BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

HAT CREEK PROJECT

Beak Consultants Limited - Hat Creek Project - Detailed Environmental Studies - Inventory Volume 2 - June 1978.

ENVIRONMENTAL IMPACT STATEMENT REFERENCE NUMBER: 19b

Beak Consultants Limited

Montreal
Toronto
Calgary
Vancouver

Suite 602/1550 Alberni Street
Vancouver/British Columbia
Canada/V6G 1A5
Telephone (604) 684-8361
Telex 04-508735

beak
Environmental Specialists

HAT CREEK PROJECT
DETAILED ENVIRONMENTAL STUDIES
WATER RESOURCES SUBGROUP
HYDROLOGY, DRAINAGE, WATER QUALITY AND USE

VOLUME 2
INVENTORY

A Report for:

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY
Vancouver, B.C.

Prepared by:

BEAK CONSULTANTS LIMITED
Vancouver, B.C.

File: K4242

Date: JUNE 1978

A MEMBER OF THE SANDWELL GROUP

TABLE OF CONTENTS

Page

3.2 FIELD INVESTIGATION METHODOLOGY

4.0 RESOURCES INVENTORY

4.1 HYDROLOGY

4.2 PRESENT WATER QUALITY

4.3 WATER USE

5.0 PROJECTED RESOURCES WITHOUT THE PROJECT

5.1 HYDROLOGY

5.2 WATER QUALITY

TABLES

SECTION 3.0

SECTION 4.0

SECTION 5.0

FIGURES

SECTION 2.0

SECTION 3.0

SECTION 4.0

SECTION 5.0

2.0 INTRODUCTION TO THE STUDY

2.1 TERMS OF REFERENCE

(a) Inventory

The inventory studies presented herein were undertaken in response to the following general Terms of Reference with respect to hydrology, water quality and water use:

> *Determine the seasonal variation in discharge of surface flows, stream morphology and areas subject to flooding in the Hat Creek Valley.*
>
> *Identify the subsurface flow regime and areas of interaction between subsurface and surface flows in the valley.*
>
> *Conduct a comprehensive water quality survey of water courses which may be affected by the proposed development including selected standing water bodies to provide baseline data. Document the location of known wells and analyze the well water quality.*
>
> *Establish the present and future consumptive use of water supplies in the Hat Creek Valley.*

(b) Impact Assessment

The impact assessment presented herein was developed in response to the following general Terms of Reference relating to effects of the development:

> *Evaluate the Hat Creek Diversion in terms of any effects on water quality and surface hydrology.*

Assess the implications of proposed reservoirs, lagoons and impoundments on water quality and water use.

Examine drainage systems for hazards to the environment. Quantify and qualify leachates and surface runoffs from waste rock, overburden, ash disposal and storage areas.

Estimate the quantity, quality, and disposal of pit area waters.

Examine the potential for wastewater re-use and ultimate disposal.

Assess the overall effect of the proposed development on the quality and quantity of the water resources of the area including any impacts on the consumptive water use in the Hat Creek Valley and by downstream communities.

2.2 PURPOSE AND SCOPE

British Columbia Hydro and Power Authority have proposed to establish a 2,000 megawatt thermal generating station and coal mine in the Hat Creek Valley. Within this goal, environmental studies were commissioned to provide an inventory of resources in sufficient detail to provide baseline data from which to establish and evaluate impacts of the proposed development in comparison with predictions of the evolution of these resources without the development.

(a) Inventory

The inventory sections of this report document the findings of the resource studies undertaken for the Hat Creek Project in respect to hydrology, water quality and water use. The relationship of the inventory phase studies to the overall environmental study program is illustrated in Figure 2-1.

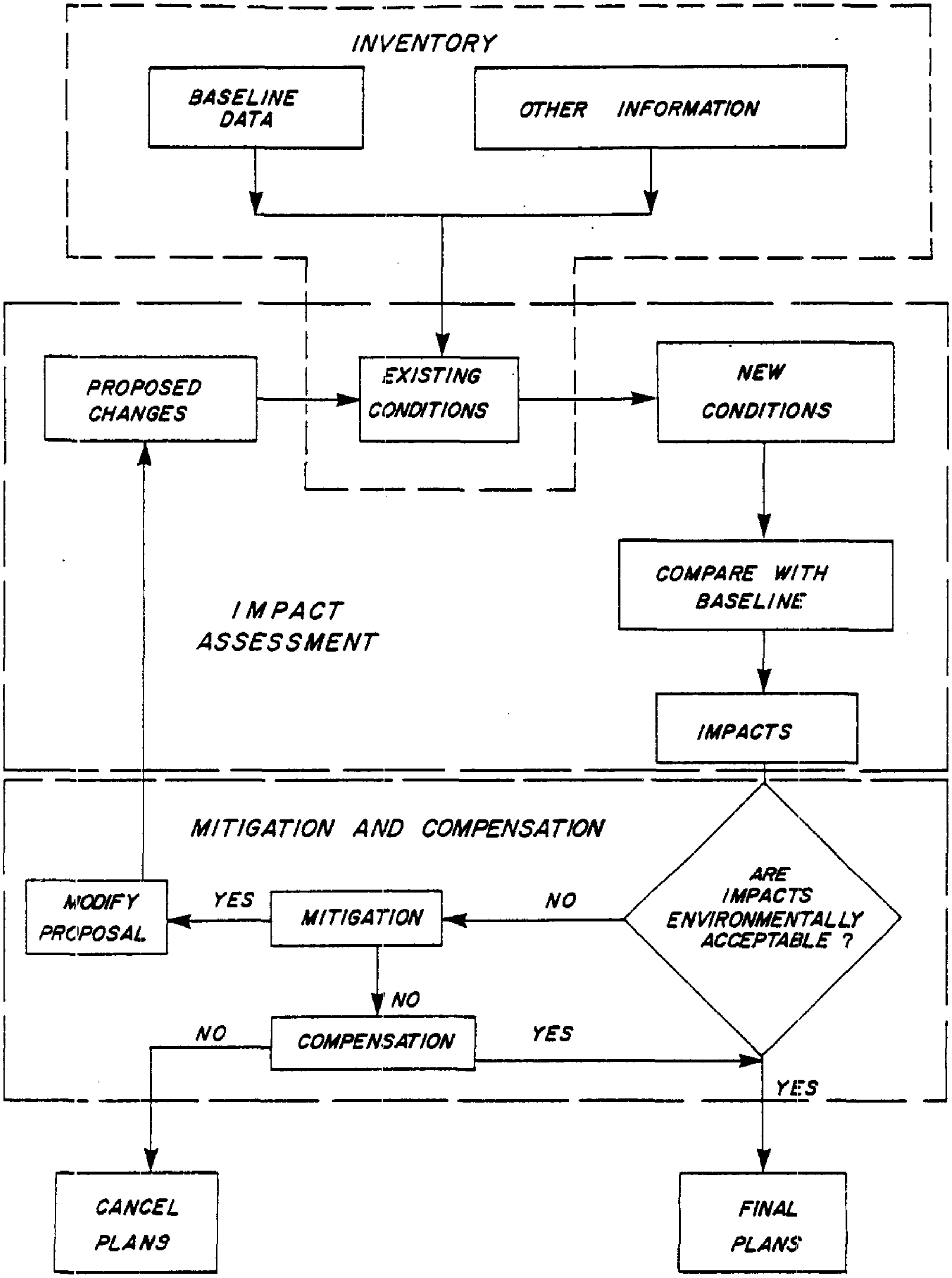


FIGURE 2-1: DIAGRAM OF ENVIRONMENTAL STUDY PROGRAM

DATE	Mar78	DF	2-1
PROJECT	K4242		
DWG NO			

The inventory information derived in this study is set out in two main sections. Section 3.0 RESOURCES INVENTORY METHODOLOGY discusses the sources of data and information utilized as well as the methodology utilized in defining the nature of the existing water resources in terms of hydrology, water quality and water use. Section 4.0 RESOURCE INVENTORY describes in detail the findings of the inventory studies. Supplementary data and information pertaining to the inventory studies are contained in Appendices A to D. Section 5.0 PROJECT RESOURCES WITHOUT THE PROJECT presents a brief scenario of the future water resource regime without the influences of a major coal mining and thermal power plant development in the Hat Creek Valley.

(b) Impact Assessment

The impact sections of the report, document the assessment findings in respect to interactions of the proposed development with the water resources of the area.

The impact assessment is contained in Section 6.0 IMPACTS OF THE PROJECT. Section 7.0 OPPORTUNITIES FOR MITIGATION, COMPENSATION, AND ENHANCEMENT outlines measures which should be examined by project designers in order to ameliorate the potentially significant impacts identified in the assessments. Section 8.0 RESEARCH AND MONITORING RECOMMENDATIONS points out areas where further study is recommended and outlines consideraitons for monitoring programs.

2.3 STUDY TEAM

The participating consultants in the phases of the detailed environment studies reported on in this document were as follows:

BEAK CONSULTANTS LIMITED
: *Study Co-ordination and Management*
: *Water Quality and Water Use*

GOLDER GEOTECHNICAL CONSULTANTS LTD.
: *Ground Water Hydrology*

KELLERHALS ENGINEERING SERVICES LTD.
: *Surface Water Hydrology*

CANADIAN BIO-RESOURCE CONSULTANTS LTD.
: *Agricultural Water Use*

Beak Consultants Limited on behalf of the study team wishes to acknowledge the valuable guidance provided by British Columbia Hydro and Power Authority for whom the studies were conducted and by the co-ordinator of the environmental studies EBASCO SERVICES OF CANADA LIMITED.

3.0 RESOURCES INVENTORY METHODOLOGY

3.1 DATA AND INFORMATION SOURCES

(a) Hydrology

(i) Ground Water

A. Data Required

The inventory information required for an environmental hydrogeology program must be based upon the objectives of the study. This information can be divided into two parts. These are: collection of base line data; construction of models of flow systems.

Collection of Base Line Data

This data includes geometry and hydrogeologic characteristics of the local bedrock and unconsolidated sedimentary materials present in the Hat Creek Region. The data collected for this study is directed at providing information for the evaluations required, rather than for the less well defined task of achieving a comprehensive understanding of the entire ground water flow system in the region. Specific items include:

- location of all known wells, piezometers, springs
- regional geologic data, formation permeability
- geochemical characteristics of ground waters.

These data were primarily collected for the evaluation of the flow systems and served as additional data to the ground water quality study.

Construction of Models of Flow Systems

The ground water resources of an area are normally studied by determining the physical features of local flow systems, and by evaluating the flow quantities and the changing chemical characteristics of the water along these flow systems. The essential components of a ground water flow system are:-

- a recharge zone: where water (either surface water or direct precipitation) infiltrates to the ground water table

- an intermediate zone: where the infiltrated water moves through the rock or soil
- a discharge zone: where the ground water seeps upwards and out of the particular flow system. This seepage can pass into another flow system or discharge out of the ground and either evaporates or becomes part of a surface water system.

Using the base line data and knowing where the impacts are likely to occur, simplified models of ground water flow systems were constructed for these areas. The following data had to be determined (or if necessary assumed):

- subsurface flow patterns, including location of ground water recharge and discharge areas
- major aquifer delineation and characteristics
- quantity of ground water flow.

B. Information Sources

Very little information on ground water movements can be observed above the ground and hence most of the data is based on information collected from drilled boreholes and a knowledge of the regional geology. The data used in this Hat Creek study were derived from existing reports and also from field studies, including a drilling program. The data sources can be summarized under the following categories:

Government and Consultant Reports

There are no published reports which deal directly with the study of ground water in the region. Much of the data has been interpreted from regional geological reports and from mining and geotechnical studies in the area, noteably Duffel and McTaggart 1951 [1], Ryder 1976[2] and Church 1977[3]. In addition some site specific geologic studies were available, for example McCullough 1977[4].

Hat Creek Geotechnical Study

This study was reported in March 1977 by Golder Associates Ltd.[5] and includes a significant amount of geological and ground water data, particularly around the proposed coal pit and waste dump areas. Over one hundred piezometers were installed and falling head permeability tests were carried out in all the three major lithologic units around the pit: clastic sediments of the Coldwater Formations (claystone ranging up to conglomerate) coal and basaltic rock. One pump test was carried out to evaluate the hydrogeologic behaviour of the Coldwater claystone unit.

Some preliminary geotechnical information is available on boreholes drilled for investigation of dam sites for water storage reservoirs and ash ponds in the Upper Medicine Creek Valley.

Air Photo Interpretation

Coloured and black and white stereo paired photographs are available. These aid in identification of rock types, geological features, vegetation types, surface water bodies, and saline soil zones.

Logs of Water Wells

These include logs of five drilled water wells, land owners' information on ten dug wells and developed springs and information on two dug wells provided by the Ground Water Section British Columbia, Department of Environment. The data includes: well construction details, lithology, well yield, depth to static water and pumping water level and seasonal influences and water temperature.

Borehole Drilling Program

A five hole drilling program was carried out in 1977 for Golder Associates in order to provide ground water data in selected critical areas where information was very scarce. These holes provided data on lithology, piezometric elevations (see glossary of terms Appendix A1.0), ground water quality and isotopic composition, and hydraulic conductivity of rock and soil.

Water Quality Data

Chemical and isotopic analyses of water samples collected in the field were run and were used to make interpretations on the changes taking place as the ground water moved along a particular flow system.

Observations of Base Flow Recession in Houth Creek

The base flow recession in Houth Creek (see location in Figure 3-4) was measured, and can be used to assess the quantity of ground water discharged into the proposed Houth Meadows waste dump area.

Observations of Water Levels in Existing and Installed Piezometers

Piezometric data are available from existing records and in the field from existing and new piezometers installed in the five boreholes. These data were used to interpret the direction of movement of ground water flow systems.

(ii) Surface Water

The surface water regime of an area is normally studied on the basis of precipitation, snowmelt and runoff data, combined with information about physical features and general climate.

Table 3-1 lists all the Atmospheric Environment Service climatic stations within the general region (defined by latitudes 50° and 50°30', and longitudes 120° and 122°30') for which some relevant data are available[6]. The type of data collected is also indicated in Table 3-1. Figure 3-1 shows the corresponding station locations. Considering that much of the runoff-producing terrain lies about 1,500 m in elevation, coverage for the purposes of the present study is sparse, but it is fortunate that one climatological station "Hat Creek" El.899 m, lies within the perimeter of the proposed mine and has over 15 years of daily precipitation and temperature data.

Snow accumulation in B.C. is being monitored by the Water Investigations Branch of the Ministry of the Environment.[7] Table 3-2 lists the snow courses in the Hat Creek region and their location is indicated on Figure 3-1. Unfortunately, there is only one year of record for the two snow courses in the Hat Creek drainage (Nos. 284 and 285) but the general region is covered reasonably well.

The Water Survey of Canada[8] is responsible for streamflow measurements in B.C. On Hat Creek, stream flow records start in 1911, but were unfortunately discontinued after a few years, not to resume again until 1960. Useable records for Hat Creek exist for three sites with drainage areas of 73, 350 and 666 km^2.

Table 3-3 gives a summary of operating periods and type of record (e.g. continuous recordings, manual gauge readings, year-round or seasonal) and Figure 3-2 indicates how drainage area increases along Hat Creek and shows the relative position of the gauging sites.

For the regional analysis, Section 4.1 (b) (i)C, streamflow records from 85 stations located on the interior plateau of B.C. have been analyzed (See Table B1-1 Appendix B). A summary of these records is published including detailed descriptions of the location and type of record available for all stream gauging sites in B.C. operated by the Water Survey of Canada.[8,9]

The flood plain mapping of Section 4.1 (b) (ii)F is based partially on aerial photographs taken in September 1976 by McElhanney Surveying and Engineering

TABLE 3-1

CLIMATIC STATIONS IN THE HAT CREEK REGION

(as defined by latitudes 50°-51° 30' and longitudes 120°-122° 30')

Station Number	Station Name	Latitude	Longitude	Elevation (m)	Period of Record: Began Year	Period of Record: Began Mo.	Period of Record: Ended Year	Period of Record: Ended Mo.	Synoptic Report	Hourly Weather	Temperature	Precipitation	Rate of Rain	Wind Mileage	Sunshine
1160540	Ashcroft M	50° 43	121° 20	488	1944	11			X	X	X	X		X	
1160510	Ashcroft *	50° 43	121° 17	305	1912	09					X	X			
1161660	Clinton *	51° 05	121° 34	892	1881	01	1965	01				X			
1163340	Hat Creek	50° 45	121° 35	899	1960	11					X	X			
1163468	Highland Valley BCCL	50° 31	121° 01	1472	1966	12					X	X			
1163469	Highland Valley Lornex	50° 28	121° 02	1582	1967	01					X	X			
1163779	Kamloops *	50° 41	120° 28	350	1878	01			X	X	X	X			X
1163780	Kamloops A	50° 43	120° 25	345	1951	01			X	X	X	X	X	X	X
1123835	Kamloops Meadow Creek	50° 28	120° 36	1189	1965	06							X		
1114435	Kwotlenemo Lake	50° 40	121° 50	914	1969	01					X	X			
1114620	Lillooet *	50° 42	121° 56	290	1878	01					X	X			
1114740	Lytton	50° 14	121° 34	175	1944	08	1970	01	X	X	X	X			
1124860	Mamit Lake *	50° 23	120° 48	1006	1924	01	1965	03			X	X			
1125070	Merritt	50° 06	120° 47	591	1918	11	1952	06			X	X			

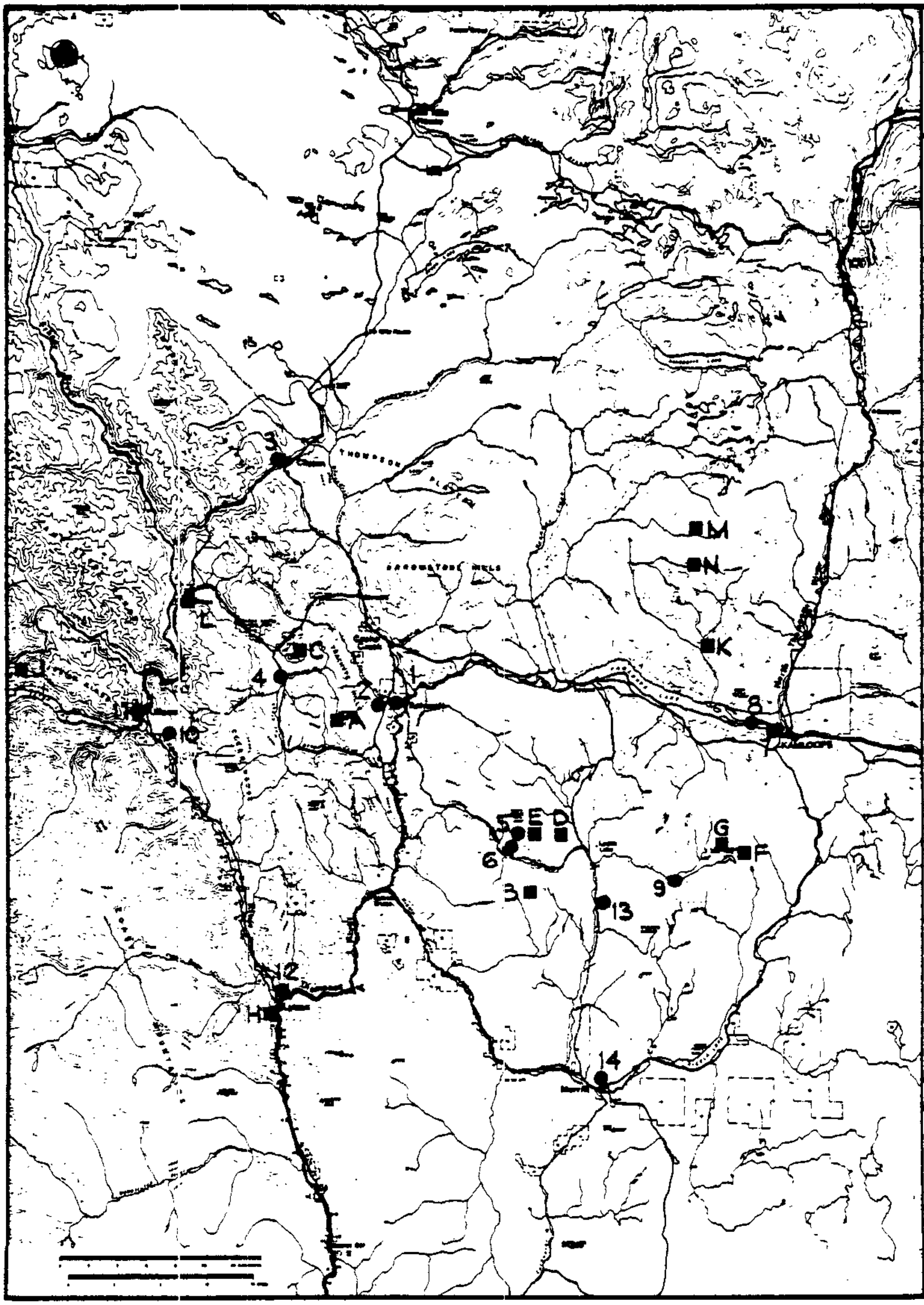
---

* Record not continuous during period shown

from Atmospheric Environment Service, Climatological Station Data Catalogue,1976.

**B.C. HYDRO
AND
POWER AUTHORITY**

**HAT CREEK PROJECT
DETAILED
ENVIRONMENTAL
STUDIES**



LOCATION MAP OF CLIMATIC AND SNOW SURVEY STATIONS

CLIMATIC STATIONS ●

1 ASHCROFT
2 ASHCROFT M
3 CLINTON
4 HAT CREEK
5 HIGHLAND VALLEY BCCL
6 HIGHLAND VALLEY LORNEX
7 KAMLOOPS
8 KAMLOOPS A
9 KAMLOOPS MEADOW CREEK
10 KWOTLENEMO LAKE
11 LILLOOET
12 LYTTON
13 MAMIT LAKE
14 MERRITT

SNOW SURVEY STATIONS ■

A CORNWALL HILLS
B GNAWED MOUNTAIN
C HARRY LAKE
D HIGHLAND VALLEY NO.1
E HIGHLAND VALLEY NO.2
F LAC le JEUNE (LOWER)
G LAC le JEUNE (UPPER)
H LYTTON
J MISSION RIDGE
K PASS LAKE
L PAVILION
M PORCUPINE RIDGE
N TRANQUILLE LAKE

FIGURE 3-1

TABLE 3-2

SNOW COURSES IN THE HAT CREEK REGION

Station No.	Station Name	Location		Elevation (m)	Record Began
		Latitude	Longitude		
285	Cornwall Hills	50° 42'	121° 27'	2,000	1977
185	Gnawed Mountain	50° 26'	120° 59'	1,580	1968
284	Harry Lake	50° 47'	121° 33'	1,350	1977
92	Highland Valley No. 1	50° 30'	120° 57'	1,550	1958
153	Highland Valley No. 2	50° 30'	120° 59'	1,510	1966
85	Lac le Jeune (lower)	50° 28'	120° 30'	1,370	1956
241	Lac le Jeune (upper)	50° 28'	120° 30'	1,460	1973
124	Lytton	50° 15'	121° 34'	270	1966
182	Mission Ridge	50° 46'	122° 12'	1,850	1967
57	Pass Lake	50° 51'	120° 30'	870	1950
81	Pavilion	50° 55'	121° 49'	1,230	1955
49	Porcupine Ridge	50° 58'	120° 33'	1,830	1950
56	Tranquille Lake	50° 56'	120° 33'	1,420	1950

---

from Water Resources Service, Snow Survey Measurements Summary, 1975.

TABLE 3-3 - STREAMFLOW RECORDS IN HAT CREEK DRAINAGE AREA

NAME	OPERATOR	TYPE	PERIOD OF OPERATION	LOCATION LAT./LONG.	DRAINAGE AREA (km^2) above gauge)	COMMENT
Ambusten Creek	BEAK	Manual	12 Sept. 1976 - 9 June, 1977	55 44 00 121 33 48	28.7	# NAT.
Anderson Creek	BEAK	Manual	16 Sept. 1976 - 10 June, 1977	50 43 39 121 37 46	31.9	# NAT.
Finney Creek	BEAK	Manual	17 May, 1977 - 10 June, 1977	50 45 06 121 37 12	9.8	# REG.
Hat Creek near Ashcroft	W.S.C.	Manual	1911-1922	50 36 44 121 34 09	73.0	S REG.
Hat Creek near Cache Creek	W.S.C.	Manual	1911-13,1960-73	50 53 03 121 29 55	658.0	C REG.
Hat Creek near Carquile	W.S.C.	Manual	1911	50 53 05 121 29 55	603.5	S REG.
Hat Creek above Marble Canyon	W.S.C.	Manual	1921,23,34	50 47 30 121 36 40	349.7	S REG.
Hat Creek near Upper Hat Creek	W.S.C.	Manual	1960-1977	50 45 22 121 35 18	349.7	C REG.
Hat Creek - Hammond diversion	W.S.C.	Manual	1912-22	50 37 15 121 34 10	82.5	S REG.
Houth Creek	BEAK	Manual	18 Oct. 1976 - 9 June, 1977	50 47 24 121 36 18	28.2	# NAT.
Medicine Creek	BEAK	Manual	15 Sept. 1976 - 8 June,1977	50 45 30 121 33 50	58.2*	# REG.
Medicine Creek diversion	BEAK	Manual	13 May, 1977 - 28 May, 1977	50 45 45 121 26 50	15.3	# REG.
Bonaparte River near Cache Creek	W.S.C.	Manual	1960-1974	50 54 57 121 24 21	4092.2	C REG.
Bonaparte River below Cache Creek	W.S.C.	Manual	1911-21, 1972-77	50 48 05 121 19 15	5024.6	C REG.

W.S.C. - Water Survey of Canada
\# - miscellaneous measurement
C - continuous measurement
* - includes Medicine Creek Diversion

S - seasonal measurement
NAT. - natural flow
REG. - flow affected by storage and/or diversion

Ash

HAT CREEK DRAINAGE AREA VS. LENGTH FROM SOURCE

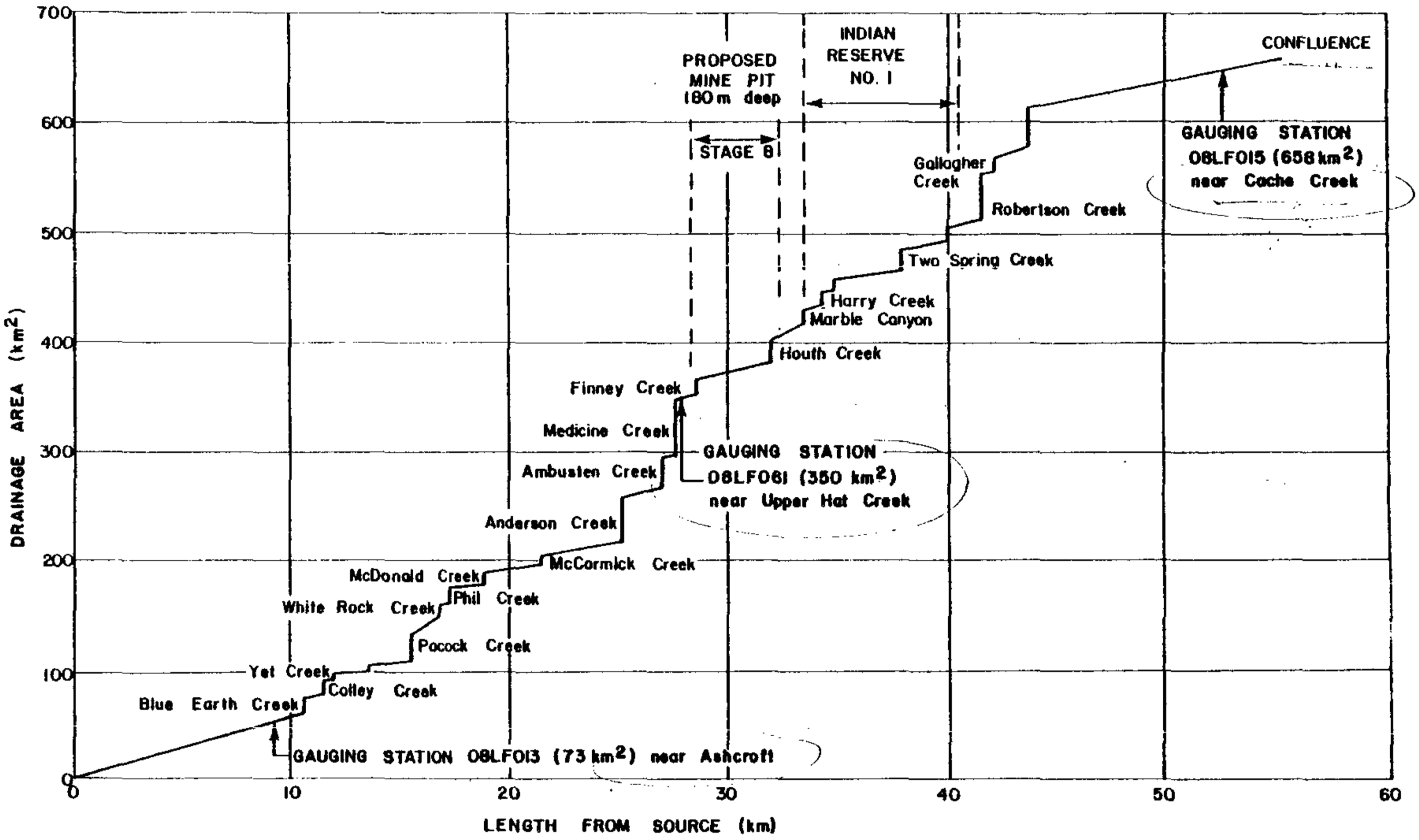


FIGURE 3-2

DATE	Dec 77 DF	3-2
PROJECT	K4242	
DWG NO	Rev. 2-1	

Limited and supplied by Ebasco Services of Canada Limited, Environmental Consultants, and partially on field surveys conducted during this study.

A wide range of other data, such as topographic maps, geologic maps (in particular a recent map and report[2] on the surficial geology of the National Topographic Series Ashcroft map sheet, NTS No. 921), black and white air photos, and interviews with local residents also form part of the background material on which the present study is based.

(b) Water Quality

The objective of this water quality analysis is to determine and characterize the present concentrations of various water constituents appearing in the major water bodies of the study area which, if altered, might cause changes to the environment. One task in meeting this objective is to determine the type of data and information available from outside sources and to assess its applicability to the study.

For the purposes of this report, the term "existing data" is defined as that data which has been collected, or was in the process of being collected, prior to the commencement of this project in July 1976. Such data are reviewed in Section 4.2.

(i) Ground Water

There are no existing ground water quality data available for the Hat Creek Valley which are pertinent to this study.

(ii) Surface Water

A. Ministry of the Environment (MOE)

The Ministry of the Environment in the Province of British Columbia has compiled water quality data on Hat Creek (at mouth), the Bonaparte River (below Cache Creek and above Clinton Creek) and the Thompson River (at Savona and at Spences Bridge). The collection of this data was instigated in 1971 and this collection provides the most comprehensive observation period available.

B. Department of Fisheries and Environment (DFE)

The only relevant data available from the DFE's NAQUADAT program is that obtained from the Thompson River at Spences Bridge and some water temperature data on Hat Creek.

C. Calgon Corporation

A water requirements report prepared by Calgon for B.C. Hydro, Systems Design Division contains a detailed monthly monitoring program of the Thompson River at a location approximately 3 km upstream of the confluence of the Bonaparte River and the Thompson River, over the period December 1974 through October 1975.

(c) Water Use

(i) Ground Water

There are no recorded sources of information on ground water use in the valley. Unlike surface water development, the land owner is not required to apply for a permit for ground water development. However, some general information was provided through interviews with home owners and water users in the valley.

(ii) Surface Water

A. Irrigation

The sources of information pertaining to the use of water for irrigation in the Hat Creek, lower Bonaparte, Cornwall, and Oregon Jack drainages were the following:

1) provincial water licence data[10,11] obtained from the B.C. Water Rights Branch, the governmental body responsible for administering these licences. Data pertain to the use or storage of surface waters and give details on the source of water, the point of diversion, the quantity of water allowed to be diverted or stored, and the specific parcel of land on which the water is to be used;

2) discussions with Hat Creek Valley ranchers regarding their use of water for irrigation;

3) the *Agriculture* report[12] of the Hat Creek Detailed Environmental Studies. Information obtained included: the theoretical irrigation requirements of Hat Creek Valley considering crops, soils and climate; the location, soil type, and amount of presently irrigated land of Hat Creek Valley; the areal distribution of potentially irrigable lands in Hat Creek Valley and the Ashcroft-Cache Creek area; and water quality guidelines for irrigation use;

4) air photographs, in natural colour, yielding information on crops and methods of irrigation in the Hat Creek Valley[13];

5) the *Fisheries and Benthos* report[14] of the Hat Creek Detailed Environmental Studies, yielding information concerning the flow requirements for maintenance of the fishery resource in Hat Creek;

6) a provincial government report, *Preliminary Feasibility Study for Oregon Jack Creek Irrigation Proposals*,[15] which yeilded information concerning a potential storage reservoir in the Hat Creek area;

7) A B.C. Ministry of Agriculture study, *Savona-Cache Creek-Basque Irrigation Development Study*,[16] which yielded information on lands having potential for intensive agricultural production with irrigation in the Cache Creek area;

8) flow probability curves, which were developed from historical flow records of hydrometric stations of Hat Creek,[8] provided information concerning additional water that would be available for irrigation use; and

9) water chemistry data, presented in Section 4.2(b) of this report, provided information pertaining to the suitability of waters in the study area for irrigation use.

B. Livestock

The sources of information regarding livestock water use in the Hat Creek Valley were two-fold:

1) the *Agriculture* report[12] of the Hat Creek Detailed Environmental studies, yielding livestock populations; and

2) a farm structures handbook, *Structures and Environment Handbook*,[17] providing information about livestock water consumption rates.

C. Domestic and Municipal

Information on present and potential surface water use for domestic purposes was obtained by examination of water licence data[18], existing and projected future population estimates[19], and utilization of per capita water use estimates.[20,21,22] Water licence data were examined for the Hat Creek Valley, the Bonaparte River reach from the confluence of Hat Creek to the Thompson River, the Cornwall Creek and the Oregon Jack Creek area. Although all water licences for domestic use may not currently be used for that purpose, it is considered so in this report because it is within the licence holders right to do so.

3.2 FIELD INVESTIGATION METHODOLOGY

(a) Hydrology

(i) Ground Water

The field work related to the ground water investigation can be divided into six main tasks: field reconnaissance, interviews with land owners, borehole drilling program, water sampling for isotope analysis, water level measurements in piezometers and weir installation for base flow monitoring.

A. Field Reconnaissance

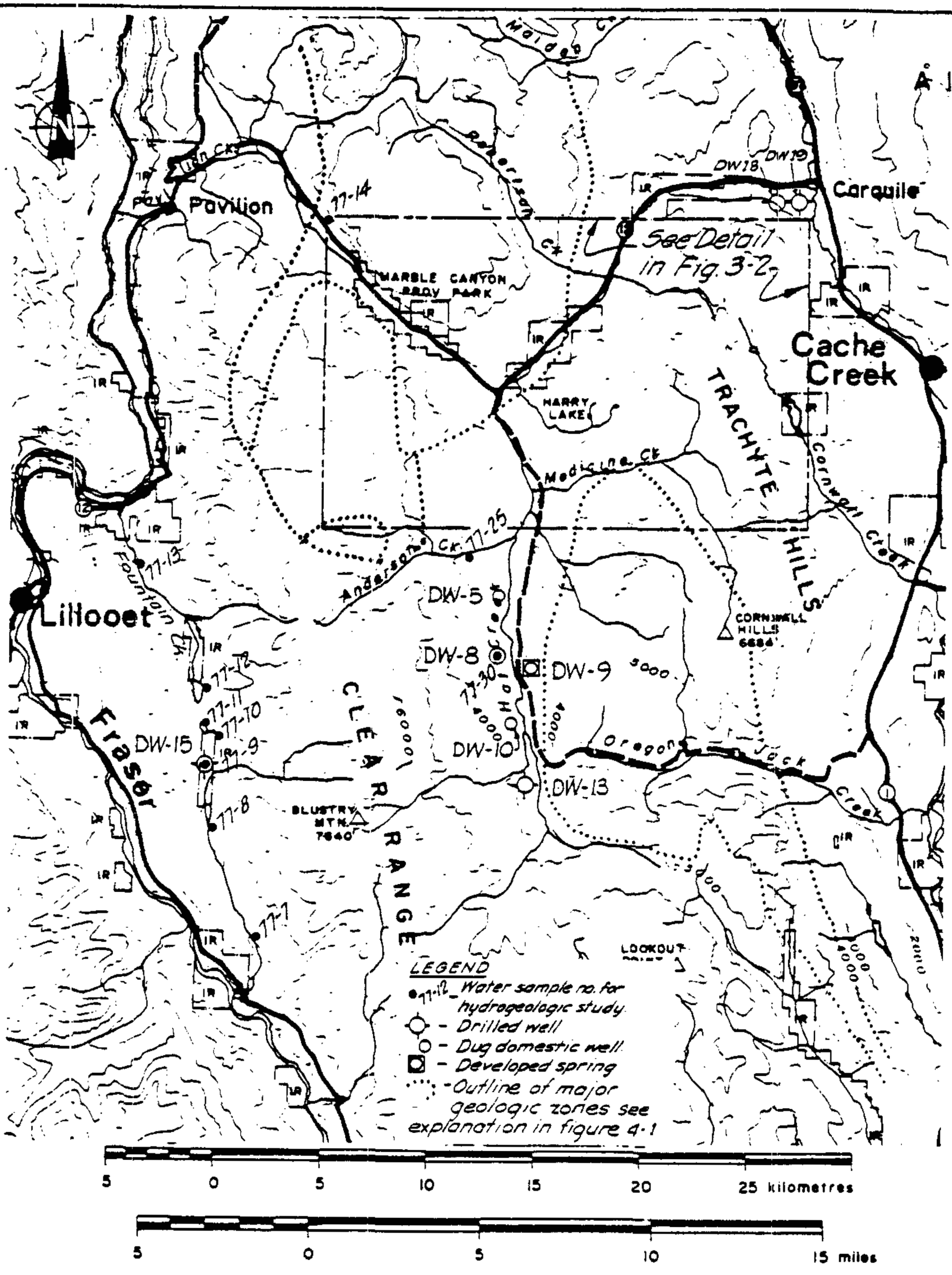
Three major expeditions were made into the Hat Creek and adjacent valleys. These trips were carried out in November 1976, April 1977 and July-August 1977, and were limited to areas which could be reached using a four-wheel drive vehicle. Investigations were concentrated around the major potential impact areas in the Hat Creek Valley. The area covered included the Fountain Creek Valley, the Hat Creek Valley and parts of the Cornwall and Oregon Jack Valleys (see locations Figure 3-3).

The trips were planned to:

1. Observe and photograph geological and other features which could provide evidence of zones of potential ground water movement, (e.g. fault zones), ground water discharge zones (e.g. springs, seeps and evaporite salt deposits), ground water recharge zones (e.g. snow melt infiltration into coarse granular surficial sediments). Many of these features had been observed in aerial photographs and the field visit was planned in order to provide better definition.

GROUND WATER EVALUATION FOR HAT CREEK COAL PROJECT ENVIRONMENTAL STUDY
AREA LOCATION MAP

Figure 3-3



Golder Associates

V76359 119 Rub Dec '77

2. Collect water samples for inorganic chemical and isotope analyses.
3. Determine the location of residences and/or irrigated farm land where wells and developed springs may be located.

B. Interviews with Local Ground Water Users

Local farmers, a limestone quarry operator, residents of Indian Reserves and recreational homeowners were interviewed. The information provided related to existing wells, springs and other ground-water-related features such as seeps and minimum stream flows. Information on seasonal changes in flows and water use were particularly valuable.

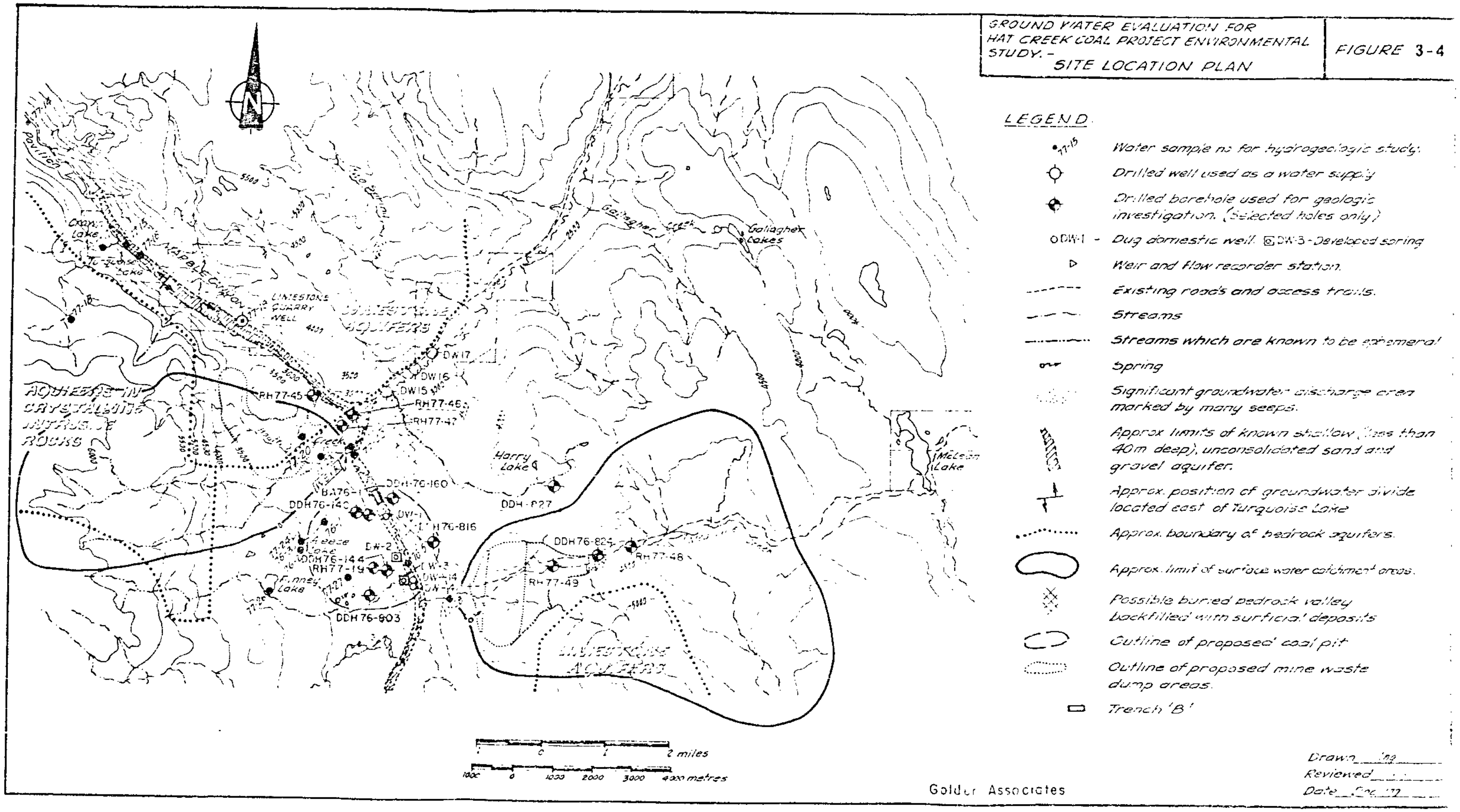
C. Borehole Drilling Program

Five 150 mm (6 inch) diameter boreholes were drilled in areas close to the proposed Houth Meadows and Medicine Creek waste dumps and the proposed ash pond in the upper Medicine Creek Valley (see locations of these five boreholes, Nos. RH-77-45 to RH-77-49, inclusive, in Figure 3-4). The purpose of these boreholes was to provide ground water data in areas where potential ground water contamination could occur as a result of the disposal of rock and ash wastes.

The boreholes averaged 91 m (300 ft.) deep and were completed as permanent installations with piezometers for both water level measurements and ground water sampling. Details of the execution and results of this drilling program are provided in Appendix A3.0.

D. Water Sampling for Isotope Analysis

Both stable and radioactive isotopes provide a useful means of determining the past history of ground waters. The stable isotopes used in this study



GROUND WATER EVALUATION FOR HAT CREEK COAL PROJECT ENVIRONMENTAL STUDY. -
SITE LOCATION PLAN

FIGURE 3-4

were oxygen-18 and deuterium, and the only radioactive isotope used was tritium. These isotopes have been used in a number of ground water studies in Canada, for example Dakin 1975 [23], Simard 1977 [24]. A brief review of the theory and use of isotope studies is given in Appendix A5.1.

Water samples were collected from different holes, springs, streams and lakes. Samples were sealed in plastic bottles, and sent to the University of Waterloo, Ontario and Chalk River Nuclear Laboratories, Ontario for oxygen-18, deuterium, and tritium analysis. The analytical methods used are described in Appendix A5.2.

The field sampling was designed to obtain a set of regional isotope values covering a variety of accessible ground and surface waters, covering as wide an area as possible. These background values would provide an average isotope content for local ground water recharge. Both oxygen and deuterium analyses were run in order to help determine the origin of the ground waters using relationships between deuterium and oxygen-18 concentrations. Tritium determinations were made in order to help identify different types of ground water and to estimate the relative age of the water.

E. Water Level Measurements in Piezometers

The depths to water were measured in a number of piezometers installed during this investigation as well as in piezometers installed during geotechnical investigations in the vicinity of the proposed coal pit (Golder Associates, 1976)[5]. The locations of the boreholes in which these piezometers were installed are shown in Figures 3-3 and 3-4. Only a limited number of measurements were required as most water level measurements were supplied by others. Measurements were made using an electrical tape for standpipe piezometers and a pressure readout box for pneumatic piezometers.

These piezometric data were used to determine hydraulic head (see glossary) at various points in the ground water flow systems (i.e. at the piezometer tips). These potentials were used to help determine the direction of ground water flow. In addition the seasonal change in the hydraulic potentials provided data on the recharge characteristics and hydraulic conductivity of the flow systems.

F. Installation of a Weir to Monitor Base Flows in Houth Creek

A 60 cm (2 ft.) wide x 30 cm (1.25 ft.) deep wooden rectangular weir was constructed in Houth Creek approximately 300 m (1,000 ft.) upstream from its confluence with Hat Creek. A Belex water bag was submerged about 3 m upstream of this dam. A Rustrack strip chart pressure recorder (Bordon tube type, pressure range 0-21 kN/m^2 (0-3 psi)) was installed to record the pressure in the water bag. The reading resolution was 0.69 kN/m^2 (6.9 cm of water) and the recording range between 0 and 475 m^3/day. The weir was installed on July 25, 1977 and recorded flows to October 20, 1977.

(ii) Surface Water

Field work related to surface water hydrology consisted of three main tasks:

1. Initial inspection of stream channels, lakes, lake outlet controls, irrigation diversions, bridges and culverts. This provided the basis for the detailed planning of items 2 and 3 below.

2. Streamflow measurements in most tributaries to Hat Creek close to the proposed mine site in order to relate their runoff regimes to that of Hat Creek (for which data are available).

3. Channel surveys along typical reaches of Hat Creek downstream of the proposed development, to serve as a basis for predicting changes in channel morphology in case the runoff regime of Hat Creek should be altered as part of the diversion scheme.

Most streamflow measurements were made with a small OTT propeller-type current meter, which proved quite suitable for the exceedingly small flows encountered. On one stream (Finney Creek) the depth was too shallow even for an OTT current meter {d (propeller) > 5 cm} and a temporary triangular weir made of steel plate attached to a plywood cutoff wall had to be installed. The stream gauging techniques are described in the literature[25], and illustrated in Figures B2-1 and B2-2, Appendix B. On several of the small streams gauged as part of the present study, permanent stream gauges are being installed by the Water Survey of Canada, acting on behalf of B.C. Hydro. The data collection periods of this study are listed in Table 3-3.

The hydraulic geometry of Hat Creek, downstream of the proposed mine, was defined by means of cross sections and profiles along typical reaches, together with photographs and notes on bed and bank materials, flood plain deposits, vegetation and other relevant features such as beaver dams, debris jams, etc. Water levels were observed at all surveyed cross sections both in fall 1976 and in May and June 1977.

(b) Water Quality

As previously stated, the objective of this water quality analysis is to determine and characterize the present concentrations of various water constituents appearing in the major water bodies of the study area which, if altered, might cause changes to the environment. To achieve this objective it then becomes necessary to establish the baseline concentrations of the water constituents, including the trace elements, plus the physical characteristics of the water such that any alteration which may occur in the future may be assessed.

The chemical composition of a particular stream or river is subject to variations for a number of reasons. The first of these is related to discharge. Over a period of time the contribution of ground water to a river remains relatively stable while the contribution of surface runoff can be extremely variable. As ground water tends to have higher dissolved solids levels than surface runoff the overall river dissolved solids concentration will vary inversely with discharge [26]. Secondly, variations in chemical composition may be attributed to location within a system insofar as tributary inflows, degree of mixing and evaporation may be determining factors of chemical composition. In general the concentration of dissolved constituents tends to increase from the source of a stream to its mouth [27].

Lake waters generally have a more stable water quality than streams or rivers but are subject to seasonal cycles, particularly in the case of small lakes. During the summer, evaporation takes place and the dissolved solids concentration may increase. Similarly, during the winter in lakes that are shallow in relation to their ice cover, the concentration of dissolved solids in the lake water may increase as the surface water freezes. Variations in lake water chemistry may cause stratification of the water mass. The extent of this stratification will depend on many factors such as depth, size, wind exposure, type of inflow (whether predominantly ground water or surface water), and overall flushing rate. Changes in lake water chemistry may also be related to biological activity, particularly in highly productive lakes. The action of photosynthesis and respiration can markedly alter the levels of oxygen, carbon dioxide, and pH depending upon which time of day samples are taken [28].

The physical factors promoting mixing in surface water bodies are much less effective or absent in ground waters. Considerable differences in composition of groundwater may be found both vertically and laterally in ground water reservoirs. In determining the nature of dissolved matter in stored ground water throughout an aquifer, discrete wells are sampled and an indication is obtained of conditions at a single point in a three dimensional system. Collection of samples from many wells distributed areally over an aquifer generally will give the probable upper and lower limits of the concentrations of the dissolved solids in the ground water body at that time and in a general way can show the distribution pattern of the water's quality[26]. In considering the variation of quality of ground water with time, it is better to think of aquifers as reservoirs subject to slow changes in quality as the water circulates, than to consider them as "pipelines" or watercourses through which water moves from one place to another[26].

Because of the natural variations in the chemical composition of waters, a water quality monitoring program must be designed in such a way as to adequately document the magnitude of spatial and temporal variability in the concentrations of the parameters selected for measurement[29]. In the following sections, the measures taken to achieve this are given.

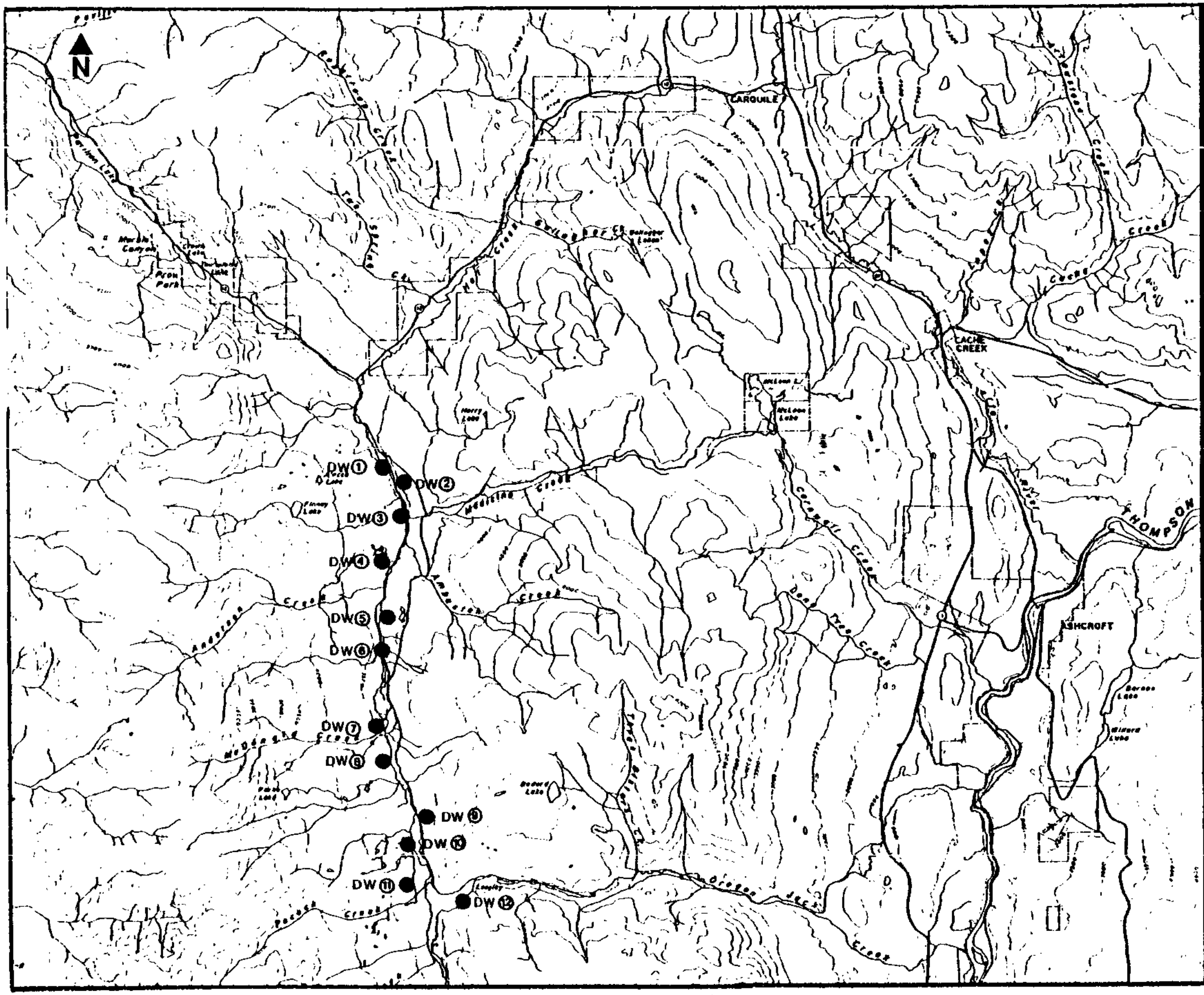
(i) Ground Water

The objective of the ground water program was to establish the baseline of the existing ground water quality in the Hat Creek Valley.

A. Programs

To establish the ground water quality in the Hat Creek Valley, a variety of different programs of sampling and analysis were carried out. Figures 3-5 to 3-7 show the location of sample sites for the ground water program. Table 3-4 shows the frequency of sampling for the different programs and Table 3-5 shows the different analyses performed for each program.

All domestic wells (DW) in the Upper Hat Creek Valley were tabulated (Table 3-6) and those of ground water origin were selected for sampling and analysis, thus excluding those wells designated as DW6, DW7, and DW11. The majority of domestic wells are located close to Hat Creek in the Upper Valley area and are less than 10 meters in depth.



B.C. HYDRO AND POWER AUTHORITY

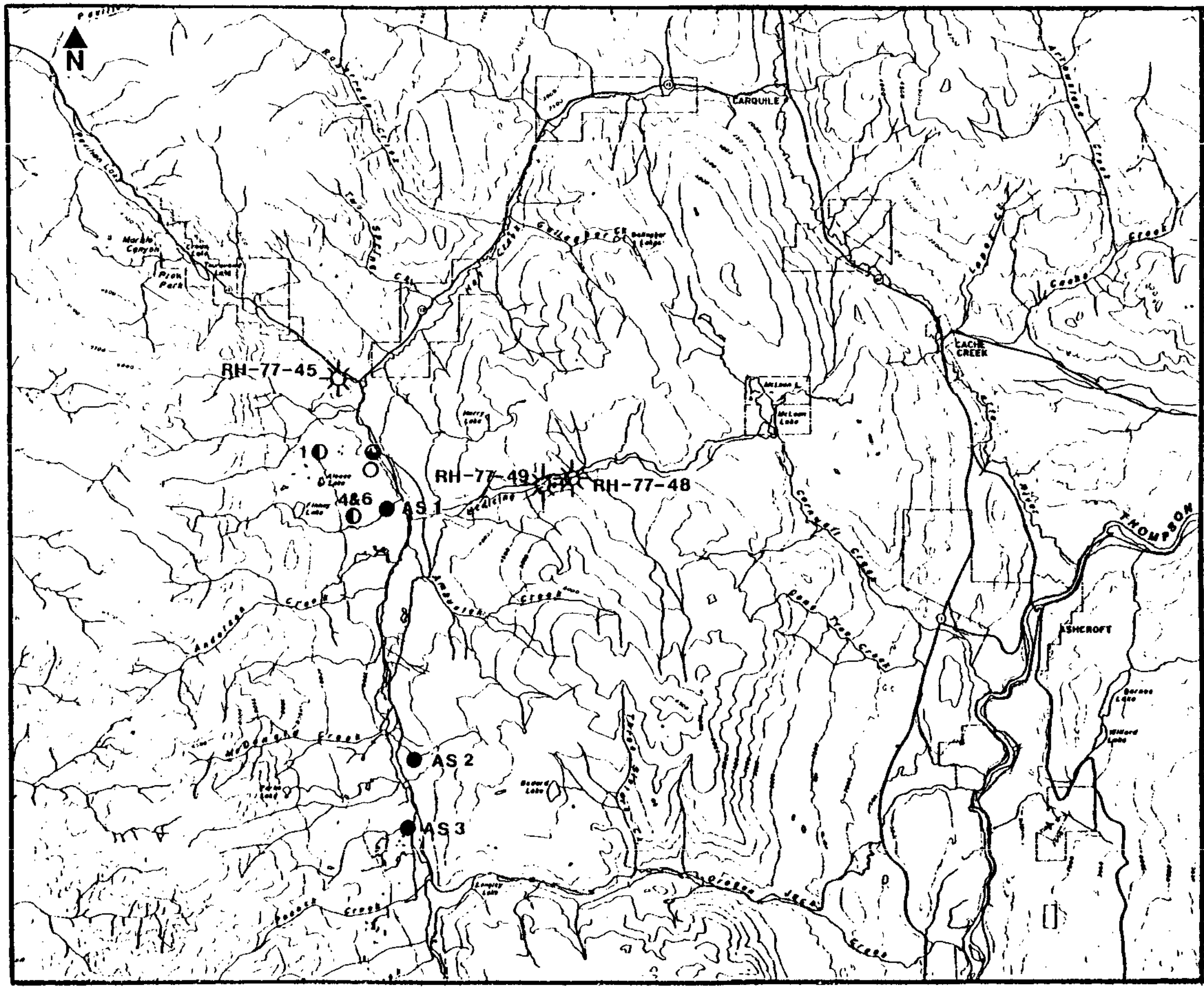
HAT CREEK PROJECT DETAILED ENVIRONMENTAL STUDIES

Figure 3-5

GROUNDWATER STATIONS

(BASE PROGRAM)

Domestic Well ●



**B.C. HYDRO
AND
POWER
AUTHORITY**

**HAT CREEK
PROJECT
DETAILED
ENVIRONMENTAL
STUDIES**

Figure 3-6:

GROUND WATER
STATIONS-
OTHER PROGRAMS

Artesian Springs
AS1, AS2, AS3 ●

1, 4&6 Pit
Hydrology Study
◐

Bucket Auger
Hole #7
(Coal Seam) ○

Power Plant Site
Study ☼

Well RH 76-19 ◒

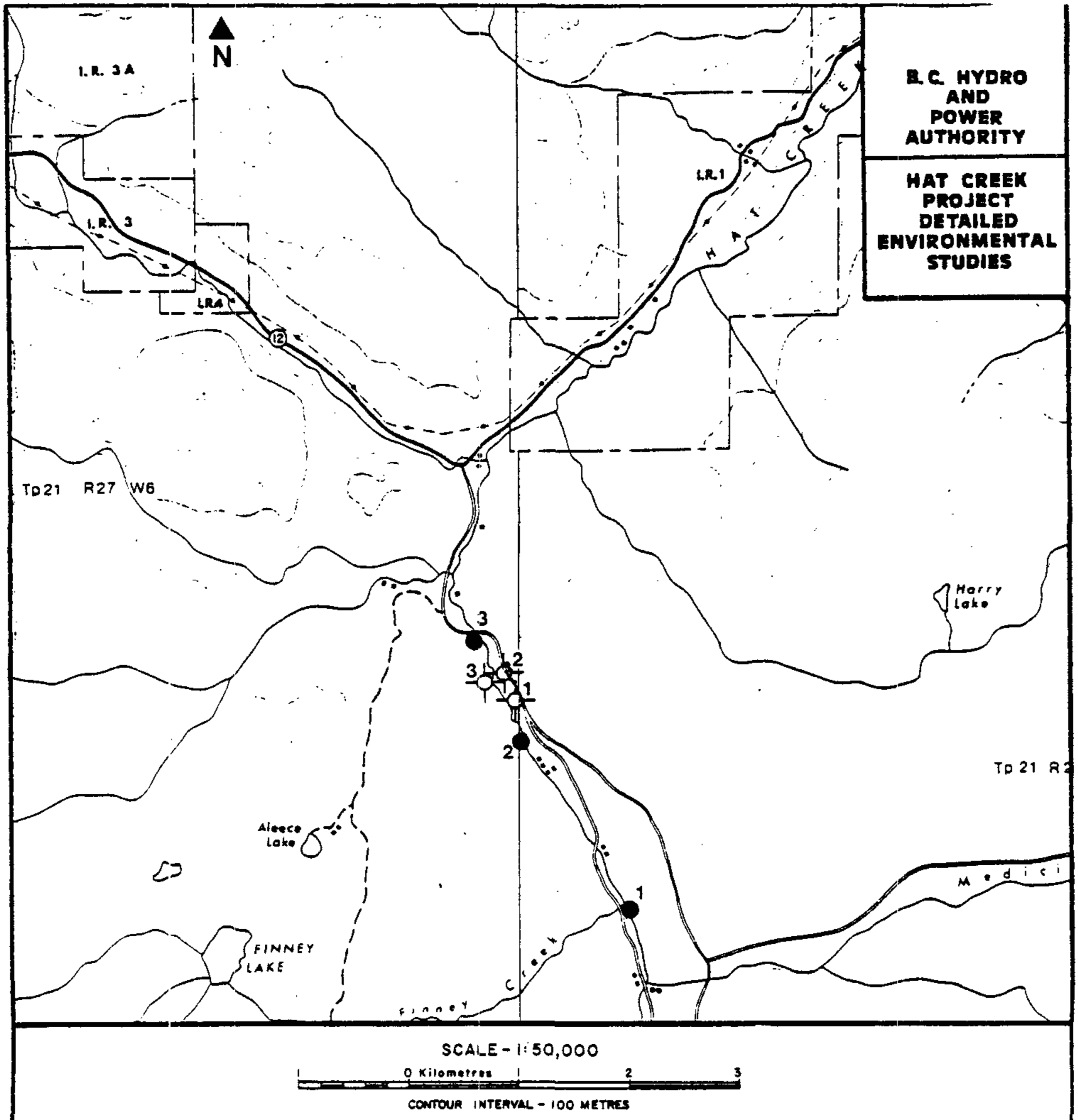


FIGURE 3-7 1977 COAL BULK SAMPLE PROGRAM SITES

WELLS ⌖

SURFACE WATER STATIONS ●

TABLE 3-4: SAMPLING PROGRAM*

PROGRAMS	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Hat Creek, Bonaparte River, Thompson River			3		4	1			3		3							
Goose & Finney Lakes			3		4	1			3		3							
Pit Hydrology Study			2															
Power Plant Site Study											3		4	1	2			
Fresnet Study											3,4	2						
Thompson River Intake Study								4	3			1						
Bulk Sample Program										4	2,4	2,4	1,3	1	2			
Pavilion Lake Study													4	1	2			

GROUNDWATER SAMPLING PROGRAM

PROGRAMS	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Domestic Wells					4	1			3,4									
Artesian Springs					4								3					
Pit Hydrology Study			2	2														
Power Plant Site Study														2				
Coal Seam			3															
Bulk Sample Program												1,3	1,3	1	2			

NOTE: Week 1 1-7
2 8-14
3 15-21
4 >21

---

* All numbers indicate the time when discrete grab samples were obtained.

TABLE 3-5: GROUND WATER PARAMETERS ANALYZED

PARAMETER	Domestic Wells	Artesian Springs	Pit Hydrology Study	Power Plant Site Study	Coal Seam	Bulk Sample Program
CATIONS Trace Metals						
Aluminum (Al)	x		x		x	x
Arsenic (As)	x		x		x	x
Cadmium (Cd)	x		x	x	x	
Chromium (Cr)	x		x		x	x
Copper (Cu)	x	x	x	x	x	x
Iron (Fe)	x	x	x	x	x	x
Lead (Pb)	x		x	x	x	x
Mercury (Hg)	x	x			x	x
Molybdenum (Mo)	x		x		x	
Selenium (Se)	x	x	x		x	x
Vanadium (V)	x	x	x	x	x	x
Zinc (Zn)	x	x	x	x	x	x
CATIONS- Alkali Earths & Metals						
Calcium (Ca)	x	x	x	x	x	x
Lithium (Li)	x	x	x		x	x
Magnesium (Mg)	x	x	x	x	x	x
Potassium (K)	x		x	x	x	
Sodium (Na)	x	x	x	x	x	x
Strontium (Sr)	x	x	x	x	x	x
ANIONS - General						
Boron (B)	x	x	x		x	x
Chloride (Cl)	x	x	x	x	x	x
Fluoride (F)	x	x	x		x	x
Sulphate (SO_4)	x	x	x	x	x	x
ANIONS - Nutrients						
Total Kjeldahl Nitrogen (N)	x		x		x	
Nitrate Nitrogen (NO_3-N)	x		x		x	
Nitrite Nitrogen (NO_2-N)	x		x		x	
Total Orthophosphate Phosphorous (P)	x	x	x		x	x
ORGANIC, NONIONIC,& CALCULATED VALUES						
COD	x					
TOC	x	x			x	x
Phenol	x					
Total Hardness (CaCo)	x	x	x	x	x	x
Total Alkalinity (CaCO)	x	x	x	x	x	x
PHYSICAL DATA						
pH (units)	x	x	x	x	x	x
Specific Conductance (umhus/cm @ 25°C)	x	x	x	x	x	x
True Colour (Pt-Co Units)	x				x	
Turbidity (NTU)	x				x	
Temperature (°C)	x				x	
PHYSICAL DATA - Residues						
Total Residue	x	x			x	x
Filtrable Residue	x	x	x		x	x
Nonfiltrable Residue	x	x			x	x
Fixed Total Residue	x				x	
Fixed Filtrable Residue	x		x		x	
Fixed Nonfiltrable Residue	x				x	
BIOCHEMICAL, DISSOLVED GASES & RELATED MEASUREMENTS						
BOD					x	
D.O.					x	
% Saturation						

TABLE 3-6

LIST OF DOMESTIC WELL SITES IN THE HAT CREEK VALLEY

STATION (MAP DESIGNATION)	LOCATION	ORIGIN	SAMPLING NOTES
DW 1	Hydro Camp - 3 m from Hat Creek	Hat Creek & Groundwater	-Galvanized culvert -Sampled at 1m (Van Dorn)
DW 2	50 m south of Hydro camp along old (low) road	Artesian	-Collected from reservoir -Seeping from Western hillside
DW 3	1.5 km south of Hydro camp - low road	Artesian (Finney Creek)	-Collected from irrigation -Possibly Finney Lake origin
DW 4	3 km south of Hydro camp - low road (south of proposed pit area)	Groundwater	-Sampled from tap -Well located about 20 m west of Hat Creek
DW 5	3/4 km north of old & new road southern junction on old road	Groundwater	-Hand pump well -15 m from Hat Creek
DW 6	1.5 km north of DW 5 on old road	Hat Creek	-Not sampled
DW 7	3/4 km south of old & new road southern juncture and west 3/4 km	Hat Creek	-Not sampled
DW 8	2 km south of DW 7	Groundwater	-Sampled from tap -15 m from Hat Creek
DW 9	3/4 km south of DW 8 and east from road (near landing strip)	Artesian	-Sealed reservoir -Sampled from tap
DW 10	2 km south of DW 9 & 100 m west of road	Groundwater	-Sealed well -6 m from Hat Creek -Collected from tap
DW 11	1.5 km south of DW 10 turnoff west	Hat Creek	-Not sampled
DW 12	3/4 km south of DW 11 turnoff west	Groundwater	-New residence -Sampled from tap

In addition to sampling domestic wells on a seasonal basis (winter and spring) five other sampling programs were carried out to meet specific information needs of the ground water hydrology program. To assess artesian flows in the Hat Creek Valley a number of sites were identified and selected for sampling and detailed analysis. To determine the hydrogeochemistry in the pit area, a well (Well RH 76-19) was sampled for various water quality parameters at a depth of 90 meters after 21 days of pumping. Local ground waters in the area were also sampled to provide comparative data. To further delineate the hydrogeochemistry of ground water in the pit area, an opportunistic sample was obtained from Bucket Auger Hole #7 located uphill from Well 59-19. This hole had a depth of 22 meters. To assist in the definition of the ground water regimes in the Medicine Creek area, Houth Meadows, and Hat Creek-Marble Canyon divide area, the water quality of several test wells was analyzed. These wells were sampled at depths ranging from 35 to 90 meters. Finally, as a means of identifying possible impacts to ground water quality as related to mining activities of the project, several wells were regularly sampled as part of the Bulk Sample Program. Well locations were chosen such that water quality in spoil and coal storage areas might be identified.

B. Sampling and Analytical Procedures

The collection dates for all ground water samples are given on Table C1-1, Appendix C.

Specific to the domestic well (DW) program, all known wells in the Hat Creek Valley were identified and those not pumped directly from Hat Creek were sampled. Inaccessible wells were sampled from the house tap after a flushing period. During sampling, comments by residents in the Valley concerning water quality were occasionally noted. Collections were carried out on a semi-annual basis in conjunction with surface water surveys.

For each program, samples were collected in either clean plastic bottles with plastic lined caps or, for the specific case of phenol, clean glass bottles. Samples were kept cool and dark. Samples for unstable parameters were preserved immediately upon collection as detailed in Table C1-2, Appendix C.

The methods used for the analysis of water quality samples and the associated references for each method are summarized in Table C1-3, Appendix C. Each method has been selected to minimize interferences and obtain suitable accuracy. The references from which they are selected are recognized as containing "standard procedures" consistent with government accepted methods, thus ensuring comparability of data.

