	9	50	100	30.0		2.70	117	0.19	50	10	10	13
2 5 78	0						1	100	0.68	0			0.8		1.80						
13 6 78	20		90	5	10	20	0	0	0.44	0	50		0.5		2.40		0.10	50	10	10	10
25 7 78	90						4	200	0.03	60			1.3		2.30						
7 9 78	40						0	200	0.14	10			1.3		3.20						
17 10 78	40		110	5	10	20	3	0	0.04	70	50		0.8		7.10		0.14	50	10	10	10

MAJOR CONSTITUENTS
SHEEP CK. @ SMOKY RIVER

DATE			TDS	Ca	Mg	Na	K	CO3	HCO3	SO4	Cl	NO3	Ca(1)	Mg(1)	pH
DD	MM	YY													
25	3	72	250	58.0	20.0	3.8	0.0	0.0	203	61.0	1	0.0			8.0
18	4	72	258	61.0	10.7	8.8	0.0	0.0	200	57.0	4	0.0			8.2
29	5	72	190	24.4	8.3	3.8	0.4	0.0	105	9.0	1	1.1			7.7
24	7	72	182	39.0	11.2	2.5	0.4	0.0	148	23.0	4	0.5			8.0
12	9	72	238	62.0	15.5	8.8	1.3	0.0	200	50.0	4	0.4			8.1
29	11	72	284	66.0	18.5	7.5	1.3	0.0	220	53.0	4	0.5			8.1
25	4	73	346	60.0	19.5	11.3	0.4	0.0	212	62.0	8	0.1			7.9
30	5	73	152	29.0	9.2	8.8	0.0	0.0	118	12.4	6	0.2			8.1
3	7	73	158	31.7	10.5	5.0	0.4	0.0	129	19.5	4	0.2			7.6
14	8	73	164	55.0	15.0	5.0	1.3	0.0	173	39.3	6	0.2			8.0
24	9	73	180	48.9	15.2	6.3	0.8	0.0	181	43.1	6	0.2			8.2
13	5	74	166	38.6	12.6	5.0	0.8	0.0	156	31.5	2	0.4			7.2
24	6	74	80	26.1	7.4	1.3	0.4	0.0	105	18.0	2	0.8			7.6
12	8	74	242	40.8	12.4	0.0	0.0	0.0	149	32.5	0	1.0			8.2
24	9	74	214	48.9	17.0	12.5	0.7	12.0	166	47.0	4	3.0			8.5
9	9	75	184	47.0	14.0	1.3	0.4	0.0	171	36.0	2	1.3	43.0	14.1	8.3
27	4	76	234	46.0	14.8	8.8	1.3	0.0	181	51.0	10	0.0	51.0	15.1	8.2
15	6	76	126	28.0	9.6	3.8	0.8	0.0	120	18.6	4	1.6	32.5	9.1	7.9
18	8	76	130	36.0	11.7	5.0	1.3	0.0	132	23.5	2	0.9	35.5	11.4	7.7
20	9	76	198	39.0	15.7	3.8	0.0	0.0	176	27.6	2	1.3			7.9
3	11	76	216	52.0	15.5	6.3	0.8	0.0	193	39.8	2	0.6			7.9
27	4	77	176	32.0	11.0	3.8	0.8	0.0	137	25.7	2	0.3	22.0	14.8	8.2
14	6	77	158	32.0	9.8	3.8	1.7	0.0	127	27.4	2	2.2	21.1	8.9	8.1
26	7	77	126	37.0	9.8	5.0	1.3	0.0	139	27.3	2	0.3	32.0	9.0	8.2
7	9	77	200	45.0	13.0	1.3	0.0	0.0	168	35.7	0	1.0	34.0	13.5	8.1
18	10	77	186	46.0	13.9	5.0	0.0	0.0	173	37.4	0	0.0	43.0	13.3	8.3
2	5	78	198	32.0	10.1	2.5	0.4	0.0	141	20.0	4	0.3	26.0	10.1	8.2
13	6	78	162	32.0	9.1	3.8	0.8	0.0	129	16.2	4	0.6	27.0	9.1	8.3
26	7	78	206	41.0	14.7	3.8	0.4	0.0	178	26.1	2	0.6	37.0	14.8	7.9
7	9	78	114	37.0	12.8	5.0	0.4	12.0	149	25.3	2	0.0	36.0	12.8	8.9
17	10	78	96	42.0	13.6	1.3	0.0	0.0	166	29.5	2	0.4	34.0	11.7	8.3

MINOR CONSTITUENTS
SHEEP CK. @ SMOKY RIVER

DATE			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
DD	MM	YY	Al	As	Ba	Be	B	Cr	Cu	Fe	Hg	Mn	Mo	P	Pb	Se	Si	Sn	Sr	Te	Ti	V	Zn
25	3	72	180					10	10	60	0.10	50				10							60
18	4	72	170					10	10	70	0.22	50				10							90
29	5	72	560					30	60	110	0.80	80				10							100
24	7	72								50													
12	9	72								50													
29	11	72								130													
25	4	73	180						50	130	0.08	350					4.45						40
30	5	73								100													
3	7	73																					
14	8	73	80						40	130	0.05	190											50
24	9	73																					
13	5	74	520						5	480	0.06	40				14.6							
24	6	74	1580						3	2500	0.16	180				8.6							
12	8	74	120						2	140	0.09	90				8.6							
24	9	74	120						0	170	0.09	10				5.4							
9	9	75	0						0	300	0.41	500				10.0							
27	4	76	60						0	100	0.10	100				0.0							
15	6	76	60						0	0	0.00	100				0.0							
18	8	76	260						0	400	0.04	100				0.0							
20	9	76	200	38	700	1	21	6	43	307		11	6	110	88.0	60	3.50	45	0.25	65	1	3	170
3	11	76	110	38	200	1	22	6	19	120		6	6	110	88.0	60	5.80	45	0.33	65	4	5	66
27	4	77								100							3.60						
14	6	77							8	0	0.61	10				4.5							
26	7	77							9	400	0.22	30				8.0							
7	9	77	136		105	5	9	20	18	69	0.62	29	50	100	59.0		7.90	485	0.17	65	10	10	39
18	10	77	100		112	5	7	20	5	32	0.03	5	50	100	32.0		2.80	51	0.19	50	10	10	19
2	5	78	20						1	100	0.58	0				0.5							
13	6	78	0		80	5	10	20	4	100	0.55	0	50			0.5			0.11	50	10	10	10
26	7	78	40						1		0.10	60				2.0							
7	9	78	90						0	400	0.07	60				0.5							
17	10	78	40		110	5	20	20	4	0	0.03	10	50			3.7			0.15	50	10	10	10

MAJOR CONSTITUENTS

STREAM 1

DATE			TDS	Ca	Mg	Na	K	CO3	HCO3	SO4	Cl	NO3	Ca(1)	Mg(1)	pH
DD	MM	YY													
12	4	72	178	30.6	11.7	10.0	0.0	0.0	109	41.8	3	0.0			7.6
29	5	72	222	29.0	11.0	11.3	2.1	0.0	116	35.0	0	0.4			8.1
25	7	72	288	53.0	17.0	11.3	1.3	0.0	150	92.0	4	0.5			8.3
25	4	73	150	30.0	11.2	8.8	0.4	0.0	115	34.8	2	0.6			7.8
30	5	73	148	25.0	8.8	7.5	0.4	0.0	95	29.7	6	0.3			7.6
2	7	73	252	42.0	16.4	10.0	1.7	0.0	137	82.0	2	0.1			7.5
13	5	74	152	22.8	8.4	8.0	0.4	0.0	81	43.5	2	0.7			6.6
24	6	74	268	42.8	22.0	10.0	0.4	0.0	127	107.0	0	0.6			8.2
27	4	76	164	25.4	8.8	7.5	1.3	0.0	90	12.1	6	10.0	28.0	9.5	7.7
15	6	76	100	31.0	11.2	10.0	1.3	0.0	110	49.7	2	0.8	32.5	11.0	8.1
18	8	76	146	29.0	10.3	10.0	1.3	0.0	98	37.2	4	1.5	28.5	9.2	7.4
20	9	76	170	34.0	15.4	3.8	0.0	0.0	129	55.0	2	1.4			7.7
2	11	76	228	47.0	13.5	10.0	0.8	0.0	146	69.0	2	0.5			7.7
27	4	77	190	28.4	10.0	6.8	1.3	0.0	117	31.1	0	2.1	19.0	13.9	7.7
14	6	77	224	34.0	12.1	11.3	1.7	0.0	116	62.0	1	1.8	22.8	11.4	8.2
26	7	77	208	44.0	13.7	11.3	1.7	0.0	132	84.0	2	0.7	38.0	13.3	8.1
7	9	77	228	33.0	13.0	7.5	0.4	0.0	124	63.0	0	1.3	30.0	16.0	8.0
18	10	77	218	39.0	13.5	8.8	0.0	0.0	137	59.0	0	0.1	36.0	12.6	8.1
2	5	78	194	27.0	9.4	6.3	0.8	0.0	105	34.6	2	1.6	27.0	9.8	8.1
13	6	78	176	35.0	11.8	10.0	1.7	0.0	127	47.3	2	1.1	31.0	11.1	8.2
26	7	78	156	36.0	13.2	8.8	0.4	0.0	124	53.0	2	0.1	35.0	13.5	7.7
7	9	78	138	40.0	14.9	10.0	0.8	0.0	154	64.0	4	0.0	39.0	14.6	8.0
17	10	78	268	41.0	14.0	8.1	1.0	0.0	134	65.0	2	0.9	33.0	21.0	8.2

MINOR CONSTITUENTS

STREAM 1

DATE			* Al	* As	* Ba	* Be	* B	* Cr	* Cu	* Fe	* Hg	* Mn	* Mo	* P	* Pb	* Se	* Si	* Sn	* Sr	* Te	* Ti	* V	* Zn
DD	MM	YY																					
12	4	72	160							90	0.12	50				0							70
29	5	72								120													
25	7	72								50													
25	4	73	1750							1830	0.18	270					9.75						50
30	5	73								250													
2	7	73																					
13	5	74	1370						7	1370	0.07	90			9.4								
24	6	74	220						1	200	0.09	30			7.8								
27	4	76	700						0	800	0.08	100			0.0		5.60						
15	6	76	240						10	100	0.06	100			0.0		6.40						
18	8	76	240						0	200	0.06	100			0.0		7.30						
20	9	76	300	38	200	1	53	6	62	480		8	6	110	88.0	60	8.30	45	0.22	65	1	3	180
2	11	76	220	38	200	1	42	6	37	420		8	6	110	88.0	60	7.00	45	0.23	65	5	5	44
27	4	77								100							6.40						
14	6	77							11	0	0.77	0			4.5		6.10						
26	7	77							3	0	0.11	10			4.5		3.00						
7	9	77	100		70	5	36	31	16	115	1.24	22	84	101	76.0		8.20	198	0.16	71	10	10	41
18	10	77	100		69	5	31	20	5	45	0.39	6	50	100	30.0		6.90	99	0.17	50	10	10	18
2	5	78	20						5	100	1.06	0			1.1		2.90						
13	6	78	20		70	5	30	20	0	100	0.99	0	50		0.8		5.90		0.14	50	10	10	10
26	7	78	40						3	0	0.13	40			1.3		8.00						
7	9	78	40						0	200	0.07	20			0.3		7.60						
17	10	78	40		70	5	30	20	7	0	0.04	30	50		4.2		2.90		0.15	50	10	10	10

