GROUND WATER-SURFACE WATER RELATIONS IN THE FLATHEAD RIVER VALLEY NEAR THE PROPOSED CABIN CREEK COAL MINE, BRITISH COLUMBIA, CANADA

By Joe A. Moreland, Hugh Liebscher, Wayne A. Van Voast, and R. D. Feltis

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CONVERSION FACTORS

The following factors can be used to convert the International System (SI) of units to inch-pound units.

Multiply SI unit	By	To obtain inch-pound unit
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
megagram per cubic meter	1,359	ton per acre-foot (ton/acre-ft)

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ABSTRACT

The area of the proposed Cabin Creek coal mine was studied to obtain information needed to respond to questions posed by the International Joint Commission advisors concerning water resources near the international border. Specific interest focused on determining the extent and character of surficial material in the Flathead River valley, identifying gaining and losing reaches of the river and major tributaries, and documenting ambient water quality at selected sites.

Quaternary alluvial streambed deposits consisting of clean sand, gravel, and boulders underlie the valleys of the Flathead River and major tributaries. Thickness of the alluvial deposits depends on depth to underlying Quaternary glacial deposits or Tertiary bedrock. The alluvial deposits in the Flathead River valley thin to a veneer of cobbles near the mouth of Couldrey Creek.

Measurements of streamflow at 20 sites in the Flathead River valley indicate that water discharges from the alluvial deposits to most of the tributaries and to the river near the proposed mine. The Flathead River gained 0.87 cubic meter per second (31 cubic feet per second) of flow near Howell Creek. The Flathead River and Couldrey Creek gained about 0.81 cubic meter per second (28.5 cubic feet per second) of flow near the mouth of Couldrey Creek where bedrock crops out in the streambeds. Bedrock outcrops effectively interrupt the alluvial aquifer system between the proposed mine site and the international border. The Flathead River lost 0.87 cubic meter per second (31 cubic feet per second) of flow between the bedrock outcrops and the international border; this streamflow loss enters alluvial deposits and flows across the international border as subsurface flow.

Analysis of samples from 18 stream sites and 1 spring site indicates general trends in water quality. In Howell Creek, concentrations of calcium, magnesium, and sulfate increased slightly downstream. Conversely, samples from Sage and Couldrey Creeks indicate downstream increases in concentrations of calcium, magnesium, and alkalinity, but decreases in concentrations of sulfate. Water quality of Cabin Creek was relatively stable through the sampled reach. Decreased concentrations of calcium and alkalinity in the Flathead River reflect the effect of inflow from Couldrey Creek and the ground-water inflow documented by streamflow measurements.

INTRODUCTION

In 1975, Sage Creek Coal Limited submitted a plan to develop an open-pit coal mine in British Columbia near the international border. The proposed mine site is located on and near Cabin Creek, a tributary to Howell Creek, which flows into the Flathead River (North Fork Flathead River in the United States) about 10 km (6 mi) north of the border (fig. 1). Early in 1984, the British Columbia Ministry of Environment granted Stage II approval-in-principal (with conditions) to Sage Creek Coal Limited to proceed with their plans for Stage III approval.

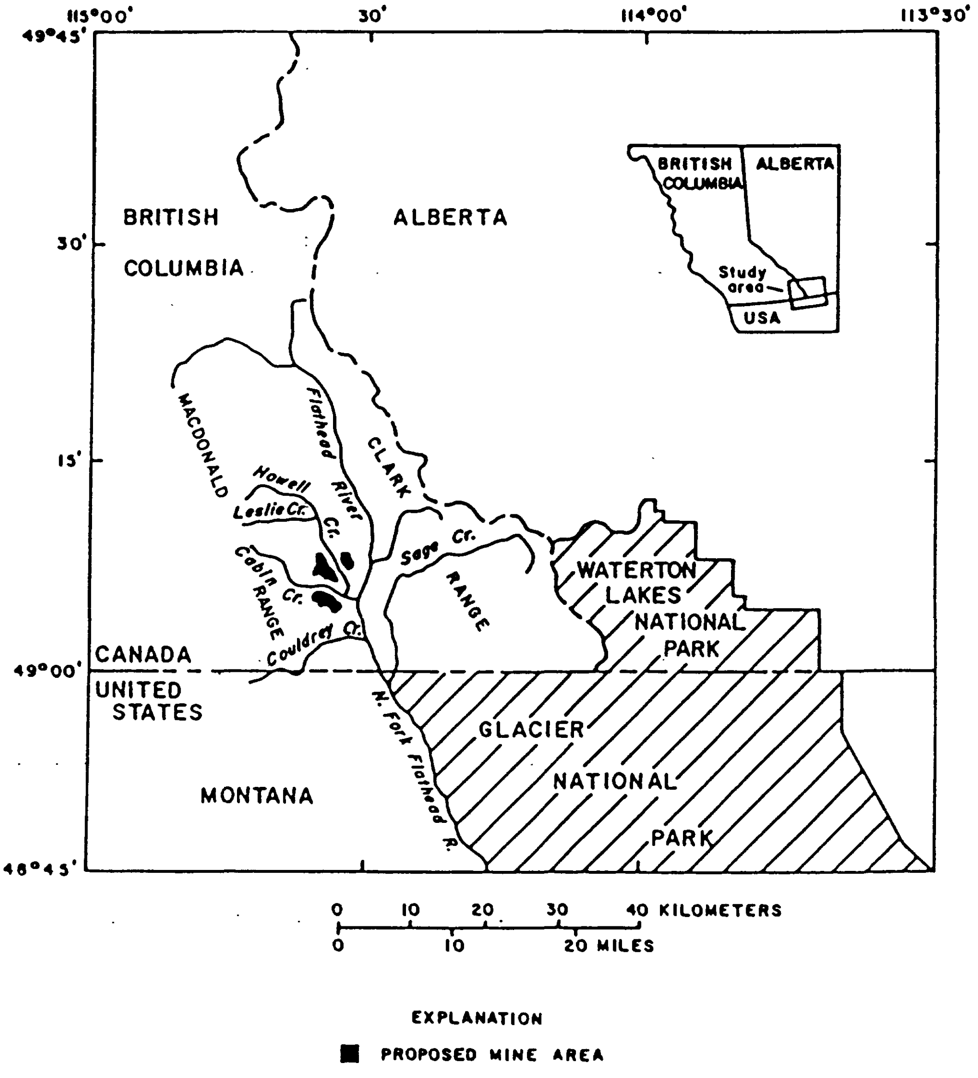

Figure 1.--Location of proposed coal mine.

Shortly thereafter, the governments of the United States and Canada forwarded a reference to the International Joint Commission requesting the Commission to conduct an investigation and prepare a report pursuant to Article IX of the Boundary Waters Treaty of 1909 regarding the potential transboundary effects of the coal mine. The reference requested that the Commission investigate and report on:

1. The present state of water quality and quantity at the border (including fluctuations) and the current water uses (including water-dependent uses, such as recreation) in the Flathead River basin;

2. The nature, location, and significance of fisheries currently dependent on the waters of the Flathead River and potentially affected tributaries, Howell and Cabin Creeks;

3. The effects on present water quality and quantity at the international border and the consequent effects on current water uses (including water-dependent uses, such as recreation) that would result from the construction, operation, and post-mining reclamation of the proposed Cabin Creek coal mine; and

4. Such other matters as the Commission may deem appropriate and relevant to water quality and quantity at the international border (including downstream effects in the United States) as occasioned by the proposed Cabin Creek Coal Mine.

The Commission established a Flathead River International Study Board to undertake the necessary investigations. The Board then developed technical committees to address specific topics including: (1) mine development, (2) water quality and quantity, (3) water use, and (4) biological resources.