C. Precision and Accuracy

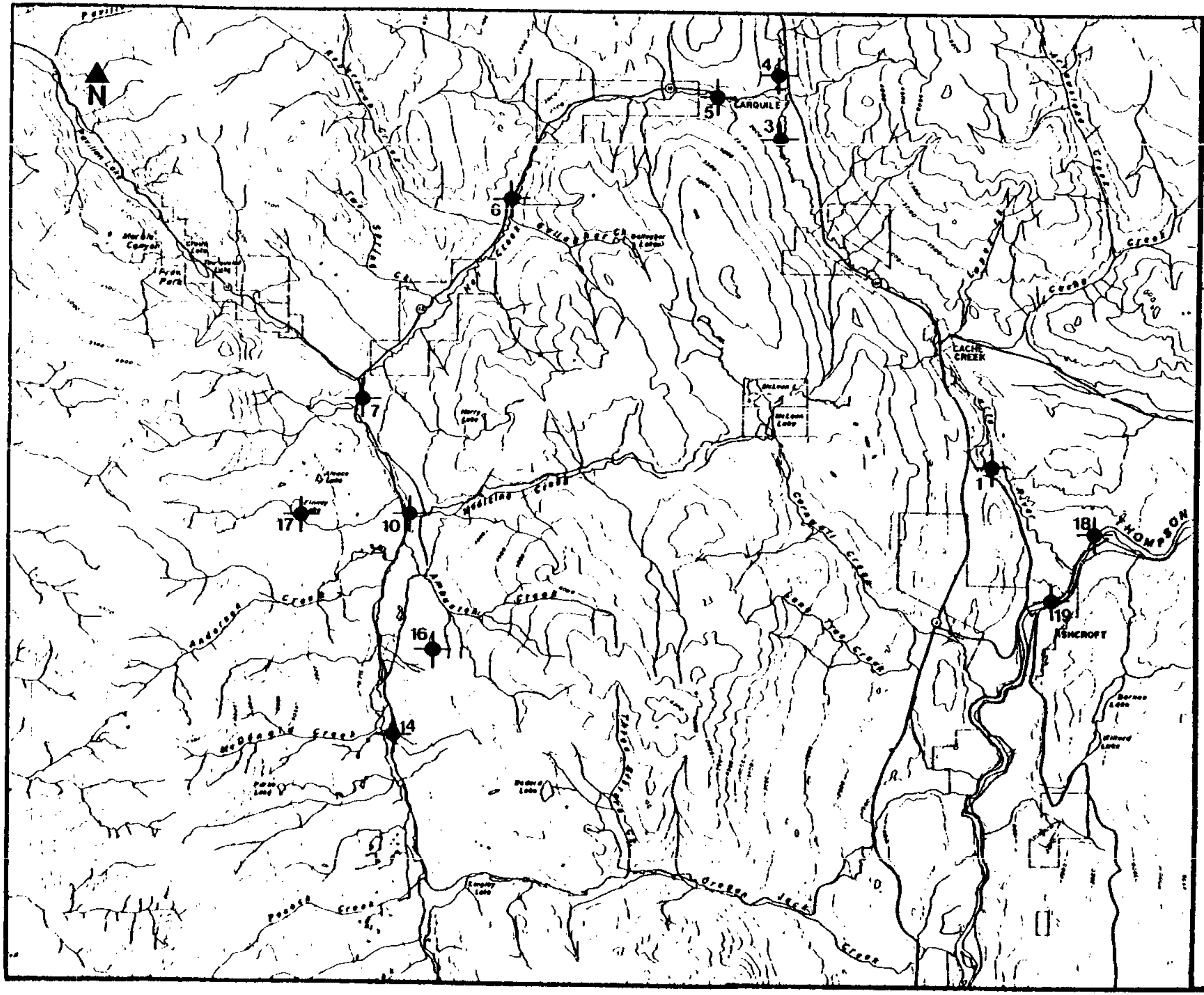
In establishing a comparative data base over a long period of time it is essential that strict quality control procedures be assumed. These measures involve analyzing duplicate aliquots of each sample (precision) and reference control samples (accuracy). This procedure has been performed on 10 to 20 percent of the samples analyzed, sufficient to ensure the validity of the resultant data. A further check on the accuracy of the laboratory procedures and also the completeness of the parameters selected, may be conducted by performing a cation-anion balance. The sum of all major cations expressed as equivalents/liter should be equal, within certain limits, to the sum of the major anions expressed similarly (Figures C2-1 to C2-3). The data contained in this report are expressed in mg/l, however, these values may be easily converted to equivalents/ liter. Several cation-anion balances are included in the detailed discussions that follow and may be used not only as an accuracy check but also as an indication of ionic distribution.

(ii) Surface Water

The objective of the surface water program was to establish the baseline water quality of Hat Creek above and below the proposed development plus the water quality of the water courses which could be influenced by Hat Creek.

A. Programs

To establish the existing surface water quality in the Hat Creek Valley and in the Bonaparte and Thompson Rivers, a variety of different programs of sampling and analysis were carried out. Figures 3-8 and 3-9 are maps of the



B.C. HYDRO AND POWER AUTHORITY

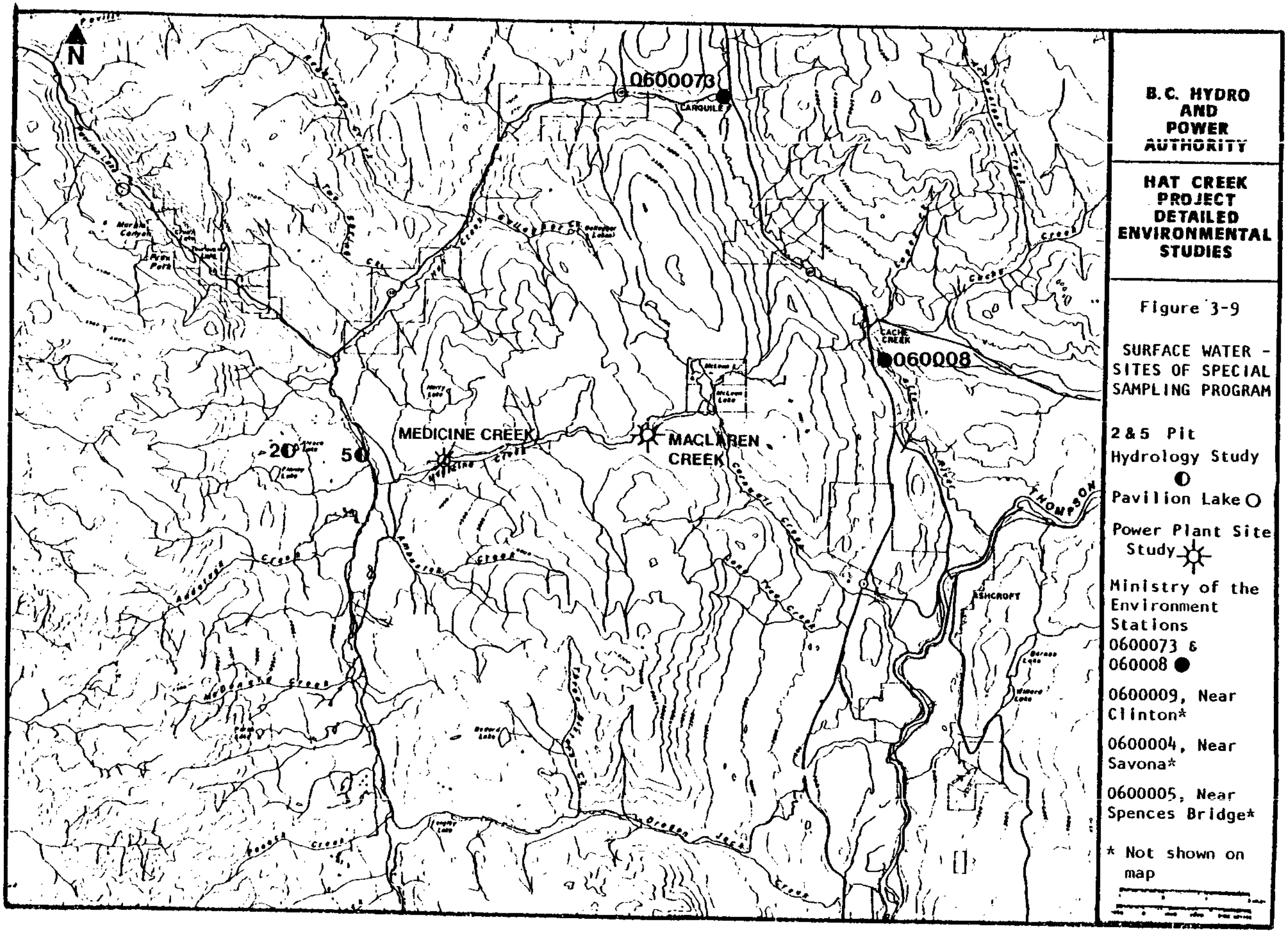
HAT CREEK PROJECT DETAILED ENVIRONMENTAL STUDIES

Figure 3-8

SURFACE WATER STATIONS

(BASE PROGRAM)

⌖



B.C. HYDRO AND POWER AUTHORITY

HAT CREEK PROJECT DETAILED ENVIRONMENTAL STUDIES

Figure 3-9

SURFACE WATER - SITES OF SPECIAL SAMPLING PROGRAM surface water sampling stations. Table 3-4 (also Table C1-4, Appendix C) shows the sampling dates for the various programs and Table 3-7 shows the parameters analyzed.

In deciding the locations for the temporally systematic sampling of Hat Creek and the Bonaparte and Thompson Rivers, care was taken to delineate spatial variations. The rationale behind the sample site location selection was to place sample sites above and below the entry of major tributaries to the stream of interest. In addition, the number of sample sites decreases in the order of Hat Creek, Bonaparte River and Thompson River. The reasons for this were two fold; first, from the standpoint of water quality, this is the order of importance of these water courses to the project; second, the available historical data follows a reverse order to this in terms of completeness.

During the course of this study five additional surface water sampling programs were initiated to assist in specific studies. These were the Pit Hydrology Study, Power Plant Generation Site Study, Freshet Study, Intake Design Study and the Coal Bulk Sample Program. In the Pit Hydrology Study the intent was to delineate the ground water composition in the proposed pit area. However, components of the data concern Hat Creek and Aleece Lake and have, therefore, been incorporated in the surface water section. Additional water quality data in the vicinity of the proposed power plant site was required to help delineate ground water flow regimes in the area. This necessitated the establishment of monitoring stations on Medicine Creek and MacLaren Creek. Pavilion Lake was sampled to document the water quality of this nearby standing water body. To determine the change in suspended solids loading during the freshet period a number of stations on Hat Creek and the Bonaparte River were selected and sampled daily over certain periods of the 1977 freshet. Changes in flow during this period were very low reflecting the very small spring runoff. Suspended solid concentrations and algae numbers in the Thompson River were determined from samples taken at the Walhachin Bridge located approximately 21.5 km upstream of the junction of the Bonaparte with the Thompson River. The purpose of the study was to delineate fluctuations of these parameters with particular reference to intake design. To

TABLE 3-7: SURFACE WATER PARAMETERS ANALYZED

	PROGRAM									
PARAMETER	Hat Creek	Bonaparte River	Thompson River	Pit Hydrology Study	Bulk Sample Program	Power Plant Site Study	Freshet Study	Thompson R. Intake Study	Goose/Fish Hook Lake	Finney Lake
CATIONS - Trace Metals										
Aluminum (Al)	x	x	x		x	x			x	x
Arsenic (As)	x	x	x		x	x			x	x
Cadmium (Cd)	x	x	x		x	x			x	x
Chromium (Cr)	x	x	x		x	x			x	x
Copper (Cu)	x	x	x		x	x			x	x
Iron (Fe)	x	x	x	x	x	x			x	x
Lead (Pb)	x	x	x			x			x	x
Mercury (Hg)	x	x	x		x	x			x	x
Molybdenum (Mo)	x	x	x			x			x	x
Selenium (Se)	x	x	x		x	x			x	x
Vanadium (V)	x	x	x		x	x			x	x
Zinc (Zn)	x	x	x		x	x			x	x
CATIONS- Alkali Earths & Metals										
Calcium (Ca)	x	x	x	x	x	x			x	x
Lithium (Li)	x	x	x		x	x			x	x
Magnesium (Mg)	x	x	x	x	x	x			x	x
Potassium (K)	x	x	x	x					x	x
Sodium (Na)	x	x	x	x	x	x			x	x
Strontium (Sr)	x	x	x		x	x			x	x
ANIONS - General										
Boron (B)	x	x	x		x	x			x	x
Chloride (Cl)	x	x	x	x	x	x			x	x
Fluoride (F)	x	x	x		x	x			x	x
Sulphate (SO_4)	x	x	x	x	x	x			x	x
ANIONS - Nutrients										
Total Kjeldahl Nitrogen (N)	x	x	x			x			x	x
Nitrate Nitrogen (NO_3-N)	x	x	x			x			x	x
Nitrite Nitrogen (NO_2-N)	x	x	x			x			x	x
Total Orthophosphate Phosphorous (P)	x	x	x		x	x			x	x
ORGANIC, NONIONIC,& CALCULATED VALUES										
COD	x	x	x			x			x	x
TOC	x	x	x		x	x			x	x
Phenol	x	x	x			x			x	x
Total Hardness (CaCo)	x	x	x	x	x	x			x	x
Total Alkalinity (CaCO)	x	x	x	x	x	x			x	x
PHYSICAL DATA										
pH (units)	x	x	x	x	x	x			x	x
Specific Conductance (umhos/cm @ 25°C)	x	x	x	x	x	x	x		x	x
True Colour (Pt-Co Units)	x	x	x			x			x	x
Turbidity (NTU)	x	x	x			x	x		x	x
Temperature (°C)	x	x	x			x			x	x
PHYSICAL DATA - Residues										
Total Residue	x	x	x		x	x			x	x
Filtrable Residue	x	x	x		x	x			x	x
Nonfiltrable Residue	x	x	x		x	x	x	x	x	x
Fixed Total Residue	x	x	x			x			x	x
Fixed Filtrable Residue	x	x	x		x				x	x
Fixed Nonfiltrable Residue	x	x	x			x			x	x
BIOCHEMICAL, DISSOLVED GASES & RELATED MEASUREMENTS										
BOD	x	x	x			x			x	x
D.O.	x	x	x						x	x
% Saturation	x	x	x						x	x

provide more detailed data on the possible effects of mining activities, three surface water stations were established on and near Hat Creek in association with the Bulk Sample Program.

B. Sampling and Analytical Procedures

The sampling and analytical procedures used were as outlined in Section 3.2 (b)(i) B Ground Water. Stream and small river samples (Hat Creek and Bonaparte River) were obtained at mid-width and in areas free from turbulence. The Thompson River was sampled 1-2 m from the stream bank. Lake samples for detailed analysis were obtained near the surface.

During the initial survey carried out in September 1976 total concentrations and, where the total concentration was greater than the minimum detectable concentration (MDC), dissolved concentrations were determined. The procedure was modified in future samples so that, with the exception of mercury, only dissolved concentrations were measured. This was done for three main reasons:

(1) The current Ministry of the Environment (B.C.) regulations are based on dissolved concentrations with the exception of mercury[30,31].

(2) The dissolved component is a prime biologically active component[32].

(3) The great majority of ions were below the MDC in the total test.

C. Precision and Accuracy

The methods used to ensure precision and accuracy were outlined in Section 3.2 (b) (i) C Ground Water

(c) Water Use

(i) Ground Water

Interviews were carried out with water users. No metered flows were available and estimates of water consumption were made.

(ii) Surface Water

A. Irrigation

Field work was limited to the observation of irrigation practices of the area at various times during 1976 and 1977, and the discussion of irrigation practices with Hat Creek Valley ranchers.

B. Livestock

Examination of livestock water use did not involve any field work.

C. Domestic and Municipal

Examination of surface water domestic and municipal use was restricted to collection and review of existing available data.

4.0 RESOURCES INVENTORY

4.1 HYDROLOGY

(a) Ground Water

(i) General Regional Geohydrology

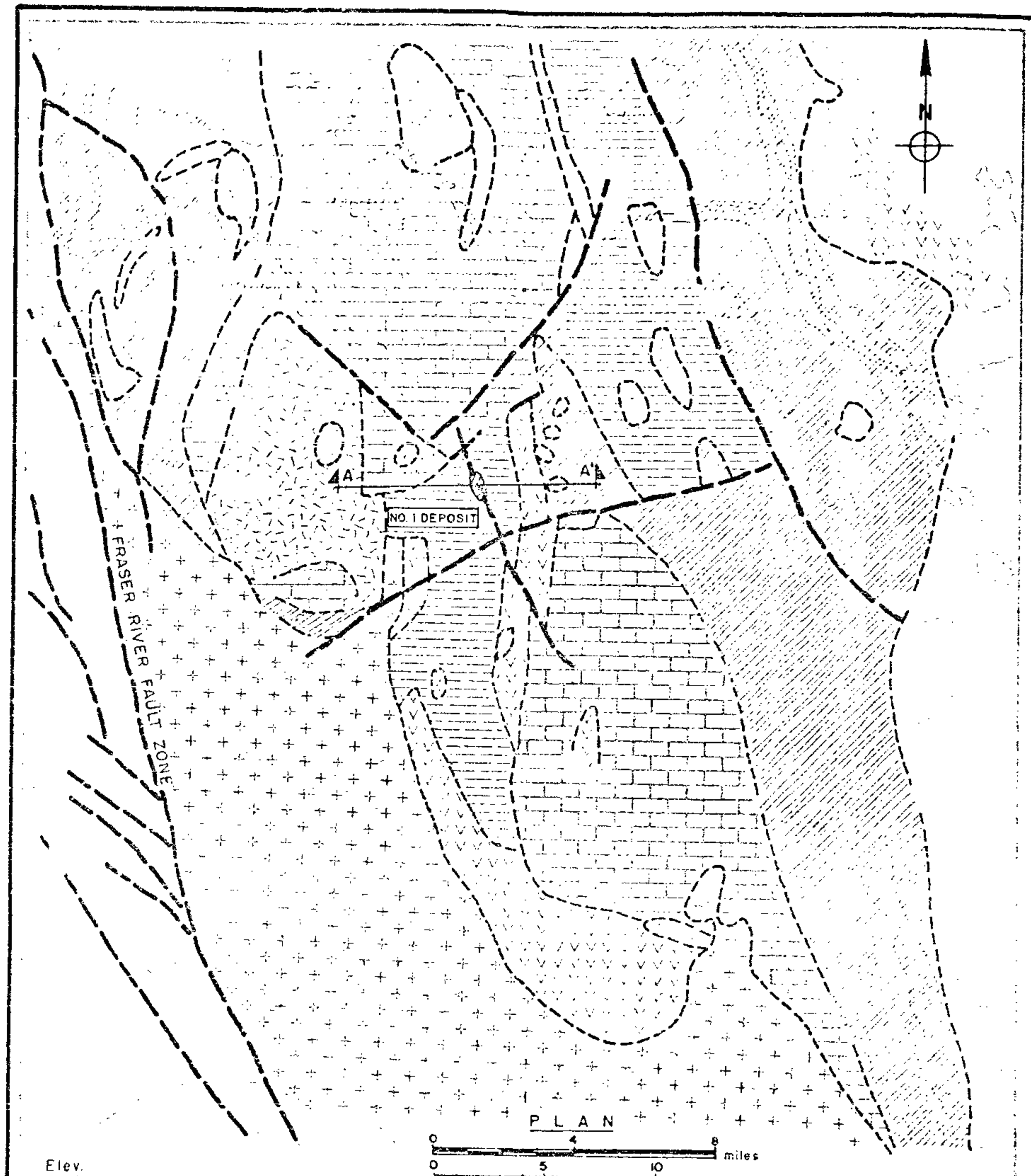
The rate of recharge and movement of ground water in any given region will depend on the topography and on the nature of local bedrock and unconsolidated sediments. The topography in the Hat Creek region varies from steep in the Marble Canyon region to rolling in the southern end of the valley. Elevations range from a high of about 1,900 m (6,230 ft.) on the west topographic divide to about 550 m (1,800 ft.) at the confluence with the Bonaparte River.

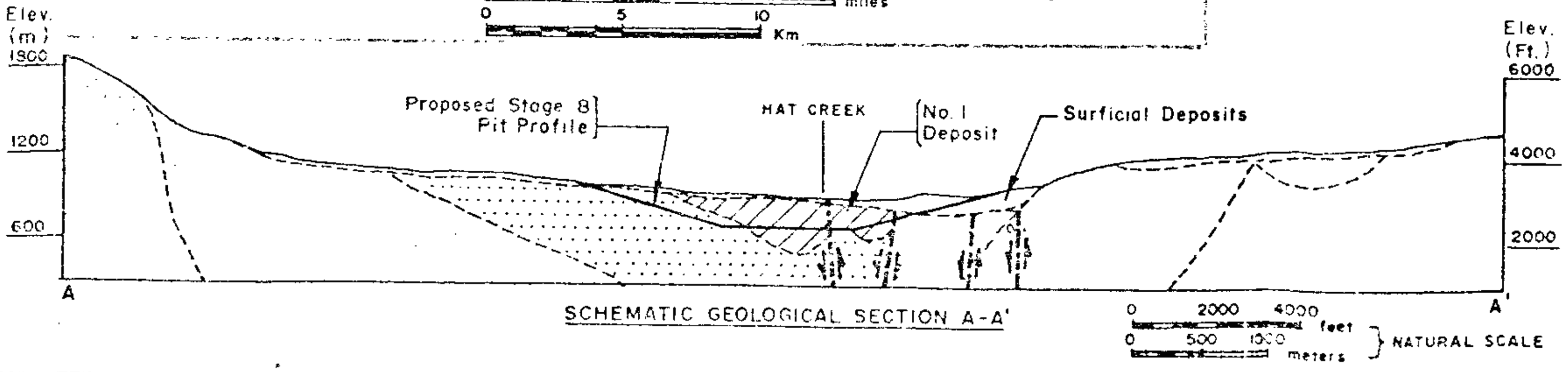
Unconsolidated surficial sediments cover much of the Hat Creek Valley and the bedrock sediments beneath are very varied (see geologic map in Figure 4-1). Most of the surficial deposits and bedrock units are made up of fine grained sediments and do not have a very high hydraulic conductivity. While some ground water does flow through these materials, this flow is generally insufficient to classify the geologic unit as an aquifer (see definition of an aquifer in Appendix A1.0). There are only three potentially distinct types of extensive aquifers in the Hat Creek area: fractured limestone bedrock; fractured intrusive bedrock; and sand and gravel aquifers in surficial deposits (see an outline of these areas in Figure 3-4).

The following is a review of the hydrogeological characteristics of each major geological unit found in the Hat Creek Valley.

A. Surficial Deposits

There is a thick and almost total cover of surficial deposits over the Hat Creek Valley (Ryder 1976)[1]. These deposits are varied and have diverse origins (including glacial till, lacustrine deposits, glacio-





SCHEMATIC GEOLOGICAL SECTION A-A'

GEOLOGICAL SUCCESSION

Cenozoic	Quaternary	Recent	alluvium, colluvium, landslide debris, peat, volcanic ash.	
		Pleistocene	glacial till, glacio-lacustrine silt, glacio-fluvial sand and gravel, landslide debris, colluvium, volcanic ash.	
	Tertiary		Olivene basalt and lahar (Miocene)	□
		Kamloops Group	Coldwater Formation; conglomerate, sandstone, siltstone, claystone and coal, often bentonitic or tuffaceous (Eocene)	□
			Kamloops Volcanics; basalt, andesite, dacite, rhyolite with associated tuffs, agglomerates and breccias (Eocene).	□
Mesozoic	Early Tertiary to Late Cretaceous	Spences Bridge Group	volcanic and minor sedimentary rocks.	□
Palaeozoic	Permian	Cache Creek Group	Marble Canyon Formation; limestone.	▨
			Greenstone, chert, argillite, quartzite, limestone and phyllite.	▨
	Intrusive Rocks			
Mesozoic	Early Cretaceous to Late Jurassic	Mount Lytton Batholith (Mount Martley Stock).	granodiorite, quartz diorite and diorite	▨

LEGEND

- - - - - Inferred Geological Contact
— — — Inferred Fault
Ground contours given in feet

REFERENCES:
G.S.C. Ashcroft Sheet - Map 1010A.
H. Trettin - Geology of the Fraser River Valley - B.C. Dept. of Mines - Bull. 44, 1961.
B.N. Church - Geology of the Hat Creek Basin - B.C. Dept of Mines - Summary of Field Work, 1975.
Dolmage Campbell & Asso. - Outline Map 1"=2000', 1976.
Golder Assoc., B.C. Hydro & Power Authority - Field Work, 1976
B.N. Church - Geology of the Hat Creek Coal Basin - B.C. Dept. of Mines - Geology in British Columbia (1975 work), 1977.

NOTES:
Glacial cover omitted from Plan.
Coldwater Formation subdivided by rock types on section as follows:

□ Siltstone and claystone (Medicine Creek Fm.)*
▨ Coal (Hat Creek Coal Fm.)*
⬚ Sandstone, conglomerate siltstone. (Coldwater Beds)*

* Nomenclature suggested by Church (1977)

Golder Associates
B.C. HYDRO & POWER AUTHORITY
HAT CREEK ENVIRONMENTAL STUDY

REGIONAL GEOLOGY

DRAWN I.D.T.	CHK'D	REVIEWED
DATE DEC., 1977	SCALE AS SHOWN	FIGURE 4-1

fluvial deposits, colluvium, alluvium and slide debris). Because of the diversity of these deposits, a detailed distribution is not shown in this report and the reader is referred to a detailed map provided in Ryder 1976 [1].

In general the surficial deposits on the western bench of the upper Hat Creek Valley are less well drained than the deposits on the eastern bench. Springs and seeps are common on the western side particularly below the 900 m (3,000 ft.) contour (Golder Associates, Reference 2) and these seeps are particularly noticeable between Finney and Anderson Creeks.

The following is a brief summary of hydrogeological characteristics of the major surficial deposits encountered around the proposed development areas. The distribution of some of these units will be described further in Section 4.1 (a) (ii).

Alluvium

Alluvium is found predominantly along the bottom of the valley (see Figure 3-4) and is made up of reworked glacial and colluvium deposits consisting of sands and gravels commonly with silt interbeds and occasional clay layers. Sufficient ground water has been encountered to classify this geologic unit as a ground water aquifer. The test trench "B" excavated for the coal bulk sample study intersected a 5 m (16 ft.) thick sequence of permeable sands and gravels with hydraulic conductivities ranging from 10^{-4} to 10^{-2} m/sec. The quantity of water pumped from this trench ranged up to a steady flow of about 1,700 m^3/day. The B.C. Hydro exploration camp wells (DW-1) yield water from the same alluvial sediments and the yield is estimated to be in the order of 10 m^3/day. Most of the shallow dug wells located along the Hat Creek Valley are producing ground water that has infiltrated through the alluvium from Hat Creek.

Till

A glacial deposit, consisting of cobbles and gravels with occasional boulders up to 1 m diameter in a matrix of sand, silt and clay is located on the west side of the valley. Hydraulic conductivities are generally very low and hence, this unit cannot be classed as an aquifer.

Glacio-fluvial Deposits

Thick sequences of glacio-fluvial sediments up to 90 m thick (Golder Associates, 1977 [2]) have been encountered in exploration drill holes along the east side of the valley in the vicinity of the proposed coal pit. These deposits consist of interbedded sands and sandy gravels with cobbles and boulders up to 0.6 m. Typically there is much variation in grading, with some interbedded tills, clays and silty sediment zones. However, while these sediments are relatively thick and potentially permeable, they are generally dry and well drained particularly in the area immediately south east of the proposed pit.

The location of a potential buried glacio-fluvial aquifer north of the proposed coal pit is shown in Figure 3-4. These deposits are an extension of the east side sediments described above. A relatively high yield aquifer was encountered in borehole RH-77-46 which is located near the junction of the Hat Creek road and Highway 12. The significance of these two aquifers is further discussed in Section 4.1 (a) (ii).

Relatively high flows (up to 270 m^3/day for short periods of time) have been observed while drilling geotechnical boreholes in the vicinity of the proposed coal pit. These high flows in glacio-fluvial sediments suggest the presence of an aquifer, however drill logs of adjacent boreholes shows that these water bearing zones are of limited areal extent (Golder Associates, 1977[2]).

Slide Debris

A substantial volume of slide debris is located on the west side of the valley especially in the northwest part of the valley. These sediments are composed of a variable assortment of till and Coldwater sediments often in a bentonite matrix. Hydraulic conductivities are very low except along slide planes and there are no known aquifers in this unit. However some shallow depressions in the typically uneven surface topography have been filled with sloughs that have been fed by shallow ground water seeps and surface water run-off.

B. Bedrock Formations

The regional bedrock geology is shown in Figure 4-1. The oldest (basement) rocks, the Cache Creek Group, consist primarily of altered sedimentary rocks. These rocks are near the ground surface over approximately 50 per cent of the study area. The more recent bedrock formations are made up of Spences Bridge Group (mainly volcanic rocks) and Kamloops Group (consisting of volcanic and sedimentary rocks). The following is a brief hydrogeologic description of the significant bedrock units found in the study area.

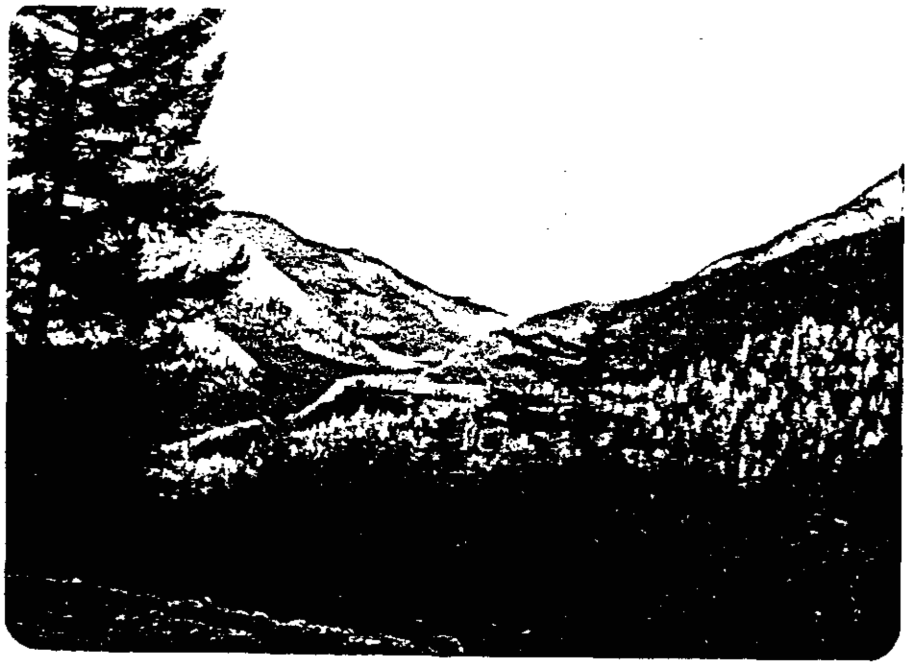
Limestones (Marble Canyon Formation)

These massive limestones are well distributed throughout the area (see Figure 4-1) and there are many exposures, noteably in the Marble Canyon Area and northern side of the Houth Meadows Area (Figures 4-2 and 4-3). Based on an examination of exposed limestone bedrock in the nortn Houth Meadows Area (McCullough 1977[3]), it appears that the fractures are steeply dipping (largely between 60 degrees and 80 degrees) and only a few fractures could be classified as extensive. No significant karstic features have been identified in this area.

Borehole RH-77-45 penetrated 49 m (160 ft.) of fractured limestone located in a fault or fracture zone north of Houth Meadows. The water yield at a

MARBLE CANYON

Figure 4-2



View of Marble Canyon from hill side south of Tranquille Lake, looking southeast towards the upper Hat Creek Valley junction. A relatively flat sediment filled valley bottom can be seen in middle of photo. These sediments are believed to be relatively permeable and is a potentially substantial aquifer.

V.76359 CG RAD Jan/78

HOUTH MEADOWS AREA

Figure 4-3

Houth Meadows waste dump area. Note exposed and fractured limestone bedrock. Borehole RH 77-45 is located in the far side of the Narrow valley leading through this bedrock.

Wrong text. See Fig 4.5.

depth of 92 m was 2 l/s (168 m^3/day) and the formation's hydraulic conductivity in this fracture zone averaged 10^{-6} m/sec. As these limestone formations are relatively permeable, particularly along fault zones, they can be regarded as a moderate yield aquifer.

Altered Clastic Sedimentary Rocks

These rocks are made up of greenstone, chert, argillite, (part of Cache Creek Group) quartzites and phyllite and may be interbedded with the limestone. Hydraulic conductivities are typically low, ranging between 10^{-10} and 10^{-8} m/sec, with the higher values being encountered in fractured or fault zones. The ground water flowing through these rocks moves very slowly and hence water quantities and qualities abstracted from any wells would be unsatisfactory due to low yields and high dissolved salts content.

Volcanic Rocks (Kamloops Group Only)

These include a diverse group of rocks: basalt, andesite, dacite, phyllite with associated tuffs, agglomerates and breccias. Falling head permeability tests indicated that typical hydraulic conductivities around 10^{-6} m/sec could be anticipated.

The Kamloops Group volcanics are believed to form the basement of the Hat Creek Basin in the proposed pit area, although it is possible that the Marble Canyon Limestone may locally underlie the Coldwater sediments in the northwest. The Kamloops Volcanics are faulted against the overlying Coldwater Formation along the eastern margin of the Hat Creek Basin.

Poorly Consolidated Sedimentary Rocks (Coldwater Formation)

These comprise a thick sequence of fine grained Tertiary clastic rocks and a substantial accumulation of low grade coal up to 460 m (1,500 ft.) thick.

Although there is much facies variation within the basin, sandstones and conglomerates with siltstones predominate below the coal, and siltstones with claystones predominate above. The Coldwater Formation is thickest in the center of the basin (1,200 m +) and is faulted along the margins, particularly along the east side of the valley. In the Medicine Creek area, the picture becomes more complex and volcaniclastic rocks are present possibly forming much of the Coldwater Formation Sequence. Thin volcanic flows are also present.

The most permeable zones in this formation are the coal units. Results of falling head permeability tests give typical values for hydraulic conductivity as follows:

Clastic Coldwater Sediments (both basal and upper units)	10^{-10} m/sec
Coal	10^{-6} m/sec

As the coal units are generally encapsulated within the low permeability claystone and siltstone units, the ground water yield from the coal will be limited to the quantity of water that can flow through the claystone. Calcite veins are relatively frequent in some areas and this mineralization is believed to further reduce the formation's hydraulic conductivities. There are no significant aquifers in these sedimentary rocks.

Intrusive Bedrock

A large body of intrusive rock is exposed at the higher elevations west of the coal pit area. The rock types include granodiorite, quartz diorite and diorite, and based on an air photo examination the rock mass appears to be relatively massive with only minor fracturing. No permeability tests have been made in this formation at Hat Creek. However based on data from other areas, hydraulic conductivities of about 10^{-7} m/sec would be expected.

(ii) Flow Patterns

Both the surficial and bedrock geology of the Hat Creek Valley are very diverse and as a consequence the ground water flow patterns are complex. In order to simplify the study of these flow patterns four areas have been selected for detailed evaluations. These areas have been selected primarily because they appear to be major potential impact locations after development commences. These are areas which could be reasonably expected to be influenced by hydrogeologic changes caused by the proposed mining and power generation activities.

A. General Flow Systems in the Upper Hat Creek Valley

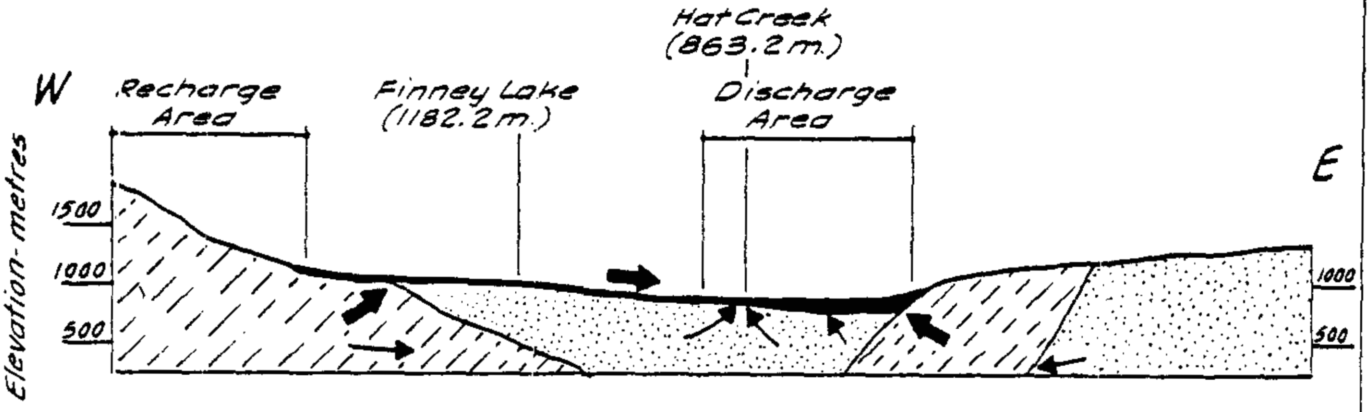
The flow systems in the upper Hat Creek Valley can be characterized by ground water recharge in the upland areas and discharge in the valley bottom. The east-west flow patterns across the valley are shown for the area around the proposed pit in Figure 4-4. These flow patterns can be regarded as typical of flows across most parts of the Hat Creek Valley.

The ground water flows typically under an approximate hydraulic gradient of 0.1 toward Hat Creek where most of the discharge occurs. Recharge in the upland areas takes place through thin surficial sediments into volcanic and limestone bedrock. Lower down the valley, the ground water flows into the clastic Coldwater sediments. A pump test of a screened well in these Coldwater sediments (RH-77-19, see location Figure 3-4) showed that ground water in the sands and gravels in the till above the Coldwater Formation was recharging water to the siltstone-claystone sediments.

Estimates of the quantity of ground water which discharges into Hat Creek have been made by considering the amounts of precipitation which fall into the upland recharge area.

SECTION THROUGH HAT CREEK VALLEY AT LOCATION OF PROPOSED COAL PIT.

Figure 4-4



Natural Scale

NOTATION:

▨ Rocks with relatively high hydraulic conductivity (greater than 10^{-4} cm/sec)

▒ Rocks with relatively low hydraulic conductivity (less than 10^{-4} cm./sec)

▬ Surficial sediments.

← Low rate of groundwater flow.

➡ Higher rate of groundwater flow.

(863.2m) Approx. elevation of water surface.

V76359 [illegible] [illegible] Jan '78

The assumptions made were:-

- that recharge zones extend approximately 2 kilometers toward Hat Creek from a ground water divide in the upland areas.

- That about 10 percent of the mean annual precipitation on the upland areas will infiltrate to the ground water table in the recharge zones. This percentage is a reasonable value based on analyses of hydrogeologic data in other regions similar to Hat Creek. The estimated accuracy is ± 30 percent.

The mean annual precipitation in the upland areas (i.e. above elevation 1,300 m) is between 355 and an assumed maximum of 430 mm at the highest elevations (see precipitation variation given in Figure 4-26, Section 4.1(b)(ii) A). We will assume that the average precipitation in these upland ground water recharge areas is 400 mm. Thus, ground water discharge is estimated to be 10 percent of 400 mm = 40 mm per year. Using Darcy's equation (see glossary) for calculating ground water seepage, the estimated ground water discharge along the valley is between 284 and 568 m^3/day per kilometer. Also it is estimated that in the order of 0.5 - 2 percent in bedrock of the ground water which discharges into Hat Creek originates from the Coldwater sediments and the remaining ground water reaches the creek through surficial sediments.

In the vicinity of the proposed coal pit, the east bench is better drained due to a greater thickness of surficials which consist predominantly of the moderately high permeability glacio-fluvial sediments. As a result ground water discharge on the east side of the valley passes through the alluvium and into Hat Creek without any surface discharge. On the west bench the surficial cover is much thinner and consists predominantly of low permeability tills with some interbedded glacio-fluvial sediments. As a result, the west bench slopes are less well drained and springs and seeps are common particularly below the 900 m contour.

At several locations in the Hat Creek Valley, small ponds exist which display a distinctive light coloured deposit around their perimeter (see Figure 4-5). These are evaporite deposits which are concentrations of salts formed by the evaporation of water from restricted basins. These

SALINE SLOUGH

Figure 4-5

A typical shallow slough that is commonly found in the Hat Creek valley. These depressions collect both shallow ground water seepage and surface water run-off. The regional water table is generally many 10's of meters below ground surface. Most of the water collecting in these ponds will evaporate and never reach the regional water table. White residual salt deposits left behind on evaporation can be seen in places around the edges of the slough.

Project No. Y-76359 Drawn CG Reviewed RD Date Jan/78 ponds appear to have a relatively impermeable silty bottom and show no indication of surface outlets.

Observations around Finney and Aleece Lakes suggest that these lakes are fed by local perched ground water flow systems and small streams flowing from the west. Intermittent surface water discharge from these lakes can occur, especially during the spring freshet. The remainder of the lake water is dissipated mainly as evaporation and only a small amount by ground water discharge. Evidence for the latter conclusion is based on isotope data and is presented in Section 4.1 (a) (iii) B.

The only potentially significant aquifers in the main Hat Creek Valley are: the valley alluvium and a bedrock valley filled with glacio-fluvial sediments northeast of the proposed coal pit.

Valley Alluvium

The depth and width of the aquifer will be variable, however by assuming an average depth of 5 m and width of 100 m, the estimated ground water flow down valley in this aquifer is 2,300 m^3/day. As the size and shape of the aquifer will vary and as the aquifer is hydraulically connected to Hat Creek, there will be an interchange of water between the creek and aquifer along the length of the creek channel. This interchange will be in both directions; either from aquifer to creek or vice versa, depending on the prevailing hydrogeologic conditions.

Glacio-fluvial Valley

As mentioned earlier a number of boreholes drilled for coal exploration in the area northeast of the proposed coal pit have delineated part of the buried bedrock valley. The approximate outline of this valley is shown in Figure 3-4. However, it should be noted that the location of the northern part of this valley has not been probed by drilling and hence its depth and location have been estimated by extrapolating existing data in the south. The channel is approximately 600 m wide and while the depth is variable the estimated average depth below the water table (elevation 833 m) is 100 m below the general bedrock surface. By assuming a hydraulic conductivity of 10^{-4} m/sec and using the Darcy equation the estimated ground water flow along this valley is 5,000 m^3/day. The discharge from the northern end of the valley will probably seep through alluvium and then into Hat Creek.

B. Houth Creek Basin

The Houth Creek Basin is located in the northwest corner of the Hat Creek Valley (see location Figure 3-4) and is of particular interest as much of the valley could possibly be used as a storage area for waste rock. The significant geological units and ground water flow systems within the basin are shown in Figure 4-6.

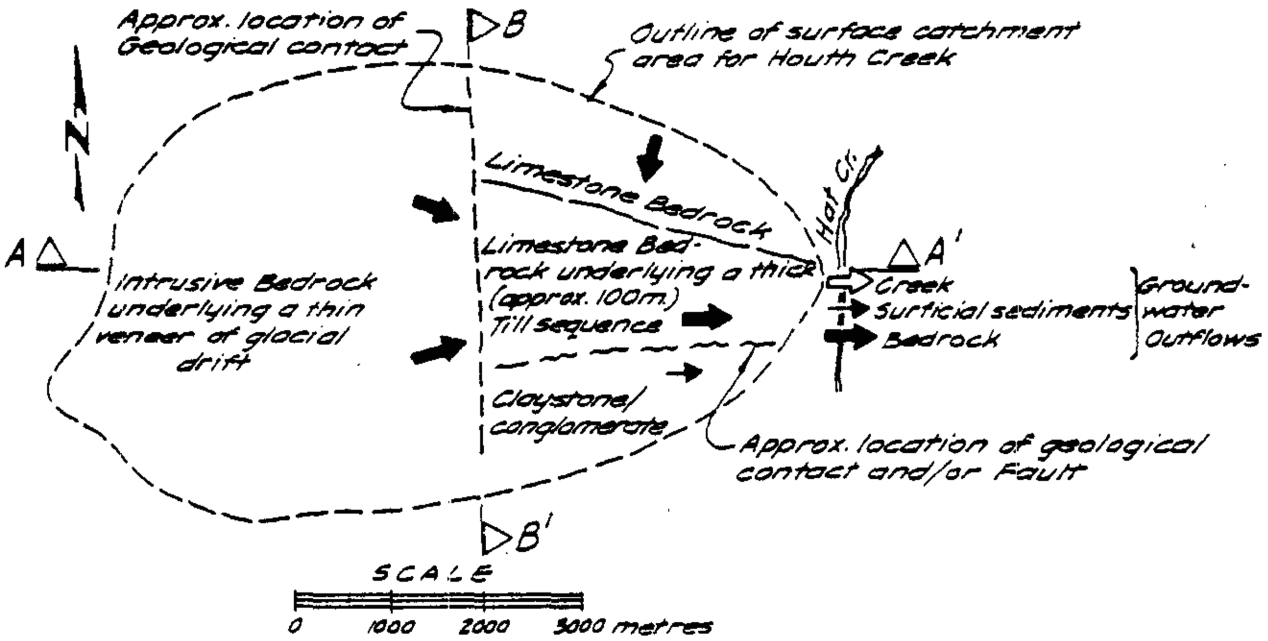
The limestone and intrusive bedrock formations are the only potential aquifer systems in the basin. Ground water recharge will take place in the upland areas along the northern and western margins of the basin. The floor of the flatter parts of the basin is covered with a thick (generally over 100 m) veneer of relatively dense till. There are no existing data on hydraulic conductivity and ground water levels for these tills. However, some data will be obtained during the 1977-1978 geotechnical drilling program. Preliminary data suggest that the tills will have a low hydraulic conductivity and that the regional ground water table will be in the order of 30 m below ground surface at the center of the basin.

[illegible]

Some of the ground water flowing south through the limestone bedrock appears to discharge as a series of springs and seeps in the valley floor along the base of the bedrock slopes. For example the small lake (Houth Lake) in the northeastern corner of the basin appears to be spring fed. These seeps, along with other ground water discharges, contribute to the base flow in the north branch of Houth Creek. The south branch of this

GROUND WATER FLOW SYSTEMS IN HOUTH CREEK BASIN

Figure 4-6



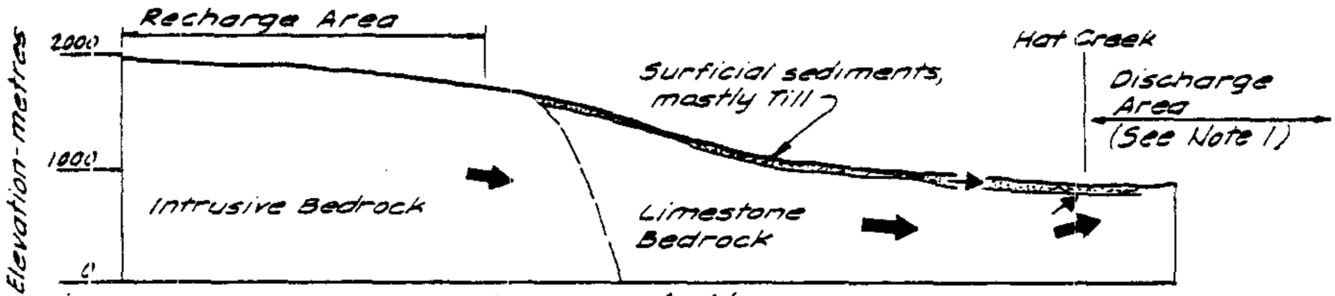
PLAN OF HOUTH CREEK CATCHMENT

Notation:

⇨ Surface groundwater flows (base flow)

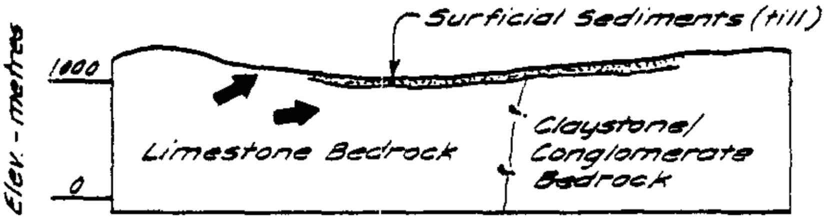
→ Groundwater flows less than 10 m^3/d.

➡ Groundwater flows greater than 10 m^3/d.



SECTION A-A'
Natural Scale

Notes: 1) Discharge area possibly extends towards the east, in the vicinity of the buried fluvio-glacial channel. See location Fig. 3-4.



SECTION B-B'
Natural Scale

Project No. V76359 lag RaD Jan '78

Golder Associates

creek drains the areas underlain by bedrock with a low hydraulic conductivity. Consequently, as the ground water discharge from the bedrock is negligible this branch of the creek would normally dry up soon after the spring run-off.

The flow in Houth Creek as recorded at its mouth, is given in Figure 4-7. As can be seen, there was very little run-off resulting from summer rain and hence, most of the discharge recorded during the monitoring period was ground water discharge.

Estimates for the total ground water budget have been made. Seepage flows can be estimated by using the Darcy equation (see Appendix A1.0) and in order to apply the equation the following assumptions were made:-

- The bedrock was assumed to be isotropic and relatively homogeneous.
- The average hydraulic conductivity for both limestone and intrusive bedrock was 10^{-7} m/sec.

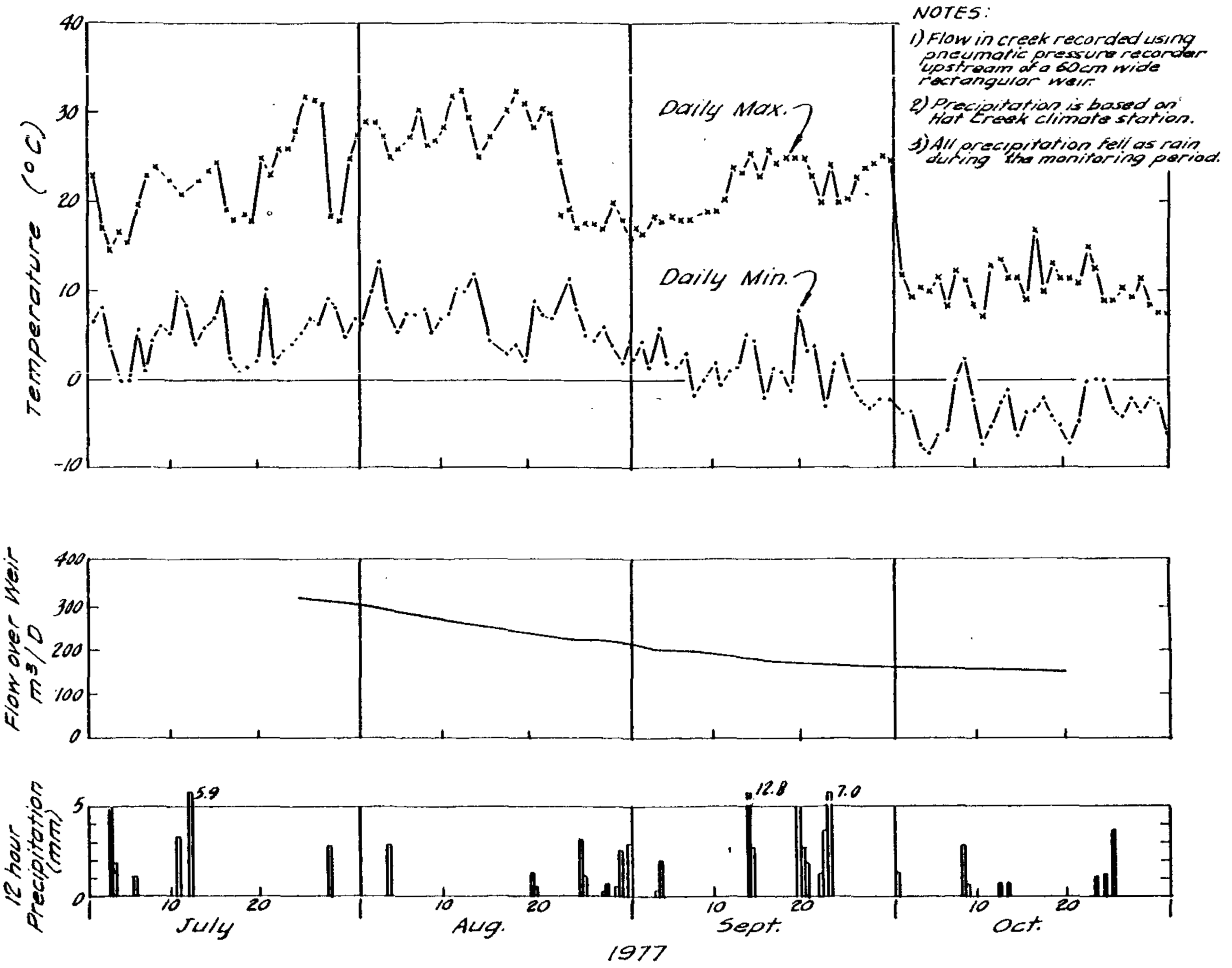
The calculated ground water flows shown in Figure 4-6 are as follows:-

Inflow:	
from north	72 m^3/d
from west	360 m^3/d
TOTAL	432 m^3/d
Outflow toward the east:	
in limestone	168 m^3/d
in till	2 m^3/d
in claystone-conglomerate	1 m^3/d
TOTAL	171 m^3/d

The difference between these two totals is the estimated ground water discharge to the ground surface within the Houth Creek Basin, i.e.:-

$$432 - 171 = 261 \ m^3/d$$

V76359 lng May '78



NOTES:

1) Flow in creek recorded using pneumatic pressure recorder upstream of a 60cm wide rectangular weir.

2) Precipitation is based on Hat Creek climate station.

3) All precipitation fell as rain during the monitoring period.

FLOW IN HOUTH CREEK AT HAT CREEK JUNCTION

Figure 4-7

Golder Associates

By inspection of the flow record given in Figure 4-7 the average annual ground water component of flow in Houth Creek is estimated to be about 220 m^3/d, the ground water lost as evapotranspiration in the wet areas especially along the toe of the hillside slopes would account for the remaining discharge, i.e.:

$$261 - 220 = 41 \text{ m}^3/\text{d}$$

This represents an annual evapotranspiration loss of about 30 mm over the estimated ground water discharge area (about 0.5 km^2). The above calculations are necessarily approximate. However, they are provided to illustrate the order of magnitude of ground water flows and discharge in this creek basin.

C. Marble Canyon

The Marble Canyon area is immediately north of the Houth Creek Basin and is of special interest because of the presence of a major aquifer in the canyon and its close proximity to the proposed development areas (see Figure 3-4). The canyon is long and narrow and extends from Pavilion Lake to a junction with the northern end of the Upper Hat Creek Valley. Massive limestone bedrock is exposed along both sides of the canyon (see Figure 4-2) and geologic evidence suggests that the canyon was formed by the scouring action of glacial ice on the fractured limestone bedrock, possibly along a fault line. The bottom of the canyon has been partly filled with a glacial and glacio-fluvial sediment to an estimated average depth of 50 m.

Borehole RH-77-46 was drilled in the valley bottom at the eastern end of the canyon (see location Figure 3-4) and a good sand and gravel aquifer was encountered at a depth of 9 m. Water yields of up to 2.8 l/s (243 m^3/d) were recorded during the drilling and a potential yield of 650 m^3/d has been estimated for a properly screened production well at this location. The aquifer encountered is about 20 m thick and is believed to be a similar thickness at the limestone quarry well, which also yields water from a similar glacio-fluvial aquifer.

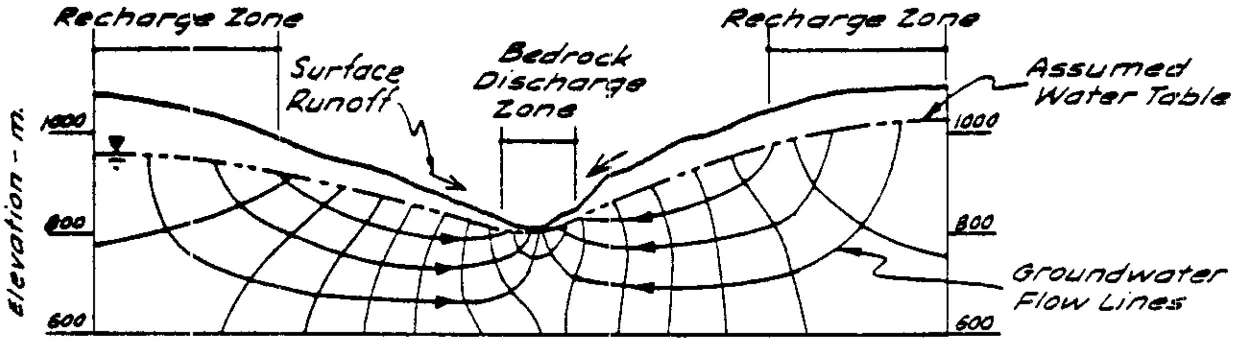
Based on geologic evidence there appears to be an aquifer or series of interconnected aquifers extending to Pavilion Lake and beyond its northwestern shores. However, based on topographic and isotope evidence there appears to be a ground water divide east of Turquoise Lake (see Figure 3-4). Thus, the water seeping from this lake would flow northwest toward Crown and Pavilion Lakes. This isotope evidence will be presented in Section 4.1 (a) (iii) B.

There are no well developed channels for collecting surface water run-off from the canyon and hence, all precipitation must either become ground water recharge or be lost as evapotranspiration. The ground water flow systems in the canyon are illustrated in Figure 4-8. This shows that the ground water flows from recharge areas at higher elevations, laterally through limestone bedrock and discharges into the surficial sediment aquifer in the canyon bottom. In addition this ground water is supplemented by surface run-off which infiltrates into the talus deposits and eventually into the surficial aquifer. The ground water in this surficial aquifer will then flow in a southeasterly direction from the ground water divide toward Hat Creek. An estimated ground water flow budget is as follows:-

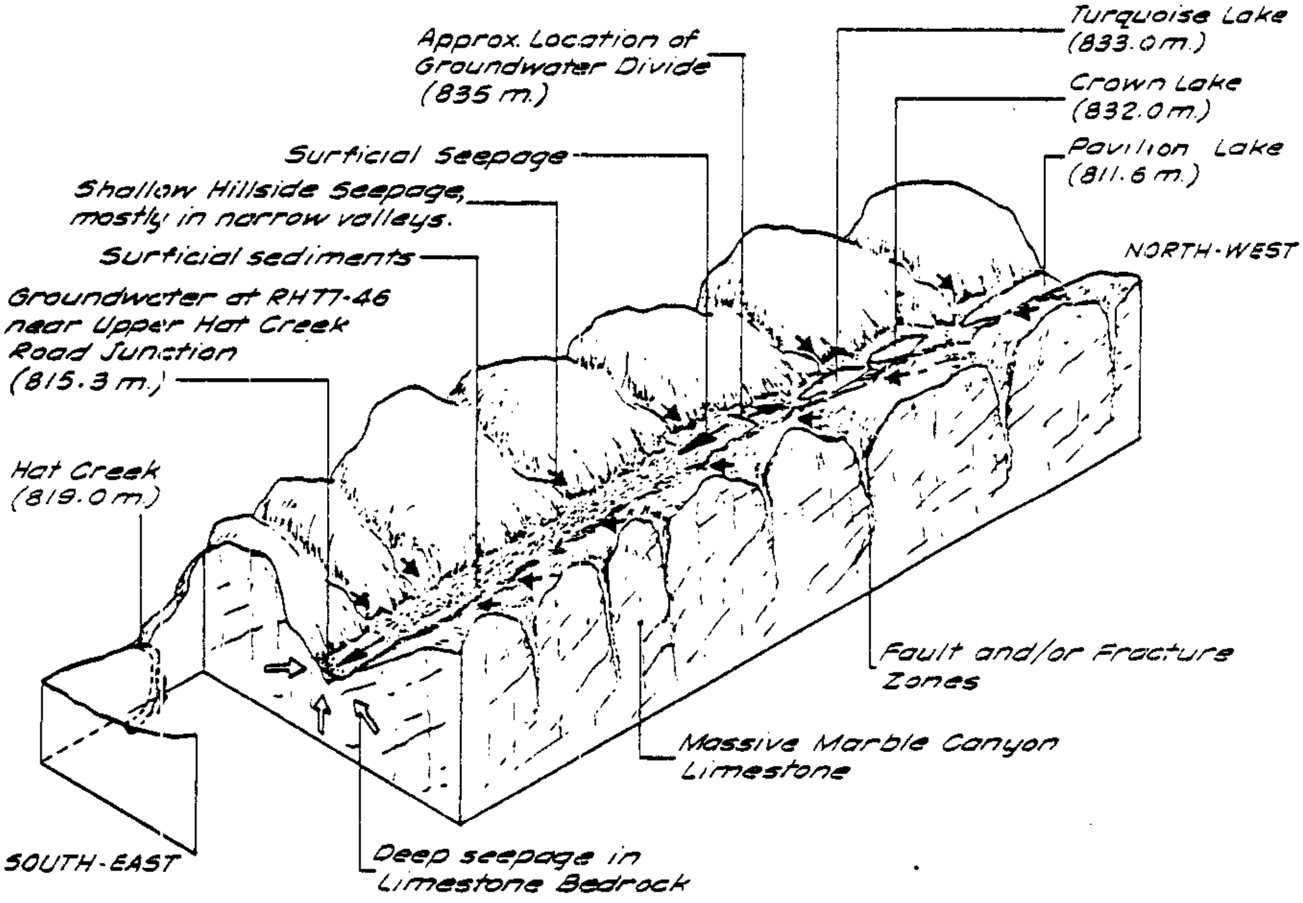
Inflows:	
Deep seepage in limestone	490 m^3/d
Canyon bottom infiltration	1564 m^3/d
TOTAL	2054 m^3/d
Outflows:	
Down valley seepage in surficial sediments	2053 m^3/d
Down valley seepage in limestone bedrock	1 m^3/d
TOTAL	2054 m^3/d

GROUND WATER FLOW SYSTEMS IN MARBLE CANYON

Figure 4-8



SECTION A-A HWY. 12 VALLEY
Natural Scale



ISOMETRIC SKETCH OF GROUNDWATER FLOW REGIME IN MARBLE CANYON.
Not to scale

NOTES: 1) There are no surface water flows in this part of the valley.
2) Surficial sediments are made up of alluvium, till, talus and fluvio-glacial sediments.

No. r/u354 ... Rao · Jan. 18

D. Medicine Creek Basin

The Medicine Creek Basin is situated on the eastern side of the Hat Creek Valley and the creek flows into Hat Creek just south of the proposed coal pit. The basin is relatively flat over much of the higher elevations and the creek valley is deeply incised (see Figure 4-9). Because of its close proximity to the proposed development areas it is an attractive area for storage of waste rock and coal ash and hence warrants a detailed hydrogeological investigation.

Most of the bedrock in this basin is covered with a low permeability till blanket. The thickness of this till is variable, but generally less than a few meters in the upland areas and ranging up to 60 m in the Medicine Creek Valley floor. Alluvium is almost absent in the creek bed.

The bedrock is comprised of limestone (Marble Canyon Formation), altered sedimentary rocks (noteably greenstone), volcanic rocks and low permeability sedimentary rocks (Coldwater Formation). All units with the exception of some of the volcanic rocks would have hydraulic conductivities less than 10^{-8} m/sec and hence, the rate of ground water flow through these rocks would be very slow. The Medicine Creek Valley follows a geological fault. However, based on data collected to date, the hydraulic conductivity along this fault is only marginally higher than the unfaulted bedrock. Piezometric information recorded in piezometers installed in boreholes RH-77-48 and RH-77-49 (see Appendix A4.0) indicates that Medicine Creek is perched above the ground water table. Generally this water table is located just above the bedrock surface as illustrated in Figure 4-10.

The ground water recharge will occur mostly in the upland areas and the movement would generally be toward the valley bottom. Preliminary seepage calculations show that most (say 90 percent) of the ground water would flow through the till or glacial drift overlying the bedrock and the remaining 10 per cent would flow through the bedrock. The total seepage flow is estimated to be 35 m^3/d per km along the length of the creek. Based on these data, the estimated down valley ground water flow at the

MEDICINE CREEK VALLEY

Figure 4-9

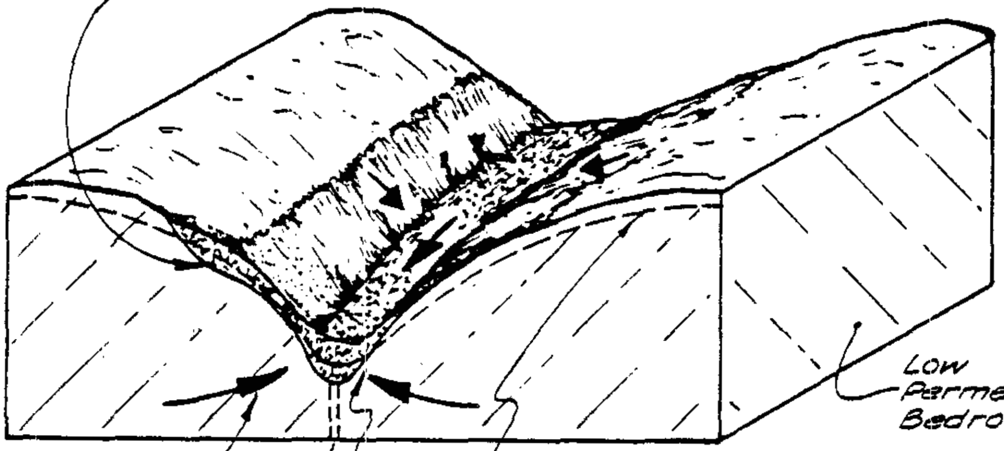
View from west side of Hat Creek valley looking east up Medicine Creek valley.

Wrong text see fig + 3

V.76359 CG RAD Jan./78

ISOMETRIC SKETCH OF TYPICAL GROUNDWATER FLOW REGIME IN MEDICINE CREEK VALLEY

Figure 4-10



Not to Scale

V70359 · Ing · KWD · Jan '78

Medicine Creek mouth is in the order of 350 m^3/d. Most of this flow is in the till and less than 1 per cent of the flow is estimated to flow in the bedrock along the fault line.

(iii) Hydrogeochemical Patterns

A. Dissolved Inorganic Chemistry

Introduction

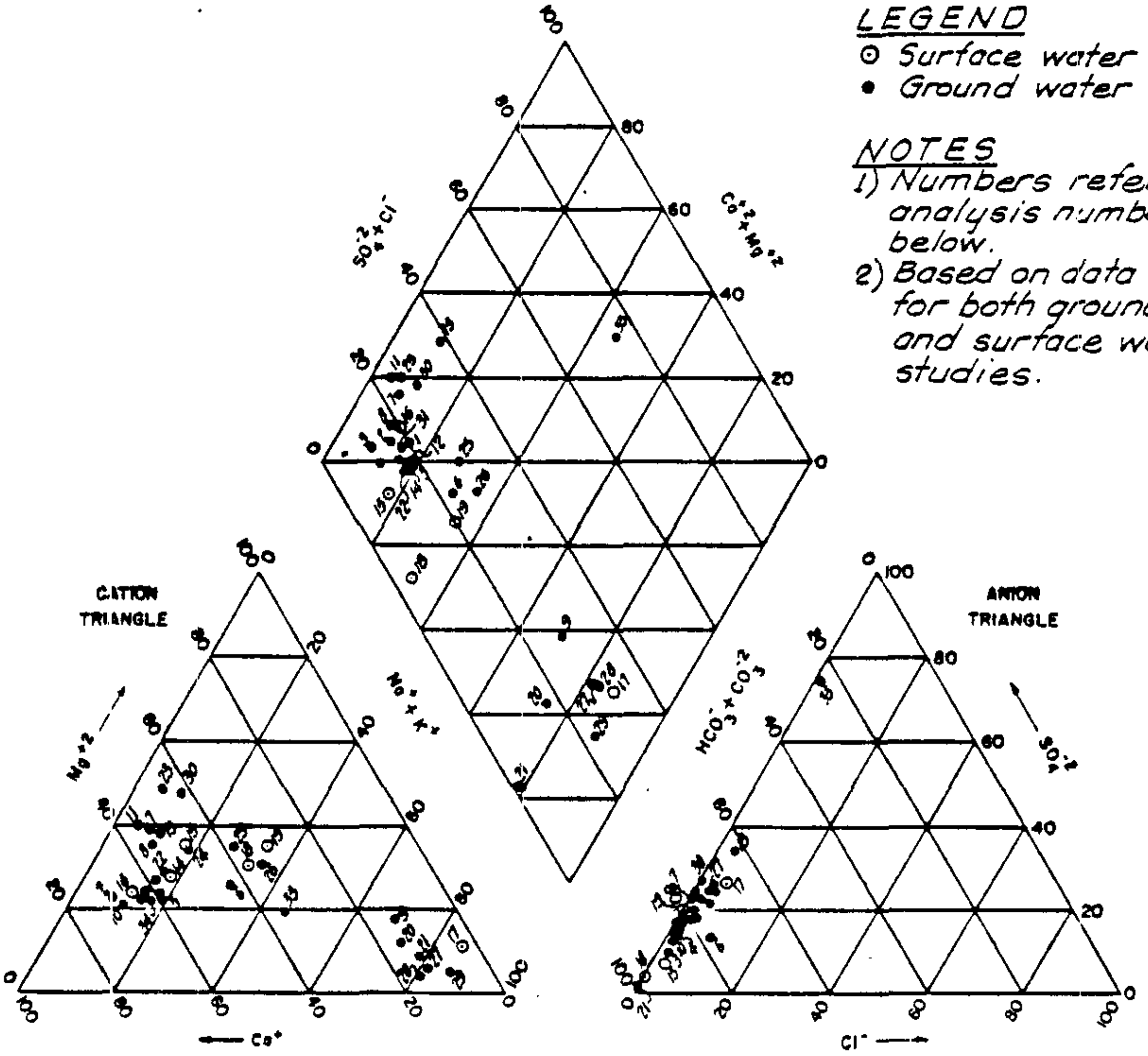
Selected water analyses for inorganic chemical content of both surface and ground waters have been used to construct a Piper diagram (Piper 1944[4]). This diagram is a convenient method for representing a particular type of water based on the relative proportions (expressed as a percentage of the total equivalent weight) of the major dissolved ions in the water (see Figure 4-11). Studies by others have shown that with few exceptions ground waters in the recharge zones are typically a calcium-magnesium bicarbonate type water (Schoeller, 1959[5]). As the ground water progresses through the flow system the increase of calcium and magnesium ions is controlled by equilibrium relationships with minerals present in the rock, such as calcite, dolomite and gypsum. Sodium ion is not subject to these controls and hence the proportions of this ion will increase relative to calcium and magnesium, and a sodium type water would result. This effect is further accelerated where ion exchange (calcium-magnesium for sodium) can take place.