MAJOR CONSTITUENTS

STREAM 2

DATE			TDS	Ca	Mg	Na	K	CO3	HCO3	SO4	Cl	NO3	Ca(1)	Mg(1)	pH
DD	MM	YY													
28	6	72	244	55.0	17.6	0.0	2.1	2.4	262	9.0	0	0.8			8.4
24	7	72	246	65.0	21.0	5.0	1.3	0.0	305	6.8	2	0.5			8.1
12	9	72	330	81.0	33.5	11.3	2.5	0.0	432	9.0	2	0.4			8.2
30	11	72	370	93.0	28.0	8.8	2.1	0.0	438	13.3	4	0.9			8.0
25	4	73	312	64.7	22.5	12.5	1.3	0.0	330	6.8	4	2.1			8.0
30	5	73	358	50.0	16.6	8.8	1.3	0.0	245	12.8	8	10.3			7.8
3	7	73	330	71.0	30.0	16.0	3.3	0.0	381	13.1	2	8.3			8.1
14	8	73	354	82.0	36.0	16.3	3.8	0.0	415	16.0	4	3.9			8.0
25	9	73	322	76.0	38.0	17.5	2.9	0.0	451	14.5	2	3.3			7.9
14	5	74	210	47.1	14.8	6.0	0.8	0.0	185	35.0	6	1.8			7.2
25	6	74	330	69.6	35.0	13.8	0.8	0.0	351	41.3	8	13.5			8.3
12	8	74	428	54.7	36.0	13.0	0.0	0.0	427	36.5	0	10.6			8.2
24	9	74	244	24.3	36.5	30.5	2.1	8.0	224	43.0	4	17.6			8.5
9	9	75	612	111.0	44.0	15.0	1.7	0.0	434	107.0	4	21.5	104.0	47.0	7.9
16	6	76	316	68.0	21.0	12.5	1.3	0.0	256	49.2	2	9.8	73.0	23.0	7.5
18	8	76	482	103.0	31.0	8.8	1.7	0.0	254	146.0	2	27.8	94.5	35.0	7.6
21	9	76	598	106.0	47.0	15.0	0.8	0.0	305	177.0	8	20.0			7.8
3	11	76	556	123.0	43.0	22.5	2.9	0.0	407	151.0	2	26.9			7.8
27	4	77	336	65.0	19.4	4.5	1.7	0.0	178	86.0	2	11.7	67.0	27.0	8.0
15	6	77	572	114.0	41.0	10.0	1.3	0.0	281	187.0	1	26.8	104.0	37.0	7.9
27	7	77	710	139.0	51.0	17.5	2.9	0.0	371	293.0	4	43.0	124.0	45.0	8.1
8	9	77	544	124.0	40.0	8.8	0.4	0.0	307	204.0	0	27.5	92.0	39.0	8.3
19	10	77	666	142.0	50.0	13.8	0.4	0.0	361	310.0	0	43.2	132.0	45.0	8.2
3	5	78	410	74.0	22.0	7.5	1.3	0.0	215	138.0	2	3.3	71.0	22.0	8.2
14	6	78	736	106.0	35.0	15.0	2.1	0.0	329	137.0	2	13.0	95.0	32.0	8.2
26	7	78	558	106.0	53.0	16.3	2.1	0.0	293	218.0	4	18.0	106.0	49.0	7.7
7	9	78	622	125.0	50.0	17.5	2.1	0.0	397	208.0	6	16.4	124.0	49.0	8.0
18	10	78	816	137.0	61.0	16.9	2.1	0.0	395	300.0	6	22.8	124.0	55.0	8.0

MINOR CONSTITUENTS

STREAM 2

DATE			Al	As	Ba	Be	B	Cr	Cu	Fe	Hg	Mn	Mo	P	Pb	Se	Si	Sn	Sr	Te	Ti	V	Zn
DD	MM	YY																					
28	6	72	160					30	90	140	1.14	100				20							130
24	7	72								50													
12	9	72	200					20	50	110	0.16	480											70
30	11	72								270													
25	4	73	1620						40	1510	0.08	290					8.65						20
30	5	73								190													
3	7	73																					
14	8	73	0						70	200	0.07	290											20
25	9	73																					
14	5	74	430						5	470	0.15	80			18.4								
25	6	74	130						1	110	0.13	10			10.2								
12	8	74	130						2	100	0.11	140			11.9		7.60						
24	9	74	120						4	100	0.11	40			9.8		1.80						
9	9	75	200						0	300	0.07	600			10.0		4.10						
16	6	76	20						0	100	0.04	100			10.0		2.40						
18	8	76	280						10	200	0.00	200			0.0		4.20						
21	9	76	400	38	1200	1	48	6	56	442		15	6	700	88.0	60	5.20	45	1.32	65	1	7	290
3	11	76	220	38	200	2	56	6	37	143		11	6	110	88.0	60	5.40	45	1.42	65	4	6	99
27	4	77								0							4.00						
15	6	77							8	0	0.34	20			6.5		3.70						
27	7	77							2	700	0.24	20			2.5		0.80						
8	9	77	245		207	5	23	20	9	107	0.06	22	50	100	30.0		3.00	20	0.83	50	10	10	34
19	10	77	100		227	5	36	20	5	21	0.03	9	79	100	30.0		4.00	58	1.14	50	10	10	13
3	5	78	0						3	0	0.13	0			1.1		2.00						
14	6	78	70		190	5	30	20	1	0	0.40	0	50		0.5		4.60		0.78	50	10	10	10
26	7	78	40						1	300	0.07	30			1.0		5.50						
7	9	78	130						0	1000	0.26	30			2.1		5.60						
18	10	78	40		240	5	40	20	8	0	0.03	20	50		2.9		5.60		1.21	50	10	10	10

MAJOR CONSTITUENTS

STREAM 4

DATE			TDS	Ca	Mg	Na	K	CO3	HCO3	SO4	Cl	NO3	Ca(1)	Mg(1)	pH
DD	MM	YY													
28	6	72	238	53.0	16.6	32.5	0.4	0.0	339	4.8	0	0.0			8.3
25	7	72	186	11.3	16.0	50.0	11.3	4.8	235	4.7	6	0.4			8.5
12	9	72	284	39.8	20.0	61.0	1.3	0.0	385	6.8	2	0.4			8.2
25	4	73	266	47.2	15.5	40.0	0.4	0.0	335	1.7	4	0.3			7.9
30	5	73	252	57.0	16.2	27.5	0.0	0.0	318	6.5	4	0.1			7.5
3	7	73	276	49.6	17.5	50.0	2.5	0.0	368	4.5	2	0.5			8.0
14	8	73	294	48.7	19.5	68.0	1.7	0.0	395	4.0	8	1.0			7.9
25	9	73	302	37.9	18.0	83.0	1.7	0.0	417	3.5	4	0.2			8.0
14	5	74	158	46.6	12.2	3.0	0.4	0.0	195	12.5	6	1.0			7.6
25	6	74	340	64.6	26.0	32.5	0.4	0.0	368	15.1	0	21.5			8.2
13	8	74	388	64.0	30.5	31.3	1.3	0.0	393	19.5	4	22.8			8.2
24	9	74	252	25.7	29.0	44.5	1.3	8.0	232	19.0	4	75.5			8.5
9	9	75	388	75.0	27.0	35.0	1.3	0.0	403	30.3	2	10.5			8.1
16	6	76	302	58.0	20.1	38.9	0.8	0.0	315	23.7	6	17.3	34.5	19.2	7.7
18	8	76	284	64.0	21.6	30.0	1.7	0.0	317	24.2	2	8.5	62.0	20.7	7.8
21	9	76	300	57.0	24.8	28.8	0.0	0.0	354	30.3	2	3.4			7.8
3	11	76	300	76.0	23.5	43.8	1.7	0.0	388	40.0	2	11.6			8.0
27	4	77	294	65.0	6.5	26.3	0.8	0.0	325	33.0	2	17.6	62.0	30.0	8.1
15	6	77	244	57.0	16.9	33.8	0.4	0.0	325	16.7	1	1.2	54.0	17.4	8.2
27	7	77	368	62.0	19.4	37.5	1.7	0.0	351	39.1	6	0.0	57.0	17.7	8.0
8	9	77	332	70.0	20.6	31.3	0.0	0.0	329	43.6	0	0.8	58.0	21.0	8.3
19	10	77	312	74.0	20.0	28.8	0.0	0.0	349	54.0	0	1.4	67.0	18.0	8.3
3	5	78	324	61.0	18.0	17.5	0.8	0.0	300	44.6	0	1.5	58.0	19.0	8.2
14	6	78	344	73.0	23.0	26.0	1.3	0.0	315	56.0	2	2.1	65.0	18.0	8.2
26	7	78	212	49.0	20.9	18.8	0.4	0.0	281	23.8	2	0.0	56.0	21.4	7.8
7	9	78	322	75.0	28.0	20.0	0.0	0.0	366	44.6	4	10.5			8.0
18	10	78	322	60.0	24.4	24.4	1.0	0.0	351	35.7	2	0.6	56.0	22.0	8.2

MINOR CONSTITUENTS

STREAM 4

DATE			Al	As	Ba	Be	B	Cr	Cu	Fe	Hg	Mn	Mo	P	Pb	Se	Si	Sn	Sr	Te	Ti	V	Zn
DD	MM	YY																					
28	6	72	170					20	30	60	0.96	20				0							100
25	7	72								30													
12	9	72	40					10	10	50	0.10	0											90
25	4	73	640					100		680	0.09	160					7.25						30
30	5	73								80													
3	7	73																					
14	8	73						10		180	0.04	150											40
25	9	73																					
14	5	74	9550					13	7700	0.28	690				12.3								
25	6	74	3200					5	3120	0.19	140				11.2								
13	8	74	2800					4	3420	0.07	320				10.2		6.70						
24	9	74	430					25	430	0.09	70				7.8		1.50						
9	9	75	600					0	1300	0.21	700				10.0		3.40						
16	6	76	20					0	100	0.00	100				0.0		2.50						
18	8	76	180					0	0	0.00	100				0.0		5.00						
21	9	76	2	38	900	1	29	6	12	100		9	6	110	88.0	60	6.30	45	1.05	65	1	4	120
3	11	76	2	38	200	1	24	6	25	130		6	6	110	88.0	60	6.00	45	1.05	65	3	5	77
27	4	77								0							5.40						
15	6	77						5		0	0.09	0			5.0		4.40						
27	7	77						2	400	0.09	10				2.5		1.30						
8	9	77	100		435	5	23	17	5	59	0.06	5	50	100	34.0		7.40	20	1.14	50	10	10	18
19	10	77	100		363	5	14	20	5	23	0.03	5	50	100	30.0		5.20	20	0.89	50	10	10	10
3	5	78	20					3		0	0.08	0			1.1		2.60						
14	6	78	70		280	5	20	20	1	0	0.06	0	50		0.8		5.20		0.83	50	10	10	10
26	7	78	40					0		0	0.07	20			0.7		6.60						
7	9	78															5.80						
18	10	78	40		330	5	30	20	2	0	0.00	20	50		0.8		6.40		1.20	50	10	10	10

MAJOR CONSTITUENTS

STREAM 5

DATE			TDS	Ca	Mg	Na	K	CO3	HCO3	SO4	Cl	NO3	Ca(1)	Mg(1)	pH
DD	MM	YY													
25	4	73	222	47.3	14.8	3.8	0.4	0.0	200	8.6	4	0.0			7.2
30	5	73	144	28.0	7.6	3.8	0.4	0.0	115	18.0	4	0.2			7.1
3	7	73	196	43.9	12.8	5.0	2.5	0.0	198	9.0	2	0.3			7.8
14	5	74	132	29.5	8.0	1.0	0.8	0.0	100	29.0	2	0.3			6.8
16	6	76	156	40.0	10.7	6.3	0.0	0.0	151	27.3	4	2.0	44.5	11.2	7.0
18	8	76	198	47.0	12.6	3.8	1.3	0.0	154	33.4	2	2.7	48.0	11.9	7.3
21	9	76	206	57.0	14.0	3.8	0.0	0.0	212	29.5	2	1.9			7.9
27	4	77	188	31.0	8.6	1.3	1.3	0.0	115	25.5	0	3.1	23.0	12.2	7.5
15	6	77	194	47.0	11.4	1.3	1.3	0.0	146	30.5	1	2.4	40.0	10.8	7.8
8	9	77	180	54.0	13.0	0.0	0.0	0.0	181	39.9	0	0.4	42.0	15.0	8.0
19	10	77	168	57.0	14.1	1.3	0.0	0.0	200	35.3	2	0.6	35.0	13.6	7.9
3	5	78	190	29.0	8.3	2.5	1.3	0.0	110	30.2	2	2.5	30.0	8.4	8.0
14	6	78	188	50.0	12.9	1.3	0.8	0.0	183	27.2	2	0.3	44.0	12.2	7.7
26	7	78	256	52.0	14.0	1.3	1.3	0.0	198	26.6	2	0.0	49.0	14.2	8.0
7	9	78	224	68.0	18.8	1.3	0.0	0.0	275	29.7	2	0.1	59.0	17.2	7.5