During the early stages of the Commission's deliberations, questions were raised about potential transboundary ground-water problems. The questions concerned the potential for degraded mine water to migrate underground to points across the international border. Because the Commission's terms of reference did not specifically identify transboundary ground-water-quality issues, they requested that United States and Canadian Commission advisors consider the problem to determine if the topic should be included in the Commission's overall review.

The Commission advisors met in Vancouver, British Columbia, on May 22, 1985, with members of the Flathead River International Study Board and technical representatives from the Environment Canada, the Montana Bureau of Mines and Geology, and the U.S. Geological Survey. The advisors posed three questions concerning ground-water resources: (1) Is there a shallow, alluvial, ground-water system that represents a channel to the international border that could be a conduit for transboundary flow; (2) are there faults or bedrock aquifers that affect ground-water flow at the international border; and (3) to what extent, if any, will contaminated surface water at the mine affect shallow ground-water resources at or south of the international border.

Purpose and Scope

A plan of study was developed to obtain information needed to respond to the questions. Specifically, the group agreed that onsite studies were needed to determine the extent and character of surficial material in the Flathead River valley, to document gaining and losing reaches of the river and its major tributaries, and to collect ambient water-quality information at selected sites.

The scope of the work was limited to reconnaissance-level investigations that would rely mostly on available information and brief onsite visits. During the week of July 23, 1985, the technical team and the Commission advisors conducted a hydrogeologic reconnaissance to evaluate the relation between the surficial deposits and semiconsolidated and consolidated rocks in the area and to select streamflow measuring sites for future investigation of streamflow gains and losses. Adverse weather conditions and logistics caused postponement of the streamflow measurements and water-quality sampling until the week of August 11, 1986. This report summarizes the information collected during the onsite studies and reports on the conclusions reached by the ground-water study team.

Participants

This study was conducted under the general direction and guidance of Andrew L. Hamilton, Senior Environmental Advisor, International Joint Commission, Canadian Section, and Donald Parsons, Engineering Advisor, International Joint Commission, United States Section. The ground-water study committee included Hugh Liebscher, Environment Canada; Wayne A. Van Voast, Montana Bureau of Mines and Geology; R. D. Feltis (retired), U.S. Geological Survey; and Joe A. Moreland, U.S. Geological Survey.

The streamflow gain and loss study team included the above members, with the exception of Mr. Van Voast, and water-quality and surface-water specialists from Environment Canada and the U.S. Geological Survey. Water-quality specialists were Steven Sheehan, Environment Canada, and J. Roger Knapton, U.S. Geological Survey. Surface-water specialists were Richard Lopaschuk, Environment Canada, and Ronald R. Shields, U.S. Geological Survey. Christopher Pharo, sedimentologist, Environment Canada, also participated in the study.

GEOLOGIC OBSERVATIONS

The coal deposits of interest to Sage Creek Coal Limited occur within a localized thrust remnant. They have been preserved from erosion by subsequent normal faulting between two resistant thrust blocks, the eastern Clark Range and the western MacDonald Range. The strata form an east-dipping monocline with an average dip of about 30° and have a general north-trending strike. The strata extend eastward downdip beneath the floor of the Flathead River valley and are truncated along the western edge of the valley by the Flathead fault (Noble and others, 1984, p. 5).

The coal beds occur in the lower part of the non-marine Jurassic-Cretaceous Kootenay Group. The Kootenay Group unconformably overlies the marine Jurassic Fernie Group, and is disconformably overlain by the non-marine Cretaceous Blairmore Group. The Tertiary Kishenehn Formation unconformably overlies Cretaceous strata, and Quaternary glacial and alluvial deposits mantle the Kishenehn Formation (Noble and others, 1984, p. 5).

The Jurassic-Cretaceous Kootenay Group includes sandstone, siltstone, shale, and coal. The overlying Cretaceous Blairmore Group includes sandstone, shale, and conglomerate. The Kishenehn Formation is composed of poorly consolidated conglomerate, sandstone, siltstone, and claystone. The pre-Tertiary rocks are exposed along the valley margins. The Kishenehn Formation underlies the Quaternary deposits beneath the valley floor and is exposed along the downstream reach of Couldrey Creek and in the Flathead River bottom near the international border.

The present-day geomorphic and geologic features have been sculpted by glacial activity and fluvial processes. At least four glaciers occupied the area, including the valley glacier in the Flathead River valley, the Sage Creek glacier on the east side of the valley, the Howell Creek glacier, and the Couldrey Creek glacier in the upstream reaches of the Couldrey Creek drainage basin.

The Howell Creek glacier very likely overdeepened the Howell Creek valley by gouging into the poorly consolidated and easily scoured Kishenehn Formation. Test holes would be needed to document the depth of scour.

The downstream part of Couldrey Creek valley is not U-shaped, which indicates that the Couldrey Creek glacier did not scour into the Kishenehn Formation. Instead, ice may have filled the bottom of the present-day valley and may have been overridden by the Flathead River valley glacier. Exposures of poorly consolidated Kishenehn Formation near the mouth of Couldrey Creek lend support to that hypothesis. The Kishenehn Formation remains as a predominant feature along the western margin of the Flathead River valley near Couldrey Creek.

The valley glacier in the Flathead River valley probably was less than 3 km, (2 mi) wide north of Howell Creek, but broadened to more than 15 km (10 mi) wide near the international border. The glacier did not erode the underlying Kishenehn Formation as deeply near the international border as it may have in the vicinity of Howell Creek. Consequently, the present-day channel of the Flathead River is incised in the Kishenehn Formation, which is clearly exposed along the banks and in the river bottom at several locations near the international border.

The unconsolidated surficial materials overlying the Tertiary bedrock are a complex assortment of glacial, fluvial, and (perhaps) eolian deposits. No attempt was made during the reconnaissance-level study to map the various units. The units that were identified have been grouped into the several types of deposits.

1. A discontinuous veneer of gray eolian or flood-plain silt or both overlies valley-floor sediments. The unit is extensive and is exposed along the Flathead River primarily on the east bank upstream from the junction with Couldrey Creek. Maximum observed thickness was about 2 m (6 ft).

2. Coarse, clean sand and gravel appear to be extensive along Howell Creek from the headwaters to the junction with the Flathead River. Minor exposures of similar materials were observed along the Flathead River. Thickness of the unit is unknown.

3. Poorly sorted sand and gravel in a matrix of silt or clay or both are extensive along Couldrey Creek upstream from the mouth and appear to be more extensive than the clean sand and gravel along both the Flathead River and in road-cut exposures.

4. Boulder pavements are localized on the streambeds of Howell Creek and the Flathead River. These rocks probably are eroded from glacial till.

5. Glacial till is locally exposed along the Flathead River and overlies Tertiary bedrock. The till primarily is light gray and has a large content of mixed silt and clay. Thickness of the unit is unknown.

6. Silty clay and clayey silt are thick and areally extensive in Couldrey Creek valley. The unit appears to be massive, but has exposed bedding structure. Observed thickness is about 30 m (100 ft). Areal extent of the unit is unknown.

The distribution of the various unconsolidated units is dependent largely on the glacial history of the area and subsequent erosion, deposition, and general reworking of sediments by the Flathead River and its tributaries. Glacial till is present throughout the area and can be seen along valley margins and in road cuts on interstream ridges. In some low-lying areas, kame-like surfaces indicate that the tills have not been reworked substantially by streams. The thickness of the glacial till generally is unknown, being dependent on depth to underlying Tertiary bedrock.

Most streams in the area have developed relatively flat alluvial fans with apexes at the flanks of the Flathead River valley. The fans probably overlie the glacial deposits except where the deposits have been removed by stream erosion.

