UNITED STATES DEPARTMENT OF THE INTERIOR
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Monitoring of thermal activity in Southwest Yellowstone National Park

by

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This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards and nomenclature

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CONTENTS

TABLES

FIGURES

Monitoring of Thermal Activity in Southwest Yellowstone National Park

Irving Friedman, Daniel R. Norton, and Roderick A.Hutchinson

Abstract

Monitoring of the thermal activity in Yellowstone National Park is being carried out for two reasons. The first is to obtain baseline information on the natural variations in activity against which to assess possible future impacts of geothermal, oil and gas and other types of development adjacent to the Park. The second is to determine changes in activity in response to both seismic activity and to the movement of magma in and adjacent to the Park. Because of the proximity of the Island Park Geothermal Area to the southwestern portion of Yellowstone National Park and the possibility of the future development of this resource, particular emphasis in this investigation was placed in this part of the Park.

Continuous measurements of thermal flux from features in the remote southwest Yellowstone National Park proved to be impractical because of the necessity to visit the sites monthly to service the equipment. A practical protocol for monitoring chloride flux in this inaccessible region of the Park is the instantaneous measurement of the thermal flux from most of the surface manifestations within this area once a year during base flow. The installation of weirs and staff gauges on most of the thermal streams has made it possible to collect the data from this area annually during the winter, utilizing a one-day trip by helicopter.

The observed changes in both discharge and chloride flux at 10 of the 11 monitoring stations were as great as 75 % over the 1986-1988 period. These large changes in hot spring discharge and chloride flux demonstrate the necessity for long-term monitoring to establish a baseline for assessing possible future adverse effects on the Park thermal features due to man's activities.which includes drilling for gas and oil, and for geothermal resources.

Introduction

Monitoring of the thermal activity in Yellowstone National Park is being carried out for two reasons. The first is to obtain baseline information on the natural variations in activity against which to assess possible future impacts of geothermal, oil and gas and other types of development adjacent to the Park. The second is to determine changes in activity in response to both seismic activity and to the movement of magma in and adjacent to the Park.

Because of the proximity of the Island Park Known Geothermal Resource area to the southwestern portion of Yellowstone National Park (figure 1) and the possibility of the future development of this resource, particular emphasis in this investigation was placed in this part of the Park. This area contains many small and medium size thermal features that may respond to disturbance by development adjacent to the Park. The thermal features of interest to us in this study are characterized by streams issuing from them which makes chloride flux monitoring feasible.

This is the first report of a long-term monitoring study. The conclusions reinforce the necessity for long-term monitoring.

Jones et al (1979) published results on discharge and chloride concentration of surface waters in the Falls River drainage that were useful in developing our experimental program for southwest Yellowstone National Park. Data on the Boundary Creek Thermal Areas were reported by Hutchinson (1980) and by Thompson and Hutchinson (1980). To orient our program in the Island Park Geothermal Area we used data reported by Whitehead (1978) on surface waters in the Upper Henrys Fork Basin.

Initial Investigations

Due to the fact that the study area was remote and difficult to access, we initially attempted to utilize automated equipment to record stream flow, water temperature and electrical conductivity at regular time intervals, and to store the data for later retrieval. It was planned to service the sites every few months. The initial site was established on the Upper Boundary Creek Thermal Area on a small stream draining a hot spring identified as Weir 3, Monitor Creek Thermal Area (figure 2, 3). The data was recorded at noon and midnight by a Campbell Scientific Co. Micrologger (Model CE 21), and stored on a magnetic tape cassette. Although the instrument was capable of running for 9 months on internal dry cells, the site was visited several times a year for servicing the equipment and retrieving the cassette containing the data.

The relative flow from the thermal stream was monitored by recording the depth of water in a weir located about 100 meters downstream from the hot spring source, which discharged at a temperature of about 80° C. For the first nine months temperatures and electrical conductivity were measured at the weir. After that time temperatures were also measured in the hot spring orifice.

Figure 4 shows the data from October 1, 1980 to June 15, 1981. Cooling of the stream due to snow melt was observed during April and early May, 1981. The low electrical conductivity and high water flow reflected the input of snow melt during this period. During late May and June, 1981 the water flow remained high, but the temperature and electrical conductivity increased. This was attributed to increased flow from the hot spring and a decreased contribution from snow melt.

The success of this effort encouraged us to install a second instrumented site on a thermal stream in the Silver Scarf Thermal Area (figure 2) located about 3.5 miles from the first site. Shortly after the equipment was installed, a series of problems arose. First, the thermistors used to measure temperature and approximate water level in the weirs failed after time periods from 1 to 10 months. Efforts to protect these devices proved unsuccessful, due probably to the continuous exposure to elevated temperatures. Secondly, the remote location of the sites, which could only be accessed by helicopter for 8 months of the year, made it impractical to service the sites at what proved to be monthly intervals.

As a result of these initial field experiments we decided on a protocol of annual visits at a multitude of uninstrumented sites rather than continuous monitoring using automated recorders at a few sites. Each site was to be visited in the winter at the time of base flow.

Subsequent Investigations

To inventory the thermal fluids that exist in the southwest portion of the Park and adjacent areas, a survey was made of the chloride flux of streams originating in these areas. From a previous investigation (Norton and Friedman, 1985), it was determined that at least 94% of the chloride present in rivers draining the Park is of geothermal origin, and therefore chloride flux could be used to assess thermal flux. To determine chloride flux, it is necessary to determine simultaneously the stream discharge and chloride concentration and to calculate chloride flux from the product of these values (Norton and Friedman, 1985).

The location of the sites inventoried are shown in figures 5 and 6, and the experimental data are given in tables 1 and 2. The chloride flux measured within the Island Park Geothermal Area is 38% of the total leaving the southwest portion of the Park. The remainder (62%) leaves via the Falls River. The chloride flux originating in the Boundary Creek drainage was about 30% of the total chloride flux that exits via the Falls River. The other 70% originates from the Pitchstone Plateau and the Three Rivers Thermal Area.

As a result of this survey, a number of sites were selected for monitoring. These include eight small thermal streams adjacent to Boundary Creek that were judged to be sensitive indicators of environmental change and whose discharge could be easily measured using small weirs. The thermal areas in which these streams are located are described by Hutchinson (1980) and are shown on the map in figure 1 and the aerial photograph in figure 2.