Area West of Proposed Coal Pit

Most of the ground water flowing in the Coldwater Formation Rocks is characterized geochemically as sodium-bicarbonate type waters (see sample Nos. 9, 20, 21, 27, 28 and 29 plotted in the Piper diagram Figure 4-11). No data is available on the nature of ground waters flowing in the intrusive grandodiorite and volcanic bedrock materials. However, a ground water with a lower percentage of dissolved sodium would be expected based

PIPER DIAGRAM

Figure 4-11



LEGEND

⊙ Surface water

● Ground water

NOTES

1) Numbers refer to the analysis numbers given below.
2) Based on data collected for both ground water and surface water studies.

Summary of Water Samples Plotted - Piper Diagram

Analysis No.	Identification	Water Types(4)	Sample Depth (m)	Rock/Sediment Type
1	Well SW-1(1)	G	less than 5	Alluvium
2	DH-2	G		Alluvium
3	DH-3	G		Alluvium
4	DH-4	G		Alluvium
5	DH-5	G		Alluvium
6	DH-8	G		Alluvium
7	DH-9	G		Alluvium
8	DH-10	G		Alluvium
9	BA-77-7(2)	G	15	Coal
10	Spring - 1 (3)	G		Alluvium
11	Spring - 2	G		Alluvium
12	Spring - 3	G		Alluvium
13	Spring - 4	G		Alluvium
14	Elk Creek (Stn. 7)	S		-
15	Bonaparte River (Stn. 4)	S		-
16	Thompson R. (Stn. 18)	S		-
17	Goose Lake (Stn. 16)	S/G		-
18	Finney Lake (Stn. 17)	S		-
19	Aleece Lake	S		-
20	RH 76-19 (before pumping)	G		Claystone
21	RH 76-19 (after pumping)	G		Claystone
22	Trench 3	G/S		Coal
23	Limestone Quarry Well	G	30	Limestone
24	RH 77-45-1	G	90	Limestone
25	RH 77-45-2	G	63	Limestone
26	RH 77-45-3	G	35	Limestone (weathered)
27	RH 77-48-1	G	90	Shale
28	RH 77-48-2	G	79	Sandstone
29	RH 77-48-3	G	58	Shale
30	RH 77-49-1	G	90	Greenstone
31	Bulk Sample Well-1	G		Coal/Alluvium
32	Bulk Sample Well-2	G		Coal/Alluvium
33	Bulk Sample Well-3	G		Coal/Alluvium
34	Trench 3	G/S		Coal/Alluvium

Notes:
1) SW-1 is domestic water supply No. 1 see locations Figures 1-1 and 1-6
2) Bucket Auger Hole No. 7 (also known as "Coal Seam").
3) Springs all represent a discharge of shallow ground water.
4) G = Groundwater
S = Surface water

V-76359 CG RRD Jan/78

on data obtained from other areas (i.e. similar to the cation proportions shown by Finney and Aleece Lakes, samples 17 and 19). Thus, for ground water flowing eastwards from intrusive or volcanic rocks into Coldwater sediments the anion proportions would be expected to remain constant (i.e. mostly bicarbonate ion) and the calcium and magnesium portion would decrease in favour of sodium ion. The basis of this prediction is related to the general hydrogeochemical trends described above and to data on the clay mineralogy of the Coldwater claystone sediments (Golder Associates 1977 [2]). The dominant cation in the montmorillonite clay was found to be sodium and hence ion exchange of calcium-magnesium ions in water for sodium ions in the sediments can be expected.

Medicine Creek Basin

Borehole RH-77-48 encountered ground water that flows through clastic sedimentary rocks (Coldwater Formation shale and sandstone) while borehole RH-77-49 encountered ground water in the greenstone bedrock. The geochemical characteristics of these two ground waters are basically very different (see Figure 4-11, samples 27 and 30 respectively). The shale-sandstone ground water is a sodium bicarbonate water and the greenstone ground water is a calcium-magnesium bicarbonate water. This distinct difference in the type of ground water in these two zones is consistent with the slow moving hydrogeologic flow patterns outlined in the last section. If the ground water flows were rapid and entirely in the bedrock in the down valley direction, then geochemical theory would predict that the ground water in the greenstone bedrock would also have a very high sodium content with respect to the other two cations.

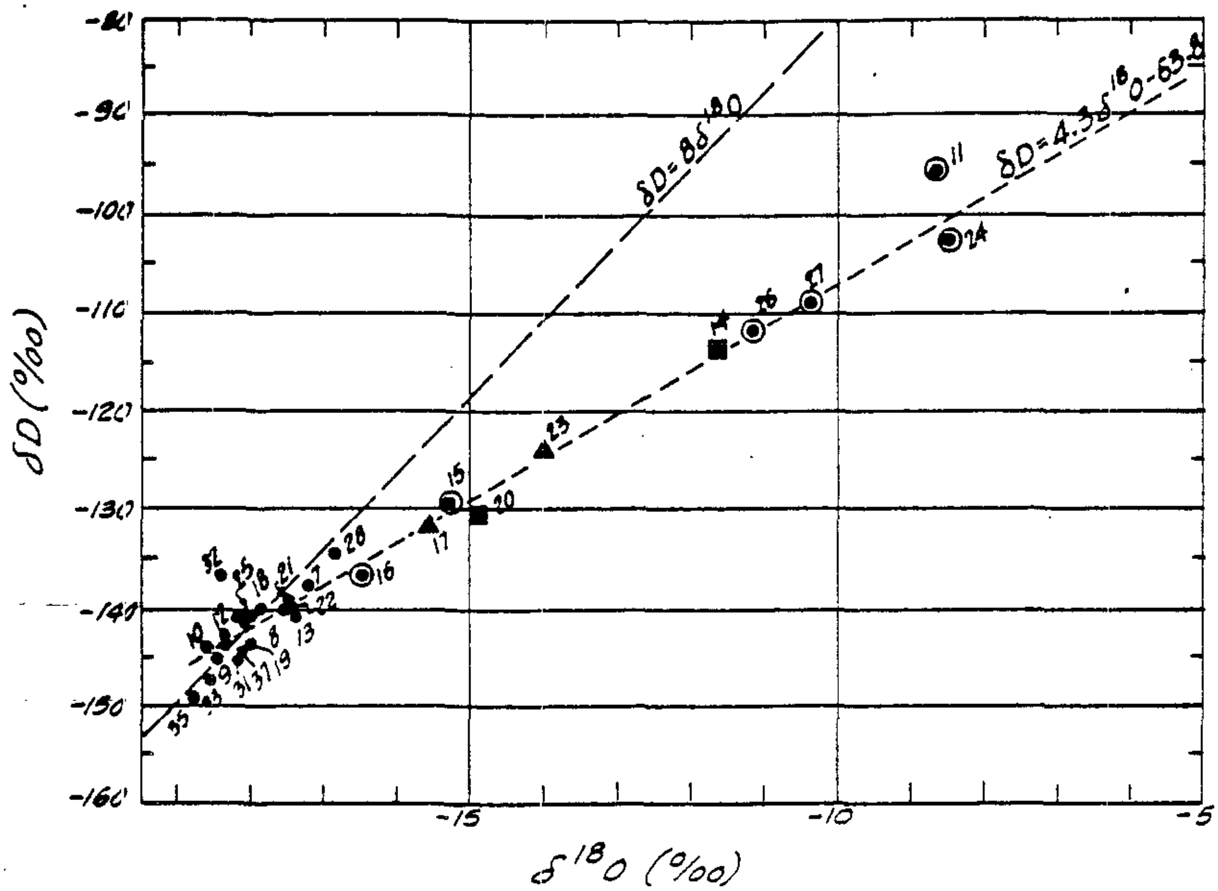
B. Isotopes

Introduction

Plots of deuterium and oxygen-18 isotope content are presented in Figure 4-12. This shows that most ground water and river water samples analyzed

PLOT OF DEUTERIUM VS. OXYGEN-18 ISOTOPE VALUES

Figure 4-12



LEGEND:

- ◉ Lakes known to be closed for at least some parts of the year
- ▲ Shallow small stream.
- ■ Lake with outlet flowing at time of sampling.
- • Ground water.

NOTES: 1) Sample No's. adjacent to plots for samples 29, 34 and 36 have been omitted for clarity.

2) Sample numbers are the same as given on table 4-1 (77 and 76 prefix omitted.)

Project No V76359 Drawn MG Approved RW Date Dec '77 fall along the line typical of meteoric waters (see explanation of theory in Appendix A5.1). The deuterium values for these waters range between -150 and -140 per mil (°/oo) and oxygen-18 values between -18.8 and -17.3 per mil. Most of the lakes and small streams have waters that have been subjected to a high degree of evaporation, falling beneath the meteoric line (see explanation in Appendix A5.1).

Tritium samples collected from a number of wells are summarized in Table 4-1 and show relatively low tritium values. As explained in Appendix A5.1 values of less than about 30 tritium units suggest that more than 16 years have passed since the water entered the ground water flow system.

Finney - Aleece Lake Area

Both Finney and Aleece Lakes have artificially raised outlets and at the time of sampling no water was flowing over the outlet structures. The oxygen -18 content of inflowing seepage water to Aleece Lake (possibly via Finney Lake) was -14.3 in November 1976 while the Aleece Lake water was -8.8. This shows that the lake is highly evaporitic and hence much of the water appears to have evaporated from the lake surface and only a small proportion of the water will leave the lake as ground water seepage.

Houth Meadows Area

Isotope data indicate that the seepage into Houth Lake is subjected to some moderate evaporation before it leaves the lake and that the discharge (in April 1977) from this lake was small in comparison to the flow in the north branch of Houth Lake.

Marble Canyon Area

A progressive change in isotope composition of surface waters can be observed in the Pavilion Lake area. This change follows along the evaporation line shown in Figure 4-12 and can be seen as follows:-

TABLE 4-1

SUMMARY OF CHEMICAL AND ISOTOPE ANALYSIS OF LOCAL WATERS USED FOR HYDROGEOLOGIC STUDY

HAT CREEK COAL PROJECT

						Inorganic Ions (ppm)									Isotopes	
Sample No.	Sample Date	Sample Site	Notes	Lithology	Temp. °C	Na^+	Ca^{+2}	Mg^{+2}	K^+	HCO_3^-	SO_4^{-2}	Cl	pH	EC	$\delta^{18}O$ (°/oo)	δD (°/oo)
76-1	9/11/76	Aleece Creek	600 m from lake outlet				44.8	21.7	9.0				7.85	508	-14.0	
76-2	9/11/76	Spring	On south shore of Aleece Lake	alluvium		33.0									-14.3	
76-3	9/11/76	Aleece Lake	At outlet from 0.6 m depth			38.0	33.9	25.2	11.5	265	52.2	<.5	7.6	508	- 8.8	
76-4	9/11/76	Well RH76-19	During Development	claystone		110.0	19.0	9.4	18.0	260	47.7	<.5	7.6	677	-18.0	
76-5	9/11/76	Hat Creek	Near Hole RH 76-20			21.3	58.0	17.4	4.0				8.0	462	-18.1	
76-6	14/10/76	Well RH76-19	At end of pump test	claystone		330.0	47.7	21.6	14.0	1150	17.3	<.5	7.6	1834	-20.1	
77-7	29/ 4/77	Seep on road	South end of Fountain Valley	alluvium	12									600	-17.3	-137.3
77-8	29/ 4/77	Cinqefoil Lake	At south outlet		13									500	-17.5	-139.7
77-9	29/ 4/77	Deep Well	Sampled from tap	alluvium	16									700	-18.5	-145.1
77-10	29/ 4/77	Ditch water	Mostly melting snow		6									500	-18.7	-143.7
77-11	29/ 4/77	Chilhil Lake	At east shore		14									520	- 8.6	- 96.4
77-12	29/ 4/77	Fountain Creek	At road culvert		8									280	-18.2	-140.2
77-13	29/ 4/77	Keatley Creek	At road culvert		11									150	-17.4	-140.3
77-14	29/ 4/77	Pavilion Lake	At north shore		8									360	-11.7	-113.7
77-15	29/ 4/77	Crown Lake	At north shore		11									340	-15.3	-129.9
77-16	29/ 4/77	Turquoise Lake	At north shore		13									335	-16.5	-136.9
77-17	29/ 4/77	Crown Creek	Above Falls		5									480	-15.6	-132.2
77-18	29/ 4/77	Crown Creek	Near source, snow melt		3									185	-17.9	-140.0
77-19	30/ 4/77	30 m Deep Well	At limestone quarry	alluvium	11	8.4	71.4	45.4	3.4	350	78	14.5	7.4	670	-18.0	-144.2
77-20	30/ 4/77	Houth Lake	At outlet		10									460	-14.9	-130.8
77-21	30/ 4/77	Houth Creek	At Hat Creek		6									200	-17.5	-139.2
77-22	30/ 4/77	Hat Creek	At Houth Creek		7	(21)	(59)	(19)	(4)	(289)	(46)	(1.2)	(8.4)	410	-17.5	-138.5
77-23	30/ 4/77	Houth Creek	South branch		6									700	-14.0	-124.7
77-24	30/ 4/77	Aleece Lake	At outlet from 0.6m depth		11									500	- 8.5	-102.9
77-25	30/ 4/77	Anderson Creek	At road culvert		3									110	-18.0	-140.5
77-26	30/ 4/77	Finney Lake	At outlet		17	(12)	(29)	(8.3)		(127)	(5.1)	(0.5)	(8.0)	210	-11.2	-112.1
77-27	30/ 4/77	Alkaline slough	2,000 m east of Finney Lake		14									3800	-10.4	-109.3
77-28	30/ 4/77	Medicine Creek	At road culvert		3	(14)	(61)	(29)		188	(40)	(0.5)	(8.4)	500	-16.9	-134.8
77-29	28/ 5/77	Spring	Upper Hat Creek Valley (East Spring)	alluvium		(28)	(140)	(66)		(439)	(250)	(7.6)	(7.6)	1100	-18.2	-142.4
77-30	28/ 5/77	OW-8	Shallow well near Hat Creek	alluvium		(120)	(180)	(67)		(685)	(160)	(79)	(7.4)	1900	-18.1	
77-31	25/ 8/77	RH-77-45 #1	From piezo. at 90m depth	limestone	9	23	64.4	29.3	4.3	325	62.4	5	7.8	626	-18.2	145.1
77-32	25/ 8/77	RH-77-45 #2	From piezo. at 63m depth	limestone	10	43.7	55.2	32.0	4.6	330	91.2	6	8.0	689	-18.4	137.6
77-33	25/ 8/77	RH-77-45 #3	From piezo. at 35m depth	weathered limestone	10	57.5	54.3	29.9	4.7	344	96	7	8.1	729	-18.5	147.1
77-34	25/ 8/77	RH 77-48 #1	From piezo. at 90m depth	shale	9	172.5	20.2	7.4	3.9	407	115.2	4	8.1	936	-18.3	144.1
77-35	25/ 8/77	RH 77-48 #2	From piezo. at 79m depth	sandstone	10	203.6	25.1	8.3	4.1	476	139.2	5	8.1	1019	-18.8	149.4
77-36	25/ 8/77	RH 77-48 #3	From piezo. at 58m depth	shale	10	170.2	15.2	4.6	3.5	408	81.6	3.5	8.4	879	-18.3	143.4
77-37	25/ 8/77	RH 77-49 #1	From piezo. at 90m depth	greenstone	9	32.2	123.4	91.2	4.7	672	196.8	2	8.0	1326	-18.1	144.9

NOTES:
1) See locations of sampling station on figures 3-3 and 3-4.
2) $\delta^{18}O$ is the oxygen isotope concentration in the water given in SMOW.
δD is the deuterium isotope concentration in the water given in SMOW.
3) EC is the electrical conductivity of the water in micro mhos/cm.
4) Inorganic chemistry shown in brackets is given here for comparison purposes only. These data are based on collected by others at another time.

- Melting snow in Crown Creek	(Sample 18)
- Turquoise Lake	(Sample 16)
- Crown Lake	(Sample 15)
- Pavilion Lake	(Sample 14)

Thus, based on isotopic data the seepage flow from Crown Lake would appear to be toward Pavilion Lake. The isotopic composition of ground water samples from borehole RH-77-45 are all, with the exception of one sample (No. 32), very close to normal meteoric water and do not show any sign of significant evaporation. The low tritium levels suggest that the rate of ground water movement is low, suggesting a relatively low rock permeability.

Medicine Creek Area

Both Medicine Creek water (Sample 28) and ground water samples from boreholes RH-77-48 and RH-77-49 lie on the meteoric line. However, the Medicine Creek water was isotopically heavier than the ground waters. This suggests that at the time of sampling (April 1977) the ground water component in the run-off in Medicine Creek was small relative to direct run-off. These conclusions are consistent with other data on the local flow systems in that the bedrock ground water does not contribute significantly to the creek flow in this basin.

(iv) Water Tables - Seasonal Variations

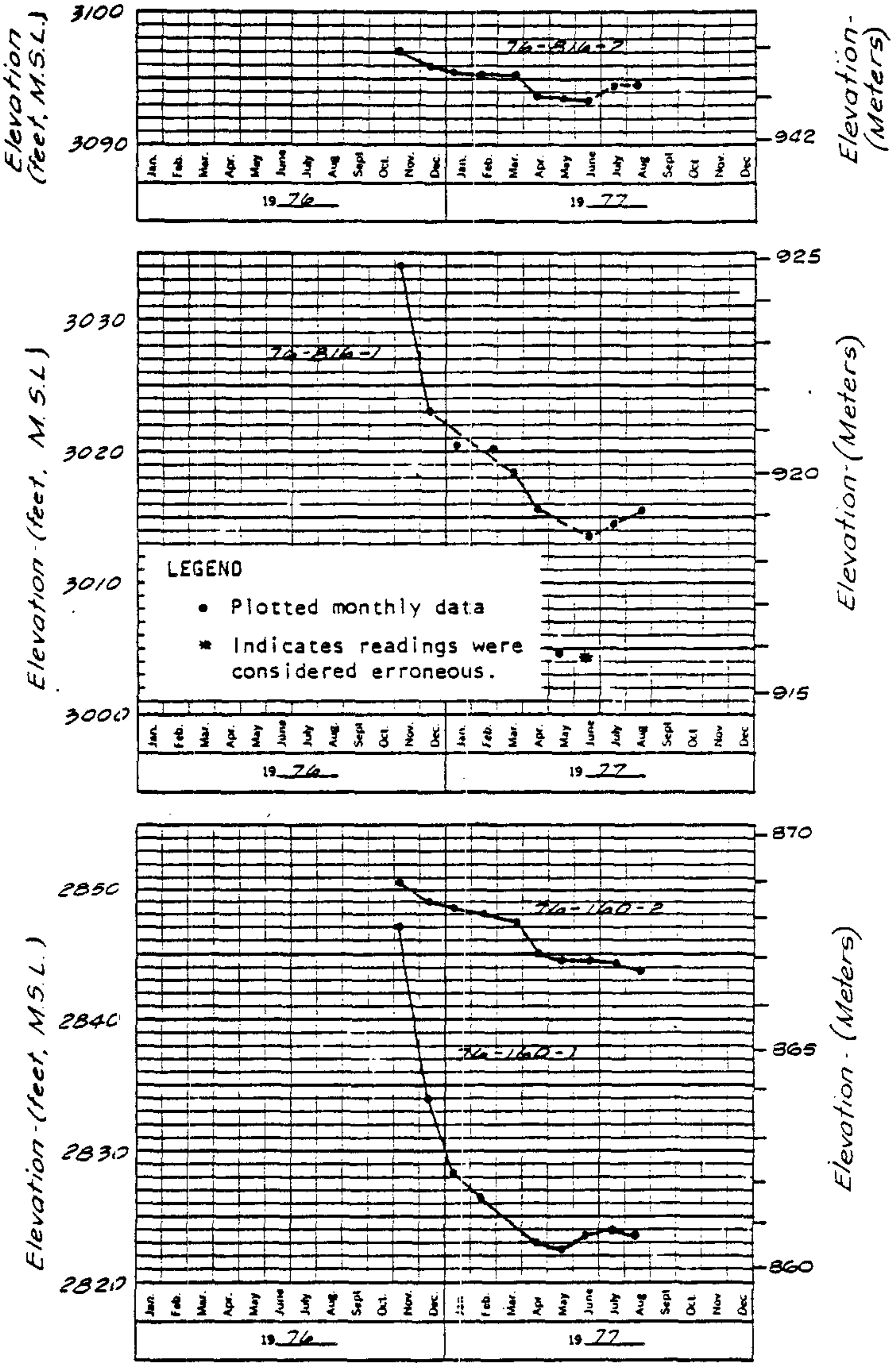
Water level data for specific geologic units have been recorded in piezometers in the Hat Creek Valley and have been converted to piezometric head elevations. These piezometric heads represent the total hydraulic head (pressure head plus position head) at a specific point in an aquifer (i.e. at the piezometer tip). The term "piezometric head" is used here as a more general term which can apply to all points within a geologic unit, while the term "water table" applies only to those points where the pressure head is atmospheric.

Monthly piezometric head data have been recorded since November 1976. Plots of piezometric head versus time for selected piezometers are shown in Figures 4-13 to 4-15 and Table 4-2 lists the relevant installation data for each of the selected piezometers. These piezometers are located mostly in the vicinity of the proposed pit area (see locations in Figure 3-4) and some are in the Medicine Creek Valley.

The general trend in all of the plotted data shows a decline of piezometric heads since November 1976. At this stage it is difficult to predict future trends, as not all of the piezometers have become fully stabilized and the period of monitoring is limited. However, based on present data, maximum annual fluctuations of piezometric heads in recharge zones are estimated to be between 3 and 10 m. Maximum annual fluctuations in the discharge area near Hat Creek should be quite small (1 or 2 m) since in this area piezometric heads are largely controlled by the creek level. A similar fluctuation is expected for piezometric levels in the Medicine Creek Valley.

HYDROGRAPHS OF SELECTED PIEZOMETERS IN THE PROPOSED PIT AREA
BOREHOLE NUMBERS 76-816 AND 76-160

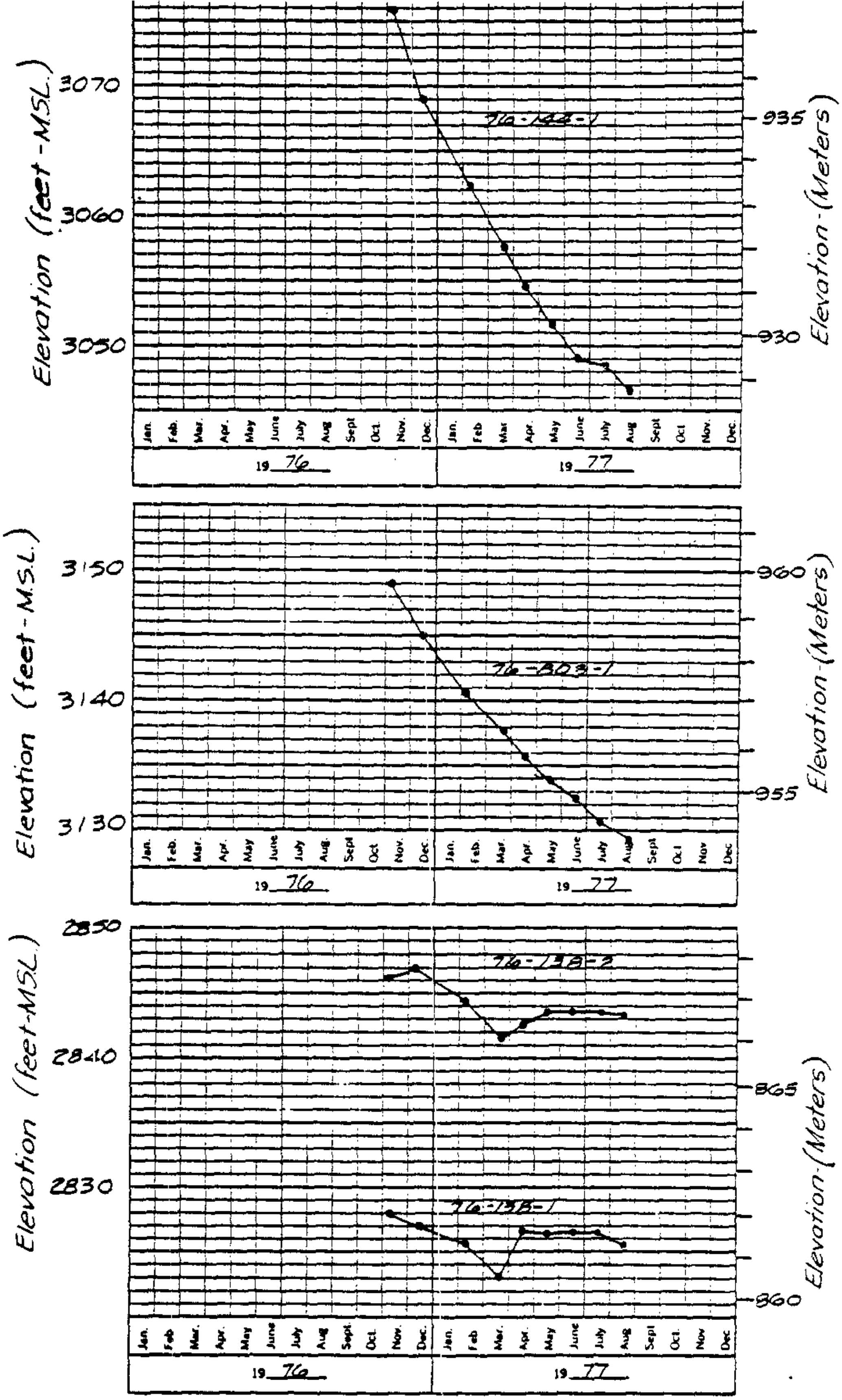
Figure 4-13



Project No V-76359 Drawn H.T. Reviewed Date July '77

HYDROGRAPHS OF SELECTED PIEZOMETERS IN THE PROPOSED PIT AREA
BOREHOLE NUMBERS 76-144, 76-803 AND 76-138

Figure 4-14

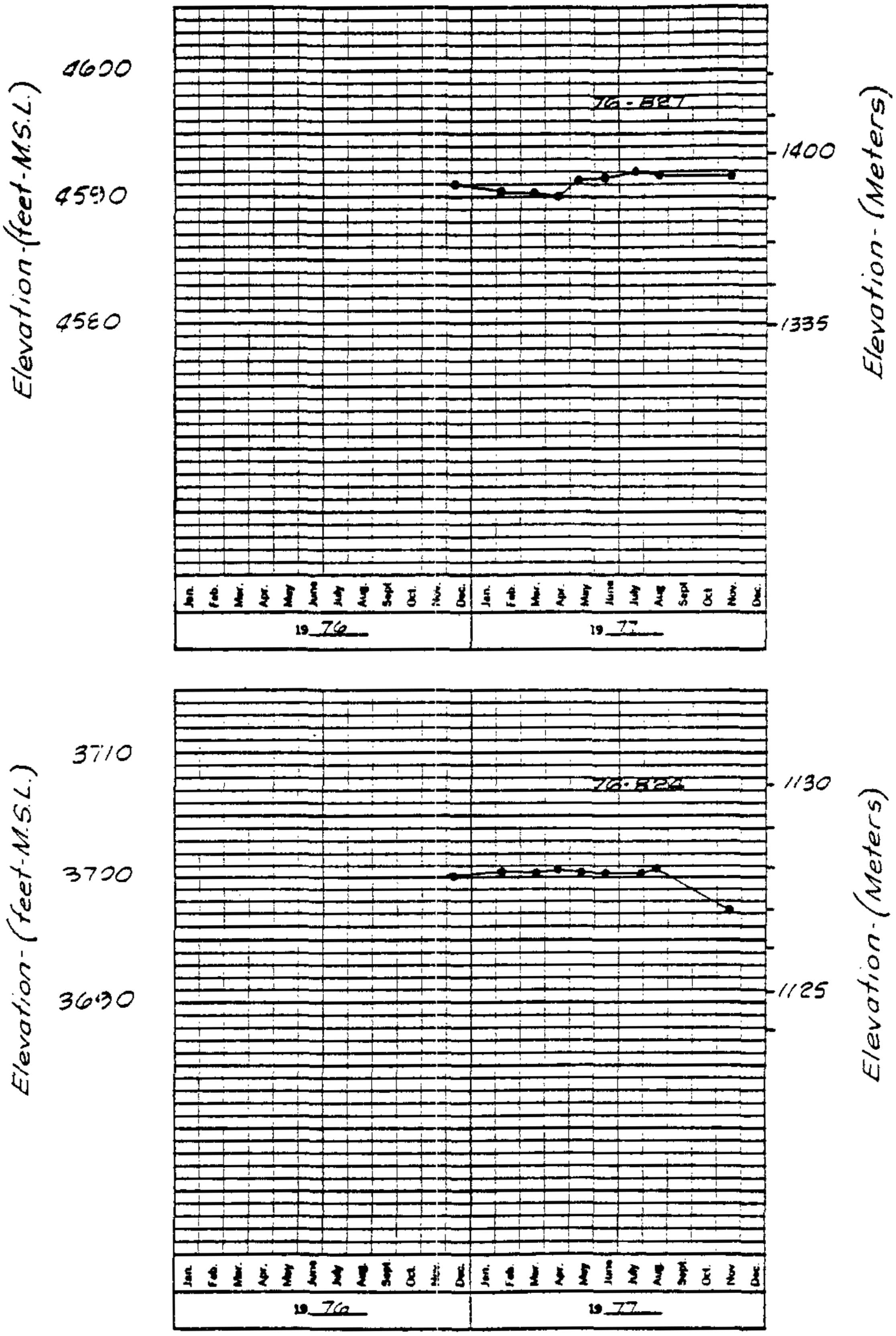


Project No. V.76359 Drawn RO Reviewed RAD Date July '77

Golder Associates

HYDROGRAPHS OF SELECTED PIEZOMETERS IN MEDICINE CREEK AREA

Figure 4-15



Project No V.76359 Drawn CG Checked RAB Date Jan/78

Golder Associates

Table 4-2

Summary Data on Geotechnical and Coal Exploration Holes Quoted in this Study

Piezometer Number (2)	Coordinates (4)	Installation Date	Piezometer (1) Elevation (m)	Piezometer Depth Below Surface (m)	Material Screened	Discharge or Recharge Zone
76-138-1	E19461 N80977	7/7/76	663.4	251.6	Siltstone, Sandstone	Discharge
76-138-2	E19471 N80977	7/7/76	854.6	60.4	Coal	Discharge
76-144-1	E20505 N76991	20/7/76	626.6	329.1	Coal	Discharge
76-160-1	E21022 N81999	10/8/76	763.4	162.3	Siltstone	Discharge
76-160-2	E21022 N81999	10/8/76	864.7	61.0	Sand, Gravel	Discharge
76-803-1	E20390 N75190	23/6/76	798.2	168.4	Clayey Siltstone	Discharge
76-816-1	E24624 N78956	26/7/76	724.7	266.3	Basalt	Recharge
76-816-2	E24624 N78956	28/7/76	891.2	99.7	Sand, Gravel, Till	Recharge
BA76-7	E19,050 N80000	1976	open hole	23 m (3)	Coal	Intermediate
76-824-1	E38493 N76601	25/9/76	1123.6	51.5	Greenstone	Discharge
76-827-1	E37163 N82798	10/10/76	1387.1	16.8	Phyllite	Recharge
RH-76-19	E19959 N76477	1/9/76	screened well	44.2-118.3 (5)	Clayey Siltstone	Intermediate

Notes:
1) All piezometers are standpipe piezometers.
2) See locations, Figure 3-4
3) Depth to bottom of open hole.
4) Coordinates given in feet.
5) Screened interval.

(b) Surface Water

(i) Regional Descriptive Hydrology

A. Thompson River

The Thompson River basin, with its drainage area of approximately 55,000 km^2, drains a large portion of south-central British Columbia. Upstream of their confluence at Kamloops, both the North and South Thompson basins are mountainous and extensively forest covered. From the outlet of Kamloops Lake to its confluence with the Nicola River, the Thompson drains 7,874 km^2 of semi-arid interior plateau, and of this area, 5,000 km^2 comprise the Bonaparte River basin[6] which includes the 660 km^2 Hat Creek basin.

The flow regime of the Thompson River is dominated by snowmelt runoff in its head water area, the Columbia Mountains, with the contribution from the interior plateau being almost negligible. At the outlet of Kamloops Lake the Thompson River runoff amounts to 564 mm from a 39,109 km^2 drainage area, based on a mean flow of 597 $m^3 \cdot s^{-1}$ while the runoff observed in the Bonaparte River near Cache Creek (drainage area 4,092 km^2) amounts to only 39 mm based on a mean flow of 5.1 $m^3 \cdot s^{-1}$. Several stream gauging sites have been in operation along the Thompson River reach from Kamloops Lake to the Fraser River confluence, but by far the most extensive records are available at Spences Bridge, downstream of the confluence with the Nicola River, where the drainage area is 54,650 km^2. At the proposed cooling water intake site, the drainage area is approximately 13,000 km^2 smaller but the high and low flows should not differ by more than 500 $m^3 \cdot s^{-1}$ and 20 $m^3 \cdot s^{-1}$ respectively, which amounts to less than 20 percent. Figure 4-16 shows maximum and minimum flow frequency curves for the Thompson River near Spences Bridge. Both curves have unusually flat slopes, indicating that the year-to-year variation in both freshet peak flow and minimum flow is relatively small.

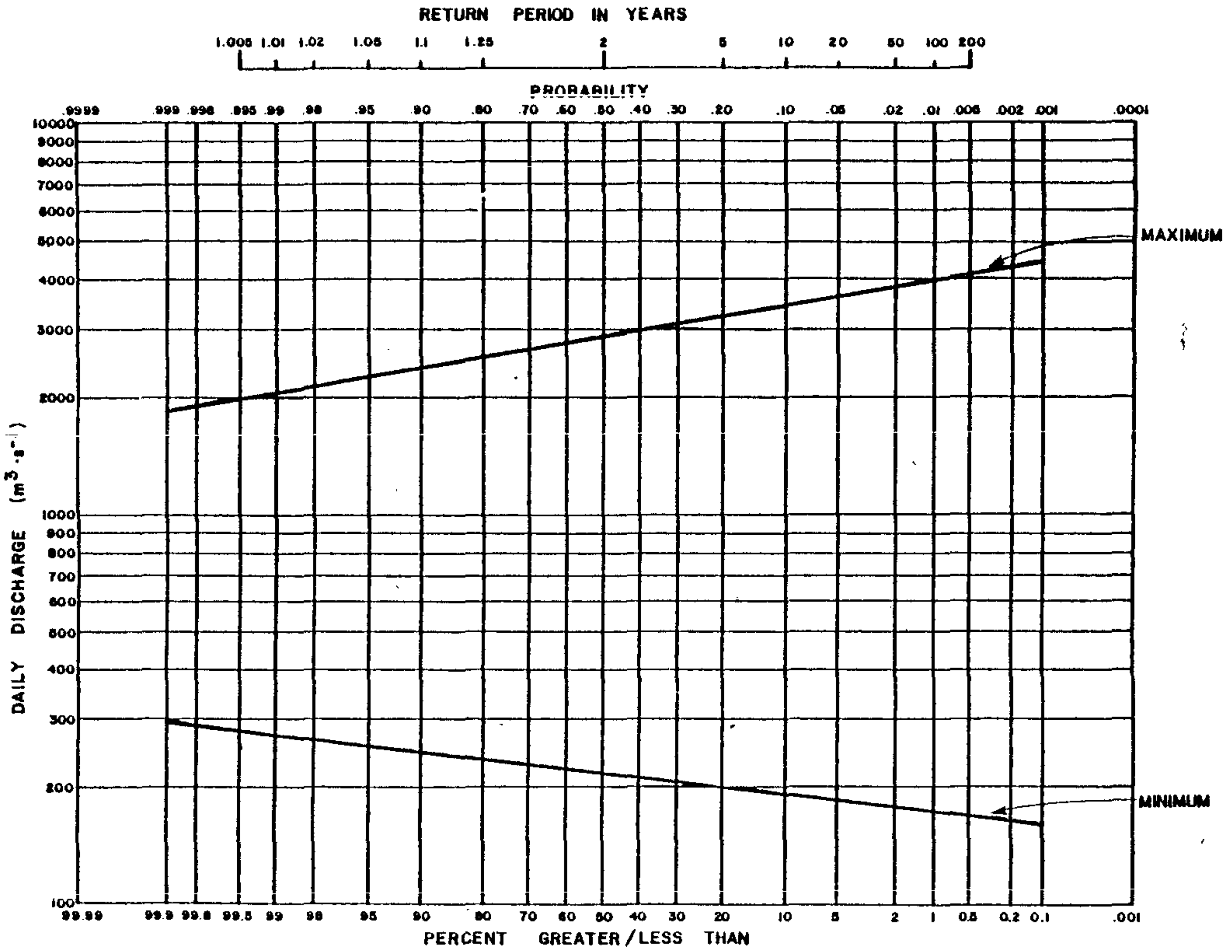


FIGURE 4-16: MAXIMUM AND MINIMUM MEAN DAILY FLOW FREQUENCY CURVES FOR THE THOMPSON RIVER NEAR SPENCES BRIDGE (Drainage area : 54908 km^2)

from : Northwest Hydraulic Consultants Ltd., Hat Creek Interim Report, November 1976.

DATE	Dec 77	DF	4-16
PROJECT	K 4242		
DWG NO			

B. Hat Creek and Bonaparte River

The Bonaparte River drainage basin, including Hat Creek, lies in the western part of the Interior Plateau of British Columbia.[7] The northern portion of the basin lies on the Fraser Plateau, while the southern portion falls into the Thompson Plateau. The Hat Creek drainage basin also straddles the line separating these two major subdivisions of the Interior Plateau. The Clear Range, west of Hat Creek, is considered part of the Fraser Plateau, while the broad valley above the mine site and the Cornwall Hills are part of the Thompson Plateau. The Clear Range is separated from the Coast Mountains by the deeply incised valley of the Fraser River, following the structural line of the Fraser River Fault.[7]

The climate of the Interior Plateau is continental, mildly so in the western part, which includes the Hat Creek region, and of medium intensity further east. Kendrew et al.[8] describes this climate as follows:

> *Winters are cold and the land is under snow (usually of no great depth in the valleys) during most of December and January. Temperature rises fast in March and spring is a pleasantly dry and bracing season, summer is warm with many hot days but cool and occasionally cold nights. Precipitation is light and well distributed over the year; it is notably light in the 'dry belt' around Ashcroft. Summer and winter get most, spring is definitely dry and in the west autumn is almost as dry. Of the months June is noticeably more cloudy and rainy than its neighbours, September (in some valleys October) notably dry. Most of the precipitation is snow in December, January, February. In summer heavy showers, many of them in thunderstorms, provide much of the rain, but the showers are soon over and summer is a season of bright skies, by far the least cloudy season in contrast to the rather bleak cloudy winters. The uplands are cool in summer, cold in winter, and have more precipitation than in the valleys, but west of the Selkirks even the uplands do not get excessive amounts (eg. Old Glory 24 inches) and their skies are not more cloudy than in the valleys.*

The details of the precipitation regime in the Hat Creek region are discussed in Section 4.1(b)(ii)A.

The hydrologic regime of streams originating on the Interior Plateau is relatively uniform, being characterized by a prominent spring freshet due to snowmelt at the higher elevations, where considerable snow packs can accumulate. It generally peaks in May or early June. Following spring freshet, stream flow tends to fall off rapidly to low summer flow. Particularly in the southern parts of the plateau, where irrigation is widespread, summer is also the time of highest consumptive use, contributing further to reduced summer stream flows. During September and October there may be slight increases in runoff, due in part to lower evapotranspiration rates and in part to reduced demand. Runoff drops again to low values in mid-winter. Snowmelt at the lower elevations begins early, leading to gradually increasing runoff during March and April.

The highest flood flows can be due to either snowmelt or rainfall or a combination of both, with snowmelt being the most frequent cause by far, particularly in the larger basins. Rain peaks due to high-intensity convective showers in midsummer are common, particularly in the smaller streams, but the intensity of such floods is rarely comparable with the larger snowmelt floods. Rain floods caused by frontal rain have occurred in some basins but are also not particularly large.

The lowest flows occur either during dry spells in late summer or in mid-winter during cold spells. On many streams it can be either one of these times, depending on weather conditions.

In order to check how the runoff patterns of the Bonaparte River and Hat Creek compare with the general region, a regional analysis based on annual mean daily peak flows was computed. The stream flow records generally contain three types of annual peak flows:

(i) Instantaneous peaks which are only available for gauging sites equipped with a continuous recorder.

(ii) Mean daily peaks based on averaging the continuous record for successive days.

(iii) Daily peaks based on once-a-day manual observations.

The data publications of the Water Survey of Canada do not distinguish between items (ii) and (iii), although they can differ by as much as 100% in small basins. The instantaneous peaks are of most practical value but, because most of the older stream flow records are based on once-a-day manual gauge readings, there are not enough instantaneous peak data available to justify a regional analysis.

Neil <u>et al</u>[9] have investigated the ratio of instantaneous to mean daily peaks for rivers in Alberta and found it to be exceedingly variable, ranging from 1.00 to 2.76, and decreasing irregularly with drainage basin size. For the case of the gauging site "Hat Creek near Upper Hat Creek" located at the mine site (drainage area 350 km^2) the ratio should fall into the range of 1.2 to 1.5, while for the Bonaparte River, with its extensive lake storage, the ratio should be well below 1.1.

The index to the records of the Water Survey of Canada[10] was searched for streamflow records for basins within the Southern Interior Plateau region. Two years of records for active stations or five years for inactive stations were specified as the minimum for inclusion in the analysis. Then somewhat subjective criteria were adopted for the following reasons: (i) hydrometric measurements are rarely discontinued after only 2 to 3 years, unless the site proves to be highly unsuitable, and (ii) it seems quite likely that a similar analysis will be recomputed in a few years to up-date the results, at which time active and inactive stations will have comparable minimum record lengths. Basins with significant lake areas, diversions or regulation were omitted from the analysis. Initially, 99 basins were selected, of which 85 were eventually retained.

Figure 4-17 shows the gauging sites included in the final analysis and Table B1-1, Appendix B lists these 85 sites.

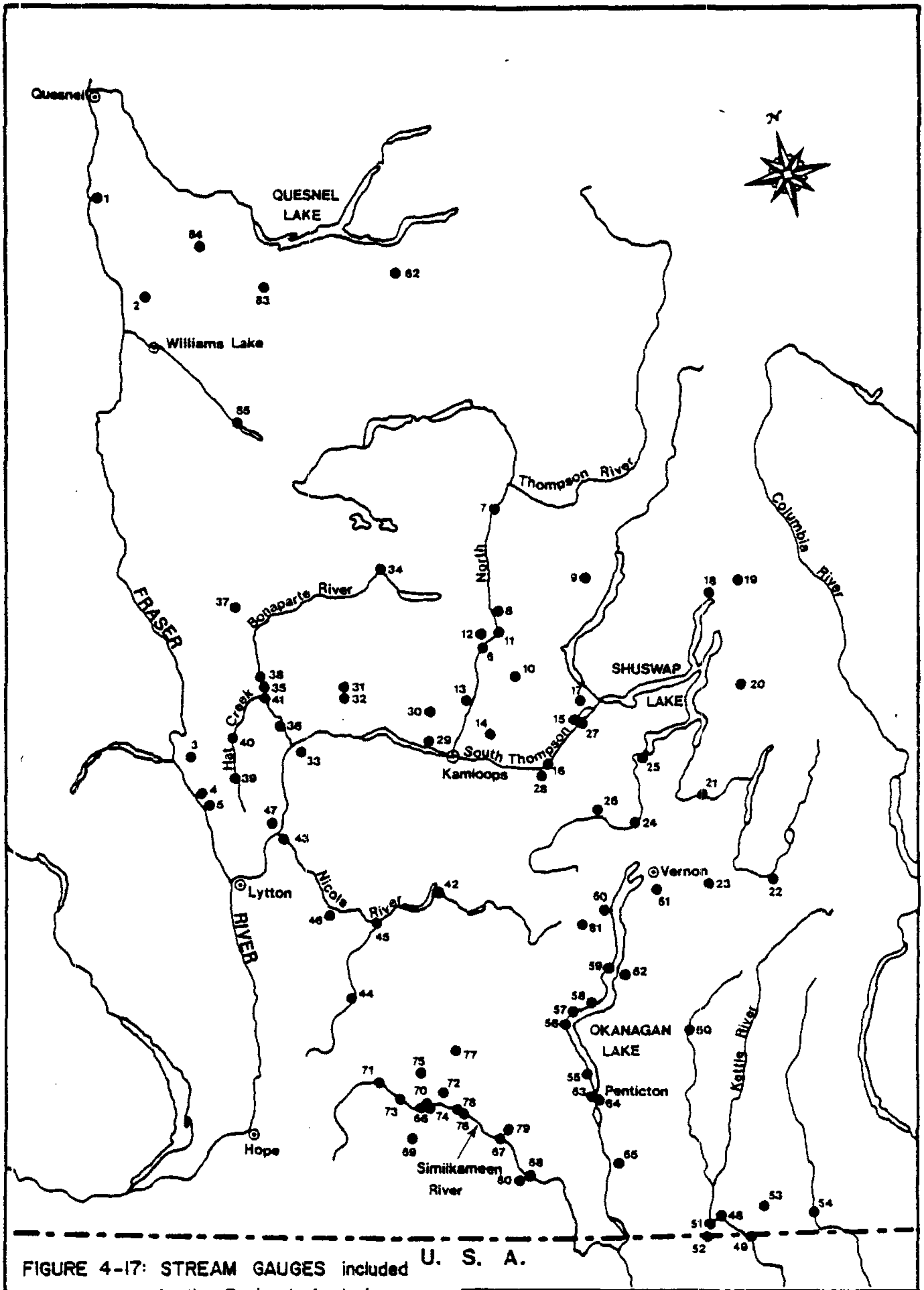


FIGURE 4-17: STREAM GAUGES included in the Regional Analysis (site numbers refer to Table B1-1, Appendix B.)

beak

DATE	7-77 CC	4-17
PROJECT	K4242	
DWG NO		

For each basin the following parameters were evaluated:

1. The geometric mean, μ, of the observed sequence of mean daily annual peak flows, X_i, as listed by Water Survey of Canada.[11]

   $$\mu = 10^{\frac{1}{n}\left[\sum_{i=1}^{n} \log X_i\right]}$$

   "log" referring to logarithms to the base 10.

2. The geometric standard deviation of the same sequence.

   $$\sigma = 10^{\left[\frac{1}{n-1}\sum_{i=1}^{n} (\log X_i - \log \mu)^2\right]^{\frac{1}{2}}}$$

3. Drainage area.

4. Slope of the main-stem stream channel between two points, 10 percent and 85 percent of the length from the source to the gauge respectively.

5. Mean basin elevations, obtained as the mean of 10 to 50 grid point elevations.

6. Standard deviation of the same grid point elevations.

7. Mean annual precipitation at the centre of the basin as shown on British Columbia Land Inventory Mean Annual Precipitation Map (Map No. 17).

8. Percent of basin area consisting of lakes as indicated by NTS maps.

9. Percent of basin covered by forest, as indicated by the green shading on NTS maps.

Initially the extreme maximum daily flows observed were plotted against drainage area as shown in Figure 4-18. All points relating to Hat Creek or to the Bonaparte River fall far below the envelope curve.

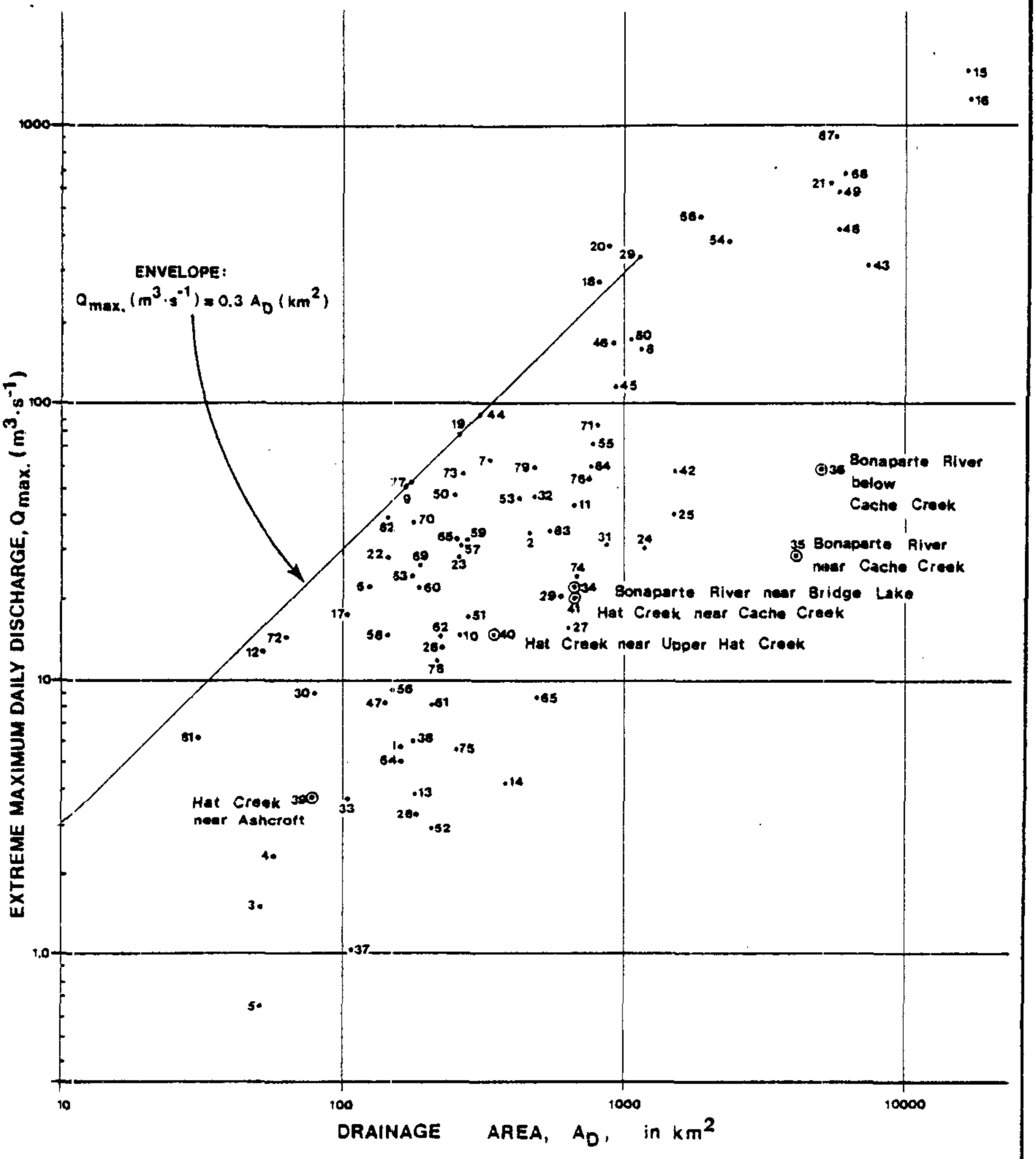


FIGURE 4-18: RELATION BETWEEN DRAINAGE AREA AND MAXIMUM DAILY PEAK FLOW FOR THE SOUTHERN INTERIOR OF B. C.

beak	DATE	JULY 77	RM	4-18
	PROJECT	K 4242		
	DWG NO			

Linear multiple regressions were then computed on the log-transformed data using the TRIP-program package available on the UBC computer.[12] The regression was weighted by the number of years of data available at each station. Two regression equations were computed, one for μ, the geometric mean of the flows and one for σ, the geometric standard deviation. The program searches through the seven independent variables and finds those which contribute significantly* to explaining the observed variation in the dependent variables, μ or σ.

Four independent variables appear to contribute significantly to explaining the mean size of floods on the southern part of the Interior Plateau. In decreasing order of importance they are:

1. drainage area, A_D, in km^2;
2. mean elevation, E, in m;
3. mean precipitation at the centre of the basin, P, in mm; and
4. percent forest cover, F.

The regression equation is:

$$\log \mu = -17.008 + 1.008 \log A_D + 2.893 \log E + 1.376 \log P$$
$$+ 1.480 \log F \text{ .... } (3)$$

It explains 87.2 percent of the variance in the data.

Figure 4-19 is a plot of the observed vs. predicted values of μ for the 85 basins included in the regression. The two dashed lines indicate the range within which the predicted values differ from the observed values by a factor of less than two. Many points fall outside that range, indicating that considerable caution is required if such regression results are to be used for design purposes. For the purpose of this study, however, Figure 4-19 is very illustrative. All the points

---

*At an F - probability level of less than 20 percent

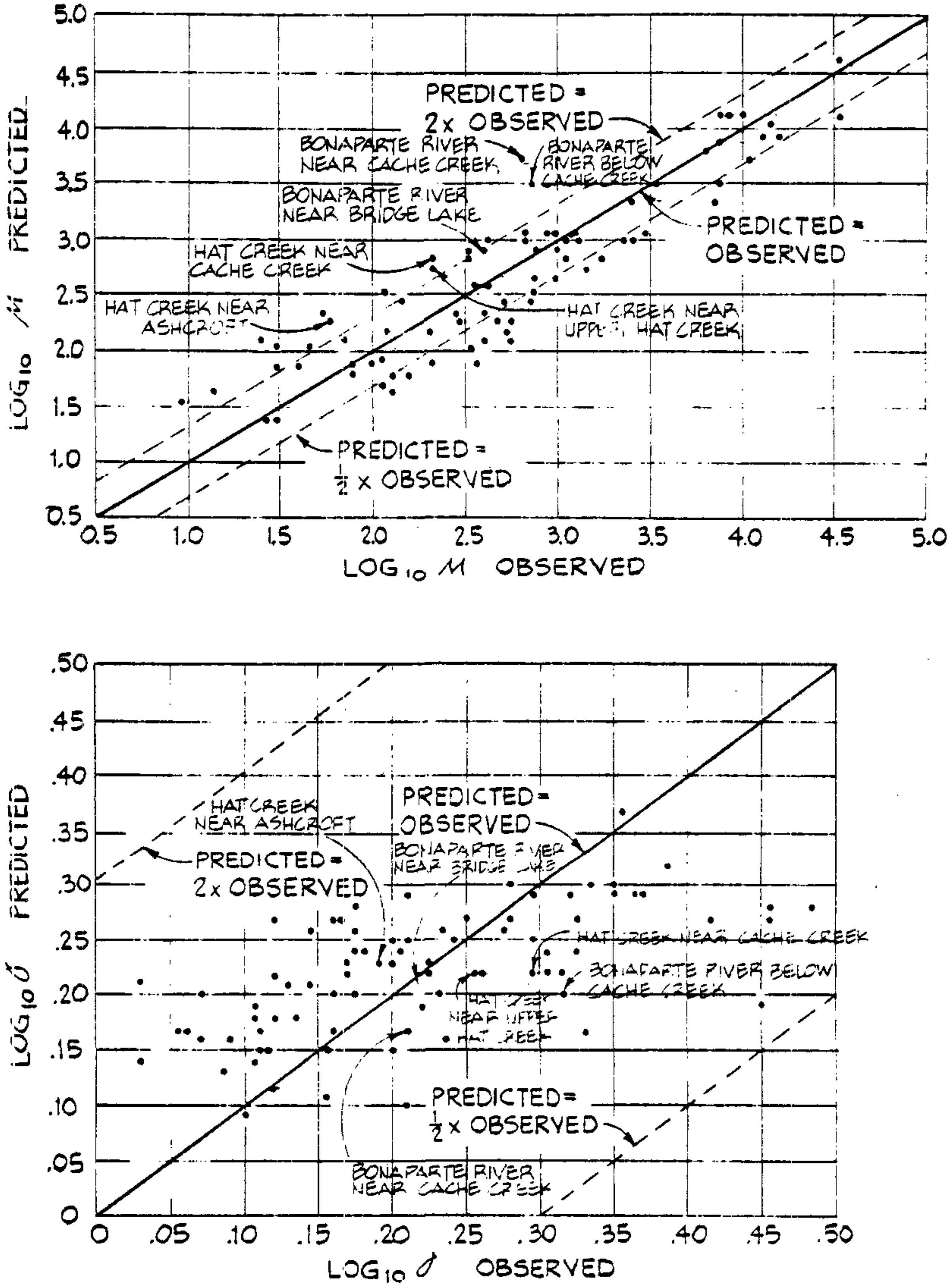


FIGURE 4-19: COMPARISON OF PREDICTED AND OBSERVED REGRESSION VARIABLES

beak

DATE	22/6/77	MH	4-19
PROJECT	K 4242		
DWG NO			

relating to Hat Creek or to the Bonaparte River lie far above the line of perfect agreement, which indicates that Hat Creek and the Bonaparte River generate roughly one third of the flood flows of comparable basins with the same independent variables, A_D, E, P and F, but located elsewhere on the Interior Plateau. This is undoubtedly related to the pronounced rain-shadow effect of the Coast Mountains, immediately to the west of the Hat Creek drainage area. The Coast Mountains are almost 1,000 m higher than the hills surrounding Hat Creek and the change in general terrain level is particularly abrupt immediately west of Hat Creek. The parameter P fails to take full account of this fact because it is based on biased data obtained mostly at low elevations. In the case of the Bonaparte River, the discrepancy is partly attributable to extensive lake storage, which reduces peak flows.

If Equation 3 is to be used for design estimates in the Hat Creek area, the regression constant should be adjusted to -17.485 (from -17.008) to correct for the discrepancy between the overall regression and the Hat Creek region. With this adjustment, the equation can be expected to give reasonable flood estimates for drainage basins greater than 20 to 50 km^2 in the general Hat Creek region.

The regression on the geometric standard deviation was performed in a similar manner. The data were first log-transformed. Note that the dependent variable, log σ, is simply the standard deviation of the logarithms of the individual annual peak flows, X_i. Exactly the same four independent variables appearing in the regression on log μ (Equation 3) reappear again in the regression on log σ. The equation is:

$$\log \sigma = 2.0265 - 0.0515 \log A_D - 0.2436 \log E - 0.1902 \log P - 0.2089 \log F \quad ....\ (4)$$

It explains 43 percent of the variance of the set of 85 standard deviations available for analysis. Observed and predicted values are compared in Figure

4-19 indicating a rather poor fit. This is not surprising since the standard deviation of flood series is generally more variable and more difficult to define than the mean value.

The points representing Hat Creek fall close to the line of perfect agreement, indicating that the observed year-to-year variability of floods in the Hat Creek region is reasonably typical for the southern Interior Plateau of B.C. The Bonaparte River is less typical, probably due to its larger basin with significant lake storage.

Similar regression equations could be computed for other parameters of the annual hydrography, such as the annual low flow, mean annual flow or mean flows for particular seasons. While the computation of further regressions was beyond the scope of this study, a rough comparison of mean annual runoff in Hat Creek with mean annual runoff elsewhere in the southern Interior Plateau appears in Figure 4-20. It confirms the earlier statement that the drainage basin of Hat Creek and the major western portion of the Bonaparte River basins are particularly dry parts of the Interior Plateau.

(ii) Hat Creek Valley Hydrology

A. Precipitation and Snowmelt

The precipitation records for the climatological station "Hat Creek", located within the proposed pit perimeter on the valley floor at an elevation of 899 m, are summarized in Table 4-3. Temperature (daily maximum and minimum) and precipitation (daily) have been observed since November 1961. Precipitation is observed twice daily, in the morning and evening, but only a total daily value is published for each day. The original, half-day observations are available, but not in published form. Peak monthly precipitation occurs in January, with a

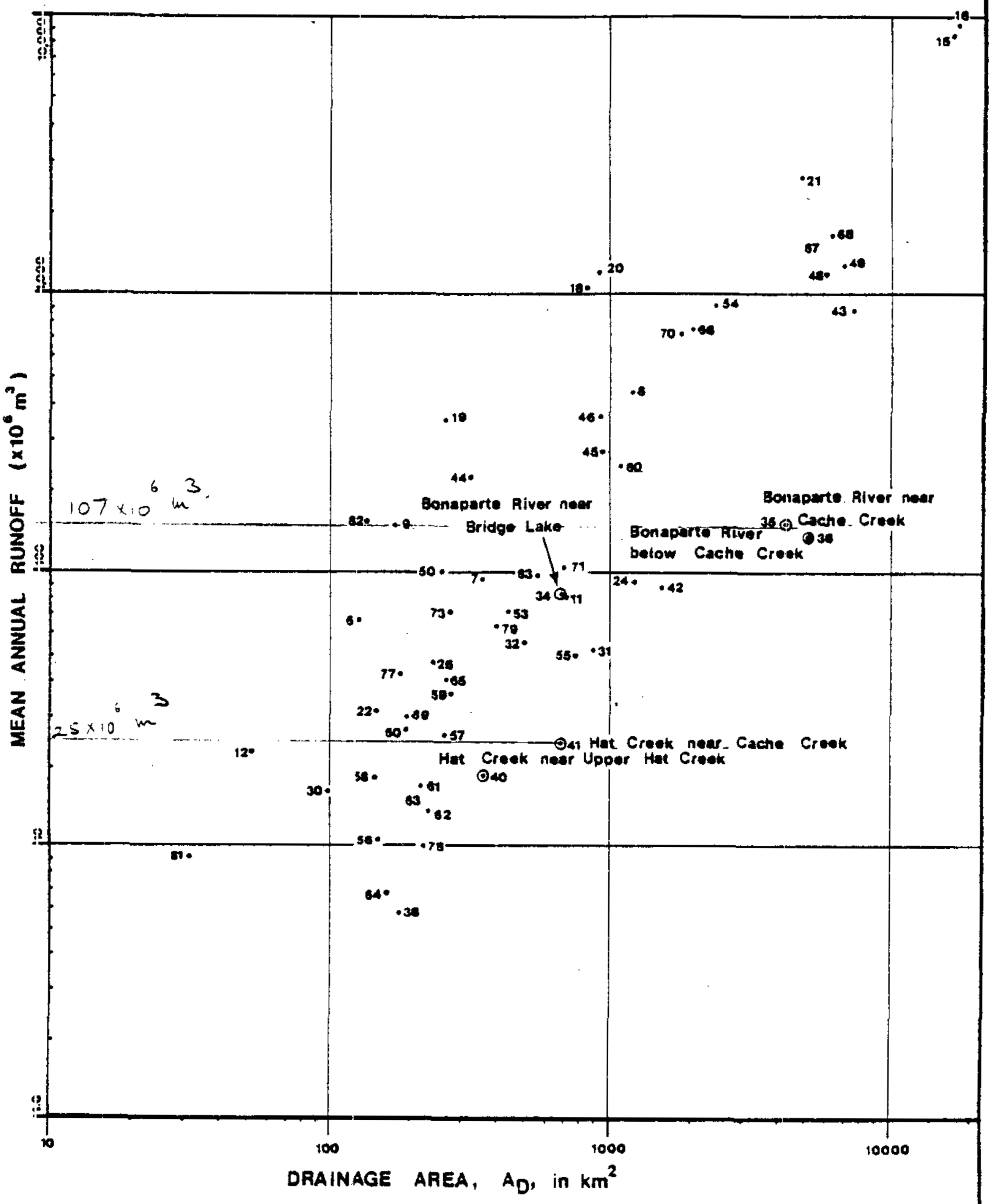


FIGURE 4-20: MEAN ANNUAL RUNOFF VS. DRAINAGE FOR THE SOUTHERN INTERIOR PLATEAU

beak	DATE	JULY 77	RM	4-20
	PROJECT	K4242		
	DWG NO			

TABLE 4-3

SUMMARY OF PRECIPITATION RECORDS FOR HAT CREEK

(based on Canadian Normals, 1941-1971)

Record	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean rainfall (mm)	2.5	2.8	5.3	8.2	17.8	35.1	29.0	31.8	20.1	21.3	6.6	3.5	183.9
Mean snowfall (cm)	36.9	15.7	10.2	8.1	3.8	0	0	0	0.5	3.8	23.1	31.0	133.1
Mean total precipitation (mm)	39.4	18.5	15.5	16.3	21.6	35.1	29.0	31.8	20.6	25.1	29.7	34.5	317.0
Greatest rainfall in 24 hrs. (mm)	10.2	5.1	3.0	8.1	16.5	22.6	38.9	30.0	26.7	17.5	5.3	7.6	38.9
Years	10	10	10	10	10	10	10	10	9	10	11	11	
Greatest snowfall in 24 hrs. (cm)	42.4	8.4	9.1	11.9	9.4	0	0	0	T	8.6	19.1	22.1	42.4
Years	10	10	10	10	10	10	10	10	10	10	11	11	
Greatest precipitation in 24 hrs. (mm)	42.4	10.2	9.1	15.7	16.5	22.6	38.9	30.0	26.7	17.5	19.1	22.1	42.4
Years	10	10	10	10	10	10	10	10	9	10	11	11	
Number of days with measurable precipitation	10	6	6	5	7	7	8	7	6	6	9	11	88

from Atmospheric Environment Service, Canadian Normals, 1973.

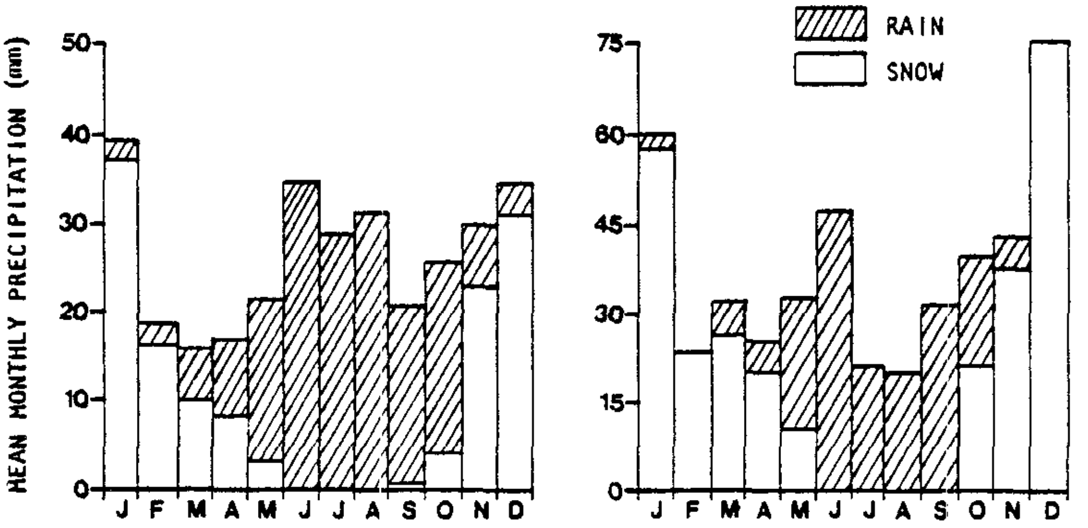
secondary peak in June. March and April are distinctly dry, with a secondary dry period in September. In Figure 4-21, the seasonal distribution of mean monthly precipitation observed at Hat Creek is compared with the distribution observed at five other sites in the general region. The Hat Creek data appear to be typical.

The year-by-year variations in total precipitation, total rainfall and greatest 24 hour rainfall are illustrated in Figures 4-22, 4-23 and 4-24, respectively and are compared with data for other sites in the general region. The frequency curves for Hat Creek are based on 14 years of data in the period 1961 to 1975 but other curves are based on different periods of record. The number of years of record are shown in brackets for each curve. With 62 years of data, Kamloops has by far the longest record. The lowest total annual precipitation observed in Hat Creek region was 71 mm at Ashcroft in 1938. Some of the largest 24 hour rains are: 114 mm in 1917 at Lillooet, 77 m in 1963 at Lytton, 57 mm in 1939 at Merritt. For Hat Creek, the highest value is 39 mm on July 23, 1966.

Data on rainfall intensities of shorter duration than 24 hours are sparse. The Rainfall Intensity-Duration-Frequency curves for Kamloops A and Kamloops-Meadow Creek, developed by the Atmospheric Environment Service, are the most relevant data available for the present study. They are the nearest stations to Hat Creek and also most compatible from a climatic point of view. The 24 hour values given for Kamloops A agree closely with the corresponding values indicated by the frequency curve for the distribution of the greatest 24 hour rainfall at Hat Creek (Figure 4-24). This is somewhat inconsistent as the Intensity-Duration-Frequency curves are for time periods that can start any time while the "greatest 24 hour rain" data are for climatic days, roughly 8 am to 8 am. The former should give significantly higher intensities.

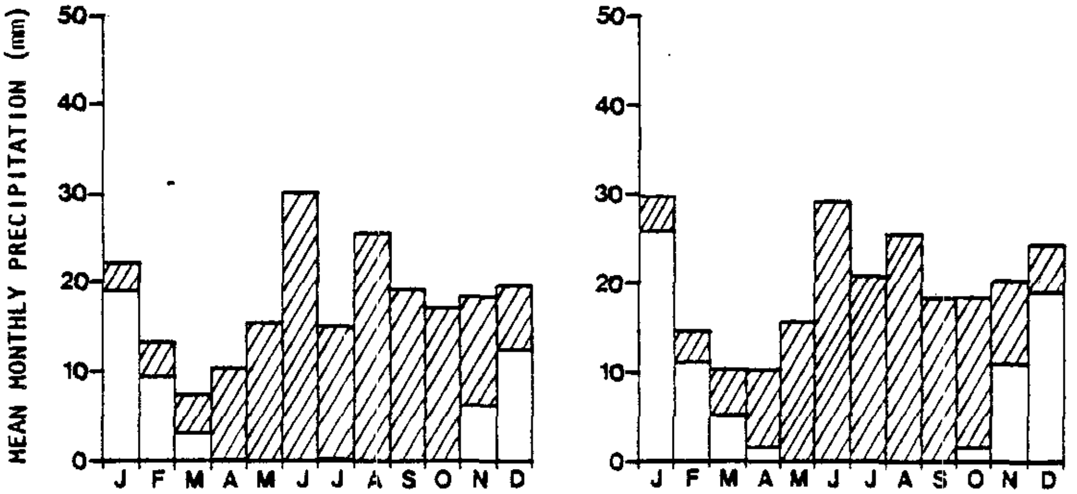
Since precipitation at Hat Creek is significantly greater than at Kamloops, the Intensity-Duration-Frequency curves for Kamloops were adjusted upwards to set the 24 hour values in agreement with the 24 hour values observed at Hat Creek, neglecting the differences in definition of the time period. The resulting three curves are shown in Figure 4-25.

