ECOLOGY OF SELECTED STREAMS IN THE FRANK CHURCH RIVER OF NO RETURN WILDERNESS AREA

A Thesis

Presented in Partial Fulfillment of the Requirements for the

DEGREE OF MASTER OF SCIENCE

with a

Major in Fishery Resources

in the

GRADUATE SCHOOL

UNIVERSITY OF IDAHO

by

EDWIN W. BUETTNER

July 1987

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AUTHORIZATION TO SUBMIT THESIS

This thesis of Edwin W. Buettner submitted for the degree of Master of Science with major in Fishery Resources and titled "Ecology of Selected Streams in the Frank Church River of No Return Wilderness Area," has been reviewed in final form and approved, as indicated by the signatures and dates given below. Permission is now granted to submit final copies to the Graduate School for approval.

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ABSTRACT

The aquatic ecology of nine pristine subalpine to montane zone forest streams in the Frank Church River of No Return Wilderness Area (FCRNRWA) was studied during the summer-fall periods of 1975 and 1976.

Streamflow was dependent on drainage area and season with the Middle Fork of the Salmon River being the largest stream sampled. Summer low flow temperatures varied from 4 to 15 C. High flow turbidity and total suspended solids were low (2.8 NTU's and 9.7 mg l^{-1}, respectively) and dropped as flows decreased. Conductivity ranged between 25-122 μmhos; highs occurred in the larger streams during low flow. Oxygen remained near saturation with little variation in concentrations. Alkalinity levels were low and never exceeded 97 mg l^{-1}. Nutrients (PO_4, NO_3, SO_4, etc.) were often near or below detection limits. Inorganic ion concentrations (Ca, Mg, Na, K) were moderate to low with the variations corresponding to changes in watershed parent material and flow. Algal and benthic invertebrate biomass values were low (<1,289 mg m^{-2} and 904 mg m^{-2}, respectively). Plant biomass in Lodgepole Creek was 2,101 mg/m^2 due to a high incidence of the bryophyte Fontinalis. Benthic invertebrate numbers were low (226-1,033 organisms per square meter). The predominant benthic invertebrate genera were Epeorus and Rithrogena, in the order Ephemeroptera (mayflies).

Limnological parameters sampled indicate the infertile and pristine nature of streams in the Frank Church River of No Return Wilderness Area.

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INTRODUCTION

Today most streams and rivers of the world have been altered in some way by man's activity (i.e. increased sedimentation rates and ionic concentrations). Even in certain wilderness areas man's presence is changing the aquatic system.

Man has used the FCRNRWA for thousands of years. The Sheepeater Indians, a renegade band of Bannock, Shoshone, and Weiser Indians, inhabited the FCRNRWA for over 8,000 years with little apparent impact on the streams (U.S.F.S., 1976). The FCRNRWA is an important resource preservation and recreational area in Idaho, but relatively little is known about the aquatic ecology of Wilderness Area streams.

Emmett (1975) conducted a study on tributaries of the upper Salmon River approximately 100 miles upstream from the Frank Church River of No Return Wilderness Area, hereafter referred to as the FCRNRWA. That study monitored physical and chemical aspects but did not cover the biological components of streams. Minshall et al. (1985) compared the benthic invertebrate communities, species diversity and equitability of the upper Salmon River to test the River Continuum Concept. Cushing et al. (1983) conducted research on periphyton, chlorophyll a, and diatoms of the Middle Fork of the Salmon River. Minshall et al. (1981) collected biological, water quality and aquatic habitat information on the Middle Fork Salmon River. Thurow (1985) conducted a river and stream investigation in which he evaluated wild steelhead (Salmo gairdneri), westslope cutthroat trout (Salmo clarki) and bull trout (Salvelinus confluentus) production in 14 tributaries of the Middle Fork Salmon River. A Middle Fork Salmon River trout fishery investigation study was conducted by Mallet (1960, 1961). Mallet (1963) also surveyed the chinook salmon spawning grounds in the upper Salmon River drainage between 1960 and 1962.

This stream ecology study was established to determine physical, chemical, and biological parameters of pristine streams in the FCRNRWA.

The objective of this study was to describe the aquatic ecology of selected pristine subalpine to montane zone streams in the FCRNRWA.

DESCRIPTION OF STUDY AREA

The 8,910 km^2 Frank Church River of No Return Wilderness Area (FCRNRWA) was established when Congress passed the central Idaho Wilderness Act on July 23, 1980. Prior to being designated as a wilderness area most of the area (4,960 km^2, south of the Salmon River) was contained within the Idaho Primitive Area. The Idaho Primitive Area was established by Congress on March 17, 1931, as an entity to be managed by the Forest Service under the Wilderness Act (Public Law 88-577). Most of the FCRNRWA is National Forest land, but a few square kilometers of privately owned lands are scattered throughout the region. Most of the private land occurs on benches along the larger streams and is used as outfitter base camps.

The FCRNRWA lies in the central part of central Idaho (Figure 1). At the time of this study the Frank Church River of No Return Wilderness Area was bounded on the north by the main Salmon River, on the east by the Big Horn Crags, Yellowjacket Range, and Sleeping Deer mountains, on the south by a line approximately four miles south of and parallel to the Middle Fork of the Salmon River west to Rapid Creek, and on the west by the western limits of the Marble, Monumental, Beaver and Chamberlain Creek watersheds.

The Wilderness Area is underlain by four major geologic rock types. The oldest occur in the central and eastern section (Figure 2) and consist of metamorphosed Pre-Cambrian

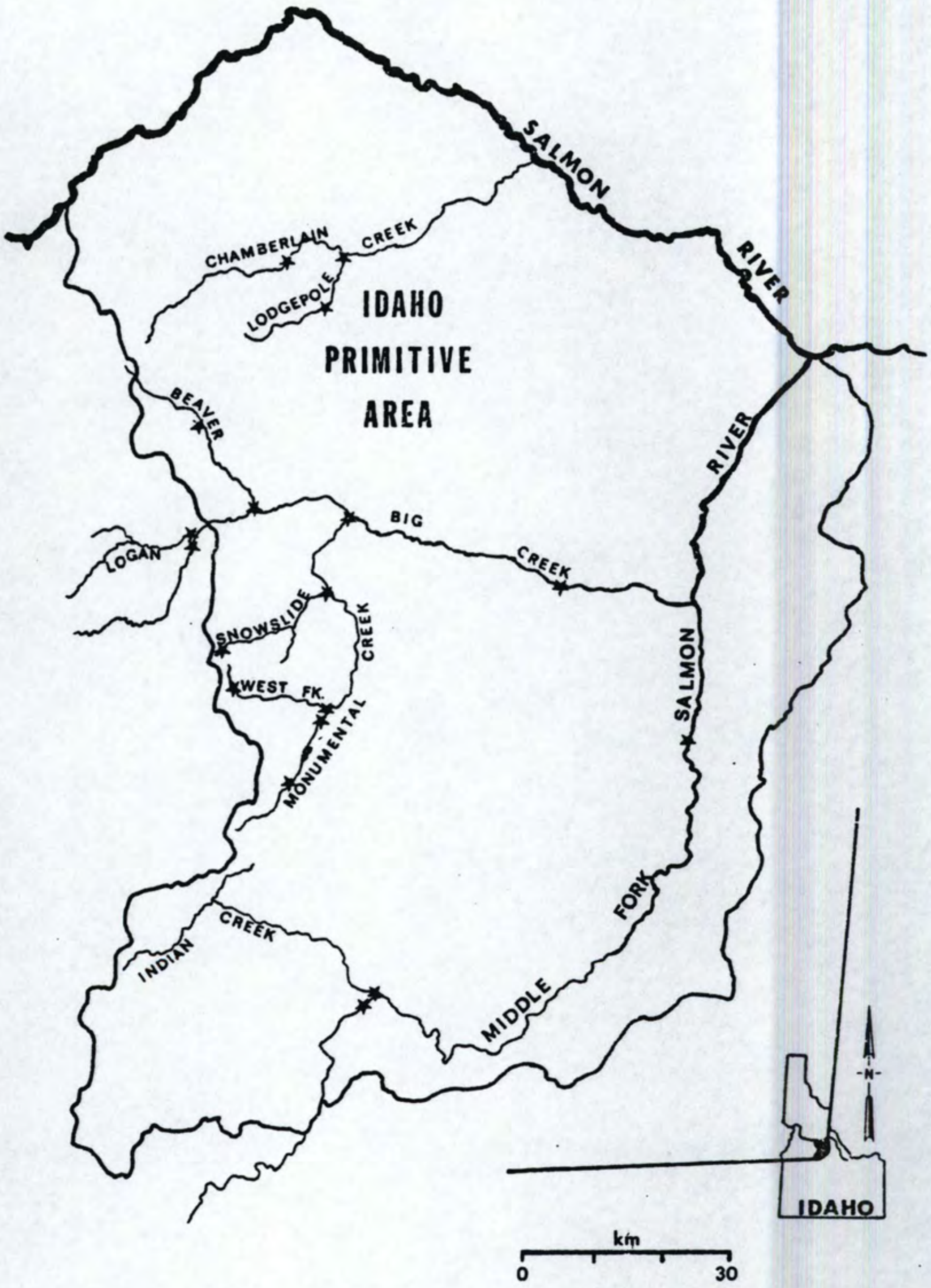

Figure 1. Map of Frank Church River of No Return Wilderness Area showing study streams and sample stations, 1975-1976.

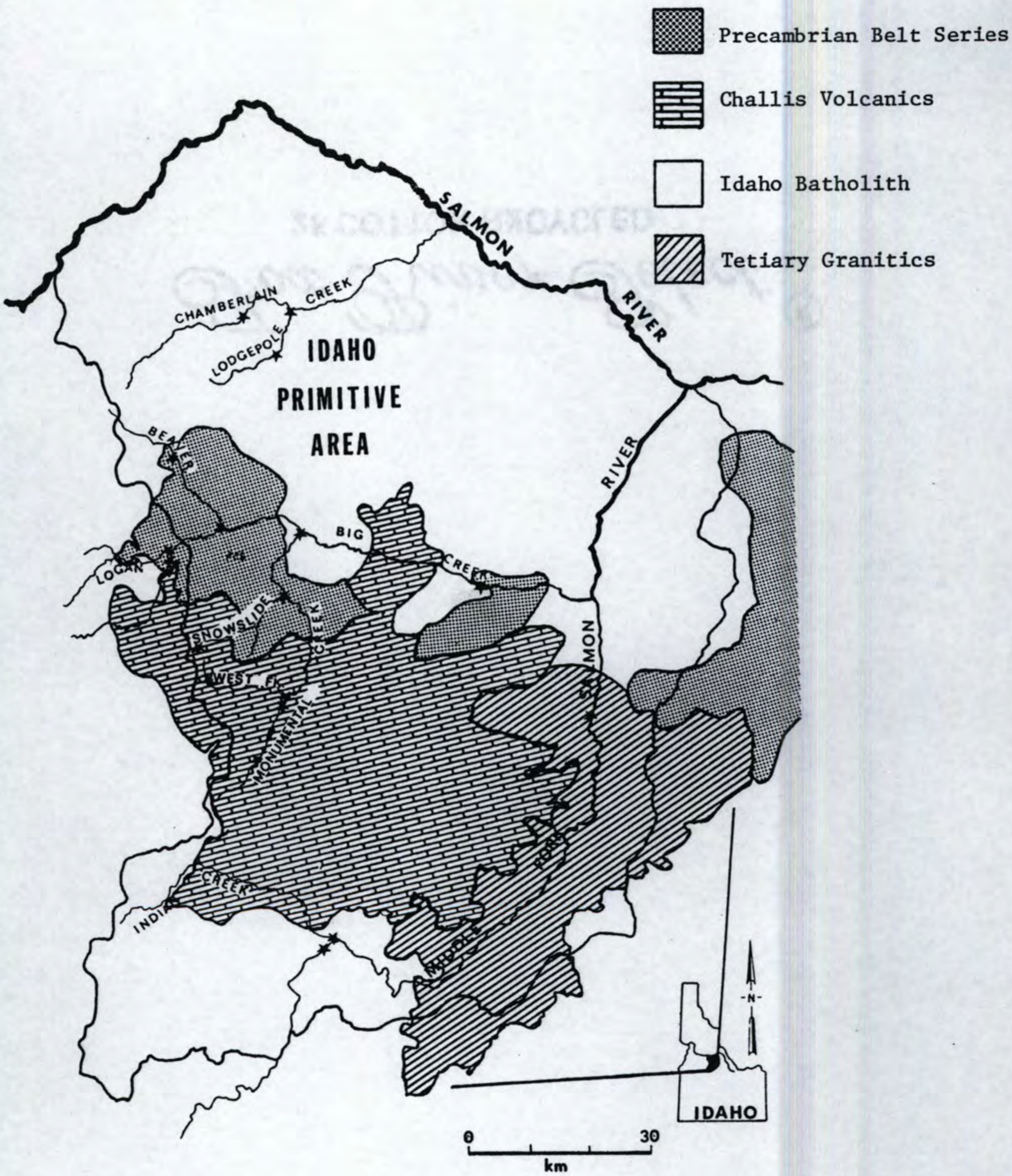

Figure 2. Geologic map of Frank Church River of No Return Wilderness Area showing four major types (Ross and Forrester, 1947).

granitic rocks (schists and gneisses). Younger Pre-Cambrian rocks, consisting of sedimentary beds subjected to low grade metamorphism, are exposed in a belt across the central part of the area (Carter et al., 1973). Cretaceous granitic rocks underlie much of the northern sector and part of the southern region (Carter et al., 1973). A thick layer of Eocene volcanic rock (Challis Volcanics) covers part of the west central area (Ross, 1937). The fourth group, largely Tertiary granitic rock, lies along the Middle Fork of the Salmon River (Figure 2). Concentrations of dissolved materials in runoff water can be expected to decrease from the Belt Series through the batholith granitics (Hembree and Rainwater, 1961; Miller, 1961; Snyder, 1976).

The area supports a large volume of timber, but harvest in much of the Wilderness Area is considered to be only barely economically justifiable because of the remote location, rugged relief, and poor quality of timber (U.S.F.S., 1976).

The Wilderness Area is spectacularly rugged, with altitudes ranging from 701 meters on the main Salmon River to 3,073 meters atop Mount McGuire. Sharp ridges with crestal altitudes of 2,100-2,700 meters and narrow canyons 900-1,200 meters deep characterize the region. The upper reaches of canyons, above 2,400 meters, are usually glaciated and have U-shaped cross sections but most of the lower canyons have a steep stream-cut V-shape with little flood plain development.

The Wilderness Area is surrounded by a highly mineralized part of Idaho. Gold discoveries on the Salmon River in 1860 and on Monumental Creek in 1896 touched off the Salmon River and Thunder Mountain gold rushes. An estimated 20,000 people subsequently came into this remote area. Due to the relatively small near-surface mineral reserves of the area, the gold rush days ended early in the 1900's. A few, more productive mines were operated until the 1940's and 50's, but at the time of this study there were no commercially active mines in the Wilderness Area.

The climate of the FCRNRWA varies from arid in the lower open canyons to cool moist alpine areas in the higher mountains. Annual precipitation at Middle Fork Lodge on the Middle Fork Salmon River (rkm 98) for 1975 and 1976 was 48.7 and 34.2 cm, respectively. Higher elevations may receive up to 150 cm annually, principally as snow during the winter months (Idaho Climatological Data, 1975, 1976).

Mean monthly temperatures at the Middle Fork Lodge range from -5C in January to 20C during August. Minimum-maximum temperatures for the region range from -23C in January to 37C during late July. At higher elevations the temperature is cooler and annual precipitation increases.

The Wilderness Area produces approximately 1.2 billion cubic meters of runoff water annually with 80 percent of this occurring from April through July as snowmelt. The FCRNRWA is considered a high elevation environment of low energy (very low production) and immaturity which reacts rapidly to stress. Disturbance of the surrounding habitat will quickly affect the quality of the stream environment, degrading this environment more than in an older, more stable lower relief system.

METHODS

Site Geology

In 1975 two streams were selected from the Pre-Cambrian Belt Series (Snowslide and Beaver creeks), two from the Challis Volcanics (Monumental and the West Fork Monumental creeks), and one stream from the Idaho Batholith (Lodgepole Creek) (Figure 1). Sample stations were placed at the mouth and headwater reach of each stream, except on Monumental Creek where the mouth station was placed a short distance above the confluence on Monumental Creek and West Fork Monumental Creek. In addition, Big Creek at the Taylor Ranch and the Middle Fork Salmon River at the Flying B Ranch were sampled. Access to study sites was accomplished by pack animals, or single engine aircraft.

During 1976, all previously established 1975 stations were sampled. In addition, a station on Big Creek above the mouth of Logan Creek, Logan Creek at the mouth, the mouth of Monumental Creek, and Chamberlain Creek below the Chamberlain Air Strip were sampled (Figure 1). The Middle Fork of the Salmon River above the mouth of Indian Creek and Indian Creek at the mouth were sampled once in July, 1976 (Figure 1). Physical and geological characteristics of the study streams and their drainages are presented in Tables 1, 2, and 3.

Table 1. Physical characteristics of 16 study sites on 9 streams in the Frank Church River of No Return Wilderness Area.

Stream	Site	Site river km	% Exposed bedrock	Stream bottom composition (cm) (% of each diameter class) <100	30-100	15-30	7.6-15	2.5-7.6	0.3-2.5	>0.3	Channel stability evaluation†	% Overhead vegetation cover
Snowslide Cr.	Mouth	0.2	0	2	10	40	30	10	8	0	106 Fair	50
	Headwater	12.9	40	0	10	10	18	17	4	1	78 Fair	80
Beaver Cr.	Mouth	0	1	10	10	45	18	10	5	1	105 Fair	20
	Headwater	9.7	0	30	30	20	10	8	1	1	107 Fair	70
West Fork Monumental Cr.	Mouth	0.3	0	2	5	37	40	10	5	1	99 Fair	40
	Headwater	11.3	30	1	25	14	15	10	4	1	83 Fair	60
Monumental Cr.	Mouth	0.8	5	10	15	40	20	5	4	1	92 Fair	30
	above West Fork	30.6	0	5	30	35	18	5	5	2	113 Fair	30
	Headwater	37.0	0	0	5	5	15	55	15	5	188 Poor	30
Lodgepole Cr.	Mouth	0	5	5	5	40	35	5	4	1	93 Fair	90
	Headwater	9.7	0	0	2	5	30	30	30	3	80 Fair	50
Logan Cr.	Mouth	0.2	5	15	30	20	10	10	7	3	103 Fair	40
Chamberlain Cr.	Chamberlain airstrip	29.0	0	1	8	20	35	30	5	1	118 Poor	20
Big Cr.	Taylor Ranch	11.3	5	20	20	20	20	5	5	5	101 Fair	5
	Big Cr. R.S.	74.2	0	2	10	25	30	20	10	3	105 Fair	40
Middle Fork Salmon River	Flying B Ranch	41.8	0	20	35	20	10	5	5	5	107 Fair	> 2

†"Channel stability evaluation" - A systemized measurement and evaluation of the resistive capacity of mountain stream channels to the detachment of bed and bank material and containing information about the capacity of streams to adjust and recover from potential changes in flow.