1) Monitor Creek Thermal Area shown in figure 3 (3 sites), is part of the Upper Boundary Creek Thermal area described by Hutchinson. The sites being monitored constitute most of the surface flow from the thermal features at this locality.

2) Middle Boundary Creek Thermal Area shown in figure 8 (4 sites), is that described by Hutchinson. The sites being monitored also constitute most of the surface flow from this feature.

3) Crescent Ridge Thermal Area (1 site) consists of a series of low temperature thermal springs (approximately 25° C) which flow into Crescent Ridge Creek. This stream flows into Little Robinson Creek which flows into Robinson Creek and then into Warm River and the Henrys Fork. It is not, therefore, in the Boundary Creek-Falls River drainage.

To minimize the environmental impact, weirs constructed of redwood with an attached metal weir plate were installed. Figure 7 shows photographs of two typical weirs, 1 and 8. In addition to the small thermal streams described above, three large streams, each of which integrates the discharge of a number of thermal features, were provided with staff gauges for the measurement of discharge. These streams have also been described by Hutchinson and are listed below:

1) Silver Scarf Creek drains a large thermal area described by Hutchinson as the Silver Scarf Thermal Area. The staff gauge is located several hundred meters below the point where the last thermal stream enters the creek.

2) Boundary Creek staff gauge was placed at a location where it integrates all of the thermal water originating in the Boundary Creek

Thermal Area, including all of the areas mentioned above, with the exception of the small flux from Crescent Ridge. The location of this site was selected to eliminate inflow of water from the Bechler Meadows. It is located about 100 meters south of the bridge where the Boundary Creek Trail crosses Boundary Creek.

3) Boundary Creek Tributary was described by Jones et al as unnamed creek No. 1783. Our site is located one-half mile upstream from the junction of the Tributary with Boundary Creek, and adjacent to the "Boundary Creek Patrol Cabin" site shown on the Warm River Butte 15' quadrangle map. The patrol cabin no longer exists but has been replaced by a campground.

Calibration of Weirs and Staff Gauges

Calibration of the discharges through the weirs were made using velocity meters. The results in table 3 show good agreement between measured flows and those derived from the standard rating tables for the weirs.

The discharges at the 3 staff gauge sites were been measured using velocity meters and standard hydrologic methods. When sufficient data has been accumulated rating tables will be prepared.

Results

The results of the discharge, chloride concentration and chloride flux determinations are given in table 4, and figures 9-12. In general all the sites show a decrease in discharge and chloride flux from late 1983 to February 1988, with the major portion of the decline occurring after 1986.

Data for the three Monitor Creek weirs are plotted in Figure 9. Weir 2 is located on a small stream that appears to drain the steam and acid water vents that are the main features of the Monitor Creek Thermal Area. The discharge and the chloride content of this stream fluctuates greatly for reasons that are not apparent.

Figure 10 contains similar plots for weirs 4,5,6,7 located in the Middle Boundary Creek Thermal Area. They all show a decrease in discharge and chloride flux as shown above.

Figure 11 are graphs for the three large streams in the Boundary Creek drainage, all of which show the large decreases in discharge and chloride flux, particularly post 1986.

Figure 12 is a plot of the data for weir 8, located in the Crescent Ridge Thermal Area and also shows the large changes previously alluded to.

The reasons for the large decreases in discharge and chloride flux may include the lowering of the water table resulting from two years of exceptionally low snowfall. In any case, these large changes in hot spring flow and chloride flux over this four year period demonstrate the need to monitor this section of the Park for a long time period in order to secure meaningful baseline data, and also to relate changes in hot spring activity to other natural phenomena.

Conclusions

1- Continuous measurements of thermal flux from features in the remote southwestern portion of Yellowstone National Park is impractical because of the necessity to visit the sites monthly to service the equipment. This activity is prohibitively expensive due to the fact that access to these sites by helicopter flights is necessary for eight months of the year. The nearest available helicopter is based in Jackson, Wyoming, a distance of 75 miles from the study area.

2- A practical protocol for monitoring chloride flux in this inaccessible region of the Park is the instantaneous measurement of the thermal flux from most of the surface manifestations within this area once a year during base flow. It is now possible to collect the data from this remote area annually during the winter utilizing a one-day trip by helicopter.

3- On the basis of the large chloride flux measured in the Island Park Geothermal Ares at Big Springs, Buffalo River, Warm River, and Robinson Creek, we suggest that these sites outside Yellowstone National Park be added to those now being monitored.

4- The chloride flux measured at the Falls River gauging site outside the Park includes most of the flux originating in the southwest portion of the Park. Some of the chloride flux measured in the Island Park Geothermal Area may also have originated in or near Yellowstone Park.

5- The observed changes in both discharge and chloride flux at 10 of the 11 monitoring stations were as great as 75% over the 1986-1988 period. These large changes in hot spring discharge and chloride flux demonstrate the necessity for long term monitoring to establish a baseline for assessing possible future effects due to mans' activities which include drilling for gas and oil and geothermal resources.

6-The discharge of the systems monitored seem to respond to the availability of meteoric water. A surprising finding is the direct relation between discharges of the thermal systems and chloride flux, inasmuch as over 94 % of the chloride is believed to originate from a hydrothermal source. Whether this relation is the result of chloride storage during low flow regimes, and release of stored chloride during periods of high discharge, or whether it is the result of the direct influence of water table height on the hydrothermal system, remains to be resolved.

Acknowledgements

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We also wish to acknowledge John D. Varley, Research Coordinator, Yellowstone National Park, for his continued interest and support of this work.