MINOR CONSTITUENTS

STREAM 5

DATE			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
DD	MM	YY	Al	As	Ba	Be	B	Cr	Cu	Fe	Hg	Mn	Mo	P	Pb	Se	Si	Sn	Sr	Te	Ti	V	Zn
25	4	73	300						60	160	0.13	140					6.40						20
30	5	73								210													
3	7	73																			1000		
14	5	74	290						1	170	0.18	50			20.0								
16	6	76	200						20	100	0.00	0			0.0		1.80						
18	8	76	60						0	100	0.04	100			0.0		4.20						
21	9	76	400	38	200	1	21	6	50	549		12	6	110	88.0	60	5.40	45	0.22	65	7	1	220
27	4	77								100							3.70						
15	6	77							8	0	0.41	0			3.0		3.90						
8	9	77	244		182	5	7	28	17	168	1.36	28	50	100	71.0		4.00	46	0.17	65	10	10	52
19	10	77	100		191	5	5	20	5	25	0.00	5	50	100	30.0		5.10	20	0.17	50	10	10	10
3	5	78	20						2	0	0.62	0			1.1		1.90						
14	6	78	0		180	5	10	20	2	0	0.33	0	50		0.8		3.60		0.17	50	10	10	10
26	7	78	40						0	0	0.00	80			0.7		4.80						
7	9	78	40						0	300	0.07	60			1.1		5.80						

MAJOR CONSTITUENTS

STREAM 6

DATE			TDS	Ca	Mg	Na	K	CO3	HCO3	SO4	Cl	NO3	Ca(1)	Mg(1)	pH
DD	MM	YY													
25	9	73	366	77.8	26.5	32.5	6.7	0.0	373	32.3	30	0.2			7.3
14	5	74	292	65.5	19.8	3.0	0.4	0.0	193	56.0	18	14.2			7.3
25	6	74	294	72.6	23.0	6.3	1.3	0.0	234	26.3	26	44.0			7.5
13	8	74	516	92.0	26.0	6.0	0.0	0.0	349	19.1	30	11.2			8.2
24	9	74	266	53.6	25.5	23.5	1.9	0.0	210	38.0	28	24.7			8.3
9	9	75	376	82.0	26.0	6.3	0.8	0.0	293	49.5	18	14.0	76.0	27.0	8.3
16	6	76	292	65.0	20.5	8.8	0.8	0.0	178	82.0	12	38.0	72.0	20.4	7.7
18	8	76	396	88.0	21.0	6.2	1.3	0.0	229	103.0	6	31.5	84.0	26.5	7.8
21	9	76	374	78.0	25.0	5.0	0.8	0.0	237	90.0	4	19.4			8.1
3	11	76	360	87.0	24.1	7.5	1.3	0.0	242	91.0	6	19.7			7.9
27	4	77	356	64.0	22.0	2.5	1.3	0.0	207	90.0	2	10.0	63.0	27.0	8.1
15	6	77	346	75.0	24.0	5.0	0.8	0.0	215	90.5	2	25.2	70.0	21.6	8.3
27	7	77	370	84.0	24.0	7.5	2.1	0.0	246	105.0	10	34.0	75.0	22.0	8.2
8	9	77	392	101.0	27.0	12.5	0.0	0.0	259	124.0	5	29.2	79.0	28.0	8.3
19	10	77	452	95.0	24.0	3.8	0.0	0.0	239	113.0	0	34.0	77.0	18.0	8.3
3	5	78	430	75.0	19.0	1.3	1.3	31.2	159	108.0	0	5.1	68.0	20.0	9.0
14	6	78	302	68.0	20.0	3.8	1.3	0.0	229	65.0	8	10.1	70.0	20.0	8.2
26	7	78	314	67.0	20.6	5.0	0.4	0.0	249	44.7	10	24.5	60.0	20.5	8.1
7	9	78	294	79.0	24.0	6.3	1.3	16.8	229	71.0	2	20.5	73.0	22.0	8.7
18	10	78	378	87.0	24.0	2.5	0.4	0.0	266	69.0	8	16.8	69.0	20.0	8.2

MINOR CONSTITUENTS

STREAM 6

DATE			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
DD	MM	YY	Al	As	Ba	Be	B	Cr	Cu	Fe	Hg	Mn	Mo	P	Pb	Se	Si	Sn	Sr	Te	Ti	V	Zn
25	9	73																					
14	5	74	1550						4	1880	0.12	210			11.9								
25	6	74	480						3	560	0.07	150			10.6								
13	8	74	6400						95	7750	0.06	720			172.0		7.90						
24	9	74	130						0	70	0.09	60			6.2		1.50						
9	9	75	100						0	200	0.16	700			10.0		4.70						
16	6	76	20						0	100	0.00	100			0.0		2.70						
18	8	76	280						10	200	0.00	100			0.0		4.50						
21	9	76	2	38	900	1	21	6	6	55		8	6	110	88.0	60	5.30	45	0.69	65	1	4	100
3	11	76	2	38	200	1	28	6	18	77		5	6	880	88.0	60	4.60	45	0.69	65	1	6	55
27	4	77								0							4.50						
15	6	77							5	0	0.84	0			4.5		3.70						
27	7	77							8	200	1.32	20			4.5		1.40						
8	9	77	100		324	5	9	24	5	49	0.06	15	21	100	45.0		10.20	20	0.53	50	10	10	16
19	10	77	100		328	5	5	20	5	154	0.24	15	50	100	30.0		4.60	20	0.54	50	10	10	10
3	5	78	0						2	0	0.51	0			1.1		2.10						
14	6	78	40		210	5	10	20	1	0	0.33	0	50		1.1		5.60		0.41	50	10	10	10
26	7	78	40						0	100	0.07	80			0.7		5.90						
7	9	78	90						0	200	0.14	60			0.3		5.40						
18	10	78	40		250	5	20	20	3	0	0.03	80	50		0.8		5.20		0.49	50	10	10	10

MAJOR CONSTITUENTS

SPRING 3

DATE			TDS	Ca	Mg	Na	K	CO3	HCO3	SO4	Cl	NO3	Ca(1)	Mg(1)	pH
DD	MM	YY													
27	6	72	394	88.0	24.5	0.0	2.1	0.0	374	23.9	2	0.7			8.1
29	7	72	404	105.0	31.0	1.3	2.9	0.0	465	17.5	6	0.5			7.9
13	9	72	354	54.0	39.0	1.3	2.9	0.0	275	50.0	14	0.5			8.1
25	4	73	464	113.0	39.0	3.8	2.9	0.0	445	63.0	14	6.0			7.9
30	5	73	354	81.0	25.5	2.5	2.1	0.0	292	66.0	6	5.8			7.8
3	7	73	450	96.0	38.0	4.0	2.9	0.0	393	81.0	6	2.5			7.8
14	8	73	456	93.8	48.0	5.0	4.6	0.0	495	58.5	8	0.9			7.7
14	5	74	366	88.6	27.0	8.0	1.7	0.0	283	88.5	6	6.8			7.7
25	6	74	438	104.0	40.0	1.3	0.8	0.0	378	111.0	4	3.6			8.1
16	6	76	468	105.0	30.0	0.0	2.1	0.0	305	125.0	2	41.6	112.0	35.0	7.6
18	8	76	620	135.0	42.0	2.5	2.1	0.0	300	205.0	12	23.5	138.0	43.0	7.8
21	9	76	700	124.0	52.0	2.5	2.1	0.0	276	293.0	0	15.6			7.6
3	11	76	750	172.0	54.0	2.5	2.5	0.0	410	273.0	2	11.6			7.6
27	4	77	502	90.0	36.0	1.3	1.7	0.0	300	132.0	0	6.8	93.0	40.0	8.0
15	6	77	632	125.0	43.0	3.8	2.1	0.0	320	231.0	2	15.5	123.0	40.0	8.0
27	7	77	946	176.0	54.0	3.8	2.5	0.0	378	327.0	2	12.5	150.0	46.0	7.7
8	9	77	782	176.0	73.0	0.0	1.3	0.0	364	348.0	5	33.0	148.0	53.0	7.8
19	10	77	848	193.0	64.0	1.3	0.8	0.0	395	392.0	0	16.8	165.0	55.0	7.8
3	5	78	512	104.0	33.0	1.3	1.7	0.0	312	170.0	2	2.9	93.0	31.0	8.1
26	7	78	614	113.0	54.0	2.5	1.7	0.0	295	229.0	2	6.0	124.0	49.0	8.2
7	9	78	716	149.0	56.0	2.5	0.8	0.0	415	250.0	2	6.2	141.0	53.0	8.2
18	10	78	1066	160.0	67.0	1.3	1.7	0.0	427	353.0	2	8.3	149.0	59.0	8.0

MINOR CONSTITUENTS

SPRING 3

DATE			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
DD	MM	YY	Al	As	Ba	Be	B	Cr	Cu	Fe	Hg	Mn	Mo	P	Pb	Se	Si	Sn	Sr	Te	Ti	V	Zn
27	6	72	320					50	190	220	0.261840					50							10
29	7	72								70													
13	9	72								120													
25	4	73	930						240	2020	0.092080						9.50						0
30	5	73								50													
3	7	73																					
14	8	73							110	1760	0.072400												0
14	5	74	250						3	320	0.14	220			8.6								
25	6	74	130						1	150	0.10	120			11.2								
16	6	76	20						10	100	0.00	100			0.0		2.30						
18	8	76	0						10	0	0.05	100			0.0		4.70						
21	9	76	200	38	200	1	21	6	11	88		7	6	1300	88.0	60	4.90	45	0.50	65	3	9	220
3	11	76	220	38	200	2	22	6	19	120		6	6	1430	88.0	60	4.80	45	0.52	65	4	10	165
27	4	77								100							4.40						
15	6	77							9	0	1.52	10				6.5	3.80						
27	7	77							2	400	0.34	0				2.5	1.50						
8	9	77	100		114	5	8	24	12	116	1.26	43	50	100	52.0		5.00	403	0.39	56	10	10	41
19	10	77	100		194	5	11	20	5	21	0.00	100	69	100	30.0		4.30	27	0.47	50	10	10	14
3	5	78	40						6	0	0.68	0				1.1	5.20						
26	7	78	40						0	100	0.07	30				2.6	5.50						
7	9	78	40						4	400	0.33	20				2.1	4.70						
18	10	78	0		100	5	10	20	4	0	0.00	60	50		0.5		5.30		0.39	50	10	10	10

MAJOR CONSTITUENTS

SPRING 4

DATE			TDS	Ca	Mg	Na	K	CO3	HCO3	SO4	Cl	NO3	Ca(1)	Mg(1)	pH
DD	MM	YY													
27	6	72	198	48.2	20.0	2.5	0.4	0.0	259	11.0	4	1.5			7.6
25	7	72	268	64.0	22.5	2.5	1.3	0.0	285	12.5	4	11.1			7.9
12	9	72	216	40.9	22.0	1.3	0.8	0.0	210	14.7	4	1.9			8.2
30	11	72	290	66.0	25.0	1.3	1.3	0.0	310	18.2	4	1.6			7.5
25	4	73	252	52.0	21.0	2.5	0.4	0.0	230	12.5	12	1.9			7.2
30	5	73	272	67.0	24.5	3.8	0.4	0.0	255	40.8	16	2.8			7.2
3	7	73	358	70.0	27.0	3.0	1.7	0.0	293	51.0	8	1.5			7.8
14	8	73	274	57.6	27.5	6.3	2.5	0.0	278	27.7	10	1.1			7.9
14	5	74	228	52.6	21.3	0.0	0.0	0.0	127	38.5	10	2.2			6.9
25	6	74	290	69.1	26.0	2.5	0.4	0.0	253	46.8	10	2.3			7.9
9	9	75	464	79.0	31.0	0.0	1.3	0.0	278	83.0	10	2.0	77.0	33.0	7.8
16	6	76	486	92.0	35.0	0.0	0.4	0.0	259	169.0	6	4.2	98.0	38.5	6.6
18	8	76	440	102.0	35.0	3.8	0.8	0.0	268	137.0	6	4.6	94.0	36.5	6.8
21	9	76	600	123.0	47.0	3.8	0.4	0.0	298	206.0	6	1.9			7.7
3	11	76	498	113.0	40.0	3.8	1.3	0.0	300	169.0	4	1.4			7.2
27	4	77	360	67.0	22.0	1.8	0.8	0.0	232	88.0	0	6.3	68.0	33.0	7.5
15	6	77	574	110.0	43.0	5.0	0.8	0.0	276	197.0	2	4.3	99.0	39.0	7.3
27	7	77	600	133.0	49.0	5.0	1.3	0.0	307	275.0	4	3.1	114.0	39.0	7.3
8	9	77	564	122.0	47.0	0.0	0.0	0.0	320	218.0	5	4.2	101.0	39.0	7.8
19	10	77	686	135.0	49.0	2.5	0.0	0.0	329	300.0	0	3.1	120.0	42.0	7.3
3	5	78	344	59.0	20.0	3.8	0.8	0.0	205	66.5	2	3.7	55.0	20.0	7.5