Table 2. Characteristics of 16 stations on 9 streams in the Frank Church River of No Return Wilderness Area.

Stream	Site	Site stream kilometer	Site altitude (meters msl)	Drainage area above site (km^2)	Drainage relief (ft)	Stream gradient %	Average width (m) Low	Average width (m) High	Average depth (cm) Low	Average depth (cm) High	Average discharge (cms) Low	Average discharge (cms) High
Snowslide Cr.	Mouth	0.2	1539	54	1539	4	5.3	9.5	25.0	41.0	0.85	9.91
	Headwater	12.9	2316	7	2783	7	0.3	-	23.0	-	0.13	-
Beaver Cr.	Mouth	0	1533	114	1533	3	7.3	9.8	30.0	61.0	2.72	11.33
	Headwater	9.7	1768	47	2661	5	4.3	-	36.0	-	1.10	-
West Fork	Mouth	0.3	1786	54	1786 to	3	3.7	9.1	28.0	43.0	0.48	5.86
Monumental Cr.	Headwater	11.3	2134	10	2743	8	1.7	-	15.0	-	0.07	-
Monumental Cr.	Mouth	0.8	1372	322	1372	3	12.8	-	33.0	-	2.71	-
	above West Fork	30.6	1786	74	to	2	4.0	9.1	33.0	38.0	0.68	5.10
	Headwater	37.0	1890	38	2843	4	3.1	-	18.0	-	0.57	-
Lodgepole Cr.	Mouth	0	1539	48	1539 to	6	2.7	-	48.0	-	0.31	-
	Headwater	9.7	1859	8	2393	4	1.5	-	20.0	-	0.20	-
Logan Cr.	Mouth	0.2	1753	57	1753	5	4.3	-	41.0	-	1.64	-
Chamberlain Cr.	Headwater	29.0	2660	(201)	2660 to 2807	3	6.4	-	56.0	-	1.93	-
Big Cr.	Taylor Ranch	11.3	1143	1425	1143 to	3	27.4	42.7	48.0	102.0	13.42	25.49
	Big Cr. R.S.	74.2	1769	77	2896	4	8.8	-	30.0	-	1.61	-
Middle Fork Salmon River	Flying B Ranch	41.0	1097	5180	1097 to 3073	3	61.0	-	91.0	-	53.10	-

Table 3. Characteristics of 16 stations on 9 streams in the Frank Church River of No Return Wilderness Area.

Stream	Site	Predominant drainage geology	Topography and comments on surrounding land
Snowslide Cr.	Mouth	Precambrian Belt Series	Steep canyon; pack trail crosses stream below site; brushy
	Headwater	Precambrian Belt Series	Glaciated sub-alpine valley; pack trail crosses stream above site; rocky sub-alpine country
Beaver Cr.	Mouth	Precambrian Belt Series	Steep canyon; adjacent trail; steep forested hills; open talus slopes
	Headwater	Precambrian Belt Series	Steep canyon; adjacent trail; steep forested hills; open talus slopes
West Fork Monumental Cr.	Mouth	Challis Volcanics	Narrow valley; adjacent trail; steep forested hills; many rock outcroppings
	Headwater	Challis Volcanics	Steep canyon; adjacent trail; steep sub-alpine mountains
Monumental Cr.	Mouth	Precambrian Belt Series	Steep canyon; adjacent trail; steep lightly forested hills; talus slopes
	above West Fork	Challis Volcanics	Narrow valley; adjacent trail; mountain meadows with sagebrush slopes
	Headwater	Challis Volcanics	Narrow valley; adjacent road; sub-alpine valley; early mining in vicinity
Lodgepole Cr.	Mouth	Idaho Batholith Granitics	Steep narrow canyon; stream covered by dense timber canopy
	Headwater	Idaho Batholith Granitics	Meadows; adjacent trail; mountain meadow with tall grass; brush along creek.
Logan Cr.	Mouth	Idaho Batholith Granitics	Steep canyon; several cabins adjacent to stream.
Big Cr.	Taylor Ranch	Idaho Batholith Granitics	Narrow valley; adjacent trail, hayfield and air strip; pack ranch
	Big Cr. R.S.	Idaho Batholith Granitics	Steep canyon; adjacent road, cabins, horse pasture
Middle Fork Salmon River	Flying B Ranch	Idaho Batholith Granitics	Steep canyon; adjacent trail, hayfield, pasture, air strip; dude ranch; large river with little cover; semi-arid area

Stream Morphology

Table 1 contains stream bottom composition in percent of each diameter class and a channel stability evaluation score (Pfankuch, 1975). The channel stability evaluation is a numerical score subjectively categorizing the resistance of stream channels to the detachment of bed and bank material. It also contains information about the capacity of streams to adjust and recover from potential flow changes. These scores are also separated into groups (<38 = excellent, 39-76 = good, 77-114 = fair, 115+ = poor). A stream channel reach that rates "poor" has a combination of many attributes that will require more judicious management of the tributary watershed lands than one rated "excellent" (Pfankuch, 1975). Undisturbed pristine watersheds may exhibit a poor score because of the fragility and geological youth of the basin. Older areas are more stable and will normally have better ratings.

Study Parameters

Physical and chemical parameters along with units of measure, methods, procedure, and references are listed in Table 4.

Stiff Diagrams

Ionic concentrations in stream waters are determined in part, by the geologic makeup of the drainage basin. To visualize similarities and differences in stream water

Table 4. Physical, chemical, and biological analyses performed on selected streams of the Frank Church River of No Return Wilderness Area, 1975-1976.

Parameter	Year	Units of measure	Method	Procedure	Reference	Comments
Flow	1975-76	CMS	General oceanics flow meter model 2030	Flow measured at 1-6' interval across stream 0.4 the depth from bottom		One ft intervals used on streams less than 10 ft wide, 3 ft intervals on streams 10-40 ft wide, 6 ft intervals on streams larger than 40 ft
Temperature	1975-76	C	Mercury thermometer	Measured 6-12" below surface		
Electrical conductivity	1975	µmhos cm^{-2}	Labline conductivity bridge	Measured in field		
	1976	µmhos cm^{-2}	Labline conductivity bridge	Measured in lab		Samples frozen and thawed before measuring
Turbidity	1975	NTU	Hellige turbidimeter	Measured in lab		Samples frozen and thawed before measuring
	1976	NTU	Hach turbidimeter	Measured in lab		Samples frozen and thawed before measuring
Total suspended solids	1975-76	mg l^{-1}	.45µ millipore method	Filter known volume sample	APHA 1976	Dry and weigh filter paper, filter water, dry and weigh
Oxygen	1975-76	mg l^{-1}	Azide modification	Measured in field	APHA 1976	
Oxygen saturation	1975-76	% O_2	Nomogram	Calculated using % O_2 nomogram	APHA 1976	Values corrected for altitude and temperature
M.O. alkalinity	1975-76	mg l^{-1}	Alkalinity	Measured in field	APHA 1976	
Nitrate-nitrogen	1975	µg l^{-1}	Brucine method	Measured in lab	APHA 1976	Samples frozen, thawed and filtered with 0.45µ filter
	1976	µg l^{-1}	Ultraviolet spectrophotometric	Measured in lab	APHA 1976	Samples frozen, thawed and filtered with 0.45µ filter
Ortho-phosphate phosphorous	1975-76	µg l^{-1}	Stannous chloride method	Measured in lab	APHA 1976	Samples frozen, thawed and filtered with 0.45µ filter
Total filterable (dissolved) phosphate	1975	µg l^{-1}	Persulfate digestion method	Measured in lab	APHA 1976	Samples frozen, thawed and filtered with 0.45µ filter
Sulfate	1975-76	mg l^{-1}	Turbidimetric method	Measured in lab	APHA 1976	Samples frozen, thawed and filtered with 0.45µ filter

Table 4. Continued.

Parameter	Year	Units of measure	Method	Procedure	Reference	Comments
Cations (Ca^{++}, Mg^{++}, Na^{+}, K^{+})	1975	mg l^{-1}	Perkin-Elmer model 290B	Samples acidified before analysis and analyzed by atomic absorption spectrophotometry	APHA 1976	Samples frozen, thawed and filtered with 0.45μ filter
	1976	mg l^{-1}	Instrumentation lab. model IL151		APHA 1976	Samples frozen, thawed and filtered with 0.45μ filter
Chlorophyll	1976	mg m^{-2}	Trichromatic method	Samples filtered in field	EPA 1973	Sample filters dried in field and frozen in lab
Periphyton biomass	1976	mg m^{-2}	Ash-free weight	Samples filtered and dried in field	EPA 1973	Samples obtained with natural substrate sampler, 9.54×10^{-3} area, by scraping rocks
Autotrophic index	1976	–	Autotrophic index	Chlorophyll a mg m^{-2}/biomass mg m^{-2}	EPA 1973	Values greater than 200 may result from organic pollution or nutrient loading
Benthic invertebrates	1975-76	No. m^{-2}	Surber sampler	3 samples per station, preserved in 10% formalin	EPA 1973 & Slack et. al 1973	Insects separated from sample by sugar flotation
Benthic biomass	1976	mg m^{-2}	Dry weight	Samples dried at 105C 18 hrs.	EPA 1973	
Shannon-Weaver diversity index	1975-76	$\bar{d}$	Diversity	$\bar{d}$ calculated on individual samples	Lloyd, Zar & Karr 1968	
Equitability	1976	e	Diversity	Range 0-1, values greater than 1 due to small sample size	Galat, D.L. 1974	Samples with less than 100 specimens should be evaluated with caution

dissolved solids, the modified Stiff diagram was used (Stiff, 1951). The Stiff diagram, using mg l^{-1} instead of Stiff's meq l^{-1}, "fingerprints" the relationships of ionic substances within a stream, allowing for a qualitative comparison between streams, stations, times, or sampling data. The diagram is constructed by plotting the major ions on the "X" axis to either side of a "Y" zero axis -- anions to the right of zero and cations to the left of zero. The plotted points are connected producing an irregular shaped polygon.

Biological Parameters

Biological parameters sampled were chlorophyll a and c (mg m^{-2}), periphyton organic biomass (Ash-free weight in mg m^{-2}), autotrophic index (Weber and McFarland, 1969), numbers of benthic macroinvertebrates per square meter, benthic biomass (mg m^{-2}), Shannon-Weaver diversity index d (Lloyd et al., 1968), and equitability e (Galat, 1974) (Table 4).

Known areas (9.54×10^{-3} m^2) of stream rocks were scraped and the material filtered through a 0.45 μ Millipore filter, then dried in the field. These samples were returned to the laboratory one to eight days after sampling and frozen for later chlorophyll analysis. This same procedure was followed for periphyton biomass. Autotrophic indices were calculated according to Weber (1973):

$$\text{Autotrophic Index} = \frac{\text{ash-free weight (mg m}^{-2}\text{)}}{\text{chlorophyll a (mg m}^{-2}\text{)}}$$

Benthic macroinvertebrates were sampled by three .093 m^2 Surber samples per station. Insects were separated from samples using a density separation method (Slack et al., 1973) and preserved in 70% alcohol. Organisms were then identified to genera using "Aquatic Insects of California" (Usinger, 1974), "Freshwater Biology" (Ward and Whipple, 1959), "Freshwater Invertebrates of the United States" (Pennak, 1953), "The Mayflies of Idaho" (Jensen, 1966), and "Larvae of the North American Caddisfly Genera (Trichoptera)" (Wiggins, 1977). Shannon-Weaver diversity (d) (Lloyd, Zar, and Karr, 1968) and equitability (e) (Galat, 1974) were calculated on each sample. Shannon-Weaver diversity combines species richness and the distribution of individuals among the species. The formula used by Lloyd, Zar and Karr (1968) is:

$$d = \frac{C}{N} (N \log_{10} N - \quad n_i \log_{10} n_i)$$

where C = 3.321928 (converts base 10 log to base 2 (bits); N = total number of individuals; and n_i = total number of individuals in the ith species.

Equitability is a ratio between S^1/S where S^1 is the number of hypothetical equitably distributed species determined using the Shannon diversity d from a table provided by Lloyd and Ghelardi (1964) and S being the number of species actually observed in the sample.

The Shannon-Weaver diversity index lacks the sensitivity to determine differences where degradation is at slight to moderate levels (EPA, 1973). The equitability index (e), which conceptually measures the same parameter as eveness and ranges from 0-1 with 1 the best possible value, was, therefore, used in addition to the Shannon-Weaver index. Benthic biomass was also measured after drying organisms overnight at 105C (EPA, 1973).

RESULTS AND DISCUSSION

Flow

Summer flows ranged from <0.09 $m^3\ s^{-1}$ (3 cfs) at headwater stations to 2.8 $m^3\ s^{-1}$ (100 cfs) at some stream mouth stations (Tables 5, 6, 7, and 8, and Figure 3).

Flow expressed as cubic meters per second per square kilometer ($m^3\ s^{-1}\ km^{-2}$) permits comparison of water delivery per unit area between watersheds of different size. Values ranged as high as 0.184 $m^3\ s^{-1}\ km^{-2}$ at peak snowmelt. During low flow periods, values usually ranged between 0.5×10^{-2} and $4.6 \times 10^{-2}\ m^3\ s^{-1}\ km^{-2}$.

The Middle Fork Salmon River yielded more runoff in 1976 than 1975 (U.S.G.S., 1976), even though maximum flows for 1975 were 56.9 $m^3\ s^{-1}$ (2,010 cfs) higher than 1976 (Figure 3). A 10 to 20-fold difference in flow was noted in some Wilderness Area streams between low and high flow conditions (Tables 5, 6, 7, and 8) with peak flows usually occurring in early June. Since climatic seasonal patterns throughout the Wilderness Area are similar, flow patterns for the study streams should be similar to those of the Middle Fork Salmon River.

Temperature

Stream water temperature within a region is dependent on time of year, streambank cover, width/depth ratios, and discharge volume. Most of the study streams flowed through steep canyons and rarely exceeded 10C. In regions where

Table 5. Physical and chemical data for Mouth and Headwater stations of two streams, Snowslide and Beaver Creeks, in the Precambrian Belt Series of the Frank Church River of No Return Wilderness Area, 1975-1976.

	Flow cms(cfs)	Flow csk(csm)	Temp. °C	O_2 mgl^{-1}	% O_2	M.O. Alk. (HCO_3) mgl^{-1}	Elect. cond. umhos	Turb. NTU	Total Susp. Sol. mgl^{-1}	SO_4 mgl^{-1}	PO_4 μgl^{-1}	NO_3 μgl^{-1}	K+ mgl^{-1}	Na+ mgl^{-1}	Mg++ mgl^{-1}	Ca++ mgl^{-1}
Snowslide Creek																
Mouth																
1975																
July 12-16	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Aug. 16-19	0.76(27)	0.014(1.3)	9.5	9.4	95	–	–	0.1	2.1	2.6	5	15	0.5	2.1	2.9	6.3*
Sept. 24-2	0.48(17)	0.009(0.8)	6.0	11.5	122	70	122	0.1	1.8	3.0	3	<10	0.5	2.2	3.1	7.3*
1976																
June 19-24	9.91(350)+	0.184(16.9)	8.0	9.8	99	66	48	2.8	9.7	3.6	3	<10	0.4	2.5	1.2	5.5
July 16-26	1.53(54)	0.028(2.6)	11.0	8.6	95	88	90	1.0	1.8	3.8	5	–	0.5	1.8	2.4	12.5
Aug. 10-17	0.85(30)	0.016(1.4)	10.0	9.5	103	71	65	1.1	11.3	3.0	6	<10	0.3	2.2	1.9	10.9
Headwater																
1975																
July 12-16	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Aug. 16-19	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Sept. 24-2	0.14(5.1)	0.02(2.0)	8.0	8.8	98	29	59	0.4	3.0	1.8	<3	12	0.2	1.2	0.4	2.5*
1976																
June 19-24	–	–	7.0	9.2	91	35	39	1.5	9.1	1.5	8	<10	0.6	1.3	0.9	3.8
July 16-26	0.27(9.4)	0.039(3.7)	15.0	7.4	97	43	45	0.5	3.3	1.0	4	23	0.2	1.4	0.5	5.8
Aug. 10-17	0.13(4.6)	0.019(1.8)	8.5	9.5	106	54	49	1.0	2.2	3.7	<3	85	0.2	1.6	0.6	8.0
Beaver Creek																
Mouth																
1975																
July 12-16	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Aug. 16-19	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Sept. 24-2	1.44(51)	0.013(1.2)	7.8	10.4	101	41	98	0.2	2.1	2.3	8	12	0.9	2.1	2.1	4.0*
1976																
June 19-24	–	–	7.0	9.2	91	35	39	1.5	9.1	1.5	8	<10	0.6	1.3	0.9	3.8
July 16-26	4.36(154)	0.038(3.5)	9.5	9.4	98	57	65	0.4	1.2	1.3	4	96	0.8	1.6	1.7	9.3
Aug. 10-17	2.72(96)	0.024(2.2)	9.5	9.5	100	70	65	0.6	2.6	3.4	4	<10	0.9	1.7	1.9	10.3
Headwater																
1975																
July 12-16	4.30(152)	0.091(8.4)	8.0	8.4	82	37	25	0.2	3.2	1.4	5	27	0.3	1.2	0.4	1.2*
Aug. 16-19	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Sept. 24-2	0.59(21)	0.013(1.2)	6.0	10.6	100	35	87	0.2	2.2	2.2	3	12	0.6	2.4	1.6	2.8*
1976																
June 19-24	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
July 16-26	2.04(72)	0.043(4.0)	9.5	8.3	91	43	44	0.5	5.3	1.0	4	14	0.5	1.6	1.0	4.5
Aug. 10-17	0.96(34)	0.020(1.9)	9.0	9.3	100	64	55	0.8	7.6	3.2	<3	<10	0.8	2.2	1.4	6.5

+ Estimated from partial data.