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Table 1

Chloride Inventory of S.W. Yellowstone Park[1]

Site	Location	Cl ppm	Disch cfs	Cl Flux g/s
Boundary Cr.	betwn. Monitor and Mid. Boundary Cr. Th. Areas	4.80	25.8	3.51
"	between Dunanda Falls and Silver Scarf Creek	12.6	34.5	12.3
"	near confluence with Bechler River	15.7	122	54.2
Silver Scarf Cr.	at gauging site below Silver Scarf Thermal Area	57.1	10.7	17.3
Bechler River	near confluence with Falls River	11.4	351	113
Mt. Ash Cr.	near confluence with Falls River	10.7	143	43.3
Calf Cr.	near confluence with Falls River	0.67	2.50	0.047
Falls River	near confluence with Mountain Ash Creek	6.30	160	28.5
Falls River	near confluence with Bechler River	8.30	277	65.1
Falls River	above confluence with Calf Creek	6.00	140	23.8
Falls River	at Squirrel,Idaho gauging site	9.08	693	178
Little Robinson Cr.	near confluence with Robinson Creek	3.30	4.47	0.42

1 measurements made 26 Sept-3 Oct 1985

Table 2

Chloride Inventory of Island Park

Location	Date	Chloride ppm	Discharge cfs	Flux g/s
Robinson Creek	3 Oct 84	6.78	123	23.6
	16 Sept 85	6.92	108	21.2
Big Springs Creek	3 Oct 84	2.64	214	16.0
	16 Sept 85	2.05	198	11.5
Buffalo River	3 Oct 84	3.77	237	25.3
	16 Sept 85	3.51	253	25.1
Warm River	3 Oct 84	6.76	424	81.2
	16 Sept 85	5.33	283	42.7

Table 3

Calibration of Weirs

Thermal Area	Weir No.	Date	Weir type	Weir width (ft)	Discharge (cfs) tables[1]	Discharge (cfs) measured[2]
Monitor Creek	1	9 Sep. 87	Cipoletti	0.75	0.15	0.16
	2	9 Sep. 87	90° V-Notch	--	0.002	0.002
	3	9 Sep. 87	90° V-Notch	--	0.05	0.08
Middle Boundary	4	9 Sep. 87	Cipoletti	1.0	0.26	0.33
	4	17 Feb 88	Cipoletti	1.0	0.26	0.18
	5	17 Feb. 88	90° V-Notch	--	0.13	0.14
	6	9 Sep. 87	Cipoletti	1.0	0.23	0.24
	7	9 Sep. 87	Cipoletti	1.0	0.38	0.32
	8	9 Sep, 87	Cipoletti	2.0	0.36	0.37

1 from standard tables of water height in weir vs. discharge

2 calculated from velocity meter measurements

Table 4

Data for Southwest Thermal Areas[1]

Date		Weir 1	Weir 2	Weir 3	Weir 4	Weir 5	Weir 6	Weir 7	Weir 8	Silver . Scarf Creek	Boundary Creek	Boundary Creek Tributary
09-Nov-83	Cl	1.470	26.000	5.900	63.70	57.20	64.30	75.00	-	-	-	-
	disch.	.520	.093	.093	.37	.24	.53	.83	-	-	-	-
	flux	.022	.068	.016	.67	.39	.97	1.76	-	-	-	-
31-Jan-84	Cl	1.660	4.000	7.600	65.50	58.70	65.90	76.90	4.80	66.70	16.90	-
	disch.	.330	.030	.138	.35	.25	.84	.61	.97	9.35	83.30	-
	flux	.016	.003	.030	.65	.42	1.57	1.33	.13	17.66	39.86	
07-Sep-86	Cl	.900	24.700	6.520	64.20	59.90	68.80	80.00	4.12	56.70	17.10	-
	disch.	.400	.055	.110	.33	.22	.34	.56	2.00	8.60	93.60	-
	flux	.010	.038	.020	.60	.37	.66	1.27	.23	13.81	45.32	-
05-Feb-87	Cl	1.300	1.400	9.680	66.70	-	68.30	78.50	3.50	72.50	22.60	6.51
	disch.	.210	.030	.075	.34	-	.35	.58	.50	8.67	78.60	31.60
	flux	.008	.001	.021	.64	-	.68	1.29	.05	17.80	50.30	5.83
24-Aug-87	Cl					-			-		-	-
	disch.	.180	.005	.054	.28	-	.18	.40	-	6.80	-	-
	flux					-			-		-	-
09-Sep-87	Cl	1.100	.200	12.700	71.30	67.10	73.30	86.60	5.00	83.60	19.70	5.98
	disch.	.150	.002	.049	.26	.11	.23	.38	.36	5.54	65.70	32.00
	flux	.005	.000	.018	.52	.21	.48	.93	.05	13.11	36.65	5.42
25-Sep-87	Cl					-			-		-	-
	disch.	.130	.001	.045	.27	-	.23	.36	-	5.54	-	-
	flux					-			-		-	-
10-Feb-88	Cl	2.600	.340	16.600	65.60	58.30	63.70	77.90	-	83.40	19.90	6.30
	disch.	.060	.040	.045	.26	.13	.23	.23	-	4.81	50.90	29.60
	flux	.004	.0004	.021	.48	.21	.41	.51		11.36	28.68	5.28