FIGURE 4-21- SEASONAL DISTRIBUTION OF MEAN MONTHLY PRECIPITATION IN THE HAT CREEK REGION



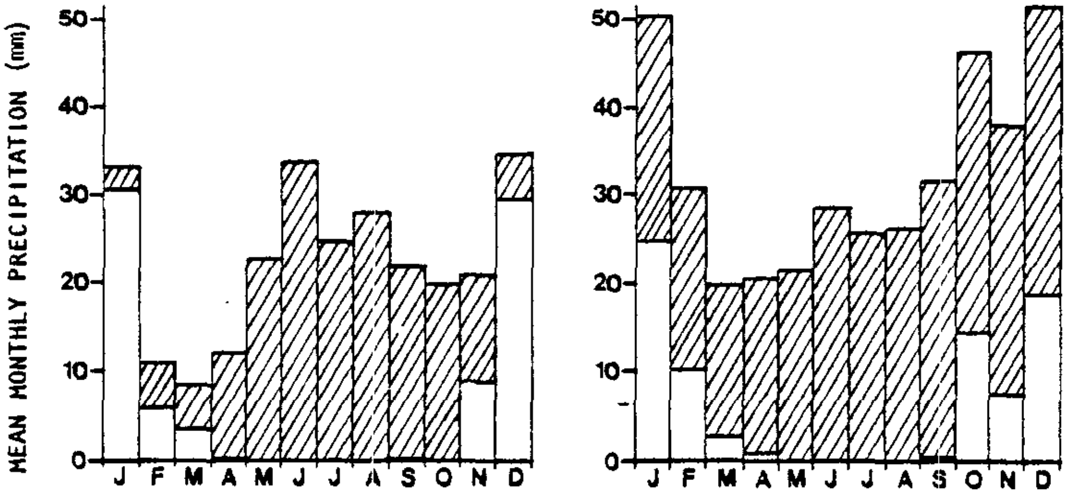
HAT CREEK, ELEV. 899 m

HIGHLAND VLY, LORNEX, ELEV. 1582 m



ASHCROFT, ELEV. 305 m

ASHCROFT M, ELEV. 488 m



KAMLOOPS, ELEV. 351 m

LILLOOET, ELEV. 290 m

from Atmospheric Environment Service
Canadian Normals, 1973.

DATE	7-77	CC	4-21
PROJECT	K4242		
DWG NO			

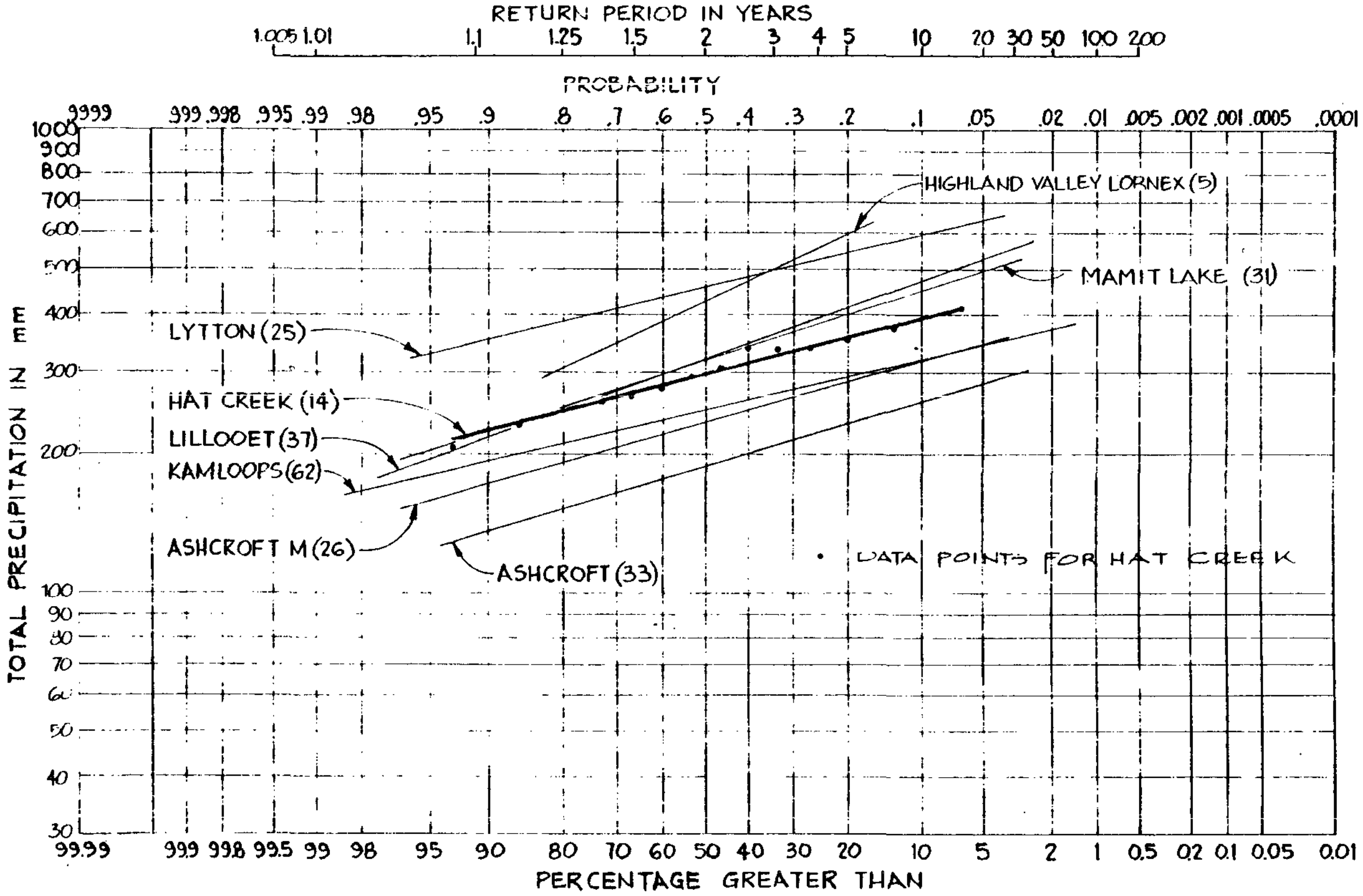


FIGURE 4-22: DISTRIBUTION OF TOTAL PRECIPITATION FOR HAT CREEK AND SURROUNDING AREAS

from Atmospheric Environment Service, Climatological Station Data

beak	DATE	22/6/77 MH	4-22
	PROJECT	K4242	
	DWG NO		

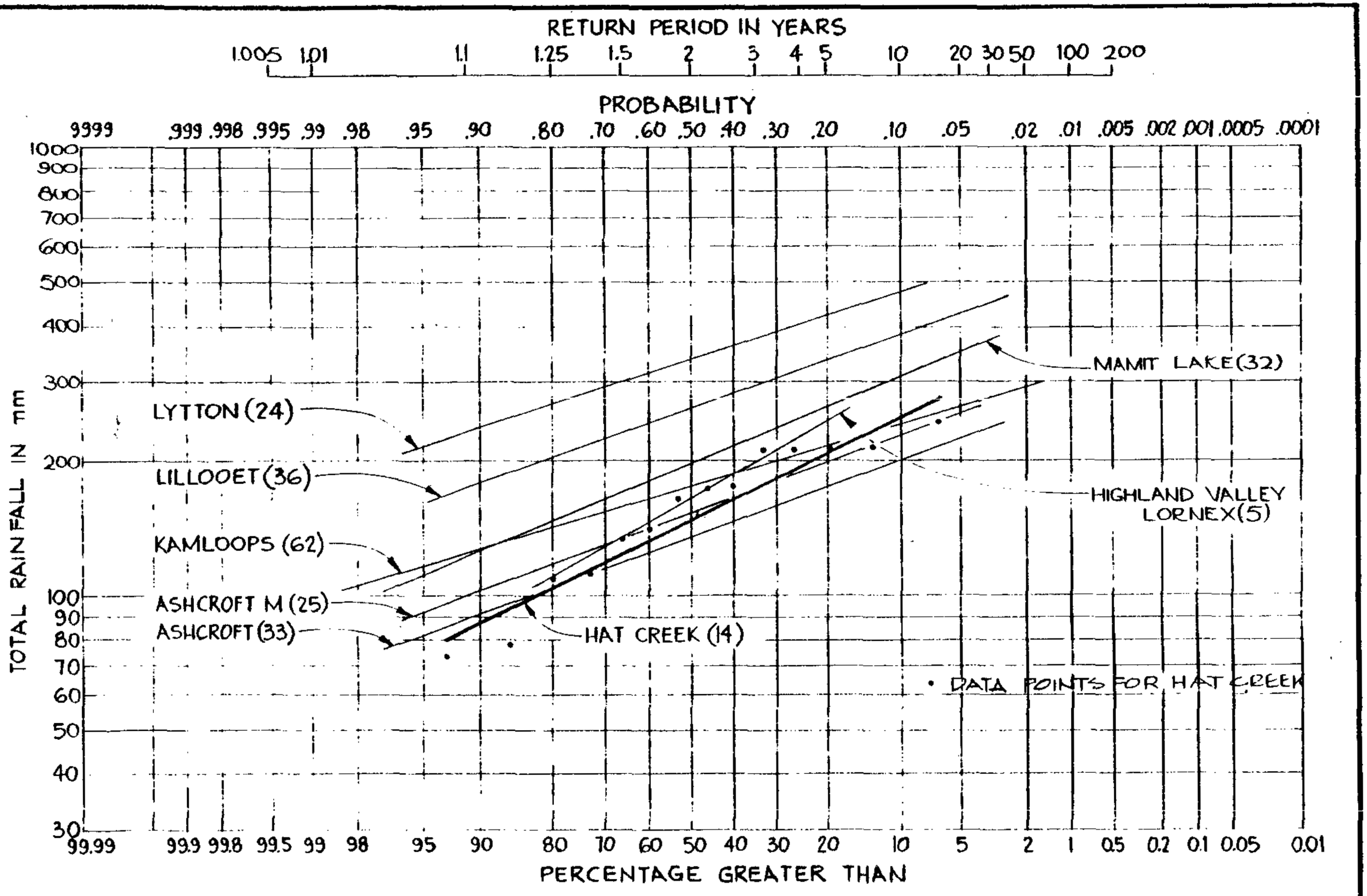


FIGURE 4-23: DISTRIBUTION OF TOTAL RAINFALL FOR HAT CREEK AND SURROUNDING AREAS

from Atmospheric Environment Service, Climatological Station Data

beak	DATE	22/6/77 MH	4-23
	PROJECT	K4242	
	DWG NO		

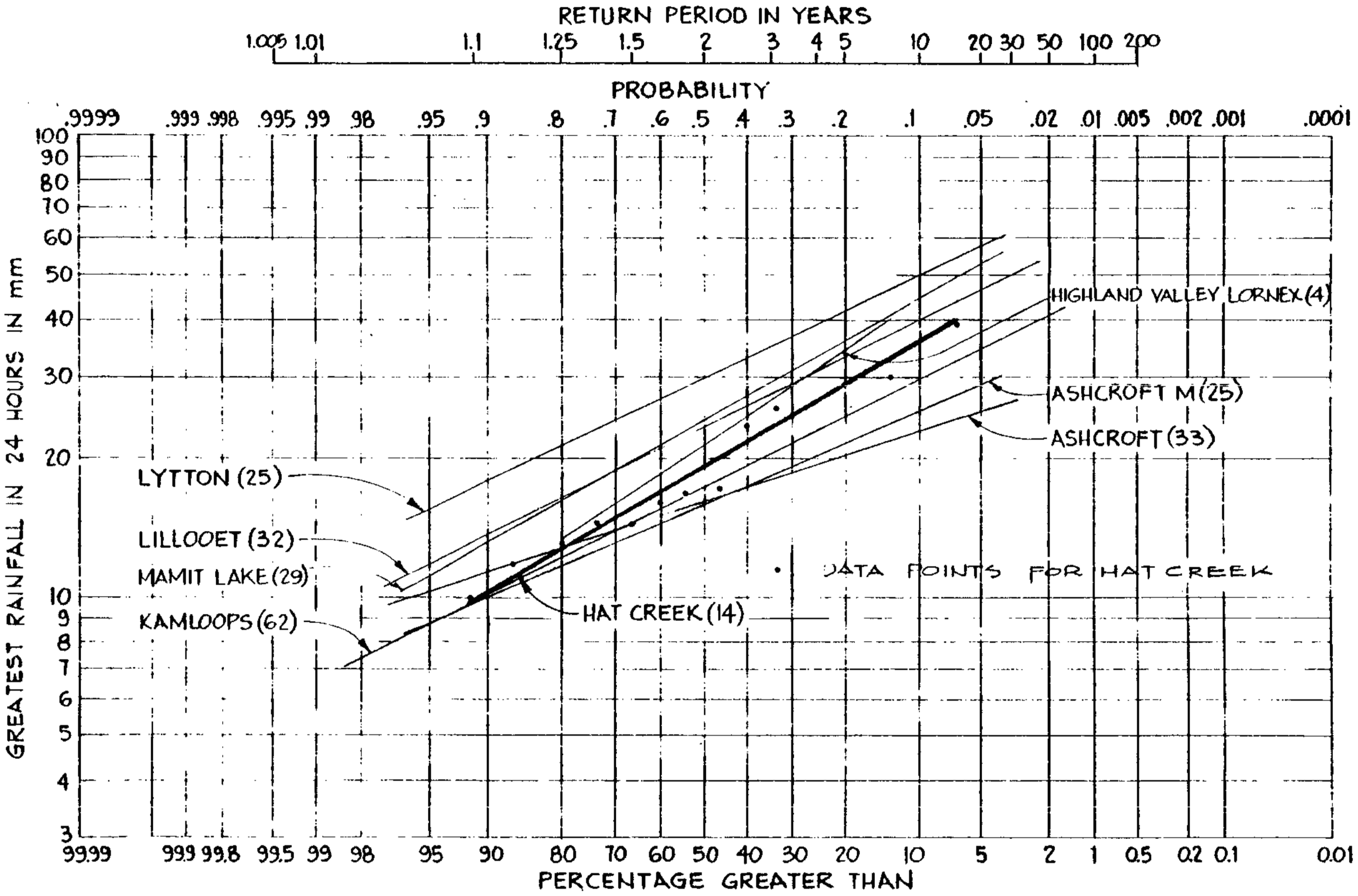
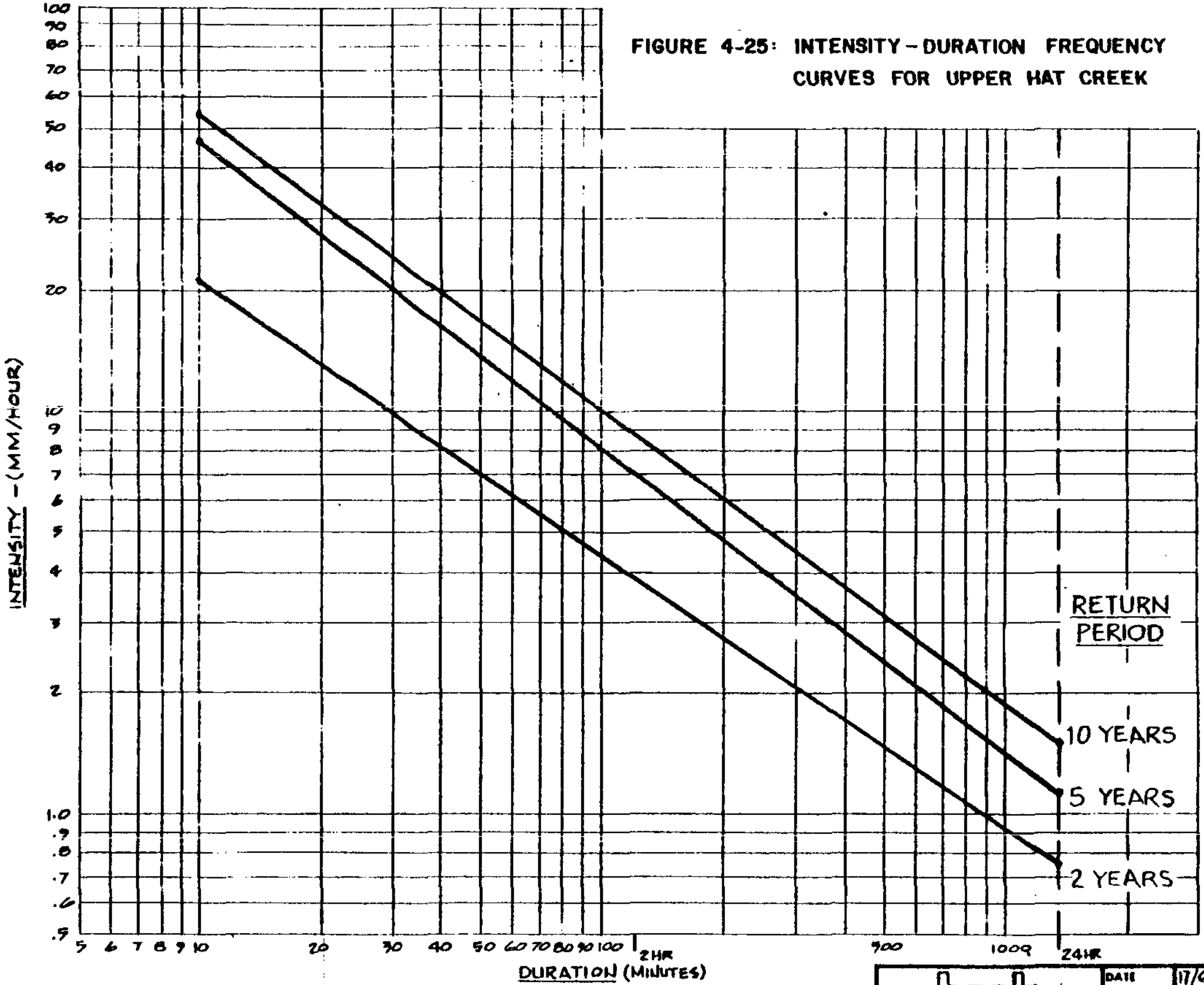


FIGURE 4-24: DISTRIBUTION OF GREATEST RAINFALL IN 24 HOURS FOR HAT CREEK AND SURROUNDING AREAS

from Atmospheric Environment Service, Climatological Station Data

DATE	22/6/77 MH	4-24
PROJECT	K 4242	
DWG NO		

FIGURE 4-25: INTENSITY-DURATION FREQUENCY CURVES FOR UPPER HAT CREEK



(based on AES supplied curves for Kamloops A, adjusted to the observed 24 hour frequencies)

DATE	17/6/77 MH	4-25
PROJECT	K 4242	
DWG NO		

Comparison between the curves for Kamloops A, situated at elevation 351 m, and Kamloops Meadow Creek, at elevation 1,188 m, suggests that there is only little variation in rainfall intensity with elevation. The curves given in Figure 4-25 should therefore be adequate for both the mine and plant sites.

Total precipitation depends strongly on elevation but in order to evaluate that dependence for a particular region, one would require information from close-by climatic stations covering a wide elevation range. This information is not available for Hat Creek. The best available data are plotted on Figure 4-26, together with a proposed curve for Hat Creek. The curve is not meant to fit all the plotted points; it is an attempt to fit those data points judged to be most relevant to Hat Creek. The data points for Lillooet and Kwotlenemo Lake show how rapidly precipitation increases westwards, while the data points for Mamit Lake and Kamloops indicate a more gradual increase eastward.

The curve of Figure 4-26, relating mean annual precipitation to elevation, can be combined with the area-elevation curves for Hat Creek and Medicine Creek (Figure 4-27),to compute a total mean precipitation input into these basins by adding up the input to successive elevation bands. For Hat Creek, the total amounts to 394 mm, evenly distributed over the basin area, which can be compared to the 317 mm mean annual precipitation observed at the Hat Creek climatological station. The figure for Medicine Creek is 390 mm.

The streamflow regime of Hat Creek is dominated by the annual accumulation and melt of a snow pack. Detailed records of this process are not available for the Hat Creek drainage but Figure 4-28 shows four years of the records for the Mission Ridge snow pillow. It is located 45 km west of Hat Creek, in the Bridge River drainage, at an elevation of 1,850 m, where it receives more snow than would sites at the same elevation in the Hat Creek Valley. The data are included here as a rough indication of the timing and rate at which the snow pack in Hat Creek can be expected to accumulate and melt. Except for the greater precipitation at the Mission Ridge site, other relevant climatic factors (e.g. temperature, humidity, hours of sunshine) are closely comparable.[8]

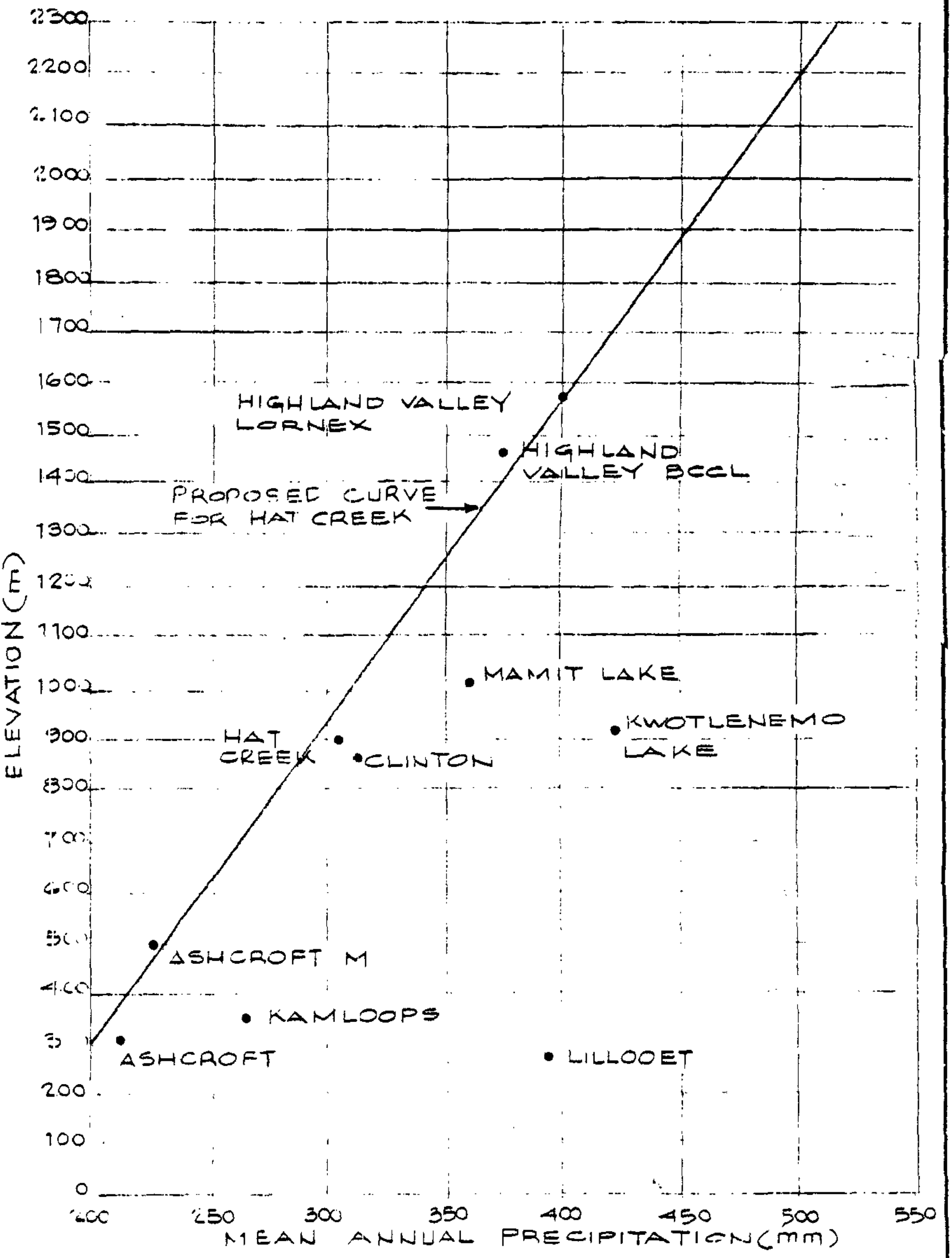


FIGURE 4-26: VARIATION OF MEAN ANNUAL PRECIPITATION WITH ELEVATION

from Atmospheric Environment Service, Climatological Station Data

beak

DATE	22/6/77	4-26
PROJECT	K 4242	
DWG NO		

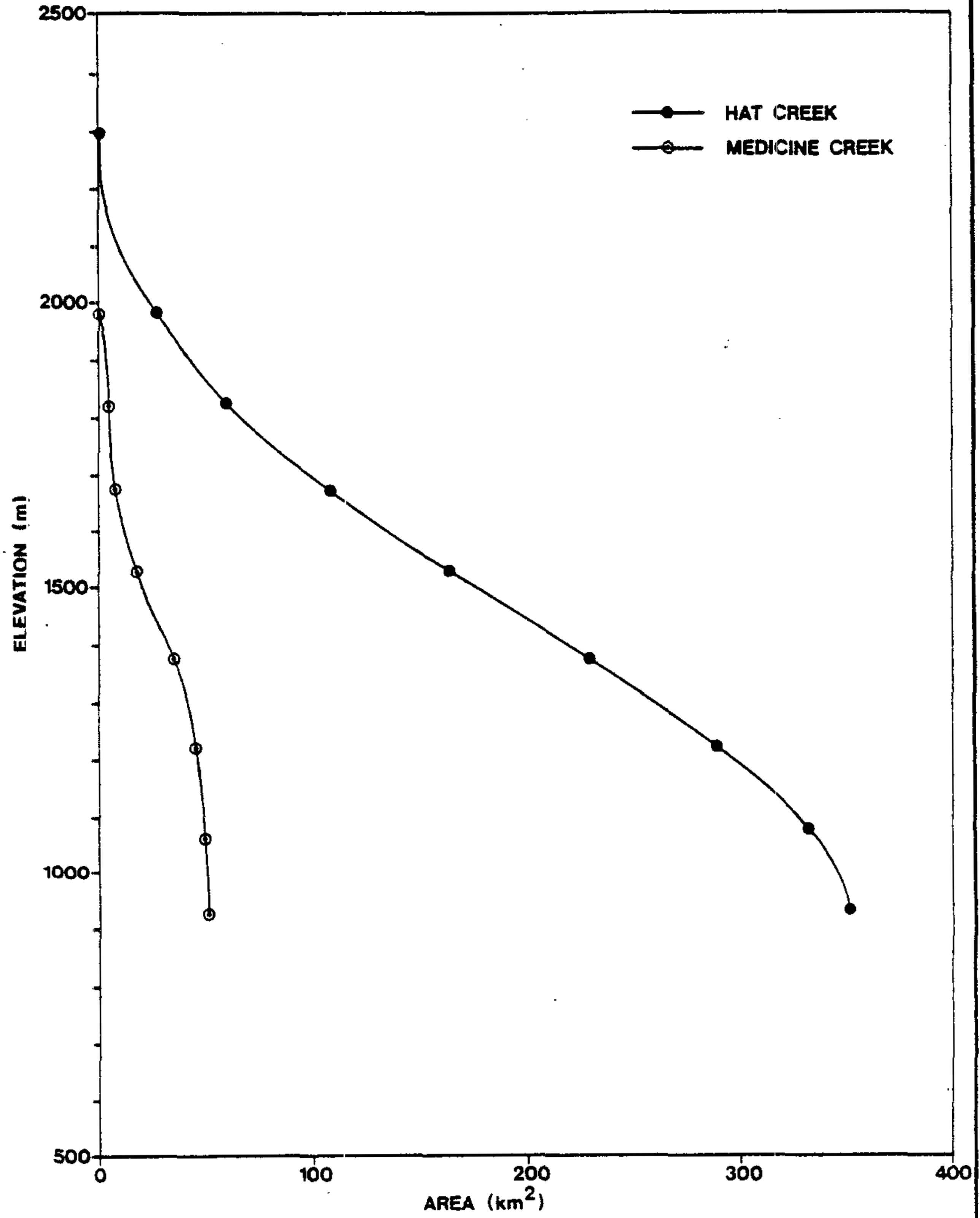


FIGURE 4-27: AREA - ELEVATION CURVES FOR HAT CREEK (AT CONFLUENCE WITH MEDICINE CREEK) AND FOR MEDICINE CREEK (AT MOUTH)

DATE	7-77	CC
PROJECT	K4242	
DWG NO		

4-27

SNOW PILLOW STATION DATA

NAME: MISSION RIDGE NO: P4 ELEVATION: 1,851 METRES

LOCATION: 50°46' LAT. 122° 12' LONG. DRAINAGE: BRIDGE RIVER

CORRESPONDING SNOW COURSE: NO. 182 MISSION RIDGE

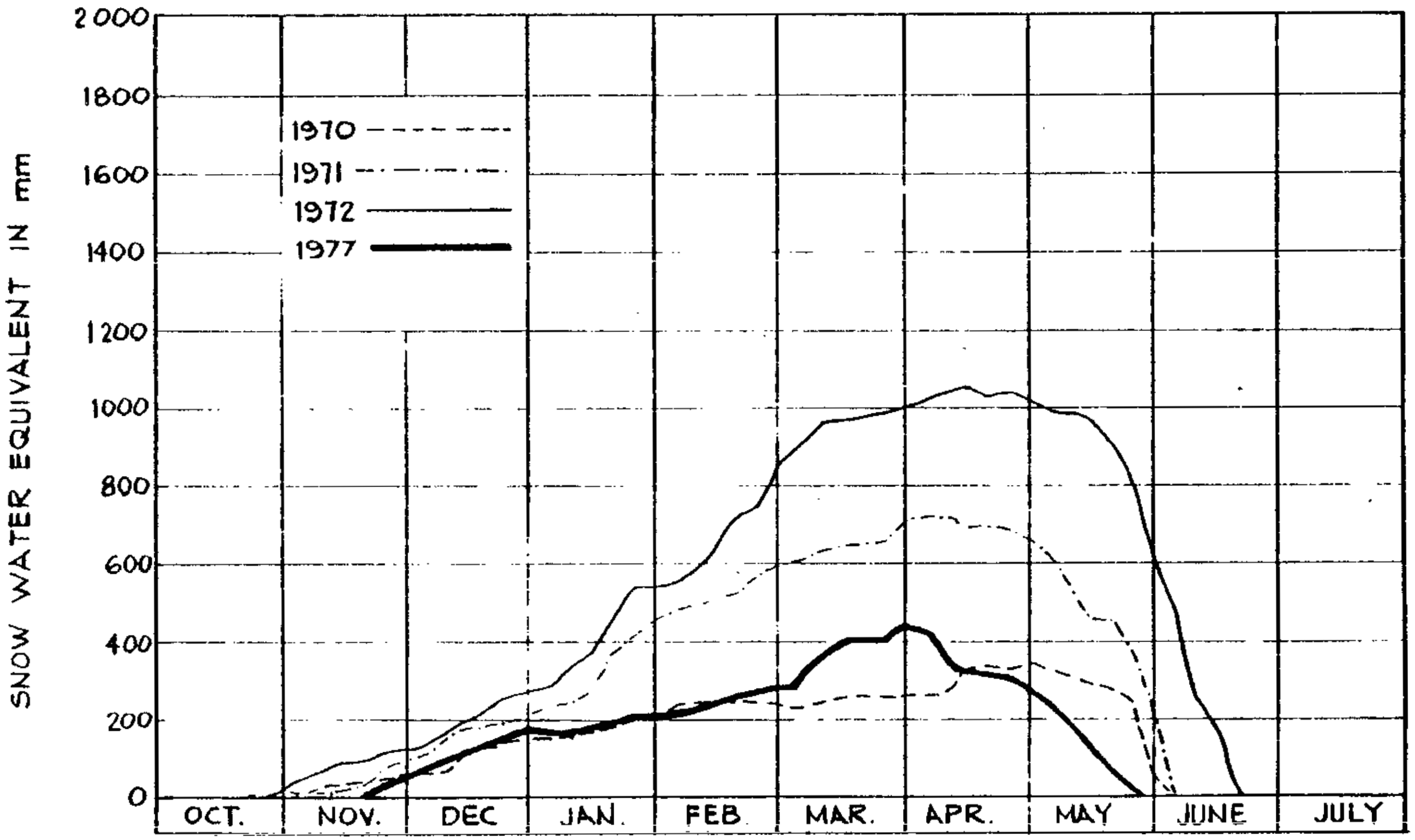


FIGURE 4-28: ACCUMULATION AND DECAY OF SNOWPACKS NEAR HAT CREEK

from Water Resources Service, Snow Survey Measurements Summary, 1975.

beak			
	DATE	22/6/77 MH	4-28
	PROJECT	K4242	
	DWG NO		

Snow accumulation is even more dependent on elevation than is mean annual precipitation. This variation can be investigated either on the basis of mean annual snowfall, as recorded by the climatological stations of AES, or on the basis of mean maximum snow water content accumulated in the snow pack, as recorded by the snow surveys of the Water Investigations Branch. The two are not truly equivalent for several reasons:

(i) The Atmospheric Environment Service uses a standard factor of 0.1 to convert the depth of newly fallen snow to its water equivalent although it is well known that the factor can vary over a wide range.

(ii) *Snowmelt can take place before the maximum snow pack is accumulated.*

(iii) Rains falling onto a deep, cold snow pack can become incorporated in it.

In Figure 4-29 these factors are neglected and data of both types are plotted against elevation. There appears to be no obvious discrepancy between the two types of data, although this naturally does not establish that they are really equivalent. As done earlier in the case of precipitation (Figure 4-26) a proposed curve for Hat Creek is drawn by eye, fitting the most relevant data points as best as possible. It indicates the variation with elevation of both mean annual snowfall and mean annual snow pack accumulation.

As in the case of annual precipitation, an average snow pack can be computed for Hat Creek on the basis of Figures 4-27, and 4-29 by adding up the accumulation in each elevation band. It amounts to $6.09 \cdot 10^7 \cdot m^3$ of snow-water equivalent, or 176 mm over the total basin area. Comparing it with the earlier mean annual precipitation input to the basin of 394 mm, indicates that, on average, 45 per*cent of the total precipitation input into the basin is incorporated in the snow* pack before becoming runoff.

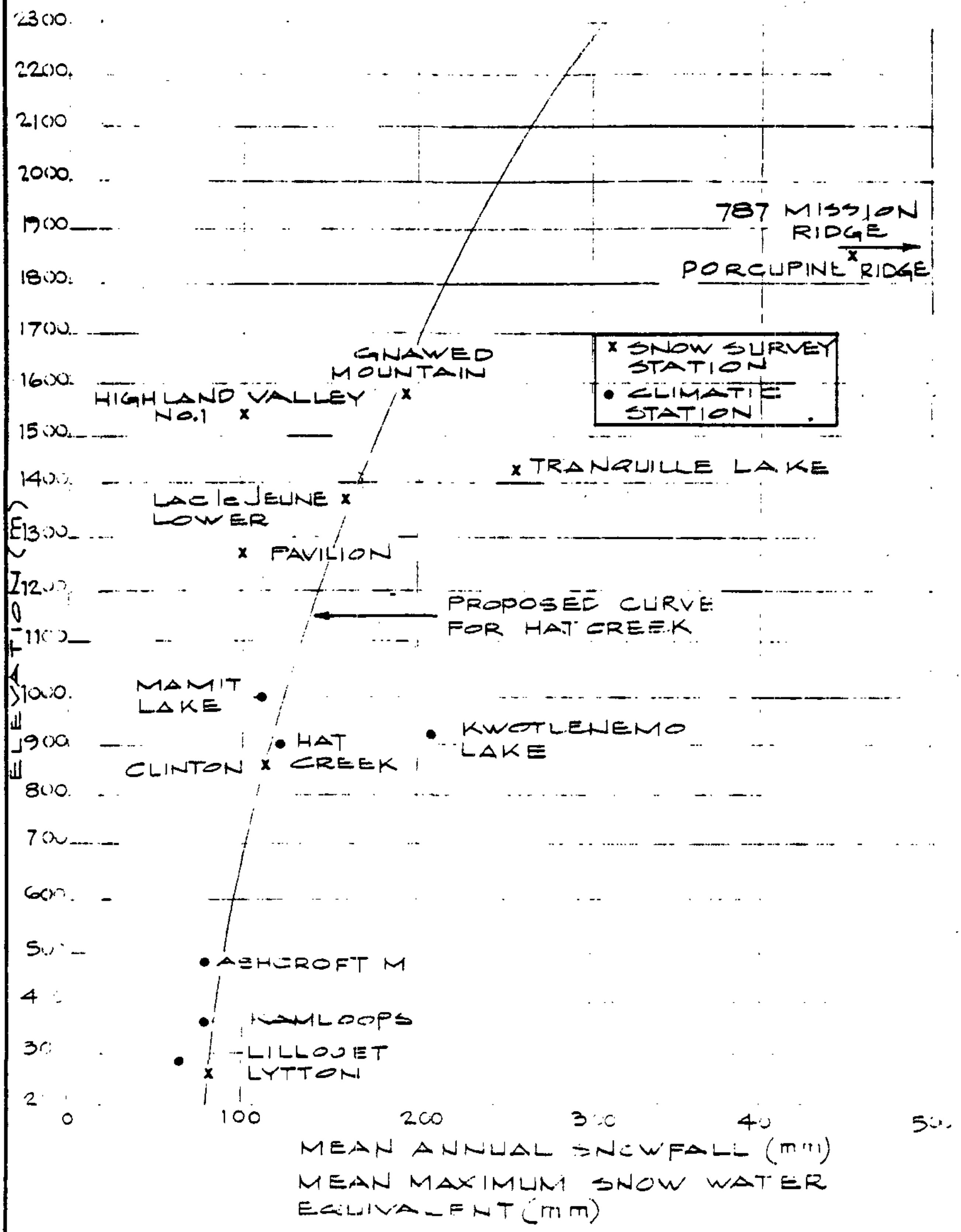


FIGURE 4-29: VARIATION OF MAXIMUM SNOW ACCUMULATION WITH ELEVATION

beak

DATE	22/4/77	4-29
PROJECT	K4242	
DWG NO		

The year to year variation in snow accumulation is illustrated by the frequency curves of Figure 4-30. In each case the 1977 snow pack is illustrated with a separate point. A tendency for sites with a small snow pack to also have the most variable pack is apparent but not well defined. Spring 1977 is truly outstanding for its lack of snow.

B. Flow Regime

As discussed in Section 3.1(a)(ii) significant records exist for three gauging sites along Hat Creek. The uppermost gauging station (73 km^2), "Hat Creek near Ashcroft", was operated seasonally from 1911 to 1922 only. The middle station (350 km^2), "Hat Creek near Upper Hat Creek", has almost continuous records since 1961, and the lowermost station near the mouth of Hat Creek, (658 km^2) "Hat Creek near Cache Creek", has records from 1911 to 1913 and again from 1960 to 1973. This last station has recently (May 1977) been re-established. Table 3-3 gives a summary of operating periods and type of records. Figure 3-2 is a plot of Hat Creek drainage area versus length from source. The three important stream gauging sites are shown on this figure.

Almost all streamflow records for Hat Creek are based on once-a-day manual gauge observations. As pointed out earlier, it is therefore quite probable that some flood peaks may have been considerably larger than indicated by the daily data.

In Figure 4-31, which were originally prepared by B.C. Hydro's Hydroelectric Design Division for Beak Consultants Limited, the records for Hat Creek and for the Bonaparte River immediately upstream of Hat Creek are summarized as 5-Day Probability Curves. For each site the daily flow records for successive 5 day periods are combined into groups. The distribution of flows in each group is then analyzed to obtain the following parameters: maximum, 10 percent exceeded value, median, 90 percent value and minimum. These parameters are plotted at the middle of the 5 day period. The curves provide an excellent summary of the range and seasonal distribution of flows observed in the past. Late August and early

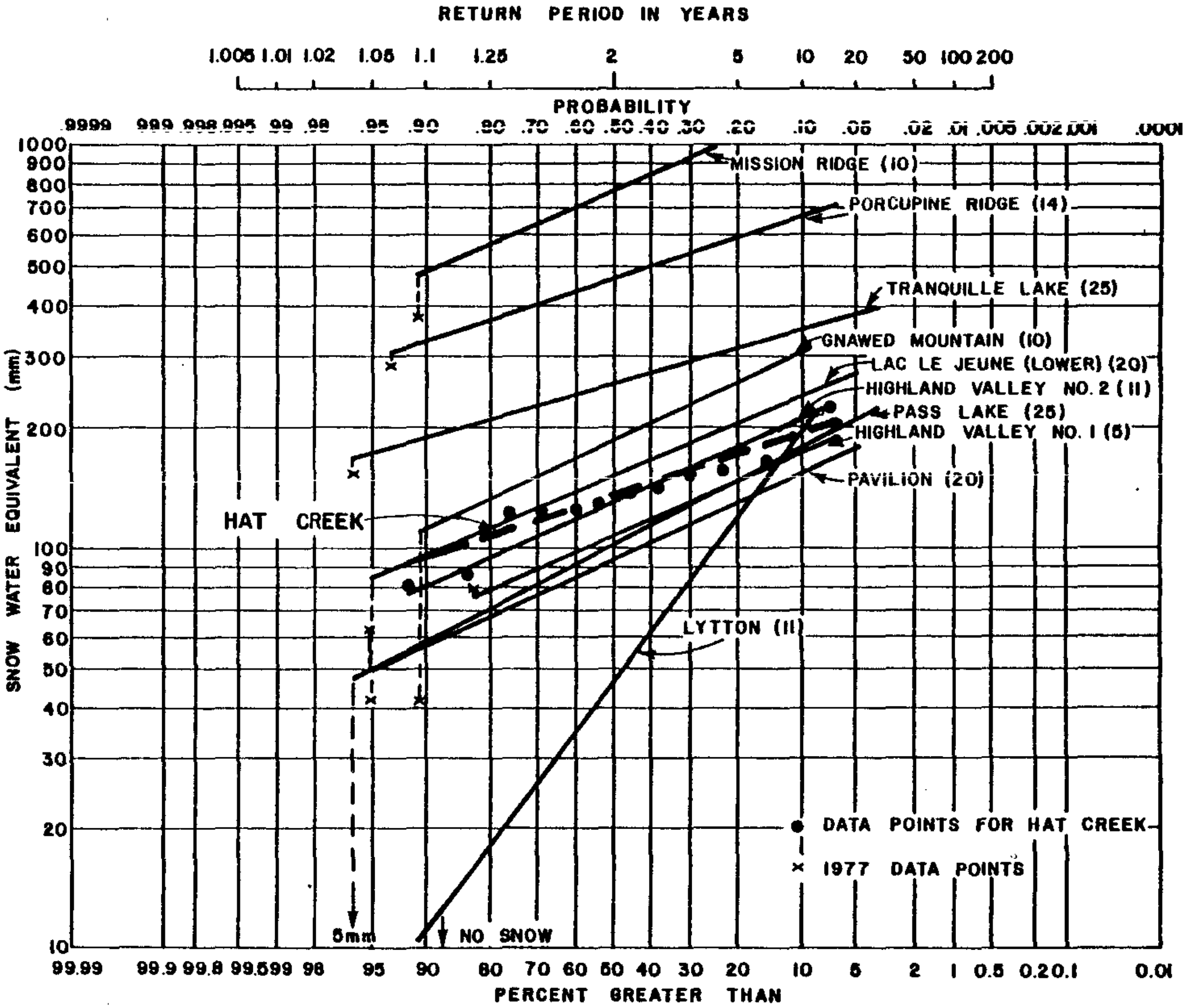
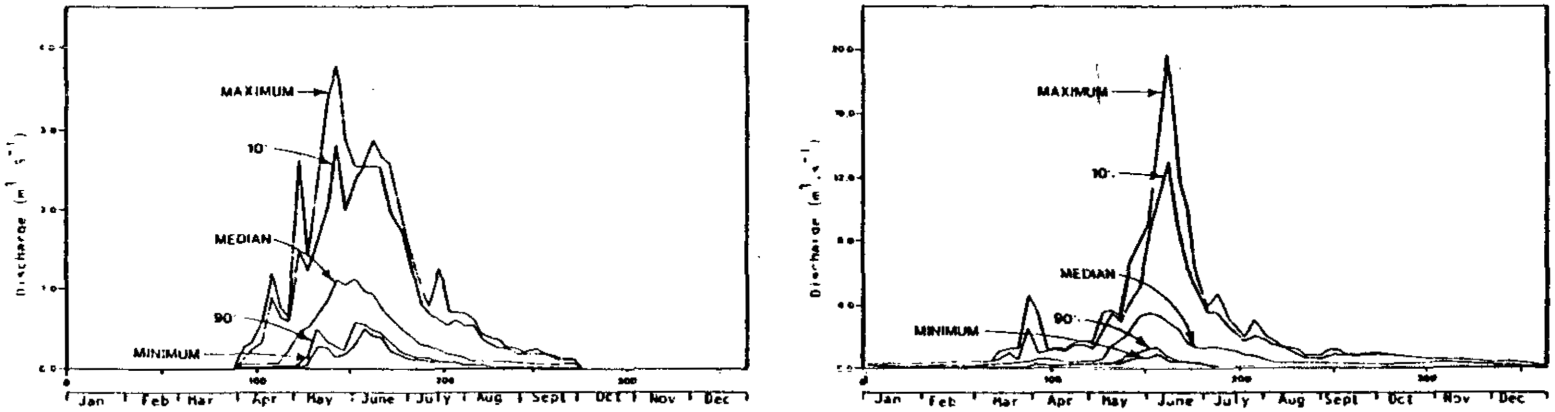


FIGURE 4-30 DISTRIBUTION OF MAXIMUM ANNUAL SNOW WATER EQUIVALENT

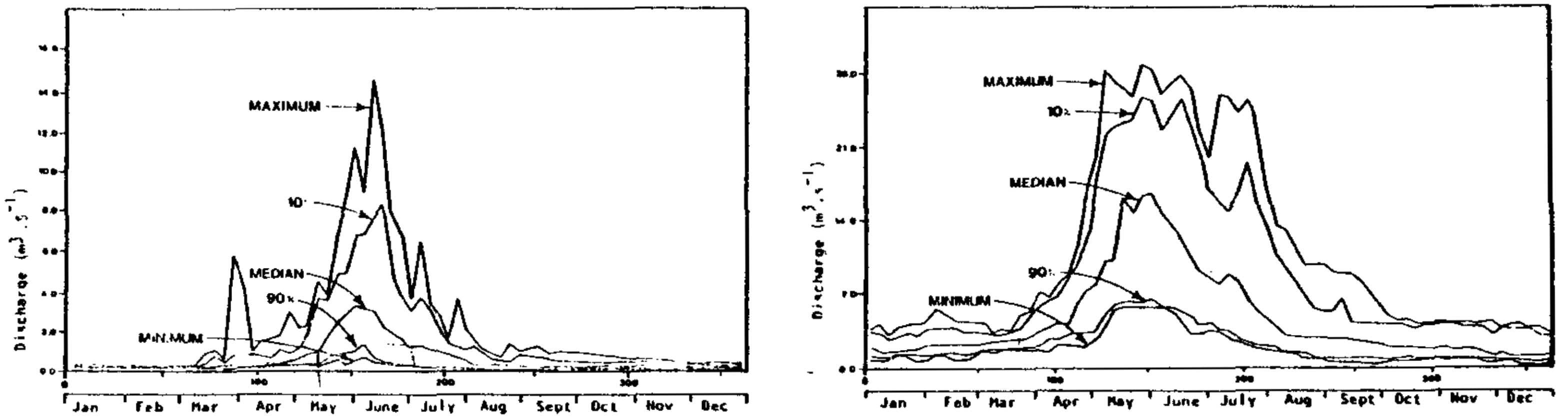
from Water Resources Service, Snow Survey Measurements Summary, 1975.

beak	DATE	Nov 77 DF	4-30
	PROJECT	K4242	
	DWG. NO	Rev. 17-1	



A: Hat Creek near Ashcroft, 08LF013, 1911-22; drainage area = 73 km^2

C: Hat Creek near Cache Creek, 08LF015, 1961-73: drainage area = 658 km^2



B: Hat Creek near Upper Hat Creek, 08LF061, 1961-75; drainage area = 350 km^2

D: Bonaparte River near Cache Creek, 08LF060, 1961-74; drainage area = 4092 km^2

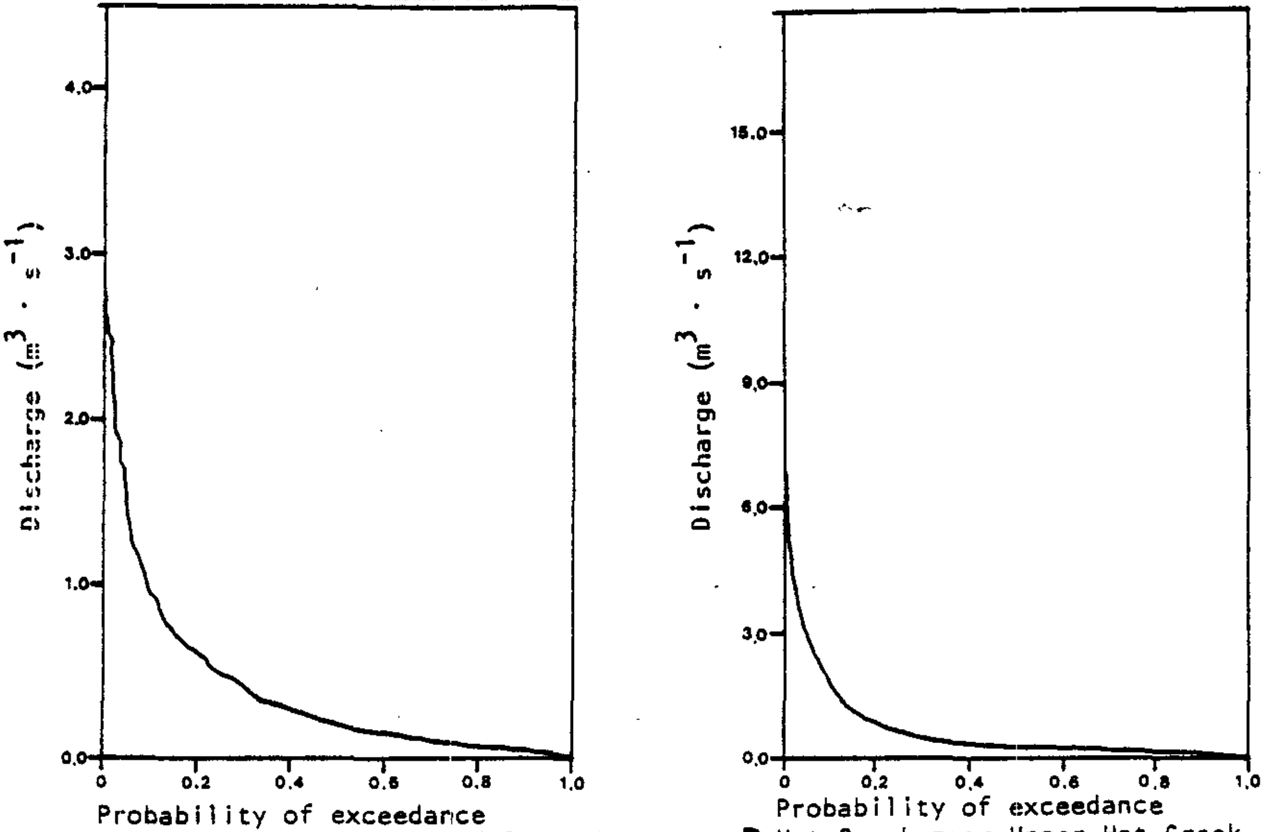
FIGURE 4-31: 5-DAY FLOW PROBABILITY CURVES FOR HAT CREEK AND BONAPARTE RIVER

beak
DATE
PROJECT K4242
DWG NO
4-31

September show up clearly as critical low flow periods. Rain-caused peaks can occur in summer but do not reach the magnitude of spring freshet flows. The possibility of significant early snowmelt in March or April is indicated but does not appear to be common. The Bonaparte River appears to have a much more regulated flow behaviour. This is partly due to significant lake storage but also due to its very large drainage basin.

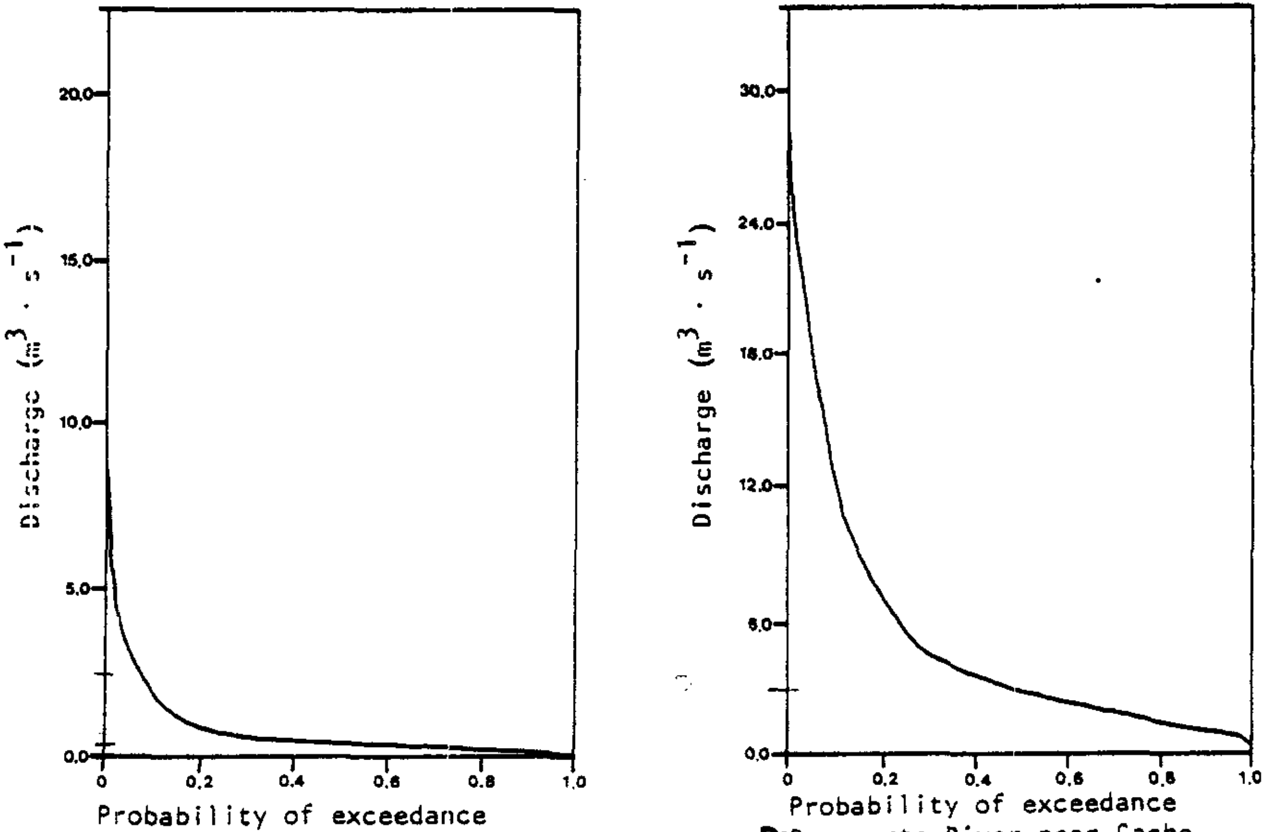
The standard flow-duration curves for the same four sites are shown on Figure 4-32, and the corresponding flood-frequency curves are shown on Figure 4-33. Also shown on Figure 4-33 are the predicted flood frequency curves based on the regional analysis regression equation for μ, the mean daily peak flow, and adjusted to the Hat Creek region, as discussed in Section 4.1 (b) (i)B. In Figure 4-34, the adjusted regional analysis has been used to obtain flood frequency curves for Harry, Medicine, Ambusten, Anderson, Finney and Houth Creeks. An existing diversion from Medicine Creek to MacLaren and Cornwall Creeks affects the topmost 15.3 km^2 of Medicine Creek drainage. Its capacity is unknown, but based on field inspection it appears to be around 0.5 $m^3 s^{-1}$. In Figure 4-34 the diversion is ignored as there is no assurance that it will, in fact, be in operation at any given time. The basin parameters used as independent variables in the regression equations are listed in Table 4-4. Where available, peak flows observed by BEAK in the course of the freshet survey of spring 1977 are also plotted and show that this was an unusually dry spring.

The year to year variability of total runoff from Hat Creek can only be analyzed for stream gauging sites with year-round operation. This eliminates the uppermost Hat Creek station and part of the record for the other two stations. Figure 4-35 shows the year to year distribution of runoff from Hat Creek. Mean annual runoff, for the station "Hat Creek near Upper Hat Creek" based on 14 years of data, including 1976, is 21.0 x 10^6 m^3. The total licenced use upstream of the gauge is 9.79 x 10^6 m^3, of which 5.49 x 10^6 m^3 is licenced for use in the Hat Creek drainage basin. The remainder consists of 2.06 x 10^6 m^3 licenced for diversions to Oregon Jack Creek, a diversion that has not been used for years (Figure B2-3 Appendix B) and 2.24 x 10^6 m^3 licenced for diversion to MacLaren and Cornwall Creek, which appears to be in full use. While these numbers indicate a considerable



A: Hat Creek near Ashcroft (08LF013)
Apr.-Sept. flows 1911-22

B: Hat Creek near Upper Hat Creek
(08LF061), 1961-75



C: Hat Creek near Cache Creek
(08LF015), 1961-73

D: Bonaparte River near Cache
Creek (08LF060), 1960-74

FIGURE 4-32 - FLOW DURATION CURVES FOR HAT CREEK AND BONAPARTE RIVER

DATE	7-77	C C	4-32
PROJECT	K4242		
DWG NO			

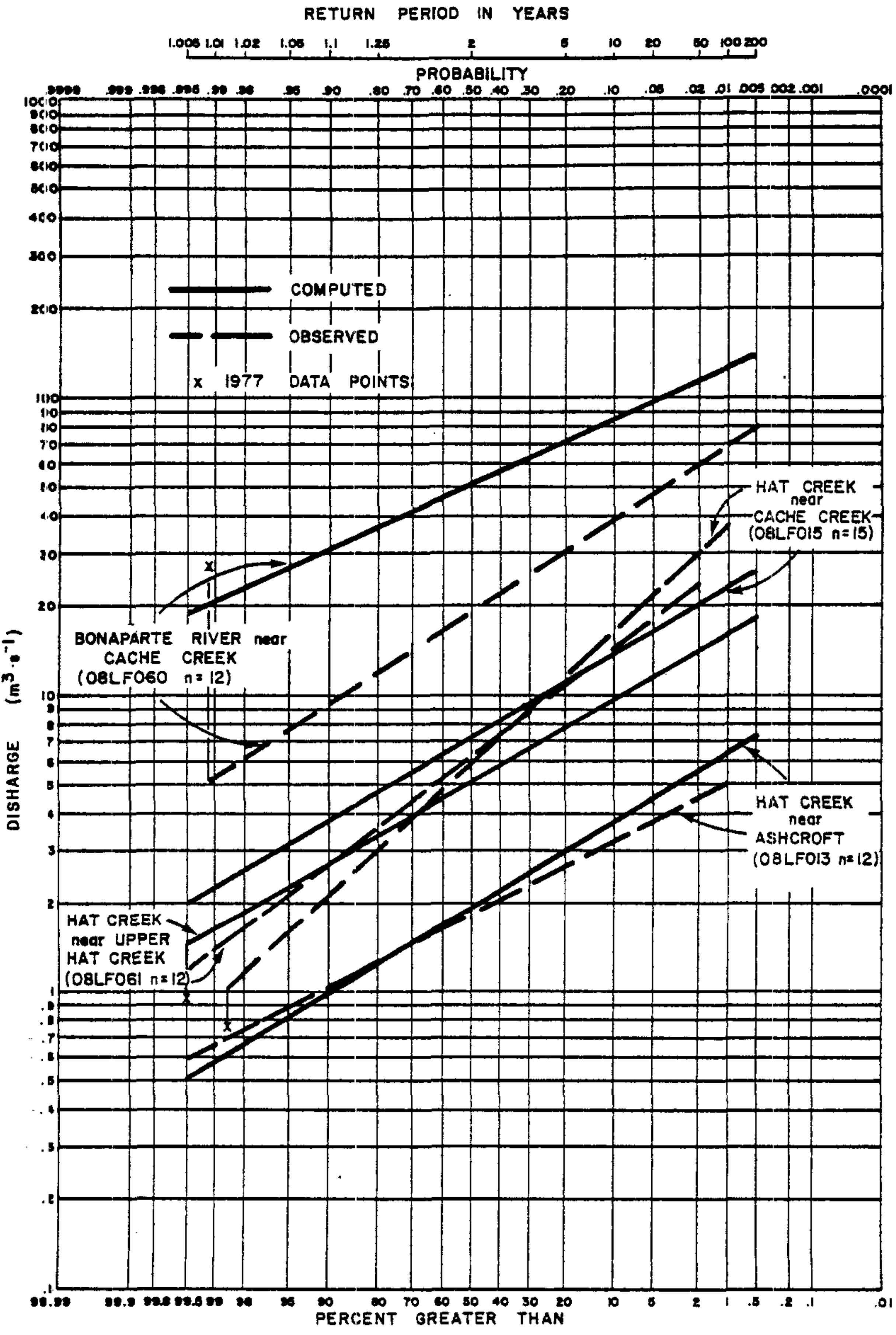


FIGURE 4-33: FLOOD FREQUENCY CURVES FOR HAT CREEK AND BONAPARTE RIVER.

DATE	Nov. 77	DF
PROJECT	K4242	
DWG NO	Rev. 20-1	

4-33

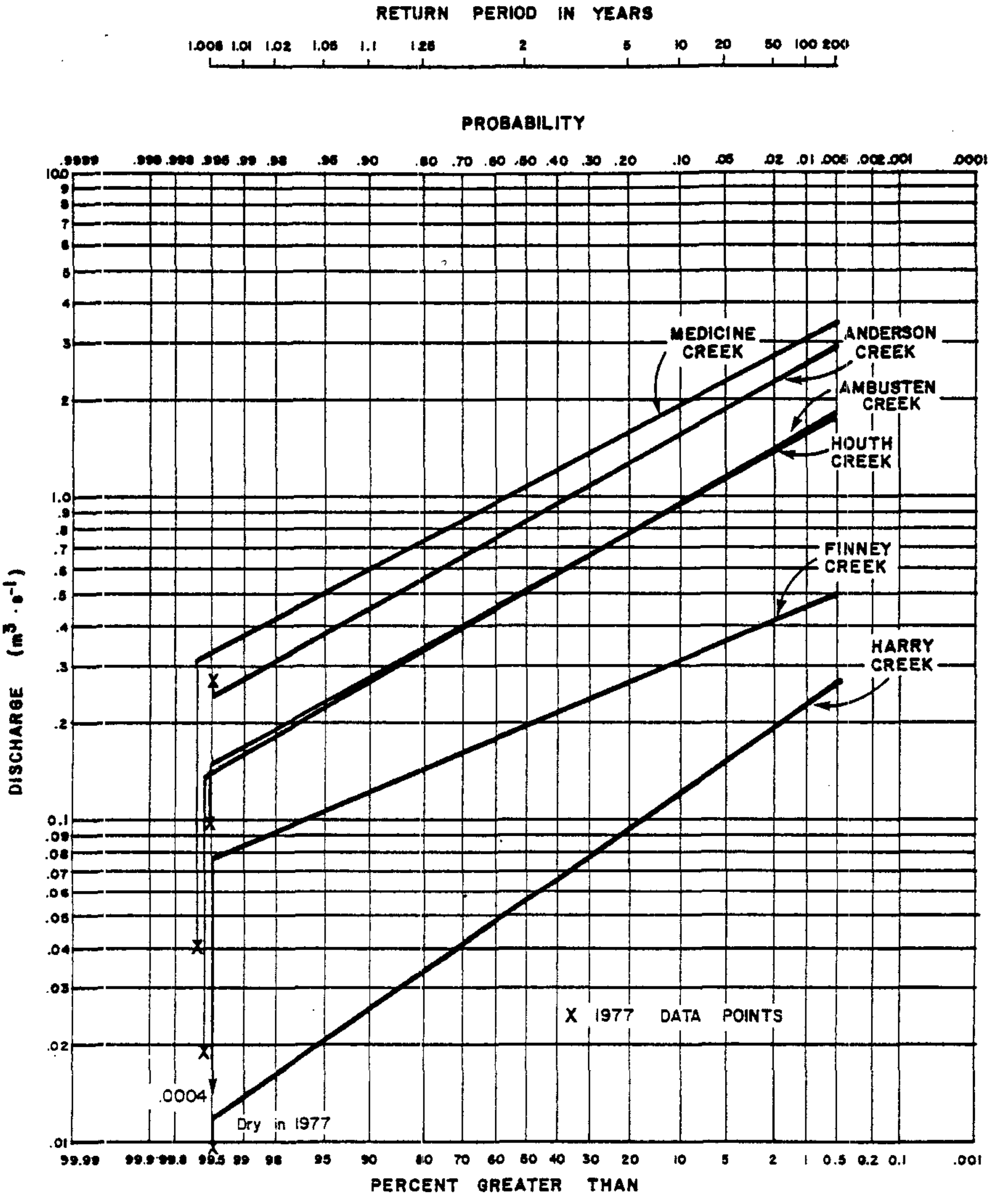


FIGURE 4-34: ESTIMATED FLOOD FREQUENCY CURVES FOR MAJOR HAT CREEK TRIBUTARIES IN THE VICINITY OF THE PROPOSED MINE.

DATE	Nov.77 DF	4-34
PROJECT	K 4242	
DWG NO	Rev. 21-1	

TABLE 4-4: Basin Parameters for Flood Frequency Curves

Name	Drainage Area (km^2)	Elevation (m)	Precipitation (mm)	Forest Cover (%)
Hat Creek near Ashcroft	72.52	1612	457.2	94.18
Hat Creek near Cache Creek	658	1336	406.4	85.08
Hat Creek near Upper Hat Creek	349.7	1443	457.2	80.28
Bonaparte River near Cache Creek	4092	1266	457.2	92.48
Anderson Creek	39.03	1623	508.0	77.7
Ambusten Creek	30.32	1508	457.2	82.8
Harry Creek	9.68	1177	406.4	74.6
Finney Creek	14.52	1367	406.4	84.8
Houth Creek	30.32	1389	457.2	97.8
Medicine Creek including diversion	58.21	1432	457.2	96.4

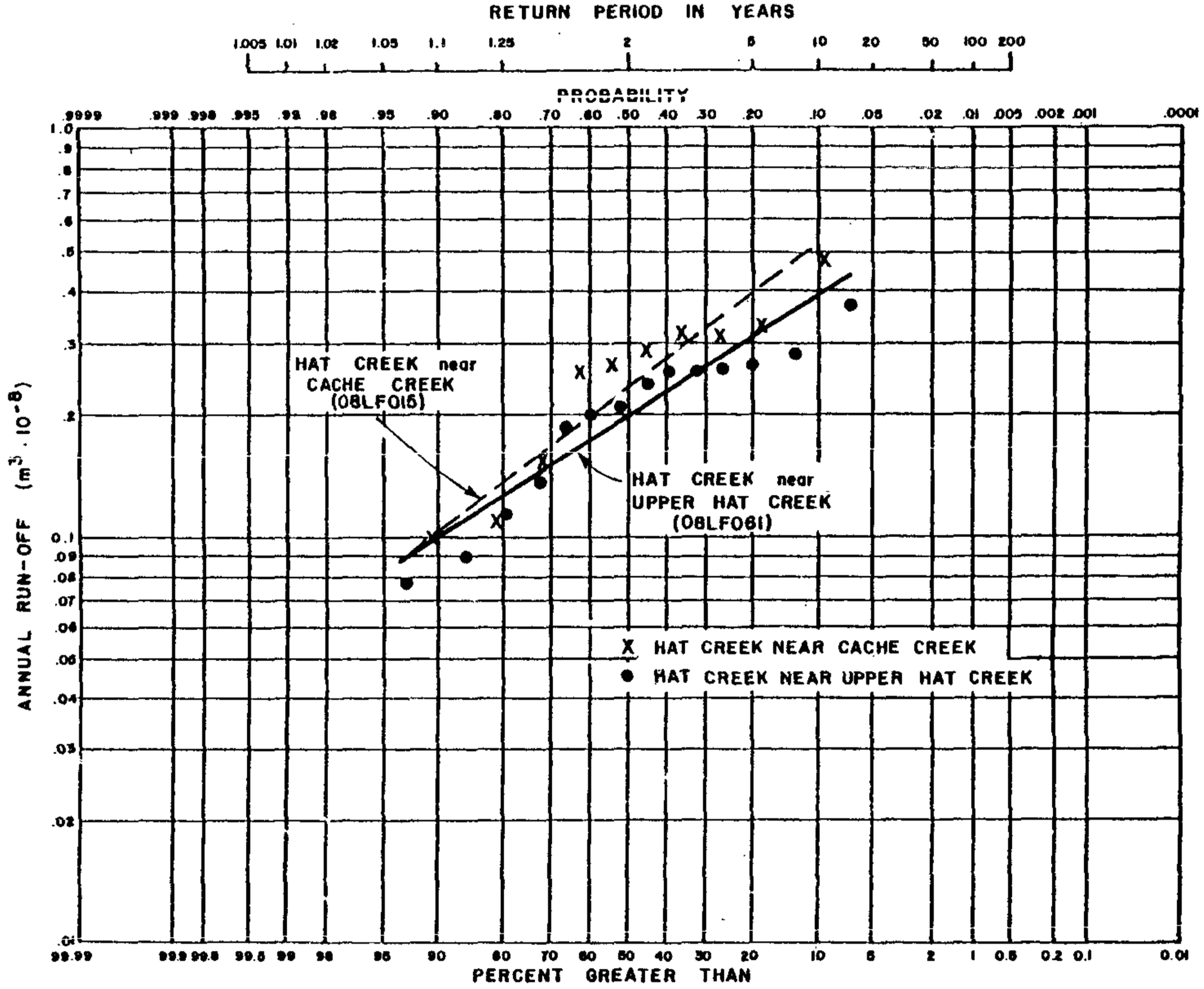


FIGURE 4-35: DISTRIBUTION OF HAT CREEK RUN-OFF

DATE	Nov. 77 DF	4-35
PROJECT	K 4242	
DWG NO	Rev. 22-1	

surplus of water in most years, this is somewhat misleading due to the fact that the seasonal distribution of runoff and irrigation water demand are out of phase, and there is little natural or artifical storage in the Hat Creek drainage area.

In Hat Creek, the lowest mean daily flows of the year can occur either in late summer on in mid-winter. Both these low flow periods are of considerable, but different biological and economic significance. They are therefore analyzed separately here. The streamflow records for Hat Creek near Upper Hat Creek have been broken into yearly periods running from June 1 to May 31 and low flow frequencies curves for the late summer low, mid-winter low and combined low have been prepared as shown on Figure 4-36. (The individual curves which include the data points are contained in Appendix B, Figures B2-4, B2-5, and B2-6). The two low flow periods are quite similar in magnitude of observed flow but the late summer flows are considerably more variable. Summer 1977 appears to have been the driest summer of record.