Alluvial streambed deposits underlie the floors of major tributaries and the Flathead River valley. The deposits are composed of clean sand, gravel, and boulders. The deposits extend across the meander bands of the streams and are thought to be relatively thin. Most streams in the area appear to be downcutting through associated alluvial fans, which probably limits the lateral extent of the flood-plain deposits. Thickness of the alluvial deposits depends on depth to underlying tills or Tertiary bedrock. Near the international border, the Kishenehn Formation is exposed in the Flathead River channel, indicating that thickness of the alluvial deposits is limited to a veneer along the streambed.

GROUND-WATER OBSERVATIONS

Water in the pre-Tertiary consolidated rocks occurs in porous sandstone units and in fractures and joints. The density of fractures and joints probably is greatest in faulted zones, which would provide a preferential flow path for ground water. Determination of direction and rates of flow in the permeable zones in the pre-Tertiary rocks would require extensive drilling and testing beyond the scope of this reconnaissance study. However, pumping tests in holes drilled into these older rocks indicate that fracture permeability is small, which would restrict rates of flow (Flathead River International Study Board, Mine Development Committee, written commun., 1986).

Water levels in test holes in the pre-Tertiary rocks stand at or above land surface in the valley. This condition indicates that water in these older rocks is confined by overlying formations and, therefore, is hydraulically separated from water in the surficial alluvial deposits. Direction of vertical movement is upward through the confining layers which, under present hydraulic-head conditions, would preclude downward migration of water into the pre-Tertiary rocks in the study area.

The Tertiary Kishenehn Formation is composed of poorly consolidated sediments including conglomerate, sandstone, and siltstone. Coarse-grained deposits were observed north of the proposed mine area, but exposures in the study area and near the international border were predominantly fine-grained siltstone and claystone. These fine-grained deposits are relatively impermeable and function as the confining unit overlying the older fractured rocks.

Faults in poorly consolidated rocks generally do not form open fractures or joint systems. Instead, the faults produce a fine-grained gouge material along the slip face. Any fractures associated with the fault would tend to heal, particularly in rocks at depth. Therefore, fault zones through the Kishenehen Formation probably would be barriers to ground-water flow rather than conduits.

Because the alluvial fans and flood-plain deposits probably have values of hydraulic conductivity several orders of magnitude larger than those of the glacial till, mixed silt and clay deposits, and consolidated rocks, they transmit most of the ground-water flow in the area. The direction of flow in the sand and gravel aquifers generally is from the margins of the Flathead River valley to the river, with a substantial downvalley component of flow. Although no test wells are available to map potentiometric surfaces, evidence from streamflow measurements and the location of springs along the river banks confirm this hypothesis. Several springs were observed along the Flathead River issuing from contact zones between the more permeable flood-plain, outwash, and alluvial-fan deposits and the underlying glacial till, mixed silt and clay deposits, and Tertiary bedrock.

GAIN OR LOSS IN STREAMFLOW

To determine gain or loss in streamflow in selected reaches of the Flathead River and its major tributaries, several discharge measurements were made on August 12-13, 1986. Measurements were made by a team of hydrographers, including U.S. Geological Survey and Water Survey of Canada personnel, using standard measuring techniques (Rantz and others, 1982). At most sites, measurements were made by the Canadian hydrographer and notes were recorded by the United States representative. At a few locations, for expediency, measurements were made and notes were recorded by U.S. Geological Survey personnel. A helicopter was used to gain access to remote sites and to minimize travel time between measuring sites.

No precipitation fell in the study area for several days preceding the measurement period, although thunderstorms had been observed in the general area. Unsettled weather conditions during the measurement period caused concern that a runoff-producing storm might affect streamflow in the study area. To preclude such a storm rendering the study invalid, measurements of the critical west-side tributaries were made on August 12. The study team reasoned that a local thunderstorm might not substantially affect flow in the Flathead River even if runoff affected flows in tributary streams.

On the evening of August 12, rain fell in the study area. Based on visual observations, no streams were appreciably affected although a minor stage rise was recorded at the Flathead River gage near the international border (site F-5). The stage change was considered to be insignificant because the equivalent change in discharge was less than measurement error expected from standard streamflow-measuring techniques.

The measuring sites are located in figure 2 and listed in table 1. No measurements of flow were made at sites C-3 (mouth of Cabin Creek) or G-1 (spring). Measurements were made near the valley margins, at the junctions of streams, and at intermediate sites to document gaining and losing reaches of the river and its tributaries. Measuring sites were initially selected by examining maps of the area, but actual measurement sites were selected onsite based on channel and flow conditions. Careful selection of sites to minimize measurement error was considered to be more important than obtaining measurements at preselected sites based only on map or aerial interpretations. With the exception of the measurement made at the mouth of Couldrey Creek (site Co-2), measurement error at all sites was

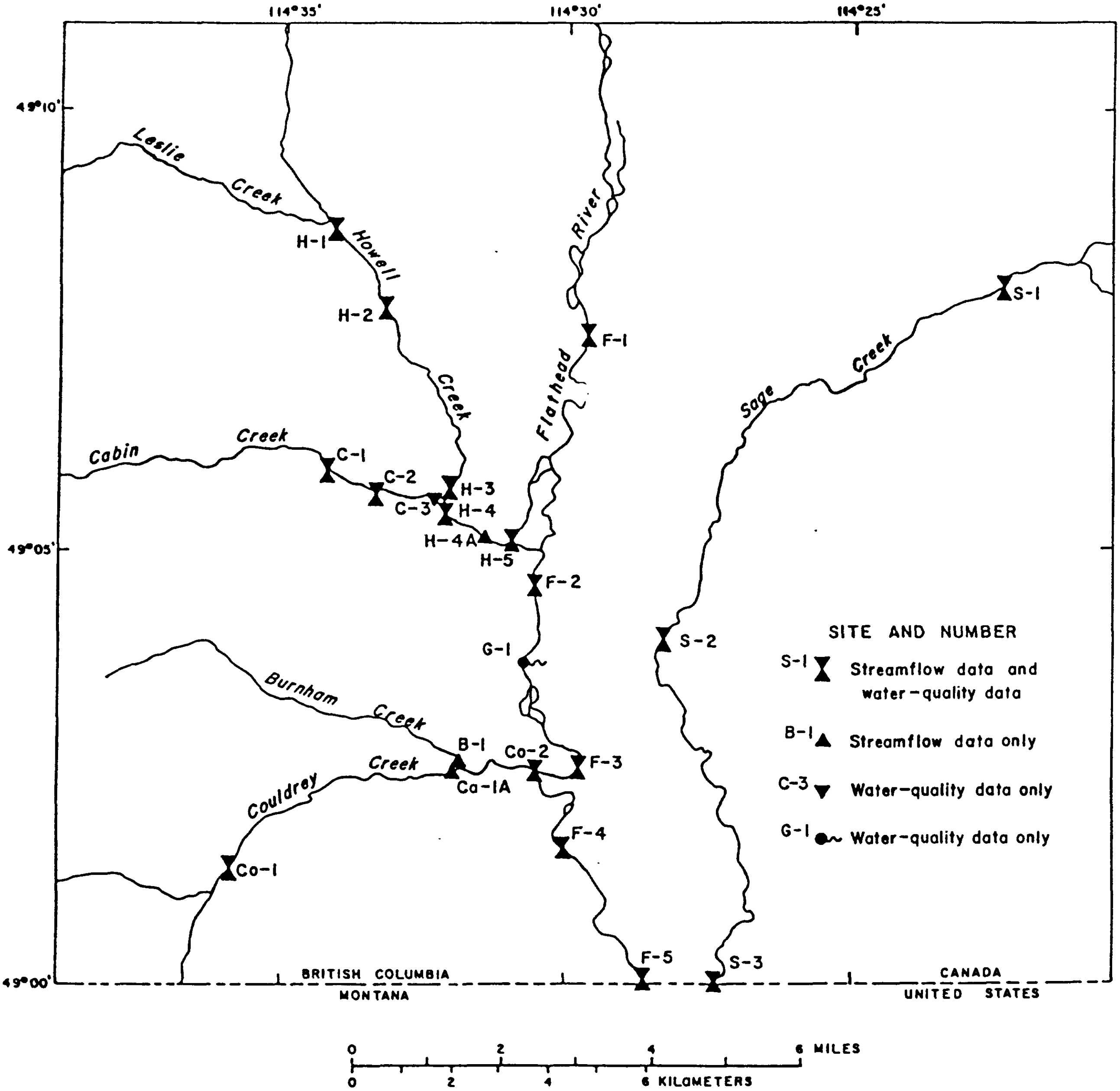

Figure 2.--Location of data-collection sites.

judged to be less than 5 percent and probably less than 2 percent. At the mouth of Couldrey Creek, the steep gradient of the stream channel and coarse bed material may have resulted in a measurement with an error of as much as 10 percent.