[1] measurement units: Cl in ppm; discharge in cfs; flux in g/s

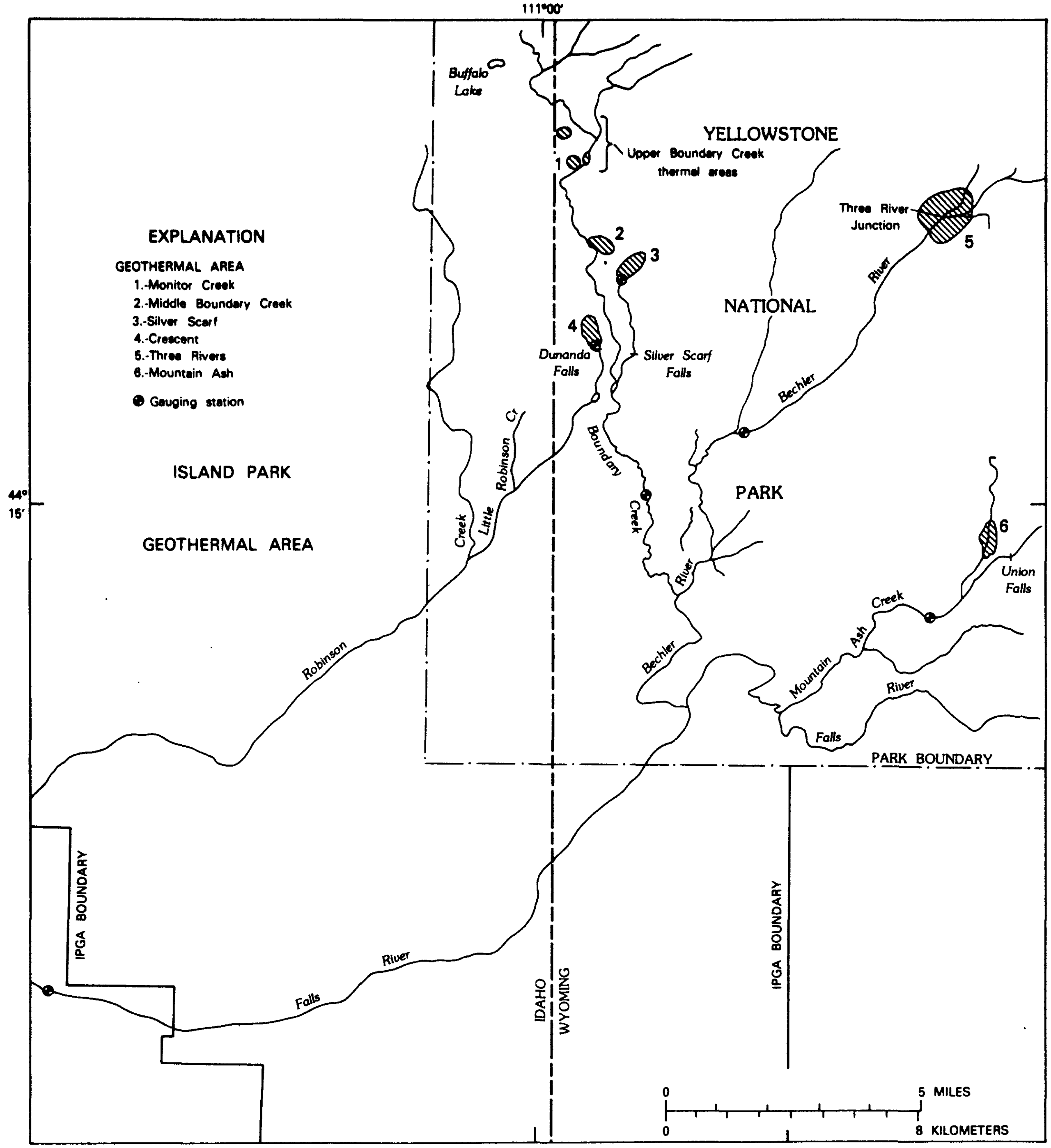


Figure 1. Map showing the Island Park Geothermal Area and the southwestern portion of Yellowstone National Park

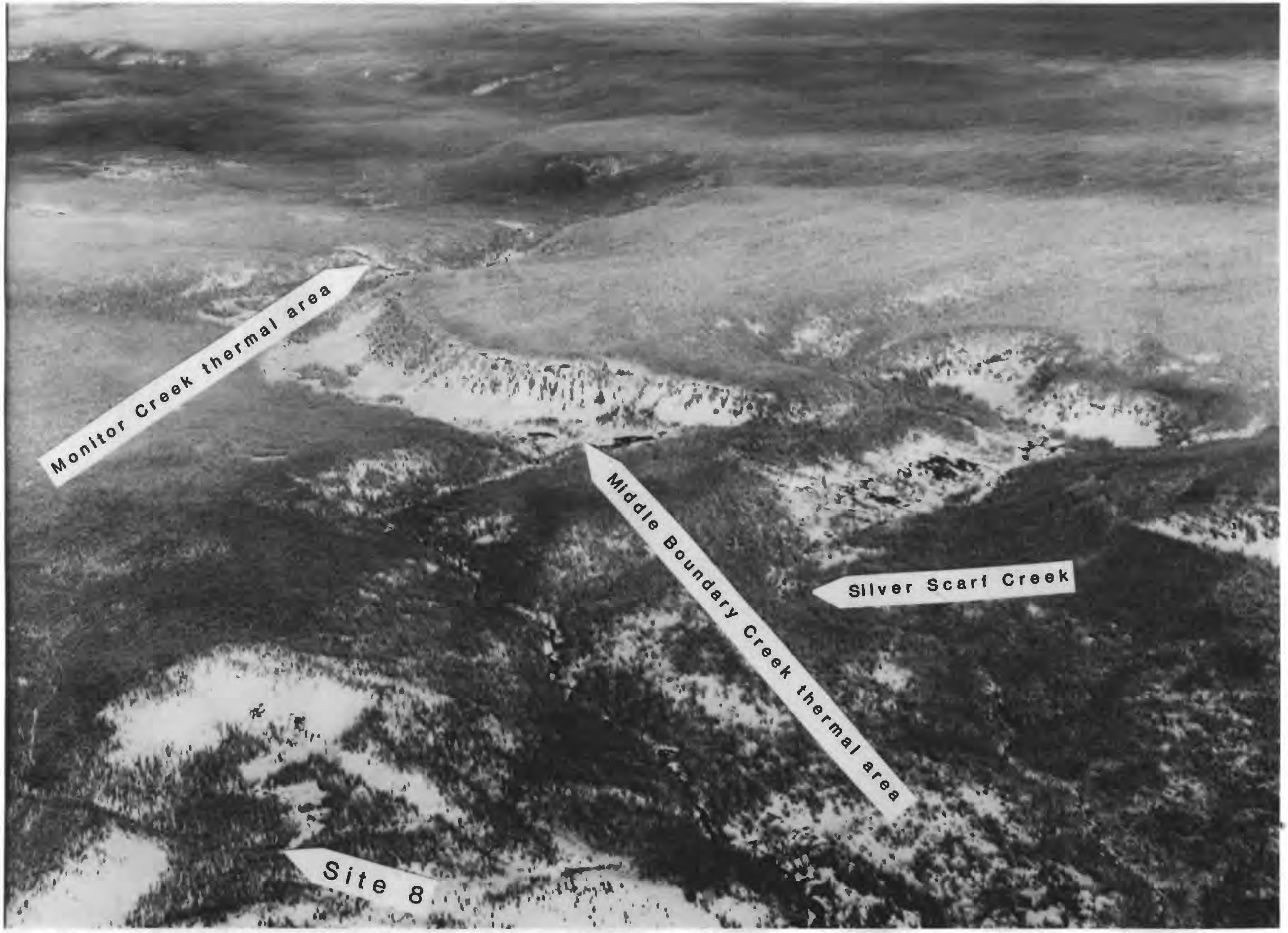


Figure 2. Aerial photograph of the Boundary Creek area, Yellowstone National Park. Photo taken 31 Jan. 1984, looking north

Figure 3. Aerial photograph of the Monitor Creek Thermal Area taken 1 Nov. 1980 looking west, and showing sites 1, 2, 3.