On two occasions during Fall 1976 and again during a four week period in May and June 1977, streamflow measurements were carried out in all the major tributaries to Hat Creek near the proposed mine site. With 1976 having been a year of relatively low flows in Hat Creek, (mean discharge of 0.39 $m^3 \cdot s^{-1}$, with long term mean being 0.69 $m^3 \cdot s^{-1}$), the fall discharge measurements give an indication of normal minimum flows to be expected in these tributaries. Under very unusual conditions, such as occurred in 1977, even lower flows are possible. The measurements of fall 1976 are listed in Table 4-5.

The data collected during spring 1977 are shown in Figures B2-7, B2-8, and B2-9. The gauging sites for the spring program are listed in Table 3-3 and are not always identical to those of fall 1976; although the differences are minor. For comparison, the Water Survey of Canada records of the same period for the gauges "Hat Creek near Upper Hat Creek" (at the mine site) and "Hat Creek near Cache Creek" (at the mouth) are similarly shown in Figure B2-10, Appendix B. Harry Creek was visited as part of the field program and was found to be dry.

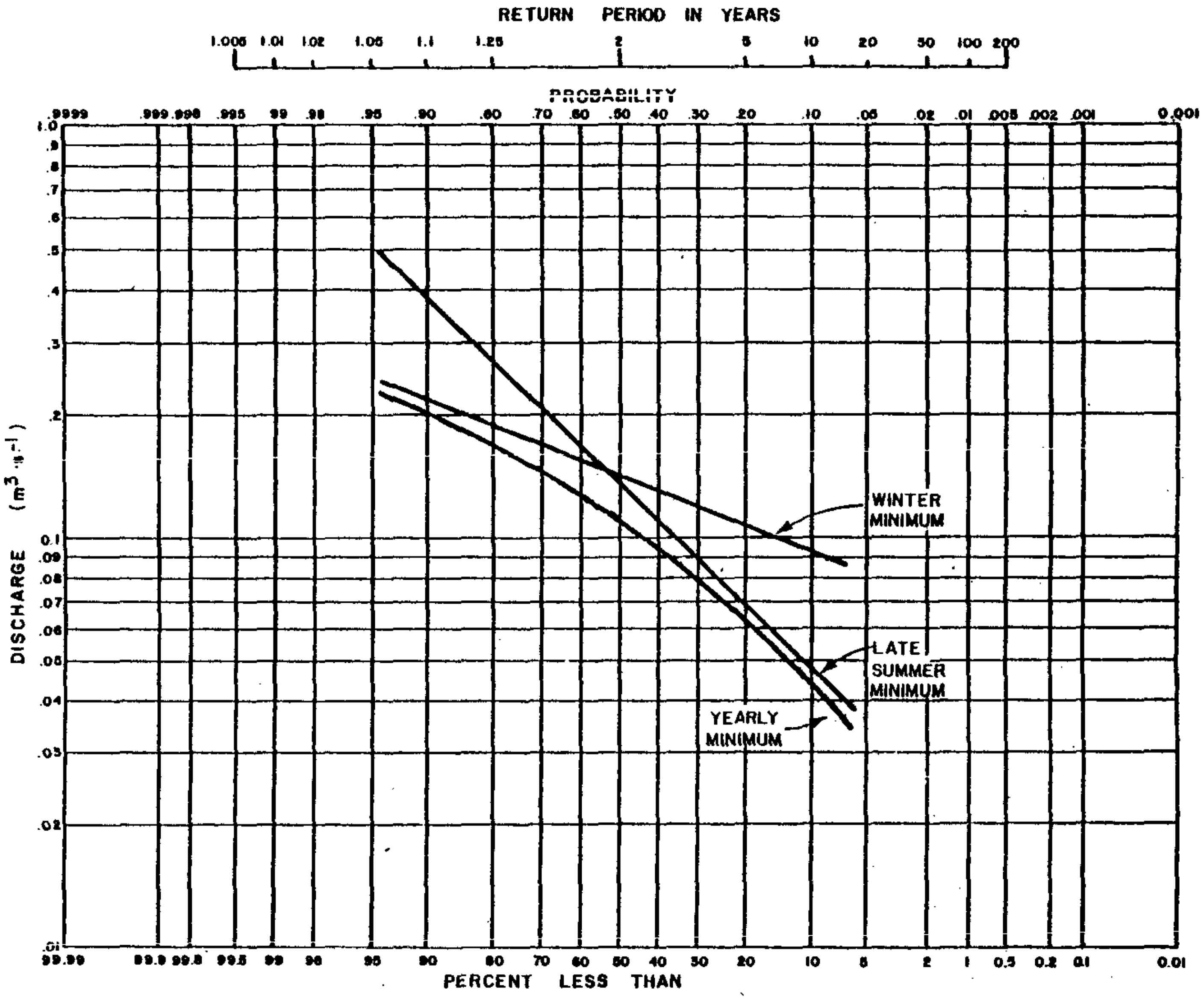


FIGURE 4-36: COMPARISON OF LOW FLOW FREQUENCY CURVES FOR HAT CREEK NEAR UPPER HAT CREEK (08LF061)

beak	DATE	Dec 77 DF	4-36
	PROJECT	K 4242	
	DWG NO		

TABLE 4-5: Streamflow Measurements of Fall 1976

Stream	Gauging Site Latitude	Gauging Site Longitude	Date and Time		Discharge $(m^3 . s^{-1})$
Ambusten	50 44 00	121 33 48	15 Sept.	4:30 P.M.	0.0147
	50 44 00	121 33 48	18 Oct.	3:55 P.M.	0.0099
Anderson	50 43 39	121 37 46	16 Sept.	8:30 A.M.	0.0419
	50 43 39	121 37 46	18 Oct.	6:00 P.M.	0.0201
Hat	50 47 35	121 36 20	18 Oct.	5:15 P.M.	0.2996
Houth	50 47 24	121 36 18	18 Oct.	4:45 P.M.	0.0110
Medicine (lower)	50 45 30	121 34 50	15 Sept.	10:30 A.M.	0.0147
Medicine (upper)	50 45 50	121 30 50	15 Sept.	1:30 P.M.	0.0136
Medicine (lower)	50 45 30	121 34 50	18 Oct.	3:00 P.M.	0.0110

The period of observations does include the highest flow of spring 1977 at the mine site (June 7, 1977), which indicates that the timing of the field program was correct. The weather did unfortunately not cooperate, in that there was an unusually low snow pack, combined with a long, relatively cool melt period. This combination of factors produced by far the lowest freshet peak ever observed in Hat Creek.

In order to illustrate the distribution of runoff during Spring 1977, the observed runoff values for the period May 13 - June 9, 1977 have been integrated and plotted against the corresponding drainage areas in Figure 4-37. It indicates that Anderson, Ambusten and Medicine Creek runoff accounts for approximately one third of the runoff above the "Hat Creek near Upper Hat Creek" gauge during this period. Also of note is that the tributaries on the west side of the valley contributed the greatest runoff per unit drainage area.

The response of Hat Creek to significant rainstorms has been investigated by searching the streamflow records for rain-caused flood events, and then plotting streamflow at the Upper Hat Creek gauge, and rainfall, maximum, minimum and mean temperature observed at the Hat Creek climatological station. Figure B2-11 Appendix B, shows a sample of such plots and the results are summarized in Table 4-6. Column 8 gives the amount of runoff in the hydrograph as mm over the 350 km^2 drainage basin and Column 9 gives this runoff as a proportion of the rainfall input. It ranges from 1 percent to 10 percent, with the larger values associated with rainstorms during or shortly after the main snowmelt season. The one recorded value of 28.5 percent is almost certainly invalid, with the hydrograph representing mainly snowmelt. Column 10 gives a simple runoff coefficient, based on the highest 24 hour rainfall rate during the storm and the peak flow, including baseflow. Since the data are based on daily observations, irregularly spaced in the case of stream flow, basin lag is poorly defined. The lag appears to be in the order of 24 hours, but it is probably closer to 12 hours for the largest flows. Runoff coefficients for rain peaks in later summer and fall range from 1 percent to 3.5 percent, but for rain storms occurring during or shortly after the snow melt season, this goes up to 17 percent. The one event with 30 percent is probably mainly snowmelt.

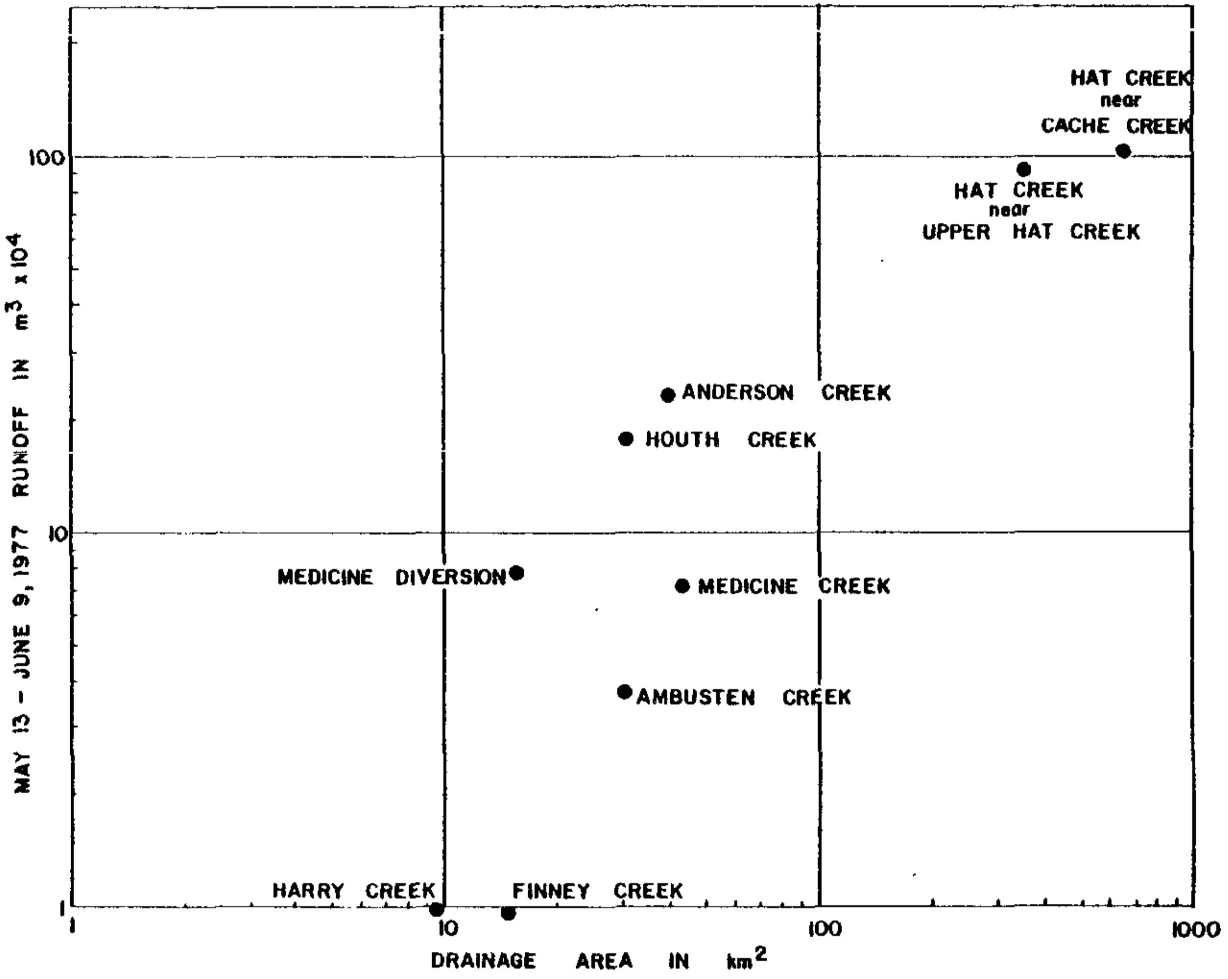


FIGURE 4-37: COMPARISON OF HAT CREEK RUNOFF WITH RUNOFF IN SOME HAT CREEK TRIBUTARIES FOR PERIOD MAY 13 - JUNE 9, 1977.

beak	DATE	Dec 77 DF	4-37
	PROJECT	K4242	
	DWG. NO		

TABLE 4-6

HYDROGRAPH ANALYSIS FOR THE STREAMGAUGE "HAT CREEK NEAR UPPER HAT CREEK"

(note: A drainage area of 350 km^2 has been assumed)

Period Analyzed 1	RAIN			STREAMFLOW			Fast runoff (mm) 8	Fast runoff as proportion of rainfall 9	Runoff coefficient based on 24 hr. period 10	Comments 11
	Total over period (mm) 2	Date of highest rate 3	Highest 24 hr. rate (mm) 4	Date of peak flow 5	Peak flow ($m^3 \cdot s^{-1}$) 6	Lag (days) 7				
May 26-31, 1961	21	May 26	15	May 27	4.90	1	1.079	.0514	.0806	Rain during snowmelt
July 21-25, 1961	7.4	July 21	7.4	July 22	0.608	1	0.149	.0202	.0203	Distinct rain peak
May 23-30, 1962	26	May 25	10	May 26	12.06	1	7.40	.285	.300	Rain on snow, followed by hot weather
Sept. 10-14, 1962	22.5	Sept. 10	22.5	Sept. 11	0.440	1	0.109	.0048	.0054	Distinct, small rain peak
Oct. 11-17, 1962	28.5	Oct. 12	16.3	Oct. 13	0.710	1	0.159	.0056	.0061	Sharp rain peak
Oct. 20-30, 1963	13	Oct. 21	13	Oct. 22	0.400	1	0.184	.0141	.0076	Rectangular hydrograph probably rain at low el. and fast melting snow higher up
June 10-14, 1964	34.6	June 11	22.3	June 11	14.5	~1/2	3.28	.0949	.1605	Rain during period of high snowmelt flow
June 16-22, 1964	32.9	June 18	17.6	June 18	12.1	1	2.64	.0803	.170	Rain at declining snowmelt flows
Sept. 6-11, 1964	31.4	Sept. 7	26.6	Sept. 8	1.24	1	0.358	.0114	.0115	Prominent rain peak on a wet basin
Aug. 22-30, 1965	45.8	Aug. 23	30	Aug. 24	1.38	1	0.699	.0153	.0114	Rain peak
July 5-9, 1966	27.9	July 5	26.9	July 6	3.70	1	1.00	.0358	.0340	Rain peak
July 23-Aug. 3, 1966	47	July 24	39	July 25	3.62	1	2.13	.0454	.0229	Rain peak, possibly some snowmelt
July 1-12, 1969	54.6	July 5	14.5	July 6	6.60	1	3.95	.0724	.112	Rain peak during later snow runoff
Aug. 10-17, 1974	46.2	Aug. 12	23.2	Aug. 12	1.09	<1	0.439	.0189	.0116	Rain peak

The one climatic record from a site at the edge and lowest point of the drainage basin is naturally not adequate to define precipitation over the entire basin. The true runoff coefficients and proportions of runoff are certainly different and probably often smaller than the values shown in Table 4-6, since the low elevation of the climatological station will often lead to under-estimated precipitation.

The Hat Creek Valley contains only a few small lakes. Finney Lake (Figure B2-12, Appendix B, 16 ha surface area) and Aleece Lake (4 ha) fall within the Stage 9 pit perimeter. According to Section 4.1 (a) (ii) A, these lakes are fed by perched ground water flow systems and small surface streams. Both lakes have intermittent surface outflows, intermittent streams flowing into them and intermittent surface outflow. The water level of Finney Lake has been raised by a small dam and outflow is controlled by a simple, manual sluice gate (Figure B2-13, Appendix B). The lakes in the valley do not significantly affect the basin runoff regime.

C. Evaporation and Water Balance

Evaporation and transpiration can be estimated by various means. Estimates for specific drainage basins or for large areas (greater than a few km^2) are normally obtained from a water balance which can be stated as

$$E = P - O - S$$

P is precipitation input, O is outflow, S is storage change and E is the residual and can be assumed to represent evapotranspiration, as long as the area under study does not have significant ground water inflows or outflows. S, the storage change, can be neglected if long-term mean values are being considered.

Applying this equation to the Hat Creek drainage basin upstream of the streamgauge at the mine site (drainage area 350 km^2), where the long-term runoff is 60 mm, and using the elevation adjusted mean annual precipitation of 394 mm as input, one obtains an evapotranspiration loss of 334 mm. With proper adjustments for irrigation and diversion losses, the natural runoff should be approximately 75 mm, giving a natural evapotranspiration loss of 319 mm.

Besides the above water balance method, several other techniques are available for estimating evapotranspiration from climatological data but they generally require far more detailed data than is available for Hat Creek. One procedure specifically developed for sites with only temperature and precipitation data is the Thornthwaite method.[13] It was intended mainly for the central and eastern U.S. and is well known to lead significant discrepancies during spring snowmelt if applied to Canadian data. The Atmospheric Environment Service has modified the procedure and is applying it to some of its standard climatological data.[14] The computations are performed on mean monthly data and take the form of a water balance. The input consists of measured precipitation and the output is made up of computed evapotranspiration and runoff as a residual term (that part of the input which cannot be accommodated in soil storage). The results depend greatly on the assumed value for soils storage (depth of water that can be stored in the soil for later evapotranspiration). In the field, soil storage is highly variable but the values of 100 to 200 mm, for which the Atmospheric Environment Service performs its computations, cover the commonly observed range of average regional values. Locally, the range can naturally be much larger.

The water balances for Hat Creek, Ashcroft and Highland Valley are shown in Tables B1-2, B1-3 and B1-4, Appendix B.

In Figure 4-38, the main terms of monthly Thornthwaite water balances are plotted for six climatological stations covering as wide an elevation range as possible in or near Hat Creek, using the AES results for 200 mm soil moisture storage. All the graphs show how actual evaporation in late summer becomes severely limited by dry soil conditions. This effect is most pronounced at the lower elevations. Runoff occurs only at the highest elevations and is concentrated in spring. The fact that this does not correspond exactly to the time distribution of flow in Hat Creek is not surprising. The water balances only apply to sites with exactly 200 m soil water storage, while in fact a wide range of soil storage capacities occur in any natural drainage basin. There are small areas of open water or areas with a ground water level practically at the surface all along Hat Creek and its

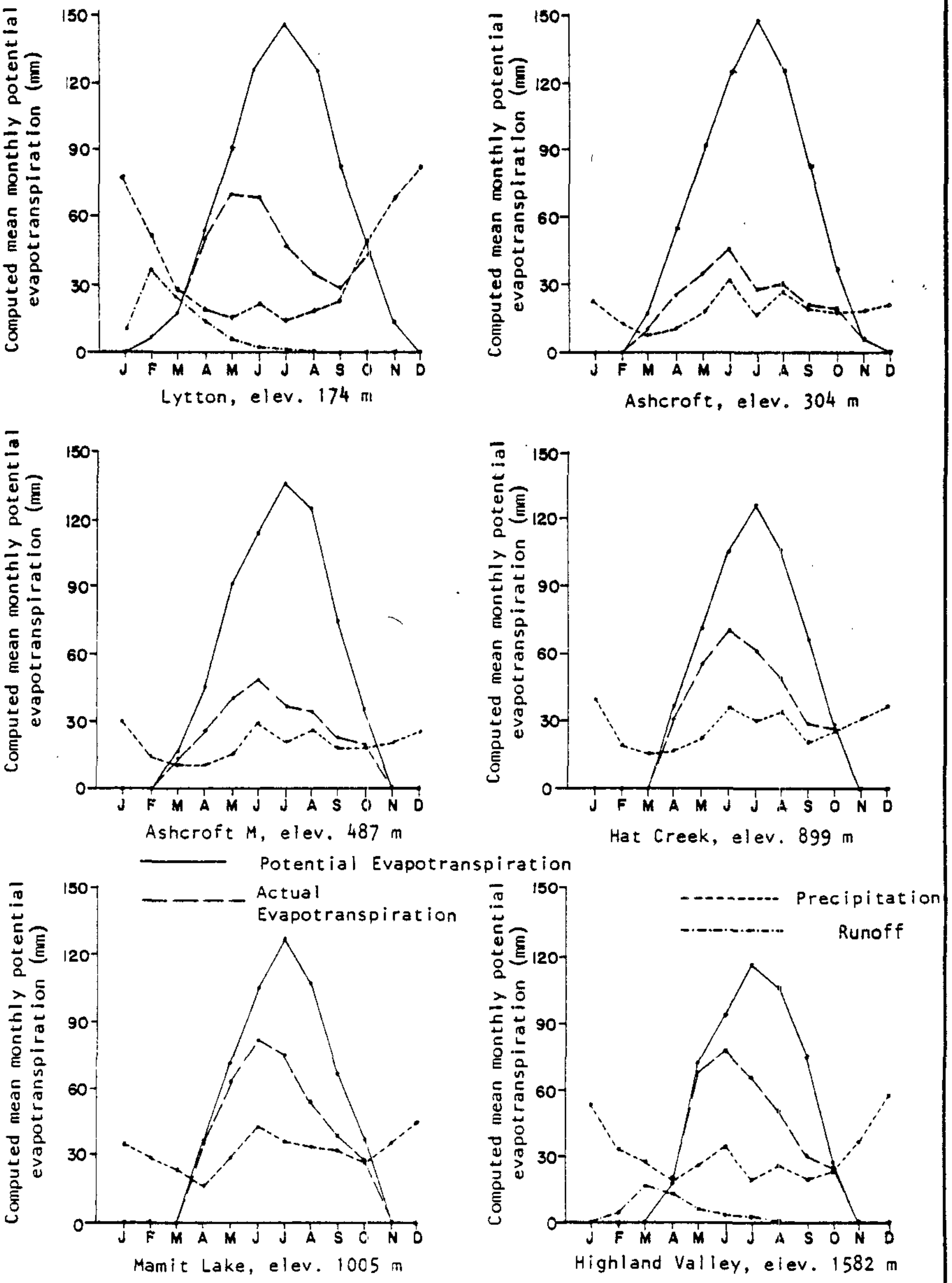


FIGURE 4-38: EVAPOTRANSPIRATION DATA
(computed for 200 mm soil storage)

beak

DATE	Dec 77	DF
PROJECT	K 4242	
DWG NO	Rev. 24-1	

tributaries and it is these areas that produce some runoff from summer and fall rains. There are also extensive aquifers below the root zone which store water and release it gradually, maintaining some year-round streamflow.

In Figure 4-39 the elevation-dependence of the main water balance terms is examined. The data points correspond to the six sites plotted on Figure 4-38 and in addition, Kamloops A (El. 345), Kamloops (El. 378) and Merrit (El. 585). Curves for use in the Hat Creek area are indicated. They have been obtained by trial and error, assuming that the runoff curve, if combined with the area-elevation curve of Figure 4-27, should give the natural mean runoff at the mine site of 75 mm. The same result could naturally be achieved with a wide range of differently shaped curves so that the internal consistency between observed runoff and proposed water balance terms does not guarantee correctness of the latter. However it does indicate that curves of Figure 4-39 are probably not far off the mark and shows that computed evapotranspiration is compatible with observed runoff. It also shows that an average of close to 200 m soil storage has to be assumed to obtain the low observed runoff values. Given the extensive forest cover over much of the basin, this is not an unreasonable assumption.

The only evaporation measurements (Class A pan evaporation) available near Hat Creek were made at the Highland Valley climatological station. The records are short and discontinuous but do confirm the computed potential evapotranspiration reasonably closely (Figure 4-40).

D. Channel Morphology

Hat Creek, as it appears presently, is not responsible for the major landforms of the Hat Creek Valley. The valley is mainly the result of glacial processes, combined with structural factors and stream erosion by earlier and probably larger streams. Present-day Hat Creek has been too small to alter the valley, as left by the retreating ice, in a major way. It has, however, been able to cut canyons,

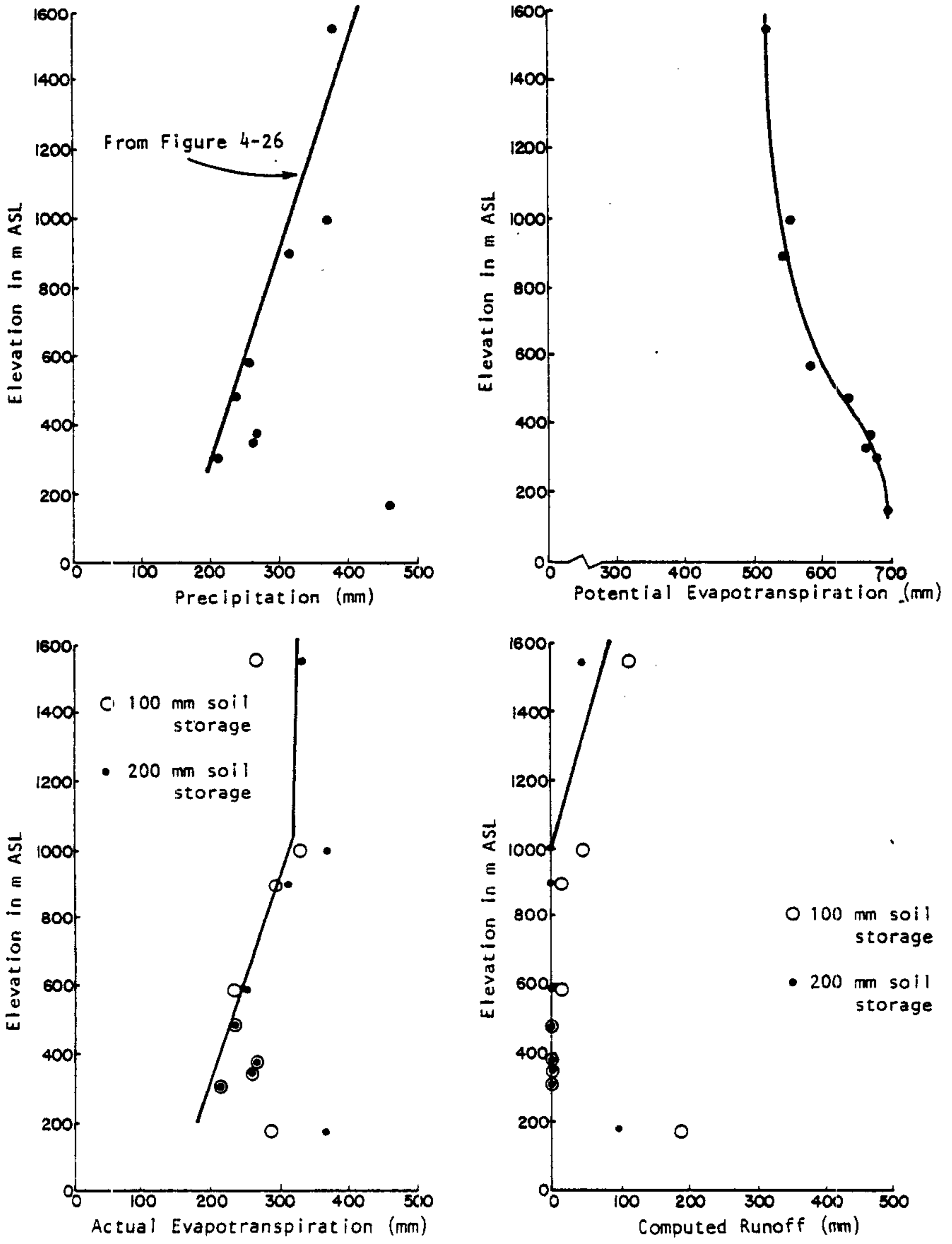


FIGURE 4-39: PROPOSED AVERAGE WATER BALANCE TERMS FOR THE HAT CREEK AREA.

Note: Data points correspond to those of Figure 4-38 plus Kamloops A (El. 345), Kamloops (El. 378) and Merritt (El. 585).

beak			
DATE	Dec. 77	DF	4-39
PROJECT	K 4242		
DWG NO	Rev. 24A-1		

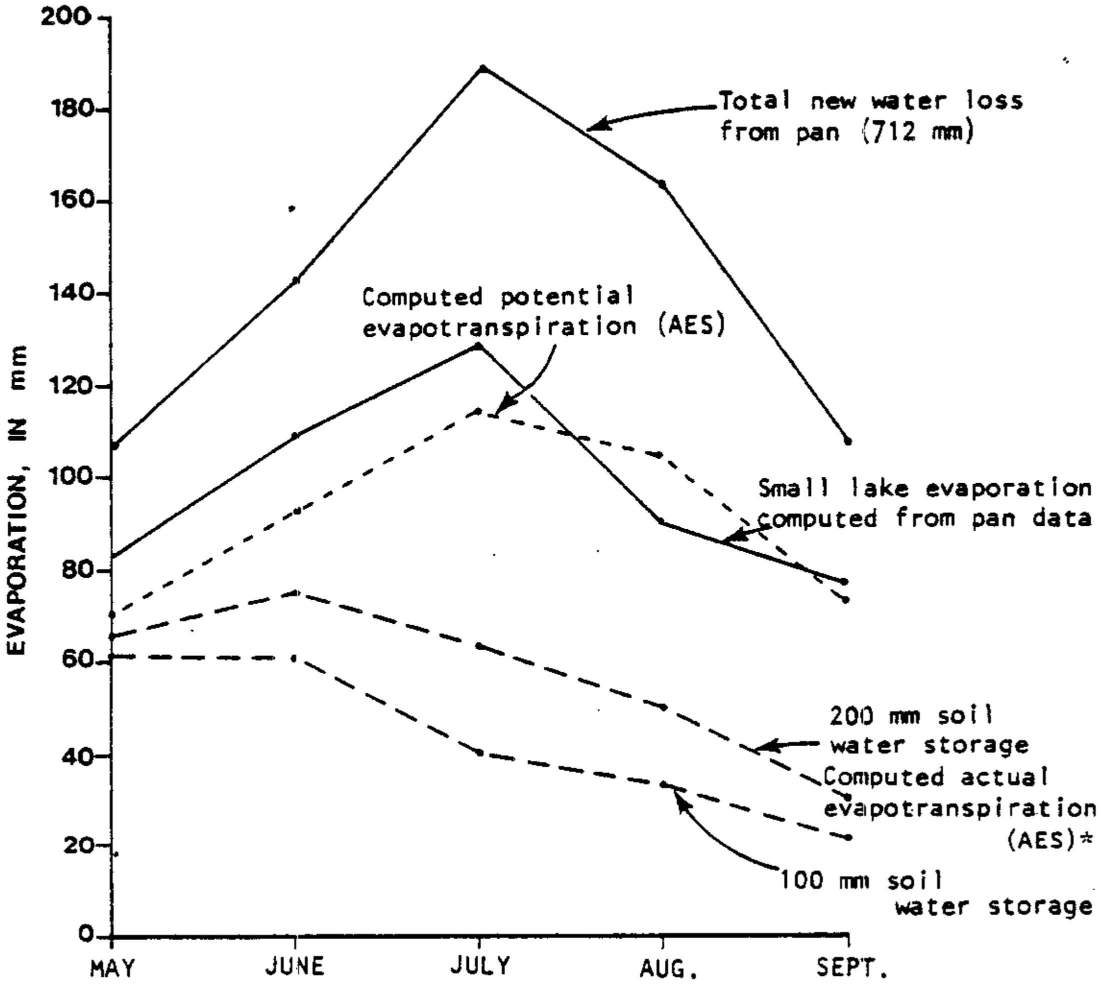


FIGURE 4-40: HIGHLAND VALLEY PAN AND LAKE EVAPORATION, ALSO SHOWING COMPUTED POTENTIAL AND ACTUAL EVAPOTRANSPIRATION.

*from the Thornthwaite water balance computations of the Atmospheric Environment Service.

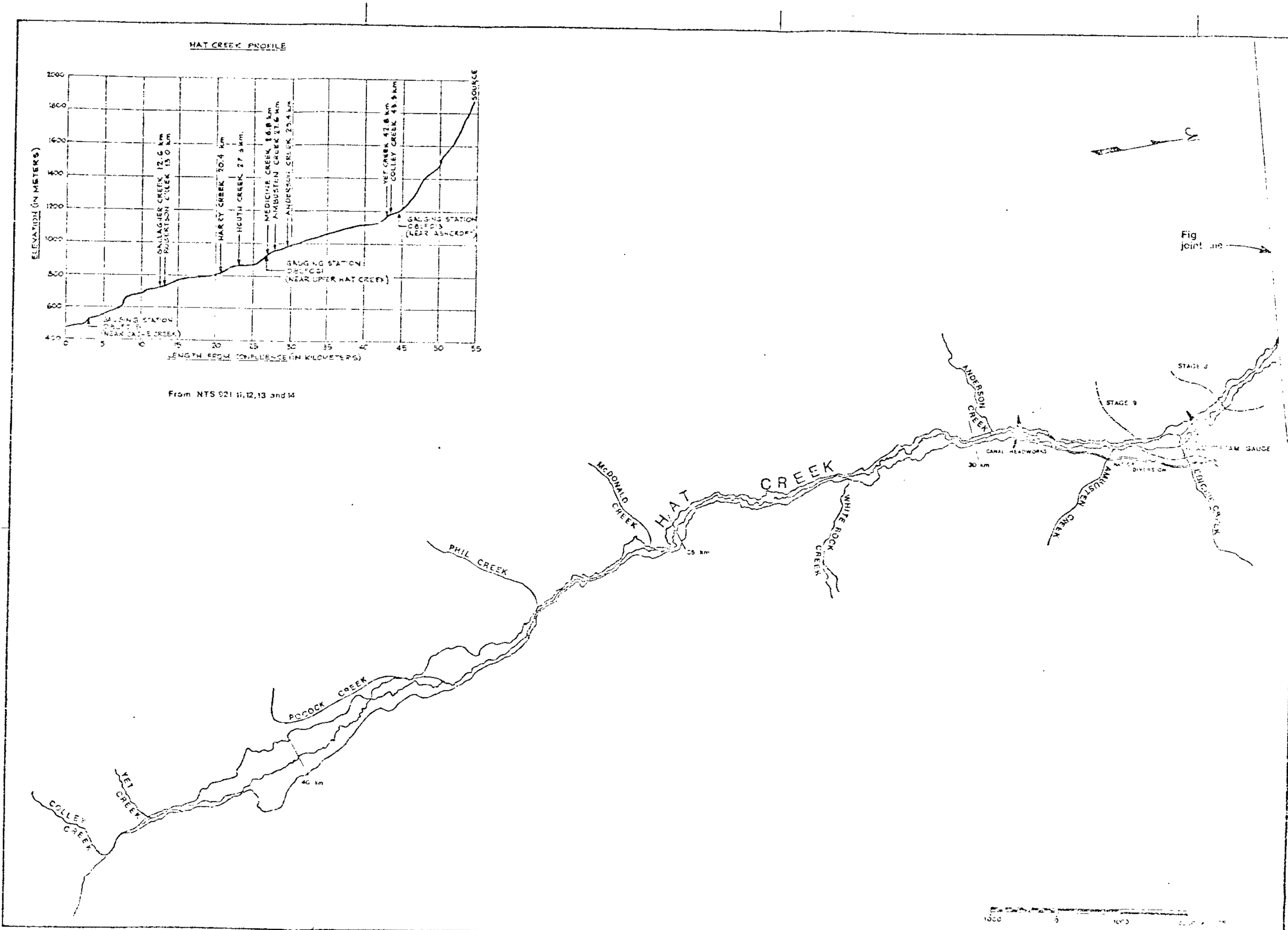
DATE	7-77	RM	4-40
PROJECT	K4242		
DWG NO			

20 to 50 m deep, through obstructions of bedrock or coarse unconsolidated sediments, leaving terrace remnants behind (Figures B2-14, B2-15, Appendix B). The channel profile of Figure 4-41 (insert), shows the location of steep canyon sections, where the channel is bedrock or boulder-controlled, alternating with flatter sections in unconsolidated sediments. Except for the large alluvial fan where Hat Creek emerges into the Bonaparte Valley (Figure B2-16, Appendix B) there are no truly alluvial sections.

Hat Creek, between the proposed mine and the alluvial fan in the Bonaparte Valley, can be classified as follows[15, 16]: In plan, the channel is irregular and split to anastomosing. The valley cross sections show an entrenched or partly entrenched channel, whose lateral development is continuously confined by resistant valley walls or high banks of unconsolidated sediments. Except along some deeply entrenched canyon sections, the valley flat generally consists of several fragmentary narrow and low terrace levels, some of which may be subject to infrequent flooding, and a narrow genetic flood plain, rarely more than a few channel widths wide (Figure B2-15, Appendix B). The stream channel itself is affected by beaver workings, debris jams and local coarse lag deposits and it is consequently highly irregular in shape and often poorly defined. The dominant channel bed material is gravel to cobble with some sand. Some flood plain and terrace areas are covered by a thin veneer of sandy-silty suspended sediment deposits (Figure B2-17, Appendix B).

In order to define the hydraulic geometry of Hat Creek quantitatively, three short channel profiles (Figure B2-18, Appendix B) and 12 cross sections were surveyed (Figure B2-19, B2-20, B2-21, B2-22, B2-23, Appendix B). The location of all surveys is indicated in Figure 4-41 and 4-42.

The channel slope, outside of canyon sections, appears to be about 1 percent and is relatively constant along morphologically homogeneous reaches. The third profile on Figure B2-18, Appendix B, for Reach No. 9, covers almost the entire length of the alluvial fan in the Bonaparte Valley.

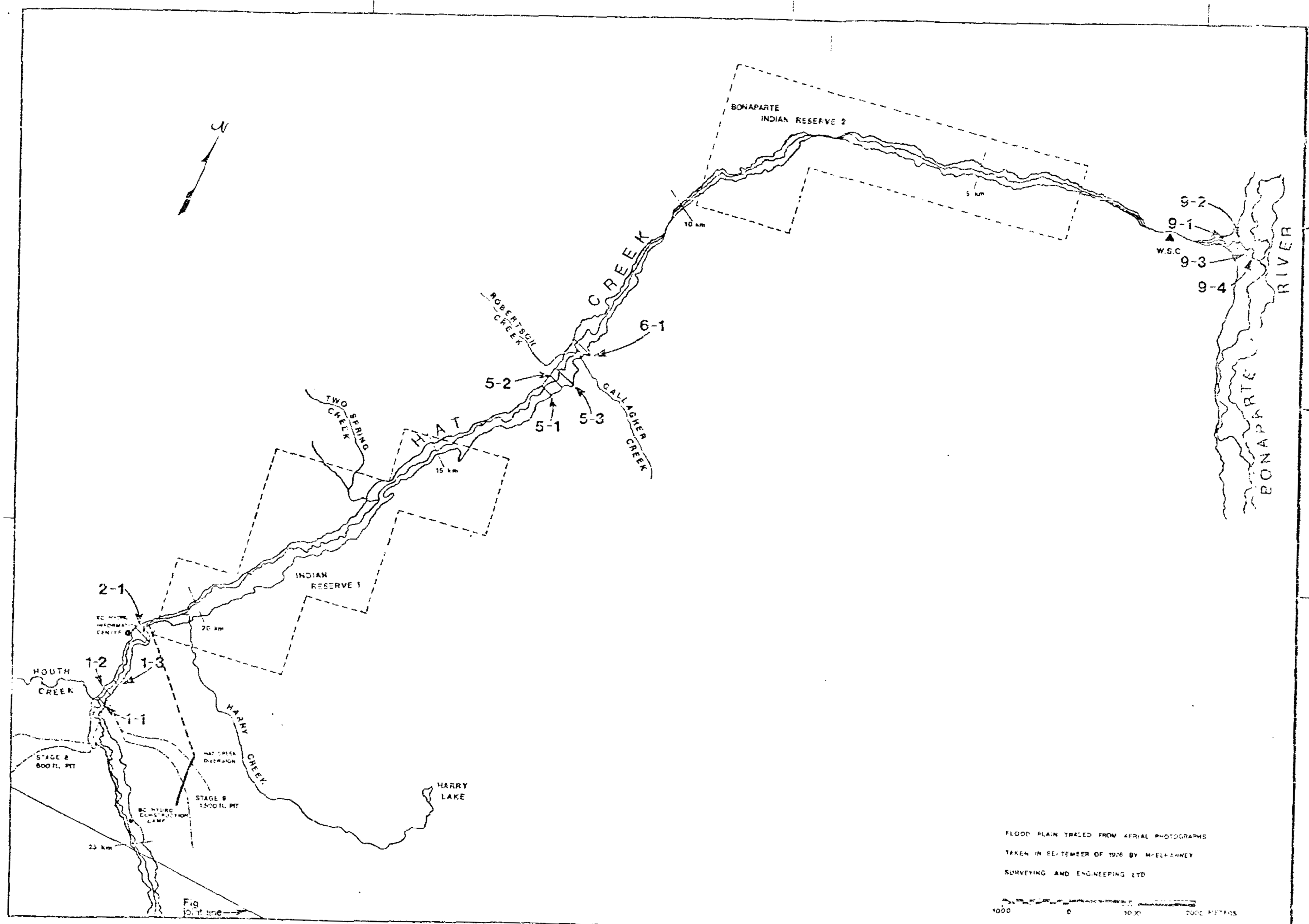


B.C. HYDRO AND POWER AUTHORITY

HAT CREEK PROJECT DETAILED ENVIRONMENTAL STUDIES

HAT CREEK FLOOD PLAIN AND MORPHOLOGIC SURVEYS

FIGURE 4-41



FLOOD PLAIN TRACED FROM AERIAL PHOTOGRAPHS
TAKEN IN SEPTEMBER OF 1976 BY McELHANNEY
SURVEYING AND ENGINEERING LTD

B.C. HYDRO AND POWER AUTHORITY

HAT CREEK PROJECT DETAILED ENVIRONMENTAL STUDIES

HAT CREEK FLOOD PLAIN AND MORPHOLOGIC SURVEYS

AREA OF FLOOD PLAIN

A) BOUNDED BY INDIAN RESERVE NO. 2 .... 0.80 km²
B) BETWEEN INDIAN RESERVE NO. 2
AND INDIAN RESERVE NO. 1 .... 0.57 km²
C) BOUNDED BY INDIAN RESERVE NO. 1 .... 1.22 km²
D) WITHIN 800 FT. PIT .... 0.67 km²
E) BETWEEN SOUTH BOUNDARY OF THE 800 FT.
PIT AND HAT CREEK DIVERSION [illegible] .... 0.47 km²

FIGURE 4-42

The cross sections illustrate how the valley floor generally consists of a narrow genetic flood plain and several equally narrow low terrace levels. At the time of survey flow was very low and unfortunately it has not been possible to obtain water levels corresponding to relatively high flows. The hydraulic performance of the Hat Creek channel is therefore only poorly defined. The observed hydraulic geometry is summarized in Table 4-7.

On a geologic time scale, Hat Creek is degrading along almost its entire channel length, the alluvial fan at its downstream end being the main exception. The dimensions of such channels are generally most closely related to relatively high flows, since only such high flows can move the coarse lag deposits armoring much of the channel perimeter. While it is not possible to state exactly what flows are needed to maintain the present channel size, flows at or above the two-year flood level of 6.0 $m^3 \cdot s^{-1}$ would certainly be required regularly.

Bankfull flows can serve as a rough indicator of channel-forming discharge. Using the bankfull levels indicated on Figures B2-19, B2-21, and B2-23, Appendix B, flows have been estimated for Reaches 1, 5 and 9 as 22.4, 25.5, and 9.6 $m^3 \cdot s^{-1}$ respectively. This can be compared with the two-year flood at Upper Hat Creek of 6.0 $m^3 \cdot s^{-1}$, and indicates that the channel forming discharge is ill-defined and probably of order 10 to 25 $m^3 \cdot s^{-1}$ with a return period somewhere between 4 and 30 years.

The tributaries to Hat Creek in the vicinity of the proposed mine are all steep, degrading mountain streams flowing over coarse lag deposits or over bedrock (Figures B2-1 and B2-2, Appendix B).

E. Flood Plains

No significant development has occurred on areas along Hat Creek (downstream of the proposed mine) subject to occasional flooding. These areas are presently either used for grazing and hay or are covered by dense willow thickets, beaver ponds and marshes.

TABLE 4-7

HAT CREEK HYDRAULIC GEOMETRY

Cross Section	Discharge $(m^3 \cdot s^{-1})$	Slope	Surface Width (m)	Area (m^2)	Mean Velocity $(m \cdot s^{-1})$	Mean Depth (m)	Manning n
1-1	0.937	0.011	4.41	0.90	1.04	0.20	0.034
	0.286	0.011	3.03	0.32	0.89	0.10	0.025
1-2	0.937	0.012	8.88	1.88	0.50	0.21	0.077
	0.572	0.012	8.75	1.55	0.37	0.18	0.094
1-3	0.937	0.014	7.25	1.70	0.55	0.23	0.080
	0.286	0.014	5.25	0.81	0.35	0.15	0.095
2-1	0.937	0.014	7.50	1.95	0.48	0.26	0.10
	0.269	0.014	4.25	0.42	0.64	0.10	0.040
5-1	0.951	0.014	5.12	1.54	0.62	0.30	0.085
	0.277	0.014	4.12	0.79	0.35	0.19	0.11
5-2	0.951	0.011	6.00	1.52	0.63	0.25	0.066
	0.277	0.011	2.38	0.30	0.92	0.13	0.029
5-3	0.951	0.0090	3.75	0.77	1.24	0.20	0.026
	0.294	0.0090	3.00	0.33	0.89	0.11	0.024
6-1	0.965	0.010	8.25	1.81	0.53	0.22	0.020
	0.302	0.010	7.12	0.95	0.32	0.13	0.080
9-1	0.654	0.0090	10.25	1.77	0.37	0.17	0.078
	0.271	0.0090	9.12	1.18	0.23	0.13	0.10
9-2	0.654	0.0079	7.75	1.50	0.44	0.19	0.066
	0.271	0.0079	6.62	0.90	0.30	0.14	0.079
9-3	0.654	0.0087	3.50	0.48	1.36	0.14	0.18
	0.271	0.0087	2.88	0.35	0.77	0.12	0.19
9-4	0.654	0.0096	4.75	1.06	0.62	0.22	0.16
	0.271	0.0096	4.62	1.03	0.26	0.22	0.14

Due to the irregular nature of the Hat Creek channel and the many low terrace fragments making up the valley flat, exact definition of a flood plain zone (for a specified frequency of flooding) would be a massive undertaking that could not be justified. As an alternative, a flood plain zone, based mainly on the cross section surveys and on vegetative indicators, has been defined on stereo air photos. It is delineated on Figures 4-41 and 4-42. The recurrence interval of flooding is probably quite variable over the flood plains zone, but should generally be in the order of 5 to 20 years. While the total area of flood plain downstream of the pit (see insert table on Figure 4-42) is quite small, roughly 3 km^2, this should not distract from its possible biological and economic significance.

4.2 PRESENT WATER QUALITY

The examination of the water quality data generated by this study has been divided into two main areas, viz., ground water and surface water. In the case of ground water this has been further divided into four subcategories which groups the data on the basis of the general type of aquifer that the water has come from. This, in turn, is related to different geographical areas within the program study area.

In the case of surface water, because of the general absence of fixed point waste discharges, the approach taken was to examine the different systems within the study area by water parameter quality groupings. Within each grouping, each parameter was then examined in turn to establish the influence of that parameter on water quality.

(a) Ground Water

In examining the ground water sampled in this program, it has been observed that all of the ground waters analyzed can be placed in one of four categories. These categories are:

(i) Shallow ground water in the alluvium connected to Hat Creek.
(ii) Intermediate or surficial ground water in limestone.
(iii) Deep permeable bedrock ground water.
(iv) Unique samples due to special conditions.

It is based on these four categories that the data in this section will be presented.

(i) Shallow Ground Water

This water is of the calcium-bicarbonate type and strongly resembles Hat Creek in its characteristics. This is probably due to the fact that the alluvium is hydraulically connected to Hat Creek (Section 4.1 (a)). The locations indicated as having this type of water are: All of the domestic wells sampled with the exception of DW8, the artesian springs sampled with the exception of #3 East, and the Bulk Sample Program samples with the exception of Well 3. Table 4-8 shows a comparison of the system mean for Hat Creek compared to the average values for the domestic wells, with the exception of DW8. The great similarity between Hat Creek and the domestic wells is evident, particularly when compared to the coal seam ground water which is in category (iii). The detailed results for these samples are contained in Tables C1-5 to C1-22, Appendix C.

(ii) *Intermediate or Surficial Ground Water*

These waters are intermediate between the shallow ground water characterized by the principal ions being calcium and bicarbonate and the deep bedrock where the principal ions are sodium and bicarbonate. The sample locations that are in this category are the Steel Brothers Well and drill hole RH77-45 in the Houth Meadows area plus the artesian spring #3 East. In the case of the two samples in Houth Meadows, the water most probably has come from a surficial alluvium which flows through limestone, which is a dominant formation in the area (Section 4.1 (a)). In the case of artesian spring #3 East, the factor most likely to be dominating in its water quality characteristics is the fact that the water has travelled a greater distance underground than in the cases of the other artesian springs sampled, thus permitting base exchange to take place in which sodium replaces calcium in solution. The results of these three sample locations are summarized in Table 4-9. The detailed results of these samples are contained in Tables C1-14, C1-15, and C1-18. Appendix C.

(iii) Deep Permeable Bedrock Ground Water

These waters are characterized by high sodium content when compared to calcium and generally have existed as ground water for an extended period of time (Section 4.1 (a). As a result of this they also exhibit a high filtrable

TABLE 4-8
SUMMARY OF SHALLOW GROUNDWATER DATA

STATION: PARAMETER (mg/l)	HAT CREEK	DOMESTIC WELLS Excluding DW8	COAL SEAM
CATIONS - TRACE METALS			
Aluminum (Al)	< 0.010	< 0.011	(0.030)
Arsenic (As)	< 0.005	< 0.005	(0.012)
Cadmium (Cd)	< 0.005	< 0.005	< 0.005
Chromium (Cr)	< 0.010	< 0.010	< 0.010
Copper (Cu)	< 0.005	< 0.009	< 0.005
Iron (Fe)	< 0.026	< 0.284	0.125
Lead (Pb)	< 0.010	< 0.010	< 0.010
Mercury (Hg)	< 0.00040	< 0.00028	(0.00039)
Molybdenum (Mo)	< 0.020	< 0.020	-
Selenium (Se)	< 0.003	< 0.003	< 0.003
Vanadium (V)	< 0.005	< 0.005	< 0.005
Zinc (Zn)	< 0.007	0.074	0.008
CATIONS - ALKALI EARTHS & METALS			
Calcium (Ca)	57	69	48
Lithium (Li)	0.002	0.004	< 0.008
Magnesium (Mg)	19	21	41
Potassium (K)	4.0	-	27
Sodium (Na)	20	15	300
Strontium (Sr)	0.32	0.33	0.14
ANIONS - GENERAL			
Boron (B)	< 0.10	< 0.10	< 0.10
Chloride (Cl)	1.1	< 1.4	8.2
Fluoride (F)	0.16	0.35	0.33
Sulfate (SO_4)	54	50	260
ANIONS - NUTRIENTS			
Total - Kjeldahl - Nitrogen (N)	0.19	0.16	5.7
Nitrate - Nitrogen (NO_3 - N)	< 0.05	< 0.10	0.02
Nitrate - Nitrogen (NO_2 - N)	< 0.002	< 0.0011	0.001
Total - Orthophosphate - Phosphorus (P)	0.043	0.037	0.037
ORGANIC, NONIONIC & CALCULATED VALUES			
COD	21	< 37	-
TOC	9	19	21
Phenol	< 0.002	< 0.002	-
Total Hardness ($CaCo_3$)	224	247	289
Total Alkalinity ($CaCo_3$)	226	246	791
PHYSICAL DATA			
pH (units)	8.4	7.8	7.3
Specific Conductance (umhos/cm @ 25°C)	489	519	1700
True Color (Pt-Co Units)	12	< 9	20
Turbidity (NTU)	1.5	1.3	3.3
Temperature (°C)	6.6	-	10
PHYSICAL DATA - RESIDUES			
Total residue	348	357	1244
Filtrable residue	342	353	1220
Non-filtrable residue	6	4	24
Fixed total residue	281	309	1088
Fixed filtrable residue	278	308	1080
Fixed non-filtrable residue	4	< 3	8
BIOCHEMICAL, DISSOLVED GASES & RELATED MEASUREMENTS			
BOD	< 1	-	7
D.O.	11.1	-	0.8
% Saturation	90.2	-	7.1

( ) Denotes Total Concentration

TABLE 4-9
SUMMARY OF SURFICIAL GROUNDWATER DATA

STATION: PARAMETER (mg/l)	STEEL BROS WELL	RH77-45	AS 3 EAST
CATIONS - TRACE METALS	-	-	-
Aluminum (Al)	-	-	-
Arsenic (As)	-	-	-
Cadmium (Cd)	-	< 0.001	-
Chromium (Cr)	-	-	-
Copper (Cu)	-	< 0.002	-
Iron (Fe)	-	< 0.041	-
Lead (Pb)	-	< 0.001	-
Mercury (Hg)	-	-	-
Molybdenum (Mo)	-	-	-
Selenium (Se)	-	-	-
Vanadium (V)	-	< 0.04	-
Zinc (Zn)	-	0.008	-
CATIONS - ALKALI EARTHS & METALS			
Calcium (Ca)	71.4	58.0	140
Lithium (Li)	-	-	-
Magnesium (Mg)	45.4	30.4	66
Potassium (K)	3.4	4.6	-
Sodium (Na)	8.4	41.4	28
Strontium (Sr)	-	0.50	-
ANIONS - GENERAL			
Boron (B)	-	-	-
Chloride (Cl)	14.5	6.0	7.6
Fluoride (F)	-	-	-
Sulfate (SO_4)	78	83.2	250
ANIONS - NUTRIENTS			
Total - Kjeldahl - Nitrogen (N)	-	-	-
Nitrate - Nitrogen (NO_3 - N)	-	-	-
Nitrate - Nitrogen (NO_2 - N)	-	-	-
Total - Orthophosphate - Phosphorus (P)	-	-	-
ORGANIC, NONIONIC & CALCULATED VALUES			
COD	-	-	-
TOC	-	-	-
Phenol	-	-	-
Total Hardness ($CaCo_3$)	-	269	-
Total Alkalinity ($CaCo_3$)	350	333	439
PHYSICAL DATA			
pH (units)	7.4	8.0	7.6
Specific Conductance (umhos/cm @ 25°C)	666	681	1100
True Color (Pt-Co Units)	-	-	-
Turbidity (NTU)	-	-	-
Temperature (°C)	-	-	-
PHYSICAL DATA - RESIDUES			
Total residue	-	-	-
Filtrable residue	-	-	-
Non-filtrable residue	-	-	-
Fixed total residue	-	-	-
Fixed Filtrable Residue	-	-	-
Fixed non-filtrable residue	-	-	-
BIOCHEMICAL, DISSOLVED GASES & RELATED MEASUREMENTS			
BOD	-	-	-
D.O.	-	-	-
% Saturation	-	-	-

residue with a correspondingly high specific conductance. The sample locations exhibiting this type of water are drill hole RH76-19 (after 21 days of pumping), Bucket Auger Hole #7, drill hole RH77-48, and drill hole RH77-49. The first two of these locations are in the proposed pit area while the last two are in the area of Medicine Creek. The results from drill hole RH76-19 are of special interest in that, due to its depth, they represent the most probable composition of the pit water and thus represent a worst case situation of the water discharge from the pit area. A comparison of these results with those from the Medicine Creek area shows that, of the parameters analyzed, only vanadium shows a significant difference at RH76-19 (1.97 mg/l compared to < 0.04 mg/I for the two stations at Medicine Creek). This increase in vanadium content is most probable due to contact with the coal deposit, as vanadium is a common trace constituent of coal. The results of these sample locations are summarized in Table 4-10. The detailed results of these samples are contained in Tables C1-16 to C1-18, Appendix C.

(iv) Unique Samples Due To Special Conditions

There are two sample locations in this category, Well #3 of the Bulk Sample Program and Domestic Well 8. In the case of Well #3 the water was most likely dominated in terms of water quality by having percolated through the dry lake immediately adjacent to the well. This dry lake has left a large amount of a variety of salts similar to those found in Goose/Fish Hook Lake. This can be seen in Table 4-11 which compares the average of the other ground waters in the Bulk Sample Program with Well #3 and Goose/Fish Hook Lake. In the case of DW8, it would appear that the water feeding this well has come from a different aquifer than that feeding the other wells in the area, and that this aquifer has travelled a greater distance underground. This conclusion is based on the much higher levels of sodium and chloride ions to be found in this well.

In general, while the different ground water samples examined showed many differences, a comparison of the ground water results with the Canadian

TABLE 4-10

SUMMARY OF BEDROCK GROUNDWATER DATA

STATION: PARAMETER (mg/l)	RH 76-19	Bucket Auger Hole #7	RH 77-48	RH 77-49
CATIONS - TRACE METALS				
Aluminum (Al)	0.004	(0.030)	-	-
Arsenic (As)	<0.005	(0.012)	-	-
Cadmium (Cd)	<0.001	<0.005	< 0.001	< 0.001
Chromium (Cr)	<0.001	<0.010	-	-
Copper (Cu)	0.007	<0.005	0.004	< 0.001
Iron (Fe)	<0.05	0.125	< 0.035	0.073
Lead (Pb)	<0.002	<0.010	0.002	< 0.001
Mercury (Hg)	-	(0.00039)	-	-
Molybdenum (Mo)	<0.004	-	-	-
Selenium (Se)	<0.10	<0.003	-	-
Vanadium (V)	1.97	<0.005	<0.04	<0.04
Zinc (Zn)	0.020	0.008	<0.015	<0.001
CATIONS - ALKALI EARTHS & METALS				
Calcium (Ca)	47.7	48	20.2	123.4
Lithium (Li)	0.05	<0.008	-	-
Magnesium (Mg)	21.6	41	6.8	91.2
Potassium (K)	34.0	27	3.8	4.7
Sodium (Na)	330	300	182.1	32.2
Strontium (Sr)	0.06	0.14	0.34	1.26
ANIONS - GENERAL				
Boron (B)	<0.10	<0.10	-	-
Chloride (Cl)	<0.5	8.2	4.2	2.0
Fluoride (F)	0.067	0.33	-	-
Sulfate (SO_4)	17.3	260	112.0	196.8
ANIONS - NUTRIENTS				
Total - Kjeldahl - Nitrogen (N)	22.2	5.7	-	-
Nitrate - Nitrogen (NO_3 - N)	<0.10	0.02	-	-
Nitrate - Nitrogen (NO_2 - N)	<0.001	0.001	-	-
Total - Orthophosphate - Phosphorus (P)	<0.01	0.037	-	-
ORGANIC, NONIONIC & CALCULATED VALUES				
COD	-	-	-	-
TOC	-	21	-	-
Phenol	-	-	-	-
Total Hardness ($CaCo_3$)	208	289	78	682
Total Alkalinity ($CaCo_3$)	943	791	431	672
PHYSICAL DATA				
pH (units)	7.6	7.3	8.2	8.0
Specific Conductance (umhos/cm @ 25°C)	1834	1700	942	1326
True Color (Pt-Co Units)	-	20	-	-
Turbidity (NTU)	-	3.3	-	-
Temperature (°C)	-	10	-	-
PHYSICAL DATA - RESIDUES				
Total residue	-	1244	-	-
Filtrable residue	1600	1220	-	-
Non-filtrable residue	-	24		
Fixed total residue	-	1088	-	-
Fixed filtrable residue	1400	1080	-	-
Fixed non-filtrable residue	-	8	-	-
BIOCHEMICAL, DISSOLVED GASES & RELATED MEASUREMENTS				
BOD	-	7	--	-
D.O.	-	0.8	-	-
% Saturation	-	7.1	-	-

( ) Denotes Total Concentration

TABLE 4-11

SUMMARY OF UNIQUE SAMPLE DATA

STATION: PARAMETER (mg/l)	WELL 1, 2, and Trench B	WELL 3	GOOSE/FISH HOOK LAKE
CATIONS - TRACE METALS			
Aluminum (Al)	< 0.014	< 0.011	< 0.010
Arsenic (As)	< 0.005	< 0.005	< 0.005
Cadmium (Cd)	-	-	< 0.005
Chromium (Cr)	< 0.010	< 0.010	< 0.010
Copper (Cu)	< 0.009	< 0.005	< 0.005
Iron (Fe)	0.323	0.162	< 0.018
Lead (Pb)	-	-	< 0.010
Mercury (Hg)	(<0.00012)	(< 0.00013)	(< 0.0040)
Molybdenum (Mo)	-	-	0.03
Selenium (Se)	<0.004	< 0.003	< 0.003
Vanadium (V)	<0.005	< 0.005	0.006
Zinc (Zn)	<0.016	0.038	< 0.030
CATIONS - ALKALI EARTHS & METALS			
Calcium (Ca)	66	246	11
Lithium (Li)	0.004	0.051	0.070
Magnesium (Mg)	16	80	99
Potassium (K)	-	-	190
Sodium (Na)	20	384	1390
Strontium (Sr)	0.25	1.26	1.2
ANIONS - GENERAL			
Boron (B)	<0.10	0.18	0.3
Chloride (Cl)	1.3	7.5	96
Fluoride (F)	0.120	0.128	< 0.57
Sulfate (SO_4)	49	1328	2140
ANIONS - NUTRIENTS			
Total - Kjeldahl - Nitrogen (N)	-	-	3.2
Nitrate - Nitrogen (NO_3 - N)	-	-	< 0.067
Nitrate - Nitrogen (NO_2 - N)	-	-	< 0.0016
Total - Orthophosphate - Phosphorus (P)	0.027	0.040	1.5
ORGANIC, NONIONIC & CALCULATED VALUES			
COD	-	-	124
TOC	38	88	164
Phenol	-	-	< 0.002
Total Hardness ($CaCo_3$)	231	945	436
Total Alkalinity ($CaCo_3$)	233	533	1520
PHYSICAL DATA			
pH (units)	7.8	7.4	9.8
Specific Conductance (umhos/cm @ 25°C)	530	3010	6700
True Color (Pt-Co Units)	-	-	50
Turbidity (NTU)	-	-	3.9
Temperature (°C)	-	-	6.4
PHYSICAL DATA - RESIDUES			
Total residue	379	2858	5076
Filtrable residue	347	2714	5070
Non-filtrable residue	32	144	6
Fixed total residue	-	-	4706
Fixed Filtrable Residue	-	-	4703
Fixed non-filtrable residue	-	-	3
BIOCHEMICAL, DISSOLVED GASES & RELATED MEASUREMENTS			
BOD	-	-	1
D.O.	-	-	9.6
% Saturation	-	-	90.3

Drinking Water Standards (Table 4-12) shows that in all cases the ground waters sampled meet the Drinking Water Standards for Toxic Chemicals and, with the exception of calcium in one location, meet the recommended limits for other chemicals in drinking water. The location where calcium did not meet the recommended limits was Well #3 of the Bulk Sample Program.

(b) Surface Water - Streams and Rivers

To date a large amount of surface water data is available. To reduce this data to a size amenable to analysis, annual means were calculated for each station. Also, to highlight the differences between Hat Creek, the Bonaparte River, and the Thompson River, annual means of each watershed were calculated. Such a method of data treatment will, upon inception of a regular monitoring program, result in an efficient and substantive means of assessment.

Data for programs other than temporally systematic sampling of Hat Creek and the Bonaparte and Thompson Rivers have not been included in this statistical treatment. The reason for the exclusion is that any baseline description developed must be rational and consistent over the long-term in both time and space. Not all sampling programs met these criteria as they were designed to meet varying information needs. Nevertheless, the non-routine programs do provide information against which the baseline description formulated from systematic sampling may be tested.

The data for surface waters are presented in Tables C1-23 to C1-39, Appendix C. Annual means for stations on Hat Creek, the Bonaparte River, and the Thompson River are presented in Tables 4-13, 4-14 and 4-15, respectively. A comparison of the annual means for each watershed is presented in Table 4-16.

TABLE 4-12

RECOMMENDED DRINKING WATER STANDARDS & OBJECTIVES

PARAMETER	Drinking Water Standards for Toxic Chemicals			Recommended Limits for Other Chemicals in Drinking Water	
	Objective (mg/l)	Acceptable Limit (mg/l)	Maximum Permissible Limit (mg/l)	Objective (mg/l)	Acceptable Limit (mg/l)
CATIONS - Trace Metals					
Aluminum	-	-	-	-	-
Arsenic (As)	N.D.	0.01	0.05	-	-
Cadmium (Cd)	N.D.	<0.01	0.01	-	-
Chromium - Hexavalent (Cr^{6+})	N.D.	<0.05	0.05	-	-
Copper (Cu)	-	-	-	<0.01	1.0
Iron (Fe)	-	-	-	<0.05	0.3
Lead (Pb)	N.D.	<0.05	0.05	-	-
Mercury (Hg)	-	-	-	-	-
Molybdenum (Mo)	-	-	-	-	-
Selenium (Se)	N.D.	<0.01	0.01	-	-
Vanadium (V)	-	-	-	-	-
Zinc (Zn)	-	-	-	<1.0	5.0
CATIONS - Alkali Earths & Metals					
Calcium (Ca)	-	-	-	<75	200
Lithium (Li)	-	-	-	-	-
Magnesium (Mg)	-	-	-	<50	150
Potassium (K)	-	-	-	-	-
Sodium (Na)	-	-	-	-	-
Strontium (Sr)	-	-	-	-	-
Total Hardness (as $CaCO_3$)	-	-	-	<120	**
ANIONS					
Boron (B)	-	<5.0	5.0	-	-
Chloride (Cl)	-	-	-	<250	250
Fluoride (F)	-	-	-	-	-
Sulfate (SO_4)	-	-	-	<250	500
Nitrogen (NO_2 & NO_3 as N)	<10.0	<10.0	10.0	-	-
Total Alkalinity (as $CaCO_3$)	-	-	-	-	30-500*
Phosphates (as PO_4)	-	-	-	<0.2	<0.2
OTHER					
Total Dissolved Solids	-	-	-	<500	1000
Phenol	-	-	-	N.D.	0.002

	Physical Quality of Treated Water	
	Objective	Acceptable Limit
PHYSICAL PARAMETERS		
pH (units)	-	6.5-8.3
Specific Conductance (μmhos/cm @ 25°)	-	-
True Color (Pt-Co units)	<5	15
Turbidity (JTU)	<1	5
Temperature (°C)	<10	15

N.D. = Not detectable

* Generally acceptable although it does not guarantee that problems due to this characteristic, in this range, will not occur.

** There are no known instances where substances causing or contributing to hardness are directly implicated as causing health problems >500 mg/l may be unsuitable for domestic or industrial use.