* Values low due to interference with silicone in analytical procedure used.

Table 6. Physical and chemical data for Mouth and Headwater stations of two streams, Monumental and West Fork Monumental Creeks, in the Challis Volcanics of the Frank Church River of No Return Wilderness Area, 1975-1976.

	Flow cms(cfs)	Flow csk(csm)	Temp. °C	O_2 mgl^{-1}	% O_2	M.O. Alk. (HCO_3) mgl^{-1}	Elect. cond. umhos	Turb. NTU	Total Susp. Sol. mgl^{-1}	SO_4 mgl^{-1}	PO_4 μgl^{-1}	NO_3 μgl^{-1}	K+ mgl^{-1}	Na+ mgl^{-1}	Mg++ mgl^{-1}	Ca++ mgl^{-1}
Monumental Creek																
Mouth																
1975																
July 12-16	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Aug. 16-19	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Sept. 24-2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
1976																
June 19-24	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
July 16-26	6.34(224)	0.020(1.8)	14	8.6	103	69	74	1.2	6.4	8.9	7	13	0.6	2.1	2.0	8.5
Aug. 10-17	2.72(96)	0.008(0.8)	13	9.1	105	67	–	–	–	–	–	–	–	–	–	–
above West Fork																
1975																
July 12-16	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Aug. 16-19	0.71(25)	0.010(0.9)	11.5	8.8	95	25	–	0.4	4.0	2.2	5	37	0.7	2.5	0.4	2.0*
Sept. 24-2	0.37(13)	0.005(0.5)	11	9.0	96	27	61	0.2	2.8	2.6	5	<10	0.8	2.4	0.4	2.2*
1976																
June 19-24	5.10(180)	0.069(6.3)	9	9.8	105	34	27	0.6	2.5	2.3	5	5	0.7	2.0	0.3	2.5
July 16-26	1.22(43)	0.017(1.5)	15	7.4	92	45	46	0.7	7.5	3.2	4	43	0.8	2.0	0.4	5.2
Aug. 10-17	0.68(24)	0.008(0.8)	12	9.3	106	49	46	0.8	2.2	4.0	3	<10	0.8	2.0	0.5	5.8
Headwater																
1975																
July 12-16	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Aug. 16-19	0.62(22)	0.016(1.5)	8	8.9	92	–	–	0.2	3.1	2.2	<3	34	0.6	2.2	0.3	2.0*
Sept. 24-2	0.31(11)	0.008(0.8)	5.5	10.1	98	23	57	0.2	2.2	2.6	3	<10	0.7	2.3	0.4	2.2*
1976																
June 19-24	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
July 16-26	0.82(29)	0.022(2.0)	12	8.1	95	41	46	0.6	9.9	2.8	5	150	0.8	1.8	0.4	4.8
Aug. 10-17	0.57(20)	0.015(1.4)	11	8.8	99	55	46	0.9	5.6	4.0	7	<10	0.9	3.1	0.5	5.7

Table 6. Continued.

	Flow cms(cfs)	Flow csk(csm)	Temp. °C	O_2 mgl^{-1}	% O_2	M.O. Alk. (HCO_3) mgl^{-1}	Elect. cond. umhos	Turb. NTU	Total Susp. Sol. mgl^{-1}	SO_4 mgl^{-1}	PO_4 μgl^{-1}	NO_3 μgl^{-1}	K^+ mgl^{-1}	Na^+ mgl^{-1}	Mg^{++} mgl^{-1}	Ca^{++} mgl^{-1}
West Fork Monumental Creek																
Mouth																
1975																
July 12-16	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Aug. 16-19	0.48(17)	0.009	10	9.0	95	28	–	0.2	3.1	1.8	8	11	0.2	2.6	0.4	2.5*
Sept. 24-2	0.37(13)	0.007	7.5	9.6	93	31	58	0.2	1.8	2.0	<3	18	0.6	2.3	0.4	2.8*
1976																
June 19-24	5.86(207)	0.109	8	8.9	93	32	32	0.7	1.8	2.1	4	<10	0.2	2.7	0.2	2.7
July 16-26	1.47(52)	0.027	10	8.7	96	46	44	0.3	1.6	<1.0	3	50	0.2	1.6	0.4	4.7
Aug. 10-17	0.48(17)	0.009	10	9.1	100	71	50	0.6	2.9	2.4	3	–	0.4	2.2	0.5	6.8
Headwater																
1975																
July 12-16	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Aug. 16-19	–	–	8.5	9.1	102	29	–	0.2	5.8	1.8	<3	11	0.4	1.7	0.5	3.5*
Sept. 24-2	0.05(1.8)	0.005	7	9.8	106	34	87	0.2	2.1	2.4	<3	<10	0.3	2.0	1.1	4.2*
1976																
June 19-24	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
July 16-26	0.10(3.6)	0.010	15	7.4	96	44	44	0.7	3.4	1.0	4	26	0.1	1.2	0.6	5.7
Aug. 10-17	0.07(2.5)	0.007	7	9.1	98	66	53	0.4	2.4	3.8	<3	<10	0.1	1.6	0.8	7.3

Table 7. Physical and chemical data for Mouth and Headwater stations of two streams, Lodgepole and Logan Creeks, in the Batholith Granitics, without negligible intrusive activity, of the Frank Church River of No Return Wilderness Area, 1975-1976.

	Flow cms(cfs)	Flow csk(csm)	Temp. °C	O_2 mgl^{-1}	% O_2	M.O. Alk. (HCO_3) mgl^{-1}	Elect. cond. umhos	Turb. NTU	Total Susp. Sol. mgl^{-1}	SO_4 mgl^{-1}	PO_4 μgl^{-1}	NO_3 μgl^{-1}	K+ mgl^{-1}	Na+ mgl^{-1}	Mg++ mgl^{-1}	Ca++ mgl^{-1}
Lodgepole Creek																
Mouth																
1975																
July 12-16	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Aug. 16-19	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Sept. 24-2	0.29(10.3)	0.006(0.6)	4	11.3	104	53	85	0.2	3.7	1.7	7	22	1.0	4.2	1.3	2.8*
1976																
June 19-24	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
July 16-26	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Aug. 10-17	0.31(10.8)	0.006(0.6)	11	8.6	94	92	69	0.6	6.9	2.4	<3	<10	1.1	3.4	1.6	8.4
Headwater																
1975																
July 12-16	0.47(16.5)	0.059(5.3)	10	7.7	87	18	32	0.2	5.1	1.8	3	39	0.5	2.2	0.3	1.3*
Aug. 16-19	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Sept. 24-2	0.24(8.4)	0.030(2.7)	6	10.2	102	25	45	0.6	3.6	1.4	9	25	0.5	3.0	0.5	1.7*
1976																
June 19-24	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
July 16-26	0.37(13)	0.046(4.2)	11	8.3	96	37	38	0.6	15.7	3.8	7	25	0.6	2.3	0.7	3.2
Aug. 10-17	0.20(7.1)	0.025(3.3)	12.5	9.4	113	50	43	0.5	3.4	2.2	<3	<10	0.6	2.7	0.7	4.0
Logan Creek																
Mouth																
1975																
July 12-16	–	–	–	–	–	–	–	0.2	4.3	1.5	3	20	0.7	1.9	0.5	1.3*
1976																
July 16-26	2.52(89)	0.044(4.1)	7	9.5	97	66	58	0.7	2.6	5.2	4	–	0.4	1.5	1.3	7.9
Aug. 10-17	1.61(57)	0.028(2.6)	8	8.9	93	78	65	0.9	4.6	2.6	<3	<10	0.6	1.7	1.6	9.1

* Values low due to interference with silicone in analytical procedure used.

Table 8. Physical and chemical data for Big Creek at Taylor Ranch and Big Creek Ranger Station, above Indian Creek on the Middle Fork of the Salmon River, at the Flying B Ranch and at the mouth of Indian Creek, and on Chamberlain Creek at Chamberlain Basin, 1975-1976.

	Flow cms(cfs)	Flow csk(csm)	Temp. °C	O_2 mgl^{-1}	% O_2	M.O. Alk. (HCO_3) mgl^{-1}	Elect. cond. umhos	Turb. NTU	Total Susp. Sol. mgl^{-1}	SO_4 mgl^{-1}	PO_4 μgl^{-1}	NO_3 μgl^{-1}	K+ mgl^{-1}	Na+ mgl^{-1}	Mg++ mgl^{-1}	Ca++ mgl^{-1}
Big Creek																
Taylor Ranch																
1975																
July 12-16	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Aug. 16-19	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Sept. 24-2	10.56(373)	0.007(0.7)	7.5	10.8	104	56	116	0.2	2.4	1.5	<3	18	0.4	1.2	0.4	1.5*
1976																
June 19-24	–	–	6	10.9	101	55	47	1.5	9.6	2.6	8	<10	0.6	2.1	1.2	5.8
July 16-26	17.00(600)+	0.012(1.1)	11	8.9	93	85	79	0.5	4.0	2.7	6	45	0.7	2.0	2.0	11.0
Aug. 10-17	13.42(474)	0.009(0.9)	9.5	9.3	93	97	75	1.2	11.2	4.4	<3	73	1.0	2.8	2.4	10.3
Ranger Station																
1976																
July 16-26	3.48(123)	0.045(4.1)	12	8.2	94	61	48	0.9	2.1	2.4	3	40	0.2	1.1	0.8	6.1
Aug. 10-17	1.61(57)	0.021(1.9)	12	8.0	94	69	56	3.4	7.1	3.1	<3	<10	0.5	1.9	1.3	8.0
Middle Fork Salmon River																
Flying B Ranch																
1975																
Sept. 24-2	–	–	11	11.3	117	45	103	0.4	4.0	2.5	3	21	0.5	4.6	1.2	4.1*
1976																
June 19-24	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
July 16-26	70.79(2500)+	0.014(1.3)	16.5	9.0	107	81	89	0.4	7.0	4.2	4	32	0.7	3.5	1.2	12.7
Aug. 10-17	53.09(1875)+	0.010(0.9)	13	9.7	106	85	81	1.0	7.8	4.3	<3	<10	0.8	3.9	1.3	11.6
above Indian Creek																
1976																
July 1	99.11(3500)+	0.052(4.4)	12.5	11.3	130	60	58	1.3	1.6	1.5	7	<10	0.4	2.0	0.7	7.0
Indian Creek																
1976																
July 1	2.83(100)+	0.034(1.2)	10	9.3	98	66	50	0.5	1.6	1.5	4	<10	0.5	2.1	0.9	6.2
Chamberlain Creek																
1975																
July 12-16	–	–	–	–	–	–	–	0.2	5.8	1.5	<3	30	0.7	1.9	0.5	1.3*
1976																
Aug. 10-17	1.93(68)	0.034(1.2)	12	8.4	96	67	52	0.4	2.8	11.6	<3	<10	0.8	2.8	1.2	5.4

+ Estimated from partial data.

* Values low due to interference with silicone in analytical procedure used.

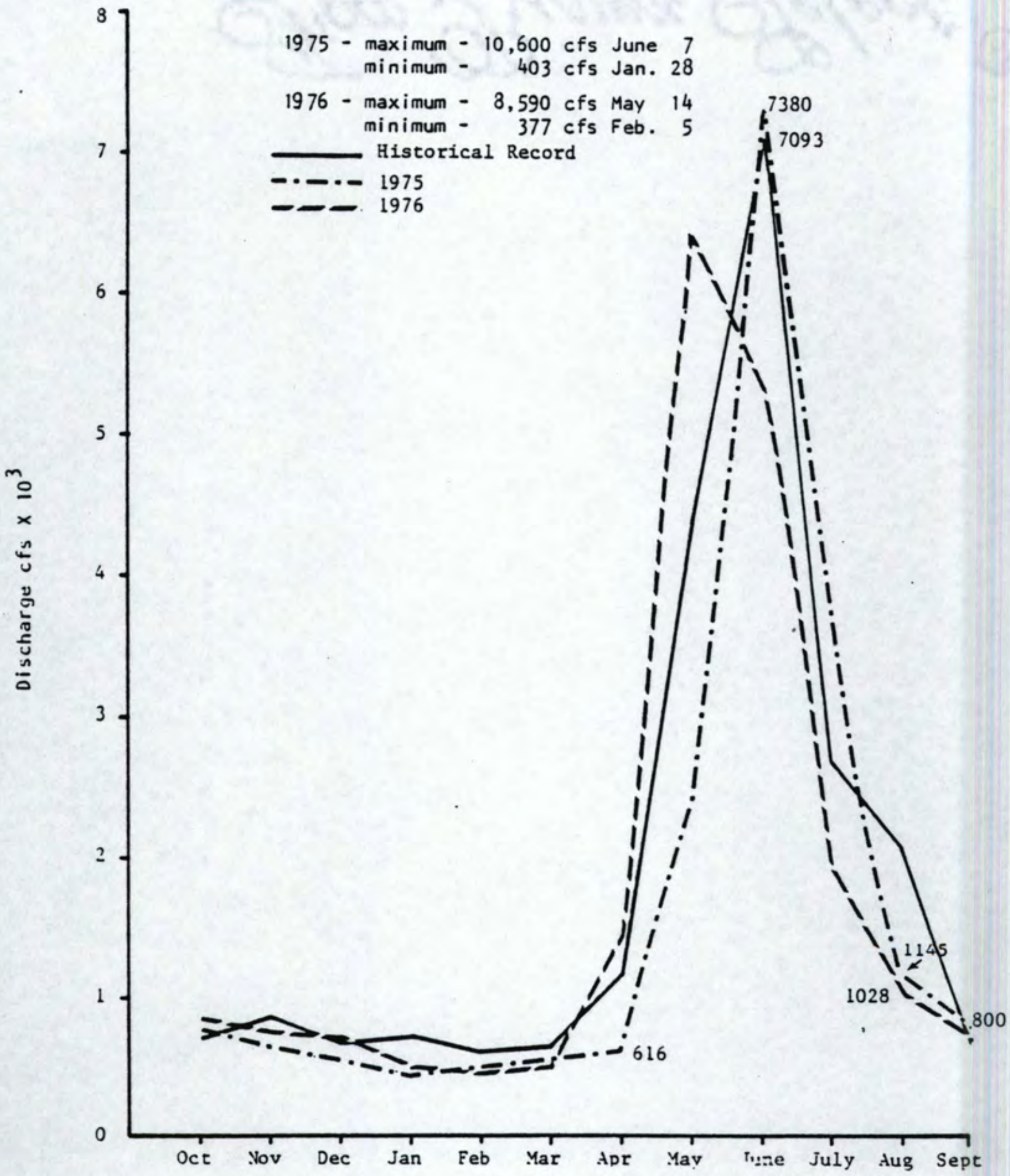

Figure 3. Discharge for Middle Fork Salmon River at Middle Fork Lodge, 1975-1976 water years and historical flow.

*Historical flow is a mean of 3.5 years.

streams flowed through open areas, such as meadows on upper Monumental Creek and upper Lodgepole Creek, temperatures attained 15C on warm summer days (Tables 6 and 7).

Emmett (1975) found the summer daily stream water temperature varied 1-4C in the upper Salmon drainage. Daily variation in temperature was not sampled during this study but daytime stream temperature ranges in the FCRNRWA should be similar. Low temperatures near the mouth of Lodgepole and Snowslide creeks and in the headwaters of West Fork Monumental Creek probably were a result of morning sampling, before water temperatures increased (Tables 5, 6, 7, and 8).

Electrical Conductivity

Electrical conductivity in the study streams ranged from 25 μmhos on upper Beaver Creek at high flow to 122 μmhos at the mouth of Snowslide Creek at low flow (Table 5 and Figure 4).

Bayly and Williams' (1973) work in Australia and Wetzel's (1975) work in North America determined that the major ions contributing to conductivity in most temperate waters are HCO_3, Ca, Mg, and SO_4. Ion concentrations, as indicated by electrical conductivity, were smaller in headwater areas and small feeder streams and greater in downstream areas (Figure 4).