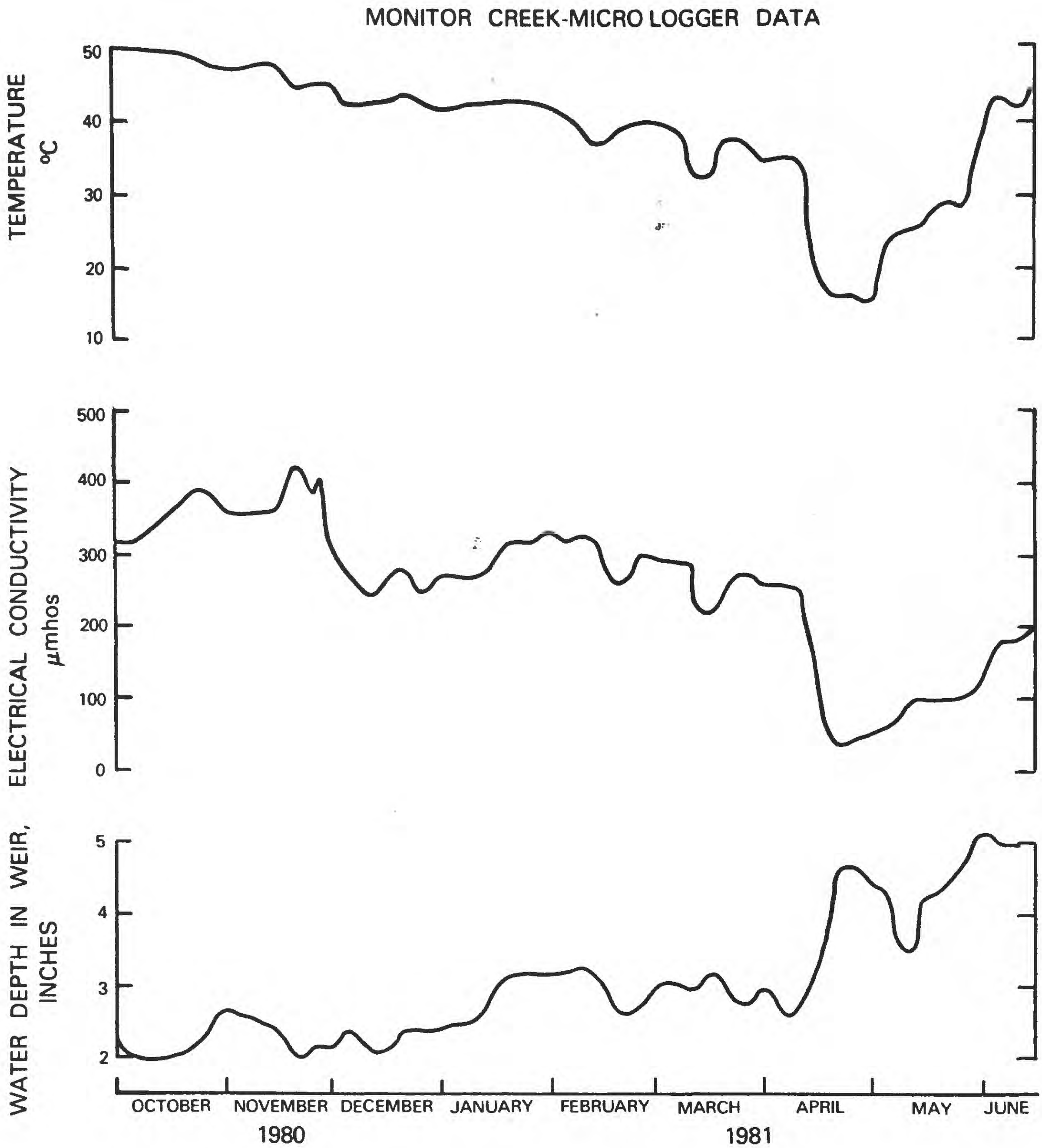


Figure 4. Plot of Micrologger data from Monitor Creek, Monitor Creek Thermal Area. Temperature, electrical conductivity and water depth in the weir is plotted as a function of time from October, 1980 to mid-June, 1981.