MINOR CONSTITUENTS

SPRING 4

DATE			* Al	* As	* Ba	* Be	* B	* Cr	* Cu	* Fe	* Hg	* Mn	* Mo	* P	* Pb	* Se	* Si	* Sn	* Sr	* Te	* Ti	* V	* Zn
DD	MM	YY																					
27	6	72								60													
25	7	72								50													
12	9	72								50													
30	11	72								150													
25	4	73	2650						60	2160	0.11	200					11.60						20
30	5	73								80													
3	7	73																					
14	8	73							40	600	0.01	450											50
14	5	74	210						0	150	0.16	60			5.8								
25	6	74	480						0	490	0.18	40			7.8								
9	9	75	900						0	1200	0.04	500			10.0		4.80						
16	6	76	40						10	0	0.00	100			0.0		2.80						
18	8	76	20						10	0	0.00	100			0.0		5.40						
21	9	76	2	38	1900	1	23	6	21	94		8	6	110	88.0	60	6.10	45	0.98	65	1	7	170
3	11	76	220	38	200	1	31	6	14	77		1	6	110	88.0	60	6.80	45	0.88	65	1	6	77
27	4	77								100							5.50						
15	6	77							8	0	0.27	0			5.0		5.00						
27	7	77							2	400	0.07	40			4.0		1.60						
8	9	77	100		445	5	7	20	10	62	1.05	10	50	100	46.0		9.90	358	0.69	55	10	10	35
19	10	77	100		481	5	12	20	5	33	0.03	8	103	100	30.0		5.70	26	0.80	50	10	10	19
3	5	78	20						4	0	0.08	0			1.9		2.50						

MAJOR CONSTITUENTS

SPRING 8

DATE			TDS	Ca	Mg	Na	K	CO3	HCO3	SO4	Cl	NO3	Ca (l)	Mg (l)	pH
DD	MM	YY													
27	6	72	380	77.0	22.0	0.0	1.3	0.0	188	21.1	48	81.0			8.2
24	7	72	402	79.0	22.5	5.0	1.7	0.0	224	15.5	42	67.0			8.0
12	9	72	342	81.0	21.5	3.8	1.3	0.0	238	16.0	36	70.0			8.2
30	11	72	388	90.0	23.5	5.0	1.7	0.0	252	13.8	34	101.0			7.2
30	5	73	612	93.0	25.0	5.0	0.0	0.0	172	16.2	62	118.0			7.3
3	7	73	654	116.0	33.0	6.0	2.9	0.0	212	14.5	52	170.0			7.7
14	8	73	492	101.0	33.0	11.3	2.9	0.0	239	15.6	50	118.0			7.5
25	9	73	456	103.0	30.0	10.0	2.9	0.0	259	13.2	38	132.0			7.3
14	5	74	282	57.7	15.2	3.0	1.3	0.0	134	16.5	30	62.0			6.7
25	6	74	846	159.0	48.0	6.3	0.4	0.0	220	18.7	48	375.0			8.0
13	8	74	802	137.0	41.5	0.0	0.0	0.0	246	16.0	40	330.0			8.1
24	9	74	578	106.0	45.5	22.5	1.7	0.0	115	19.0	50	432.0			7.6
9	9	75	862	147.0	43.0	5.0	1.3	0.0	237	13.1	28	410.0	137.0	41.0	7.6
16	6	76	572	108.0	29.0	10.0	1.7	0.0	198	23.2	22	262.0	108.0	31.0	8.1
18	8	76	448	96.0	22.0	6.2	2.1	0.0	215	31.4	24	149.0	95.0	23.5	7.6
21	9	76	514	110.0	33.0	7.5	0.8	0.0	239	17.3	8	265.0		0.0	7.7
3	11	76	566	117.0	33.0	8.8	1.7	0.0	288	12.0	8	290.0			7.5
27	4	77	432	70.0	20.7	5.0	1.3	0.0	198	16.6	6	120.0	73.0	27.0	7.7
15	6	77	558	104.0	31.0	7.5	1.3	0.0	215	23.3	8	263.0	94.0	28.0	7.3
27	7	77	564	113.0	35.0	10.0	1.3	0.0	239	17.7	16	240.0	105.0	29.0	7.6
8	9	77	440	99.0	27.0	5.0	0.4	0.0	256	22.8	15	184.0	87.0	27.0	8.1
19	10	77	522	112.0	30.0	6.3	0.0	0.0	261	19.2	4	262.0	105.0	27.0	7.7
3	5	78	264	46.0	12.3	2.5	1.3	0.0	143	12.5	6	45.5	41.0	13.6	7.8
14	6	78	450	90.0	26.0	5.0	1.3	0.0	227	12.6	16	166.0	84.0	25.0	7.4
26	7	78	466	93.0	32.0	6.3	1.3	0.0	232	14.7	12	182.0	84.0	27.0	7.6
7	9	78	362	83.0	26.0	6.3	0.4	0.0	250	10.3	14	137.0	79.0	24.0	7.8
18	10	78	500	105.0	32.0	5.0	0.8	0.0	256	16.2	18	161.0	75.0	24.0	7.7

MINOR CONSTITUENTS

SPRING 8

DATE			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
DD	MM	YY	Al	As	Ba	Be	B	Cr	Cu	Fe	Hg	Mn	Mo	P	Pb	Se	Si	Sn	Sr	Te	Ti	V	Zn
27	6	72	220					20	60	60	0.24	100				0							110
24	7	72								70													
12	9	72								120													
30	11	72								130													
30	5	73								70													
3	7	73																					
14	8	73																					
25	9	73																					
14	5	74	1000						9	980	0.18	80			16.5								
25	6	74	370						5	360	0.17	20			18.4								
13	8	74	100						9	80	0.13	150			15.6		7.00						
24	9	74	160						3	80	0.11	10			7.1		1.50						
9	9	75	100						0	200	0.09	400			10.0		3.60						
16	6	76	100						10	100	0.05	100			0.0		2.50						
18	8	76	0						0	100	0.00	100			0.0		5.40						
21	9	76	330	38	990	1	28	6	40	654		14	6	1100	88.0	60	7.00	45	1.51	65	6	9	275
3	11	76	2	38	200	2	24	6	33	132		6	6	880	88.0	60	7.00	45	1.56	65	1	6	88
27	4	77								0							5.20						
15	6	77							8	0	1.48	0			5.0		5.20						
27	7	77							2	300	0.22	10			6.5		1.60						
8	9	77	100		397	5	12	20	6	27	0.26	5	50	100	30.0		6.40	38	1.06	50	10	10	27
19	10	77	100		466	5	7	20	5	20	0.03	5	50	100	30.0		6.00	20	1.25	50	10	10	10
3	5	78	0						6	0	0.91	0			1.3		2.40						
14	6	78	40		380	5	10	20	0	0	0.80	10	50		0.5		5.10		0.98	50	10	10	10
26	7	78	40						2	100	0.03	40			0.3		7.40						
7	9	78	90						0	100	0.11	30			1.1		6.60						
18	10	78	40		410	5	20	20	7	0	0.04	30	50		2.4		5.90		1.04	50	10	10	10

MAJOR CONSTITUENTS

STREAM 9-1

DATE			TDS	Ca	Mg	Na	K	CO3	HCO3	SO4	Cl	NO3	Ca(l)	Mg(l)	pH
DD	MM	YY													
29	5	73	150	24.0	8.4	5.0	0.4	0.0	125	12.7	4	0.3			7.5
3	7	73	174	31.5	11.2	5.0	1.3	0.0	154	13.1	4	0.3			7.8
15	8	73	190	51.0	16.6	12.5	2.1	0.0	207	21.8	16	0.3			8.0
24	9	73	154	43.9	17.0	11.3	1.3	0.0	215	24.8	4	0.1			8.1
14	5	74	82	24.6	8.8	4.0	0.4	0.0	117	18.5	2	0.7			7.0
25	6	74	176	30.1	11.0	6.3	0.4	0.0	146	19.8	2	1.0			8.1
12	8	74	264	45.7	18.1	0.0	0.0	8.0	205	24.0	2	1.4			8.4
24	9	74	198	42.4	17.0	17.5	0.9	16.0	188	21.0	4	3.0			8.7
9	9	75	220	42.0	15.1	11.3	1.3	0.0	202	19.7	2	0.7	41.0	14.6	8.2
27	4	76	190	35.0	13.2	15.0	1.7	0.0	173	18.2	4	0.0	38.5	12.4	8.2
15	6	76	142	30.0	11.2	2.5	1.3	0.0	142	18.2	4	2.8	33.5	11.1	8.0
17	8	76	148	32.0	10.4	8.8	0.8	0.0	139	16.1	4	1.8	31.0	10.0	7.6
20	9	76	164	35.0	14.8	8.8	0.0	0.0	178	15.6	2	0.8			7.9
2	11	76	168	42.0	12.5	15.0	0.8	0.0	190	17.2	2	0.5			7.7
26	4	77	320	26.4	8.9	8.8	4.6	0.0	127	20.0	0	6.3	17.1	11.0	7.8
14	6	77	158	26.0	9.4	10.0	1.3	0.0	127	20.7	2	1.7	19.0	8.6	8.1
26	7	77	186	35.0	12.5	10.0	1.3	0.0	168	12.2	4	0.3	33.0	111.0	8.2
7	9	77	114	33.0	11.0	5.0	0.0	0.0	156	13.1	0	1.3	28.0	11.5	8.1
18	10	77	194	37.0	12.0	6.3	0.0	0.0	183	15.8	0	0.6	34.0	11.6	8.3
2	5	78	210	29.0	9.8	10.0	0.8	26.4	100	12.3	2	0.3	25.0	9.4	8.8
13	6	78	136	34.0	11.3	10.0	0.8	0.0	168	14.7	2	0.6	25.0	10.9	8.3
25	7	78	202	32.0	11.6	6.3	0.0	0.0	154	16.2	2	0.1	25.0	10.4	8.3
7	9	78	116	28.0	10.5	8.8	0.4	0.0	156	13.3	2	0.7	31.0	10.6	7.7
17	10	78	184	38.0	13.7	8.1	0.8	0.0	190	17.3	2	0.5	31.0	11.5	8.1