The amount of ionized salts contributed to a stream is dependent on the geology and prevailing precipitation of the watershed (Hem, 1975). Normally, as watershed area

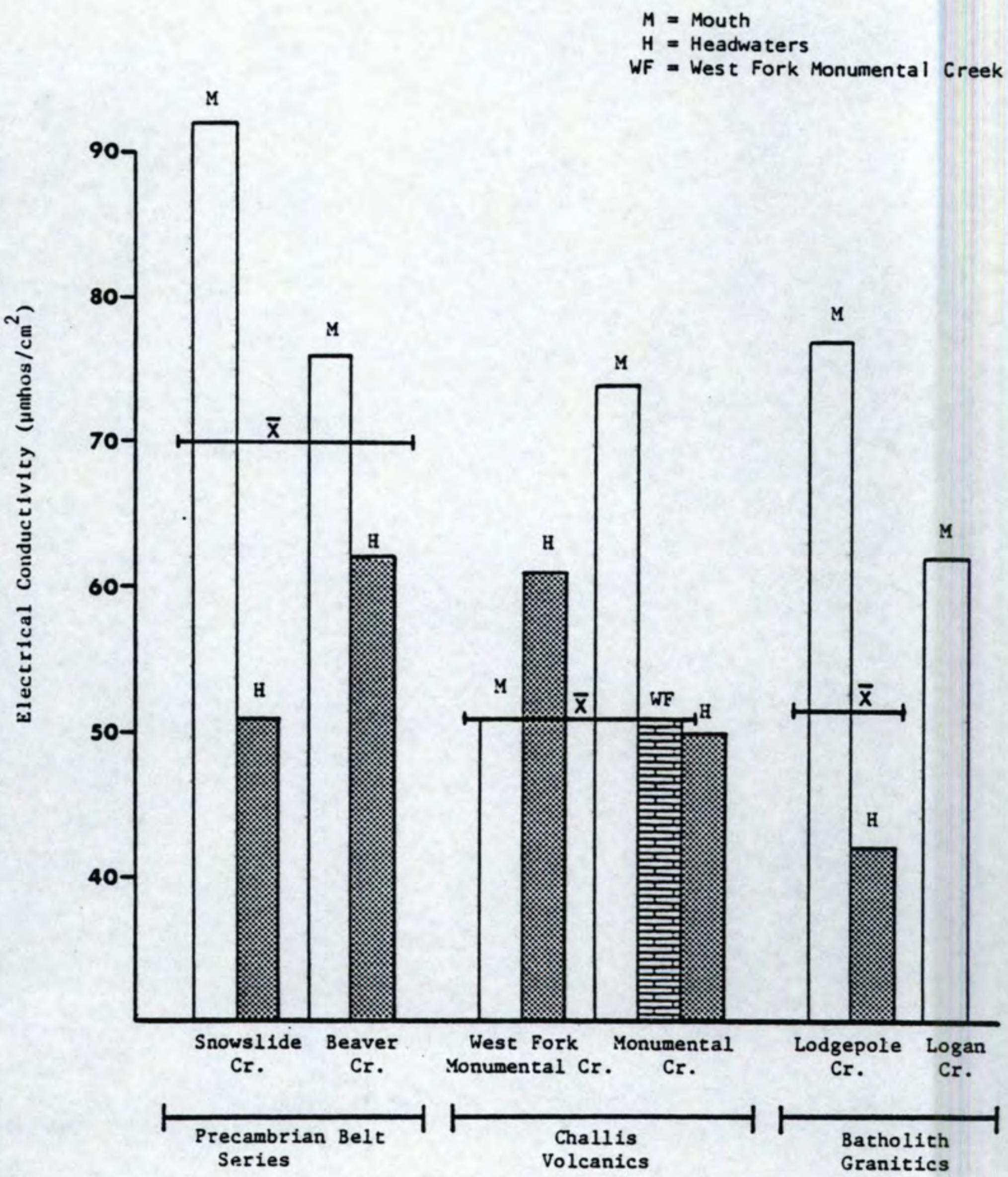

Figure 4. Mean low flow electrical conductivity (µmhos/cm^2) of selected streams in the Frank Church River of No Return Wilderness Area, Idaho, 1975-1976.

increases, electrical conductivity does also (Reid, 1964). Miller (1961) found the average solute concentrations of stream water draining the major rock types; quartzite (metamorphic), granite (igneous), and sandstone (sedimentary), to occur in a 1.0:2.5:10.0 ratio. The specific rock types within the Wilderness Area were the Pre-Cambrian Belt Series (metamorphic) where streams had the highest conductivity, the Idaho Batholith (igneous) where stream conductivity was less than the Belt Series, and the Challis Volcanics (igneous) with conductivity values comparable to those of the Batholith (Figure 4). Variability in weathering rates within these geologic types explain why ion concentrations contributed to the Wilderness Area streams do not follow Miller's ratio. Also, the Pre-Cambrian Belt rocks of this area were subjected to low-grade metamorphism and therefore are more soluble than the metamorphic rock Miller studied (Carter et al., 1973).

Few additional ionized salts are contributed to Wilderness Area streams via precipitation since conductivity of snowmelt water in the western United States is low, ranging from 2 to 42 μmhos (Feth, Rogers, and Roberson, 1964). Snyder (1973) determined the conductivity of precipitation to be 24 μmhos in the northern Idaho region. He also determined mean yearly conductivity of several undisturbed north Idaho streams to range between 31 and 58 μmhos. Conductivity of the Wilderness Area streams sampled (25-122 μmhos) is higher because these samples were summer means and not yearly means. Snyder determined summer conductivity of his study streams to range between 40 and 75 µmhos (approximately). Conductivity values are further lowered during periods of snowmelt in Wilderness Area streams.

Turbidity and Total Suspended Solids

Turbidity (NTU's) was highest in the large streams (Tables 5, 6, 7, and 8). Values were generally low and exceeded 2 NTU's only once, at the mouth of Snowslide Creek during June (Table 5). Readings were normally below 1 NTU.

Turbidity was so low (0.3 to 2.8 NTU's) even during periods of high flow that no trends with respect to mouth and headwater relationships or to geology were evident (Tables 5, 6, 7, and 8). Several localized incidents of large quantities of turbid water were observed. Chamberlain Creek received runoff from pack trails during heavy summer thundershowers and Monumental Creek turned a milky color from thunderstorm activity on Mud, Talc, and Milk creeks. During this thunderstorm, turbidity at the mouth of Monumental Creek increased from 1.2 to 23.0 NTU's in less than 15 minutes and total suspended solids increased from 6.4 to 54.9 mg l^{-1}.

Total suspended solids (mg l^{-1}) were usually very low in streams in the Wilderness Area, typically ranging from 1.2 mg l^{-1} at the mouth of Beaver Creek to 15.7 mg l^{-1} in the headwaters of Lodgepole Creek. Highs occurred during periods of high flow or just after heavy summer rain showers (Tables 5, 6, 7, and 8). Total suspended solids (TSS) concentrations most often were between 1.5 and 7 mg l^{-1}. TSS also showed no trends with respect to time of year, region of stream, or geology of the watershed (Tables 5, 6, 7, and 8). Increases in TSS were noted during or after periods of heavy rain. Total suspended solid values increased at many stations in July, 1976, a month of heavy storm events.

Oxygen and Percent Oxygen Saturation

Dissolved oxygen concentrations were high at all sample sites throughout the study. The low was 7.4 mg l^{-1} on Monumental Creek (92% saturation after altitude correction). The high was 11.5 mg l^{-1} at the mouth of Snowslide Creek. Values normally ranged between 8.5 and 10 mg l^{-1} (Tables 5, 6, 7, and 8). Percent oxygen saturation, corrected for altitude and temperature, usually approximated 100%. The low was 81.9% during July in Beaver Creek (Table 5).

Because of rapidly changing input and consumption rates, the oxygen content of a stream is highly variable, depending on location and time of sampling (Emmett, 1975). Oxygen in the stream is derived from atmospheric oxygen and photosynthesis. Oxygen levels in these study streams were high, falling below 90% oxygen saturation only on two occasions (in July, 1975). The percent saturation values were consistently close to 100% and are considered applicable to other pristine streams in the Wilderness Area. It appears that dissolved oxygen is not a limiting factor to aquatic life in area streams.

Methyl Orange Alkalinity

Alkalinity, the capacity of a solution to neutralize acid, is comprised primarily of bicarbonate and carbonate ions. Levels of methyl orange alkalinity in study streams were low to moderate and inversely related to flow (Tables 5, 6, 7, and 8). Methyl orange alkalinity ranged from 23.0 mg l^{-1} in the headwaters of Monumental Creek to 97.2 mg l^{-1} in Big Creek at Taylor Ranch (Tables 5, 6, 7, and 8). Higher values measured at the stations near stream mouths (Figure 5) were often double the concentration at headwater stations. The increase was due to an accumulation of carbonate and bicarbonate ions with increased drainage area downstream. Based on neutral pH and low alkalinity, streams in the Wilderness Area are classified as soft water streams (Reid, 1976).

Alkalinity levels are highest in the Pre-Cambrian Belt Series. The Idaho Batholith and the Challis Volcanics are both igneous type rock which weather more slowly than the Belt series. Also, the streams of these geologic types drain almost 50% less area than the Belt Series and therefore have lower alkalinity values (Figure 5).

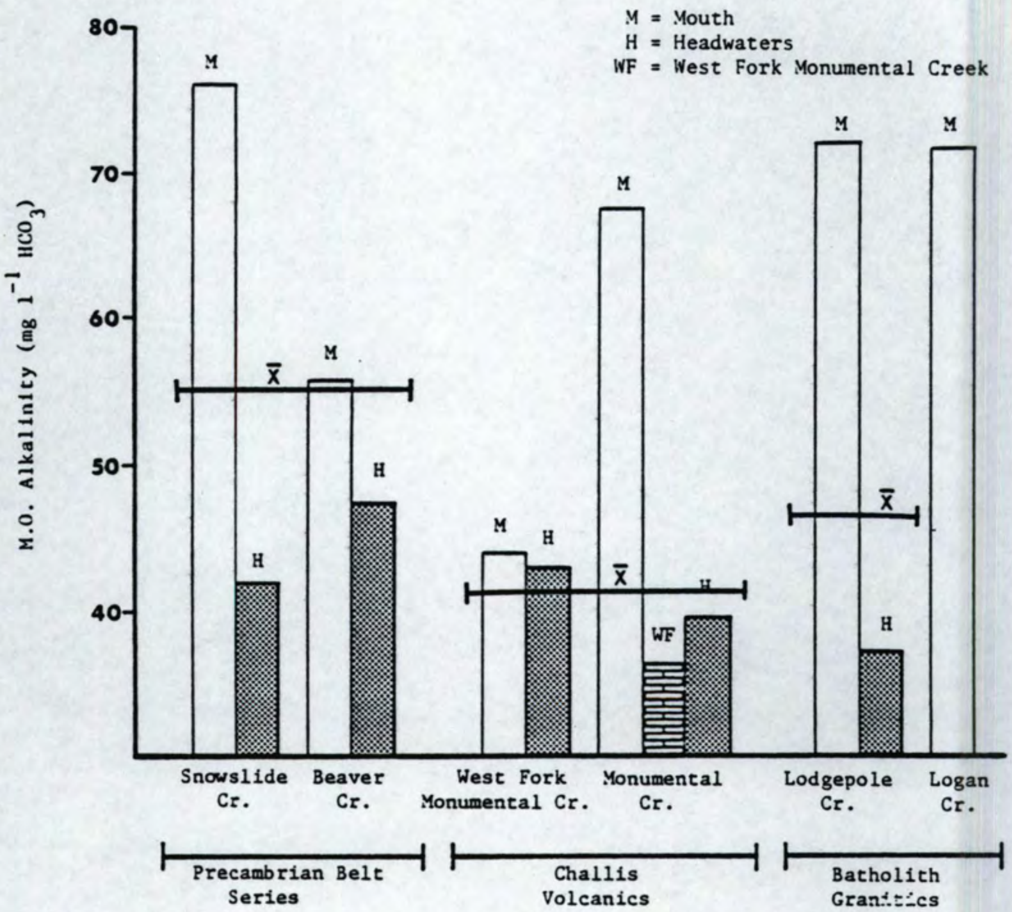

Figure 5. Mean low flow M.O. Alkalinity (mg l^{-1} HCO_3) of selected streams in the Frank Church River of No Return Wilderness Area, Idaho, 1975-1976.

pH

Stream pH was only measured during 1975. Values were close to neutrality, ranging from 6.9 to 8.1. The high was measured on Big Creek during September, 1975.

Nitrate and Phosphate

Nitrate-nitrogen (NO_3-N) levels in sample streams of the Wilderness Area were low and variable, often below detection limits (10 g l^{-1}) (Tables 5, 6, 7, and 8). Nitrate concentrations ranged from below detection limits to 150 g l^{-1} in the headwaters of Monumental Creek during July, 1976.

Levels of ortho-phosphate in study streams were low. Readings were often below detection limits (3 g l^{-1}) (Tables 5, 6, 7, and 8). The high of 9 g l^{-1} PO_4-P occurred in the headwaters of Lodgepole Creek during fall algal die off. Total filterable (dissolved) phosphate levels were typically 0 to 6 g l^{-1} higher than ortho-phosphate levels.

Biological production of a stream is related to plant nutrient availability. The concentration of NO_3 and PO_4 changes with ion uptake by algae and irregular changes of this nature are seen in certain streams of the Wilderness Area. No patterns were evident with respect to mouth and headwater station or geology of the watershed. Hem (1975) stated that nutrients often peak early in streams during periods of overland flows caused by snowmelt or heavy rains.

Nitrate levels were greatest during July, 1976, a period of heavy summer rains.

Sulfate

Sulfates varied from 1 mg l^{-1} in the headwaters of Snowslide Creek and mouth of the West Fork Monumental Creek to 11.6 mg l^{-1} in Chamberlain Creek. Sulfate levels usually ranged between 1 and 5 mg l^{-1} (Tables 5, 6, 7, and 8).

Igneous and sedimentary rocks have widely distributed sulfur deposits in reduced forms as metallic sulfides. During the weathering process these sulfides are oxidized to yield sulfate ions which are carried off by water. Pyrites constitute a potent source of sulfates, hydrogen ions, and iron in ground water (Hem, 1975).

Sulfates in our study streams increased as flows decreased through the summer (Tables 5, 6, 7, and 8). The Middle Fork Salmon River at the Flying B Ranch had slightly higher (1.5X to 2X) sulfate levels than other streams. Mouth stations also had higher sulfate levels than headwater stations (Tables 5, 6, 7, and 8). Emmett's (1975) work on undisturbed drainages of the upper Salmon River showed similar trends. No difference in sulfate levels was observed between geologies.

Snyder (1973) found mean summer sulfate levels from 0.5 to 9 mg l^{-1} in north Idaho streams.

Calcium Ion (Ca^{++})

Calcium is a constituent of many igneous rock minerals, especially of the chain silicates. Calcium also occurs in other silicate minerals produced in metamorphism. Concentrations in surface waters are usually low due to the slow rate of release from rocks of such minerals (Hem, 1975).

Calcium ion levels in the study streams were the highest of the metal ions tested. Calcium ion concentrations ranged from 2.6 mg l^{-1} Ca^{++} in Monumental Creek just above the mouth of the West Fork to 12.7 mg l^{-1} Ca^{++} at the Flying B Ranch (rkm 41.8) on the Middle Fork of the Salmon River (Figure 6). Only 1976 data are reported. Calcium samples from 1975 were analyzed by a technique where an interference with silicon often occurs. In 1976, samples were analyzed by a different technique where no interference occurs. Therefore, 1975 calcium data were considered invalid and not added to this report.

Calcium concentrations in the sample streams were up to 2X higher at mouth stations versus headwater stations (Figure 6). Study streams flowing through the Pre-Cambrian Belt rocks had levels of Ca^{++} almost twice that found in streams in the other two geologies. Calcium concentrations increased as flows decreased.

Snyder (1973) found considerably lower calcium levels in north Idaho streams than were observed in FCRNRWA streams; mean summer values ranged between 0.7 and 1.6

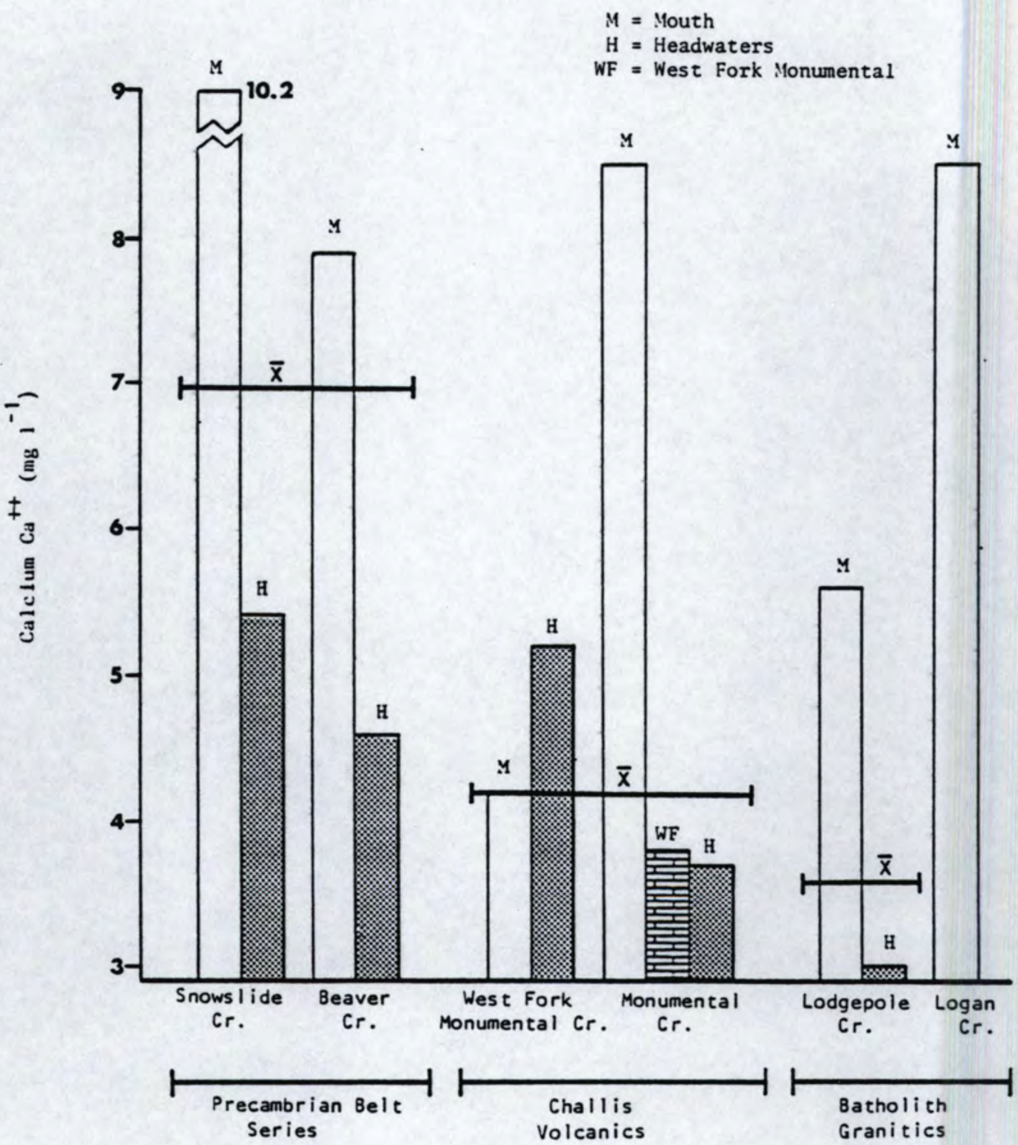

Figure 6. Mean low flow calcium concentrations (mg l^{-1} Ca) of selected streams in three geologic types of the Frank Church River of No Return Wilderness, Idaho, 1975-1976.

mg l^{-1}. These values were less than Wilderness Area stream values because of the small size of streams sampled in north Idaho (<0.03 m^3 s^{-1} to 0.3 m^3 s^{-1}) compared to 0.09 to 2.8 m^3 s^{-1} in FCRNRWA streams.