TABLE 4-13

ANNUAL MEANS

HAT CREEK SYSTEM

STATION:	14	10	7	6	5
PARAMETER (mg/ℓ)	$\bar{X}$	$\bar{X}$	$\bar{X}$	$\bar{X}$	$\bar{X}$
CATIONS - Trace Metals					
Aluminum (Al)	<0.010	<0.010	<0.010	-	<0.010
Arsenic (As)	<0.005	<0.005	<0.005	-	<0.005
Cadmium (Cd)	<0.005	<0.005	<0.005	-	<0.005
Chromium (Cr)	<0.010	<0.010	<0.010	-	<0.010
Copper (Cu)	<0.005	<0.005	<0.005	-	<0.005
Iron (Fe)	0.048	0.037	<0.018	<0.0.0	<0.010
Lead (Pb)	<0.010	<0.010	<0.010	-	<0.010
Mercury (Hg)	<0.00027	<0.0012	<0.00038	-	<0.00029
Molybdenum (Mo)	<0.020	<0.020	<0.020	-	<0.020
Selenium (Se)	<0.003	<0.003	0.003	-	<0.003
Vanadium (V)	<0.005	<0.005	<0.005	-	<0.005
Zinc (Zn)	0.007	<0.005	0.008	<0.005	<0.010
CATIONS - Alkali Earths & Metals					
Calcium (Ca)	49	58	58	64	64
Lithium (Li)	<0.0025	<0.0025	<0.002	<0.001	<0.002
Magnesium (Mg)	16	20	17	20	25
Potassium (K)	4.9	4.5	4.0	3.1	3.3
Sodium (Na)	17	24	20	17	22
Strontium (Sr)	0.28	0.34	0.30	0.28	0.36
ANIONS - General					
Boron (B)	<0.1	<0.1	<0.1	-	<0.1
Chloride (Cl)	0.61	1.0	1.2	0.87	1.5
Fluoride (F)	0.15	0.18	0.14	0.24	0.15
Sulfate (SO_4)	50	57	50	41	65
ANIONS - Nutrients					
Total Kjeldahl Nitrogen (N)	0.19	0.27	0.19	0.12	0.18
Nitrate Nitrogen ($NO_3 - N$)	0.06	0.04	<0.06	0.04	<0.04
Nitrite Nitrogen ($NO_2 - N$)	<0.0017	<0.001	<0.0018	<0.001	<0.002
Total Orthophosphate Phosphorus (P)	0.050	0.065	0.038	0.059	0.025
ORGANIC, NONIONIC & CALCULATED VALUES					
COD	45	10	17	-	10
TOC	8.5	16	8	4	6
Phenol	<0.002	<0.002	<0.002	-	<0.002
Total Hardness ($CaCO_3$)	189	226	215	242	260
Total Alkalinity ($CaCO_3$)	99	228	212	247	262
PHYSICAL DATA					
pH (units)	8.1	8.4	8.4	8.5	8.5
Specific Conductance (µmhos/cm @ 25°)	450	495	472	470	545
True Color (Pt-Co Units)	12	18	11	10	8.8
Turbidity (NTU)	1.6	1.40	2.5	1.2	0.68
Temperature (°C)	4.6	9.8	6.4	12.5	5.8
PHYSICAL DATA - Residues					
Total Residue	321	356	344	337	378
Filtrable Residue	312	350	336	333	376
Nonfiltrable Residue	8	5	8	4	<2
Fixed Total Residue	266	280	274	259	310
Fixed Filtrable Residue	261	276	269	259	310
Fixed Nonfiltrable Residue	<8	4	<5	<1	<1
BIOCHEMICAL, DISSOLVED GASES & RELATED MEASUREMENTS					
BOD	<1	<1	<1	<1	<1
D.O.	11.2	10	11.1	9.5	11.9

TABLE 4-14
ANNUAL MEANS
BONAPARTE RIVER SYSTEM

STATION:

PARAMETER (mg/ℓ)	4 $\bar{X}$	3 $\bar{X}$	1 $\bar{X}$
CATIONS - Trace Metals			
Aluminum (Al)	<0.010	<0.010	<0.010
Arsenic (As)	<0.005	<0.005	<0.005
Cadmium (Cd)	<0.005	<0.005	<0.005
Chromium (Cr)	<0.010	<0.010	<0.010
Copper (Cu)	<0.005	<0.005	0.005
Iron (Fe)	0.052	0.050	0.042
Lead (Pb)	<0.010	<0.010	<0.010
Mercury (Hg)	<0.00038	<0.00025	<0.00025
Molybdenum (Mo)	<0.030	<0.020	<0.020
Selenium (Se)	<0.003	<0.003	<0.003
Vanadium (V)	<0.005	<0.005	<0.005
Zinc (Zn)	<0.018	<0.013	0.036
CATIONS - Alkali Earths & Metals			
Calcium (Ca)	26	28	31
Lithium (Li)	<0.001	<0.001	<0.001
Magnesium (Mg)	15	15	17
Potassium (K)	1.9	1.7	1.7
Sodium (Na)	11	12	13
Strontium (Sr)	0.13	0.16	0.17
ANIONS - General			
Boron (B)	<0.1	<0.1	<0.1
Chloride (Cl)	0.88	0.81	1.0
Fluoride (F)	0.16	0.16	0.18
Sulfate (SO_4)	15	19	21
ANIONS - Nutrients			
Total Kjeldahl Nitrogen (N)	0.25	0.29	0.26
Nitrate Nitrogen (NO_3 - N)	0.06	<0.06	0.05
Nitrite Nitrogen (NO_2 - N)	<0.0012	<0.0016	<0.0027
Total Orthophosphate Phosphorus (P)	0.034	0.034	0.049
ORGANIC, NONIONIC & CALCULATED VALUES			
COD	27	21	<10
TOC	12	12	8
Phenol	<0.002	<0.002	0.004
Total Hardness ($CaCO_3$)	126	132	147
Total Alkalinity ($CaCO_3$)	141	146	155
PHYSICAL DATA			
pH (units)	8.2	8.2	8.3
Specific Conductance (µmhos/cm @ 25°)	280	290	312
True Color (Pt-Co Units)	16	18	15
Turbidity (NTU)	1.7	2.1	2.45
Temperature (°C)	6.1	6.5	7.2
PHYSICAL DATA - Residues			
Total Residue	212	225	232
Filtrable Residue	197	208	216
Nonfiltrable Residue	15	18	16
Fixed Total Residue	145	154	166
Fixed Filtrable Residue	134	142	154
Fixed Nonfiltrable Residue	12	15	12
BIOCHEMICAL, DISSOLVED & RELATED MEASUREMENTS			
BOD	<1	<1	<1
D.O.	11.2	11.2	11.3

TABLE 4-15

ANNUAL MEANS

THOMPSON RIVER SYSTEM

STATION:

PARAMETER (mg/ℓ)	18 $\bar{X}$	19 $\bar{X}$
CATIONS - Trace Metals		
Aluminum (Al)	<0.010	0.023
Arsenic (As)	<0.005	<0.005
Cadmium (Cd)	<0.005	<0.005
Chromium (Cr)	<0.010	<0.010
Copper (Cu)	<0.005	<0.005
Iron (Fe)	<0.018	0.026
Lead (Pb)	<0.010	<0.010
Mercury (Hg)	<0.00035	<0.00032
Molybdenum (Mo)	<0.020	<0.020
Selenium (Se)	<0.003	<0.003
Vanadium (V)	<0.005	<0.005
Zinc (Zn)	0.018	0.016
CATIONS - Alkali Earths & Metals		
Calcium (Ca)	11	12
Lithium (Li)	<0.001	<0.001
Magnesium (Mg)	2.2	2.4
Potassium (K)	0.60	0.65
Sodium (Na)	3.1	3.5
Strontium (Sr)	<0.055	<0.054
ANIONS - General		
Boron (B)	<0.1	<0.1
Chloride (Cl)	1.7	1.6
Fluoride (F)	0.12	<0.11
Sulfate (SO_4)	7.3	7.9
ANIONS - Nutrients		
Total Kjeldahl Nitrogen (N)	0.07	0.09
Nitrate Nitrogen (NO_3 - N)	0.08	<0.07
Nitrite Nitrogen (NO_2 - N)	<0.0017	<0.0018
Total Orthophosphate Phosphorus (P)	0.028	0.012
ORGANIC, NONIONIC & CALCULATED VALUES		
COD	<10	31
TOC	4	2
Phenol	<0.002	<0.002
Total Hardness ($CaCO_3$)	38	39
Total Alkalinity ($CaCO_3$)	34	35
PHYSICAL DATA		
pH (units)	7.8	7.8
Specific Conductance (µmhos/cm @ 25°)	95	96
True Color (Pt-Co Units)	8.8	8.8
Turbidity (NTU)	0.82	0.80
Temperature (°C)	7.9	8.1
PHYSICAL DATA - Residues		
Total Residue	73	80
Filtrable Residue	71	78
Nonfiltrable Residue	2	< 3
Fixed Total Residue	52	48
Fixed Filtrable Residue	51	47
Fixed Nonfiltrable Residue	< 1	< 2
BIOCHEMICAL, DISSOLVED GASES & RELATED MEASUREMENTS		
BOD	1	< 1
D.O.	11.0	11.1

TABLE 4-16
ANNUAL SYSTEM MEANS
SURFACE WATERS

STATION:	Hat Creek	Bonaparte	Thompson
PARAMETER (mg/ℓ)	$\bar{X}$	$\bar{X}$	$\bar{X}$
CATIONS - Trace Metals			
Aluminum (Al)	<0.010	<0.010	<0.017
Arsenic (As)	<0.005	<0.005	<0.005
Cadmium (Cd)	<0.005	<0.005	<0.005
Chromium (Cr)	<0.010	<0.010	<0.010
Copper (Cu)	<0.005	<0.005	<0.005
Iron (Fe)	<0.026	0.048	<0.022
Lead (Pb)	<0.010	<0.010	<0.010
Mercury (Hg)	<0.00040	<0.00029	<0.00034
Molybdenum (Mo)	<0.020	<0.023	<0.020
Selenium (Se)	<0.003	<0.003	<0.003
Vanadium (V)	<0.005	<0.005	<0.005
Zinc (Zn)	<0.007	<0.023	0.017
CATIONS - Alkali Earths & Metals			
Calcium (Ca)	57	28	11
Lithium (Li)	0.002	<0.001	<0.001
Magnesium (Mg)	19	16	2.3
Potassium (K)	4.0	1.8	0.63
Sodium (Na)	20	12	3.3
Strontium (Sr)	0.32	0.15	0.055
ANIONS - General			
Boron (B)	<0.10	<0.10	<0.10
Chloride (Cl)	1.1	0.94	1.6
Fluoride (F)	0.16	0.17	0.11
Sulfate (SO_4)	54	18	7.6
ANIONS - Nutrients			
Total Kjeldahl Nitrogen (N)	0.19	0.27	0.08
Nitrate Nitrogen (NO_3-N)	<0.05	<0.06	<0.07
Nitrite Nitrogen (NO_2-N)	<0.002	<0.002	<0.002
Total Orthophosphate Phosphorus (P)	0.043	0.039	0.020
ORGANIC, NONIONIC & CALCULATED VALUES			
COD	21	19	21
TOC	9	10	3
Phenol	<0.002	<0.003	<0.002
Total Hardness ($CaCO_3$)	224	135	38
Total Alkalinity ($CaCO_3$)	226	147	35
PHYSICAL DATA			
pH (units)	8.4	8.2	7.8
Specific Conductance (µmhos/cm @ 25°)	489	294	93
True Color (Pt-Co units)	12	16	9
Turbidity (NTU)	1.5	2.1	0.81
Temperature (°C)	6.6	6.6	8.0
PHYSICAL DATA - Residues			
Total Residue	348	223	77
Filtrable Residue	342	207	74
Nonfiltrable Residue	6	16	3
Fixed Total Residue	281	160	50
Fixed Filtrable Residue	278	144	49
Fixed Nonfiltrable Residue	4	13	2
BIOCHEMICAL, DISSOLVED GASES & RELATED MEASUREMENTS			
BOD	<1	<1	<1
D.O.	11.1	11.2	11.1

(i) Cations: Trace Metals

This group consists of those cations that are normally found in natural waters at levels of 0.1 mg/l or less. In this study, the cations which were determined were: Aluminum, arsenic, cadmium, chromium, copper, iron, lead, mercury, molybdenum, selenium, vanadium, and zinc. Typical concentrations for these ions are shown in Table 4-17, which shows mean concentrations of these ions for waters in the United States.

Aluminum is one of a group of metals that can exhibit amphoteric qualities[17]. *For aluminum to be present in appreciable quantities as the ion* Al^{+3}, *requires* that the pH of the solution be less than 5. For aluminum to be present in appreciable quantities as the ion $Al_2O_4^{-2}$ requires a pH greater than 9. Both of these conditions are rare in natural waters. In acid waters, values greater than 100 mg/l can occur, but this is usually caused by industrial waste or mine drainage[18]. As to be expected from the foregoing discussion, levels of aluminum found were very low. Indeed, with the exception of Station 19 on the Thompson River, all of the values reported are less than the MDC (0.010 mg/l).

Arsenic generally exists in natural water as the ions AsO_4^{-3} and AsO_2^{-1}. Concentrations of up to 1 mg/l exhibit no lethal effects given that the lethal dose for animals is approximately 40 mg/kg[19] of body weight. At all stations examined arsenic levels were less than the MDC (0.005 mg/l).

Cadmium is a very rare ion in natural waters, however, it can be introduced by waste disposal. Cadmium is removed from solution by hydrolyzate and oxidate sediments and also by precipitation of the cadmium as the carbonate[19]. At all stations examined cadmium levels were less than the MDC (0.005 mg/l).

Chromium is another of the group of metals that can exhibit amphoteric qualities. It is present in minor amounts in igneous rock but is more common in basic and

TABLE 4-17

SUMMARY OF TRACE ELEMENTS IN WATERS OF THE UNITED STATES[1,2]

Element	No. of Positive Occurrences	Frequency of detection, %	Observed Positive Values (mg/ℓ) Min.	Max.	Mean
Zinc	1207	76.5	0.002	1.183	0.064
Cadmium	40	2.5	0.001	0.120	0.0095
Arsenic	87	5.5	0.005	0.336	0.064
Boron	1546	98.0	0.001	5.000	0.101
Phosphorus	747	47.4	0.001	5.040	0.120
Iron	1192	75.6	0.001	4.600	0.052
Molybdenum	516	32.7	0.002	1.500	0.068
Manganese	810	51.4	0.0003	3.230	0.058
Aluminum[3]	456	31.2	0.001	2.2760	0.074
Beryllium	85	5.4	0.00001	0.00122	0.00019
Copper	1173	74.4	0.001	0.280	0.015
Silver	104	6.6	0.0001	0.038	0.0026
Nickel	256	16.2	0.001	0.130	0.019
Cobalt	44	2.8	0.001	0.048	0.017
Lead	305	19.3	0.002	0.140	0.023
Chromium	386	24.5	0.001	0.112	0.0097
Vanadium	54	3.4	0.002	0.300	0.040
Barium	1568	99.4	0.002	0.340	0.043
Strontium	1571	99.6	0.003	5.000	0.217

---

[1] From J.F. Kopp and R.C. Kroner, Trace Metals in Waters of the United States, Federal Water Pollution Control Administration, Cincinnati

[2] 1577 samples (Oct. 1, 1962 - Sept. 30, 1967)

[3] 1464 aluminum analyses

ultrabasic rocks than in the more silicic types of rock[20]. Strong oxidizing conditions produce the CrO_4^{-2} ion[17], however, the natural occurrence of this is very rare and is more usually the result of industrial waste disposal. At all stations examined chromium levels were less than the MDC (0.010 mg/l).

Copper is a fairly common trace constituent which occurs most commonly in rocks as the sulphide. In the process of weathering this sulphide is oxidized to the sulphate which is water soluble. However, a considerable amount of the copper thus dissolved may be subsequently precipitated as the carbonate[19]. At all stations examined copper levels were less than the MDC (0.005 mg/l).

Iron can exist in many forms in natural waters. It may be in true solution, in a colloidal state that may be peptized by organic matter, in the inorganic or organic iron complexes, or in relatively coarse suspended particles. It may be either ferric or ferrous[21]. Because of these factors, iron is generally not a good constituent on which to base conclusions in the chemical interpretation of water analyses[19]. The dissolved ferrous plus ferric content of the systems examined ranged from 0.022 mg/l for the Thompson River to 0.048 mg/l for the Bonaparte River. The World Health Organization (WHO) recommended limit for iron in drinking water is 1 mg/l. This limit is based not upon physiological considerations, for iron in trace amounts is essential for nutrition. Rather the limit is based on aesthetic and taste considerations. For example, iron and manganese tend to precipitate as hydroxides and stain laundry and porcelain fixtures and the ferric iron will also combine with tannin in tea to produce a dark violet colour[22]. Based on the foregoing, the values found are below the level at which iron begins to cause problems in water quality.

Lead occurs in rock primarily as the sulphide (galena), and occasionally as the oxide[19]. In these forms, lead is not readily soluble at a pH greater than approximately 4.5. At all stations examined lead levels were less than the MDC (0.010 mg/l).

Mercury is strongly absorbed by minerals in hydrolyzates which normally prevents natural waters from carrying more than trace concentrations except under unusual circumstances[23]. The mercury levels in the systems examined ranged from 0.00029 mg/l for the Bonaparte River to 0.00040 mg/l for Hat Creek. The Canadian Public Health Standards do not include a standard for mercury but the U.S. Environmental Protection Agency National Interim Primary Drinking Water Regulations specify 0.002 mg/l.[61] Based on this information it is considered that the levels of mercury found do not exert a significant effect on the water quality of the systems examined.

Molybdenum acts as a catalyst in the conversion of gaseous nitrogen into a usable form by free-living, nitrogen fixing bacteria and blue-green algae. However, high concentrations of molybdenum cause heart disease in ruminants[24]. Molybdenum levels in the systems examined were below the MDC (0.020 mg/l) in the case of Hat Creek and the Thompson River, and only slightly above the MDC in the case of the Bonaparte River.

Selenium generally occurs in natural waters as the ion SeO_4^{-2}. It may be absorbed on hydroxide precipitates such as ferric hydroxide or on hydrolyzate sediments. Selenium is generally only present in trace quantities in natural waters[19]. At all stations examined selenium levels were less than the MDC (0.003 mg/l).

Vanadium is not normally present in natural waters in significant amounts, although values of up to 0.150 mg/l have been reported[21]. At all stations examined vanadium levels were less than the MDC (0.005 mg/l).

Zinc is an essential and beneficial element in body growth but is not normally found in more than trace amounts in natural waters[19]. However, concentrations above 5 mg/l can cause a bitter astringent taste and opalescence in natural waters[21]. Fish and other aquatic life exhibit a high sensitivity to zinc. In soft water, levels of zinc ranging from 0.1 to 1.0 mg/l are lethal, but calcium is antagonistic toward such toxicity[22]. The annual system means for zinc found in this study ranged from 0.007 mg/l for Hat Creek to 0.023 mg/l for the Bonaparte River. These values are well below those given in the foregoing discussion, and hence it is considered that these levels are below those that would cause any concern with respect to water quality.

(ii) Cations: Alkali Earths and Metals

The alkali metals are a group of elements that consist of lithium, sodium, potassium, rubidium, cesium, and francium. Of these, rubidium and cesium are exceedingly rare in a natural environment, while francium is an artificial element which has only short lived isotopes. These three elements were not determined and will not be considered here. All of the common salts of the alkali metals are water soluble with solubility increasing in the order lithium-sodium-potassium[25]. Because of this high solubility it is only rarely that these elements are not found in natural waters.

The alkali earths are a group of elements that consist of beryllium, magnesium, calcium, strontium, barium, and radium. Of these, only magnesium, calcium, and strontium are normally present in natural waters. The alkali earths are much less water soluble than the alkali metals[25], and the importance of this group of compounds lies mainly in their contribution to water hardness.

The ions to be considered in this section are calcium, lithium, magnesium, potassium, sodium, and strontium. As shown in the previous discussion, these ions make up the commonly occurring alkali earths and metals.

Calcium is present in nearly all natural waters because of its widespread occurrence in rocks and soils. High concentrations of calcium and sulphate indicate the possibility of solution of gypsum or anhydrite, and low concentrations of calcium compared to sodium may indicate absence of readily soluble calcium minerals or the action of base exchange whereby calcium originally in the water has been exchanged for sodium[2]. An examination of the data for the different systems shows that calcium is present in appreciable quantities with the calcium to sodium ratio being approximately 3:1. This would tend to indicate that the water has come in contact with calcium bearing minerals. Particularly in the case of Hat Creek, with an annual system mean of 57 mg/l of calcium as Ca^{+2}, there is an indication of a significant ground water component which has been in contact with calcium bearing minerals (see also Section 4.1 (a)).

Lithium is comparatively rare. The scarcity of lithium in rocks more than any other factor probably is responsible for the relatively minor amounts of the element found in water. Lithium should not be adsorbed in base exchange reactions because all the common cations are reported to be able to replace lithium from base exchange material [26]. Any base exchange reactions which occur, therefore, should bring lithium into solution rather than remove it from solution. These points are borne out by the results obtained in this survey. Of the systems examined, only Hat Creek had a mean annual value greater than the MDC (0.001 mg/l), and even here the value for lithium was only 0.002 mg/l.

Magnesium content is considerably less than calcium in most waters of low to moderate dissolved solids concentration even when computed on the basis of concentrations expressed in equivalents. The Ca:Mg ratio for natural waters computed from equivalents commonly ranges from about 5:1 to about 1:1. High values suggest that the water obtained calcium from relatively pure limestone or other calcium carbonate deposits or that gypsum was available for solution. Low values of the ratio indicate that magnesium silicate minerals are being dissolved or that dolomitic rocks are being attacked[19]. Converting the means for the systems studied to equivalents and calculating the Ca:Mg ratios shows that the value for these ratios range from 1.1 for the Bonaparte River to 1.8 for Hat Creek to 2.9 for the Thompson River. From this it can be inferred that, at least in the case of the Bonaparte River and Hat Creek, the water has been in contact with either magnesium silicate minerals or dolomite. In the case of the Thompson River, the situation is not clear, as the value of the ratio obtained is almost exactly at mid-range. This probably reflects the size of the Thompson River watershed with its much larger diversity, which would tend to produce a more average condition.

Potassium in resistate and hydrolyzate sediments is largely in the form of unaltered silicate minerals and clay minerals, respectively. In these forms the potassium is less readily available for solution in water than are the soluble sodium salts that often are found in clastic sediments. Only in certain kinds of evaporates are large quantities of potassium salts available for direct solution in water. Potassium salts are highly soluble and are among the last to be separated as solutions are evaporated; hence evaporates that contain much potassium are rather rare. Because of the foregoing, most natural waters contain much more sodium than potassium, even though amounts of both that would appear to be available for solution are nearly the same[19]. An examination of the data for the three systems examined in this study shows that in all cases the foregoing applies here. The sodium levels found are in the region of 5 to 7 times that of the potassium.

Sodium, when leached from rocks, tends to remain in solution. It takes part in no important precipitation reactions like calcium and magnesium since nearly all sodium compounds are readily soluble. Sodium bearing waters may, under some circumstances, participate in base exchange reactions. All natural waters contain at least some sodium and values of less than 1 mg/l are very rare[19]. The foregoing is borne out by the results obtained for all three systems examined. The rather high sodium value for Hat Creek (20 mg/l) when compared to the Bonaparte and Thompson Rivers may reflect the combination of low flow and high evaporation rate that occurs in Hat Creek (see also Section 4.1 (a)).

Strontium is a typical alkali earth element similar chemically to calcium. Strontium is one of the most abundant minor constituents of igneous rock and is important also in carbonate sediments. Strontium is more plentiful in syenitic and granitic rocks and occurs in very minor quantities, if at all, in ultrabasic rocks. Strontium sulphate (celestite) is a common component of carbonate sediments and strontium may partly replace calcium in aragonite[23]. An examination of the results indicates that the water present in Hat Creek has probably been in contact with some form of strontium bearing mineral, as the values obtained are above those that would otherwise be expected (0.32 mg/l as compared to 0.217 mg/l, the United States average as shown in Table 4-17).

(iii) Anions: General

The ions to be considered in this section are borate (as boron), chloride, fluoride, and sulphate.

Boron is essential in trace quantities in plant nutrition but becomes toxic to some plants when present in amounts as small as 1 mg/l in irrigating water[27]. Most plants are somewhat more tolerant than this but many are damaged by concentrations of 2 mg/l. In a very general way, the waters that are highest in boron concentration seem usually to be sodium waters, which might be expected because the sodium borates are more soluble than the calcium or magnesium borates[28]. This is borne out by the results of this survey in that in all cases we are dealing with a calcium type water and we find that in all cases the boron level is less than the MDC (0.1 mg/l).

Chloride is present in all natural waters. In waters associated with sedimentary rocks, concentrations do not usually exceed 5 mg/l. Waters high in chloride usually are also high in sodium. This generalization is based on the fact that, in the more highly mineralized waters, common salt (NaCl) is the main mineral in solution[19]. All of the indications are that in the Hat Creek Valley the main types of rock formations are sedimentary in origin (Section 4.1 (a)).

The values obtained for chloride for all three systems studied were less than 5 mg/l in all cases. Again, because these waters are calcium and not sodium waters the chloride content tends to be lower.

Fluorides exhibit moderate to high solubility. Resistate sedimentary rocks frequently contain calcium fluoride (fluorite) as a minor constituent, and possibly other fluoride bearing minerals may constitute part of the grain material of resistates, where chemical weathering has not been complete. Fluoride in natural waters has been attributed to solution of micas which contain fluoride[29]. Water containing less than 0.9 mg/l is not likely to cause mottled enamel in children or cause endemic cumulative fluorosis and skeletal effects[30]. The WHO European Drinking Water Standards set an upper limit of 1.5 mg/l for drinking water[22]. The fluoride content of the systems studied ranged from 0.11 mg/l for the Thompson River to 0.17 mg/l for the Bonaparte River. Based on the foregoing, it is not considered that the fluoride levels found is cause for concern for the water quality. The results do indicate the presence of some fluoride bearing minerals in the area.

Sulphates of most of the common metallic elements are readily soluble in water. The sulphate ion, once formed, is chemically stable in most of the environments to which natural waters are subjected. These two factors are of basic importance in governing the behaviour of sulphate ions in water. Gypsum and anhydrite are important components of many evaporate rock formations and are present in small amounts in a great many resistate and hydrolyzate rocks. Because of their relatively high solubility, these minerals are an important source of sulphate in water, even though in the individual formation they may be present only as a minor constituent[19]. With the exception of the bicarbonate-carbonate group, sulphate is the most important anion present in terms of concentration. In the case of Hat Creek the results for sulphate tend to bear out the fact that there is a comparatively large groundwater input to Hat Creek and that this groundwater has been in contact with either a gypsum or anhydrite type of rock, most probably incorporated in resistate or hydrolyzate rocks (see also Section 4.1 (a)).

(iv) Anions : Nutrients

The ions composing this group are total Kjeldahl nitrogen, nitrate nitrogen, nitrite nitrogen, and total orthophosphate phosphorous. In considering the nitrogenous compounds present in a water system, it is helpful to consider them as components of the nitrogen cycle. In this cycle, decomposition of nitrogenous organic matter either by aerobic or anaerobic bacteria gives rise to ammonia. The sum of the "organic nitrogen" and the ammonia nitrogen present constitutes the total Kjeldahl nitrogen. The oxidation of ammonia by aerobic bacteria, a process usually referred to as nitrification, produces first nitrites and then nitrates. Nitrate, the final oxidation product of the ammonia, serves as food for plant life and is used by plants for the building up of plant proteins. The decay of proteins leads to the formation of ammonia, thus completing the nitrogen cycle[31]. Somewhat high levels for total Kjeldahl nitrogen in comparison to the nitrate and nitrite nitrogen levels were noted. This could be due to agricultural runoff from urea type fertilizer or from animal waste. It is also possible that it is due to some factor inhibiting the action of the nitrifying bacteria. For example, manganese, even in low concentrations, is toxic to this group of bacteria.

Phosphate minerals, compared to the carbonates or sulphates, are comparatively rare. Phosphate tends to redeposit in hydrolyzates and elsewhere in the form of iron and calcium phosphates. Generally the amount of phosphate present in natural waters is less than 1 mg/l, although a few examples of natural waters are known where the value is as high as 30 mg/l. In natural waters, the nitrogen: phosphorous ratio is near to 10:1[19]. An examination of the results of this study shows an anomaly in the nitrogen to phosphorous ratio, particularly in the case of Hat Creek. Nitrogen to phosphorous ratios calculated from the annual system means give values for this ratio of 5.6, 8.5, and 7.6 for Hat Creek, Bonaparte River and Thompson River respectively. This difference, particularly in the case of Hat Creek, must be due to one of two causes. Either the nitrogen level is lower than normal for natural waters or the phosphorous level is higher than normal. The latter is more likely due to input of phosphorous from fertilizer contained in runoff to the water system.

(v) Organic, Nonionic, & Calculated Values

The parameters contained in this group are chemical oxygen demand (COD), total organic carbon (TOC), phenol, total hardness as equivalent $CaCO_3$, and total alkalinity as $CaCO_3$.

COD, TOC, and phenol when considered together are indicators of environmental contamination of an organic nature. Levels of these three parameters were found to be quite low indicating that there is a low level of organic loading to these systems.

Hardness in water is one means of expressing the concentration of certain "soap consuming" cations, specificially: calcium, magnesium, strontium, iron, aluminum, zinc and manganese. When considering domestic uses, hardness of water does not become particularly objectionable until it reaches approximately 100 mg/l. Hardness can greatly exceed this level. In many places, especially where waters have come in contact with limestone or gypsum, few natural waters will be found to have a hardness of much less than 200-300 mg/l. In gypsiferous waters hardness over 1000 mg/l is common. As a broad classification, waters with a hardness of less than 100 mg/l are considered soft, from 100 to 200 mg/l moderately hard and greater than 200 mg/l very hard[19]. Hat Creek may be classified as being very hard with a annual mean of 224 mg/l, the Bonaparte River as moderately hard with an annual system mean of 135 mg/l, and the Thompson River as soft with an annual system mean of 38 mg/l.

Alkalinity (total) represents those anions which form acids that are only weakly dissociated in solution, and which thus enter into hydrolysis reactions. Thus, chloride, sulphate, and nitrate ions do not affect alkalinity but carbonates do. In general, because of the relative abundance of carbonate minerals and because carbon dioxide, which enters into equilibria with them in water solution, is readily available, bicarbonate and carbonate are to be expected in most waters. The presence of hydroxide ions in natural water in amounts sufficient to affect the alkalinity determination directly is very rare, unless artificial contamination has occured.

In addition to the carbonates and bicarbonates formed by equilibria with carbon dioxide in the atmosphere, these ions can also be formed by way of the carbon cycle. Organic carbonaceous matter in rivers, which may arise from dead and living animals and plants, from sewage and industrial wastes, and from soil erosion is oxidized by aerobic bacteria in the presence of dissolved oxygen to carbon dioxide, which may then be neutralized in part by the alkali earths and metals to bicarbonates or carbonates. The reverse process (production of oxygen from carbon dioxide) is termed photosynthesis and is carried out only by green plants containing chlorophyll, such as algae, in the presence of sunlight; it involves the formation of oxygen and the utilization of the carbon for the synthesis of complex organic compounds such as fats, carbohydrates, etc. In the absence of oxygen anaerobic bacteria metabolize carbohydrates and other organic compounds leading to the reduction of carbon to methane. This occurs in septic tanks and in sludge and mud deposits and decomposing vegetation at the bottom of streams[31]. The alkalinity levels were found to range from 226 for Hat Creek to 147 for the Bonaparte River, to 35 for the Thompson River, tending to follow the alkali earths and filtrable residue levels.

(vi) Physical Data

The parameters contained in this group are pH, specific conductance, true colour, turbidity, and temperature.

The pH value of a water solution represents the overall balance of a series of equilibria existing in solution. Most natural waters have pH values ranging from about 5.5 to slightly over 8.0[19]. In all cases the waters sampled were on the alkaline side of the pH scale and, as the alkalinity of the water decreases, so does the pH so that the highest pH is in Hat Creek, followed by the Bonaparte River, with the lowest values being recorded for the Thompson River.

Electrical conductance is the ability of a substance to conduct an electrical current. Specific electrical conductance is the conductance of a cube of the substance 1 cm on a side[32]. The specific conductance of an aqueous solution is an indication of the concentration of dissolved ionic species present and is thus an indication of the filtrable residue present[19]. In natural waters the specific conductance of the water multiplied by a factor, which varies from 0.5 to 1.0, gives the value for the filterable residue[19]. Figure 4-43 shows the relationship between the specific conductance and the filtrable residue for Hat Creek. Using standard statistical methods[33], a linear regression analysis was performed on the data, and the slope of the regression line was calculated. The value of the slope, which is the factor mentioned above, was found to be 0.68. The regression coefficient was calculated at 0.781, indicating a good correlation between specific conductance and filtrable residue.

Colour may indicate the possible presence of organic material. Thus, surface waters that leach decaying vegetation may be coloured, and groundwaters that pass through peat, lignite, or other buried plant remains may take on a colour. The determination is mainly significant in the evaluation of drinking water supplies or for other uses where colour is not desirable[19]. The low colour levels found for all three systems is a further indication of the low level of organic matter in the water and tends to substantiate the low levels indicated by the low COD, TOC, and phenol determinations.

Turbidity is caused by the presence of suspended matter such as clay, silt, finely divided organic matter, bacteria, plankton, and other microscopic organisms. Turbidity is an expression of the optical property of a sample of water which causes light to be scattered rather than transmitted in straight lines through the sample. Excessive turbidity reduces light penetration into the water and, therefore, reduces photosynthesis by phytoplankton, attached algae, and submerged vegetation[22]. From this it is evident that there should be a

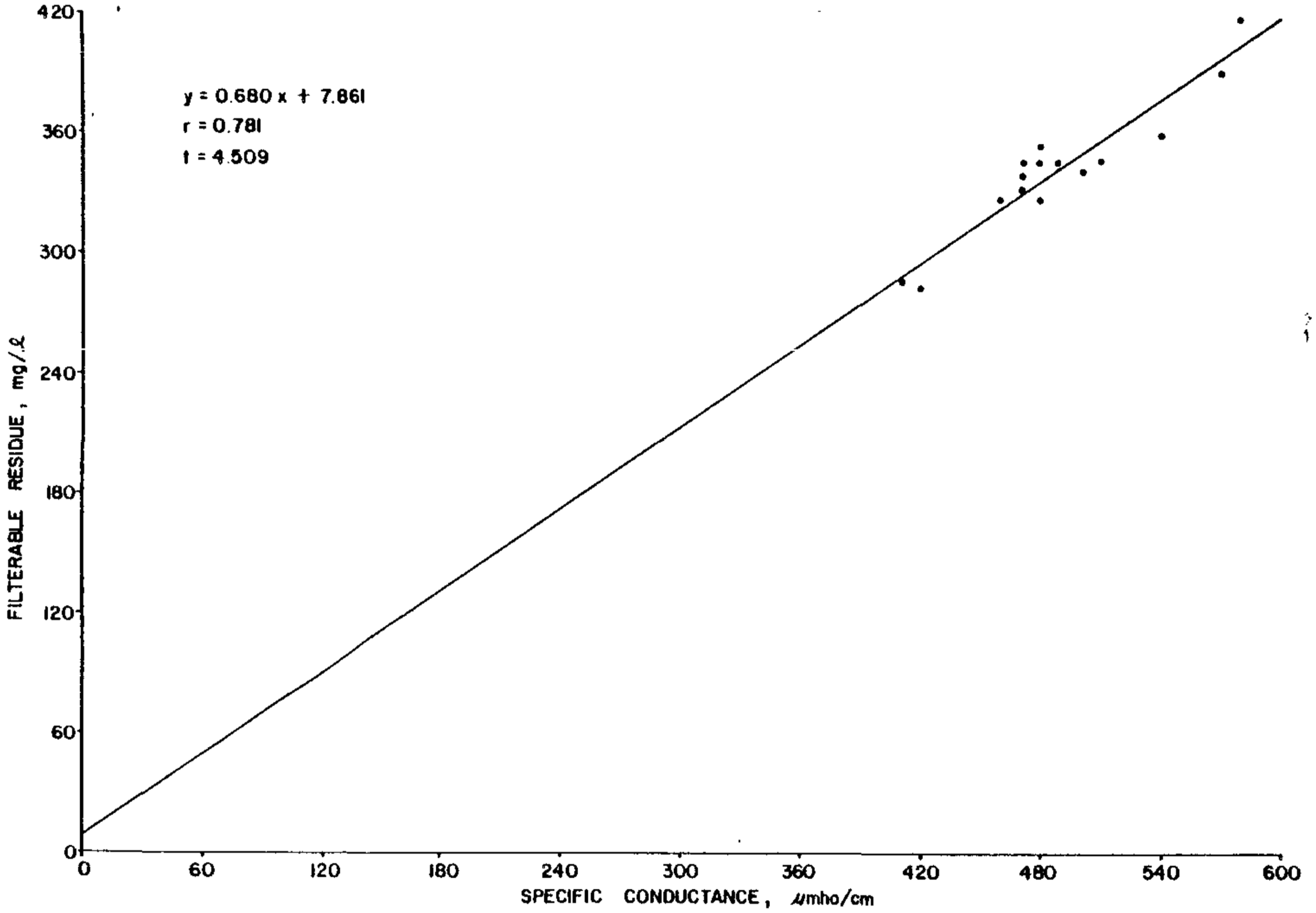


FIGURE 4-43: RELATION BETWEEN FILTERABLE RESIDUE AND SPECIFIC CONDUCTANCE FOR HAT CREEK

beak	DATE	Mar 78 DF	4-43
	PROJECT	K4242	
	DWG NO		

relationship between turbidity and non-filtrable residue. Figure 4-44 shows this relationship for Hat Creek. Using standard statistical methods[33], a linear regression analysis was performed on the data, and the slope of the regression line was calculated. The value of the slope, which gives the factor relating turbidity to non-filtrable residue, was found to be 3.1. The regression coefficient was calculated at 0.862, indicating a good correlation between non-filtrable residue and turbidity.

Temperature changes in bodies or streams of water may result from natural climatic phenomena or from the introduction of industrial wastes such as cooling waters. Temperature is important, and sometimes critical, for many uses of water. It affects the palatability of water, treatment processes, the value of water for many industrial uses, including cooling processes, and its suitability as a habitat for aquatic life [22]. For drinking purposes, water with a temperature of 10°C is usually satisfactory. Temperatures of 15°C or higher are usually objectionable[34]. Below 10°C water weeds grow very sparsely, between 10-15°C growth is prolific reaching a maximum above 15°C[35]. Changes in water temperature as a result of human activity are generally upwards. This increase in the temperature of receiving waters results in the following concomitant effects: (1) higher temperatures diminish the solubility of dissolved oxygen and thus decrease the availability of this essential gas, (2) elevated temperatures increase the metabolism, respiration, and oxygen demand of fish and other aquatic life, thus increasing the demand for oxygen under conditions where the supply is lowered, (3) the toxicity of many substances is increased as the temperature rises, (4) higher temperatures militate against desirable fish life by favouring the growth of sewage fungus and the putrefaction of sludge deposits, and finally (5) even with adequate dissolved oxygen and the absence of any toxic substances, there is a maximum temperature that each species of fish or other organism can tolerate; in the case of lake trout and brook trout this figure is approximately 23 - 25°C. However, the optimum or preferred temperature for these fish is 13 - 17°C.[22] Based on the foregoing, we can conclude that temperatures over 17°C represent marginal quality and temperatures over 25°C indicate poor quality. Figure 4 - 45 shows the water

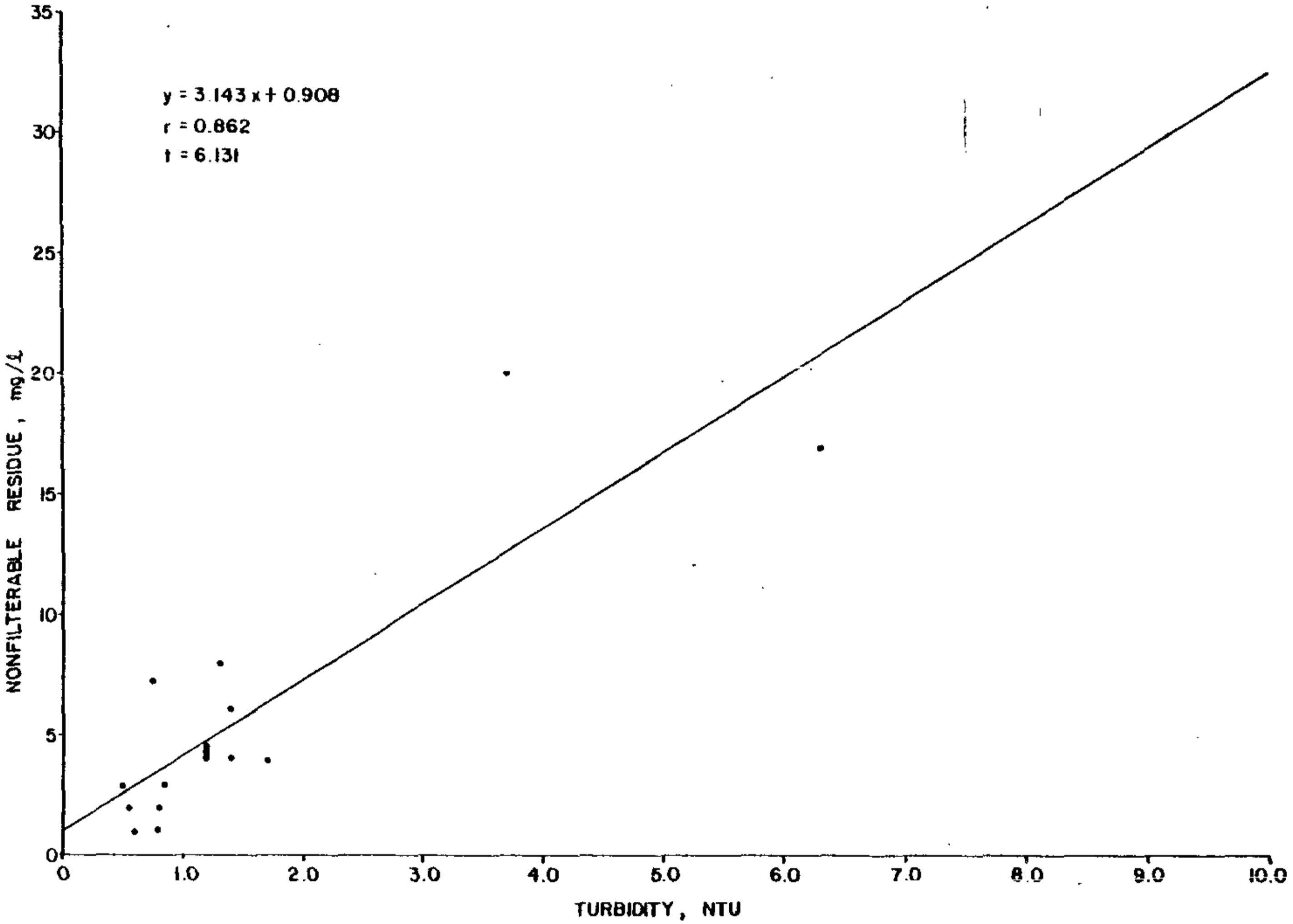
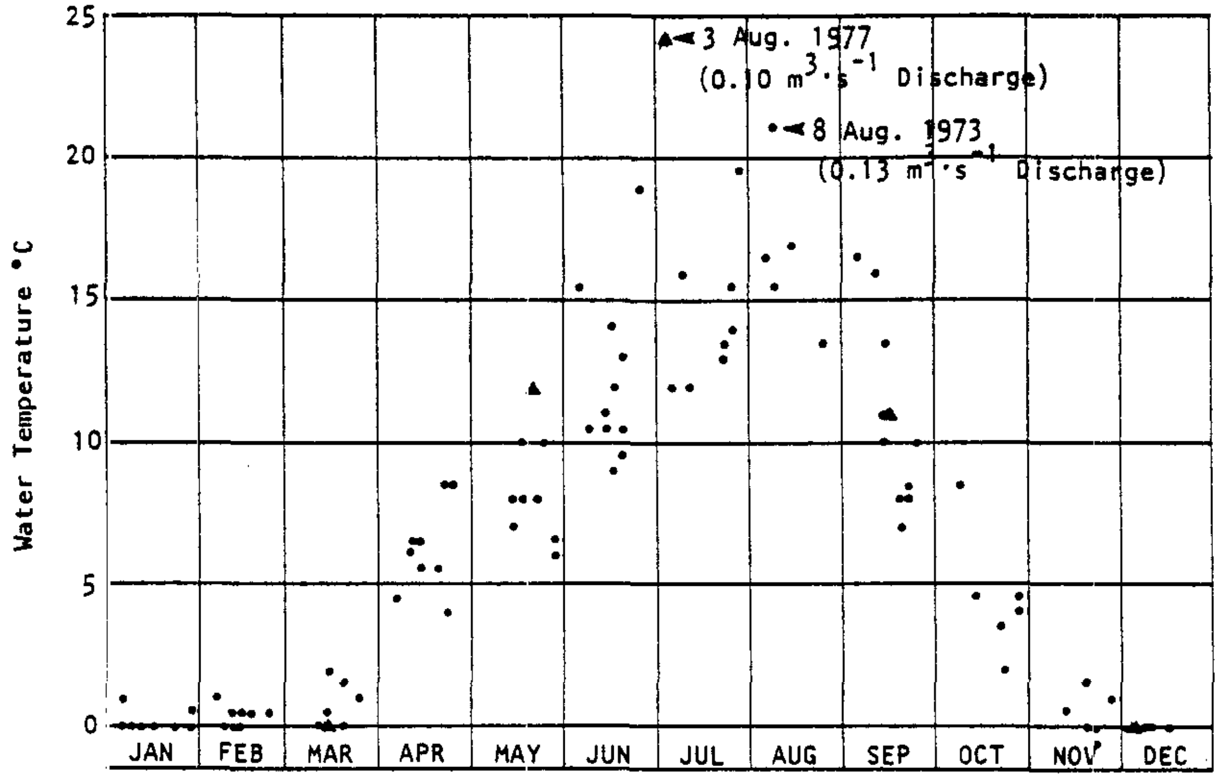
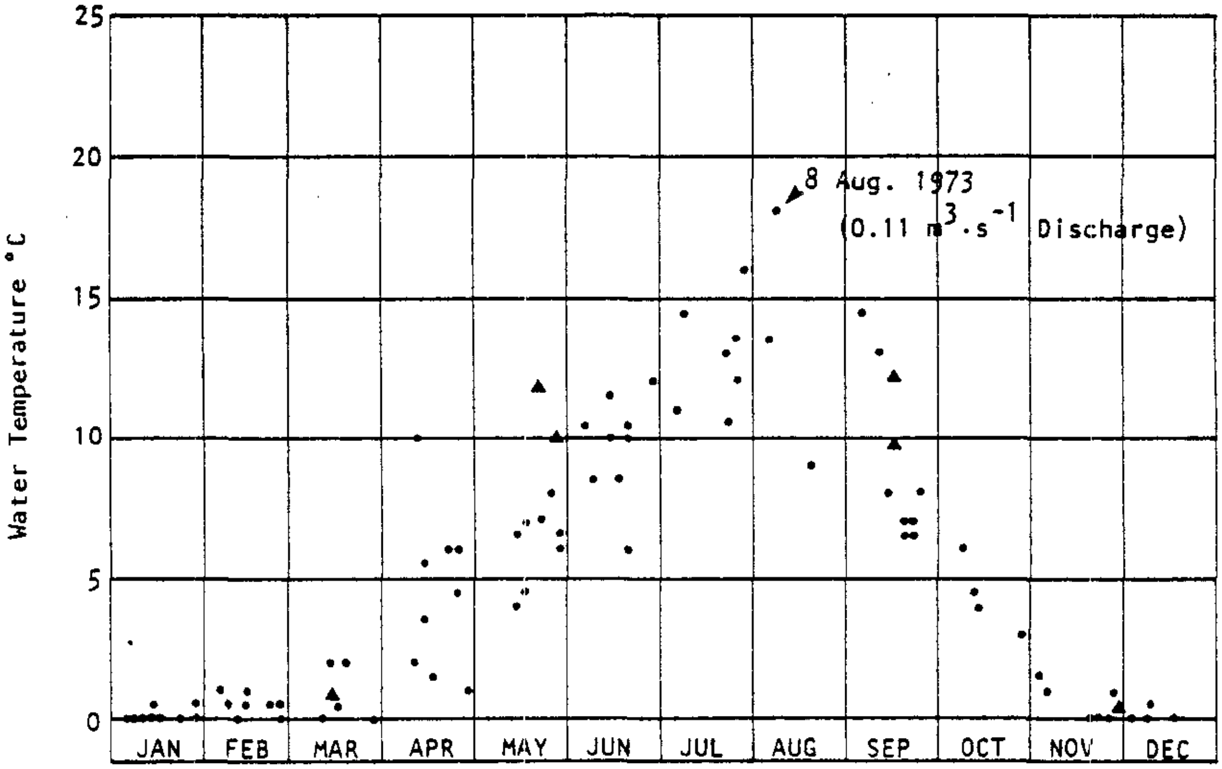


FIGURE 4-44: RELATION BETWEEN NONFILTERABLE RESIDUE AND TURBIDITY FOR HAT CREEK

DATE	Mar 78 DF	4-44
PROJECT	K4242	
DWG NO		



HAT CREEK NEAR CACHE CREEK - STATION NO. 08LF015



HAT CREEK NEAR UPPER HAT CREEK - STATION NO. 08LF061

FIGURE 4-45: WATER TEMPERATURE DATA

- • Environment Canada data
- ▲ BEAK data

beak

DATE	Dec77 DF	4-45
PROJECT	K4242	
DWG NO		

temperatures for two different stations on Hat Creek. Using the above criteria it can be seen that Hat Creek near Upper Hat Creek rarely exceeds 15°C (two test results in 86) and can, therefore, be classed as having good water quality with respect to temperature. At Hat Creek near Cache Creek, however, it is observed that during the months of June to September the water temperature periodically exceeds 17°C. Based on this it may be concluded that Hat Creek near Cache Creek has water of only marginal quality with respect to temperature during the summer months. In the case of the Thompson and Bonaparte Rivers, the highest temperatures recorded were 13 and 14°C respectively. Thus in these two rivers we may conclude that the water quality with respect to temperature is good.

(vii) Physical Data: Residues

The parameters contained in this group are total residue, filtrable residue, non-filtrable residue, fixed total residue, fixed filtrable residue, and fixed non-filtrable residue. Total residue is the term applied to the material left in the vessel after evaporation of a sample of water and its subsequent drying in an oven at a definite temperature. Total residue includes non-filtrable residue - that is, the portion of the total residue retained by a filter and filtrable residue, that portion of the total residue which passes through the filter[21]. The relationships of non-filtrable residue with turbidity and filtrable residue with specific conductance have already been discussed (see (vi) above).

Based on the results of the freshet study shown in Table 4-18 and based on graphical analysis of the suspended sediment and dissolved solids concentrations versus discharge (Figures C2-4 to C2-9, Appendix C), predictions have been made of the load variation over a hypothetical mean discharge year in both Hat Creek and the Bonaparte River as shown in Figure 4-46. Suspended sediment concentrations are likely to average approximately 300 mg/l in Hat Creek and 65 mg/l in the Bonaparte River during mean freshet discharge. The suspended sediment yield in Hat Creek varies from less than 2 metric tonnes (t)/month during winter to upwards of 2400 t/month during freshet. This translates into

TABLE 4-18

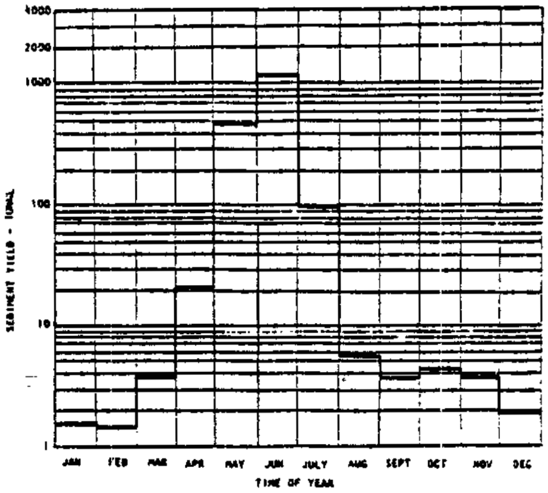
FRESHET 1977 - DAILY COLLECTION DATA

Station (Base)	and Parameter	19 May	20 May	21 May	22 May	23 May	24 May	25 May	26 May	27 May	28 May	8 June	9 June	10 June
1	Conductivity	* 250	250	250	250	250	240	250	250	250	260	270	270	260
	Nonfiltrable Residue	** 36	29	35	36	37	57	59	59	57	156	33	35	29
	Turbidity	*** 4.0	1.7	2.6	2.5	2.2	4.1	6.4	5.0	4.8	79	5.5	5.7	4.3
	Flow, m^3s^{-1}	19.3	18.1	16.4	15.3	14.6	17.5	21.0	22.9	25.9	27.7	11.6	10.7	10.1
3	Conductivity	230	230	230	230	230	220	230	230	230	240	250	240	240
	Nonfiltrable Residue	28	24	27	39	26	50	43	45	50	116	27	25	23
	Turbidity	2.3	1.1	2.2	1.8	2.3	2.4	3.7	5.7	7.2	45	4.0	3.7	3.3
4	Conductivity	220	220	220	220	220	210	230	220	220	230	230	230	230
	Nonfiltrable Residue	26	26	28	27	24	43	38	42	47	95	29	27	31
	Turbidity	2.8	1.6	2.2	1.6	1.4	3.1	3.7	4.0	6.4	36	2.8	3.7	3.7
5	Conductivity	540	550	540	530	540	530	530	530	530	530	490	480	490
	Nonfiltrable Residue	1	1	4	6	4	4	10	4	3	2	32	12	6
	Turbidity	1.0	0.90	1.1	0.55	0.75	0.80	1.1	0.80	0.65	0.70	7.5	4.1	1.7
	Flow, m^3s^{-1}	0.44	0.41	0.39	0.40	0.44	0.61	0.62	0.55	0.51	0.46	0.75	0.66	0.54
6	Conductivity	520	520	510	510	520	510	500	500	500	500	430	420	460
	Nonfiltrable Residue	4	5	2	4	7	8	6	3	4	4	24	12	8
	Turbidity	0.60	0.65	0.60	0.90	0.75	1.0	1.0	1.1	0.90	1.0	8.2	4.7	2.8
7	Conductivity	480	470	490	490	480	470	450	440	460	470	340	390	420
	Nonfiltrable Residue	3	7	6	9	10	24	10	7	4	3	38	15	8
	Turbidity	0.85	0.95	1.1	1.2	1.0	2.1	2.1	0.75	1.4	1.1	13	4.5	2.4
14	Conductivity	480	510	510	490	500	480	460	450	450	460	290	350	380
	Nonfiltrable Residue	<1	<1	3	3	4	9	4	3	7	3	25	9	3
	Turbidity	0.45	0.45	0.50	0.50	0.55	0.95	0.75	1.0	1.4	0.90	7.8	2.2	1.1
	Flow, m^3s^{-1}	0.29	0.29	0.35	0.38	0.58	0.60	0.43	0.41	0.35	0.32	0.80	0.52	0.43

* µmhos/cm @ 25°

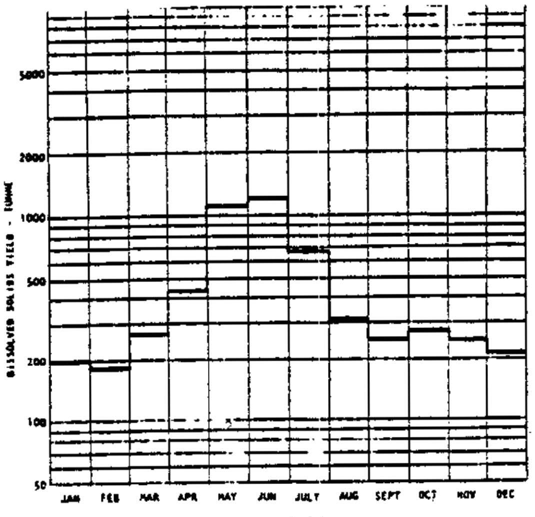
** mg/ℓ

*** NTU



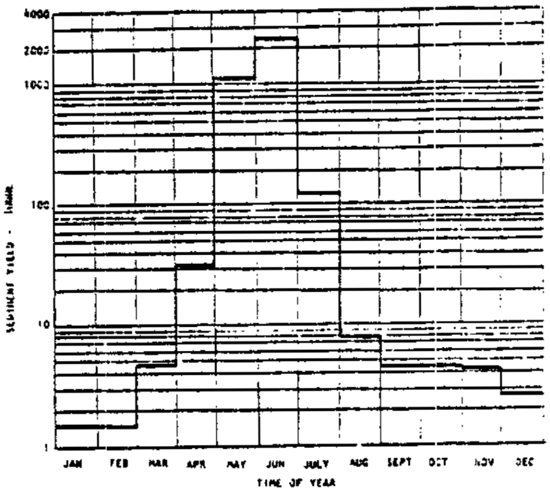
SEDIMENT YIELD
HAT CREEK - NEAR UPPER HAT CREEK

PREDICTED USING MEAN FLOW AT STA. 08LF061



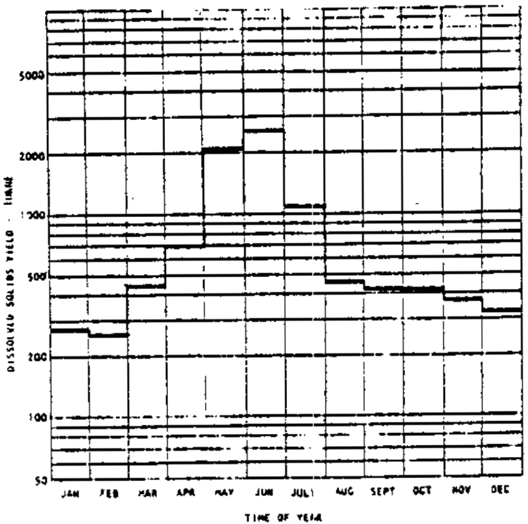
DISSOLVED SOLIDS YIELD
HAT CREEK - UPPER HAT CREEK

PREDICTED USING MEAN FLOW AT STA. 08LF061



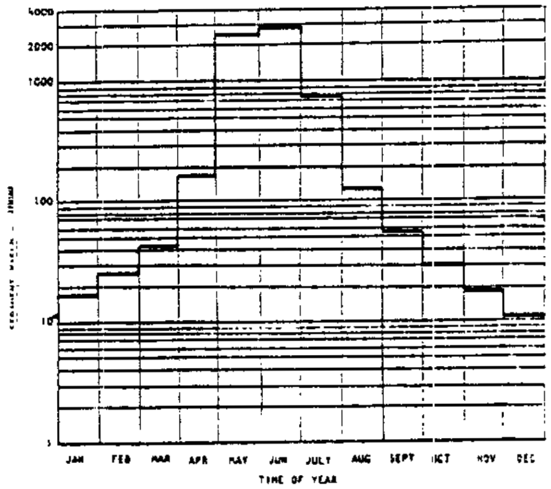
SEDIMENT YIELD
HAT CREEK - NEAR CACHE CREEK

PREDICTED USING MEAN FLOW AT STA. 08LF015 W.S.C.



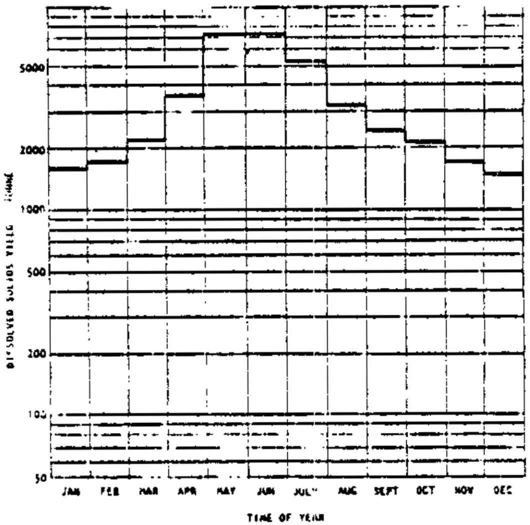
DISSOLVED SOLIDS YIELD
HAT CREEK - NEAR CACHE CREEK

PREDICTED USING MEAN FLOW TO 1973 AT 08LF015



SEDIMENT YIELD
BONAPARTE RIVER - BELOW CACHE CREEK

PREDICTED USING MEAN FLOW AT 08LF062 PLUS FLOW AT 08LF015



DISSOLVED SOLIDS YIELD
BONAPARTE RIVER - BELOW CACHE CREEK

PREDICTED USING MEAN FLOW TO 1973 AT 08LF002 PLUS FLOW FROM HAT CREEK USING MEAN FLOW AT 08LF015

FIGURE 4-46: SEDIMENT AND DISSOLVED SOLIDS YIELD
HAT CREEK AND BONAPARTE RIVER

beak

DATE	Dec77
PROJECT	K4242
DWG NO	

4-46

a calculated mean annual sediment yield of 5.6 t/km^2/year at the mouth of Hat Creek which has a basin drainage area of 660 km^2. The Bonaparte River below Cache Creek carries a sediment load of 10-25 t/month during the winter and upwards of 2700 t/month during freshet. The calculated mean annual sediment yield at this location based on a drainage area of 5,205 km^2 is 1.3 t/km^2/year.

The dissolved solids load in Hat Creek ranges from 260-400 t/month in winter to upwards of 3,000 t/month during freshet. The corresponding calculated mean annual dissolved solids yield on a budgetary basis is 14.3 t/km^2/year, from a total basin drainage area of 660 km^2. This compares with a calculated yield of 12.5 t/km^2/year from 430 km^2 in Upper Hat Creek (BEAK Water Quality Station 7). These figures indicate the calculated mean annual dissolved solids pick-up in the lower 230 km^2 of drainage area is about 18 t km^2/year.

The dissolved solids load in the Bonaparte River below Cache Creek ranges from 1,600 - 2,200 t/month in the winter to upwards of 7,200 t/month during freshet. The calculated mean yield over the year would be about 8 t/km^2/year, based on the basin drainage area of 5,025 km^2.

The budgetary values generated indicate Hat Creek runoff is considerably more turbid in the spring than the Bonaparte, and it also yields considerably more dissolved solids per unit area of drainage than does the Bonaparte River. The sediment yield characteristics reflects the surficial geology, channel morphology and gradient and runoff regime in the valley. The dissolved solids yield is a product of the ground water contribution to surface flow, agricultural practices and high evaporation in the arid climate of the valley.

(viii) Biochemical, Dissolved Gases, and Related Measurements

Biochemical oxygen demand (BOD) is a measure of the amount of oxygen required to remove organic matter from the water in the process of decomposition by bacteria. It provides an index of the degree of the biodegradable organic content of water[36]. In this study the BOD at all stations examined was less than the MDC (1 mg/1) indicating a very low level of biodegradable organic matter in the three systems examined.

Dissolved oxygen in surface water is necessary for the support of aquatic life, which in turn is necessary for the removal of organic contaminants. For cold water biota, dissolved oxygen levels should be at or near saturation[36]. If fish are present in a river receiving a heavy organic load, mortality may occur when the dissolved oxygen falls below a certain critical level - in the case of many fish this is about 5 mg/1[31]. An examination of the results shows that at no time in any of the systems studied did the dissolved oxygen level even approach the value of 5 mg/l and the average percentage saturation for each system was 90.2, 91.1, and 93.3 percent for Hat Creek, Bonaparte River, and Thompson River respectively.

(c) Surface Water - Lakes

Lakes in general are chemically more stable than streams or rivers and do not show such striking changes in the amount and proportions of the principal dissolved substances. In most lakes the major ions, except the components of the carbonate buffer system, remain relatively constant in amount, and large changes in water chemistry are restricted to the scarcer biologically important substances.

In deciding which lakes in the Hat Creek Valley to analyze, the decision was made to analyze two lakes which most probably represent the two extremes on a spectrum of water quality. Other lakes in the Hat Creek Valley may then be considered to exist on a continuum between these two extremes. The two lakes chosen to represent these two extremes were Goose/Fish Hook Lake and Finney Lake.

Goose/Fish Hook Lake is typical of the type of alkali slough found in the southern interior of the province. These sloughs typically contain very high levels of alkali metals and sulphate, which, of course, results in high values for pH, conductivity, and filtrable residue[37].

Finney Lake, on the other hand, is more typical of a "wilderness lake" or oligotrophic lake, characterized by low nutrient levels and high levels of dissolved oxygen in the epilimnion[38].

The results obtained in the analysis of these two lakes are presented in Tables 4 - 19 and 4 - 20. The format of presentation in this section is the same as in Section 4.2 (b) (Surface Water: Streams and Rivers). The general chemistry discussion in that section applies equally to this section and, for the purpose of brevity, will not be repeated.

The following cations were less than the MDC in both Finney and Goose/Fish Hook Lake: aluminum, cadmium, chromium, copper, lead, and selenium. Of the remaining cations in this group, all of the levels found were very similar to those found in Hat Creek, with the possible exception of vanadium, and that only in Goose/Fish Hook Lake. In this one case there was found, in one test, a value of 1.0 mg/l for total vanadium. The cause of this one high value is not known.

In the case of Goose/Fish Hook Lake the clacium level is lower than that found in Hat Creek resulting in a Ca:Na ratio of 0.008:1. This very low ratio is probably due to the fact that Goose/Fish Hook Lake is a shallow slough located in a depression which collects shallow ground water seepage and surface water runoff. Water leaves these types of sloughs almost exclusively by evaporation, resulting in concentration of the dissolved components. As the calcium compounds are much less soluble than the sodium compounds, the calcium tends to precipitate out of solution forming a calcium type sludge on the bottom and resulting in a lower ratio of calcium to sodium in the remaining water. In addition, base exchange reactions in which calcium is replaced by sodium in solution would appear to be occurring.

TABLE 4-19.

SURFACE WATERS - FINNEY LAKE

STATION: 17, Finney Lake

PARAMETER (mg/ℓ)		Sept. 76	Dec. 76	Mar. 77	May 77	$\overline{X}_{17}$	S_{17}	R
CATIONS - Trace Metals								
Aluminum (Al)	(*)		-	-	*	<0.010	0	-
Arsenic (As)	(*)		-	-	*	<0.005	0	-
Cadmium (Cd)	(*)		-	-	*	<0.005	0	-
Chromium (Cr)	(*)		-	-	*	<0.010	0	-
Copper (Cu)	(*)		-	-	*	<0.005	0	-
Iron (Fe)	(0.083)	*	-	-	0.072	<0.041	0.044	0.062
Lead (Pb)	(*)		-	-	*	<0.010	0	-
Mercury (Hg)	(*)		*	0.00050	*	<0.00033	0.00014	0.00025
Molybdenum (Mo)		-	-	-	*	<0.020	0	-
Selenium (Se)	(*)		-	-	*	<0.003	0	-
Vanadium (V)	(*)		-	-	*	<0.005	0	-
Zinc (Zn)	(0.019)	0.007	-	-	*	<0.0060	0.0014	0.002
CATIONS - Alkali Earths & Metals								
Calcium (Ca)		15	24	29	29	24	6.6	14
Lithium (Li)	(*)	*	-	-	0.001	<0.001	0	0
Magnesium (Mg)		7.4	8.5	9.0	8.3	8.3	0.67	1.6
Potassium (K)		2.4	-	-	-	2.4	0	-
Sodium (Na)		13	18	16	12	15	2.8	6
Strontium (Sr)	(0.07)	0.05	0.15	0.16	0.15	0.13	0.053	0.11
ANIONS - General								
Boron (B)	(0.1)		-	-	*	<0.1	0	-
Chloride (Cl)		0.30	0.48	0.82	0.50	0.53	0.22	0.52
Fluoride (F)		0.24	0.42	0.11	0.11	0.22	0.15	0.31
Sulfate (SO_4)		4	5	6.1	5.1	5.0	0.86	2.1
ANIONS - Nutrients								
Total Kjeldahl Nitrogen (N)		0.69	0.73	1.2	0.71	0.83	0.25	0.51
Nitrate Nitrogen (NO_3 - N)		0.03	*	0.03	*	<0.02	0.005	0.01
Nitrite Nitrogen (NO_2 - N)		*	0.003	0.0027	*	<0.0019	0.0010	0.002
Total Orthophosphate Phosphorus (P)		0.042	0.018	0.015	0.024	0.025	0.012	0.027
ORGANIC, NONIONIC & CALCULATED VALUES								
COD		-	-	-	72	72	0	-
TOC		13	-	-	23	18	7.1	10
Phenol		-	-	-	*	<0.002	0	-
Total Hardness ($CaCO_3$)		68	95	109	107	94.8	18.9	41
Total Alkalinity ($CaCO_3$)		94	125	146	127	123	21.5	50
PHYSICAL DATA								
pH (units)		8.6	8.3	7.7	8.0	8.2	0.39	0.9
Specific Conductance (µmhos/cm @ 25°)		180	240	270	240	232	37.7	90
True Color (Pt-Co Units)		10	20	30	15	19	8.5	20
Turbidity (NTU)		0.70	1.3	1.3	1.2	1.1	0.29	0.6
Temperature (°C)		13	0	0	10	5.8	6.8	13
PHYSICAL DATA - Residues								
Total Residue		152	182	213	169	179	25.8	61
Filtrable Residue		150	178	210	167	176	25.3	60
Nonfiltrable Residue		2	4	3	2	3	1	2
Fixed Total Residue		82	133	120	116	113	21.8	51
Fixed Filtrable Residue		82	133	120	115	112	21.7	51
Fixed Nonfiltrable Residue		*	*	2	1	<1	0.5	1
BIOCHEMICAL, DISSOLVED GASES & RELATED MEASUREMENTS								
BOD		1	-	-	-	1	0	-
D.O.		8.6	10.6	7.6	9.1	9.0	1.2	3
% Saturation		93.2	83.5	59.8	92.7			

---

* Denotes <MDC
() Denotes Total Concentration

TABLE 4-20

SURFACE WATERS - GOOSE/FISH HOOK LAKE

STATION: 16, Goose/Fish Hook Lake

PARAMETER (mg/ℓ)		Sept. 76	Dec. 76	Mar. 77	May 77	$\bar{X}_{16}$	S_{16}	R
CATIONS - Trace Metals								
Aluminum (Al)	(*)		-	-	*	<0.010	ø	-
Arsenic (As)	(0.009)		-	-	*	<0.005	ø	-
Cadmium (Cd)	(*)		-	-	*	<0.005	ø	-
Chromium (Cr)	(*)		-	-	*	<0.010	ø	-
Copper (Cu)	(*)		-	-	*	<0.005	ø	-
Iron (Fe)	(0.076)	*	-	-	0.026	<0.018	0.011	0.016
Lead (Pb)	(*)		-	-	*	<0.010	ø	-
Mercury (Hg)	(0.0011)		0.00035	0.00061	*	<0.00040	0.00018	0.00026
Molybdenum (Mo)		-	-	-	0.03	0.03	ø	-
Selenium (Se)	(*)		-	-	*	<0.003	ø	-
Vanadium (V)	(1.0)		-	-	0.006	0.006	ø	-
Zinc (Zn)	(*)	*	-	-	0.054	<0.030	0.035	0.049
CATIONS - Alkali Earths & Metals								
Calcium (Ca)		13	13	8.0	11	11	2.4	5
Lithium (Li)	(0.060)	0.082	-	-	0.057	0.070	0.018	0.025
Magnesium (Mg)		130	150	16	100	99	59	134
Potassium (K)		190	-	-	-	190	ø	-
Sodium (Na)		1900	2000	160	1500	1390	848	1840
Strontium (Sr)	(1.5)	1.5	2.0	0.18	1.1	1.2	0.77	1.82
ANIONS - General								
Boron (B)	(0.3)		-	-	0.3	0.3	ø	-
Chloride (Cl)		120	150	16	99	96	57	134
Fluoride (F)		1.6	0.51	*	0.13	<0.57	0.71	1.55
Sulfate (SO_4)		2900	3300	260	2100	2140	139	3040
ANIONS - Nutrients								
Total Kjeldahl Nitrogen (N)		2.8	5.2	1.1	4.0	3.2	1.8	4.1
Nitrate Nitrogen (NO_3 - N)		0.20	*	0.03	0.02	<0.067	0.088	0.18
Nitrite Nitrogen (NO_2 - N)		0.003	*	0.0015	*	<0.0016	0.0009	0.002
Total Orthophosphate Phosphorus (P)		1.9	1.9	0.48	1.9	1.5	0.71	1.42
ORGANIC, NONIONIC & CALCULATED VALUES								
COD		-	-	-	124	124	ø	-
TOC		156	-	-	173	164	12.0	17
Phenol		-	-	-	*	<0.002	ø	-
Total Hardness ($CaCO_3$)		568	649	86	439	436	248	563
Total Alkalinity ($CaCO_3$)		1983	2353	186	1557	1520	946.8	2167
PHYSICAL DATA								
pH (units)		9.9	10.0	9.7	9.6	9.8	0.18	0.3
Specific Conductance (µmhos/cm @ 25°)		7800	8900	970	9300	6700	3900	8330
True Color (Pt-Co Units)		40	60	60	40	50	12	20
Turbidity (NTU)		3.2	5.7	4.7	1.9	3.9	1.7	3.8
Temperature (°C)		14	-	-	11.5	6.4	7.4	14
PHYSICAL DATA - Residues								
Total Residue		6507	7968	657	5174	5076	3160	7311
Filtrable Residue		6500	7960	650	5170	5070	3159	7310
Nonfiltrable Residue		7	8	7	4	6	2	4
Fixed Total Residue		6043	7475	545	4762	4706	2987	6930
Fixed Filtrable Residue		6040	7470	543	4760	4703	2086	6927
Fixed Nonfiltrable Residue		3	5	2	2	3	1	3
BIOCHEMICAL, DISSOLVED GASES & RELATED MEASUREMENTS								
BOD		1	-	-	-	1	ø	-
D.O.		14.1	12.0	5.4	6.8	9.6	4.1	8.7
% Saturation		155	93.6	42.1	70.6			

---

* Denotes <MDC

() Denotes Total Concentration

The lithium level in Finney Lake was found to be less than the MDC. This is in agreement with the results of Hat Creek. In the case of Goose/Fish Hook Lake the lithium levels found again indicate the evaporative concentration which has taken place.