The results of the stream gain and loss study are summarized in table 1 and described in the following narrative:

1. Flow in Howell Creek at the most upstream measuring site downstream from the junction with Leslie Creek (site H-1) was 1.43 m^3/s (50.5 ft^3/s). The creek gained 0.07 m^3/s (2.5 ft^3/s) from that site to the measuring site just upstream

from the junction with Cabin Creek (site H-3). Downstream from Cabin Creek (site H-4), Howell Creek meanders and braids over coarse, clean alluvial material. From the mouth of Cabin Creek to the Flathead River road crossing (site H-4A), the creek lost 0.15 m^3/s (5.3 ft^3/s). Downstream from the road crossing, the creek regained 0.03 m^3/s (1.0 ft^3/s) before entering the Flathead River (site H-5). The flow in Howell Creek at the mouth was 1.91 m^3/s (67.4 ft^3/s).

2. Flow in Cabin Creek (site C-1) measured about 1 km (0.6 mi) upstream from the Environment Canada gaging station (site C-2) was 0.484 m^3/s (17.1 ft^3/s). The creek lost about 0.02 m^3/s (0.7 ft^3/s) between site C-1 and the gaging station (site C-2). Flow in Cabin Creek at the mouth, calculated as the flow difference between measuring sites on Howell Creek upstream and downstream from the junction with Cabin Creek (sites H-3 and H-4), was 0.53 m^3/s (18.7 ft^3/s). Thus, Cabin Creek gained about 0.07 m^3/s (2.3 ft^3/s) between the gaging station (site C-2) and the mouth.

3. Flow in Couldrey Creek at the Environment Canada gaging station (site Co-1) was 0.932 m^3/s (32.9 ft^3/s). The creek apparently gained 0.005 m^3/s (0.2 ft^3/s) between the gaging station and the Flathead River road crossing (site Co-1A). Couldrey Creek flows over exposures of Kishenehn Formation near the road crossing and water in the alluvial deposits in the valley is forced to the surface in this area. Taking into account 0.036 m^3/s (1.28 ft^3/s) of inflow from Burnham Creek (site B-1), Couldrey Creek apparently gained about 0.33 m^3/s (11.5 ft^3/s) between the road crossing (site Co-1A) and the mouth (site Co-2). Discharge at the mouth was 1.30 m^3/s (45.9 ft^3/s) but, as mentioned previously, the measurement could have been in error by as much as 10 percent.

4. Flow in Sage Creek near the margin of the Flathead River valley (site S-1) was 0.800 m^3/s (28.2 ft^3/s). The stream gained about 0.038 m^3/s (1.4 ft^3/s) between site S-1 and site S-2 located about midway to the international border. The stream gained 0.009 m^3/s (0.3 ft^3/s) from site S-2 to the measuring site near the international border (site S-3). Because the stream braids into several channels between the international border and the junction with the North Fork Flathead River in the United States, a measurement was not made near the mouth.

5. Flow in the Flathead River was measured upstream from the proposed mine site near the Sage Creek road crossing (site F-1). Flow was 4.53 m^3/s (160 ft^3/s). From the upstream site to the measuring site downstream from the junction with Howell Creek (site F-2) the river gained about 0.87 m^3/s (31 ft^3/s) in addition to the inflow from Howell Creek. From site F-2 to the measuring site upstream from the mouth of Couldrey Creek (site F-3), the river apparently lost 0.15 m^3/s (5 ft^3/s) of flow. The difference in flow between the two sites was about 2 percent of the total flow, which is comparable to the possible measurement error. From site F-3 upstream from the mouth of Couldrey Creek to site F-4 where the river crosses a bedrock outcrop downstream from the mouth of Couldrey Creek, the flow increased about 1.8 m^3/s (63 ft^3/s). Assuming that the discharge measurement at the mouth of Couldrey Creek was accurate, this gain indicates about 0.48 m^3/s (17 ft^3/s) of inflow in addition to the contribution from Couldrey Creek. Discounting the measurement at the mouth of Couldrey Creek, the total increase in flow to the downstream reach of Couldrey Creek and the Flathead River between site F-3 and the bedrock outcrop (site F-4) was about 0.82 m^3/s (29 ft^3/s). Downstream from the bedrock outcrop at site F-4, the river lost 0.87 m^3/s (31 ft^3/s) before crossing the international border (site F-5).

Thus, based on the data, the streams in the area of the proposed coal mine (with the exception of a short reach of Howell Creek downstream from the mouth of Cabin Creek) gained water as they flowed across the valley toward the Flathead River. The river gained flow in the vicinity of Howell Creek and near the mouth of Couldrey Creek. The gain in flow near Howell Creek probably is discharge from the alluvial deposits underlying Howell Creek valley. Gain in flow in the river and Couldrey Creek near the mouth of the creek coincides with outcrops of the Kishenehn Formation and probably represents ground water that is forced to the surface by the bedrock.

Downstream from the junction with Couldrey Creek, the river lost flow to the alluvial flood-plain deposits north of the international border. This water flows downvalley in the alluvial material and crosses the international border as subsurface flow.

The water that is lost from the river between sites F-4 and F-5 is a composite mixture of all inflows to the river upstream from site F-4 including tributary stream inflow and ground-water inflow. About 0.87 m^3/s (31 ft^3/s) of the 8.95 m^3/s (316 ft^3/s) of flow at site F-4 entered the river as ground-water inflow between sites F-1 and F-2. Thus, the water that percolates into the ground and flows across the international border as subsurface flow contains a substantial component that originated as ground-water flow through the proposed mine area. The proportion of inflow that comes from the mine area would decrease as flow in the river increases during runoff periods; however, during the base-flow period of this study, about 10 percent of the river flow entered as ground-water discharge from the Howell Creek area. Any contaminants that enter the river from upstream sources would be an integral part of the river flow at site F-4 and, therefore, would be a component of the subsurface flow downstream from that point.

WATER-QUALITY INVESTIGATION

Water-quality samples were collected by the U.S. Geological Survey at 19 sites--18 stream sites and 1 spring site (see fig. 2). No samples were collected at site H-4A (Howell Creek at Flathead River road), at site Co-1A (Couldrey Creek at Flathead River road), or at site B-1 (Burnham Creek at mouth). Environment Canada also collected samples at five of the sites to provide comparison between Canadian and United States sampling techniques and analytical methods. The U.S. Geological Survey split 4 of the 19 samples to obtain duplicate sets of samples for quality-control purposes. All U.S. Geological Survey samples were analyzed at the Geological Survey laboratory in Denver, Colorado. Environment Canada samples were submitted in triplicate to the National Water Quality Laboratory, Burlington, Ontario, for analysis.