Magnesium Ion (Mg^{++})

Magnesium is a constituent of the dark colored ferromagnesium minerals of igneous rock and of the chlorite, montmorillonite, and serpentine of metamorphosed rock (Hem, 1975). The weathering rate of these different rock types influences the amount of magnesium that enters the stream. Streams in the Pre-Cambrian Belt Series had the highest concentration of magnesium; Challis Volcanic streams had the lowest (Figure 7).

Magnesium concentrations ranged from 0.2 mg l^{-1} at the mouth of the West Fork Monumental Creek to 3.1 mg l^{-1} at the mouth of Snowslide Creek (Tables 5, 6, 7, and 8). Readings were lowest during periods of high flow, increasing in concentration as flows decreased. Magnesium levels at stream mouth stations were up to five times greater than at headwater stations (Figure 7).

In most temperate zone streams magnesium concentrations are much lower than calcium concentrations and slightly less than sodium concentrations (Livingstone, 1963). Streams sampled in the Wilderness Area follow this pattern (Tables 5, 6, 7, and 8).

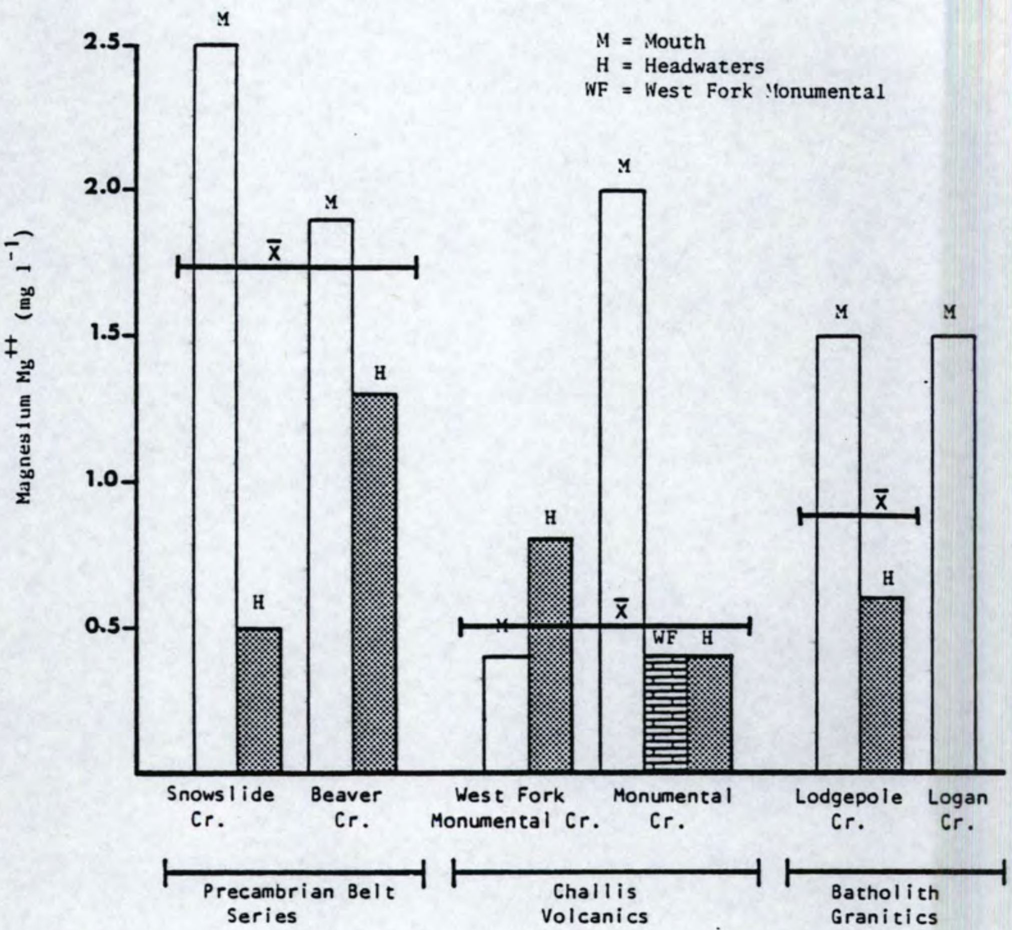

Figure 7. Mean low flow magnesium concentrations (mg l^{-1} Mg) of selected streams in three geologic types of the Frank Church River of No Return Wilderness Area, Idaho, 1975-1976.

Sodium Ion (Na^+)

In stream and spring water of the Sierra Nevada Mountains of California and Nevada, calcium and sodium were the most abundant ions, reflecting the abundance of these ions in the parent rock types and the rate at which the minerals were weathered (Feth, Roberson, and Polzer, 1964). In streams of the Wilderness Area calcium and sodium were the most abundant of the metal ions tested (Tables 5, 6, 7, and 8).

Concentrations of sodium ion ranged between 1.0 mg l^{-1} sodium ion in Smith Creek to 4.6 mg l^{-1} in the Middle Fork Salmon River at the Flying B Ranch. Most sodium ion levels fell within the range of 1.5 to 3.0 mg l^{-1} (Tables 5, 6, 7, and 8).

Stations near stream mouths had higher concentrations of sodium than the headwater stations in all streams except Beaver Creek (Figure 8), which originates in and flows through the Idaho Batholith for approximately three miles before passing into rocks of the Pre-Cambrian Belt Series. The batholith, with proportionately higher sodium levels, results in a headwater sodium concentration higher than at the mouth. The lower portion of the Beaver Creek drainage dilutes the sodium levels of the stream, lowering concentrations at the mouth relative to the headwaters. Sodium concentrations were highest in streams of the Idaho Batholith and lowest in streams of the Pre-Cambrian Belt Series (Figure 8).

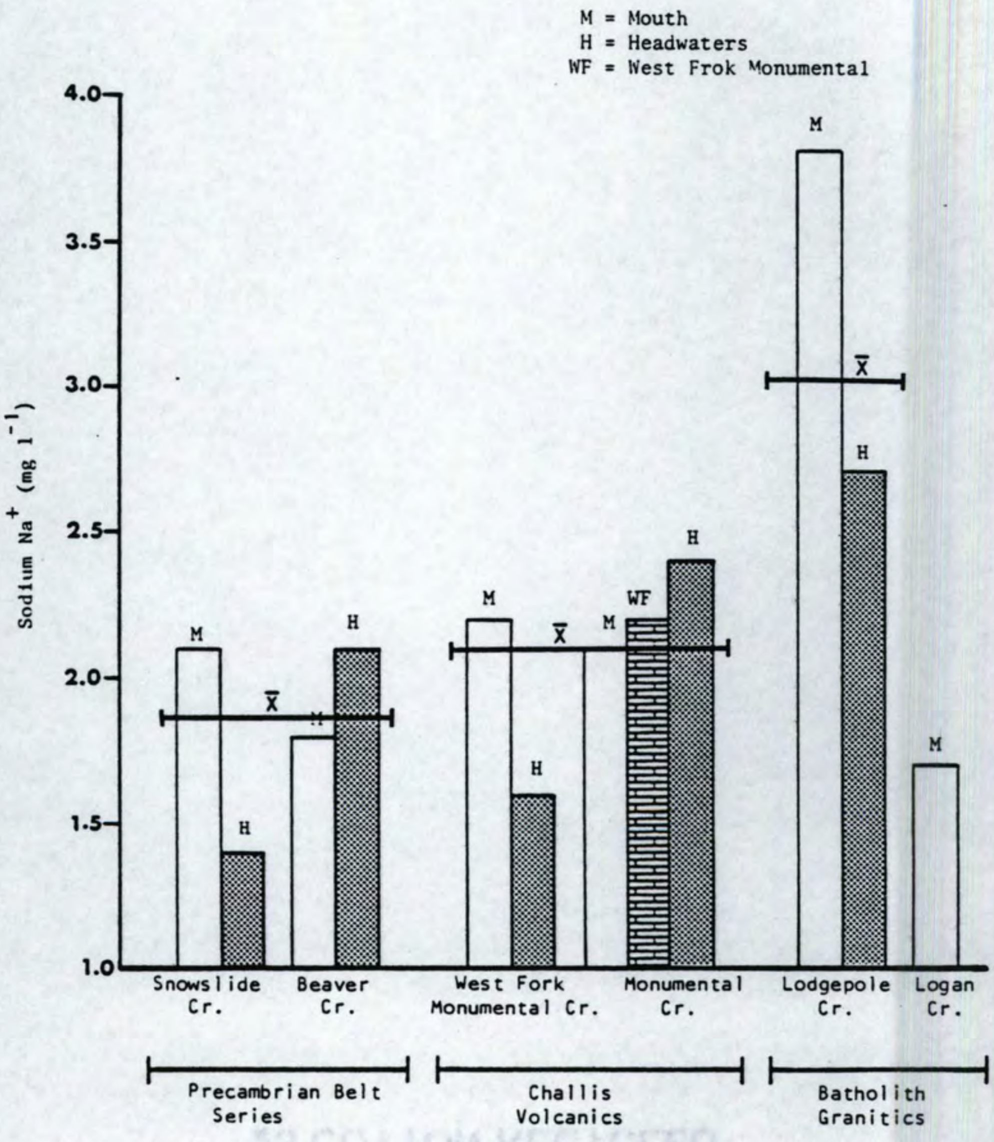

Figure 8. Mean low flow sodium concentrations (mg l^{-1} Na) of selected streams in three geologic types of the Frank Church River of No Return Wilderness Area, Idaho, 1975-1976.

A similar phenomenon occurred on Monumental Creek where the upper 24 kilometers flow through Challis Volcanics, a formation relatively rich in sodium. The lower portion drains the Pre-Cambrian Belt Series, which are lower in sodium than the Volcanics. These near-mouth waters are diluted by the lower tributaries carrying less sodium because of the localized parent geology (Figure 8).

Small montane zone forest streams of northern Idaho had sodium levels of 3-5 mg l^{-1} (Snyder, 1973).

Potassium Ion (K^+)

Potassium ion concentrations were moderate to low ranging from 0.1 mg l^{-1} in the headwaters of the West Fork Monumental Creek to 1.1 mg l^{-1} at the mouth of Lodgepole Creek (Tables 5, 6, 7, and 8).

The principal potassium minerals of silicate rocks are the micas and feldspathoid leucite which are very resistant to weathering by water. Upon release through weathering, potassium ion tend to be reincorporated into solid weathering products, especially certain clay minerals (Hem, 1975). The somewhat narrow range in concentrations of potassium observed in these unpolluted waters suggests that such a chemical control mechanism may be involved. This may be why differences in potassium concentrations were often more variable within geologic types than between different geologic types (Figure 9).

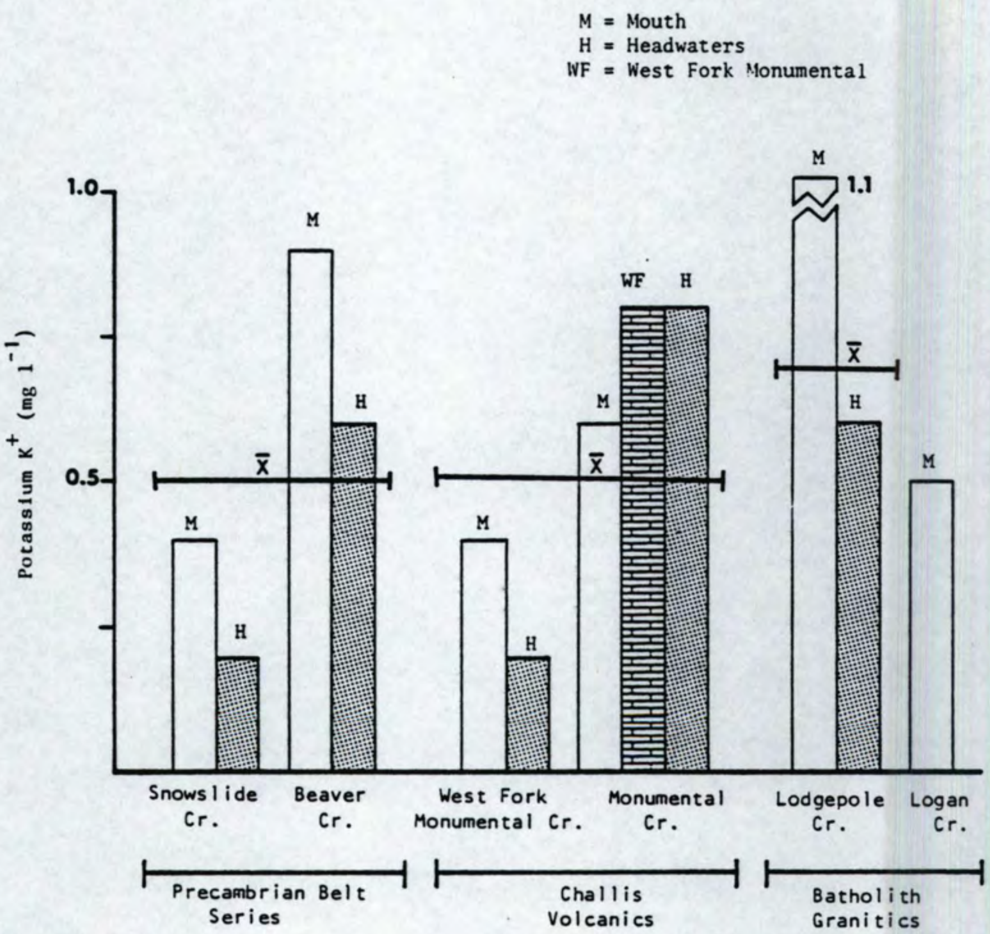

Figure 9. Mean low flow potassium (mg l^{-1} K) for selected streams in the Frank Church River of No Return Wilderness Area, Idaho, 1975-1976.

Potassium concentrations increased from headwater to mouth stations at all streams except Monumental Creek (Figure 9). The decrease from headwater to mouth stations on Monumental Creek is due to the dilution of the stream by the West Fork Monumental and Snowslide creeks, where potassium concentrations are about half that of Monumental Creek above the mouth of the West Fork.

All streams showed an increase in potassium ion concentration with declining flow (Tables 5, 6, 7, and 8). In small north Idaho streams draining predominately Pre-Cambrian metamorphic bedrock, potassium levels were normally between 0.5 and 1.7 mg l^{-1} (Snyder, 1973).

West Fork Monumental Creek

Several parameters in the West Fork Monumental Creek had higher concentrations in the headwaters than at the mouth. Conductivity was 10 μmhos higher in the headwaters, alkalinity was only 1 mg l^{-1} less in the headwater than the mouth, and calcium was 1 mg l^{-1} higher in the headwaters (Tables 5, 6, 7, and 8). This was unusual for a stream that flows entirely within one geologic type. A plausible explanation is that the West Fork drainage is very narrow. There are a great number of small, steep feeder streams, less that two kilometers long, draining into the West Fork. These small streams normally have very low levels of dissolved solids and undoubtedly dilute the headwater stream, causing a decrease in concentration of some parameters.

Stiff Diagrams

Within temperate zone streams, dissolved solids are generally lowest during periods of peak snowmelt runoff and highest during low flow periods. A Stiff diagram of a station during low and high flows emphasizes this point (Figure 10). The shape of the Stiff diagram remains similar at both flow regimes, except that at high flow there is a compression along the X-axis indicating a dilution of the ionic concentrations caused by snowmelt runoff.

In streams flowing entirely within one geologic type, different ions increased proportionately downstream. A Stiff diagram graphically describes the relationship between mouth and headwater stations (Figure 11). The mouth station polygon is expanded along the X-axis because of an accumulation of ions downstream due to evaporation of stream waters and to extended exposure of stream waters to surface rock and soil of the drainage.

Ionic concentrations of two streams from the Pre-Cambrian Belt Series are visually compared by a Stiff diagram (Figure 12). That the ions contributed to the streams are similar is substantiated by similar size and shape of the polygons from each stream (Snowslide and Beaver creeks). The Beaver Creek drainage is twice the size of the Snowslide watershed, but produces approximately three times

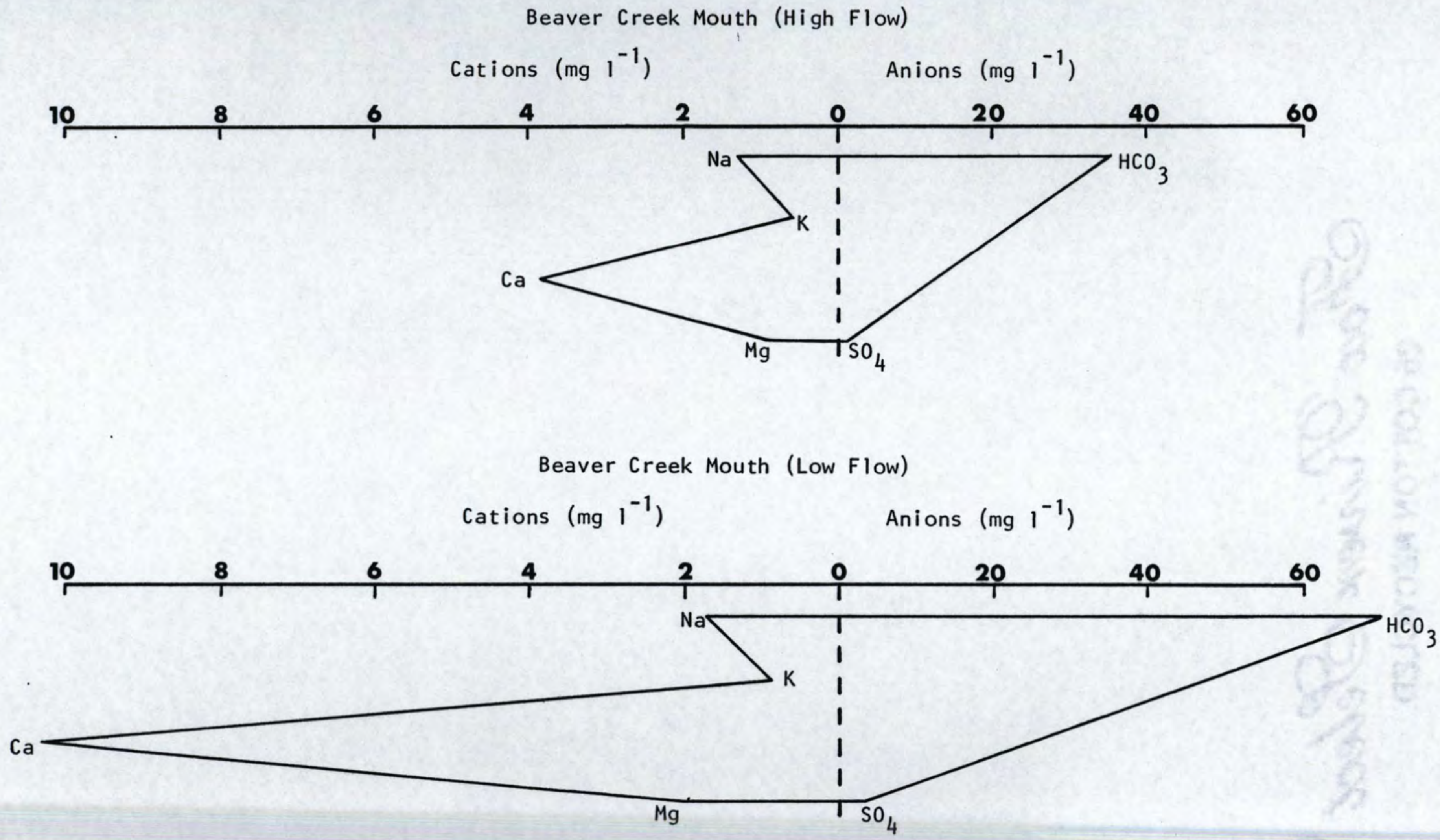

Figure 10. Stiff Diagram: Effect of high and low flows on certain dissolved ions in Beaver Creek, 1976.