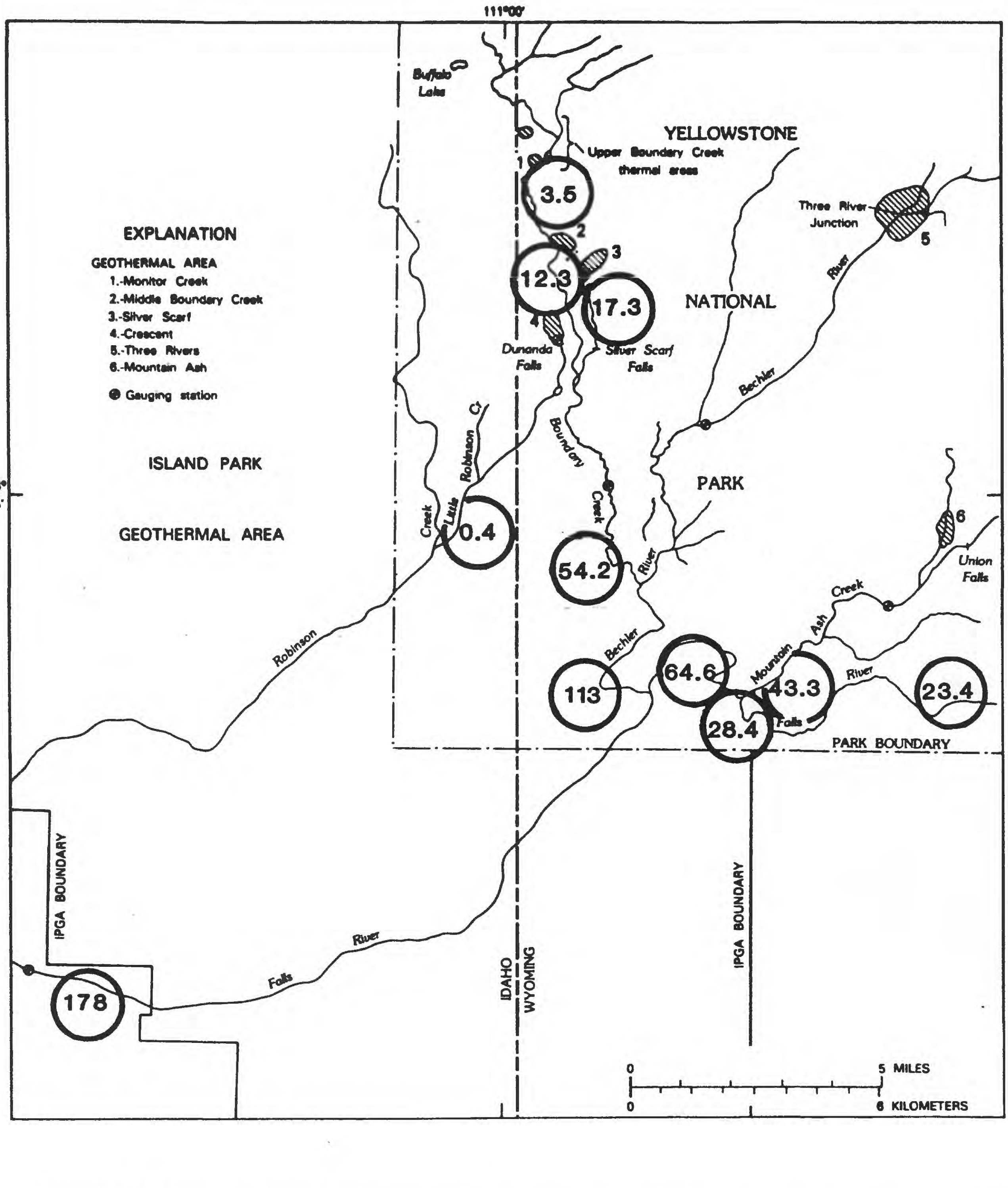


Figure 5. Map of the Island Park area and adjacent portion of Yellowstone National Park showing sites where chloride flux was measured. Chloride flux is given in grams per second.

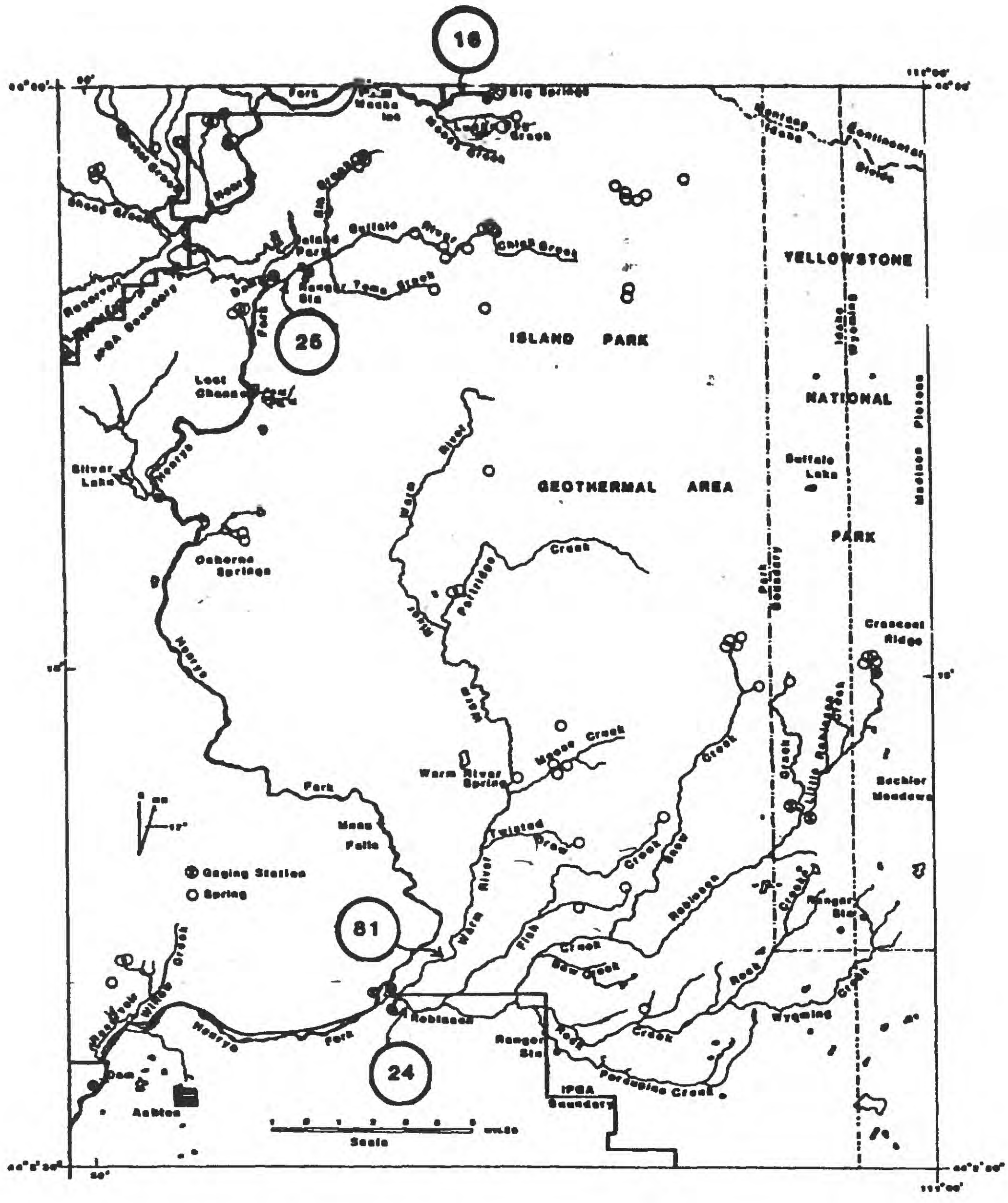


Figure 6. Map of the Island Park area west of the Park boundary showing instantaneous chloride flux at springs and streams. The chloride flux is given in grams per second.