The U.S. Geological Survey collected samples with a DH-48 hand-held sampler using the equal-width increment method where possible (Guy and Norman, 1970). Where stream depth was insufficient to allow use of the DH-48 sampler, dip samples were collected near the midpoint of flow. Environment Canada filled sample bottles by immersion near the center of flow.

A U.S. Geological Survey mobile laboratory was positioned near the center of the study area. All samples were flown to the mobile laboratory, where they were processed and preserved for shipment to the laboratories. Measurements of specific conductance and pH were made for U.S. Geological Survey samples at the mobile laboratory.

Samples submitted to the Geological Survey laboratory were analyzed for common ions, nutrients, and selected trace elements. Results are listed in table 2. Environment Canada samples were analyzed for similar constituents. Results are listed in table 3.

The two data sets are similar. Only minor differences exist between common ions. The disagreements can be attributed to minor differences in analytical procedures and sampling techniques. Environment Canada samples do not include a measurement of pH made at the mobile laboratory. Laboratory values of pH were consistently less than those for the U.S. Geological Survey samples measured at the mobile laboratory. These differences can be attributed to subtle changes in the samples between field collection and laboratory analysis. Several Environment Canada analyses contained much larger concentrations of trace elements than U.S. Geological Survey analyses. The large differences can be attributed to more complete digestion procedures used by Environment Canada.

The several water samples from each of the major tributaries have characteristics that make samples from each tributary identifiably different from the others. Even though the sample sets are different, many of the differences are relatively subtle. The notable differences include: (1) Water samples from Sage Creek contained about one-half the concentration of calcium as water samples from the Flathead River, Cabin Creek, and Howell Creek; (2) water samples from Sage Creek contained nearly twice the concentration of sulfate as water samples from Cabin Creek; (3) water samples from Couldrey Creek contained smaller concentrations of most major ions than water samples from Cabin and Howell Creeks; and (4) water samples from Howell Creek contained smaller concentrations of sodium than water samples from any other tributaries.

Close inspection of the sample data from each tributary generally indicated downstream trends in selected constituents that indicate inflow of water with different quality characteristics. Samples from Howell Creek, for example, indicate slight increases in concentrations of calcium, magnesium, and sulfate in a downstream direction. Conversely, samples from Sage and Couldrey Creeks indicate downstream increases in the concentrations of calcium, magnesium, and alkalinity, but decreases in concentration of sulfate. The concentrations of major ions in samples from Cabin Creek were relatively stable through the sampled reach.

Where the streams join, mixing of water types generally can be detected between the upstream and downstream samples. Concentrations of magnesium and sulfate in Howell Creek indicate the effect of mixing with water from Cabin Creek, which contains larger concentration of those constituents. Decreased concentrations of calcium and alkalinity in the Flathead River between sites F-3 and F-4 indicate the effect of inflow from Couldrey Creek and the ground-water inflow documented by streamflow measurements.

Because most of the water-quality differences are small, quantitative estimates of the quality of inflow waters are difficult to make. At most sites, measured differences in flow were almost within the margin of error for discharge measurements. Using these small flow differences--and the equally small water-quality differences between sites--to calculate quality of inflow water yields constituent concentrations that are variable and imprecise. However, where inflow is substantial, calculations can provide a reasonable approximation of constituent concentrations in the inflow water.

Instantaneous loads of the major ions were calculated for the water samples from Howell Creek (site H-5) and the Flathead River upstream from the junction of the two streams (site F-1). The instantaneous loads were compared to the instantaneous loads in the Flathead River just downstream from the junction with Howell Creek (site F-2) and the differences were attributed to inflow of ground water. Based on the calculated inflow rate of 0.87 m^3/s (31 ft^3/s) from table 1, the calculations yielded a calcium concentration of 50 mg/L (milligrams per liter), magnesium concentration of 10 mg/L, sodium concentration of 1.9 mg/L, alkalinity of 167 mg/L, chloride concentration of 0.2 mg/L, and sulfate concentration of 4.3 mg/L. These concentrations compare remarkably well with concentrations of constituents in the sample of ground water from site G-1 listed in table 2.

Similar calculations for inflow to the Flathead River near the mouth of Couldrey Creek yielded a calcium concentration of 46 mg/L, magnesium concentration of 10 mg/L, sodium concentration of 0.9 mg/L, alkalinity of 150 mg/L, chloride concentration of 0.2 mg/L, and sulfate concentration of 5.1 mg/L. These concentrations were based on quality and flow measurements at the Couldrey Creek gage (site Co-1) and at the Flathead River upstream from and downstream from the mouth of Couldrey Creek (sites F-3 and F-4). The data from the measurements made at the mouth of Couldrey Creek (site Co-2) were not used because of the inaccuracy in the flow measurement at that site.

Concentrations of trace elements and nutrients in U.S. Geological Survey samples generally were very small and, in most instances, less than laboratory detection limits. Larger concentrations of trace elements in the Environment Canada samples can be attributed to differences in sampling and analytical techniques. With the exception of phosphorus, concentrations did not differ greatly between streams nor did they indicate a progression of downstream dilution or enrichment. Orthophosphorus concentrations in samples from Cabin Creek were significantly larger than in other samples, which may reflect the effect of phosphatic strata in the headwaters area described by Price (1962).

SUMMARY AND CONCLUSIONS

Onsite observations, literature reviews, measurements of streamflow, and analyses of water samples provide the following information on ground water-surface water relations in the proposed Cabin Creek coal mine area:

1. Ground water occurs in porous sandstone and in fractures and joints in the pre-Tertiary consolidated rocks. Water in these older rocks is confined by overlying fine-grained material and is under artesian pressure that raises water levels in test holes to the land surface or above in the valley area. Fracture permeability and flow rates along faulted zones are small.

2. The Kishenehn Formation is composed of poorly consolidated, fine-grained sediments in the proposed mine area and near the international border. The formation is a confining layer overlying the older pre-Tertiary consolidated rocks. Faults in the Kishenehn Formation probably are not conduits for ground-water flow.

3. Alluvial material is an important aquifer in the area and transmits water across the valley to the Flathead River. Water discharges from the alluvial deposits to most of the streams and to the Flathead River near the proposed mine.

4. The alluvial deposits in the Flathead River valley thin to a veneer of cobbles near the mouth of Couldrey Creek. Ground water discharges into Couldrey Creek and the Flathead River where the alluvial deposits pinch out at the bedrock exposures in the streambeds.

5. The Flathead River loses water to the alluvium downstream from outcrops of the Kishenehn Formation near the mouth of Couldrey Creek. This water flows southward as subsurface flow through the alluvial material underlying the Flathead River valley north of the international border.

6. Water-quality changes in the Flathead River near the mouth of Howell Creek and near the mouth of Couldrey Creek indicate the effects of ground-water inflow. Calculated concentrations of dissolved constituents for the inflow are similar to measured concentrations of dissolved constituents in a sample of ground water from a spring.

On the basis of onsite observations and literature review, the ground-water study committee reached the following conclusions concerning the specific questions posed by the Commission advisors:

1. Is there a shallow, alluvial, ground-water system that represents a channel to the international border that could be a conduit for transboundary flow?

Bedrock exposures of the Kishenehn Formation near the mouth of Couldrey Creek truncate alluvial deposits in the Flathead River valley. The alluvial material thins to a veneer of cobbles at the outcrops and is virtually terminated between the proposed mine site and the international border. Alluvial deposits in the Flathead River valley south of the outcrops transmit subsurface flow across the international border but do not represent an uninterrupted conduit of permeable material between the proposed mine site and the international border.

2. Are there faults or bedrock aquifers that affect ground-water flow at the international border?

Faulting in the pre-Tertiary consolidated rocks has produced fractures and joints that may provide preferential ground-water flow paths. However, the fracture permeability is small and fractures do not constitute a major flow path. Sandstone units in these older rocks also transmit water. The bedrock aquifers are confined by overlying fine-grained deposits in the proposed mine area. Hydraulic heads in the bedrock aquifers are at or above land surface, which would preclude downward migration of water under current hydrologic conditions. Determination of direction and rates of flow in fractured zones and deeply buried sandstone aquifers would require extensive drilling and testing.