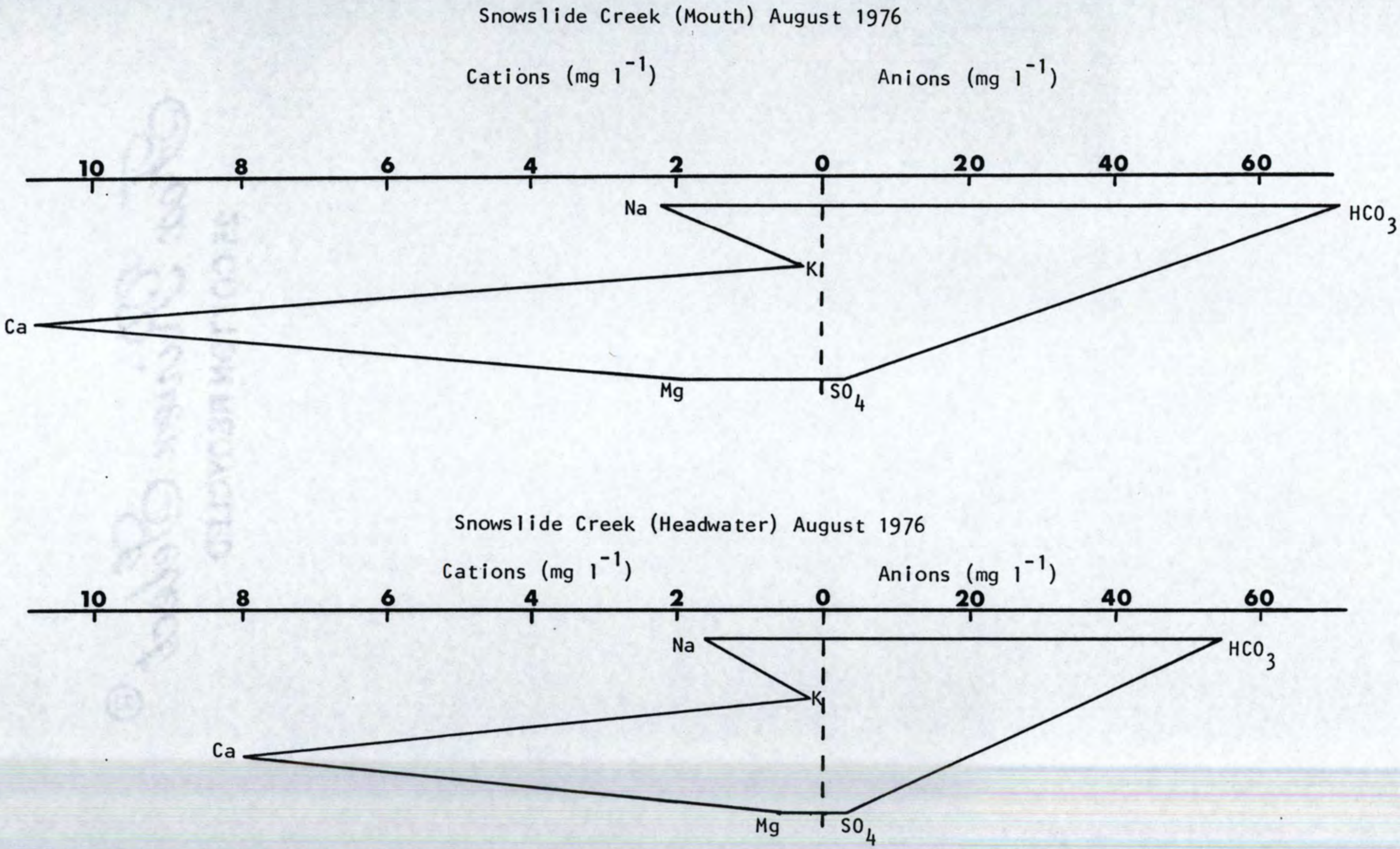

Figure 11. Stiff Diagram: The ion relationships of near mouth and headwater stations of a stream (Snowslide Creek) in the Frank Church River of No Return Wilderness Area, Idaho, August 1976.

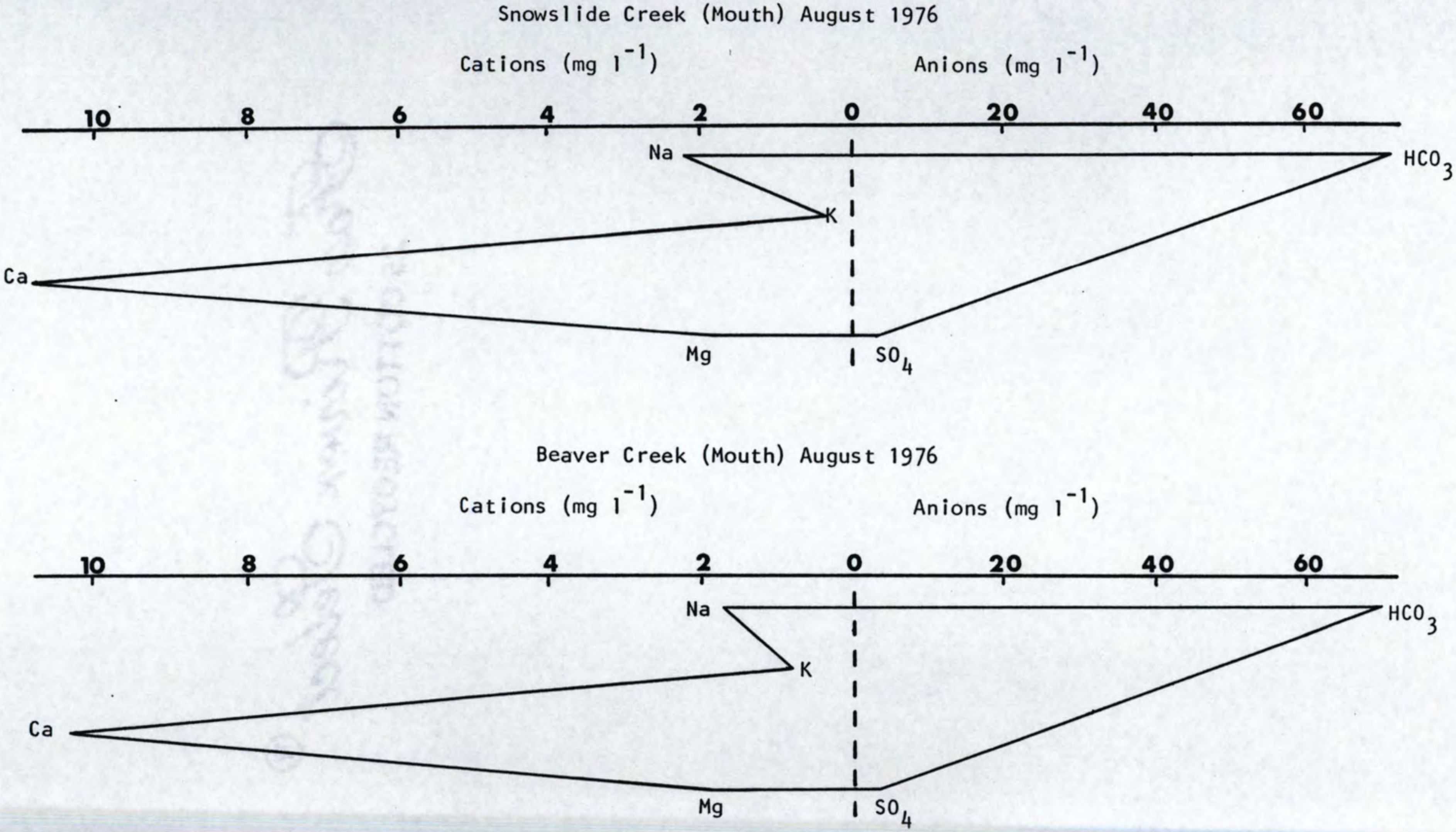

Figure 12. Stiff Diagram: Relationship between near mouth stations of two streams flowing through the same geologic type (Precambrian Belt Series). Data is from one low flow sampling, August, 1976.

the runoff; therefore, the dissolved solids concentrations within both streams are similar. The important feature shown by the Stiff diagrams is the similarity of relative ion proportions.

Dissimilar geological types have different geochemistries and weather at different rates, thereby contributing differing amounts of dissolved solids to their streams. The Stiff diagram graphically represents this relationship (Figure 13) between Monumental Creek at the West Fork (Challis Volcanics) and Snowslide Creek (Pre-Cambrian Belt Series). The Belt Series is higher in calcium, magnesium, and carbonate while having equal or slightly lower concentrations of sodium, potassium, and sulfates. The relative ionic proportions differ with geology: the Pre-Cambrian Belt Series had the highest overall concentrations of dissolved ions, while the Volcanics and Batholith had lower but similar dissolved ion levels.

Chlorophyll, Biomass, and Autotrophic Index

Algae contain three characteristic types of pigments: chlorophylls, xanthophylls, and carotenes. Attached benthic algae contain three chlorophyll pigments that are easily monitored, a, b, and c. Since algae may contain up to 2% of the dry weight of its organic material as chlorophyll a, chlorophyll a is an effective indicator of actively

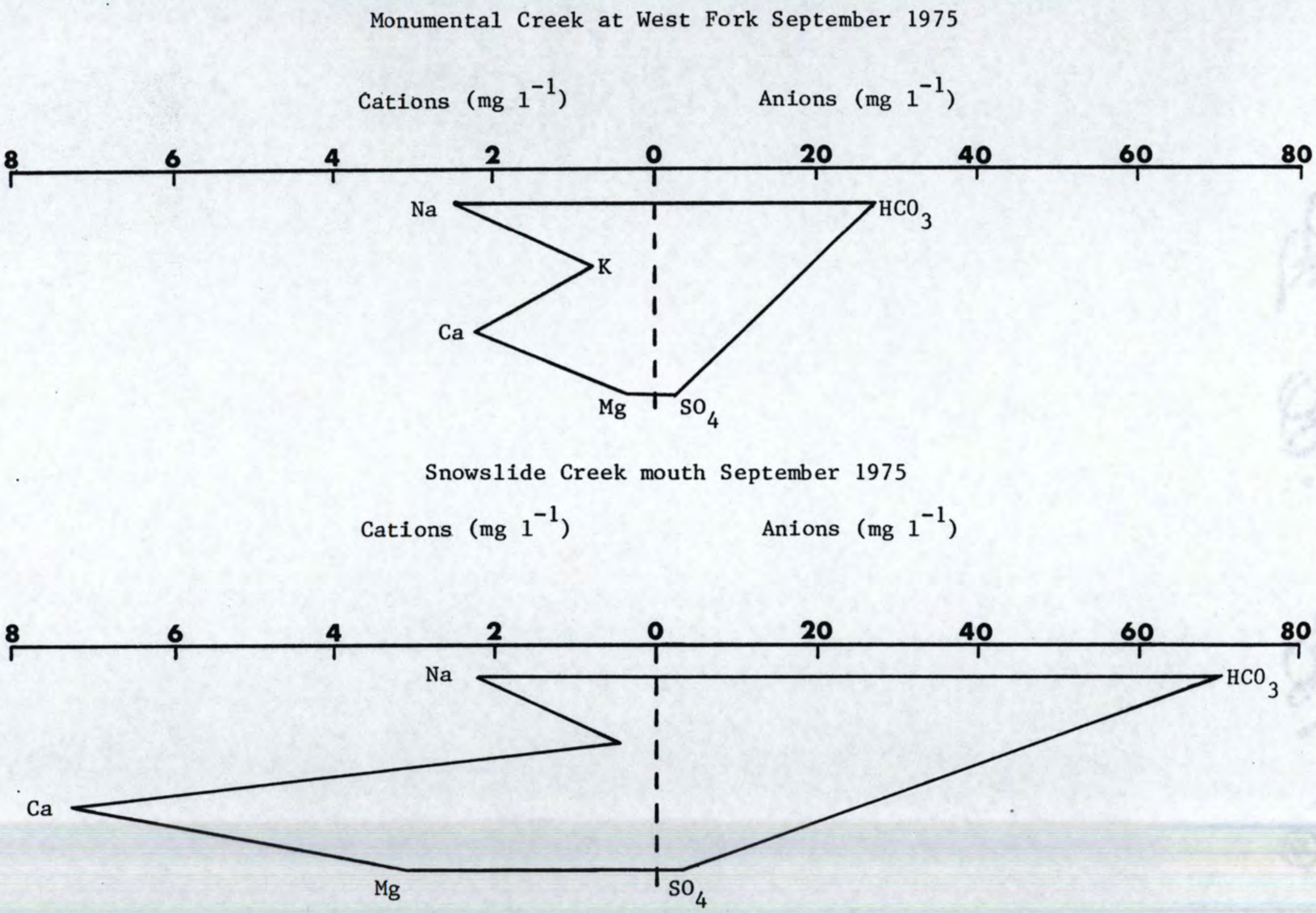

Figure 13. Stiff Diagram: The relationship between ions of near mouth stations of two streams (Monumental Creek and Snowslide Creek), each flowing through a different geologic type (Challis Volcanics, Precambrian Belt Series respectively). Data is from one low flow sampling, September, 1975.

photosynthesizing algal biomass (Weber and McFarland, 1969; Weber, 1973).

Individual chlorophyll a values ranged from 1.91 mg m^{-2} at the headwaters of Monumental Creek to 11.70 mg m^{-2} at the headwaters of Lodgepole Creek. Mean values are represented in Table 9.

Mean algal biomass varied from 342 mg m^{-2} at the headwaters of West Fork Monumental Creek to 2,101 mg m^{-2} in the headwaters of Lodgepole Creek. Upper Lodgepole Creek chlorophyll a and attached plant biomass was high because the bryophyte Fontinalis was heavy in this portion of the stream. Algal biomass was less than 56% of the high for all other stations sampled, typically ranging between 350-980 mg m^{-2} (Table 9).

Vannote et al. (1980) proposed the River Continuum Concept to explain the interrelationships and changes in selected variables along a stream continuum. That concept states that toward their headwaters, undisturbed streams in timbered watersheds will be heterotrophic because of their intimate association with the terrestrial environment with subsequent heavy shading by the forest canopy, inhibition of instream primary production, and large input of allochthonous organic matter. As the stream and canyons widen, sunlight reaches enough of the streambed to allow more autochthonous primary production in the mid-reaches of a river system. Wilderness Area streams follow Vannote's

Table 9. Mean low flow potassium (mg l^{-1} K) for selected streams in the Frank Church River of No Return Wilderness Area, Idaho, 1975-1976.

Stream	Station	Benthic invertebrate biomass (mg m^{-2})	Shannon species diversity ($\bar{d}$)	Equitability (e)	Algal biomass (ash-free) (mg m^{-2})	Chlorophyll a (mg m^{-2})	Chlorophyll c (mg m^{-2})	Autotrophic index
Snowslide Creek	Mouth	409	2.85	0.91	580	6.87	4.72	84
	Headwater	269	2.91	0.79	656	3.18	4.91	206
Beaver Creek	Mouth	710	3.06	0.95	815	3.60	3.73	227
	Headwater	280	2.61	0.87	839	4.09	3.05	205
West Fork Monumental Creek	Mouth	904	2.82	0.74	841	3.39	2.43	248
	Headwater	398	3.07	0.95	455	5.97	4.03	76
Monumental Creek	Mouth	517	2.96	0.85	560	7.36	4.11	76
	West Fork	258	2.63	0.84	580	5.31	5.36	109
	Headwater	248	2.95	0.90	342	1.91	3.46	179
Lodgepole Creek	Mouth	--	--	--	762	--	--	--
	Headwater	355	3.24	1.03	2,101	11.70	3.48	180
Logan Creek	Mouth	377	2.35	0.87	549	1.95	2.50	282
Big Creek	Taylor Ranch	409	2.97	1.00	1,289	10.84	5.63	119
	Big Creek Ranger Station	452	2.11	0.83	980	4.65	3.54	211
Middle Fork Salmon River	Flying B Ranch	527	2.76	1.07	814	5.77	4.63	141
Number of replicates per sample		3	3	3	6	6	6	

hypothesis. Primary production, measured as mg m^{-2} chlorophyll a, increased with drainage area size. Cushing et al. (1983) found a similar trend on the Middle Fork Salmon River, Idaho and its tributaries.

Headwater stations normally had less filamentous algae attached to rocks but more of the bryophyte Fontinalis. This caused biomass to increase without a corresponding increase in chlorophyll, resulting in a higher autotrophic index at headwater stations where Fontinalis was found (Table 9).