The magnesium level in Finney Lake is lower than that found in Hat Creek for the same reasons as for calcium, that is, a lower ground water input to Finney Lake than to Hat Creek. Generally speaking, magnesium compounds are more soluble than the corresponding calcium compounds. More specifically, the solubility of magnesium carbonate and sulphate at 25°C is 0.0106 g/100 cc and 38 g/100 cc respectively while the corresponding values for the calcium salts are 0.00153 and 0.241 g/100 cc respectively[25]. The levels of magnesium found in Goose/Fish Hook Lake reflect this increased solubility of magnesium compounds when compared to calcium.

The potassium level in Finney Lake is lower than that found in Hat Creek. This is probably due to lower ground water input to Finney Lake. Goose/Fish Hook Lake potassium levels again reflect the evaporative concentration taking place.

The sodium level in Finney Lake again is lower than in Hat Creek due to reasons already mentioned, while Goose/Fish Hook Lake exhibits very high sodium levels for the reasons already discussed under calcium.

The strontium levels found in both of the lakes studied repeat the pattern found for the other parameters already discussed.

If the ratio of concentrations for different parameters, outside of the trace constituents, is calculated for Hat Creek compared to Finney Lake, it is found that, with only a few exceptions, this ratio averages at 2.05 with a standard deviation of 0.32. The exceptions to this are fluoride, sulphate, Kjeldahl nitrogen, chemical oxygen demand, and total organic carbon. This would indicate that in Finney Lake the various constituents bear the same relationship to each other as they do in Hat Creek but there is a dilution factor of approximately 2 from a higher input of surface water compared to ground water.

If similar ratios are calculated for Goose/Fish Hook Lake compared to Hat Creek, the situation is not so clear. The average ratio is found to be 20.47, but the standard deviation is 24.62. This large variability is probably due to the complicating factor of precipitation of dissolved materials due to concentration by evaporation resulting in the exceeding of the solubility of some of the dissolved salts. That this occurs may be seen by the deposits of salts to be found around the perimeter of the lake.

The fluoride level in Finney Lake was found to be higher than that in Hat Creek (0.22 mg/l compared to 0.16 mg/l). This would seem to indicate that the streams feeding Finney Lake flow through an area bearing soluble fluoride rocks, possibly fluorite. This is probably one of the sources of the somewhat high fluoride level found in Hat Creek which was previously mentioned.

The sulphate level found in Finney Lake is much lower than can be accounted for by simple dilution when compared to Hat Creek (5.0 mg/l compared to 54 mg/l). This is probably due to the ground water input to Hat Creek having been in contact with sulphate type minerals resulting in an elevated level for this ion in Hat Creek.

The Kjeldahl nitrogen, COD, and TOC levels in Finney Lake may be best understood when considered together. The higher levels for these three parameters indicate that, while intrinsically not high, the level of biological activity in Finney Lake is greater than that shown by Hat Creek.

Figure 4-47 shows a temperature and dissolved oxygen profile for Finney Lake obtained in September 1976. The figure shows a typical pattern for a shallow oligotrophic lake[38], with a high dissolved oxygen level in the epilimnion, and a hypolimnion with a low level of dissolved oxygen. The absence of a thermocline, the third criteria for a shallow oligotrophic lake, may be due to the fact that the lake was sampled in September which would be the period of the fall overturn or it may be that the lake is too shallow for a thermocline at any time of the year.

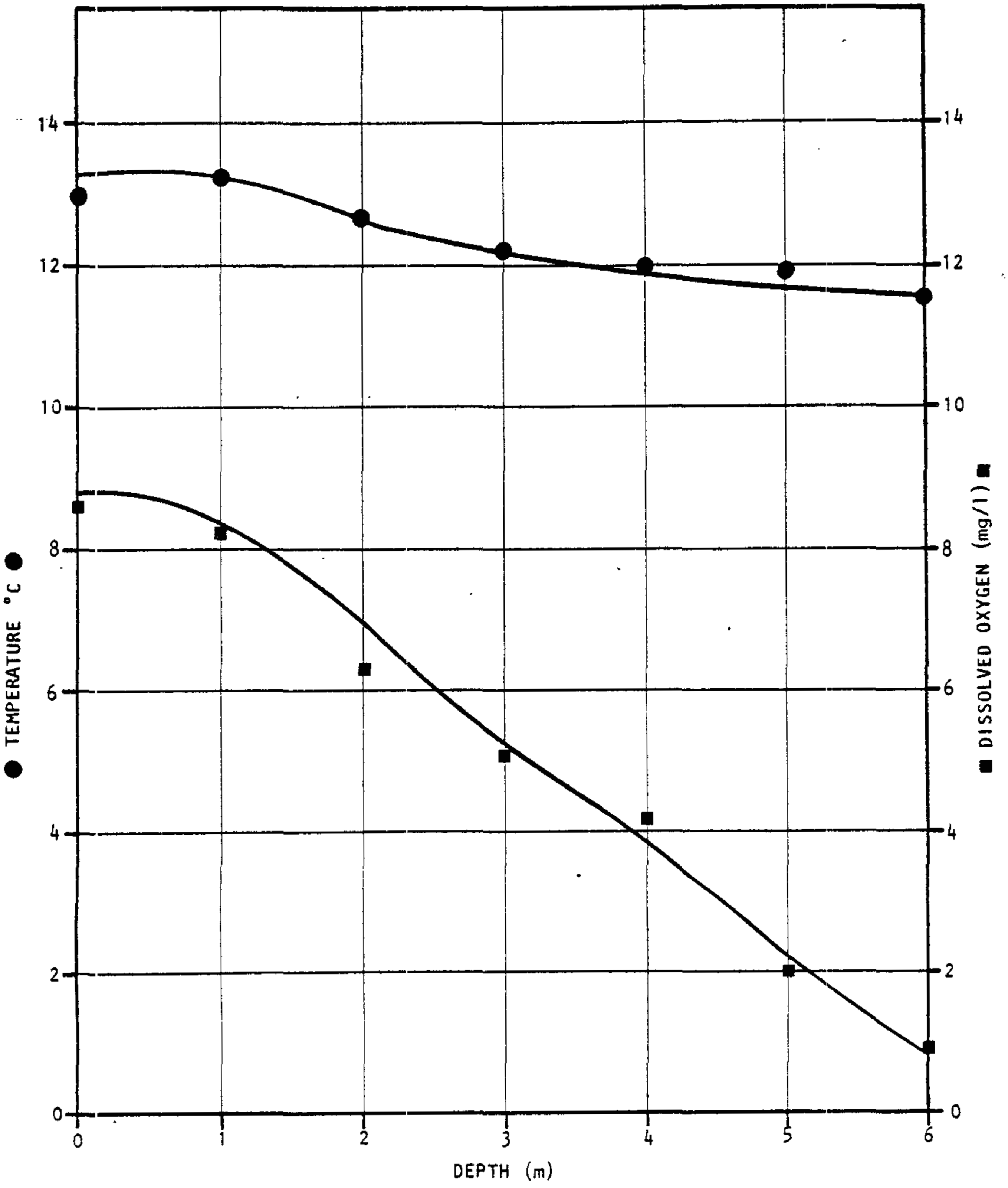


FIGURE 4-47: TEMPERATURE AND DISSOLVED OXYGEN PROFILES IN FINNEY LAKE

17 SEPT. 1976

beak	DATE	Dec 77 DF	4-47
	PROJECT	K4242	
	DWG NO		

(d) Surface Water - Other Programs

These programs provide a limited amount of information on surface water quality and are discussed briefly in this section.

(i) Pit Hydrology Study

Aleece Lake (outlet) and Hat Creek (below Finney Creek) were sampled and a limited analysis of the samples was performed. The results of these analyses are collated in Table C1-33 , Appendix C. The only points worthy of note in terms of surface water quality are the somewhat high values of sodium and potassium found in Aleece Lake, possibly indicating an input to Aleece Lake of deep permeable bedrock groundwater.

(ii) Power Plant Site Study

A series of samples was obtained from Medicine Creek, MacLaren Creek, and Pavilion Lake. The results of the analyses of these samples are collated in Tables C1-34 , C1-35 , and C1-36 , Appendix C. These results are very similar to the results obtained for the Hat Creek area.

(iii) Thompson River Intake Study

In this study,[60] referenced here only for completeness, suspended sediment concentrations were found to range from < 1.0 - 2.0 mg/l during three separate samplings in February, March, and June 1977. The report however does indicate suspended concentrations as high as 91 mg/l have been observed in other studies[39]. The study also measured suspended sediment size distributions.

A total of 46 - 55 different taxa of algae were found during the study with a mean algal density ranging from 262,000 units/liter in February to 695,000 units/liter in June. The algae density was found to vary proportionately with the river discharge and inversely with river ice cover.

For further information it is suggested that the reader consult the report.

(iv) Bulk Sample Program

Three sample stations were established on Hat Creek with respect to the coal Bulk Sample Program. The results of the analyses carried out on samples from these stations are collated in Tables C1- 37 , C1- 38 , and C1- 39 , Appendix C. The main points of difference between these samples and the annual mean values for Hat Creek lie in the higher values for total organic carbon and non-filtrable residue. These higher values are attributed to samples taken during the spring freshet.

(e) Comparison With Existing Data

As stated in Section 3.1 (b), for the purposes of this report, the term "existing data" is defined as that data which has been collected, or was in the process of being collected, prior to the commencement of this project in July 1976.

(i) Ministry of the Environment (MOE)

Table 4-21 shows the MOE data for their sample stations of interest to this project. The data for Station 0600073, Hat Creek at mouth, shows very simlar values to those for the Hat Creek System mean values with the exception of the total orthophosphate phosphorous. The MOE mean value for this parameter is 0.012 mg/1, while the program mean value is 0.043 mg/1. A possible explanation for this variation may be found in the sampling dates of the MOE data. Out of a total of 16 samples collected, 10 were collected in the period of June to August inclusive. An examination of the data for Lower Hat Creek for the samples taken in March and May 1977 show that the average total orthophosphate phosphorous for these dates is 0.019 mg/1. This value is much closer to the MOE figure which might indicate a seasonal bias in the MOE data.

TABLE 4-21

MEANS OF HAT CREEK, BONAPARTE RIVER & THOMPSON RIVER

1971 - 1977

MINISTRY OF THE ENVIRONMENT DATA

STATION: PARAMETER (mg/ℓ)	Hat Creek at mouth 0600073	Bonaparte R. above *Clinton Cr.* 0600017	Bonaparte R. below *Cache Creek* 0600008	Thompson R. at Savona 0600004	Thompson R. at Spences Bridge 0600005
CATIONS -					
Aluminum (Al)	* < 0.01	-	-	-	-
Arsenic (As)	* < 0.005	-	-	* < 0.005	* < 0.005
Cadmium (Cd)	-	-	-	* < 0.0005	* < 0.0005
Chromium (Cr)	-	-	-	< 0.005	-
Copper (Cu)	< 0.001	< 0.002	< 0.016	< 0.006	< 0.024
Iron (Fe)	< 0.1	< 0.1	< 0.07	< 0.09	< 0.06
Lead (Pb)	< 0.001	< 0.001	* < 0.003	< 0.001	< 0.001
Mercury (Hg) (μg/ℓ)	* <(0.05)	* <(0.05)	-	<(0.05)	* <(0.03)
Molybdenum (Mo)	* < 0.0019	-	-	< 0.0005	< 0.0007
Selenium (Se)	-	-	-	< 0.0005	< 0.0007
Vanadium (V)	-	-	-	-	-
Zinc (Zn)	* < 0.005	* 0.006	< 0.019	< 0.021	< 0.013
CATIONS - ALKALI EARTHS & METALS					
Calcium (Ca)	61.6	19.6	42.6	11.9	13.4
Lithium (Li)	-	-	-	-	-
Magnesium (Mg)	24.8	13.8	26.3	2.0	2.4
Potassium (K)	* 2.7	-	-	0.9	0.8
Sodium (Na)	* 22.9	-	-	2.7	2.2
Strontium (Sr)	-	-	-	-	-
ANIONS - GENERAL					
Boron (B)	* < 0.1	-	-	-	* < 0.1
Chloride (Cl)	* 2.0	* 0.9	2.6	< 1.5	0.7
Fluoride (F)	0.12	-	-	< 0.11	0.09
Sulfate (SO_4)	51.4	< 5.3	38.6	< 7.1	8.9
ANIONS - NUTRIENTS					
Total - Kjeldahl - Nitrogen (N)	< 0.16	0.20	0.35	< 0.108	< 0.093
Nitrate - Nitrogen (NO_3 - N)	< 0.03	< 0.03	< 0.12	< 0.08	0.08
Nitrate - Nitrogen (NO_2 - N)	< 0.005	< 0.005	< 0.01	< 0.005	< 0.005
Total - Orthophosphate - Phosphorus (P)	0.012	0.004	0.061	< 0.003	< 0.003
ORGANIC, NONIONIC & CALCULATED VALUES					
COD	-	-	-	* < 10	* < 10
TOC	* 5	7	7	< 3	< 4
Phenol	-	-	-	< 0.002	< 0.004
Total Hardness ($CaCo_3$)	247	96	194	38	43
Total Alkalinity ($CaCo_3$)	243	115	193	35	38
PHYSICAL DATA					
pH (units)	8.5	8.1	8.3	7.6	7.7
Specific Conductance (umhos/cm @ 25°)	522	230	440	< 95	107
True Color (Pt-Co Units)	9	13	12	< 7	< 8
Turbidity (NTU)	8.6	2.0	7.8	1.6	2.6
Temperature (°C)	6.5	7.8	6.5	6.8	8.5
PHYSICAL DATA - RESIDUES					
Total residue	355	155	305	60	71
Filtrable residue	338	147	266	57	64
Non-filtrable residue	* 3	* 11	63	2.6	7
Fixed total residue	-	-	-	-	-
Fixed filtrabel residue	-	-	-	-	-
Fixed non-filtrable residue	-	-	-	-	-
BIOCHEMICAL, DISSOLVED GASES & RELATED MEASUREMENTS					
BOD	-	-	< 10	-	* < 10
D.O.	9.6	9.7	9.8	10.0	> 9.1
% Saturation	-	-	-	-	-

( ) Denotes Total Concentration

* Denotes Less than 5 Samples

A comparison of the data for the Bonaparte River with the MOE data is complicated by the fact that the sample locations used do not coincide. Therefore, the few small differences observed (sulphate, total orthophosphate phosphorous, hardness, and alkalinity) are probably as much due to sampling location difference as they are to any other variable such as flow or seasonality.

A comparison of the data for the Thompson River with the MOE data shows that the only point of difference is that the program value for the chemical oxygen demand for the Lower Thompson River (Station 19) is much higher than the MOE value for the Thompson River at Spences Bridge (Station 0600005). Because this difference is the result of one very high test in the program (31 mg/1, May 1977) it is considered that this point is an unexplained outlier and that the norm would not show this high value.

(ii) Department of Fisheries and Environment (DFE)

The DFE temperature data for Hat Creek has already been discussed in Section 4.2 (b) (vi) (Surface Water: Streams and Rivers) (Physical Data). The other DFE data available is the data provided by the NAQUADAT program for the Thompson River. The data for this system are summarized in Table 4-22. The only points of difference between the NAQUADAT data and the program data for Station 19 is in the iron and zinc values. The values reported by DFE for iron and zinc are 0.117 and 0.002 mg/1, respectively. The program values obtained for the same parameters are 0.026 and 0.016 mg/1 respectively. The most probable cause of these differences lies in the fact that the analytical techniques used for their determination were different. In the case of the DFE data, the values reported are the extractable values. In the case of the program data, the values reported are the dissolved values. The reasons for determining the dissolved values were discussed in Section 3.2 (b) (ii) (B) (Sampling and Analytical Procedures).

(iii) Calgon Corporation

This data, contained in a Calgon Corporation report to B.C. Hydro, covers the

TABLE 4-22
MEANS OF THOMPSON RIVER
ENVIRONMENT CANADA DATA
1973 - 1976

STATION:

PARAMETER (mg/l)		Thompson River Near Spences Bridge 008LF001
CATIONS - HEAVY METALS		
Aluminum (Al)		-
Arsenic (As)	Extractable	0.0002+
Cadmium (Cd)	Extractable	< 0.001+
Chromium (Cr)	Extractable	0.0002+
Copper (Cu)	Extractable	< 0.001
Iron (Fe)	Extractable	0.117
Lead (Pb)	Extractable	< 0.002+
Manganese (Mn)		-
Mercury (Hg)	Extractable (µg/l)	< 0.05
Molybdenum (Mo)	Extractable	0.013+
Selenium (Se)	Extractable	0.001+
Vanadium (V)		-
Zinc (Zn)	Extractable	< 0.002
CATIONS - ALKALI EARTHS & METALS		
Calcium (Ca)		12.7
Lithium (Li)		-
Magnesium (Mg)		-
Potassium (K)		0.86
Sodium (Na)		3.0
Strontium (Sr)		-
ANIONS - GENERAL		
Boron (B)		-
Chloride (Cl)		1.5
Fluoride (F)		0.07
Sulfate (SO_4)		11.6
ANIONS - NUTRIENTS		
Total - Kjeldahl - Nitrogen (N)		< 0.32
Nitrate - Nitrogen (NO_3 - N) Nitrate - Nitrogen (NO_2 - N)		0.068
Total - Orthophosphate - Phosphorus (P)		-
ORGANIC, NONIONIC & CALCULATED VALUES		
COD		-
TOC		3.7
Phenol		-
Total Hardness ($CaCo_3$) Calcd.		44
Total Alkalinity ($CaCo_3$)		38
PHYSICAL DATA		
pH (units)		7.2-8.0
Specific Conductance (USIE/cm)		101
Apparent Color (Rel. Units)		< 3
Turbidity (JTU)		2
Temperature (°C)		8.6
PHYSICAL DATA - RESIDUES		
Total residue		-
Filtrable residue Calcd.		57
Non-filtrable residue		*
Fixed total residue		*
Fixed filtrabel residue		*
Fixed non-filtrable residue		*
BIOCHEMICAL, DISSOLVED GASES & RELATED MEASUREMENTS		
BOD		-
D.O.		11.0

period December 1974 to October 1975 inclusive for the Thompson River and is summarized in Table C1-40 , Appendix C. The two major differences between the data contained in the Calgon report and the data contained in this program lie in the very high values given in the Calgon report for aluminum and turbidity (0.2 mg/1 and 5 respectively compared to program values of < 0.017 mg/1 and 0.81 respectively). The high turbidity reported in the Calgon study is somewhat questionable when compared to the value of 4 mg/1 for the nonfiltrable residue. Use of the regression equation developed in Section 4.2 (b) (vi) (Physical Data) indicates that a turbidity of 5 corresponds to a nonfiltrable residue of approximately 17 mg/1 or, conversely, a nonfiltrable residue of 4 mg/1 corresponds to a turbidity of 0.89. The latter is more consistent with the program data. No explainable reason can be found for the high aluminum values.

4.3 WATER USE

(a) Ground Water

Within the Hat Creek Valley there are 12 domestic wells, and three developed springs. The locations of all wells are shown in Figures 3-3 and 3-4 and details of these wells are included in Appendix A2.0. As mentioned earlier, metered flows were not available so that water consumption from these sources had to be estimated. It is estimated that the domestic water consumption in the Hat Creek Valley is approximately 30 m^3/d.

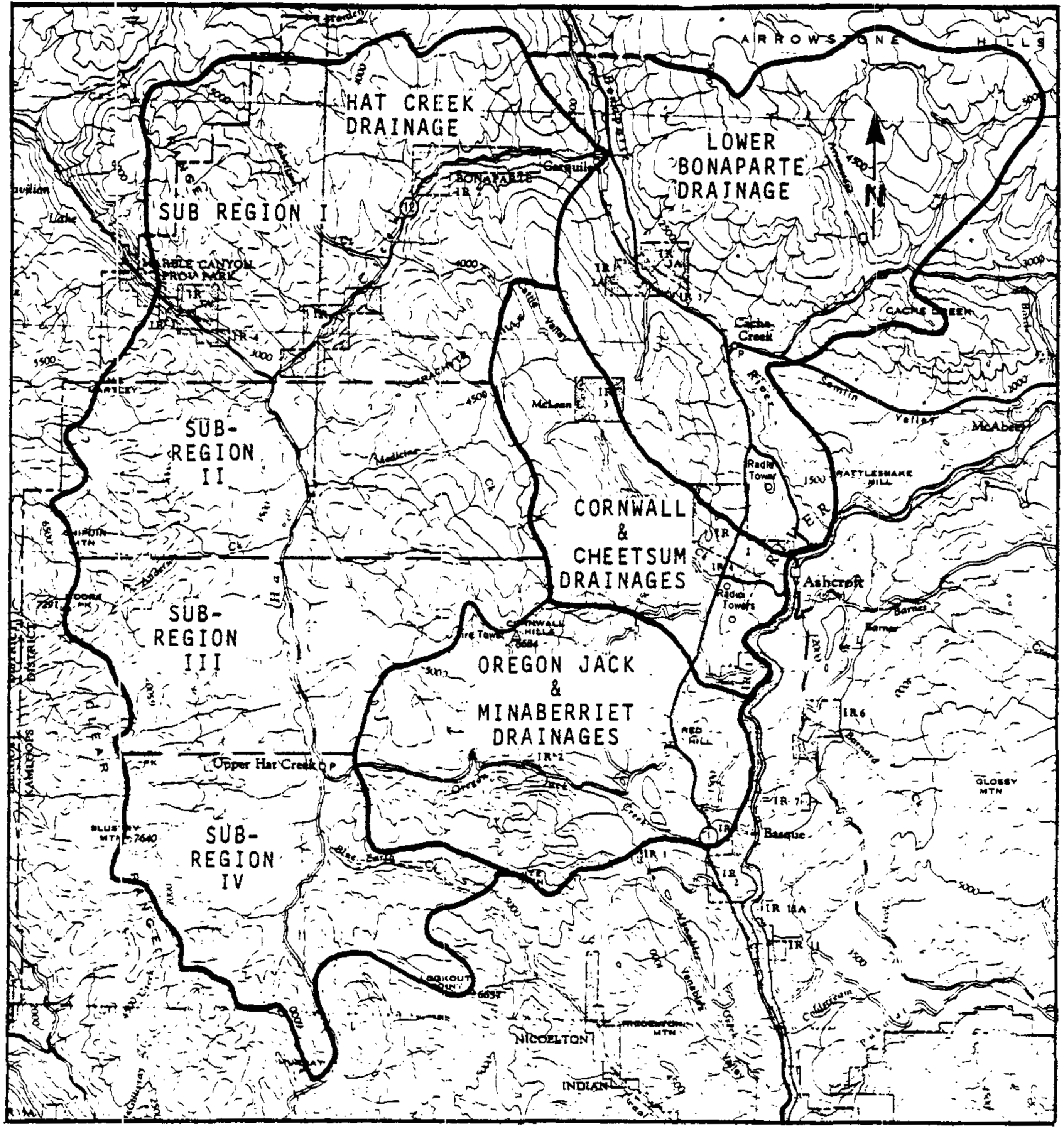
There are no wells or springs which are used for irrigation purposes in the valley, however in some places ditches have been dug to divert ground water from areas of bogs or seeps into dry soil areas. This is a limited practice since minor amounts of ground water are available.

A large capacity well supplies wash water for a limestone quarry located in the Marble Canyon area. This well is estimated to deliver 500 m^3/d of which about 75 per cent is returned to the ground water table as infiltrated waste water.

(b) Surface Water

(i) Irrigation

Two analyses were carried out to estimate the amount of water presently used for irrigation in the study area: (A) an analysis of water licence information, carried out for the Hat Creek, Lower Bonaparte, Cornwall, and Oregon Jack drainages (refer to Figure 4-48 for the location of these drainage areas) and (B), an analysis based on a water use model carried out for the Hat Creek Valley considering specific soil, crop, climate, and irrigation system characteristics. The two analyses provide a useful comparison or check on the other water use estimate. While water licences



Scale: 1:250,000

IRRIGATION WATER USE STUDY AREAS

FIGURE 4-48

are based on established irrigation practices and supply needs of a specific area, they do not necessarily represent present use, insofar as less water (or none at all in the case of an unused individual licence) or more water may on the average be currently used than accounted for by water licences. Water licences do not account for use of ground water, nor do they account for naturally occurring subsurface irrigation. The water use model, on the other hand, while based on site specific conditions, may not completely account for variation in water use caused by very localized conditions. It should be noted that in both analyses, the water use estimate represents a gross quantity including any amounts that may reenter the surface water system as return flow.

A. Water Licence Analysis

Water licence information for the study area is summarized in Table 4-23 according to the source (specific creek) from which water is licenced for irrigation or storage purposes.

Hat Creek Drainage (includes Medicine Creek)

The water licence information for the Hat Creek drainage basin was categorized in Table 4-23 on the basis of four subregions (refer to Figure 4-48) which contain approximately equal lowland areas of the Hat Creek Valley. This summary format was envisaged as being useful, not only in reporting present use results, but in assessing and reporting future water use with and without the B.C. Hydro project.

Details of water licences are shown on Figure 4-49 (sheet 1). The location of the licenced point of diversion and the quantity of irrigation water licenced per season are depicted in this figure, as well as the location of presently irrigated lands (as determined in the *Agriculture* study[40] from 1976 aerial photographs[41]).

TABLE 4-23/1

IRRIGATION WATER LICENCE INFORMATION

Location of Diversion	Irrigation Licence***			Supplemental Licence**		Storage Licence		
	Number of Licences	Water Quantity (ha-m)	Land Area	Number of Licences	Water Quantity (ha-m)	Number of Licences	Water Quantity (ha-m)	Storage Location
<u>Hat Creek Drainage</u>								
Subregion I								
Hat Creek	2	165 (37)*		-	-			
Gallagher Creek	1	11		-	-	1	11	Gallagher Lakes
Robertson Creek	2	12		-	-			
Sub Total	5	188 (37)*	205 (40)*	-	-	1	11	
Subregion II								
Hat Creek	4	21		-	-			
Lloyd (Houth) Creek	1	11		-	-		2	Lloyd Reservoirs
Medicine Creek	5	236 (224)*		-	-	3	216*****	McLean Lake
Finney Creek	2	24		-	-		12	Finney Lake
Anderson Creek	-	-		1	12			
Ambusten Creek****	1	4		-	-			
Sub Total	13	296 (224)*	346 (318)*	1	12	3	230	
Subregion III								
Hat Creek	6	89		-	-			
Anderson Creek	3	24		1	28			
Ambusten Creek****	1	12		-	-			
Cashmere Creek	1	2		1	2			
Martin Creek	1	7		-	-			
McCormick Creek	2	34		-	-			
McDonald Creek	4	40		1	10			
White Rock Creek	2	5		-	-	1	4	White Rock Lake
Schneider Br.	1	7		-	-		6	Schneider Swamp
Parke Creek	-	-		1	4		2	Parke Lake
Phil Creek****	2	28		1	6	1	5	Parke Lake
Crater Creek	1	3		-	-			
Darough Creek****	3	20		-	-			
Pocock Creek	2	17		-	-			
Sub Total	29	288	538	5	50	2	17	

TABLE 4-23/2

IRRIGATION WATER LICENCE INFORMATION

Location of Diversion	Irrigation Licence***			Supplemental Licence**		Storage Licence		
	Number of Licences	Water Quantity (ha-m)	Land Area	Number of Licences	Water Quantity (ha-m)	Number of Licences	Water Quantity (ha-m)	Storage Location
Subregion IV								
Hat Creek	6	184 (158)*		1	48 (48)*	2	36	Langley Lake & Oregon Jack Swamp
Pocock Creek	6	49		-	-			
Yet Creek****	-	-		1	7			
Colley Creek	4	40		-	-			
Darough Creek	1	Whole Flow		-	-			
Sub Total	17	273 (158)*	510 (325)*	2	55 (48)*	2	36	
Totals	64	1045 (419)*	1698 (683)*	8	117 (48)*	8	294	

* Used outside of Hat Creek watershed.

** Used only when primary source is inadequate, but not available for other licencees.

*** Supplemental licences not included.

**** Fully recorded

***** The same licence for 37 ha-m included in both totals.

TABLE 4-23/3

IRRIGATION WATER LICENCE INFORMATION

Location of Diversion	Irrigation Licence***			Supplemental Licence**		Storage Licence		
	Number of Licences	Water Quantity (ha-m)	Land Area	Number of Licences	Water Quantity (ha-m)	Number of Licences	Water Quantity (ha-m)	Storage Location
Bonaparte Drainage (South of Township 23)								
Bonaparte River	38	684		1	49			
Settlement Brook	1	1		-	-			
Walker Brook	1	2		-	-			
Perry Brook	1	8		-	-			
Craig Spring	2	44		-	-			
Cache Creek	12	379		1	26	2	66	Semlin Lake and Reservoir, West Fork Cache Creek
Cache Swamp	1	24		-	-			
Thompson River	1	148		-	-			
Total	57	1290	1246	2	75	2	66	
Cornwall & Cheetsum Drainages								
Cornwall Creek	5	59		1	45	3	64*****	McLean, Fitzellan & Henry Lakes
Cheetsum Creek****	1	10		-	-			
Lone Tree Creek	1	18		-	-	1	18	UK Lake
Ashcroft Creek	1	15		-	-	1	15	UK Lake
102 Gulch Creek	1	10		-	-			
Mahashket & Tingley Springs	1	13		-	-			
Total	10	125	307	1	45	5	97	

TABLE 4-23/4

IRRIGATION WATER LICENCE INFORMATION

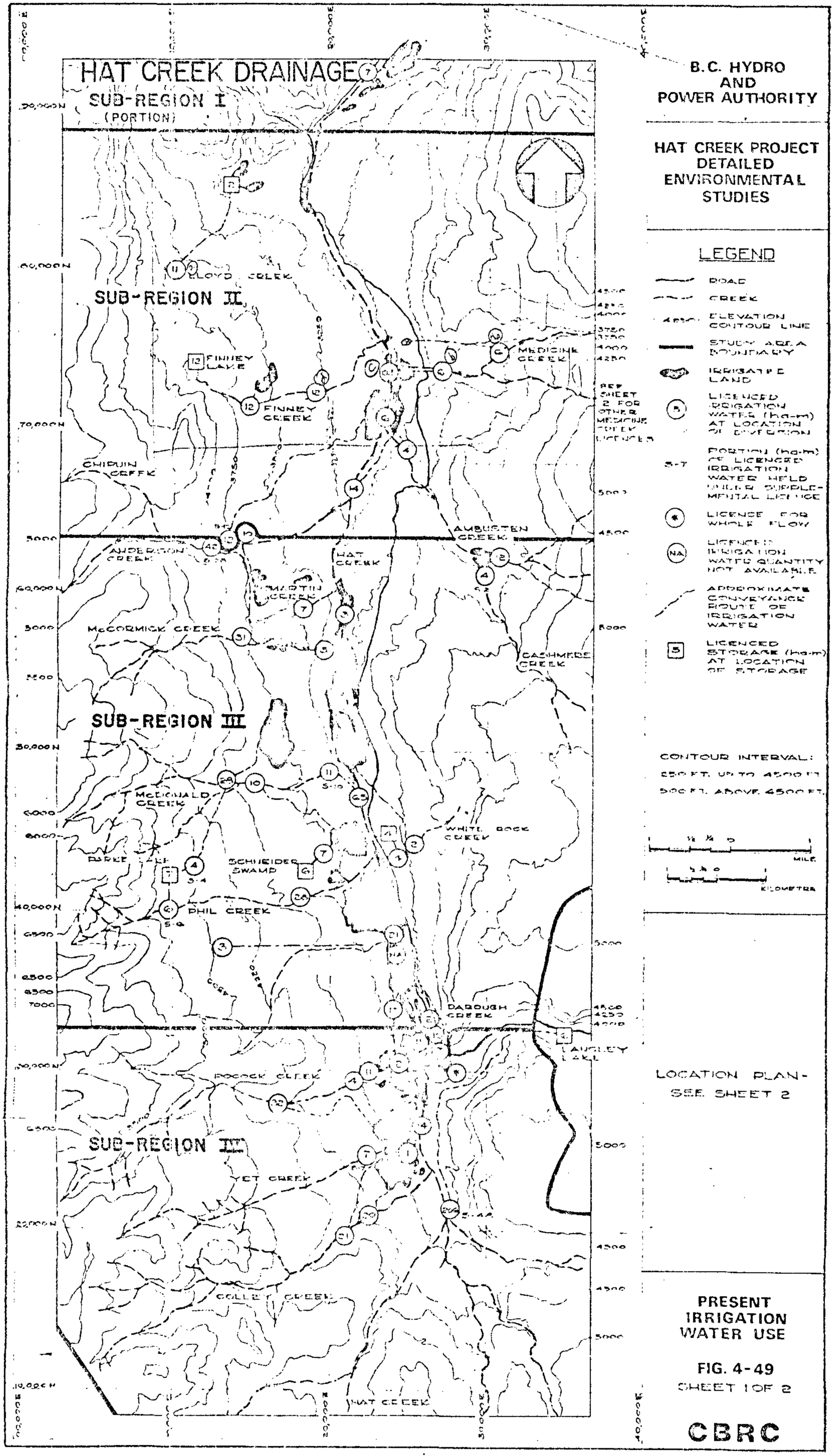
Location of Diversion	Irrigation Licence***			Supplemental Licence**		Storage Licence		
	Number of Licences	Water Quantity (ha-m)	Land Area	Number of Licences	Water Quantity (ha-m)	Number of Licences	Water Quantity (ha-m)	Storage Location
Oregon Jack & Minaberriet Drainages								
Oregon Jack Creek	7	136		3	92	4	68	Pond
Minaberriet Creek	1	6		-	-			
Basque Swamp	1	Whole Flow		-	-	-	-	
Lulu Brook	1	5		-	-			
McKenna Brook	1	1		-	-			
Total	11	148	166	3	92	4	68	

** Used only when primary source is inadequate, but not available for other licencees.

*** Supplemental licences not included.

**** Fully recorded (note that the licence for Cheetsum Creek also uses some water Minaberriet Creek).

***** The same licence for 37 ha-m included in both totals.



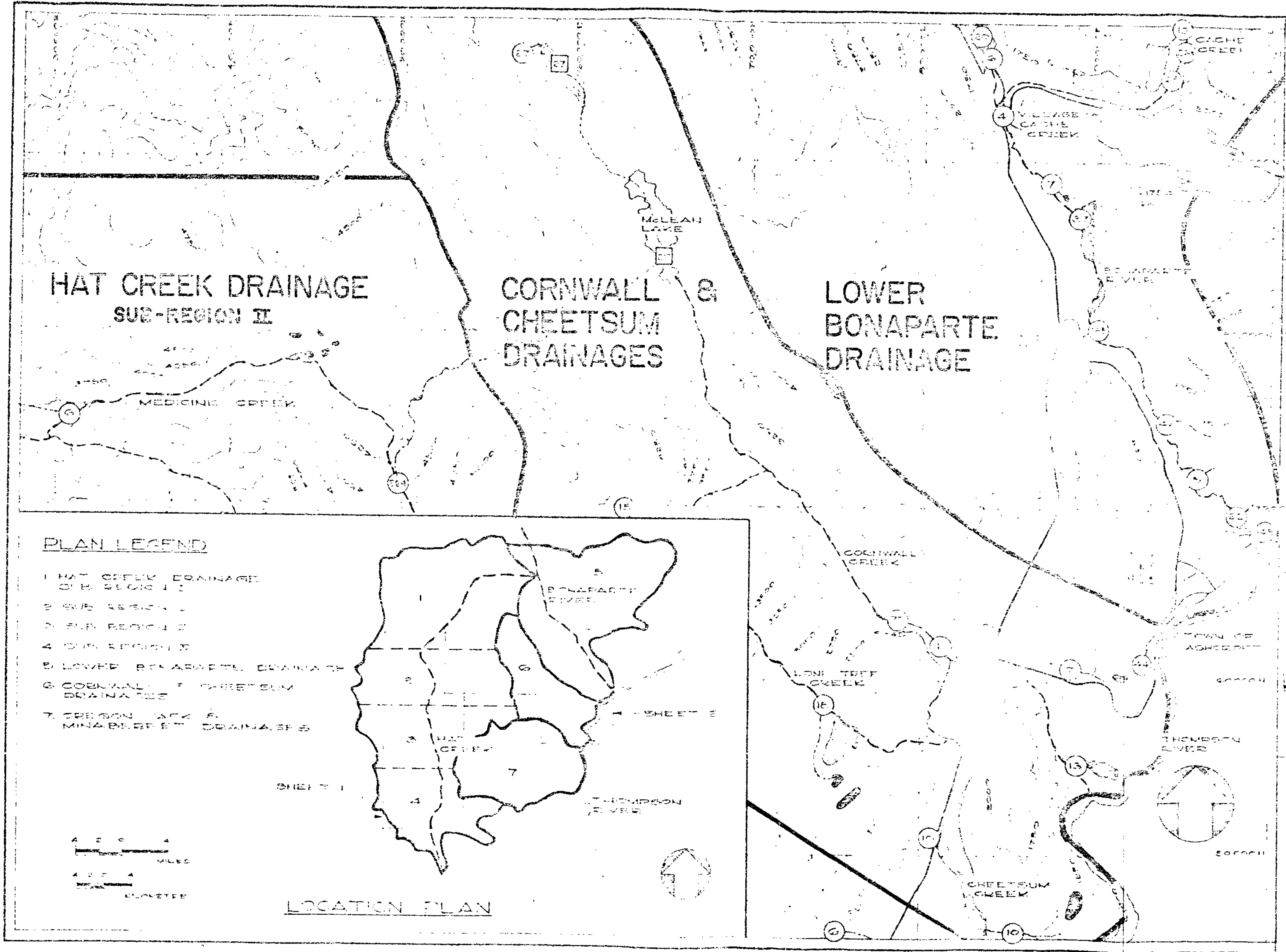
B.C. HYDRO
AND
POWER AUTHORITY

HAT CREEK PROJECT
DETAILED
ENVIRONMENTAL
STUDIES

PRESENT
IRRIGATION
WATER USE

FIG. 4-49
SHEET 1 OF 2

CBRC



B.C. HYDRO AND POWER AUTHORITY

HAT CREEK PROJECT DETAILED ENVIRONMENTAL STUDIES

PRESENT IRRIGATION WATER USE

FIG. 4-49

SHEET 2 OF 2

CBRC

A total of 1050 ha-m of water of the Hat Creek drainage is licenced annually for irrigation use. This amount is distributed between subregions I, II, III, & IV by the amounts of 188 ha-m, 296 ha-m, 288 ha-m, and 278 ha-m respectively.

The major source of water is Hat Creek which is licenced for the diversion of 459 ha-m; Medicine Creek is the next largest source, licenced for 236 ha-m; the remaining 355 ha-m is distributed between 19 other creeks. Four small creeks, Ambusten, Phil, Darough, and Yet are considered by the B.C. Water Rights Branch as being fully licenced.

Of the 1050 ha-m of Hat Creek Valley water licenced for irrigation use, 631 ha-m are licenced for use on land that lies within the Hat Creek drainage basin while 419 ha-m are licenced for use on land that lies outside. There are two major components of the water that is used on land outside the Hat Creek drainage: (1) in subregion II, 224 ha-m is licenced for diversion from Medicine Creek into the Cornwall drainage; and (2) in subregion IV, 158 ha-m are licenced to be diverted from upper Hat Creek to the Oregon Jack drainage. This latter diversion, however, has not been operational for some time.

The area of lands that are licenced for irrigation water use from Hat Creek totals 1698 ha, which consists of 1015 ha within the Hat Creek drainage basin and 683 ha lying outside associated with the water quantities noted above.

In addition to the irrigation licences (primary licences) discussed above, supplemental irrigation licences can be issued for a secondary source to make up the total amount of water of a primary licence when it is not possible to withdraw the complete amount from the primary source. A total of 117 ha-m have been licenced under supplemental licences for points of diversion within the Hat Creek drainage.

Irrigation storage licences for a total of 294 ha-m have been issued for waters originating in the Hat Creek drainage, the largest being the storage of 216 ha-m of water from Medicine Creek in McLean Lake for irrigation use on the benchlands of the Thompson River.

A relatively small amount of water, 42 ha-m, is licenced for storage in Gallagher Lakes, Lloyd Reservoirs, Finney Lake, White Rock Lake, Schneider Swamp, and Park Lakes for use in Hat Creek Valley itself. The remaining amount, 36 ha-m, is licenced for storage in Langley Lake and Oregon Jack Creek Swamp for use outside Hat Creek Valley. However, water is not being diverted to fulfill this latter storage licence due to the disrepair of the diversion ditch.

Bonaparte Drainage (south of Township 23)

A total of 1290 ha-m of the surface waters of the Bonaparte drainage (south of Township 23) is licenced for irrigation use. The major source is the Bonaparte River itself, accounting for 684 ha-m. Cache Creek is the next largest source, accounting for 379 ha-m. One irrigation licence for 148 ha-m is held on the Thompson River. The lands associated with these water licences totals 1246 ha. A total of 75 ha-m of water is under supplemental irrigation licence. Storage is licenced for Semlin Lake and a reservoir on the west fork of Cache Creek in the total amount of 66 ha-m. Licence letails for the lower portion of this area are shown on Figure 4-49 (sheet 2).

Cornwall & Cheetsum Drainages

A total of 125 ha-m of the waters of the Cornwall and Cheetsum (immediately south of Cornwall) drainages is licenced for irrigation use. The major source is Cornwall Creek, accounting for 59 ha-m. The other five sources in this drainage are licenced for between 10 ha-m and 18 ha-m each. The land associated with these licences totals 307 ha. One supplemental irrigation licence is held on waters of Cornwall Creek in the amount of 45 ha-m. Licenced storage totals 97 ha-m and is held in McLean, Fitzellan, Henry, and UK Lakes. Licence details for this area are shown on Figure 4-49 (sheet 2).

Oregon Jack and Minaberriet Drainages

A total of over 148 ha-m of the surface waters of the Oregon Jack and Minaberriet (immediately north of Oregon Jack) drainages is licenced for irrigation use. Oregon Jack Creek is the primary source, accounting for 136 ha-m of the total. The lands associated with these licenced waters totals over 166 ha. A total of 92 ha-m of water is held under supplemental irrigation licence, the source of which is entirely Oregon Jack Creek. Storage is licenced for one pond in the Oregon Jack Creek drainage in the amount of over 68 ha-m.

B. Water Use Model Analysis

The amount of water required for irrigation is a function of climate, soil, crop, and irrigation system characteristics. In general, this amount is made up of two major components: the irrigation requirement of the crop (water used by the plant); and the amount of water that is lost during the conveyance from source to field and during field application (water not available to the plant). The ratio of the irrigation requirement of the crop to the total amount of water used (i.e. diverted from source) represents an irrigation efficiency value for a particular system. For the Hat Creek Valley, both the irrigation requirement of the crop and the irrigation efficiency were determined on a field specific basis to provide a second (to the water licence analysis) estimate of present water use.

Determination of Irrigation Requirement

The following model and associated results (Table 4-24 were developed in the *Agriculture* report[40]. The model is similar to a computer model used by Agriculture Canada in their determination of irrigation requirements for other agricultural areas in British Columbia[42].

$$IR = R\left[(f \cdot PE)-P-SU\right] \text{, not less than zero} \qquad (1)$$

where,

IR represents the irrigation requirement of the crop, expressed as a depth of water;

Determination of Irrigation Requirement

The following model and associated results (Table 4-24) were developed in the *Agriculture* report[40]. The model is similar to a computer model used by Agriculture Canada in their determination of irrigation requirements for other agricultural areas in British Columbia[42].

$$IR = R\left[(f \cdot PE) - P - SU\right], \text{ not less than zero} \qquad (1)$$

where,

IR represents the irrigation requirement of the crop, expressed as a depth of water;

R represents a risk factor, which is a function of the risk of not having enough irrigation water to meet the consumptive needs of the crop. Risk is synonymous with probability, but usually implies a hazard. It is expressed as a cumulative percentage and indicates the number of years out of 100 when the values used are exceeded. When the risk factor is greater than 1, the risk is less than 50 percent.

A reasonable planning risk of not having enough water for the irrigation of hay and pasture, the major crops of the Hat Creek valley, was determined to be 20 percent (i.e., there would be the probability that 20 years out of 100, the calculated seasonal irrigation requirement would be less than the water requirement based on actual climatic conditions). This figure was based on current design specifications[43] and discussion with a B.C. Ministry of Agriculture irrigation specialist regarding actual risks assumed in current farming practices.

The risk factor, R, was obtained by averaging the ratio of irrigation requirements for the desired risk (in this case 20

TABLE 4-24

MONTHLY HAT CREEK VALLEY IRRIGATION MODEL PARAMETERS AND IRRIGATION REQUIREMENT RESULTS

$$IR = R\left[(f \cdot PE) - P - SU\right], \text{ not less than zero} \qquad (1)$$

	April	May	June	July	Aug	Sept	Oct	Total
R	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15
f	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
PE (cm)	3.58	7.70	9.14	11.96	10.24	5.38	0.0	48.0
PE (in)	1.41	3.03	3.60	4.71	4.03	2.12	0.0	18.9
P (cm)	1.63	2.16	3.51	2.90	3.18	2.06	2.51	17.9
P (in)	0.64	0.85	1.38	1.14	1.25	0.81	0.99	7.1
SU								
Hay/Pasture* on Upland Soil (cm)	1.95	1.22	0.04	0.0	0.0	0.0	0.0	3.2
Hay/Pasture* on Upland Soil (in)	0.77	0.48	0.02	0.0	0.0	0.0	0.0	1.27
Hay on Floodplain Soil (cm)	1.95	2.49	0.55	0.25	0.0	0.0	0.0	5.0
Hay on Floodplain Soil (in)	0.77	0.98	0.22	0.10	0.0	0.0	0.0	1.97
IR								
Hay/Pasture* on Upland Soil (cm)	0.0	4.98**	6.43	10.44	8.13	3.84	0.0	33.8
Hay/Pasture* on Upland Soil (in)	0.0	1.96	2.53	4.11	3.20	1.51	0.0	13.3
Hay on Floodplain Soil (cm)	0.0	3.51***	5.84	10.13	8.13	3.84	0.0	31.5
Hay on Floodplain Soil (in)	0.0	1.38	2.30	3.99	3.20	1.51	0.0	12.4

* Assumes that pasture is irrigated the full irrigation season.
** Start of irrigation season calculated to be May 5th.
*** Start of irrigation season calculated to be May 15th.

R represents a risk factor, which is a function of the risk of not having enough irrigation water to meet the consumptive needs of the crop. Risk is synonymous with probability, but usually implies a hazard. It is expressed as a cumulative percentage and indicates the number of years out of 100 when the values used are exceeded. When the risk factor is greater than 1, the risk is less than 50 percent.

A reasonable planning risk of not having enough water for the irrigation of hay and pasture, the major crops of the Hat Creek Valley, was determined to be 20 percent (i.e., there would be the probability that 20 years out of 100, the calculated seasonal irrigation requirement would be less than the water requirement based on actual climatic conditions). This figure was based on current design specifications[43] and discussion with a B.C. Ministry of Agriculture irrigation specialist regarding actual risks assumed in current farming practices.

The risk factor, R, was obtained by averaging the ratio of irrigation requirements for the desired risk (in this case 20 percent) to irrigation requirements for a 50 percent risk, as documented for various surrounding locations by Canada Department of Agriculture computer analyses[42,44,45,46]. The risk factor so obtained was:

$$R = 1.15;$$

f represents a consumptive use factor. This is defined as the ratio of consumptive use of water by a crop to potential evapotranspiration. Consumptive use is defined as the sum of the depths of water transpired by the plants, evaporated from the soil surface, and intercepted precipitation evaporated from plant foliage. Potential evapotranspiration is the maximum quantity of water capable of being lost as water vapor, for a given climate, by a continuous stretch of vegetation covering the whole ground and well supplied with water.

The consumptive use factor, f, is 1.00 for an actively growing crop that completely covers the soil over a large area and that has access to an ample supply of readily available soil water (water that is within the root zone of the crop and that supplies the water requirements of the crop without limitation to transpiration). If the crop area is small or the individual plants are high and spaced in rows so that heat can be carried into the space below the top of the canopy, the consumptive use factor may exceed 1.00. Where plants are short and do not cover the ground so that bare soil is showing, the consumptive use factor is less than 1.00. Maturing crops that are not actively transpiring have a consumptive factor of less than 1.00. Consumptive use factors have been established for a number of crops and climatic conditions[47,48]. The hay and pasture of Hat Creek Valley are representative of crop cover with a consumptive use factor of 1.00.

<u>PE</u> *represents <u>potential evapotranspiration</u>, which is defined as the maximum* quantity of water capable of being lost as water vapor, in a given climate, by a continuous stretch of vegetation covering the whole ground and well supplied with water. It depends only on meteorological conditions.

Potential evapotranspiration was determined by utilizing a formula that is currently used by the Canada Department of Agriculture[42] in estimating irrigation requirements. This formula, which is a modified version of an original regression model proposed by Baier and Robertson[49] is based on energy balance principles and relates daily latent evaporation to meteorological and astronomical variables. This method differs from the less rigorous Thornthwaite method of determining potential evapotranspiration (values reported for the study area in Section 4.1 (b) (i) C).

The Thronthwaite method uses the parameters of mean monthly temperature and length of day, and the assumption of a fixed sharing of the heat budget. It was developed primarily for arriving at an annual consumptive use value for *hydrological studies but is not considered as reliable as some other methods* for calculating specific irrigation requirements for shorter periods[50]. Comparison of results shows that the Baier and Robertson formula is more conservative, i.e., yields higher potential evapotranspiration rates.

The particulars of the formula used for estimating the potential evapotranspiration in the Hat Creek Valley are given below:

$$\begin{aligned} LE = &-53.39 + 0.337\ \text{Max} + 0.531\ \text{Range} + 0.0107\ Q_o \\ &+ 0.0512\ Q_s + 0.0977\ \text{Wind} + 1.77\ (e_w - e_s) \end{aligned} \qquad (2)$$

where,

LE = estimated latent evaporation, in cc/day, as observed from black Bellani plate atmometers.

Estimates of LE (in cc/day) convert to estimates of PE (in inches/day) by a factor of 0.0034 inch/cc.

Max = daily maximum temperature (°F),

Range = difference between daily maximum and minimum temperature (°F),

Q_o = solar energy at the top of the atmosphere, in cal cm^{-2} day^{-1} obtainable from published tables[40].

Q_s = total sky and solar energy on a horizontal surface, in cal cm^{-2} day^{-1}.

Q_s is estimated from the formula:

$$Q_s = Q_o(0.251 + 0.616\ (n/N)) \qquad (3)$$

where,

n = duration of bright sunshine, in hours,

N = length of day, in hours, obtainable from published tables[40].

Wind = total daily wind run, in miles, at 6 feet above the ground. Wind records taken at higher levels were adjusted to the 6-foot height by the formula:

$$U_6 = U_x \frac{\log 6}{\log h_x} \qquad (4)$$

where,

U_6 = wind run at 6-foot height,

U_x = wind run at height (h_x),

h_x = height of anemometer, in feet.

$e_w - e_s$ = Vapor pressure deficit (mb) from saturation vapor pressure at mean air temperature ($\frac{\text{Max} + \text{Min}}{2}$) and mean daily dew-point temperature.

Long-term records of daily extreme temperatures and precipitation are available for many stations, but the corresponding records of daily sunshine, wind run, and dew-point temperature are often missing or incomplete. Special procedures have been developed to use available daily temperature and precipitation records and to estimate daily values of the missing elements in equation (2). An equation relating minimum and maximum temperatures to mean daily dew-point temperature (T_d) was evolved from daily climatological records at eight Canada Department of Agriculture stations across Canada for 1956-57:

$$T_d = -12.58 + 0.52\ \text{Min} + 0.92\ \text{Max} - 0.005\ \text{Max}^2 \tag{5}$$

Monthly values for potential evapotranspiration were derived for the Hat Creek Valley from the above formulae by using specific climatic and physical properties data[50,51.52,53,54]. Climatic variables were assumed to be constant for the valley lowlands, on which all irrigation occurs, though some variation would be expected due to the difference in elevation between the south end of the valley and the north end where Hat Creek joins the Bonaparte River. At the time this derivation was made, climatic information for Hat Creek Valley was limited and did not allow for the possible variation in climate to be taken into account. The monthly values determined for potential evapotranspiration, PE, for the irrigation season are shown on Table 4-24.

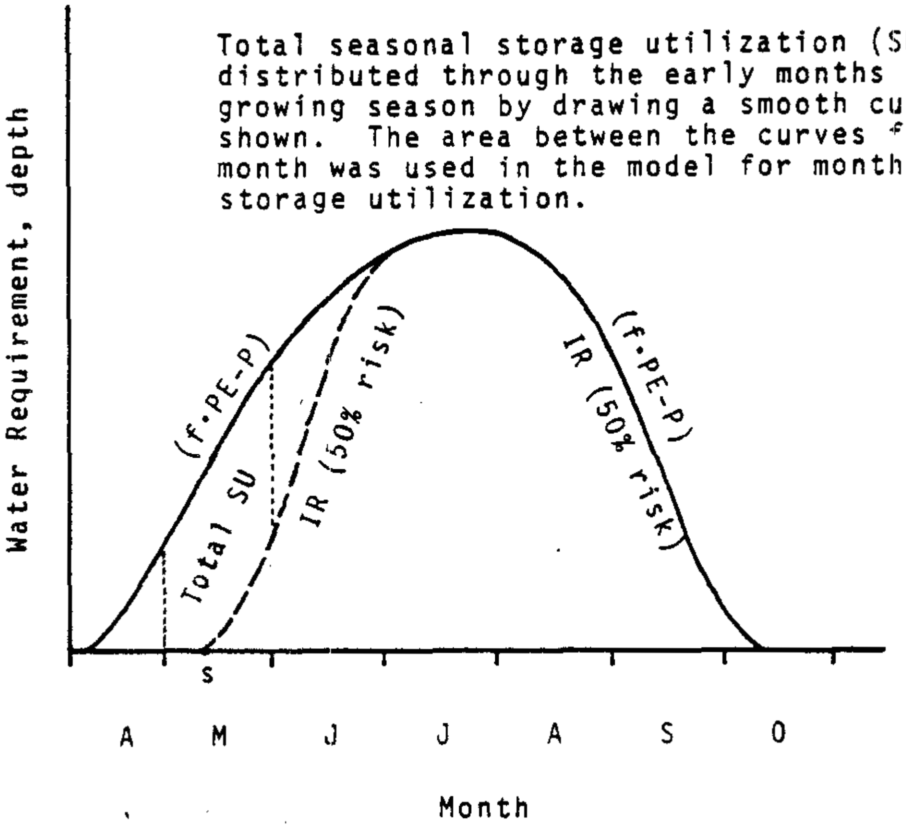
P represents precipitation. Data for average monthly precipitation were obtained from meteorological records of the Atmospheric Environment Service[51] monitoring station, "Hat Creek", and are shown in Table 4-24.

SU represents storage utilization, which is the amount of water stored in the soil at the start of the season that could be utilized efficiently under normal irrigation scheduling.

The amount of storage utilization is a function of the soil texture and crop rooting depth. Based on current irrigation scheduling practices the total seasonal storage utilization would be one-half of the readily available water, which, in turn, for most crop types is 50 percent of the total soil water between field capacity and wilting point (available water storage capacity, AWSC).

For Hat Creek Valley, storage utilization was determined for two dominant soil-crop combinations presently found in the valley: hay on floodplain soils and hay or pasture on upland soils. The value of AWSC for these soil-crop combinations was based on published AWSC values[43] representative of soil textures encountered in typical soil profiles (ground surface to crop rooting depth) of each soil type. The resulting available water storage capacities were 20 cm for the floodplain soils and 12 cm for the upland soils. Seasonal storage utilization was calculated as 5 cm and 3 cm for the floodplain and upland soils respectively.

The seasonal storage utilization (for each of the two soil types) was distributed throughout the early months of the irrigation season by the graphical technique shown in Figure 4-50. The curve for net consumptive use (f·PE-P) is representative of values as given in Table 4-24. The starting date of the irrigation season was calculated to be the date at which there would remain a 15 percent risk (current design value for determining irrigation cycle[43]) of not meeting the irrigation requirements during the first irrigation cycle. This date was determined for each soil type as the number of days of a maximum length cycle before the date at which all readily available water would be depleted if no irrigation water was applied. The calculated irrigation starting dates, May 5 for upland soils and May 15 for floodplain soils, agreed well with field observations of farm practices in Hat Creek.



Total seasonal storage utilization (SU) was distributed through the early months of the growing season by drawing a smooth curve as shown. The area between the curves for each month was used in the model for monthly storage utilization.

point "s" represents the start of the irrigation season.

MONTHLY DISTRIBUTION OF SEASONAL STORAGE UTILIZATION (SU)

FIGURE 4-50

The monthly values of storage utilization for both the floodplain and upland soil types of the Hat Creek Valley are presented in Table 4-24.

The calculated monthly irrigation requirements, IR, for the floodplain and upland soils are given in Table 4-24. The table shows that the irrigation season is from May to September inclusive. The seasonal irrigation requirement of the two soils are 31 cm and 34 cm for the floodplain and upland soils respectively. The floodplain soil type requires less irrigation water in May and June because of their greater storage utilization.

Determination of Irrigation Efficiency

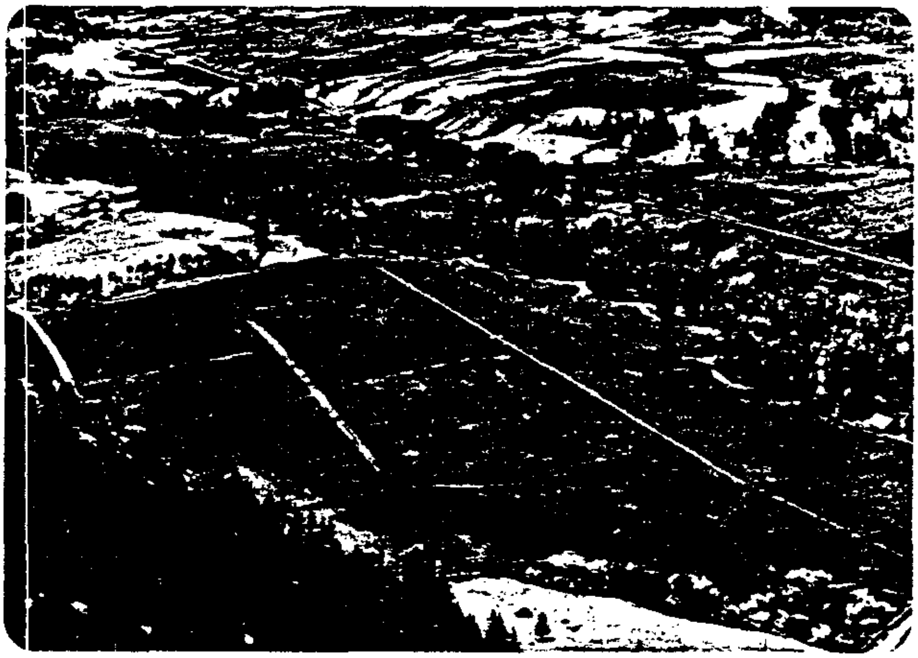
The irrigation requirements in Table 4-24 do not take into account water conveyance losses, spray losses, and deep percolation losses. These water losses are primarily a function of the method of irrigation and type of soil. Two artificial methods of irrigation are used in Hat Creek Valley: sprinkler irrigation; and diversion of creeks via ditches for surface irrigation which is the predominant method. Water needs are supplemented by natural subsurface irrigation on most of the floodplain lands.

Sprinkler system efficiences are reported to range from 60 percent to 80 percent and surface system efficiencies from 40 percent to 80 percent[43,56]. Interpretation of stereo-pair coloured air photos[41] and field observations showed uneven water distribution on many fields, indicating a wide range of actual application efficiencies in Hat Creek Valley. Significant conveyance losses were assumed since, in many cases, creek water is diverted over long distances before reaching the fields to be irrigated. Because of these losses and the irregular topography and shape of many fields, efficiencies used to estimate present water use were chosen on the low end of the theoretical ranges and are shown in Table 4-25.

TABLE 4-25

OVERALL IRRIGATION EFFICIENCIES USED IN THE ESTIMATE OF PRESENT WATER USE, HAT CREEK VALLEY

Soil Type	Application Method	
	Sprinkler	Ditch
Upland	60%	50%
Floodplain	70%	60%



Irregularly shaped fields showing contrast between sprinkler irrigation (foreground) and ditch irrigation (background in the Hat Creek valley.

IRRIGATED LAND FIGURE 4-51

Figure 4-51 is a photograph that illustrates the irregularly shaped fields in Hat Creek Valley and also shows the contrast between sprinkler and ditch irrigation.

Water Use Model Estimates

The quantity of water presently used to irrigate lands within the Hat Creek Valley was estimated by superimposing the irrigation requirements (IR, Table 4-24) developed for each combination of Hat Creek climate, soil and crop type onto the amount of presently irrigated land within each combination. The differentiation of crop type, hay or pasture, on a field specific basis was established by visual interpretation of stereo-pair coloured air photographs[41].

The location of soil type, upland or floodplain, as given in the *Agriculture* report[40] was established by soil survey methods. The water quantity for each combination was adjusted by superimposing the efficiency factor (Table 4-25) accounting for water losses due to method of conveyance, method of application, and deep percolation. The differentiation of method of water application, ditch or sprinkler, on a field specific basis was established by interpretation of coloured air photos[41].

The results (Table 4-26) for both the quantities of land presently irrigated and the estimate of the quantities of water used for irrigation were summarized and reported on the basis of the four subregions defined for the Hat Creek drainage basin (Figure 4-48). The estimate of total water used for irrigation is 679 ha-m (5502 acre-ft) per year. Regions III and IV, which roughly cover the south half of the valley, account for the majority of present irrigation use with a combined total of 746 ha (1843 ac) of irrigated land representing a water quantity of 455 ha-m (3689 acre-ft). Regions I and II are estimated to have 338 ha (838 ac) of irrigated land and associated water quantity of 224 ha-m (1815 acre-ft). Presently irrigated lands are shown in Figure 4-49.

Examination of Table 4-26, shows that the quantity of annual irrigation water is approximately distributed through the irrigation season as follows: May, 14%; June, 19%; July, 31%; August 24%; and September, 12%

TABLE 4 26/1

MODEL ESTIMATE OF AVERAGE IRRIGATION WATER USE IN HAT CREEK VALLEY - PRESENT

TOTAL WATERSHED

Soil Group	Irrigation Method & Crop Type						Total	
	Sprinkler-Hay		Ditch-Hay		Ditch-Pasture			
	Area (ha)	Water Volume (ha-m)	Area (ha)	Water Volume (ha-m)	Area (ha)	Water Volume (ha-m)	Area (ha)	Water Volume (ha-m)
Floodplain Soils	173	77	32	17	-	-	205	94
Upland Soils	98	57	576	389	205	139	879	585
TOTAL	271	134	608	406	205	139	1084	679

Average Seasonal Distribution (ha-m)

May	June	July	August	Sept	Total
96	128	211	165	79	679

TABLE 4-26/2

MODEL ESTIMATE OF AVERAGE IRRIGATION WATER USE IN HAT CREEK VALLEY - PRESENT

SUB-REGION I

Soil Group	Irrigation Method & Crop Type						Total	
	Sprinkler-Hay		Ditch-Hay		Ditch-Pasture			
	Area (ha)	Water Volume (ha-m)	Area (ha)	Water Volume (ha-m)	Area (ha)	Water Volume (ha-m)	Area (ha)	Water Volume (ha-m)
*Upland Soils	-	-	157	107	53	36	210	143

Average Seasonal Distribution (ha-m)

May	June	July	August	Sept	Total
21	27	44	34	17	143

---

* As soils information for this region did not allow a breakdown into floodplain and upland soils; all soils were assumed to be characterized by upland soils.

TABLE 4- 26/3

MODEL ESTIMATE OF AVERAGE IRRIGATION WATER USE IN HAT CREEK VALLEY - PRESENT

SUB-REGION II

Soil Group	Irrigation Method & Crop Type						Total	
	Sprinkler-Hay		Ditch-Hay		Ditch-Pasture			
	Area (ha)	Water Volume (ha-m)	Area (ha)	Water Volume (ha-m)	Area (ha)	Water Volume (ha-m)	Area (ha)	Water Volume (ha-m)
Floodplain Soils	16	7	-	-	-	-	16	7
Upland Soils	18	11	35	23	59	40	112	74
Total	34	18	35	23	59	40	128	81

Average Seasonal Distribution (ha-m)

May	June	July	August	Sept	Total
12	15	25	20	9	81

TABLE 4-26/4

MODEL ESTIMATE OF AVERAGE IRRIGATION WATER USE IN HAT CREEK VALLEY - PRESENT

SUB-REGION III

Soil Group	Irrigation Method & Crop Type						Total	
	Sprinkler-Hay		Ditch-Hay		Ditch-Pasture			
	Area (ha)	Water Volume (ha-m)	Area (ha)	Water Volume (ha-m)	Area (ha)	Water Volume (ha-m)	Area (ha)	Water Volume (ha-m)
Floodplain Soils	157	70	32	17	-	-	189	87
Upland Soils	10	6	271	183	87	59	368	248
TOTAL	167	76	303	200	87	59	557	335

Average Seasonal Distribution (ha-m)

May	June	July	August	Sept	Total
46	63	105	82	39	335

TABLE 4-26/5

MODEL ESTIMATE OF AVERAGE IRRIGATION WATER USE IN HAT CREEK VALLEY - PRESENT

SUB-REGION IV

	Irrigation Method & Crop Type						Total	
	Sprinkler-Hay		Ditch-Hay		Ditch-Pasture			
Soil Group	Area (ha)	Water Volume (ha-m)	Area (ha)	Water Volume (ha-m)	Area (ha)	Water Volume (ha-m)	Area (ha)	Water Volume (ha-m)
Floodplain Soils	-	-	-	-	-	-	-	-
Upland Soils	70	40	113	76	6	4	189	120
TOTAL	70	40	113	76	6	4	189	120

Average Seasonal Distribution (ha-m)

May	June	July	August	Sept	Total
17	23	37	29	14	120

Discussion of Water Use Results

A comparison of water use estimates determined by the two analyses, i.e., the water licence analysis and the water use model analysis, is shown for the Hat Creek Valley by subregion in Table 4-27.

Although, in general, the water quantities defined by water licences would be expected to represent an upper limit of surface water use, (by legal definition), these quantities were not expected to be greatly different from the model prediction of average use. Examination of the summary shows a good correlation between both analyses for both the water quantity and irrigated land quantity results. This close comparison suggests that both analyses provide a reasonable estimate at present irrigation water use in Hat Creek Valley.

Based on the aerial photographs and water licence maps a few small irrigation licences were not being utilized in 1976, at least on the land for which they were issued; as well, a relatively small amount of land, principally in subregion I, was being irrigated in 1976 for which recorded water licences could not be associated. This is probably the main reason for the difference of 45 hectares between the two analyses for subregion I (Table 4-26), although part of this difference would also be made up of subsurface irrigated land which do not have water licences associated with them.

The average rate of water use (water quantity ÷ land quantity) for subregion I is roughly one-third higher for the water licence analysis than the water use model analysis. Although the water quantity result for the water licence analysis is low because it does not account for the irrigation of approximately 45 ha mentioned previously, this is not evident in the results because of a greater opposite effect due to the fact that the model analysis did not take into account the slightly warmer climate during the growing season and therefore higher irrigation requirement in this area. An average application rate of 0.76 m (2.5 ft) for subregion I, which is between the licenced application rates of 0.61 m (2 ft) for the Upper Hat Creek area and 0.91 m (3 ft) for the Bonaparte Valley, would give

TABLE 4- 27

COMPARISON OF WATER USE ESTIMATES
HAT CREEK VALLEY

Subregion	Water Use Estimates Water Licence Analysis Water Quantity, ha-m	Water Use Model Water Quantity, ha-m
I	151	143
II	72	81
III	288	335
IV	120	120
Total	631	679
	Irrigated Land, ha	Irrigated Land, ha
I	165	210
II	128	128
III	538	557
IV	185	189
Total	1016	1084

a better estimate of present water use. Multiplying this rate by the amount of irrigated land in subregion I, 210 ha, gives a value for present irrigation water use of 160 ha-m.

Actual irrigation water use would vary somewhat from year to year depending on management practices, climatic conditions, land ownership change, etc. For example, in a year with much greater than normal spring precipitation, the start of irrigation would be delayed somewhat; and in a year with lower than normal water flows, as has happened in the past due to low snowfall and/or precipitation, the quantity of water normally used in irrigation may just not be available. This latter condition is accentuated in Hat Creek Valley due to the fact that storage of irrigation water is minimal.

(ii) Livestock

The quantity of water presently used by livestock was estimated by multiplying the livestock population, reported to be about 2000 cattle within the Hat Creek drainage basin[40], by an average daily rate of water consumption for a beef animal of 0.033 m^3/day (8.6 U.S. gallons per day) taken from the literature[57]. The total daily consumption, then, was estimated to be 66 m^3/day (17,300 USGPD). During the summer the daily consumption would be greater than this amount and during the winter it would be less.

The estimate of the total annual quantity of water presently used by livestock is $2.4 \times 10^4 m^3$ (6.4 million U.S. gallons). This amount represents approximately 0.4 percent of water presently used for irrigation in the Hat Creek Valley.

In the spring, summer, and fall when cattle are grazing on pasture and rangelands, livestock water is supplied by the creeks, lakes, and many small catchment ponds that exist in the Hat Creek drainage basin. During the wintering period, the source of livestock water is frequently the same as that of the domestic supply to the farm residence.

Estimates of cattle populations were not available for other portions of the study area; however, it is judged that the ratio between livestock water use and irrigation water use for the Bonaparte, Cornwall, and Oregon Jack drainage would not be radically different from that estimated for the Hat Creek drainage.

(iii) Domestic and Municipal

A. Present Use

Hat Creek Valley

The existing population of Upper Hat Creek Valley, south of Highway 12, is approximately 25 persons who are mainly in ranching operations. Lower Hat Creek Valley, to the Bonaparte River, has an estimated population of 85 persons; of these, about 80 reside on two Indian Reserves (I.R. 1 and 2) and about five are involved in ranching operations near the mouth of Hat Creek. Thus, the total population of Hat Creek Valley is estimated at 110 persons.

On the basis of water licence data (See Table D1-1 Appendix D), a total water usage of 84 m^3d^{-1}(22,200 USGPD) is licenced for withdrawal from Hat Creek and its tributaries for domestic and stock watering purposes. 18.2 m^3d^{-1} (4,800 USGPD) of this amount is diverted out of the Hat Creek watershed for use in the Cornwall Creek and Oregon Jack Creek areas.

Within the valley itself, of the 65.8 m^3d^{-1} (17,400 USGPD) licenced, 36.3 m^3d^{-1} (9,600 USGPD) is licenced for withdrawal from Hat Creek and the remainder is licenced for withdrawal from its tributaries. The total licenced for withdrawal from Hat Creek downstream of the proposed mine is 25 m^3d^{-1} (6,600 USGPD). The licenced quantity for use on Indian Reserves Nos. 1 and 2 in Lower Hat Creek Valley is 13.6 m^3d^{-1} (3,600 USGPD).