3. To what extent, if any, will contaminated surface water at the mine affect shallow ground-water resources at or south of the international border?

Water in the Flathead River recharges the alluvial deposits between Couldrey Creek and the international border. Potentially degraded surface water at the mine would affect water resources in the alluvial aquifer at the international border to the same extent that it affects water quality in the Flathead River downstream from the mine area. The degree of degradation would be dependent on the rate and quality of flow of the potentially degraded water and the rate and quality of flow in the Flathead River at the time of inflow.

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Table 1.--*Gain or loss in streamflow*

[Abbreviations: m^3/s, cubic meter per second; ft^3/s, cubic feet per second; --, no data]

Site No. (fig.2)	Location	Date (month-day-year)	Discharge		Gain (+) or loss (-) from upstream measuring site	
			m^3/s	ft^3/s	m^3/s	ft^3/s
F-1	Flathead River at Sage Creek road crossing.	08-13-86	4.53	160	--	--
H-1	Howell Creek downstream from mouth of Leslie Creek.	08-12-86	1.43	50.5	--	--
H-2	Howell Creek upstream from gage.	08-12-86	1.49	52.6	+0.06	+2.1
H-3	Howell Creek at gage	08-12-86	1.50	53.0	+.01	+.4
C-1	Cabin Creek upstream from gage	08-12-86	.484	17.1	--	--
C-2	Cabin Creek at gage	08-12-86	.465	16.4	-.02	- .7
H-4	Howell Creek downstream from mouth of Cabin Creek.	08-12-86	2.03	71.7	+.06	+2.3
H-4A	Howell Creek at Flathead River road.	08-13-86	1.88	66.4	-.15	-5.3
H-5	Howell Creek at mouth	08-12-86	1.91	67.4	+.03	+1.0
F-2	Flathead River downstream from mouth of Howell Creek.	08-13-86	7.31	258	+.87	+31
F-3	Flathead River upstream from mouth of Couldrey Creek.	08-13-86	7.16	253	-.15	-5
Co-1	Couldrey Creek at gage	08-12-86	.932	32.9	--	--
Co-1A	Couldrey Creek at Flathead River road.	08-13-86	.937	33.1	+.005	+.2
B-1	Burnham Creek at mouth	08-13-86	.036	1.28	--	--
Co-2	Couldrey Creek at mouth	08-12-86	1.30	45.9	+.33	+11.5
F-4	Flathead River downstream from mouth of Couldrey Creek.	08-13-86	8.95	316	+.49	+17
F-5	Flathead River at international border.	08-13-86	8.08	285	-.87	-31
S-1	Sage Creek upstream from edge of Flathead River valley.	08-12-86	.800	28.2	--	--
S-2	Sage Creek upstream from international border.	08-12-86	.838	29.6	+.038	+1.4
S-3	Sage Creek at international border.	08-12-86	.847	29.9	+.009	+.3

Table 2.--*Water-quality analyses, U.S. Geological Survey*

[Five-digit code in column heading is parameter code number. Abbreviations: µS/cm, microsiemens per centimeter at 25 °Celsius; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than detection limit; --, no data]

Site No. (fig.2)	Location	Date	Time	Specific con-duct-ance, onsite (µS/cm) (00095)	Specific con-duct-ance, laboratory (µS/cm) (90095)	pH, onsite (stand-ard units) (00400)	Temper-ature, air (°C) (00020)
C-1	Cabin Creek upstream from gage	08-12-86	1120	292	260	8.5	19.5
C-2	Cabin Creek at gage	08-12-86	1110	263	263	8.4	20.5
C-3	Cabin Creek at mouth	08-12-86	1150	299	266	8.5	20.5
C-3	Cabin Creek at mouth	08-12-86	1151	299	266	8.5	20.5
H-1	Howell Creek downstream from mouth of Leslie Creek.	08-12-86	1010	255	256	8.3	14.0
H-2	Howell Creek upstream from gage	08-12-86	0930	261	262	8.2	13.0
H-3	Howell Creek at gage	08-12-86	0905	266	271	8.1	13.0
H-4	Howell Creek downstream from mouth of Cabin Creek.	08-12-86	0825	269	270	8.2	13.0
H-5	Howell Creek at mouth	08-12-86	0815	268	272	8.1	14.0
H-5	Howell Creek at mouth	08-12-86	0816	268	272	8.1	14.0
S-1	Sage Creek upstream from edge of Flathead River valley.	08-12-86	1450	146	149	8.2	20.5
S-1	Sage Creek upstream from edge of Flathead River valley.	08-12-86	1451	146	149	8.2	20.5
S-2	Sage Creek upstream from international border.	08-12-86	1525	159	162	7.7	23.0
S-3	Sage Creek at international border	08-12-86	1645	191	198	7.8	20.0
Co-1	Couldrey Creek at gage	08-12-86	1305	168	169	8.3	29.0
Co-2	Couldrey Creek at mouth	08-12-86	1355	181	192	8.2	--
G-1	GB Spring	08-12-86	1325	313	310	7.9	28.5
F-1	Flathead River at Sage Creek road crossing	08-13-86	1320	268	270	8.3	21.0
F-2	Flathead River downstream from mouth of Howell Creek.	08-13-86	1120	269	275	8.3	19.0
F-3	Flathead River upstream from mouth of Couldrey Creek.	08-13-86	1030	269	275	8.4	15.0
F-4	Flathead River downstream from mouth of Couldrey Creek.	08-13-86	0930	262	264	8.4	13.5
F-4	Flathead River downstream from mouth of Couldrey Creek.	08-13-86	0931	262	266	8.4	13.5
F-5	Flathead River at international border	08-13-86	0830	259	263	8.4	11.5

Site No. (fig.2)	Date	Time	Temperature, water (°C) (00010)	Turbidity (NTU) (00076)	Hardness (mg/L as CaCO3) (00900)	Hardness, noncarbonate (mg/L CaCO3) (00902)	Calcium, dissolved (mg/L as Ca) (00915)	Magnesium, dissolved (mg/L as Mg) (00925)	Sodium, dissolved (mg/L as Na) (00930)	Percent sodium (00932)	Potassium, dissolved (mg/L as K) (00935)
C-1	08-12-86	1120	11.5	0.6	140	3	36	11	1.2	2	0.4
C-2	08-12-86	1110	10.5	.6	140	4	37	11	1.2	2	.4
C-3	08-12-86	1150	12.5	.4	140	--	36	11	1.3	2	.5
C-3	08-12-86	1151	12.5	.6	140	--	36	11	1.2	2	.5
H-1	08-12-86	1010	7.5	.6	130	--	40	8.1	.6	1	.3
H-2	08-12-86	0930	7.5	.5	140	--	42	8.2	.6	1	.4
H-3	08-12-86	0905	8.0	.5	140	1	44	8.5	.7	1	.4
H-4	08-12-86	0825	8.5	.5	140	--	42	9.2	.8	1	.3
H-5	08-12-86	0815	9.0	.7	140	--	42	9.1	.8	1	.4
H-5	08-12-86	0816	9.0	.7	140	--	41	8.9	.8	1	.4
S-1	08-12-86	1450	16.0	.5	68	9	18	5.7	1.8	5	.5
S-1	08-12-86	1451	16.0	.5	68	9	18	5.7	1.9	6	.5
S-2	08-12-86	1525	17.0	.5	75	3	20	6.0	1.9	5	.6
S-3	08-12-86	1645	16.5	.5	99	3	28	7.0	1.8	4	.5
Co-1	08-12-86	1305	10.5	.7	81	--	22	6.3	.8	2	.4
Co-2	08-12-86	1355	12.5	.5	97	--	27	7.1	1.1	2	.4
G-1	08-12-86	1325	10.0	.8	160	--	49	10	1.3	2	.4
F-1	08-13-86	1320	14.5	.5	140	--	42	8.9	.9	1	.3
F-2	08-13-86	1120	13.5	.4	140	--	43	9.1	1.0	1	.4
F-3	08-13-86	1030	12.0	.6	140	--	43	9.0	.9	1	.4
F-4	08-13-86	0930	11.5	.6	140	--	41	8.8	.9	1	.3
F-4	08-13-86	0931	11.5	.4	140	--	41	8.9	.9	1	.4
F-5	08-13-86	0830	11.5	.5	140	--	41	8.8	.9	1	.4