MINOR CONSTITUENTS

STREAM 9-1

DATE			* Al	* As	* Ba	* Be	* B	* Cr	* Cu	* Fe	* Hg	* Mn	* Mo	* P	* Pb	* Se	* Si	* Sn	* Sr	* Te	* Ti	* V	* Zn
DD	MM	YY																					
29	5	73								330													
3	7	73																					
15	8	73	120						80	170	0.02	200											30
24	9	73																					
14	5	74	1530						3	1850	0.11	100			11.9								
25	6	74	1270						5	1730	0.13	40			21.1								
12	8	74	330						5	320	0.06	50			7.1		5.70						
24	9	74	190						0	150	0.05	10			4.7		1.20						
9	9	75	100						10	200	0.07	600			10.0		3.80						
27	4	76	100						0	200	0.04	100			10.0		3.50						
15	6	76	140						0	100	0.02	100			0.0		3.50						
17	8	76	200						0	300	0.06	200			0.0		4.10						
20	9	76	1400	38	200	1	59	6	216	2000		50	6	1000	88.0	60	4.40	45	0.21	65	19	8	530
2	11	76	2	38	200	1	12	6	24	99		1	6	660	88.0	60	3.90	45	0.21	65	1	1	22
26	4	77								100							4.00						
14	6	77							9	0	1.10	10			6.0		4.00						
26	7	77							5	0	0.16	20			6.0		3.90						
7	9	77	100		145	5	13	22	8	108	0.22	9	50	100	37.0		8.10	20	0.12	50	10	10	20
18	10	77	100		143	5	5	20	5	59	0.03	5	50	100	30.0		6.00	20	0.14	50	10	10	10
2	5	78	0						2	100	0.13	0			1.1		2.10						
13	6	78	0		140	5	20	20	0	0	2.31	0	50		0.5		3.80		0.13	50	10	10	10
25	7	78	130						10	100	0.03	60			1.1		3.40						
7	9	78	40						0	700	0.11	30			1.3		4.40						
17	10	78	40		150	5	20	20	3	0	0.04	20	50		0.5		5.30		0.14	50	10	10	10

MAJOR CONSTITUENTS

STREAM 9-2

DATE			TDS	Ca	Mg	Na	K	CO3	HCO3	SO4	Cl	NO3	Ca(1)	Mg(1)	pH
DD	MM	YY													
3	7	73	254	53.0	18.0	13.0	2.9	0.0	273	7.5	4	0.1			8.1
15	8	73	272	67.8	22.5	15.0	2.1	0.0	317	7.0	10	0.2			7.8
24	9	73	234	68.9	23.5	13.8	2.1	0.0	349	3.9	4	0.1			7.8
14	5	74	150	35.1	11.8	9.0	0.4	0.0	171	12.0	2	0.4			7.4
25	6	74	280	57.6	18.0	11.3	0.4	0.0	285	10.2	2	0.9			8.3
12	8	74	394	74.0	21.5	10.0	0.0	0.0	439	7.5	0	2.0			8.1
24	9	74	300	56.3	30.0	32.0	2.5	0.0	342	18.5	4	3.8			8.2
9	9	75	432	78.0	30.0	17.5	0.8	0.0	417	12.3	2	1.0	82.0	33.0	8.0
27	4	76	390	82.0	28.4	18.7	1.3	0.0	412	18.4	8	0.0	89.5	33.0	8.2
15	6	76	438	98.0	36.0	13.8	1.7	0.0	444	37.3	14	11.6	108.0	35.0	8.0
17	8	76	526	123.0	37.0	22.5	2.1	0.0	493	62.0	2	13.6	93.0	42.0	7.9
20	9	76	632	76.0	57.0	21.3	0.4	0.0	342	164.0	6	38.7			7.6
2	11	76	516	122.0	49.0	25.0	2.5	0.0	429	127.0	6	40.5			7.9
14	6	77	598	92.0	52.0	25.0	2.5	0.0	264	101.0	20	76.0	113.0	50.0	8.1
26	7	77	680	120.0	60.0	25.0	3.8	0.0	422	160.0	26	75.0	120.0	56.0	8.0
7	9	77	708	115.0	78.0	26.3	2.1	0.0	442	154.0	20	124.0	115.0	69.0	8.2
18	10	77	657	126.0	65.0	28.8	1.3	0.0	490	140.0	6	117.0	117.0	59.0	8.3
3	5	78	478	69.0	24.0	60.0	3.3	19.2	281	36.7	2	109.0	64.0	22.0	8.7
25	7	78	832	96.0	77.0	28.8	1.6	0.0	381	183.0	26	51.0	92.0	75.0	7.8
7	9	78	648	110.0	72.0	31.3	1.7	0.0	488	152.0	26	71.0	111.0	60.0	8.1
17	10	78	794	114.0	79.0	36.3	2.9	2.4	456	238.0	24	47.6	105.0	68.0	8.4

MINOR CONSTITUENTS

STREAM 9-2

DATE			* Al	* As	* Ba	* Be	* B	* Cr	* Cu	* Fe	* Hg	* Mn	* Mo	* P	* Pb	* Se	* Si	* Sn	* Sr	* Te	* Ti	* V	* Zn
DD	MM	YY																					
3	7	73																					
15	8	73	50						50	40	0.01	140											50
24	9	73																					
14	5	74	430						0	240	0.07	20			10.2								
25	6	74	120						0	60	0.07	20			6.2								
12	8	74	20500						200	20700	0.064	600			43.0		9.50						
24	9	74	5030						13	5290	0.13	710			17.4		2.20						
9	9	75	200						0	400	0.40	600			10.0		6.60						
27	4	76	0						10	0	1.33	100			0.0		6.00						
15	6	76	0						10	100	0.00	100			0.0		6.00						
17	8	76	0						0	0	0.00	100			0.0		7.00						
20	9	76	200	38	1300	2	52	6	24	130		8	6	900	88.0	60	6.80	45	1.14	65	1	9	280
2	11	76	2	38	200	1	8	6	5	88		1	6	770	88.0	60	7.20	45	0.97	65	1	1	66
14	6	77							13	0	0.50	10			5.0		5.80						
26	7	77							14	100	1.76	0			4.0		6.40						
7	9	77	371		412	5	26	20	20	76	1.68	32	50	100	40.0		11.50	269	0.97	50	10	10	44
18	10	77	100		329	5	19	20	9	20	0.22	21	50	100	30.0		7.10	20	0.98	50	10	10	13
3	5	78	70						6	0	0.57	0			1.1		2.60						
25	7	78	40						3	0	0.07	10			1.0		7.60						
7	9	78	90						0	200	0.20	20			1.9		7.40						
17	10	78	40		420	5	30	20	4	0	0.06	30	50		0.8		6.40		0.93	50	10	10	10

MAJOR CONSTITUENTS

STREAM 9-3

DATE			TDS	Ca	Mg	Na	K	CO3	HCO3	SO4	Cl	NO3	Ca(l)	Mg(l)	pH
DD	MM	YY													
4	7	73	214	44.5	14.5	15.0	2.1	0.0	242	5.3	2	0.1			8.1
15	8	73	242	66.0	19.5	26.3	2.1	0.0	317	6.2	8	0.3			7.7
26	9	73	240	59.2	20.0	30.0	2.1	0.0	346	4.8	4	0.1			7.8
14	5	74	104	28.1	8.0	6.0	0.4	0.0	134	10.5	6	0.5			7.2
25	6	74	202	44.4	13.0	16.3	0.8	8.0	229	7.8	4	0.6			8.4
13	8	74	280	51.8	17.8	26.3	1.3	32.0	283	9.5	0	1.4			8.4
24	9	74	198	25.1	20.0	47.5	1.8	7.2	249	7.5	2	3.0			8.5
9	9	75	422	68.0	20.4	53.0	1.7	0.0	356	22.0	2	52.0	65.0	20.2	8.2
27	4	76	230	41.0	15.3	21.3	1.3	0.0	237	74.0	4	0.6	47.0	16.1	8.1
16	6	76	266	48.0	17.6	32.5	2.1	0.0	256	17.6	2	46.2	55.0	16.9	7.8
18	8	76	314	61.0	18.9	25.0	2.5	0.0	261	36.0	4	61.0	61.0	19.2	7.9
21	9	76	306	52.0	23.8	29.0	0.0	0.0	337	15.2	2	8.8			7.9
3	11	76	506	70.0	24.4	100.0	2.5	0.0	366	90.0	2	82.0			8.0
27	4	77	464	52.0	18.7	81.0	2.1	0.0	334	53.0	2	86.0	54.0	24.0	8.3
15	6	77	352	58.0	21.0	46.3	1.7	9.6	278	25.5	1	61.0	55.0	20.9	8.5
27	7	77	698	71.0	26.0	125.0	5.4	0.0	315	117.0	22	205.0	58.0	21.0	7.9
8	9	77	470	75.0	31.0	59.0	2.5	0.0	373	60.0	5	73.0	61.0	27.0	7.8
19	10	77	346	63.0	22.0	55.0	1.7	0.0	388	34.7	2	42.0	55.0	18.0	8.4
14	6	78	450	57.0	27.0	71.0	2.9	0.0	356	41.0	4	71.0	57.0	26.0	7.9
26	7	78	360	43.0	27.0	56.0	2.5	0.0	307	47.2	6	50.0	50.0	26.0	8.0
7	9	78	460	58.0	30.0	68.0	1.3	0.0	329	91.0	6	79.0	61.0	28.0	8.3
18	10	78	492	53.0	30.4	83.0	1.7	0.0	393	70.0	10	38.7	50.0	27.0	8.1

MINOR CONSTITUENTS

STREAM 9-3

DATE			* Al	* As	* Ba	* Be	* B	* Cr	* Cu	* Fe	* Hg	* Mn	* Mo	* P	* Pb	* Se	* Si	* Sn	* Sr	* Te	* Ti	* V	* Zn
4	7	73																					
15	8	73	120						50	240	0.04	170											40
26	9	73																					
14	5	74	3950						6	3360	0.24	250			8.6								
25	6	74	250						0	220	0.25	50			5.4								
13	8	74	430						1	940	0.10	310			7.8								
24	9	74	190						0	340	0.10	350			6.2								
9	9	75	100						0	700	0.39	600			10.0								
27	4	76	480						0	300	0.00	100			0.0								
16	6	76	60						0	0	0.00	100			0.0								
18	8	76	180						10	100	0.04	200			0.0								
21	9	76	2	38	700	1	31	6	6	46		102	6	110	88.0	60	5.20	45	0.67	65	1	6	100
3	11	76	100	38	200	1	56	6	15	8		66	6	660	88.0	60	5.20	45	1.37	65	3	5	55
27	4	77								0													
15	6	77							8	0	0.18	70			5.0								
27	7	77							14	300	1.64	50			6.5								
8	9	77	376		244	5	23	22	26	148	2.40	257	50	102	68.0								
19	10	77	100		232	5	51	20	6	52	0.08	13	50	100	30.0								
14	6	78	70		210	5	40	20	1	0	1.30	40	50		0.3								
26	7	78	40						0	100	0.07	60			1.0								
7	9	78	90						1	700	0.11	40			0.5								
18	10	78	40		200	5	50	20	3	0	0.06	40	50		1.5								

MAJOR CONSTITUENTS

STREAM 9-4

DATE			TDS	Ca	Mg	Na	K	CO3	HCO3	SO4	Cl	NO3	Ca(1)	Mg(1)	pH
DD	MM	YY													
4	7	73	172	33.0	9.8	11.0	1.7	0.0	166	19.0	2	0.2			7.9
15	8	73	214	47.4	13.6	22.5	1.7	0.0	246	2.7	6	0.2			8.1
26	9	73	216	48.9	15.2	26.3	1.3	0.0	276	9.9	4	0.1			8.1
14	5	74	110	21.7	6.2	6.0	0.4	0.0	102	12.0	2	0.5			7.0
25	6	74	182	30.6	8.9	11.3	0.4	0.0	159	6.6	0	0.5			8.2
13	8	74	288	50.8	16.0	15.0	0.0	24.0	244	15.5	0	2.4			8.4
24	9	74	254	45.7	14.0	27.2	1.5	14.6	224	16.0	2	3.9			8.8
9	9	75	230	41.0	11.9	18.8	0.4	0.0	222	11.5	2	1.3	40.0	11.6	8.3
27	4	76	156	23.6	7.3	12.5	3.8	0.0	117	11.0	4	3.7	27.0	7.2	7.8
16	6	76	146	28.0	7.9	11.3	0.0	0.0	122	10.6	16	2.0	27.5	7.3	7.4
18	8	76	126	31.0	8.6	10.0	0.8	0.0	132	10.7	2	1.7	32.0	8.6	7.6
21	9	76	180	32.0	11.6	10.0	0.0	0.0	163	9.2	0	1.4			7.6
3	11	76	178	38.0	9.6	15.0	0.8	0.0	185	10.2	2	0.5			7.8
27	4	77	192	19.7	6.5	9.0	0.4	0.0	107	13.6	0	0.7	15.4	9.4	8.1
15	6	77	132	24.0	7.4	6.3	0.0	0.0	132	11.7	1	4.5	18.1	7.0	8.1
27	7	77	164	35.0	9.2	12.5	1.7	0.0	161	11.0	4	2.5	31.0	8.0	8.2
8	9	77	174	30.0	8.3	5.0	0.0	0.0	142	11.0	0	1.3	26.0	8.3	7.9
19	10	77	184	30.0	8.7	8.8	0.0	0.0	149	11.0	0	0.3	28.0	8.0	8.2
3	5	78	180	24.0	7.0	8.8	0.8	0.0	122	7.5	0	1.1	23.0	7.4	8.1
14	6	78	140	28.0	8.3	10.0	0.8	0.0	137	9.0	2	1.0	24.0	7.7	8.1
26	7	78	152	31.0	8.9	8.8	0.4	0.0	159	7.7	4	0.0	26.0	8.9	7.9
7	9	78	76	28.0	8.4	7.5	0.0	0.0	146	10.3	2	0.3	29.0	8.2	7.9
18	10	78	146	32.0	9.8	10.6	0.6	0.0	168	10.0	2	0.4	29.0	7.9	8.2