Downstream Bonaparte and Thompson River

The 1976 population estimates for the downstream communities of Cache Creek and Ashcroft are 1,050 and 2,030 persons respectively. In addition, the rural population not including inhabitants of area Indian Reserves is estimated at 220 persons for the unincorporated areas surrounding these centers. The population of Indian Reserve No. 3 north of Cache Creek is estimated to be 100 persons.

The water licence data indicate a total licenced quantity, for domestic, municipal and industrial purposes, of 9,222 m^3d^{-1} (2,438,800 USGPD) from the Bonaparte River between the junction of Hat Creek and the Thompson River. The total licenced withdrawal in this category for Indian Reserve No. 3 (Bonaparte) is 11.3 m^3d^{-1} (3,000 USGPD) and the total licenced quantity for Cache Creek municipal use is 8,070 m^3d^{-1} (2,133,960 USGPD). The remainder is licenced to many other users in this reach, made up of individual withdrawal rights ranging from 2.3 to 726 m^3d^{-1} (600 to 192,000 USGPD).

The community of Cache Creek presently utilizes an infiltration gallery adjacent to the Bonaparte River and current water system intake capacity is approximately 4,990 m^3d^{-1} (1,300,000 USGPD). Based on this value and present (1976) population, the peak per capita demand rate in Cache Creek is 4.8 m^3d^{-1} (1,260 USGPD) which reflects the peak dry weather requirements. The average daily demand is approximately 0.91 m^3d^{-1} per capita (240 USGPD per capita) or 955 m^3d^{-1}(248,900 USGPD).

The community of Ashcroft presently withdraws its water supply from the Thompson River, downstream of the confluence of the Bonaparte River, via a wet well type intake. The current licenced withdrawal rate is 1,815 m^3d^{-1} (480,000 USGPD); however, summer demand reaches 7,260 m^3d^{-1} (1,920,000 USGPD), which translates to a peak per capita demand rate of 3.6 m^3d^{-1} (950 USGPD) based on 1976 population.[58] The average daily demand is approximately 0.91 m^3d^{-1} per capita (240 USGPD per capita) or 1,847 m^3d^{-1} (488,500 USGPD).

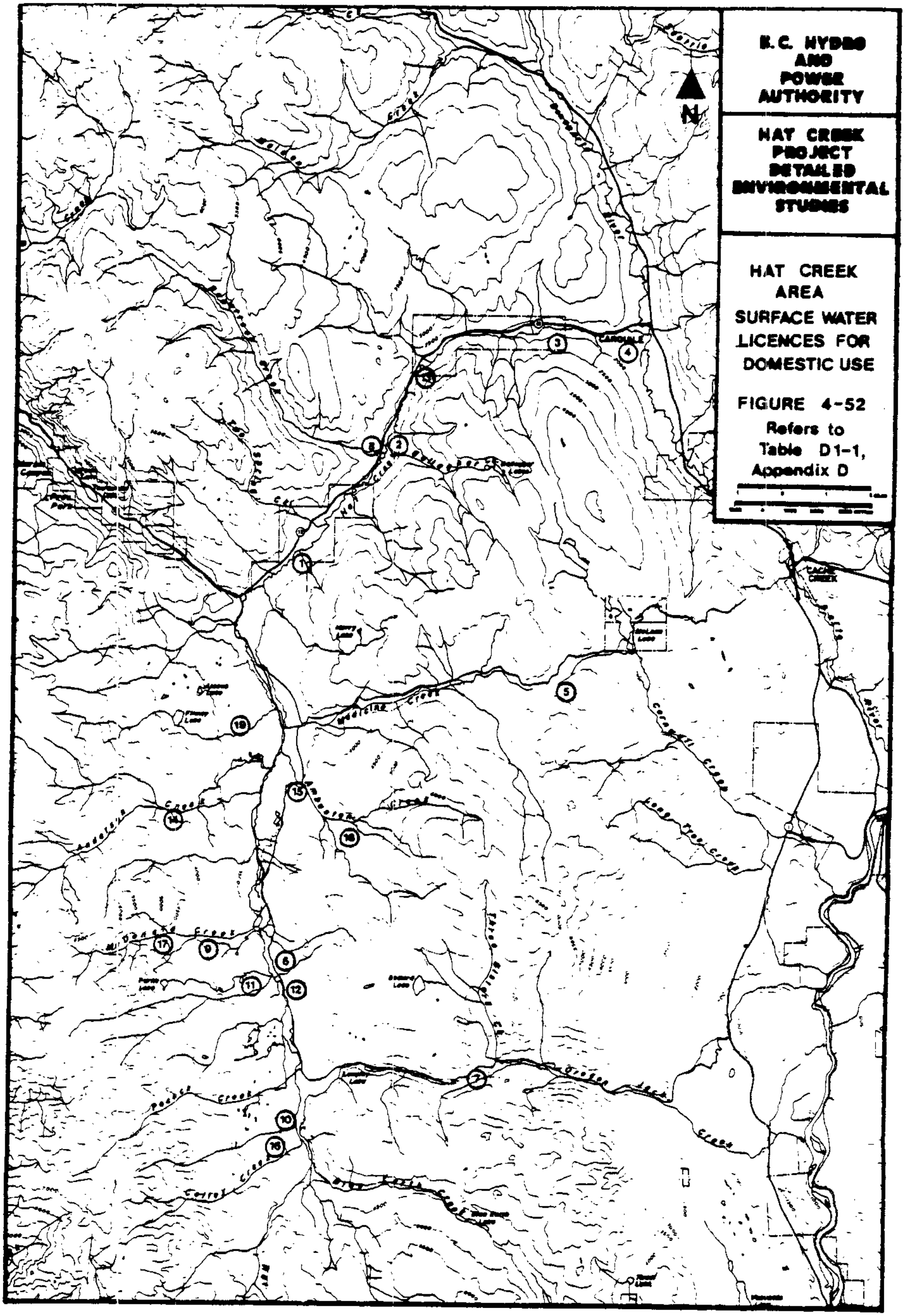
The water licence data for the Thompson River between Wallachin and Lytton B.C. have been reviewed by others.[59] The information derived indicated a licenced quantity for domestic purposes as 477 m^3d^{-1} (126,150 USGPD) excluding Ashcroft's licenced amount. The total quantity licenced or in application status for industrial use including mining totals 86,885 m^3d^{-1} (22,975,000 USGPD). The majority of this industrial demand is for the Lornex mine in the Highland Valley.

Cornwall and Oregon Jack Creek Areas

The current population of the Oregon Jack Indian Reserve is 13 persons and a further 40 persons reside on the Ashcroft Indian Reserves Nos. 1, 2 and 4. It is reported that no people live on the McLean Lake Reserve. The quantity of water licenced for domestic and stock watering purposes in the Cornwall Creek watershed, including domestic water diverted from the Hat Creek basin, is 48.8 m^3d^{-1} (12,900 USGPD). The quantity licenced for industrial use is 12.3 m^3d^{-1} (3,240 USGPD).

The total licenced surface water for domestic and stock watering purposes in the Oregon Jack Creek basin, including surface water from the Hat Creek watershed, is 15.9 m^3d^{-1} (4,200 USGPD).

A summary of the existing domestic water use licences by area is given in Table D1-1 Appendix D, with locations of existing surface water licences in the Hat Creek Valley having possible domestic or municipal water use shown in Figure 4-52.



B.C. HYDRO AND POWER AUTHORITY

HAT CREEK PROJECT DETAILED ENVIRONMENTAL STUDIES

HAT CREEK AREA
SURFACE WATER LICENCES FOR DOMESTIC USE

FIGURE 4-52
Refers to Table D1-1, Appendix D

5.0 PROJECTED RESOURCES WITHOUT THE PROJECT

5.1 HYDROLOGY

(a) Ground Water

The ground water hydrology in the study area has not altered substantially during recent times. Existing data suggest that without the proposed Hat Creek Coal Project, there will be no noticeable hydrogeologic changes in the foreseeable future.

(b) Surface Water

The runoff regime of Hat Creek and its tributaries is stable and would likely remain so without the project. The same applies to the other streams which could be affected by the project. As discussed in Section 5.3, there exists a considerable potential for expansion of irrigation. Some additional irrigation water could be obtained simply by increasing the capacity of existing diversions or by building new diversions, but upstream storage would need to be provided for any large-scale expansion of the irrigated area in the Hat Creek Valley. This, in turn, would reduce spring freshet flows and extend the duration of late summer low flows.

Reactivation of the Oregon Jack Creek diversion is presently under study[1]. It would divert up to 4.5 x $10^6 \cdot m^3$ $year^{-1}$ of water out of Upper Hat Creek for irrigation in the Ashcroft area. There is considerable storage along that diversion route, so that most of the diversion could take place during spring freshet.

The three lakes which would be affected by the project, Finney, Aleece and McLean are also stable and unlikely to undergo significant natural changes during the next few decades. Finney and McLean lakes are presently being used for irrigation storage. This usage could be expanded and intensified by providing increased inflows through new diversions, and by building higher dams and more elaborate outlet works. Aleece Lake could also be converted to a storage reservoir, although the topography is not particularly favourable.

5.2 WATER QUALITY

(a) Ground Water

Unless there is development of other industry or a marked increase in residential dwellings in the Hat Creek Valley, no noticeable change in the water quality of the ground water is anticipated.

(b) Surface Water

The factors most likely to influence surface water quality in the Hat Creek Valley, in the absence of the development of the proposed thermal power station, would be agricultural activities including increased irrigation and fertilization of land and clearing of trees close to the banks of Hat Creek. At present, the phosphorous level compared to the nitrogen level is already high. Any further nutrient additions could possibly result in a marked increase in algal growth in the creek.

Currently, the water quality of Lower Hat Creek, with respect.to temperature during the summer months, is only marginal. Any activity which would tend to cause further increases in temperature would be detrimental.

The projected increase of agriculturally utilized land of almost 100 percent by the year 2000, as discussed in Section 5.3 (b) (i), could have an adverse affect on Hat Creek water quality. Industrial or municipal development is expected to be minimal and therefore have little impact on surface water quality.

5.3 WATER USE

(a) Ground Water

The total consumption of ground water in the Hat Creek Valley is estimated to be about 530 $m^3 \cdot d^{-1}$ and this represents less than 5 percent of the total potential ground water resource in the valley. Most of the present ground water consumption (94 percent) is used to supply wash water for a limestone quarry. Domestic wells use very little ground water and hence unless other industries, municipal subdivisions or perhaps irrigation is developed using ground water in the valley, the future ground water use will remain essentially the same as it is at present.

(b) Surface Water

(i) Irrigation

The projected water use analysis considered two cases, that of maximum potential use and that of probable use. Maximum potential use assumes that the amount of irrigable land is limiting while water quantity and quality are nonlimiting; probable use considers all significant constraints, including the availability of good quality water. Both cases include, as part of the total, lands that are presently irrigated. It should be noted that all water use estimates represent a gross quantity including any amounts that may reenter the surface water system as return flow.

Projected irrigation water use is reported for the Hat Creek drainage on the basis of the same four subregions as in the present use inventory (Figure 4-48). Because less information was available for the Bonaparte, Cornwall and Oregon Jack regions, these were combined for the analysis of projected use.

A. Hat Creek Drainage

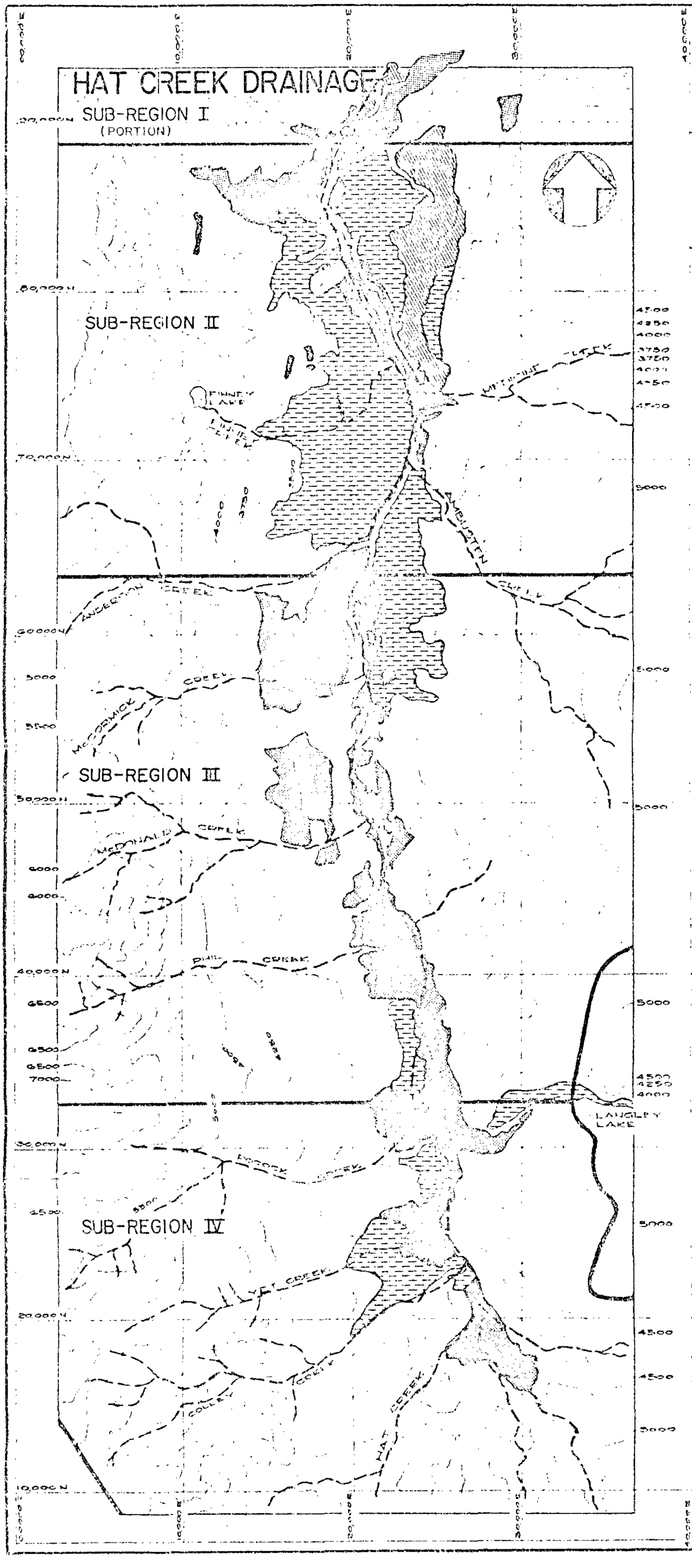
Potential Use

Figure 5-1 shows the location of potentially irrigable lands (i.e., all land areas that would benefit, in a convential agricultural sense, from irrigation) in the Upper Hat Creek Valley and Table 5-1 gives the associated potential water use quantities and land areas.

The areal extent of irrigable lands in Subregions II, III, and IV were measured from the potential use map. The maximum potential water demand for irrigation in these subregions was estimated by the same methodology utilized for the present use case (Water Use Model Analysis, Section 4.3 (b) (i) B) except that potential irrigable lands were substituted in the analysis. Corn, as well as hay and pasture are the crop types considered in potential use. Although the actual water use by corn would be slightly less than hay or pasture during the earlier months of the irrigation season, this difference was not considered significant enough to alter the water specifications provided for pasture and hay. Thus, the annual irrigation requirement and its monthly distribution over the irrigation season were taken to be the same for each of the three crop types considered in potential use.

It was assumed that the irrigation efficiencies of the present use case would represent the future use case as well. Therefore, the overall irrigation efficiencies, for each of the two soil types, implied by the present use analysis were used for the potential use analysis. For upland soils this was 51 percent and for floodplain soils, 69 percent.

For Subregion I, Canada Land Inventory agricultural capability classes 1 - 4 as reported and mapped for the *Agriculture* study[2] were used for the potential use analysis. These lands were measured for areal extent and the potential water use estimated by applying the annual water use rate



B.C. HYDRO AND POWER AUTHORITY

HAT CREEK PROJECT DETAILED ENVIRONMENTAL STUDIES

LOCATION PLAN-
SEE FIG. 4-49
SHEET 2

POTENTIALLY IRRIGABLE LAND

UPPER HAT CREEK

FIG. 5-1

CBRC

TABLE 5-1/1

AVERAGE IRRIGATION WATER USE IN HAT CREEK VALLEY - POTENTIAL

TOTAL WATERSHED

Area (ha)	Water Volume (ha-m)
6033	4164

SEASONAL DISTRIBUTION (ha-m)

May	June	July	August	Sept	Total
594	791	1290	1004	485	4164

TABLE 5-1/2

AVERAGE IRRIGATION WATER USE IN HAT CREEK VALLEY - POTENTIAL

SUBREGION I

Location*	Area (ha)	Water Volume (ha-m)
Lowlands	790	602
Highlands	1440	1098
Total	2230	1700

SEASONAL DISTRIBUTION (ha-m)

May	June	July	August	Sept	Total
238	323	527	408	204	1700

* Soils information for Subregion I was not at the same level of detail as for the rest of Hat Creek valley; the above estimate of potential water use is a rough estimate based on CLI agricultural capability information. CLI classes 1 - 4 represent potential irrigable lands for this subregion. The lowlands are located in the valley bottom and are comparable with the irrigable lands for Subregions II, III, and IV. The highlands are located at the extreme north end of the watershed and do not have a counterpart in the other subregions.

TABLE 5-1/3

AVERAGE IRRIGATION WATER USE IN HAT CREEK VALLEY - POTENTIAL

SUBREGION II

Soil Group	Area (ha)	Water Volume (ha-m)
Floodplain Soils	64	29
Upland Soils	1652	1095
Total	1716	1124

SEASONAL DISTRIBUTION (ha-m)

May	June	July	August	Sept	Total
164	213	347	271	129	1124

TABLE 5-1/4

AVERAGE IRRIGATION WATER USE IN HAT CREEK VALLEY - POTENTIAL

SUBREGION III

Soil Group	Area (ha)	Water Volume (ha-m)
Floodplain Soils	183	84
Upland Soils	1129	748
Total	1312	832

SEASONAL DISTRIBUTION (ha-m)

May	June	July	August	Sept	Total
119	158	258	202	95	832

TABLE 5-1/5

AVERAGE IRRIGATION WATER USE IN HAT CREEK VALLEY - POTENTIAL

SUBREGION IV

Soil Group	Area (ha)	Water Volume (ha-m)
Floodplain Soils	25	11
Upland Soils	750	497
Total	775	508

SEASONAL DISTRIBUTION (ha-m)

May	June	July	August	Sept	Total
73	97	158	123	57	508

of 0.76 m (2.5 ft) determined in the present use analysis. Seasonal distribution of irrigation water in Subregion I was assumed to be the same as in the present use analysis.

It was estimated that 4164 ha-m (33,744 ac ft) would be required to irrigate all of the potentially irrigable lands in Hat Creek Valley, 6033 ha (14,908 ac). This water quantity is approximately six times greater than that presently being used for irrigation in the Hat Creek drainage. The monthly distribution of this water over the irrigation season was estimated to be: May - 594 ha-m; June - 791 ha-m; July - 1290 ha-m; August - 1004 ha-m; and September - 485 ha-m. Potential irrigation water use by subregion was projected to be: Subregion I - 1700 ha-m; Subregion II - 1124 ha-m; Subregion III - 832 ha-m; and Subregion IV - 508 ha-m. The greatest increase over present irrigation water use would be in Subregions I and II where present use represents only about 10 percent of potential.

The probable future use of surface water for irrigation in Hat Creek Valley is dependent on the availability of irrigable land, the availability of suitable water and future socio-economic conditions. Since the constraint of water availability turned out to be very dominant, consideration of future economic conditions was limited to the assumption that they would favor the production of beef cattle as they do at present. Irrigation water therefore, would continue to be used to assist in the production of forage crops.

Land Availability. The availability of irrigable land in the Hat Creek Valley was reported in the previous subsection (Potential Use) and represents all the land that would be considered for irrigation use.

Water Quality. The suitability of potential irrigation water was assessed using water chemistry information reported in Section 4.2(b) and water quality specifications reported in the *Agriculture* assessment[2].

A comparison of water chemistry results and the water quality specifications for irrigation (Table 5-2) shows that most surface water resources in Hat Creek appear to be suitable for irrigation use. Exceptions include the few scattered alkali lakes. The quality of one of these, Goose/Fish Hook Lake, showed high values of pH, electrical conductivity, total dissolved solids, sulphates, and the sodium adsorption ratio, all of which indicate unsuitability for irrigation use.

Water Quantity. The quantity of available irrigation water was based on flow records of hydrometric stations in the valley and the flows in Hat Creek required for the maintenance of the fisheries resource. The conditions of risk under which irrigation developments would proceed were assumed to be the same as used in the present use water model analyses. The risk, 20 percent, indicates that insufficient water would be tolerated not more than 20 years out of 100, thereby requiring corresponding flows having an 80 percent probability of occurrence. The 80 percent flows were interpolated from the hydrograph of the hydrometric station of Hat Creek near Upper Hat Creek shown in Figure 5-2 and these flows reported for the months May through September in Table 5-3. The flow required by the fisheries resource was based on results of the *Fisheries and Benthos* report[6] and is shown in Table 5-3.

Available water for irrigation use was estimated by subtracting the monthly fisheries requirement from the 80 percent probability flows. As shown in Table 5-3 the fisheries requirements during August and September are greater than the existing 80 percent probability flows eliminating the possibility of expansion of present all-season irrigation use without additional storage. Fisheries also require a two week flushing flow of 1.42 $m^3 \cdot s^{-1}$. This requirement can almost be met in the last two weeks in June based on the monthly average 80 percent probability flow quantity of 1.34 $m^3 \cdot s^{-1}$; however, in most years

TABLE 5-2
WATER QUALITY LIMITS FOR IRRIGATION USE IN HAT CREEK VALLEY*****

Item	Maximum
Temperature	55°C at source
pH	4.5* - 9
Electrical Conductivity	2 mmhos/cm @ 25°C
Total Dissolved Solids	1400 mg/l
Suspended Solids	**
Chemical or Biochemical Oxygen Demand	**
Chlorides	15 meq/l
Sulphates	15 meq/l
Sodium Adsorption Ratio	10
Residual Sodium Carbonate	2 meq/l
Radionuclides:	
Alpha Concentration	1 picocurie/l
Beta Concentration	10 picocuries/l
Trace Elements:	
Aluminum	20.0 mg/l
Arsenic	2.0 mg/l
Beryllium	0.5 mg/l
Boron	1.0*** - 2.0**** mg/l
Cadmium	0.05 mg/l
Chromium	1.0 mg/l
Cobalt	5.0 mg/l
Copper	5.0 mg/l
Fluoride	15.0 mg/l
Iron	20.0 mg/l
Lead	10.0 mg/l
Lithium	2.5 mg/l
Manganese	10.0 mg/l
Molybdenum	0.01 mg/l
Nickel	2.0 mg/l
Selenium	0.02 mg/l
Vanadium	1.0 mg/l
Zinc	10.0 mg/l

* Minimum

** Limited information available on maximum limit but literature suggests that high values may leave adverse effects.

*** Semi-tolerant crops including potato, tomato, corn and oat.[10]

**** Tolerant crops including alfalfa, cabbage, lettuce and carrot.[10]

***** From the Agricultural Report - Reference 2.

HAT CREEK NEAR UPPER HAT CREEK STATION 08LF061
MONTHLY MEAN BASIS (1960-1975)

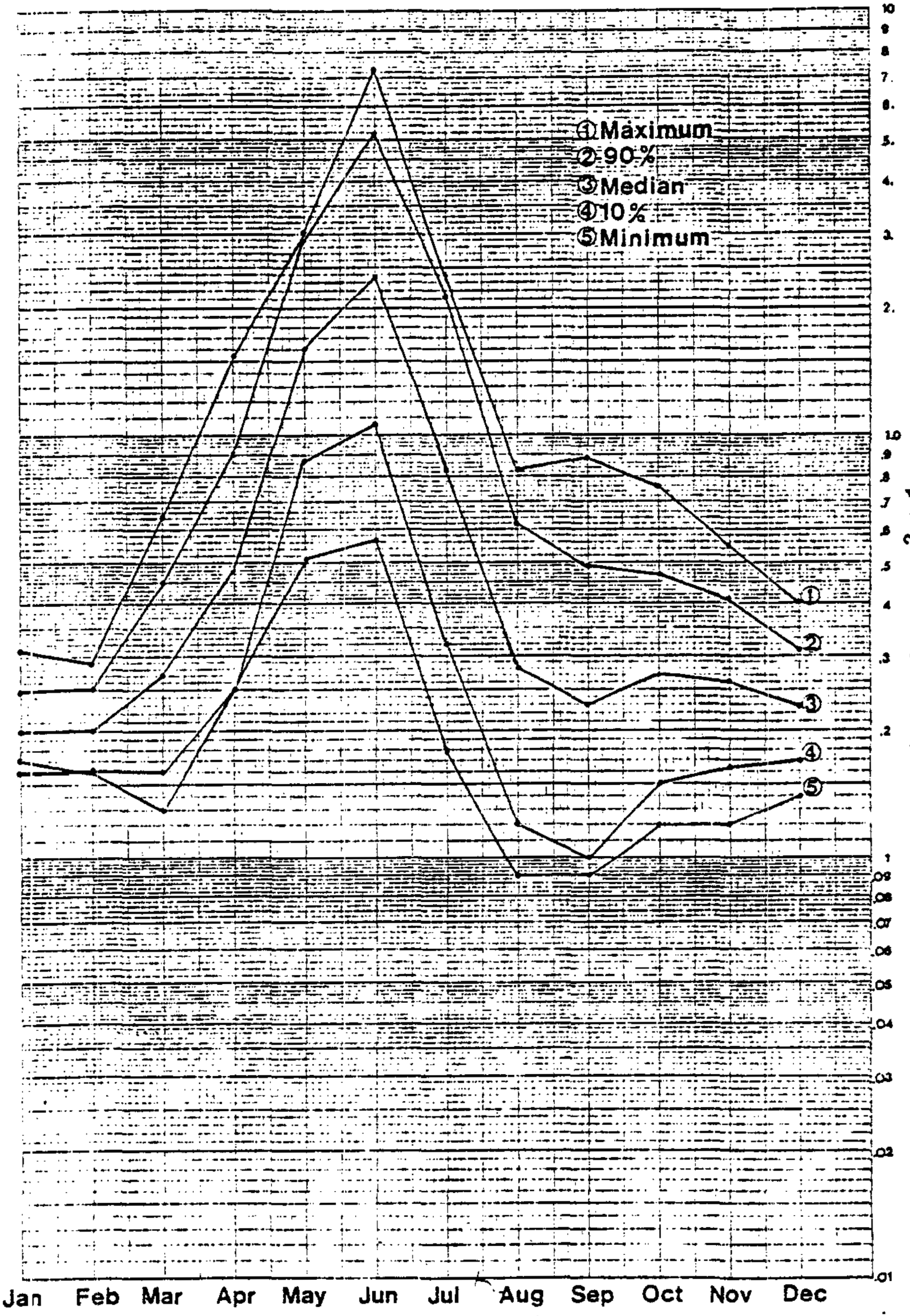


Figure 5-2

TABLE 5-3

HAT CREEK WATER FLOW AVAILABLE FOR EXPANDED AGRICULTURAL USE $(m^3 \cdot s^{-1})$

	May	June		July	Aug	Sept
Existing 80% Probability Flow	1.07	1.34		0.45	0.16	0.13
Subtract Fisheries Minimum Flow Requirement[6]	0.28	1st wk 0.28	2nd wk 1.42	0.28	0.28	0.28
Net Water Available For Agricultural Use	0.79 (212 ha-m)	1.06 (137 ha-m)	NIL	0.17 (44 ha-m)	NIL	NIL

393

this requirement will be well satisfied. Assuming that this placement satisfies the fisheries flushing flow requirement, water is available for expanded agricultural development during May and the first half of June. A similar analysis of the flow hydrographs for Hat Creek near the Bonaparte River support the above conclusions, as the available water quantities were not significantly different.

The maximum amount of water that would be available for storage would approach 1589 ha-m as shown in Table 5-4. This figure was calculated by subtracting the fisheries requirement of Hat Creek from the average annual runoff of the Hat Creek drainage basin (above Carquile).

The feasibility of developing new reservoirs was only briefly assessed. A report by the B.C. Water Investigation Branch[1] indicates that a reservoir near Langley Lake could be developed for storage of up to 691 ha-m (5,600 ac-ft) of Hat Creek water for irrigation with the expectation of a favorable cost-benefit ratio.

In this case, most of this water would probably be used for irrigation of land on the benches of the west side of the Thompson River since these lands are generally of higher agricultural capability than those in the Hat Creek Valley. The feasibility of developing other reservoirs in the Hat Creek drainage basin was not addressed.

Probable Use Results. The superimposition of land availability and water availability was used to project probable future water use in the Hat Creek drainage basin. The *Agriculture* study[2] reports that no additional hay or pasture lands (all-season irrigation) would be expected to be developed in the future due to the lack of available stream water in August and September (Table 5-3). This study[2] further states that water available in spring would probably be used for developing spring pasture and that storage would probably be developed to provide water for corn production on the high capability lands of the valley. Probable water use results are tabulated in Table 5-5.

TABLE 5-4

MAXIMUM WATER AVAILABLE FOR STORAGE, TOTAL HAT CREEK DRAINAGE BASIN

		Volume (ha-m)
Average Net Runoff (~~Table~~ Fig. 4-35)	$25 \times 10^6 m^3$	2500
	This refers to outflow a Creek mouth at Anderson Creek	
Minus Fisheries Requirement[6]		2000
October - March	@ $0.21\ m^3 \cdot s^{-1}$	331
April - September	@ $0.28\ m^3 \cdot s^{-1}$	442
Flushing Flow	@ $1.13\ m^3 \cdot s^{-1}$	138
Remaining Runoff Available for Storage		1589

Where is the map of these

TABLE 5-5/1

AVERAGE IRRIGATION WATER USE IN HAT CREEK VALLEY - PROBABLE

TOTAL WATERSHED

	All Season		Spring Pasture (6 wks)		Total	
Soil Group	Area (ha)	Water Volume (ha-m)	Area (ha)	Water Volume (ha-m)	Area (ha)	Water Volume (ha-m)
Floodplain Soils	205	94	12	1	217	95
Upland Soils	1211	827	506	83	1717	910
Total	1416	921	518	84	1934	1005

SEASONAL DISTRIBUTION (ha-m)

May	June	July	August	Sept	Total
182	207	286	224	106	1005

TABLE 5-5/2

AVERAGE IRRIGATION WATER USE IN HAT CREEK VALLEY - PROBABLE

SUBREGION I

Soil Group	All Season		Spring Pasture (6 wks)		Total	
	Area (ha)	Water Volume (ha-m)	Area (ha)	Water Volume (ha-m)	Area (ha)	Water Volume (ha-m)
Upland Soils*	260	198	105	19	365	217

[illegible]

SEASONAL DISTRIBUTION (ha-m)

May	June	July	August	Sept	Total
39	46	61	48	23	217

* As soils information for this region did not allow a breakdown into floodplain and upland soils; all soils were assumed to be characterized by upland soils.

TABLE 5-5/3

AVERAGE IRRIGATION WATER USE IN HAT CREEK VALLEY - PROBABLE

SUBREGION II

Soil Group	All Season		Spring Pasture (6 wks)		Total	
	Area (ha)	Water Volume (ha-m)	Area (ha)	Water Volume (ha-m)	Area (ha)	Water Volume (ha-m)
Floodplain Soils	16	7	-	-	16	7
Upland Soils	394	261	57	9	451	270
Total	410	268	57	9	467	277

SEASONAL DISTRIBUTION (ha-m)

May	June	July	August	Sept	Total
45	54	83	65	30	277

TABLE 5-5/4

AVERAGE IRRIGATION WATER USE IN HAT CREEK VALLEY - PROBABLE

SUBREGION III

	All Season		Spring Pasture (6 wks)		Total	
Soil Group	Area (ha)	Water Volume (ha-m)	Area (ha)	Water Volume (ha-m)	Area (ha)	Water Volume (ha-m)
Floodplain Soils	189	87	-	-	189	87
Upland Soils	368	248	261	42	629	290
Total	557	335	261	42	818	377

SEASONAL DISTRIBUTION (ha-m)

May	June	July	August	Sept	Total
72	79	105	82	39	377

TABLE 5-5/5

AVERAGE IRRIGATION WATER USE IN HAT CREEK VALLEY - PROBABLE

SUBREGION IV

	All Season		Spring Pasture (6 wks)		Total	
Soil Group	Area (ha)	Water Volume (ha-m)	Area (ha)	Water Volume (ha-m)	Area (ha)	Water Volume (ha-m)
Floodplain Soils	-	-	12	1	12	1
Upland Soils	189	120	83	13	272	133
Total	189	120	95	14	284	134

SEASONAL DISTRIBUTION (ha-m)

May	June	July	August	Sept	Total
26	28	37	29	14	134

It should be noted that any increase in the overall irrigation efficiency in the Hat Creek Valley would allow additional lands to be irrigated without increasing the total amount of water use. This aspect, which has not been quantified, would only affect the distribution of irrigated lands and not water quantity.

The stream water available for irrigation in May and two weeks of June would likely be utilized to irrigate spring pasture lands. This use was assumed to be dependent on existing irrigation facilities and consequently was limited to 518 ha (1280 ac). The associated water use quantity was estimated to be 84 ha-m (681 ac ft) which is about one-quarter of the water available in May and June for irrigation. This amount was calculated from monthly irrigation requirements determined in the water use model analysis (Table 4-24) in the case of spring pasture lands in Subregions II, III, and IV, and the overall irrigation efficiencies reported in the potential use section for floodplain and upland soil types. For spring pasture lands located in Subregion I, monthly irrigation requirements were extracted from the results of the potential use section (Table 5-1). The subregional breakdown of projected water use associated with irrigated spring pasture (Table 5-5) is: Subregion I - 19 ha-m; Subregion II - 9 ha-m; Subregion III - 42 ha-m; and Subregion IV - 14 ha-m. The distribution of spring pastures is much the same as present irrigated lands due to its dependency on existing irrigation facilities.

The *Agriculture* study report[2] further states that besides the all-season hay and pasture land presently under irrigation, that 332 ha of additional land will probably be developed for irrigation of corn. Most of this land lies in Subregion II. Calculations using the water use model specifications for upland soils (Table 4-24) indicate that storage would have to be developed to supply 220 ha-m (1783 ac ft). This amount is about one-third of the maximum storage of the proposed Langley Lake reservoir[1] and roughly 15 percent of the maximum storage availability remaining in the Hat Creek drainage basin after spring pasture irrigation water use is subtracted. Assessment as to the location of a suitable storage facility for this water supply was not carried out.

The total area projected for all-season irrigation within the Hat Creek drainage is 1416 ha (3499 ac). The associated water use is 921 ha-m (7464 ac ft). The distribution of this probable all-season irrigation water use on a subregional basis is: Subregion I - 198 ha-m; Subregion II - 268 ha-m; Subregion III - 335 ha-m; and Subregion IV - 120 ha-m.

The projected probable water use in Hat Creek Valley, including all-season and spring pasture uses, is 1005 ha-m (8144 ac ft). This is roughly one and one-half times present irrigation use. About three-quarters of the additional water would have to be supplied by new storage.

B. Bonaparte, Cornwall, and Oregon Jack Study Areas

Potential Use

The B.C. Ministry of Agriculture (BCMA) has identified 8137 ha (20,107 ac) in the Savona-Cache Creek area as having potential for intensive agricultural production with irrigation[3]. This includes 2405 ha that are presently irrigated. A rough estimate of the amount of irrigable land lying within the water use study areas (Bonaparte, Cornwall, and Oregon Jack drainages), based on the map accompanying the above BCMA analysis, is 4500 ha (11,120 ac). The normal annual water use rate for these areas as per water licencing is 0.91 m (3 ft). This is higher than the other regions within the study area because of the warmer climate. Multiplying the quantity of potentially irrigable land by this rate gives a total potential water use of 4095 ha-m (33,360 ac ft). This quantity of water is about two and one-half times greater than that presently licenced for irrigation use (Section 4.3 (b) (i)A).

Probable Use

The probable use of water without the project for irrigation within the Bonaparte, Cornwall, and Oregon Jack study area was estimated on the basis of additional information contained in the BCMA analysis[3] and results reported in the *Agriculture* assessment report[2]. The former work identified four distinct areas totalling 1257 ha (3106 ac) that because of size and configuration of irrigable land could be practically developed. The latter report judged that three of these areas, totalling 786 ha (1942 ac), were favorably disposed to probable irrigation development because of their proximity to irrigation water supplies. As well, this report[2] identified a further 151 ha (374 ac) of land that would have a good probability of being developed within the life time of the proposed B.C. Hydro project.

Adding the estimate of presently irrigated lands, 1719 ha (4248 ac) (Section 4.3 (b) (i)A) to the 937 ha considered to be most probable for future development, a total quantity of probable use irrigated lands within the study area, then, was estimated to be 2656 ha (6564 ac). The probable water use associated with this quantity of land was estimated by multiplying this quantity of land by the normal annual water use rate for this area of 0.91 m (3 ft), giving a total of 2417 ha-m (19,692 ac ft). This quantity of water is just over 50 percent more than is presently licenced for irrigation use and just about 60 percent of the total potential.

The sources of additional irrigation water to fulfill the requirements of probable use was not assessed in any detail. Some water may still be available for licencing from the Bonaparte and other small creeks of the area but information did not allow quantification of this potential. Water is available from the Thompson River and could be supplied to the irrigable lands, most likely, via a regional irrigation system since the lifts are quite high. Another possibility is development of a reservoir near Langley Lake for storage of Hat Creek water. This proposal has been studied by the B.C. Ministry of the Environment and is discussed further in a previous subsection (Hat Creek Drainage).

(ii) Livestock

The quantity of livestock water use projected without the project was based on the probable livestock population reported in the *Agriculture* assessment[2]. By the year 1996, the cattle population supported in the Hat Creek drainage basin was projected to be 3360 animals. Multiplying this number by the average daily rate of water consumption for a beef animal of 0.033 $m^3 \cdot d^{-1}$ (8.6 USGPD)[4], gives a daily livestock water consumption of about 111 $m^3 \cdot d^{-1}$ (29,318 USGPD). Annually, this is $4.1 \times 10^4 m^3$ (4.1 ha-m) (10.7 million U.S. gallons) which is about 0.4 percent of the irrigation water use projected for the Hat Ceek Valley. This is approximately 70 percent more than is estimated as being used by livestock at present in the Hat Creek drainage basin.

The source of livestock water within the length of projected future use would be the same as at present (see Section 4.3(b)(ii)).

Estimates of future cattle populations in the other portions of the study area were not available. However, it is expected that the proportion of livestock water use to irrigation water use would not be radically different from that projected for the Hat Creek Valley.

(iii) Domestic and Municipal

Potential Use

The population to 1990 in the Hat Creek Valley, excluding the Indian Reserves, is expected to remain unchanged or to show negligible increase. Thus the potential domestic use without the Hat Creek Project will approximate the existing use. The projected changes in population of the various Indian Reserves, based on the trend from 1965 to 1975, are negligible to slight decreases.

POPULATION TREND - INDIAN RESERVES[7]

Year	Bonaparte Reserves	Ashcroft Reserves
1965	203	46
1970	170	37
1975	179	41

The only significant anticipated increase in water demand for municipal purposes will be for the communities of Cache Creek and Ashcroft.

The projected populations of Cache Creek and Ashcroft for year 1990 are 1,595 and 3,035 persons respectively, as shown below:

ASHCROFT AND CACHE CREEK POPULATION ESTIMATES AND PROJECTIONS WITHOUT HAT CREEK PROJECT[8]

Year	Ashcroft	Cache Creek
1976	2,030	1,050
1980	2,455	1,205
1986	2,685	1,355
1990	3,035	1,595

Based on present peak municipal per capita demands in these centers the projected potential water use rate for 1990 will be 7,580 $m^3 \cdot d^{-1}$ (2,005,200 USGPD) for Cache Creek and 10,854 $m^3 \cdot d^{-1}$ (2,870,400 USGPD) for Ashcroft. The average daily demands based on 0.910 $m^3 \cdot d^{-1}$ per capita (240 USGPD per capita) would be 1,451 $m^3 \cdot d^{-1}$ (384,000 USGPD) for Cache Creek and 2,760 $m^3 \cdot d^{-1}$ (730,400 USGPD) for Ashcroft.

No major industrial plants which would have significant surface water use are anticipated in either of these centres to 1990[9].

REFERENCES

SECTION 3

1. Duffel, S., and McTaggart, K.C. 1951. Ashcroft map - area B.C. memoir 262 Geol. Surv. Canada (including map No. 1010A).

2. Ryder, J.M., 1976. Terrain inventory and quaternary geology Ashcroft, B.C. Paper 74-49, Geol. Surv. Canada.

3. Church, B.N., 1977. Geology of Hat Creek Coal Basin. Geology of British Columbia, 1975. B.C. Ministry of Mines and Petroleum Resources, p. 99-118.

4. McCullough, P.T., 1977. Mapping of limestone north of Houth Meadows. British Columbia Hydro and Power Authority Report unpublished, 29 pp.

5. Golder Associates Ltd., 1977. Hat Creek geotechnical study; volume one of unpublished final report (No. 6) submitted to British Columbia Hydro and Power Authority.

6. Environment Canada, 1976. Climatological Station Data Catalogue - British Columbia, Atmospheric Environment Service.

7. British Columbia Water Investigations Branch, Water Resources Service; 1975, Snow Survey Measurements Summary 1935-1975. Department of Lands, Forests and Water Resources.

8. Water Survey of Canada. 1974. Historical Streamflow Summary, British Columbia to 1973. Inland Waters Directorate, Environment Canada, Ottawa.

9. Water Survey of Canada. Surface Water Data, Reference Index, 1975, Inland Waters Directorate, Environment Canada, Ottawa, 1975.

10. B.C. Water Rights Branch, Victoria, B.C. 1976. Water Rights Maps and list of licence details, map sheets at 20-chain scale: 321, 322, 323, 325, 326, 361, 362, 363, 364 & 365.

11. B.C. Water Rights Branch, Victoria, B.C. 1978. Water Rights Maps and list of licence details, map sheets at 20-chain scale: 311, 320, 328, 328A, 362, 363, 363A, & 364.

12. Canadian Bio Resources Consultants Ltd. 1978. Agriculture Assessment - Hat Creek Detailed Environmental Studies.

13. McElhanney Surveying & Engineering Ltd. September, 1976. Coloured air photographs, Roll MA 1045.

14. Beak Consultants Limited. 1978. Fisheries and Benthos Assessment - Hat Creek Detailed Environmental Studies.

15. B.C. Water Investigation Branch, Ministry of the Environment. June, 1977. Preliminary Feasibility Study for Oregon Jack Creek Irrigation Proposals.

16. B.C. Ministry of Agriculture, Kamloops office. March, 1977. Savona-Cache Creek - Basque Irrigation Development Study.

17. Midwest Plan Service. 1975. Structures and Environment Handbook, Seventh Edition, p. 379.

18. B.C. Water Rights Branch, Kamloops, B.C. List of Surface Water Licences for Hat Creek, Bonaparte River.

19. Personal Communication. Strong, Hall & Associates, January 1978.

20. Personal Communication. Urban Systems Ltd., January 1977, March 1978.

21. Steel, E.N. 1960. Water Supply and Sewerage. McGraw-Hill Book Company, Inc.

22. Fair, Geyer and Okun. 1966. Water and Wastewater Engineering. John Willy & Sons, Inc.

23. Cakin, R.A., 1975. The origin of goundwater, Mayne Island, British Columbia; unpublished, MSc Thesis, University of Waterloo, Ontario, 204 p .

24. Simard, G., 1977. Carbon-14 and tritium measurements of groundwaters in the Eaton River Basin and in the Mirabel area, Quebec; Canadian Journal of Earth Sciences, Vol. 14 p. 2325-2338.

25. Church, M. and Kellerhals, R., 1970. Stream Gauging Techniques for Remote Areas Using Portable Equipment, Technical Bulletin No. 25, Inland Waters Branch, Department of Energy, Mines and Resource, Ottawa, Canada. (Now: Inland Waters Directorate, Environment Canada).

26. Hem, J.D. 1962. Study and Interpretation of the Chemical Characteristics of Natural Water, U.S. Geological Survey Water Supply Paper 1473.

27. Oguss E. and Erlebach W.E. 1976. Limitations of Single Water Samples In Representing Mean Water Quality, Technical Bulletin No. 95, Inland Waters Directorate, Pacific and Yukon Region, Water Quality Branch.

28. Livingstone, 1963. Data of Geochemistry, Sixth Edition, Chapter G, Chemical Composition of Rivers and Lakes, U.S. Geological Survey Professional Paper 440-G.

29. Ciaccio, L.L. 1973. Water and Water Pollution Handbook, Vol. 3, Marcel Dekker Inc., New York, N.Y.

30. Anon., January, 1978. Brief presented by the Mining Association of British Columbia to the Public Inquiry Into Pollution Control Objectives for Mining, Mine-Milling, and Smelting Industries of British Columbia.

31. Anon. December 1973. Pollution Control Objectives for Mining, Mine-Milling, and Smelting Industries of British Columbia.

32. Lee G.F. and Mariani, G.M. 1977. Special Technical Publication 634, pp. 196-213, American Society for Testing and Materials, Philadelphia, Pa.

SECTION 4

1. Ryder, J.M. 1976. Terrain Inventory of Quarternary Geology, Ashcroft, British Columbia, Geological Survey of Canada, Paper 74-79.

2. Golder Associates Ltd., 1977. Hat Creek Geotechnical study; volume one of unpublished final report (No. 6) submitted to British Columbia Hydro and Power Authority.

3. McCullough, P.T. 1977. Mapping of limestone north of Houth Meadows; unpublished, British Columbia Hydro and Power Authority report 29 p.

4. Piper, A.M. 1944. A graphic procedure in the geochemical interpretation of water analysis; Trans. Amer. Geophys. Union. Vol 25, p. 914-923.

5. Schoeller, H. 1959. Geochemistry of groundwater; Chapter IV in Arid Zone Hydrology, Unesco.

6. Northwest Hydraulic Consultants Ltd. 1976. Hat Creek Water Supply, Hydrology, Interim Report. Prepared for Sandwell and Company Limited.

7. Holland, Stuart S. 1976. Landforms of British Columbia: a Physiographic Outline, British Columbia Department of Mines and Petroleum Resources, Bull. 48. Victoria.

8. Kendriew, G.W. and Kerr, D. 1955. The Climate of British Columbia and the Yukon Territory, Queen's Printer, Ottawa.

9. Neill, C.R. et al, 1970. Selected Characteristics of Streamflow in Alberta. Research Council of Alberta. River Engineering and Surface Hydrology Report 70-1.

10. Environment Canada. 1975. Surface Water Data, Reference Index, 1975. Water Survey of Canada. Inland Waters Directorate, Ottawa.

11. Environment Canada. 1974. Historical Streamflow Summary, British Columbia to 1973. Water Survey of Canada, Inland Waters Directorate, Ottawa.

12. Bjerring, James H. and Seagraves, Paul. June 1974. UBC TRIP, Triangular Regression Package. The University of British Columbia, Vancouver, B.C.

13. Thornthwaite, C.W. nad Mather, R.R. 1955. The Water Balance, Publications in Climatology, Drexel Inst. of Technology, Laboratory of Climatology, Vol. 8, 86 p.

14. Phillips, David W. 1976. Monthly Water Balance Tabulations for Climatological Stations in Canada, Atmospheric Environment Service, Publication DS #4-76.

15. Kellerhals, R., Church, M., and Bray, D.I. July 1976. Classification and Analysis of River Processes, American Society of Civil Engineering, Journal of the Hydraulic Division, Vol. 102, No. HY7.

16. Ministry of the Environment. March 1977. Aquatic Systems Inventory and Analysis, Report prepared by Resource Analysis Branch, Victoria, B.C.

17. Cotton F.A. and Wilkinson, G. 1962. Advanced Inorganic Chemistry, Interscience, New York, N.Y.

18. Busch, W. Zeitsohr. 1927. Anorg. Chem., V. 161.

19. Hem, J.D. 1962. Study and Interpretation of the Chemical Characteristics of Natural Water, U.S. Geological Survey Water Supply Paper 1473.

20. Goldschmidt, V.M. 1937. J. Chem. Soc., 655.

21. Standard Methods for the Examination of Water and Wastewater. 1971. 13th Edition, American Public Health Association, et al., Washington, D.C.

22. McKee J.E. and Wolf, H.W. 1963. Water Quality Criteria. The Resource Agency of California, State Water Resources Control Board.

23. Rankama K. and Sahama, T.G. 1950. Geochemistry. Chicago University Press, Chicago, Illinois.

24. Smith R.L. 1966. Ecology and Field Biology, Harper and Row.

25. Lange, N.A. 1967. Handbook of Chemistry, McGraw Hill.

26. Kelley, W.P. 1948. *Cation Exchange In Soils. Reinhold Publishing* Corp.

27. Scofield C.S. and Wilcox, L.V. 1931. Boron In Irrigation Water. U.S. Department of Agriculture Tech. Bull. 264.

28. Eaton, F.M. 1935. Boron In Soils and Irrigation Waters and Its Effects on Plants. U.S. Department of Agriculture Tech. Bull. 448.

29. Cedarstrom, D.J. 1945. Geology and Groundwater Resources of the Coastal Plain in Southeastern Virginia. Virginia Geol. Survey Bull. 63.

30. Anon. 1971. Water Quality Criteria. Second Edition. California State Water Resources Control Board.

31. Klein, L. 1962. River Pollution, Vol. II Causes and Effects, Butterworths, London.

32. Condon, E.V. and Odishaw, H. 1967. Handbook of Physics, McGraw Hill, New York, N.Y.

33. Byrkit, D.R. 1972. Elements of Statistics, D. Van Nostrand Company.

34. Burnson, B. 1938. J.A.W.W.A., 30, 793.

35. Arnold, G.E. 1935. J.A.W.W.A., 27, 1968.

36. Anon. 1972. Report of the Committee on Water Quality Criteria, Federal Water Pollution Control Administration.

37. Livingstone, D.A. 1963. *Data of Geochemistry, Sixth Edition, Chapter* G, Chemical Composition of Rivers and Lakes, Geological Survey Paper 440-G.

38. McGauley, P.H. 1968. Engineering Management of Water Quality, McGraw Hill, New York, N.Y.

39. Anon. 1976. Hat Creek Water Supply, Hydrology (Interim Report), Northwest Hydraulic Consultants Ltd.

40. Canadian Bio Resources Consultants Ltd. 1978. Agriculture Assessment - Hat Creek Detailed Environmental Studies.

41. McElhanney Surveying & Engineering Ltd. September, 1976. Coloured air photographs, Roll MA 1045.

42. Canada Department of Agriculture. 1968. Tech. Bull. 69. A Computer Program for Estimating Risks of Irrigation Requirements from Climatic Data.

43. B.C. Department of Agriculture. 1975. Irrigation Design Manual.

44. Agrometeorology Section, Canada Department of Agriculture. August 1968. Tech. Bull. 54, Risk Analyses of Weekly Climatic Data for Agricultural and Irrigation Planning, Kamloops, B.C.

45. Agrometeorology Section, Canada Department of Agriculture. April 1969. Tech. Bull. 76, Risk Analyses of Weekly Climatic Data for Agricultural and Irrigation Planning, Princeton, B.C.

46. Agrometeorology Section, Canada Department of Agriculture. August 1968. Tech. Bull. 57, Risk Analyses of Weekly Climatic Data for Agricultural and Irrigation Planning, Summerland, B.C.

47. Blaney, H.F., and W.D. Criddle. 1966. Determining consumptive use for planning water developments, p. 1-34. In Methods for estimating evapotranspiration. Irrigation and Drainage Speciality Conference, Las Vegas, Nev. 1966. Amer. Soc. Civil Eng., United Engineering Center, New York.

48. Hobbs, E.H., and K.K. Krogman. Observed and estimated evapotranspiration in Southern Alberta. Trans. Am. Soc. Agr. Eng. In press.

49. Baier, W., and Geo. W. Robertson, 1965. Estimation of Latent Evaporation From Simple Weather Observations. Can. J. Plant Sci. 45: 278-284.

50. Canadian National Committee for the International Hydrologic Decade. September 1966. Familiarization Seminar on Principles of Hydrology.

51. Atmospheric Environment Service. Undated. Temperature and Precipitation 1941-1970 British Columbia.

52. Canada Department of Transport. 1968. Climatic Normals, Volume 3, Sunshine, Cloud, Pressure and Thunderstorms.

53. Meteorological Branch, Canada Department of Transport. 1968. Climatic Normals, Volume 5, Wind.

54. Combustion Engineering, Inc. 1967. Steam Tables, Properties of Saturated and Superheated Steam.

55. B.C. Water Rights Branch, Victoria, B.C. 1976. Water Rights Maps and Lists of licence details, map sheets at 20-chain scale: 321, 322, 323, 325, 326, 361, 362, 363, 364 and 365.

56. Israelsen, O.W. and Hansen, V.E. 1962. Irrigation Principles and Practices. 447 pp.

57. Midwest Plan Service. 1975. Structures and Environment Handbook, Seventh Edition, p. 379.

58. Personal Communication, Strong Hall & Associates. January 1978.

59. Integ-Ebasco, Hat Creek Project-Site Evaluation Study. October 1976.

60. Beak Consultants Limited. December, 1977. Suspended Sediment Characteristics of the Thompson River and Effects of Algae Growth on Hat Creek Water Supply Systems. Prepared for Sandwell and Company Limited.

61. Environmental Protection Agency. September, 1977. Multimedia Levels - Mercury. Office of Toxic Substances. EPA 560/6-77-031. Washington, D.C.

SECTION 5

1. B.C. Water Investigations Branch, Ministry of the Environment. June 1977. Preliminary Feasibility Study for Oregon Jack Creek Irrigation Proposals.

2. Canadian Bio Resources Consultants Ltd. 1978. Agriculture Assessment - Hat Creek Detailed Environmental Studies.

3. B.C. Ministry of Agriculture, Kamloops Office. March 1977. Savona-Cache Creek-Basque Irrigation Development Study.

4. Midwest Plan Service. 1975. Structures and Environment Handbook, Seventh Edition. p. 379.

5. Water Survey of Canada. 1974. Historical Streamflow Summary, British Columbia to 1973. Inland Waters Directorate, Environment Canada, Ottawa.

6. Beak Consultants Limited. 1978. Fisheries and Benthos Assessment - Hat Creek Detailed Environmental Studies.

7. Personal Communication. July 1977. Strong, Hall & Associates.

8. Personal Communication. December 1977. Strong, Hall & Associates.

9. Personal Communication. December 1976. Strong, Hall & Associates.

10. U.S. Environmental Protection Agency. 1973. Water Quality Criteria 1972. EPA.R3.73.003.

POPULATION TREND - INDIAN RESERVES[7]

Year	Bonaparte Reserves	Ashcroft Reserves
1965	203	46
1970	170	37
1975	179	41

The only significant anticipated increase in water demand for municipal purposes will be for the communities of Cache Creek and Ashcroft.

The projected populations of Cache Creek and Ashcroft for year 1990 are 1,595 and 3,035 persons respectively, as shown below:

ASHCROFT AND CACHE CREEK POPULATION ESTIMATES AND PROJECTIONS WITHOUT HAT CREEK PROJECT[8]

Year	Ashcroft	Cache Creek
1976	2,030	1,050
1980	2,455	1,205
1986	2,685	1,355
1990	3,035	1,595

Based on present peak municipal per capita demands in these centers the projected potential water use rate for 1990 will be 7,580 $m^3 \cdot d^{-1}$ (2,005,200 USGPD) for Cache Creek and 10,854 $m^3 \cdot d^{-1}$ (2,870,400 USGPD) for Ashcroft. The average daily demands based on 0.910 $m^3 \cdot d^{-1}$ per capita (240 USGPD per capita) would be 1,451 $m^3 \cdot d^{-1}$ (384,000 USGPD) for Cache Creek and 2,760 $m^3 \cdot d^{-1}$ (730,400 USGPD) for Ashcroft.

No major industrial plants which would have significant surface water use are articipated in either of these centres to 1990[9].

REFERENCES

SECTION 3

1. Duffel, S., and McTaggart, K.C. 1951. Ashcroft map - area B.C. memoir 262 Geol. Surv. Canada (including map No. 1010A).

2. Ryder, J.M., 1976. Terrain inventory and quaternary geology Ashcroft, B.C. Paper 74-49, Geol. Surv. Canada.

3. Church, B.N., 1977. Geology of Hat Creek Coal Basin. Geology of British Columbia, 1975. B.C. Ministry of Mines and Petroleum Resources, p. 99-118.

4. McCullough, P.T., 1977. Mapping of limestone north of Houth Meadows. British Columbia Hydro and Power Authority Report unpublished, 29 pp.

5. Golder Associates Ltd., 1977. Hat Creek geotechnical study; volume one of unpublished final report (No. 6) submitted to British Columbia Hydro and Power Authority.

6. Environment Canada, 1976. Climatological Station Data Catalogue - British Columbia, Atmospheric Environment Service.

7. British Columbia Water Investigations Branch, Water Resources Service; 1975, Snow Survey Measurements Summary 1935-1975. Department of Lands, Forests and Water Resources.

8. Water Survey of Canada. 1974. Historical Streamflow Summary, British Columbia to 1973. Inland Waters Directorate, Environment Canada, Ottawa.

9. Water Survey of Canada. Surface Water Data, Reference Index, 1975, Inland Waters Directorate, Environment Canada, Ottawa, 1975.

10. B.C. Water Rights Branch, Victoria, B.C. 1976. Water Rights Maps and list of licence details, map sheets at 20-chain scale: 321, 322, 323, 325, 326, 361, 362, 363, 364 & 365.

11. B.C. Water Rights Branch, Victoria, B.C. 1978. Water Rights Maps and list of licence details, map sheets at 20-chain scale: 311, 320, 328, 328A, 362, 363, 363A, & 364.

12. Canadian Bio Resources Consultants Ltd. 1978. Agriculture Assessment - Hat Creek Detailed Environmental Studies.

13. McElhanney Surveying & Engineering Ltd. September, 1976. Coloured air photographs, Roll MA 1045.

14. Beak Consultants Limited. 1978. Fisheries and Benthos Assessment - Hat Creek Detailed Environmental Studies.

15. B.C. Water Investigation Branch, Ministry of the Environment. June, 1977. Preliminary Feasibility Study for Oregon Jack Creek Irrigation Proposals.

16. B.C. Ministry of Agriculture, Kamloops office. March, 1977. Savona-Cache Creek - Basque Irrigation Development Study.

17. Midwest Plan Service. 1975. Structures and Environment Handbook, Seventh Edition, p. 379.

18. B.C. Water Rights Branch, Kamloops, B.C. List of Surface Water Licences for Hat Creek, Bonaparte River.

19. Personal Communication. Strong, Hall & Associates, January 1978.

20. Personal Communication. Urban Systems Ltd., January 1977, March 1978.

21. Steel, E.N. 1960. Water Supply and Sewerage. McGraw-Hill Book Company, Inc.

22. Fair, Geyer and Okun. 1966. Water and Wastewater Engineering. John Willy & Sons, Inc.

23. Dakin, R.A., 1975. The origin of goundwater, Mayne Island, British Columbia; unpublished, MSc Thesis, University of Waterloo, Ontario, 204 p .

24. Simard, G., 1977. Carbon-14 and tritium measurements of groundwaters in the Eaton River Basin and in the Mirabel area, Quebec; Canadian Journal of Earth Sciences, Vol. 14 p. 2325-2338.

25. Church, M. and Kellerhals, R., 1970. Stream Gauging Techniques for Remote Areas Using Portable Equipment, Technical Bulletin No. 25, Inland Waters Branch, Department of Energy, Mines and Resource, Ottawa, Canada. (Now: Inland Waters Directorate, Environment Canada).

26. Hem, J.D. 1962. Study and Interpretation of the Chemical Characteristics of Natural Water, U.S. Geological Survey Water Supply Paper 1473.

27. Oguss E. and Erlebach W.E. 1976. Limitations of Single Water Samples In Representing Mean Water Quality, Technical Bulletin No. 95, Inland Waters Directorate, Pacific and Yukon Region, Water Quality Branch.

28. Livingstone, 1963. Data of Geochemistry, Sixth Edition, Chapter G, Chemical Composition of Rivers and Lakes, U.S. Geological Survey Professional Paper 440-G.

29. Ciaccio, L.L. 1973. Water and Water Pollution Handbook, Vol. 3, Marcel Dekker Inc., New York, N.Y.

30. Anon., January, 1978. Brief presented by the Mining Association of British Columbia to the Public Inquiry Into Pollution Control Objectives for Mining, Mine-Milling, and Smelting Industries of British Columbia.

31. Anon. December 1973. Pollution Control Objectives for Mining, Mine-Milling, and Smelting Industries of British Columbia.

32. Lee G.F. and Mariani, G.M. 1977. Special Technical Publication 634, pp. 196-213, American Society for Testing and Materials, Philadelphia, Pa.

SECTION 4

1. Ryder, J.M. 1976. Terrain Inventory of Quarternary Geology, Ashcroft, British Columbia, Geological Survey of Canada, Paper 74-79.

2. Golder Associates Ltd., 1977. Hat Creek Geotechnical study; volume one of unpublished final report (No. 6) submitted to British Columbia Hydro and Power Authority.

3. McCullough, P.T. 1977. Mapping of limestone north of Houth Meadows; unpublished, British Columbia Hydro and Power Authority report 29 p.

4. Piper, A.M. 1944. A graphic procedure in the geochemical interpretation of water analysis; Trans. Amer. Geophys. Union. Vol 25, p. 914-923.

5. Schoeller, H. 1959. Geochemistry of groundwater; Chapter IV in Arid Zone Hydrology, Unesco.

6. Northwest Hydraulic Consultants Ltd. 1976. Hat Creek Water Supply, Hydrology, Interim Report. Prepared for Sandwell and Company Limited.

7. Holland, Stuart S. 1976. *Landforms of British Columbia: a Physiographic Outline*, British Columbia Department of Mines and Petroleum Resources, Bull. 48. Victoria.

8. Kendriew, G.W. and Kerr, D. 1955. The Climate of British Columbia and the Yukon Territory, Queen's Printer, Ottawa.

9. Neill, C.R. et al, 1970. Selected Characteristics of Streamflow in Alberta. Research Council of Alberta. River Engineering and Surface Hydrology Report 70-1.

10. Environment Canada. 1975. Surface Water Data, Reference Index, 1975. Water Survey of Canada. Inland Waters Directorate, Ottawa.

11. Environment Canada. 1974. Historical Streamflow Summary, British Columbia to 1973. Water Survey of Canada, Inland Waters Directorate, Ottawa.

12. Bjerring, James H. and Seagraves, Paul. June 1974. UBC TRIP, Triangular Regression Package. The University of British Columbia, Vancouver, B.C.

13. Thornthwaite, C.W. nad Mather, R.R. 1955. The Water Balance, Publications in Climatology, Drexel Inst. of Technology, Laboratory of Climatology, Vol. 8, 86 p.

14. Phillips, David W. 1976. Monthly Water Balance Tabulations for Climatological Stations in Canada, Atmospheric Environment Service, Publication DS #4-76.

15. Kellerhals, R., Church, M., and Bray, D.I. July 1976. Classification and Analysis of River Processes, American Society of Civil Engineering, Journal of the Hydraulic Division, Vol. 102, No. HY7.

16. Ministry of the Environment. March 1977. Aquatic Systems Inventory and Analysis, Report prepared by Resource Analysis Branch, Victoria, B.C.

17. Cotton F.A. and Wilkinson, G. 1962. Advanced Inorganic Chemistry, Interscience, New York, N.Y.

18. Busch, W. Zeitsohr. 1927. Anorg. Chem., V. 161.

19. Hem, J.D. 1962. Study and Interpretation of the Chemical Characteristics of Natural Water, U.S. Geological Survey Water Supply Paper 1473.

20. Goldschmidt, V.M. 1937. J. Chem. Soc., 655.

21. Standard Methods for the Examination of Water and Wastewater. 1971. 13th Edition, American Public Health Association, et al., Washington, D.C.

22. McKee J.E. and Wolf, H.W. 1963. Water Quality Criteria. The Resource Agency of California, State Water Resources Control Board.

23. Rankama K. and Sahama, T.G. 1950. Geochemistry. Chicago University Press, Chicago, Illinois.

24. Smith R.L. 1966. Ecology and Field Biology, Harper and Row.

25. Lange, N.A. 1967. Handbook of Chemistry, McGraw Hill.

26. Kelley, W.P. 1948. Cation Exchange In Soils. Reinhold Publishing Corp.

27. Scofield C.S. and Wilcox, L.V. 1931. Boron In Irrigation Water. U.S. Department of Agriculture Tech. Bull. 264.

28. Eaton, F.M. 1935. Boron In Soils and Irrigation Waters and Its Effects on Plants. U.S. Department of Agriculture Tech. Bull. 448.

29. Cedarstrom, D.J. 1945. Geology and Groundwater Resources of the Coastal Plain in Southeastern Virginia. Virginia Geol. Survey Bull. 63.

30. Anon. 1971. Water Quality Criteria. Second Edition. California State Water Resources Control Board.

31. Klein, L. 1962. River Pollution, Vol. II Causes and Effects, Butterworths, London.

32. Condon, E.V. and Odishaw, H. 1967. Handbook of Physics, McGraw Hill, New York, N.Y.

33. Byrkit, D.R. 1972. Elements of Statistics, D. Van Nostrand Company.

34. Burnson, B. 1938. J.A.W.W.A., 30, 793.

35. Arnold, G.E. 1935. J.A.W.W.A., 27, 1968.

36. Anon. 1972. Report of the Committee on Water Quality Criteria, Federal Water Pollution Control Administration.

37. Livingstone, D.A. 1963. Data of Geochemistry, Sixth Edition, Chapter G, Chemical Composition of Rivers and Lakes, Geological Survey Paper 440-G.

38. McGauley, P.H. 1968. Engineering Management of Water Quality, McGraw Hill, New York, N.Y.

39. Anon. 1976. Hat Creek Water Supply, Hydrology (Interim Report), Northwest Hydraulic Consultants Ltd.

40. Canadian Bio Resources Consultants Ltd. 1978. Agriculture Assessment - Hat Creek Detailed Environmental Studies.

41. McElhanney Surveying & Engineering Ltd. September, 1976. Coloured air photographs, Roll MA 1045.

42. Canada Department of Agriculture. 1968. Tech. Bull. 69. A Computer Program for Estimating Risks of Irrigation Requirements from Climatic Data.

43. B.C. Department of Agriculture. 1975. Irrigation Design Manual.

44. Agrometeorology Section, Canada Department of Agriculture. August 1968. Tech. Bull. 54, Risk Analyses of Weekly Climatic Data for Agricultural and Irrigation Planning, Kamloops, B.C.

45. Agrometeorology Section, Canada Department of Agriculture. April 1969. Tech. Bull. 76, Risk Analyses of Weekly Climatic Data for Agricultural and Irrigation Planning, Princeton, B.C.

46. Agrometeorology Section, Canada Department of Agriculture. August 1968. Tech. Bull. 57, Risk Analyses of Weekly Climatic Data for Agricultural and Irrigation Planning, Summerland, B.C.

47. Blaney, H.F., and W.D. Criddle. 1966. Determining consumptive use for planning water developments, p. 1-34. In Methods for estimating evapotranspiration. Irrigation and Drainage Speciality Conference, Las Vegas, Nev. 1966. Amer. Soc. Civil Eng., United Engineering Center, New York.

48. Hobbs, E.H., and K.K. Krogman. Observed and estimated evapotranspiration in Southern Alberta. Trans. Am. Soc. Agr. Eng. In press.

49. Baier, W., and Geo. W. Robertson, 1965. Estimation of Latent Evaporation From Simple Weather Observations. Can. J. Plant Sci. 45: 278-284.

50. Canadian National Committee for the International Hydrologic Decade. September 1966. Familiarization Seminar on Principles of Hydrology.

51. Atmospheric Environment Service. Undated. Temperature and Precipitation 1941-1970 British Columbia.

52. Canada Department of Transport. 1968. Climatic Normals, Volume 3, Sunshine, Cloud, Pressure and Thunderstorms.

53. Meteorological Branch, Canada Department of Transport. 1968. Climatic Normals, Volume 5, Wind.

54. Combustion Engineering, Inc. 1967. Steam Tables, Properties of Saturated and Superheated Steam.

55. B.C. Water Rights Branch, Victoria, B.C. 1976. Water Rights Maps and Lists of licence details, map sheets at 20-chain scale: 321, 322, 323, 325, 326, 361, 362, 363, 364 and 365.

56. Israelsen, O.W. and Hansen, V.E. 1962. Irrigation Principles and Practices. 447 pp.

57. Midwest Plan Service. 1975. Structures and Environment Handbook, Seventh Edition, p. 379.

58. Personal Communication, Strong Hall & Associates. January 1978.

59. Integ-Ebasco, Hat Creek Project-Site Evaluation Study. October 1976.

60. Beak Consultants Limited. December, 1977. Suspended Sediment Characteristics of the Thompson River and Effects of Algae Growth on Hat Creek Water Supply Systems. Prepared for Sandwell and Company Limited.

61. Environmental Protection Agency. September, 1977. Multimedia Levels - Mercury. Office of Toxic Substances. EPA 560/6-77-031. Washington, D.C.

SECTION 5

1. B.C. Water Investigations Branch, Ministry of the Environment. June 1977. Preliminary Feasibility Study for Oregon Jack Creek Irrigation Proposals.

2. Canadian Bio Resources Consultants Ltd. 1978. Agriculture Assessment - Hat Creek Detailed Environmental Studies.

3. B.C. Ministry of Agriculture, Kamloops Office. March 1977. Savona-Cache Creek-Basque Irrigation Development Study.

4. Midwest Plan Service. 1975. Structures and Environment Handbook, Seventh Edition. p. 379.

5. Water Survey of Canada. 1974. Historical Streamflow Summary, British Columbia to 1973. Inland Waters Directorate, Environment Canada, Ottawa.

6. Beak Consultants Limited. 1978. Fisheries and Benthos Assessment - Hat Creek Detailed Environmental Studies.

7. Personal Communication. July 1977. Strong, Hall & Associates.

8. Personal Communication. December 1977. Strong, Hall & Associates.

9. Personal Communication. December 1976. Strong, Hall & Associates.

10. U.S. Environmental Protection Agency. 1973. Water Quality Criteria 1972. EPA.R3.73.003.