Site No. (fig.2)	Date	Time	Alkalinity, laboratory (mg/L as CaCO3) (90410)	Carbon dioxide, dissolved (mg/L as CO2) (00405)	Sulfate, dissolved (mg/L as SO4) (00945)	Chloride, dissolved (mg/L as Cl) (00940)	Fluoride, dissolved (mg/L as F) (00950)	Silica, dissolved (mg/L as SiO2) (00955)	Solids, sum of constituents, dissolved (mg/L) (70301)	Solids, dissolved (ton/acre-ft) (70303)	Nitrogen, ammonia total (mg/L as N) (00610)
C-1	08-12-86	1120	132	0.8	10	0.3	0.3	5.0	140	0.19	<0.01
C-2	08-12-86	1110	134	1.0	10	.3	.2	5.0	150	.2	<.01
C-3	08-12-86	1150	136	.8	12	.3	.2	5.0	150	.2	<.01
C-3	08-12-86	1151	136	.8	10	.3	.3	5.0	150	.2	<.01
H-1	08-12-86	1010	135	1.3	3.4	.2	<.1	4.4	140	.19	<.01
H-2	08-12-86	0930	139	1.7	5.1	.2	.1	4.4	140	.2	<.01
H-3	08-12-86	0905	144	2.2	5.0	.5	<.1	4.6	150	.2	<.01
H-4	08-12-86	0825	143	1.7	6.3	.2	.2	4.7	150	.2	<.01
H-5	08-12-86	0815	144	2.2	6.5	.3	.1	4.7	150	.2	<.01
H-5	08-12-86	0816	144	2.2	6.3	.2	.1	4.6	150	.2	<.01
S-1	08-12-86	1450	59	.7	17	.7	<.1	4.6	84	.11	<.01
S-1	08-12-86	1451	59	.7	17	.6	<.1	4.6	84	.11	<.01
S-2	08-12-86	1525	72	2.8	11	.6	<.1	5.3	89	.12	<.01
S-3	08-12-86	1645	96	2.9	9.2	.6	<.1	5.9	110	.15	<.01
Co-1	08-12-86	1305	86	.8	6.3	.3	<.1	5.1	93	.13	<.01
Co-2	08-12-86	1355	97	1.2	6.0	.2	<.1	5.4	110	.14	<.01
G-1	08-12-86	1325	171	4.2	2.4	.3	<.1	7.5	170	.24	<.01
F-1	08-13-86	1320	144	1.4	4.7	.2	<.1	4.5	150	.2	<.01
F-2	08-13-86	1120	147	1.4	5.1	.2	.1	4.6	150	.21	<.01
F-3	08-13-86	1030	148	1.1	5.1	.1	<.1	4.6	150	.21	<.01
F-4	08-13-86	0930	141	1.1	5.2	.2	<.1	4.7	150	.2	<.01
F-4	08-13-86	0931	141	1.1	5.2	.2	<.1	4.7	150	.2	<.01
F-5	08-13-86	0830	140	1.1	5.2	.2	<.1	4.6	150	.2	<.01

Site No. (fig.2)	Date	Time	Nitrogen, nitrate total (mg/L as N) (00615)	Nitrogen, ammonia + organic total (mg/L as N) (00625)	Nitrogen, NO2+NO3 total (mg/L as N) (00630)	Phosphorus, total (mg/L as P) (00665)	Phosphorus, ortho, total (mg/L as P) (70507)	Barium, total recoverable (µg/L as Ba) (01007)	Boron, dissolved (µg/L as B) (01020)
C-1	08-12-86	1120	<0.01	<0.2	<0.10	0.022	0.013	<100	<10
C-2	08-12-86	1110	<.01	<.2	<.10	.021	.012	<100	<10
C-3	08-12-86	1150	<.01	<.2	<.10	.016	.01	<100	<10
C-3	08-12-86	1151	<.01	.2	<.10	.03	.013	<100	<10
H-1	08-12-86	1010	<.01	<.2	<.10	.013	.005	<100	<10
H-2	08-12-86	0930	<.01	<.2	<.10	.011	.004	<100	20
H-3	08-12-86	0905	<.01	<.2	<.10	.011	.003	<100	<10
H-4	08-12-86	0825	<.01	<.2	<.10	.019	.005	<100	<10
H-5	08-12-86	0815	<.01	<.2	<.10	.01	.005	<100	<10
H-5	08-12-86	0816	<.01	.2	<.10	.011	.004	<100	<10
S-1	08-12-86	1450	<.01	<.2	<.10	<.005	.001	200	10
S-1	08-12-86	1451	<.01	<.2	<.10	.005	<.001	100	10
S-2	08-12-86	1525	<.01	<.2	<.10	<.005	<.001	200	10
S-3	08-12-86	1645	<.01	<.2	<.10	.005	.001	200	<10
Co-1	08-12-86	1305	<.01	.2	<.10	.017	.002	100	<10
Co-2	08-12-86	1355	<.01	<.2	<.10	.011	.002	100	<10
G-1	08-12-86	1325	<.01	<.2	<.10	.012	.005	100	<10
F-1	08-13-86	1320	<.01	.2	<.10	.012	.004	<100	<10
F-2	08-13-86	1120	<.01	<.2	<.10	<.005	.005	<100	<10
F-3	08-13-86	1030	<.01	.5	<.10	.005	.002	<100	<10
F-4	08-13-86	0930	<.01	<.2	<.10	.01	.008	<100	<10
F-4	08-13-86	0931	<.01	<.2	<.10	.01	.002	<100	<10
F-5	08-13-86	0830	<.01	<.2	<.10	.009	<.001	<100	<10

Site No. (fig.2)	Date	Time	Cadmium, total recoverable (µg/L as Cd) (01027)	Copper, total recoverable (µg/L as Cu) (01042)	Iron, total recoverable (µg/L as Fe) (01045)	Iron, dissolved (µg/L as Fe) (01046)	Manganese, total recoverable (µg/L as Mn) (01055)	Manganese, dissolved (µg/L as Mn) (01056)	Zinc, total recoverable (µg/L as Zn) (01092)
C-1	08-12-86	1120	<10	<10	30	7	<10	4	20
C-2	08-12-86	1110	<10	<10	30	13	10	7	<10
C-3	08-12-86	1150	<10	<10	20	18	<10	8	10
C-3	08-12-86	1151	<10	<10	<10	10	<10	4	10
H-1	08-12-86	1010	<10	<10	40	<3	<10	2	<10
H-2	08-12-86	0930	<10	<10	30	8	<10	4	<10
H-3	08-12-86	0905	<10	<10	40	9	<10	3	<10
H-4	08-12-86	0825	<10	<10	40	10	<10	4	20
H-5	08-12-86	0815	<10	<10	40	8	10	4	40
H-5	08-12-86	0816	<10	<10	50	10	<10	3	<10
S-1	08-12-86	1450	<10	<10	<10	7	<10	3	<10
S-1	08-12-86	1451	<10	<10	20	7	<10	3	<10
S-2	08-12-86	1525	<10	<10	<10	5	<10	3	10
S-3	08-12-86	1645	<10	<10	10	8	<10	3	<10
Co-1	08-12-86	1305	<10	<10	50	6	<10	<1	<10
Co-2	08-12-86	1355	<10	<10	20	21	<10	17	<10
G-1	08-12-86	1325	<10	<10	20	7	<10	3	10
F-1	08-13-86	1320	10	<10	20	5	<10	3	<10
F-2	08-13-86	1120	<10	<10	40	10	<10	4	10
F-3	08-13-86	1030	<10	<10	30	6	<10	2	<10
F-4	08-13-86	0930	<10	<10	50	8	10	4	140
F-4	08-13-86	0931	<10	<10	30	11	<10	2	<10
F-5	08-13-86	0830	<10	<10	30	6	<10	3	<10