MINOR CONSTITUENTS

STREAM 9-4

DATE			* Al	* As	* Ba	* Be	* B	* Cr	* Cu	* Fe	* Hg	* Mn	* Mo	* P	* Pb	* Se	* Si	* Sn	* Sr	* Te	* Ti	* V	* Zn
DD	MM	YY																					
4	7	73																					
15	8	73	80						50	140	0.03	190											420
26	9	73																					
14	5	74	630						1	450	0.11	50			7.8								
25	6	74	240						0	130	0.09	10			4.7								
13	8	74	180						1	80	0.06	100			7.8		6.90						
24	9	74	180						3	90	0.05	20			7.1		2.10						
9	9	75	100						0	200	0.28	700			10.0		5.70						
27	4	76	120						0	100	1.20	100			0.0		4.00						
16	6	76	200						0	100	0.04	100			0.0		2.20						
18	8	76	100						0	100	0.02	100			0.0		4.50						
21	9	76	2	38	200	1	20	6	9	96		3	6	110	88.0	60	5.50	45	0.28	65	1	1	90
3	11	76	2	38	200	1	24	6	26	110		1	6	110	88.0	60	4.80	45	0.29	65	1	4	55
27	4	77								100							4.80						
15	6	77							8	0	0.49	0			4.0		4.30						
27	7	77							2	500	0.18	0			2.0		1.80						
8	9	77	100		102	5	11	20	11	108	1.36	10	50	100	57.0		3.00	427	0.16	71	10	10	29
19	10	77	100		107	5	5	20	5	65	0.08	5	50	100	30.0		5.00	20	0.17	50	10	10	62
3	5	78	20						5	100	1.33	0			1.5		2.70						
14	6	78	40		100	5	20	20	0	100	2.00	0	50		0.8		5.10		0.15	50	10	10	10
26	7	78	40						0	100	0.00	20			1.0		6.00						
7	9	78	90						0	500	0.04	60			1.3		5.20						
18	10	78	40		110	5	10	20	2	0	0.04	40	50		13.6		6.50		0.18	50	10	10	10

MAJOR CONSTITUENTS

STREAM 9-6

DATE			TDS	Ca	Mg	Na	K	CO3	HCO3	SO4	Cl	NO3	Ca(l)	Mg(l)	pH
DD	MM	YY													
14	6	77	252	40.0	12.5	32.5	1.3	4.8	220	42.4	1	8.5	39.0	11.6	8.4
26	7	77	360	55.0	18.3	53.0	2.5	14.4	307	56.0	4	21.5	51.0	15.4	8.5
7	9	77	312	54.0	17.8	50.0	0.8	0.0	302	57.0	0	11.3	49.0	17.6	8.3
18	10	77	342	55.0	16.7	50.0	0.0	12.0	298	43.8	2	3.3	53.0	16.0	8.5
2	5	78	326	40.0	12.6	56.0	0.8	21.6	273	16.2	4	0.2	38.0	13.3	8.6
13	6	78	256	49.0	14.0	59.0	2.1	9.6	312	11.4	4	0.1	36.0	13.5	8.6
25	7	78	402	45.0	16.8	58.0	0.4	0.0	320	42.5	2	0.6	41.0	17.3	8.1
7	9	78	270	47.0	17.2	63.0	1.7	0.0	342	49.0	4	4.4	46.0	16.8	8.1
17	10	78	452	54.0	19.8	70.0	1.7	0.0	368	69.0	2	1.2	48.0	16.7	8.3

MINOR CONSTITUENTS

STREAM 9-6

DATE			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
DD	MM	YY	Al	As	Ba	Be	B	Cr	Cu	Fe	Hg	Mn	Mo	P	Pb	Se	Si	Sn	Sr	Te	Ti	V	Zn
14	6	77							8	0	0.20	40			3.0		4.30						
26	7	77							9	300	1.24	50			3.0		1.70						
7	9	77	100		285	5	28	20	15	69	1.19	56	50	100	47.0		10.20	72	0.65	50	10	10	29
18	10	77	100		360	5	17	20	5	59	0.03	64	50	100	30.0		6.00	20	0.64	50	10	10	12
2	5	78	0						0	200	0.15	20			3.1		1.90						
13	6	78	0		330	5	30	20	0	0	0.44	10	50		0.8		5.40		0.50	50	10	10	10
25	7	78	40						4	0	0.03	90			0.3		5.90						
7	9	78	40						5	600	0.11	100			4.0		6.50						
17	10	78	40		350	5	30	20	4	0	0.03	40	50		0.5		5.80		0.66	50	10	10	10

MAJOR CONSTITUENTS

STREAM 9-1A

DATE			TDS	Ca	Mg	Na	K	CO3	HCO3	SO4	Cl	NO3	Ca(l)	Mg(l)	pH
DD	MM	YY													
14	6	77	116	21.0	7.7	5.0	0.0	0.0	105	13.5	1	1.5	15.6	6.9	8.3
26	7	77	156	31.0	10.0	8.8	1.7	0.0	144	13.1	4	0.7	26.0	8.7	8.0
7	9	77	192	28.0	9.6	2.5	0.0	0.0	134	11.6	0	0.9	24.0	10.9	8.0
18	10	77	172	30.0	10.0	5.0	10.0	0.0	149	13.3	2	0.5	28.0	9.6	8.3
2	5	78	134	16.5	5.6	7.5	0.4	0.0	88	10.6	0	1.0	16.4	5.8	8.1
13	6	78	98	26.0	9.1	8.8	1.7	0.0	129	12.8	6	0.3	23.0	8.6	8.1
25	7	78	202	25.0	10.1	5.0	0.0	0.0	132	10.2	2	0.6	24.0	10.3	7.5
7	9	78	96	24.0	9.0	5.0	0.0	0.0	134	10.6	2	0.9	22.0	8.4	7.9
17	10	78	164	33.2	12.2	5.6	0.4	0.0	166	12.9	2	0.3	29.0	10.3	8.2

MINOR CONSTITUENTS

STREAM 9-1A

DATE			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
DD	MM	YY	Al	As	Ba	Be	B	Cr	Cu	Fe	Hg	Mn	Mo	P	Pb	Se	Si	Sn	Sr	Te	Ti	V	Zn
14	6	77							9	0	1.32	20			5.0		3.10						
26	7	77							9	400	1.54	10			4.5		4.50						
7	9	77	100		137	5	12	24	6	108	0.10	9	50	100	42.0		2.90	62	0.10	50	10	12	18
18	10	77	100		144	5	5	18	5	96	0.08	6	50	100	48.0		3.90	23	0.11	50	11	16	10
2	5	78	90						23	100	0.63	0			4.7		2.90						
13	6	78	20		140	5	10	20	0	0	0.35	0	50		0.5		3.70		0.09	50	10	10	10
25	7	78	90						3	100	0.03	40			1.0		5.00						
7	9	78	40						0	300	0.07	30			1.1		4.10						
17	10	78	40		160	5	10	20	4	0	0.04	10	50		0.3		4.50		0.11	50	10	10	10

MAJOR CONSTITUENTS

STREAM 01

DATE			TDS	Ca	Mg	Na	K	CO3	HCO3	SO4	Cl	NO3	Ca(l)	Mg(l)	pH
DD	MM	YY													
18	10	77	218	44.0	15.0	2.5	0.0	4.8	203	9.7	0	0.0	42.0	14.3	8.4
2	5	78	168	30.0	10.2	2.5	0.4	0.0	154	8.2	2	0.0	30.0	10.5	8.3
13	6	78	112	33.0	10.3	2.5	0.4	0.0	154	4.7	2	0.5	31.0	10.5	7.9
25	7	78	204	37.0	15.3	1.3	0.0	0.0	198	7.2	2	1.0	35.0	15.2	7.9
17	10	78	174	46.0	15.7	2.5	0.8	0.0	215	9.0	2	0.4	37.0	13.9	8.3

MINOR CONSTITUENTS

STREAM 01

DATE			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
DD	MM	YY	Al	As	Ba	Be	B	Cr	Cu	Fe	Hg	Mn	Mo	P	Pb	Se	Si	Sn	Sr	Te	Ti	V	Zn
18	10	77	100		203	5	9	20	5	67	0.03	5	50	100	30.0		3.90	20	0.14	50	10	10	14
2	5	78	20						9	0	1.12	0					5.10						
13	6	78	20		150	5	10	20	1	0	0.64	0	50		1.5		3.10		0.10	50	10	10	10
25	7	78	40						6	0	0.07	10			2.0		4.80						
17	10	78	40		190	5	10	20	3	0	0.03	10	50		3.1		6.40		0.14	50	10	10	10

MAJOR CONSTITUENTS

PIEZOMETER WRI-13

DATE			TDS	Ca	Mg	Na	K	CO3	HCO3	SO4	Cl	NO3	Ca(l)	Mg(l)	pH
DD	MM	YY													
30	5	73	258	61.0	27.0	5.0	1.3	0.0	320	7.2	4	0.2			7.7
3	7	73	264	59.0	27.0	6.0	3.3	0.0	320	7.0	2	0.4			8.1
16	6	76	358	77.0	33.0	12.5	1.7	0.0	332	66.0	8	0.8	38.0	34.0	6.7
18	8	76	236	54.0	14.1	6.2	2.5	12.0	76	94.0	8	0.8	53.0	16.0	8.6
21	9	76	354	73.0	34.0	1.3	0.4	0.0	344	47.2	2	0.2			8.0
15	6	77	390	84.0	37.0	6.3	1.3	0.0	378	43.7	4	1.3	77.0	36.0	7.3
27	7	77	392	81.0	34.0	6.3	2.1	0.0	373	63.0	12	0.0	76.0	33.0	7.2
8	9	77	384	85.0	36.0	1.2	0.8	0.0	364	71.0	8	0.0	95.0	36.0	7.6

MINOR CONSTITUENTS

PIEZOMETER WRI-13

DATE			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
DD	MM	YY	Al	As	Ba	Be	B	Cr	Cu	Fe	Hg	Mn	Mo	P	Pb	Se	Si	Sn	Sr	Te	Ti	V	Zn
30	5	73								190													
3	7	73																					
16	6	76	20						0	100	1.68	100			0.0		6.90						
18	8	76	40						0	400	0.00	100			0.0		8.60						
21	9	76	300	38	200	1	30	6	22	655	0.29	336	6	800	88.0	60	10.90	45	1.35	65	6	3	310
15	6	77							5	600	0.29	310			4.5		9.70						
27	7	77							2	700	0.20	290			2.0		5.80						
8	9	77							14	600	1.44	300			6.0		10.80						