Algal biomass was low at all stations except at the headwaters of Lodgepole Creek. The high biomass levels at this station were due to heavy growths of Fontinalis.

A useful water quality indicator is the ratio of algal biomass to chlorophyll a, the autotrophic index. In pristine waters the attached plant community is composed mostly of autotrophic chlorophyllous algae. As organic enrichment of waters occurs the proportion of non-chlorophyllous organisms (heterotrophic bacteria, fungi, and non-living detritus) increases. Therefore, the autotrophic index is a means of relating changes in benthic algae to changes in water quality. Values greater than 300-500 may result from organic pollution.

Mean autotrophic index values for study streams ranged from 76 at the mouth of Monumental Creek to 282 at the mouth of Logan Creek (Table 9). The high at Logan Creek may be caused by septic tank effluent from several cabins in the vicinity.

Chlorophyll a usually comprises up to 1-2% of the dry weight of algal organic material. I found between 0.08-5.5% chlorophyll a, but levels were generally below 1%. Cushing et al. (1983) found chlorophyll levels 12X higher than mine at the mouth of Big Creek, 13 kilometers below our Big Creek sample site at Taylor Ranch, and 1.5X higher than mine in the Middle Fork Salmon River above the mouth of Big Creek compared to my sample site at Flying B Ranch. Cushing et al. generally reported chlorophyll a levels in tributaries of the Middle Fork Salmon River which were much higher than those we found. Autotrophic index values reported here are probably high due to low chlorophyll since other sample parameters indicated no organic pollution was present.

Benthic Invertebrate Numbers, Biomass, and Indices

The most common insects found in the study were of the order Ephemeroptera (mayflies). The two most common genera were Epeorus and Rithrogena (Tables 10, 11, and 12). Average total numbers of insects per square meter ranged from 226 at the mouth of Logan Creek and headwaters of Big Creek to 1,034 in the Middle Fork Salmon River at the Flying B Ranch for 1975 and 1976. A large component of the insects in the sample from the Middle Fork Salmon River were Hydropsychidae caddisflies (Table 12). The average number of genera per sample varied from 9 at the mouth of Indian

Table 10. Mean number of benthic macroinvertebrates per square foot of stream bottom for selected streams in the Frank Church River of No Return Wilderness Area, July-October, 1975.

Order	Precambrian Belt Series				Challis Volcanics				Batholith Granitics		Large Streams	
Family	Snowslide Creek		Beaver Creek		West Fork Monumental Cr.		Monumental Creek		Lodgepole Creek		Big Creek	Middle Fork Salmon River
Genus	M*	H	M	H	M	H	WF*	H	M	H	Taylor Ranch	Flying B Ranch
Replicates in Mean	6	3	3	6	6	6	6	6	3	6	3	3
Ephemeroptera												
Ameletus	–	9.0	–	–	–	1.5	–	–	–	–	–	–
Baetis	1.4	–	1.0	–	2.3	0.5	1.0	–	–	–	0.5	–
Cinygmula	3.0	1.0	–	3.0	4.5	17.8	1.0	1.5	–	1.0	5.5	0.5
Epeorus	19.2	12.0	25.0	0.5	8.5	4.3	3.5	5.5	6.0	2.0	–	–
Ephemerella	4.0	11.0	6.0	1.0	6.5	9.5	7.0	3.5	–	11.5	7.5	1.5
Paraleptophlebia	–	–	–	–	0.3	–	–	–	–	3.0	–	–
Pseudocloeon	0.2	–	–	–	4.0	–	–	–	–	–	–	7.0
Rhithrogena	10.4	5.0	24.0	5.0	14.3	4.3	11.0	12.5	13.0	1.0	35.5	17.0
Plecoptera												
Acroneuria	0.6	3.0	–	–	2.3	0.3	–	1.0	1.0	–	–	1.0
Alloperla	–	–	–	–	–	–	0.5	–	–	–	–	–
Arcynopteryx	1.0	–	2.0	–	0.8	0.5	0.5	0.5	1.0	2.0	–	–
Brachyptera	–	–	–	–	–	–	–	–	–	–	–	4.5
Claassenia	–	–	–	–	0.8	–	–	–	–	–	0.5	–
Hastaperla	3.2	2.5	1.0	0.5	4.5	0.8	0.5	1.0	–	–	0.5	–
Isogenus	3.0	0.5	–	–	2.3	–	2.0	–	–	–	1.5	–
Kathroperla	–	–	–	–	–	–	–	–	–	0.5	–	–
Nemoura	2.6	5.0	9.0	10.5	2.5	10.3	1.0	2.0	3.0	11.0	–	3.0
Neoperla	–	–	–	–	0.3	–	–	–	–	–	–	0.5
Paraperla	0.4	7.5	2.0	–	0.5	0.5	–	0.5	–	0.5	–	–
Peltoperla	–	–	–	–	1.0	3.8	–	1.5	1.0	19.5	–	0.5
Trichoptera												
Brachycentrus	–	–	–	–	–	–	–	–	–	–	–	–
Glossosoma	0.2	–	–	–	–	–	–	–	–	–	4.5	1.0
Hydropsychidae	0.4	6.0	4.0	1.5	–	2.5	–	–	11.0	4.0	13.0	55.0
Neophylax	–	–	–	–	0.3	–	–	–	–	–	–	–
Neothremma	1.6	0.5	–	–	–	0.5	0.5	–	1.0	40.0	1.5	1.0
Rhyacophila	–	1.0	1.5	2.0	0.3	1.8	–	–	–	–	–	–
Triaenodes	–	–	–	–	–	2.8	–	–	2.0	–	–	–
Diptera												
Blephariceridae	–	–	–	–	–	–	–	–	–	–	3.0	–
Chironomidae	7.8	8.5	4.0	8.5	12.3	6.0	34.5	19.0	–	2.0	7.0	12.0
Tipulidae	0.4	–	–	–	0.5	–	–	–	–	3.5	1.5	1.5
Coleoptera												
Elmidae	–	–	1.5	–	–	0.3	0.5	–	–	–	–	0.5
Hemiptera	–	–	0.5	–	0.3	–	–	–	–	0.5	–	–
Hirudinea	–	–	–	0.5	–	2.5	–	–	–	1.0	–	–
Average total number per sample	59.4	72.5	81.5	33.0	69.1	70	63.5	48.5	39.0	103.0	82	109.5
Average number of genera per sample	13	12	11	8	12	12	8	7	11	11	10	11

*M & H represent mouth and headwater stations respectively and WF represents Monumental Creek above the mouth of the West Fork Monumental Creek.

Table 11. Mean number of benthic macroinvertebrates per square foot of stream bottom for selected streams in the Frank Church River of No Return Wilderness Area, June-August, 1976.

Order / Family / Genus	Precambrian Belt Series: Snowslide Creek		Precambrian Belt Series: Beaver Creek		Challis Volcanics: West Fork Monumental Cr.		Challis Volcanics: Monumental Creek			Batholith Granitics: Lodgepole Creek		Batholith Granitics: Logan Creek	Large Streams: Big Creek		Large Streams: Middle Fork Salmon River		Indian Creek
Genus	**M***	**H**	**M**	**H**	**M**	**H**	**M**	**WF***	**H**	**M**	**H**	**M**	**M**	**H**	**Flying B**	**Indian Cr.**	**M**
Replicates in Mean	6	3	3	3	6	3	6	9	6	0	6	6	6	6	6	3	3
Ephemeroptera																	
Ameletus	–	–	–	–	1.2	–	14.2	2.0	–	–	–	–	–	–	–	–	2.7
Baetis	3.3	0.7	4.7	2	2.3	1.7	–	8.1	1.7	–	.03	7.3	5.2	0.3	4.5	4.3	–
Centroptilium	–	2.3	–	–	–	5.7	–	–	–	–	–	–	–	–	–	–	–
Cinygmula	1.8	10.7	13	14.3	11.2	12.3	7.5	4.0	7.3	–	2	2.7	7.3	0.7	–	4	2.7
Epeorus	10	1.7	4.7	4.3	10.5	3.3	17.7	12.8	17	–	4.3	4.3	10.3	10.7	3.5	35.7	12.3
Ephemerella	2.3	1	16.3	0.7	2.7	–	12.2	3.6	5.8	–	5.3	1.3	5.3	1.3	4.7	18.3	1.3
Paraleptophlebia	–	–	–	–	–	–	–	–	–	–	0.3	–	–	0.3	–	–	–
Rhithrogena	1.8	1	0.3	1.7	1.3	9	2.3	2.4	3	–	–	0.7	1	3.7	0.8	2	1.7
Plecoptera																	
Acronouria	0.5	2	–	0.3	0.2	3	0.5	0.1	–	–	–	–	0.2	–	–	0.3	–
Alloperla	0.2	2	–	–	0.2	–	0.5	0.2	0.8	–	–	–	–	–	–	–	–
Chloroperla	–	–	–	–	–	–	–	–	0.7	–	0.3	–	0.2	–	–	–	–
Claassena	–	–	–	–	–	–	–	–	–	–	–	–	–	0.3	–	0.3	–
Isogenus	–	–	0.3	–	0.7	1	–	0.2	0.5	–	–	–	–	–	–	–	–
Isoperla	–	–	0.3	–	–	–	–	–	–	–	–	–	0.2	0.3	–	0.3	0.3
Kathroperla	–	2.7	–	–	–	0.3	–	–	–	–	–	–	–	–	–	–	–
Nemoura	0.5	1.7	3	0.3	–	8.3	0.3	–	0.5	–	1.7	0.7	–	–	–	–	–
Paraperla	–	0.3	–	–	0.8	2.0	–	0.1	–	–	0.3	–	–	0.3	–	–	–
Peltoperla	–	3	–	–	–	0.7	–	–	–	–	9.7	0.3	–	–	–	–	–
Pteronarcys	–	–	–	–	–	–	0.5	–	–	–	–	–	0.2	–	–	–	–
Trichoptera																	
Arctopsyche	–	–	0.3	–	–	–	7.5	0.1	–	–	0.7	–	0.8	–	–	–	0.3
Brachycentrus	–	–	–	–	–	–	2	0.3	0.2	–	0.3	0.3	8.2	–	3.7	2.7	3.0
Glossosoma	0.2	–	1	2.3	0.5	–	0.2	0.3	–	–	1.3	–	–	–	–	–	–
Hydropsyche	0.5	–	–	–	–	–	0.7	–	–	–	–	–	0.2	–	1.2	3	–
Limnophilus	0.2	1.3	–	–	–	0.7	–	–	–	–	2	–	–	–	–	–	–
Neophylax	–	–	–	–	–	–	0.2	0.1	–	–	–	–	–	–	–	–	–
Neothremma	0.2	–	–	–	–	1.3	–	–	–	–	–	–	0.8	0.7	–	–	–
Oligophlebodes	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Parapsyche	1.3	0.7	6	1	4.5	0.7	–	0.1	0.3	–	–	–	–	–	–	0.7	–
Pseudostenophylax	–	–	–	–	0.2	–	–	–	–	–	–	0.7	–	–	–	–	–
Rhyacophila	1.8	0.3	4.3	3.3	0.5	2.7	0.3	2.0	0.5	–	5.3	–	–	–	0.3	–	–
Diptera																	
Blephariceridae	–	–	–	1.3	–	–	–	–	–	–	–	1.7	0.2	0.7	–	–	–
Chironomidae	8.3	4	32.3	1	3.8	21	12.5	4.7	17	–	2.7	0.7	6.7	–	7.3	8	–
Culicidae	–	–	–	–	–	–	0.3	–	–	–	–	–	–	–	–	–	–
Deuterophlebiidae	–	–	–	–	–	–	0.5	–	–	–	–	–	0.2	–	0.2	–	–
Empididae	0.2	0.7	–	–	–	–	–	0.1	0.2	–	–	–	–	–	–	0.3	–
Heleidae	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Table 11. continued

Order / Family / Genus	Precambrian Belt Series: Snowslide Creek		Precambrian Belt Series: Beaver Creek		Challis Volcanics: West Fork Monumental Cr.		Challis Volcanics: Monumental Creek			Batholith Granitics: Lodgepole Creek		Batholith Granitics: Logan Creek	Large Streams: Big Creek		Large Streams: Middle Fork Salmon River		Large Streams: Indian Creek
Genus	M*	H	M	H	M	H	M	WF*	H	M	H	M	M	H	Flying B	Indian Cr.	M
Replicates in Mean	6	3	3	3	6	3	6	9	6	0	6	6	6	6	6	3	3
Diptera (cont'd)																	
Rhagionidae	–	–	–	–	–	–	0.7	–	–	–	–	–	0.5	–	0.3	–	–
Simuliidae	0.3	0.3	–	3.3	1.0	1.7	1	0.2	0.7	–	0.3	0.3	0.2	0.7	–	0.7	3.0
Tabanidae	–	–	–	–	–	–	–	–	0.2	–	–	–	–	–	–	–	–
Tipulidae	0.2	0.3	0.7	–	–	–	0.2	0.7	0.7	–	0.7	–	1	0.3	0.2	0.2	–
Coleoptera																	
Elmidae	–	–	0.3	0.3	–	–	–	–	–	–	1	–	0.5	0.3	0.2	–	–
	–	–	–	0.3	–	–	–	–	–	–	–	–	–	–	–	–	–
Lepidoptera																	
Parargyractis	–	–	–	–	–	–	–	–	–	–	0.3	–	–	–	–	–	–
Oligochaeta	0.2	0.3	–	2.7	–	0.7	0.2	–	–	–	0.3	0.3	–	–	0.2	–	–
Average total number per sample	33.8	37	87.5	39.1	41.6	75.1	82	42.1	57.1	–	39.2	21.3	49.2	20.6	27.1	80.7	33.7
Average number of genera per sample	19	22	21	18	18	21	19	17	17	–	22	21	21	14	17	18	9

* M and H represent mouth and headwater stations respectively and WF represents a station on Monumental Creek above the mouth of the West Fork Monumental Creek.

Table 12. 1975 and 1976 mean numbers of benthic invertebrates per square foot of stream bottom for selected streams in the Frank Church River of No Return Wilderness Area.

Order / Family / Genus	Precambrian Belt Series: Snowslide Creek		Beaver Creek		Challis Volcanics: West Fork Monumental Cr.		Monumental Creek			Batholith Granitics: Lodgepole Creek		Logan Creek	Large Streams: Big Creek		Middle Fork Salmon River		Indian Creek
	M*	H	M	H	M	H	M	WF*	H	M	H	M	M	H	Flying B	Indian Cr.	M
Ephemeroptera																	
Ameletus	–	4.5	–	–	0.6	0.8	14.2	1.0	–	–	–	–	–	–	–	–	2.7
Baetis	2.4	0.4	2.9	1.0	2.3	1.1	–	4.6	–	–	0.2	7.3	2.9	0.3	2.3	4.3	–
Centroptilum	–	1.2	–	–	–	2.9	–	–	–	–	–	–	–	–	–	–	–
Cinygmula	2.4	5.8	6.5	8.7	7.9	15.1	7.5	2.5	1.5	–	1.5	2.7	6.4	0.7	0.3	4.0	2.7
Epeorus	14.6	6.8	14.9	2.4	9.5	3.8	17.7	8.2	5.5	6.0	3.2	4.3	5.2	10.7	1.8	35.7	12.3
Ephemerella	3.2	6.0	6.2	0.9	–	–	12.2	5.3	3.5	–	8.4	1.3	6.4	1.3	3.1	18.3	1.3
Paraleptophlebia	–	–	–	–	0.2	–	–	–	–	–	1.9	–	–	0.3	–	–	–
Pseudocloeon	0.1	–	–	–	2.0	–	–	–	–	–	–	–	–	–	3.5	–	–
Rhithrogena	6.1	3.0	12.2	3.4	7.8	6.7	2.3	6.7	12.5	13.0	0.5	0.7	18.3	3.7	8.9	2.0	1.7
Plecoptera																	
Acroneoria	0.6	2.5	–	0.2	1.3	1.7	0.5	0.1	1.0	1.0	–	–	0.1	–	0.5	0.3	–
Alloperla	0.1	1.0	–	–	0.1	–	0.5	0.4	–	–	–	–	–	–	–	–	–
Arcynopteryx	0.5	1.0	1.0	–	0.4	0.3	–	0.3	0.5	–	–	–	–	–	–	–	–
Brachyptera	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2.3	–	–
Chloroperla	–	–	–	–	–	–	–	–	–	–	0.2	–	0.1	–	–	–	–
Claassenia	–	–	–	–	0.4	–	–	–	–	–	–	–	0.3	0.3	–	0.3	–
Hastaperla	1.6	1.3	0.5	0.3	2.3	0.4	–	0.3	1.0	–	–	–	0.3	–	–	–	–
Isogenus	1.5	0.3	0.2	–	1.5	0.5	–	1.1	–	–	–	–	0.8	–	–	–	–
Isoperla	–	–	0.2	–	–	–	–	–	–	–	–	–	0.1	0.3	–	0.3	0.3
Kathroperla	–	1.4	–	–	–	0.2	–	–	–	–	0.3	–	–	–	–	–	–
Nemoura	1.6	3.3	6.0	5.4	1.3	9.3	0.3	0.7	2.0	3.0	6.4	0.7	–	–	1.5	–	–
Neoperla	–	–	–	–	0.2	–	–	–	–	–	–	–	–	–	0.3	–	–
Paraperla	0.2	3.9	1.0	–	4.3	1.3	–	–	0.5	–	0.4	–	–	0.3	–	–	–
Peltoperla	–	1.5	–	–	0.5	2.3	–	–	1.5	1.0	14.6	0.3	–	–	0.3	–	–
Pteronarcys	–	–	–	–	–	–	0.5	0.3	–	–	–	–	0.1	–	–	–	–
Trichoptera																	
Arctopsyche	–	–	0.2	–	–	–	7.5	0.1	–	–	0.4	–	0.4	–	–	–	0.3
Brachycentrus	–	–	–	–	–	–	2.0	0.2	–	–	0.2	0.3	6.4	–	2.4	2.7	3.0
Glossosoma	0.2	–	–	–	0.3	–	0.2	0.2	–	–	0.7	–	–	–	–	–	–
Hydropsyche	0.5	–	–	–	–	–	0.7	–	–	–	–	–	0.8	0.7	–	–	–
Hydropsychidae	0.4	6.0	4.0	1.5	–	2.5	–	–	–	11.0	4.0	–	15.0	–	55.0	–	–
Limnophilus	0.1	0.7	–	–	–	0.4	–	–	–	–	1.0	–	–	–	–	–	–
Neophylax	–	–	–	–	0.2	–	0.2	0.1	–	–	–	–	–	–	–	–	–
Neothremma	0.9	0.3	–	–	–	0.9	–	–	–	1.0	20.0	–	1.2	0.7	2.0	–	–
Oligophlebodes	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Parapsyche	0.7	0.4	–	–	2.3	0.3	–	0.1	–	–	–	–	–	–	–	0.7	–
Pseudostenophylax	–	–	–	–	0.1	–	–	–	–	–	–	0.7	–	–	–	–	–
Rhyacophila	0.9	0.6	2.9	2.7	0.4	2.3	0.3	1.0	–	–	2.7	–	–	–	0.2	–	–
Triaenodes	–	–	–	–	–	1.4	–	–	–	2.0	–	–	–	–	–	–	–