#4

#8

Figure 7. Photograph of weirs 4 and 8.

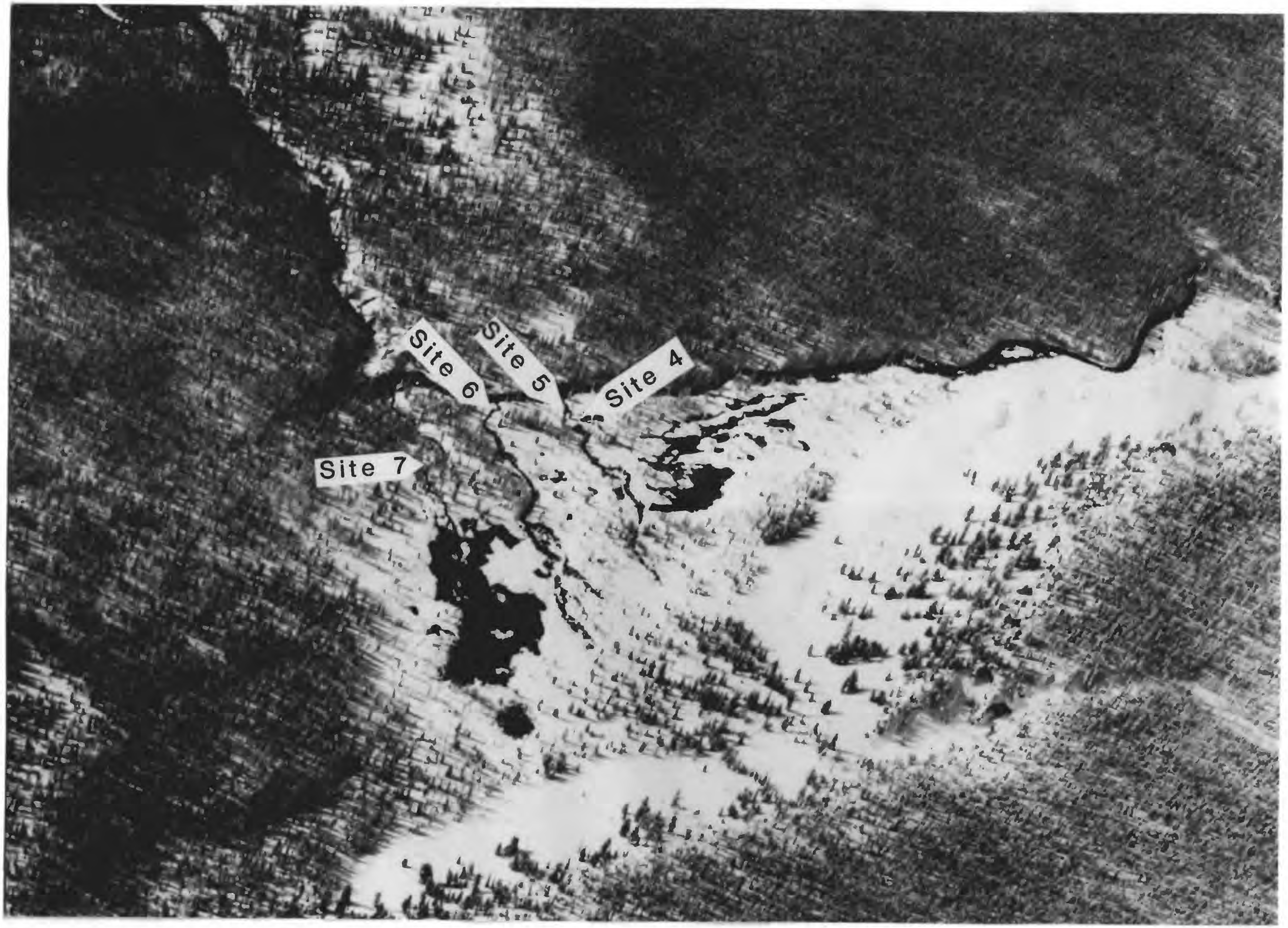


Figure 8. Aerial photograph of the Middle Boundary Creek Thermal Area looking east and showing sites 4, 5, 6, and 7.