MAJOR CONSTITUENTS

PIEZOMETER WRI-58

DATE			TDS	Ca	Mg	Na	K	CO3	HCO3	SO4	Cl	NO3	Ca(l)	Mg(l)	pH
DD	MM	YY													
3	7	73	228	49.8	22.5	5.0	3.3	0.0	244	17.0	2	0.2			7.9
16	6	76	348	77.0	32.0	0.0	1.3	0.0	332	66.0	6	0.3	60.0	35.0	6.9
18	8	76	372	82.0	32.0	5.0	1.7	0.0	349	46.7	10	0.3	76.0	34.5	7.2
21	9	76	276	53.0	34.0	3.8	0.8	0.0	281	49.7	4	0.0			7.6
27	7	77	376	83.0	35.0	6.3	2.1	0.0	373	61.0	8	0.1	75.0	31.0	7.3
8	9	77	394	81.0	35.0	2.5	0.8	0.0	310	75.0	5	0.4	70.0	38.0	7.5
19	10	77	424	91.0	36.0	3.8	0.0	0.0	376	84.0	2	0.0	79.0	31.0	7.3
14	6	78	260	48.0	12.3	11.3	2.1	0.0	129	78.0	4	0.3	36.0	11.6	7.4
26	7	78	456	90.0	40.0	5.0	2.1	0.0	422	57.0	10	0.0	75.0	36.0	7.2

MINOR CONSTITUENTS

PIEZOMETER WRI-58

DATE			* Al	* As	* Ba	* Be	* B	* Cr	* Cu	* Fe	* Hg	* Mn	* Mo	* P	* Pb	* Se	* Si	* Sn	* Sr	* Te	* Ti	* V	* Zn
DD	MM	YY																					
3	7	73																					
16	6	76	40						0	0	0.00	100			0.0		5.80						
18	8	76	20						0	400	0.02	300			0.0		9.50						
21	9	76	2	38	200	1	30	6	14	548		332	6	1300	88.0	60	10.70	45	1.34	65	900	7	290
27	7	77							8	600	1.30	300			5.0		2.80						
8	9	77	211		304	5	19	24	13	491	1.58	351	50	100	63.0		11.20	288	1.11	74	10	10	59
19	10	77	100		291	5	19	20	5	549	0.03	348	50	100	30.0		9.70	90	1.15	50	10	10	10
14	6	78	40						7	0	0.48	20			0.8		15.50						
26	7	78	40						2	100	0.03	350			1.0		22.80						

MAJOR CONSTITUENTS

PIEZOMETER WRI-115

DATE			TDS	Ca	Mg	Na	K	CO3	HCO3	SO4	Cl	NO3	Ca(l)	Mg(l)	pH
DD	MM	YY													
30	5	73	240	59.0	27.0	6.3	0.8	0.0	323	11.8	8	0.2			7.7
3	7	73	264	58.0	29.0	6.0	2.1	0.0	332	5.2	2	0.3			7.7
16	6	76	294	63.0	29.0	1.3	1.7	0.0	329	19.7	8	1.2	64.0	33.0	7.0
27	7	77	348	66.0	33.0	18.8	3.8	0.0	356	32.7	16	0.1	63.0	27.0	7.3
8	9	77	336	72.0	33.0	6.2	1.7	0.0	359	33.2	8	0.0	70.0	33.0	7.3
19	10	77	338	74.0	32.0	5.0	0.4	0.0	364	35.0	2	0.0	56.0	31.0	7.6
26	7	78	250	53.0	26.0	5.0	1.3	0.0	288	17.4	8	0.0	51.0	28.0	7.6

MINOR CONSTITUENTS

PIEZOMETER WRI-115

DATE			* Al	* As	* Ba	* Be	* B	* Cr	* Cu	* Fe	* Hg	* Mn	* Mo	* P	* Pb	* Se	* Si	* Sn	* Sr	* Te	* Ti	* V	* Zn
DD	MM	YY																					
30	5	73								140													
3	7	73																					
16	6	76	40						0	0	0.00	100			0.0		6.70						
27	7	77							47	200	1.64	170			5.0		4.70						
8	9	77							3	200	0.43	150			2.5		12.50						
19	10	77	100		609	5	23	20	8	265	0.06	177	50	100	30.0		13.40	105	2.10	50	10	10	319
26	7	78	40						33	300	0.07	230			1.3		9.80						

MAJOR CONSTITUENTS

PIEZOMETER WRI-205

DATE			TDS	Ca	Mg	Na	K	CO3	HCO3	SO4	Cl	NO3	Ca(l)	Mg(l)	pH
DD	MM	YY													
8	9	77	256	22.0	8.5	64.0	2.9	0.0	232	32.0	5	0.5	19.0	12.0	7.2
19	10	77	304	25.0	9.2	64.0	2.9	0.0	246	46.2	4	1.1			7.6
3	5	78	298	20.6	8.7	76.0	3.3	0.0	256	31.2	4	0.0			7.8
14	6	78	252	23.0	8.1	78.0	3.8	0.0	256	28.3	4	0.3			7.5
26	7	78	264	26.0	8.4	76.0	3.8	0.0	276	22.9	20	0.0	19.0	8.1	7.0

MINOR CONSTITUENTS

PIEZOMETER WRI-205

DATE			* Al	* As	* Ba	* Be	* B	* Cr	* Cu	* Fe	* Hg	* Mn	* Mo	* P	* Pb	* Se	* Si	* Sn	* Sr	* Te	* Ti	* V	* Zn
DD	MM	YY																					
8	9	77	109		129	5	36	20	17	92	0.22	146	50	100	30.0		3.20	58	0.30	50	10	10	198
19	10	77															3.50						
3	5	78								100							0.90						
14	6	78															3.60						
26	7	78	40						9	100	0.10	160			3.2		4.00						

APPENDIX 3 STREAMFLOW ESTIMATES AND DISSOLVED OXYGEN CONCENTRATIONS AT WATER SAMPLING SITES

Dissolved Oxygen Concentrations

Date	Dissolved Oxygen mg/L
<i>Sheep Creek at Bailey bridge</i>	
May 29/73	11
July 3/73	10
Aug 15/73	9
Sept 24/73	9
May 13/74	10
June 25/74	10
Aug 12/74	9
Sept 25/74	10

Dissolved Oxygen Concentrations

Date	Dissolved Oxygen mg/L
<i>Sheep Creek at Smoky River</i>	
May 29/73	11
July 3/73	10
Aug 14/73	9
Sept 24/73	9
May 13/74	11
June 24/74	10
Aug 12/74	9
Sept 24/74	10

Discharge Estimates and Dissolved Oxygen Concentrations: Stream Number 1

Date	Flow		Dissolved Oxygen mg/L
	L/sec	igpm	
April 12/72	4	50	ND
May 24/72	20	200	ND
July 25/72	1	15	ND
Sept 12/72	—	Dry	—
Nov 30/72	—	Dry	—
April 25/73	5	70	ND
May 30/73	8	100	12
July 3/73	4	50	10
Aug 14/73	—	Dry	—
Sept 24/73	—	Dry	—
May 13/74	ND	ND	11
June 25/74	1	10	9
Aug 12/74	—	Dry	—
Sept 24/74	—	Dry	—
Sept 9/75	—	Dry	—
April 27/76	ND	ND	ND
June 15/76	3	40	ND
Aug 18/76	5	60	ND
Sept 20/76	2	20	ND
Nov 2/76	2	25	ND
April 27/77	10	150	ND
June 14/77	8	100	ND
July 26/77	8	100	ND
Sept 7/77	8	100	ND
Oct 18/77	2	30	ND
May 2/78	4	50	ND
June 13/78	3	40	ND
July 26/78	4	50	ND
Sept 7/78	2	20	ND
Oct 17/78	4	40	ND

ND - Not determined

Discharge Estimates and Dissolved Oxygen Concentrations: Stream Number 2

Date	Flow		Dissolved Oxygen mg/L
	L/sec	igpm	
June 28/72	4	50	ND
July 24/72	1	10	ND
Sept 12/72	ND	ND	ND
Nov 30/72	ND	ND	ND
April 25/73	2	20	ND
May 30/73	8	100	11
July 3/73	5	70	11
Aug 14/73	3	40	11
Sept 24/73	3	40	11
May 14/74	4	50	11
June 25/74	1	10	ND
Aug 12/74	2	30	11
Sept 24/74	1	8	11
Sept 9/75	1	10	ND
June 16/76	ND	ND	ND
Aug 18/76	6	75	ND
Sept 21/76	1	15	ND
Nov 3/76	2	25	ND
April 27/77	6	80	ND
June 15/77	5	60	ND
July 27/77	4	50	ND
Sept 8/77	2	25	ND
Oct 19/77	2	30	ND
May 3/78	3	40	ND
June 14/78	3	40	ND
July 26/78	2	20	ND
Sept 7/78	3	40	ND
Oct 18/78	2	25	ND

ND - Not determined

Date	Flow		Dissolved Oxygen mg/L
	L/sec	igpm	
June 28/72	1	10	ND
July 25/72	1	10	ND
Sept 12/72	1	5	ND
Nov 30/72	—	Frozen	—
April 25/73	1	15	ND
May 30/73	5	60	10
July 3/73	4	50	9.5
Aug 14/73	1	10	9
Sept 25/73	1	10	ND
May 14/74	1	10	10
June 25/74	1	10	10
Aug 13/74	1	2	11
Sept 24/74	1	1	10
Sept 9/75	1	2	ND
June 16/76	1	10	ND
Aug 18/76	1	15	ND
Sept 21/76	1	5	ND
Nov 3/76	1	4	ND
April 27/77	1	5	ND
June 15/77	2	20	ND
July 27/77	1	5	ND
Sept 8/77	2	20	ND
Oct 19/77	1	2	ND
May 3/78	1	10	ND
June 14/78	1	7	ND
July 26/78	1	7	ND
Sept 7/78	1	1	ND
Oct 18/78	1	3	ND

ND - Not determined

Discharge Estimates and Dissolved Oxygen Concentrations:
Stream Number 6

Date	Flow		Dissolved Oxygen mg/L
	L/sec	igpm	
Sept 26/73	ND	ND	ND
May 14/74	8	100	10
June 25/74	2	30	9
Aug 13/74	1	7	ND
Sept 24/74	1	10	10
Sept 9/75	1	10	ND
June 16/76	4	50	ND
Aug 18/76	8	100	ND
Sept 21/76	4	50	ND
Nov 3/76	5	60	ND
April 27/77	10	150	ND
June 15/77	8	100	ND
July 27/77	4	50	ND
Sept 8/77	5	60	ND
Oct 19/77	2	30	ND
May 3/78	4	50	ND
June 14/78	3	40	ND
July 26/78	3	40	ND
Sept 7/78	3	40	ND
Oct 18/78	3	40	ND

Date	Flow		Dissolved Oxygen mg/L
	L/sec	igpm	
April 25/73	1	4	ND
May 30/73	4	50	10
July 3/73	1	8	8.5
Aug 14/73	—	Dry	—
May 14/74	1	10	10
June 25/74	—	Dry	—
Aug 13/74	—	Dry	—
Sept 24/74	—	Dry	—
Sept 9/75	—	Dry	—
June 16/76	1	10	ND
Aug 18/76	2	25	ND
Sept 21/76	1	2	ND
Nov 3/76	—	Frozen	—
April 27/77	2	20	ND
June 15/77	1	10	ND
July 27/77	—	Dry	—
Sept 8/77	1	5	ND
Oct 19/77	1	2	ND
May 3/78	1	15	ND
June 14/78	1	10	ND
July 26/78	1	1	ND
Sept 7/78	1	1	ND
Oct 18/78	—	Dry	—

ND - Not determined

Dissolved Estimates and Dissolved Oxygen Concentrations:
Stream Number 9-1

Date	Flow		Dissolved Oxygen mg/L
	L/sec	igpm	
May 29/73	ND	ND	11
July 3/73	40	500	9
Aug 15/73	ND	ND	9
Sept 24/73	2	20	9
May 14/74	60	800	11
June 25/74	20	300	9
Aug 12/74	8	100	8
Sept 25/74	5	60	10
Sept 9/75	4	50	ND
April 27/76	20	300	ND
June 15/76	40	500	ND
Aug 17/76	50	600	ND
Sept 20/76	8	100	ND
Nov 2/76	8	100	ND
April 26/77	30	350	ND
June 14/77	80	1000	ND
July 26/77	60	800	ND
Sept 7/77	90	1200	ND
Oct 18/77	20	200	ND
May 2/78	50	700	ND
June 13/78	40	500	ND
July 25/78	40	500	ND
Sept 7/78	20	200	ND
Oct 17/78	30	400	ND