Table 12. continued

Order / Family / Genus	Precambrian Belt Series: Snowslide Creek		Precambrian Belt Series: Beaver Creek		Challis Volcanics: West Fork Monumental Cr.		Challis Volcanics: Monumental Creek			Batholith Granitics: Lodgepole Creek		Batholith Granitics: Logan Creek	Large Streams: Big Creek		Large Streams: Middle Fork Salmon River		Large Streams: Indian Creek
	M*	H	M	H	M	H	M	WF*	H	M	H	M	M	H	Flying B	Indian Cr.	M
Replicates in Mean																	
Diptera																	
Blephariceridae	–	–	–	0.7	–	–	–	–	–	–	–	1.7	1.6	0.7	–	–	–
Chironomidae	8.0	6.3	18.2	4.8	8.1	13.5	12.5	19.6	19.0	–	2.4	0.7	6.9	–	9.7	8.0	–
Culicidae	–	–	–	–	–	–	0.3	–	–	–	–	–	–	–	–	–	–
Deuterophlebiidae	–	–	–	–	–	–	0.5	–	–	–	–	–	0.1	–	0.1	–	–
Empididae	0.1	0.4	0.5	–	–	–	–	0.1	–	–	–	–	–	–	–	0.3	–
Heleidae	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Rhagionidae	–	–	–	–	–	–	0.7	–	–	–	–	–	0.3	–	0.2	–	–
Simuliidae	0.2	0.2	–	–	0.5	0.9	1.0	0.1	–	–	0.2	0.3	0.1	0.7	–	0.7	3.0
Tabanidae	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Tipulidae	0.3	0.2	–	–	0.3	–	0.2	0.4	–	–	0.4	–	1.3	0.3	0.9	0.3	–
Coleoptera																	
Elmidae	–	–	0.9	0.2	–	0.2	–	0.3	–	–	0.5	–	0.3	0.3	0.3	–	–
Hemiptera	–	–	–	–	0.2	–	–	–	–	–	–	–	–	–	–	–	–
Hirudinea	–	–	–	0.2	–	1.3	–	–	–	–	–	–	–	–	–	–	–
Lepidoptera																	
Parargyractis	–	–	–	–	–	–	–	–	–	–	0.2	–	–	–	–	–	–
Oligochaeta	0.1	0.2	–	1.4	–	0.4	0.2	–	–	–	0.2	0.3	–	–	0.1	–	–
Average total number per sample	47.3	59.2	78.3	33.8	55.0	70.5	81.0	53.7	48.5	38	70.5	21.3	67.4	21.3	95.7	28.9	28.2
Average number of genera per sample	16	17	16	13	15	17	19	13	12	11	17	21	16	14	14	18	9

* M and H represent mouth and headwater stations respectively and WF represents a station on Monumental Creek above the mouth of the West Fork Monumental Creek.

Creek to 22 at the headwaters of Snowslide and Lodgepole creeks (Table 11).

Mean benthic macroinvertebrate biomass (dry weight) ranged from 248 mg m^{-2} in the headwaters of Monumental Creek to 904 mg m^{-2} at the mouth of the West Fork Monumental Creek (Table 9). Higher values were usually due to the occurrence of several large organisms such as Pteronarcys or Hydropsyche (Tables 11 and 12). Benthic biomass increased from headwater stations to mouth stations (Table 9).

Benthic communities vary seasonally with maximum numbers and biomass peaking between June and October (Kennedy, 1967) due to growth and recruitment (Minshall et al., 1985b). Stream bottom surface area decreases with flow causing a crowding of benthic organisms and higher numbers and biomass per unit area. Ruttner (1963) stated that fast moving water sustains a higher population per unit area than does slow moving water. Sample site selection, therefore, will account for some of the variation in numbers of organisms per sample.

The number of genera per sample showed an increase in 1976 (Tables 10 and 11) because similar genera such as Hydropsyche and Arctopsyche were not differentiated in 1975. No trends were seen between numbers of organisms per square meter and geology of the watershed or general area of the stream sampled.

Diversity indices measure the quality of the environment and reflect stress on the macroinvertebrate community structure. Shannon-Weaver diversity values greater than three indicate no pollution, one to three moderate pollution, and less than one heavy pollution (Wilhm and Dorris, 1966). Shannon-Weaver diversity indice values normally ranged near three indicating the excellent condition of the study streams. No trends were noted between mouth and headwater stations, between streams within a geology, or between different geologies.

According to the River Continuum Concept of Minshall et al. (1985a), the total number of aquatic insects and average number of genera per sample increase as stream order increases until depth and turbidity in large rivers reduces primary production. In the FCRNRWA streams, about half of the headwater stations had higher mean numbers of aquatic insects and insect genera per sample than the mouth stations. This differs slightly from the River Continuum Concept but my downstream sites were definitely smaller than the required "large river" condition. The physical characteristics of headwater stations with high diversity and numbers of insects was greatly different from the headwater stations which had lower numbers and average numbers of genera per sample. The station on upper Lodgepole Creek was unique from all other headwater stations in that it was located in a high mountain meadow. The wide canyon and open riparian canopy allowed enhanced solar input (warmer temperatures and increased production). This site had heavy growth of the bryophyte <u>Fontinalis</u>, providing a more diverse environment which presumably increased the opportunity for more genera and greater numbers of aquatic insects. The chlorophyll a level at this station was the third highest found in our study streams.

The headwater stations on Snowslide and West Fork Monumental creeks were similar to upper Lodgepole Creek in that the canyon and riparian canopy were open, allowing for greater solar input. Mean summer water temperatures at the headwater stations on these two streams were higher than at the mouth station. Chlorophyll a levels were greater at the West Fork Monumental Creek headwaters than at the mouth. Snowslide Creek did not show this trend. The headwater stations of these three streams (Lodgepole, Snowslide, and W. Fork Monumental) had greater diversity of genera and numbers because they had greater primary production and warmer water temperatures.

There was little difference in number of insects and average number of genera per sample between geologies. The Volcanics had greater production in number of insects per area but the Belt Series had greater average number of genera per sample. Species diversity d was similar in all three geologies. Swanson et al. (1982) suggested that the riparian system can be more important than climate or geology as the major factor regulating production because of the organic input from riparian zone.

The chemical data showed little difference between the three geologies. With little water quality difference, I found that stream aspect and canopy was more important in primary and secondary production, through control of solar energy reaching the stream, than was geology or relative location in the drainage.

Equitability e has been found to be very sensitive to even slight levels of degradation (Galat, 1974). Streams not affected by oxygen-demanding wastes normally range between 0.6 and 0.8. Streams of the Wilderness Area were normally above 0.8 and often close to one. In several instances, e was greater than one because the sample was more equitable than the model from which it was derived. This happens when the sample contains only a few specimens from several taxa (EPA, 1973). Equitability values indicate that the environmental quality of the streams sampled is very high.

Minshall et al. (1985b) reported Shannon-Weaver diversity and equitability values for streams in the upper Main Salmon River drainage. Diversity values were similar to those found in this study but their equitability levels were lower. The upper Salmon River has some agriculture and grazing occurring within the drainage, which may be adding some allochthoqnous organic material. This slight degradation may be the reason why equitability values in the upper Salmon River were lower than those in the undisturbed, pristine streams of the FCRNRWA.

CONCLUSIONS

1. Chemical water quality is related to watershed geochemistry. The Precambrian Belt Series geology weathers at a faster rate than the Batholith or Volcanics and therefore streams within the Belt Series had the highest levels of dissolved ions. The Batholith and Volcanics geologies weather at a very slow rate and streams within these geologies had similar dissolved ion concentration.

2. Streams flowing within similar geologic land forms had similar ionic composition as indicated by the Stiff diagrams. The Stiff diagrams also showed that streams flowing through different geologic land forms had dissimilar ionic compositions.

3. Much of the annual variation of chemical and physical parameters of Wilderness Area streams could be accounted for by the dilution of the stream with snowmelt water during spring runoff.

4. Conductivity, calcium, and magnesium increased downstream, except in the West Fork Monumental Creek where they decreased.

5. Chlorophyll a concentrations showed a sixteenfold difference between the low at the headwaters of Monumental

Creek to the high at the headwaters of Lodgepole Creek. Changes in chlorophyll a concentrations were generally not related to discharge or drainage area in Wilderness Area streams, but in some streams increased downstream.

6. Biomass of attached plants showed a sixteenfold difference between the low at the headwaters of West Fork Monumental Creek and the high at the headwater of Lodgepole Creek. Levels of attached plant biomass were not related to drainage area or discharge of sample streams.

7. Benthic numbers and biomass were low (<1,034 organisms per square meter and <904 mg m^{-2}, respectively) for pristine, undisturbed streams of the Wilderness Area during 1975 and 1976.

8. The chemical data show little difference between the three geologies. Drainage aspect and canopy cover plays a greater role in primary and secondary production through the amount of solar energy reaching the stream than geology or location.

9. Shannon-Weaver d and equitability e indices were high (d > 2.10 and e > 0.74, respectively), indicating the excellent condition of the study streams.

10. The productivity of Wilderness Area streams was considered low because of low levels of attached plant biomass, chlorophyll, benthic invertebrate biomass, and benthic invertebrate numbers.

11. Streams flowing within the Pre-Cambrian Belt Series were judged most productive. Streams flowing within the Challis Volcanics and streams of the Idaho Batholith were similar in production.

LITERATURE CITED

American Public Health Association. 1976. Standard Methods for the Examination of Water and Wastewater, 14th Ed. Washington, D.C.

Bar, A.J. and J.H. Goodnight. 1976. A User's Guide to SAS. SAS Institute, Inc., Raleigh, North Carolina.

Bayly, I.A.E. and W.D. Williams. 1973. Inland waters and their ecology. Longman Australia Pty Limited, Victoria, Australia.

Carter, F.W., D.M. Pinckney, W.B. Hamilton, R.L. Parker, R.O. Weldin, T.S. Close, and N.T. Zilku. 1973. Mineral Resources of the Idaho Primitive Area and vicinity. U.S. Geological Survey Bulletin 1304.

Cushing, C.E., K.W. Cummins, G.W. Minshall, and R.L. Vannote. 1983. Periphyton, chlorophyll a, and diatoms of the Middle Fork of the Salmon River, Idaho. Holarct. Ecol 6:221-227.

Emmett, W.W. 1975. The channels and waters of the upper Salmon River area, Idaho. Geol Survey Professional Paper, No. 870-A.

Feth, J.H., S.M. Rogers, and C.E. Roberson. 1964. Chemical composition of snow in the northern Sierra Nevada and other areas. U.S. Geological Survey Water-Supply Paper 1535-J.

Galat, D.L. 1974 A comparative assessment of several biological indices of water quality applied to aquatic macroinvertebrates collections. Colorado State University, Fort Collins, Colorado.

Hem, J.D. 1975. Study and interpretation of the chemical characteristics of natural water, 2nd Ed. U.S. Geological Survey Water-Supply Paper 1573.

Hembree, C.H. and F.H. Rainwater. 1961. Chemical degradation in opposite flanks of the Wind River Range, Wyoming; geochemistry of water. U.S. Geol Surv. Water-Supply Paper 1535-6.

Jensen, S.L. 1966. The mayflies of Idaho. M.S. Thesis, Univ. of Utah.

Kennedy, H.D. 1967. Seasonal abundance of aquatic invertebrates and their utilization by hatchery-reared rainbow trout. Tech. Papers, Bureau of Sport Fisheries and Wildlife, U.S. Dept. of Int. Fish and Wildlife Service.

Livingston, D.A. 1963. Chemical composition of rivers and lakes: in data of geochemistry, 6th Ed. U.S. Geological Survey Professional Paper 440-G.

Lloyd, M. and R.J. Ghelardi. 1964. A table for calculating the "equitability" component of species diversity. J. Animal Ecol. 33:217-225.

Lloyd, M., J.H. Zar, and J.R. Karr. 1968. On the calculation of information - theoretical measures of diversity. Am. Mid. Nat. 79(2):257-272.

Mallet, J.L. 1960. Middle Fork Salmon River trout fishery investigation. Idaho Dept. of Fish and Game Annual Progress Report, Proj. F-37-R-1.

___________. 1963. The life history and seasonal movements of cutthroat trout in the Salmon River, Idaho. M.S. Thesis, Univ. of Idaho.

Miller, J.P. 1961. Solutes in small streams draining single rock types, Sangre de Cristo Range, New Mexico. U.S. Geol. Survey Water-Supply Paper 1535.

Minshall, G.W., J.T. Brock, and D.A. Andrews. 1981. Biological, water quality, and aquatic habitat responses to wildfire in the Middle Fork of the Salmon River and its tributaries. Final Report to U.S. Forest Service.

Minshall, G.W., K.W. Cummins, R.C. Petersen, C.E. Cushing, D.A. Burns, J.R. Sedell, and R.L. Vannote. 1985a. Developments in stream ecosystem theory. Can. J. Fish. Aquat. Sci. 42:1045-1055.

Minshall, G.W., R.C. Petersen Jr., and C.F. Nimz. 1985b. Species richness in streams of different size from the same drainage basin. Am. Nat. 125:16-38.

Pennak, R.W. 1953. Freshwater invertebrates of the United States. Ronald Press Company, New York.

Pfankuch, D.J. 1975. Stream reach inventory and channel stability evaluation. U.S. Dept. of Ag., Forest Service, Northern Region.

Reid, G.E. 1964. Ecology of inland waters and estuaries. Reinhold Publishing Corp., New York.

Reid, G.K. and R.D. Wood. 1976. Ecology of inland waters and estuaries. D. Van Nostrand Co., New York.

Ross, C.P. 1937. Geology and ore deposits of the Bayhorse Region, Custer County, Idaho. U.S. Geol Survey Bull. 877.

Ross, C.P. and J.D. Forrester. 1947. Geologic map of the State of Idaho. U.S. Dept. Interior, Geol. Serv., Washington, D.C. and Idaho Bur. of Mines and Geol., Moscow, Idaho.

Ruttner, F. 1963. Fundamentals of limnology, 3rd Ed. University of Toronto Press, Toronto.

Slack, K.V., R.C. Averett, P.E. Greeson, and R.G. Lipscomb. 1973. Methods for collection and analysis of aquatic biological and microbiological samples. Techniques of Water Resources Investigations of the United States Geological Survey, Book 5, Chapter A4.

Snyder, G.G. 1973. The effects of clearcutting and burning on water quality. M.S. Thesis, University of Idaho, Moscow, Idaho.

__________. 1976. The northern Rocky Mountain water quality benchmark system: A procedure for stratifying the natural, chemical, and physical quality of stream water. Ph.D. Dissertation, University of Idaho, Moscow, Idaho.

Stiff, H.A., Jr. 1951. The interpretation of chemical water analysis by means of patterns. J. Petroleum Tech. 3(10):15-17.

Swanson, F.J., S.V. Gregory, J.R. Sedell, and A.G. Campbell. 1982. Land-water interactions: the riparian zone, p. 267-291. In R.L. Edmonds (ed.) Analysis of coniferous forest ecosystems in the western United States. US/IBP Synthesis Series 14. Hutchinson Ross Publishing Company, Stroudsburg, PA.

Thurow, R. 1985. Middle Fork Salmon River fisheries investigation. Job Completion Report, Project F-73-R-6 Idaho Department of Fish and Game.

U.S. Department of Commerce. 1975. Climatological data for Idaho. National Oceanic and Atmospheric Administration Environmental Data Services.

__________________________. 1976. Climatological data for Idaho. National Oceanic and Atmospheric Administration Environmental Data Services.

U.S. Forest Service. 1976. Management plan for the Idaho Primitive Area. U.S. Dept. Ag., Forest Service, Intermountain Region.

U.S. Geological Survey. 1973-1976. Water resources data for Idaho.

Usinger, R.L. 1974. Aquatic insects of California. University of California Press, Berkeley, Los Angeles, London.

Vannote, R.L., G.W. Minshall, K.W. Cummins, J.R. Sedell, and C.E. Cushing. 1980. The River Continuum Concept. Can. J. Fish. Aquat. Sci. 37:130-137.

Ward, H.B. and G.C. Whipple. 1959. Freshwater biology, 2nd Ed. John Wiley and Sons, Inc., New York, London, Sydney.

Weber, C.I. and B. McFarland. 1969. Periphyton biomass - chlorophyll ratio as an index of water quality. Presented at the 17th Annual Meeting, Midwest Benthological Society, Gilbertsville, Kentucky, April, 1969.

Weber, C.I. 1973. Recent developments in the measurement of the response of plankton and periphyton to changes in their environment. IN: G. Glass (Ed.), Bioassay techniques and environmental chemistry. Ann Arbor Science Publishers, Inc.

Weber, C.I. (ed.). 1973. Biological field and laboratory methods for measuring the quality of surface waters and effluents. EPA-670/4-73-001.

Wetzel, R.G. 1975. Limnology. W.B. Saunders Company, Philadelphia, London, Toronto.

Wiggins, G.B. 1977. Larvae of the North American caddisfly genera (Trichoptera). University of Toronto Press, Toronto, Buffalo.

Wilhm, J.H. and T.C. Dorris. 1966. Species diversity of benthic macroinvertebrates in a stream receiving domestic and oil refinery effluent. Am. Mid. Nat. 76:427-449.