Table 3.--*Water-quality analyses, Environment Canada*

[Abbreviations: µS/cm, microsiemens per centimeter at 25 °Celsius; JTU, Jackson Turbidity Units; mg/L, milligrams per liter; <, less than detection limit]

Site No. (fig.2)	Location	Date	Time	Specific conductance, laboratory (µS/cm)	pH, laboratory (standard units)	Turbidity (JTU)
H-1	Howell Creek downstream from mouth of Leslie Creek.	08-12-86	0958	242	7.8	0.2
H-1	Howell Creek downstream from mouth of Leslie Creek.	08-12-86	1200	246	7.8	.2
H-1	Howell Creek downstream from mouth of Leslie Creek.	08-12-86	1201	240	7.3	.3
H-2	Howell Creek upstream from gage	08-12-86	0918	248	7.7	.2
H-2	Howell Creek upstream from gage	08-12-86	1200	250	7.7	.2
H-2	Howell Creek upstream from gage	08-12-86	1201	246	7.7	.2
H-3	Howell Creek at gage	08-12-86	0825	255	7.6	.8
H-3	Howell Creek at gage	08-12-86	1200	256	7.7	.3
H-3	Howell Creek at gage	08-12-86	1201	256	7.7	.3
F-4	Flathead River downstream from mouth of Couldrey Creek.	08-13-86	0910	251	8.0	.2
F-4	Flathead River downstream from mouth of Couldrey Creek.	08-13-86	1200	253	8.0	.1
F-4	Flathead River downstream from mouth of Couldrey Creek.	08-13-86	1201	251	8.0	.2
F-5	Flathead River at international border	08-13-86	0820	251	8.0	.1
F-5	Flathead River at international border	08-13-86	1200	250	7.5	.2
F-5	Flathead River at international border	08-13-86	1201	249	8.0	.1

Site No. (fig.2)	Date	Time	Hardness (mg/L as CaCO3)	Calcium, dissolved (mg/L as Ca)	Sodium, dissolved (mg/L as Na)	Alkalinity, laboratory (mg/L as CaCO3)	Sulfate, dissolved (mg/L as SO4)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO2)	Nitrogen, NO2+NO3 total (mg/L as N)
H-1	08-12-86	0958	142	43.6	0.5	133	5	0.1	4.4	0.01
H-1	08-12-86	1200	142	43.9	.5	133	5	.1	4.4	.01
H-1	08-12-86	1201	142	43.7	.5	133	5	.1	4.4	.01
H-2	08-12-86	0918	145	44.9	.5	137	5	.1	4.5	.01
H-2	08-12-86	1200	146	45.0	.5	137	5	.1	4.5	.0
H-2	08-12-86	1201	145	44.9	.5	136	5	.1	4.5	.01
H-3	08-12-86	0825	150	45.8	.5	142	5	.1	4.5	.0
H-3	08-12-86	1200	151	46.7	.5	143	5	.1	4.5	.0
H-3	08-12-86	1201	151	46.6	.5	143	5	.1	4.5	.01
F-4	08-13-86	0910	147	44.7	.6	139	6	.1	4.7	.01
F-4	08-13-86	1200	147	44.6	.6	139	6	.1	4.7	.0
F-4	08-13-86	1201	147	44.5	.6	139	6	.1	4.7	.0
F-5	08-13-86	0820	146	44.3	.7	138	6	.1	4.6	.0
F-5	08-13-86	1200	146	44.4	.7	139	6	.1	4.6	.0
F-5	08-13-86	1201	146	44.1	.6	138	6	.1	4.7	.0

Table 3.--*Water-quality analyses, Environment Canada*--Continued

Site No. (fig.2)	Date	Time	Nitrogen, ammonia dissolved (mg/L as N)	Nitrogen, dissolved (mg/L as N)	Nitrogen, particulate (mg/L as N)	Phosphorus, total (mg/L as P)	Phosphorus, total dissolved (mg/L as P)	Barium, total (mg/L as Ba)	Cadmium, total (mg/L as Cd)
H-1	08-12-86	0958	0.006	0.02	<0.025	0.009	0.008	<0.07	<0.0
H-1	08-12-86	1200	.007	.02	<.025	.009	.007	<.07	<.0
H-1	08-12-86	1201	.009	.02	<.025	.010	.007	<.07	<.0
H-2	08-12-86	0918	<.002	.02	.015	.006	.006	<.07	<.0
H-2	08-12-86	1200	<.002	.02	.009	.013	.008	<.07	<.0
H-2	08-12-86	1201	<.002	.02	<.025	.008	.010	<.07	<.0
H-3	08-12-86	0825	.005	.02	.072	.008	.010	<.07	<.0
H-3	08-12-86	1200	.005	.02	.013	.007	.006	<.07	<.0
H-3	08-12-86	1201	.00[illegible]	.03	.011	.036	.008	<.07	<.0
F-4	08-13-86	0910	.019	.03	<.025	.005	.004	<.07	.0
F-4	08-13-86	1200	.014	.03	<.025	.006	.009	<.07	.0
F-4	08-13-86	1201	.017	.05	<.025	.004	.009	<.07	<.0
F-5	08-13-86	0820	.004	.02	<.025	.005	.003	<.07	.0
F-5	08-13-86	1200	<.002	.02	<.025	.004	.003	<.07	<.0
F-5	08-13-86	1201	.004	.02	<.025	.006	.003	<.07	<.0

Site No. (fig.2)	Date	Time	Copper, total (mg/L as Cu)	Iron, total (mg/L as Fe)	Lead, total (mg/L as Pb)	Manganese, total (mg/L as Mn)	Zinc, total (mg/L as Z)	Carbon, particulate (mg/L as C)
H-1	08-12-86	0958	0.001	0.038	<0.001	0.0	0.002	0.137
H-1	08-12-86	1200	.002	.043	<.001	.0	.001	.098
H-1	08-12-86	1201	.001	.045	<.001	.0	.001	.153
H-2	08-12-86	0918	.001	.063	<.001	.0	.001	.179
H-2	08-12-86	1200	.001	.052	<.001	.0	.001	.117
H-2	08-12-86	1201	.001	.079	<.001	.01	.001	.110
H-3	08-12-86	0825	.001	.083	<.001	.01	.003	.195
H-3	08-12-86	1200	.005	.063	<.001	.01	.001	.126
H-3	08-12-86	1201	.028	.079	<.001	.01	.007	.138
F-4	08-13-86	0910	.001	.043	.001	.01	.001	.132
F-4	08-13-86	1200	.028	.060	.003	.01	.016	.121
F-4	08-13-86	1201	.001	.050	.001	.0	.001	.152
F-5	08-13-86	0820	.038	.046	.004	.01	.023	.124
F-5	08-13-86	1200	.002	.032	<.001	<.0	.004	.119
F-5	08-13-86	1201	.001	.103	.001	.01	.001	.133