Discharge Estimates and Dissolved Oxygen Concentrations:
Stream Number 9-2

Date	Flow		Dissolved Oxygen mg/L
	L/sec	igpm	
July 3/73	5	60	9
Aug 15/73	2	20	8
Sept 24/73	1	10	8.5
May 14/74	20	200	10
June 25/74	4	50	4
Aug 12/74	ND	ND	ND
Sept 25/74	2	20	ND
Sept 9/75	1	5	ND
April 27/76	2	25	ND
June 15/76	4	50	ND
Aug 17/76	2	30	ND
Sept 20/76	2	20	ND
Nov 2/76	1	15	ND
April 26/77	—	Dry	—
June 14/77	5	70	ND
July 26/77	4	50	ND
Sept 7/77	2	25	ND
Oct 18/77	1	10	ND
May 2/78	—	Dry	—
June 13/78	1	1	ND
July 25/78	2	25	ND
Sept 7/78	2	20	ND
Oct 17/78	2	20	ND

ND - Not determined

Discharge Estimates and Dissolved Oxygen Concentrations:
Stream Number 9-3

Date	Flow		Dissolved Oxygen mg/L
	L/sec	igpm	
July 4/73	ND	ND	9.5
Aug 15/73	ND	ND	9
Sept 26/73	2	20	9
May 14/74	40	500	10
June 25/74	5	70	9
Aug 13/74	4	50	10
Sept 24/74	2	20	9
Sept 9/75	4	50	ND
April 27/76	8	100	ND
June 16/76	20	200	ND
Aug 18/76	10	175	ND
Sept 21/76	20	300	ND
Nov 3/76	8	100	ND
April 27/77	30	400	ND
June 15/77	50	600	ND
July 27/77	40	500	ND
Sept 8/77	4	50	ND
Oct 19/77	1	10	ND
May 3/78	40	500	ND
June 14/78	20	200	ND
July 26/78	20	200	ND
Sept 7/78	20	200	ND
Oct 18/78	20	200	ND

ND - Not determined

Discharge Estimates and Dissolved Oxygen Concentrations:
Stream Number 9-4

Date	Flow		Dissolved Oxygen mg/L
	L/sec	igpm	
July 4/73	20	250	ND
Aug 15/73	4	50	9
Sept 26/73	3	40	9
May 14/74	60	800	11
June 25/74	8	100	10
Aug 13/74	2	30	10
Sept 24/74	2	20	10
Sept 9/75	4	50	ND
April 27/76	40	500	ND
June 16/76	20	300	ND
Aug 18/76	20	300	ND
Sept 21/76	20	300	ND
Nov 3/76	20	300	ND
April 27/77	60	800	ND
June 15/77	70	900	ND
July 27/77	50	700	ND
Sept 8/77	50	700	ND
Oct 19/77	20	200	ND
May 3/78	80	1000	ND
June 14/78	50	700	ND
July 26/78	50	600	ND
Sept 7/78	20	200	ND
Oct 18/78	20	200	ND

ND - Not determined

Discharge Estimates: Spring Number 3

Date	Flow	
	L/sec	igpm
June 27/72	1	10
July 24/72	1	2
Sept 12/72	1	1
April 25/73	1	10
May 30/73	4	50
July 3/73	2	25
Aug 14/73	1	2
Sept 24/73	—	Dry
May 14/74	6	75
June 25/74	1	5
Aug 12/74	—	Dry
Sept 24/74	—	Dry
June 16/76	2	20
Aug 18/76	3	40
Sept 21/76	1	5
Nov 3/76	1	2
April 27/77	4	50
June 15/77	2	25
July 27/77	1	15
Sept 8/77	1	5
Oct 19/77	2	20
May 3/78	3	40
June 14/78	1	1
July 26/78	1	2
Sept 7/78	1	5
Oct 18/78	1	3

Dissolved oxygen not determined

Discharge Estimates: Spring Number 4

Date	L/sec	Flow igpm
June 27/72	1	5
July 25/72	1	4
Sept 12/72	1	5
Nov 30/72	1	1
April 25/73	1	15
May 30/73	2	20
July 3/73	4	50
Aug 14/73	1	2
Sept 24/73	—	Dry
May 14/74	2	20
June 25/74	1	10
Aug 13/74	—	Dry
Sept 24/74	—	Dry
Sept 9/75	1	1
June 16/76	1	10
Aug 18/76	2	25
Sept 21/76	1	15
Nov 3/76	1	3
April 27/77	1	5
June 15/77	2	20
July 27/77	1	15
Sept 8/77	1	15
Oct 19/77	1	10
May 3/78	—	Dry
June 14/78	—	Dry
July 26/78	—	Dry
Sept 7/78	—	Dry
Oct 18/78	—	Dry

Dissolved oxygen not determined

Discharge Estimates: Spring Number 8

Date	L/sec	Flow igpm
June 27/72	1	2
July 24/72	1	1
Sept 12/72	1	1
Nov 30/73	1	1
May 30/73	1	5
July 3/73	1	5
Aug 14/73	1	1
Sept 24/73	1	1
May 14/74	1	4
June 25/74	1	1
Aug 12/74	1	1
Sept 24/74	1	1
Sept 9/75	1	1
June 16/76	1	5
Aug 18/76	2	25
Sept 21/76	1	5
Nov 3/76	1	1
April 27/77	1	5
June 15/77	1	10
July 27/77	1	5
Sept 8/77	1	5
Oct 19/77	1	5
May 3/78	1	2
June 14/78	1	2
July 26/78	1	3
Sept 7/78	1	1
Oct 18/78	1	3

Dissolved oxygen not determined

Discharge Estimates: Stream Number 9-1A

Date	L/sec	Flow igpm
June 14/77	30	400
July 26/77	20	200
Sept 7/77	20	250
Oct 18/77	40	500
May 2/78	40	500
June 14/78	30	400
July 25/78	50	600
Sept 7/78	20	200
Oct 17/78	30	400

Discharge Estimates: Stream Number 9-6

Date	L/sec	Flow igpm
June 14/77	20	200
July 26/77	20	300
Sept 7/77	20	200
Oct 18/77	2	20
May 2/78	4	50
June 13/78	4	50
July 25/78	5	60
Sept 7/80	3	40
Oct 17/78	5	70

Discharge Estimates: Stream Number 0-1

Date	L/sec	Flow igpm
Oct 18/77	20	200
May 2/78	40	500
June 13/78	30	400
July 25/78	20	300
Oct 17/78	12	150

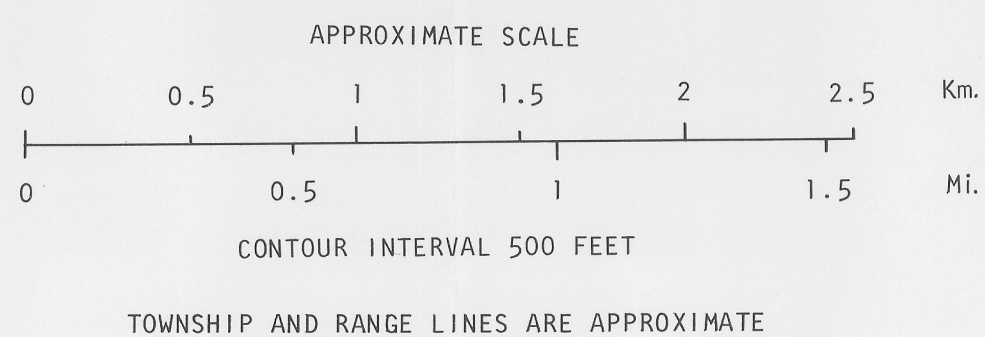
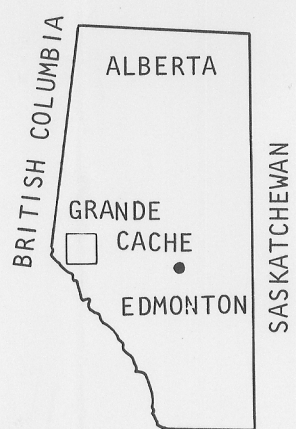
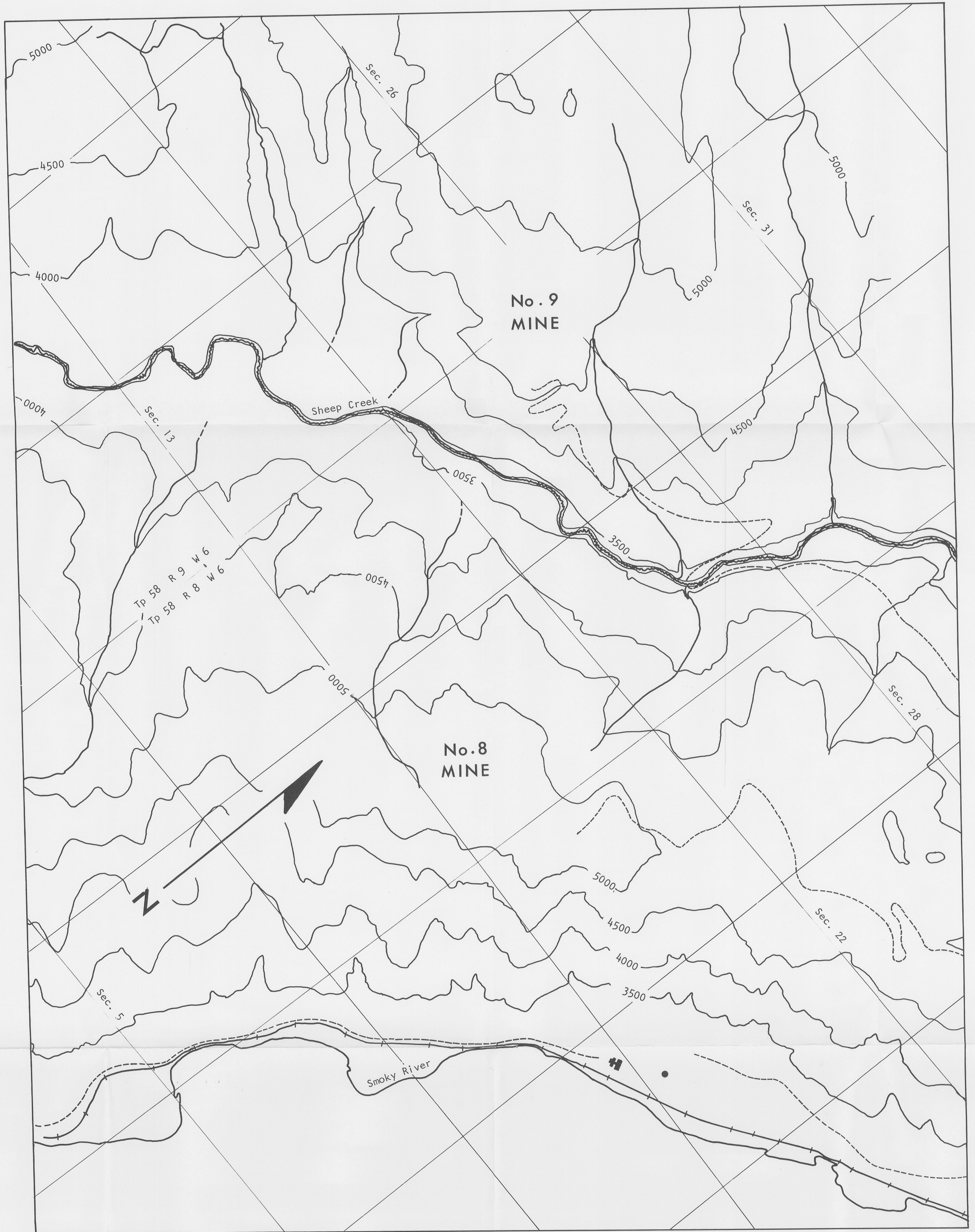


FIGURE 1. Location, topography, and drainage of study area.



FIGURE 2. Location of spoil area, roads and coal-handling facilities in No. 8 and No. 9 Mines



FIGURE 3. Location of water sampling sites in No. 8 and No. 9 Mines.