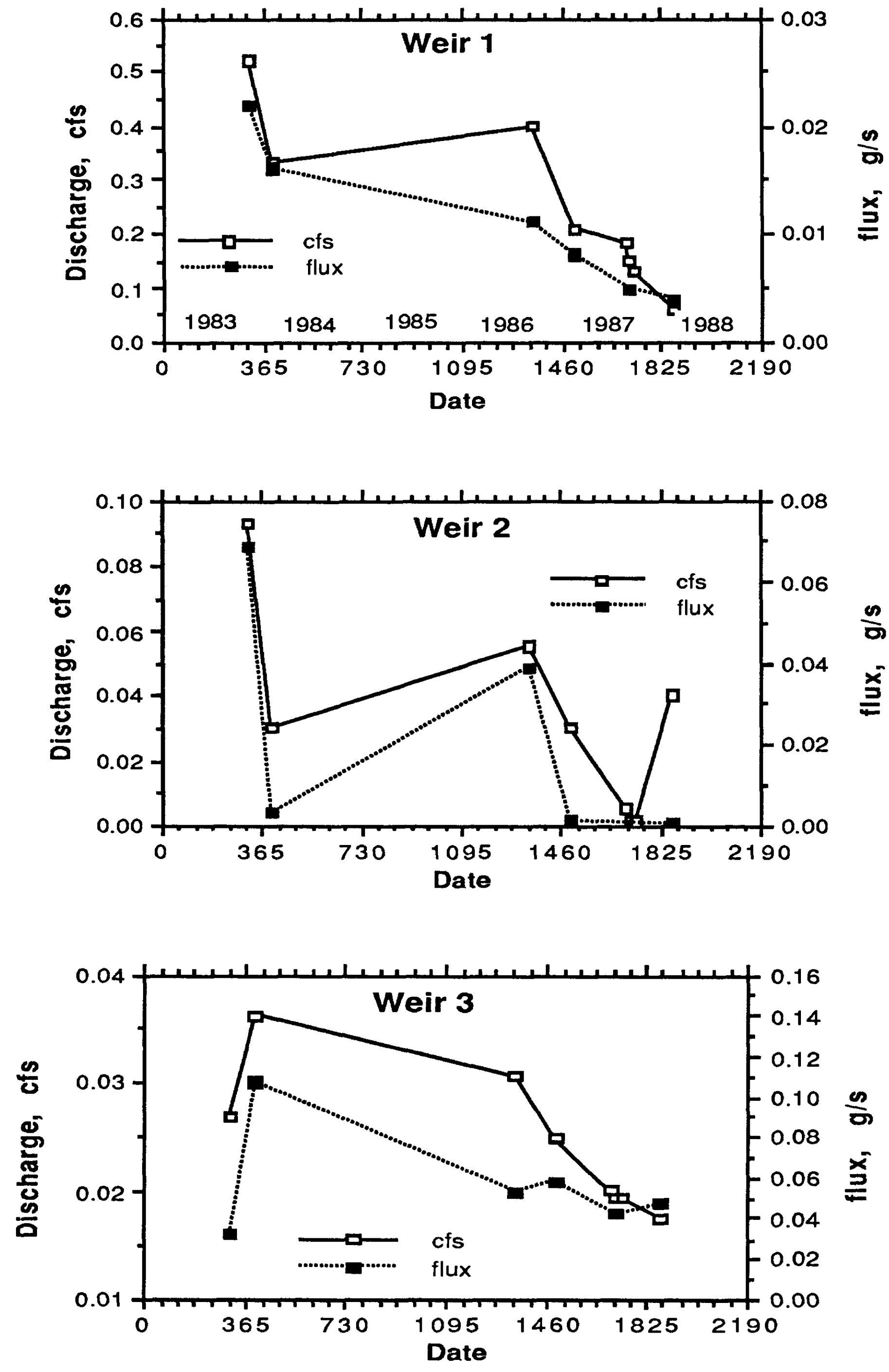


Figure 9. Plot of discharge and chloride flux for weirs 1, 2, 3 located at Monitor Creek Thermal Area

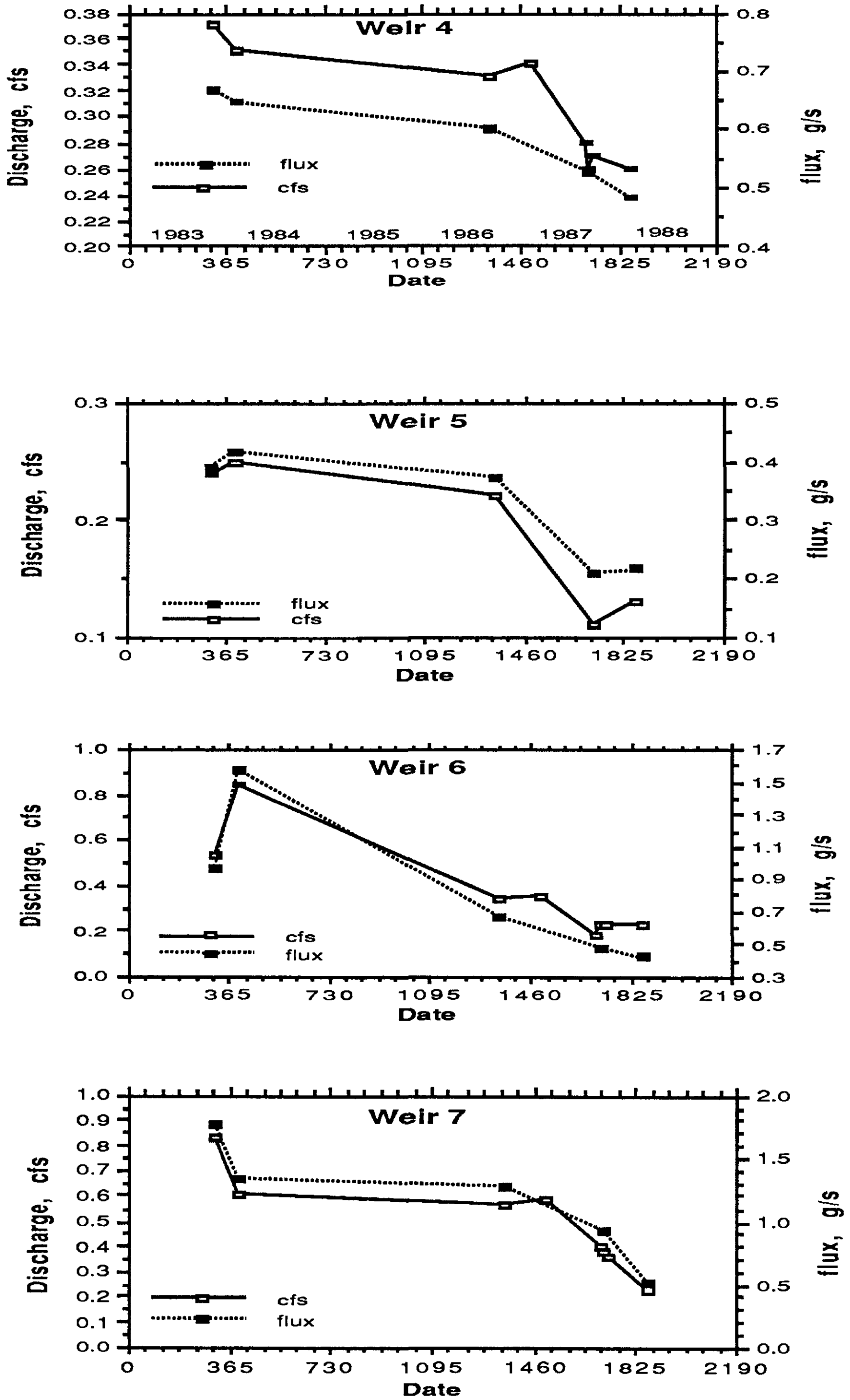
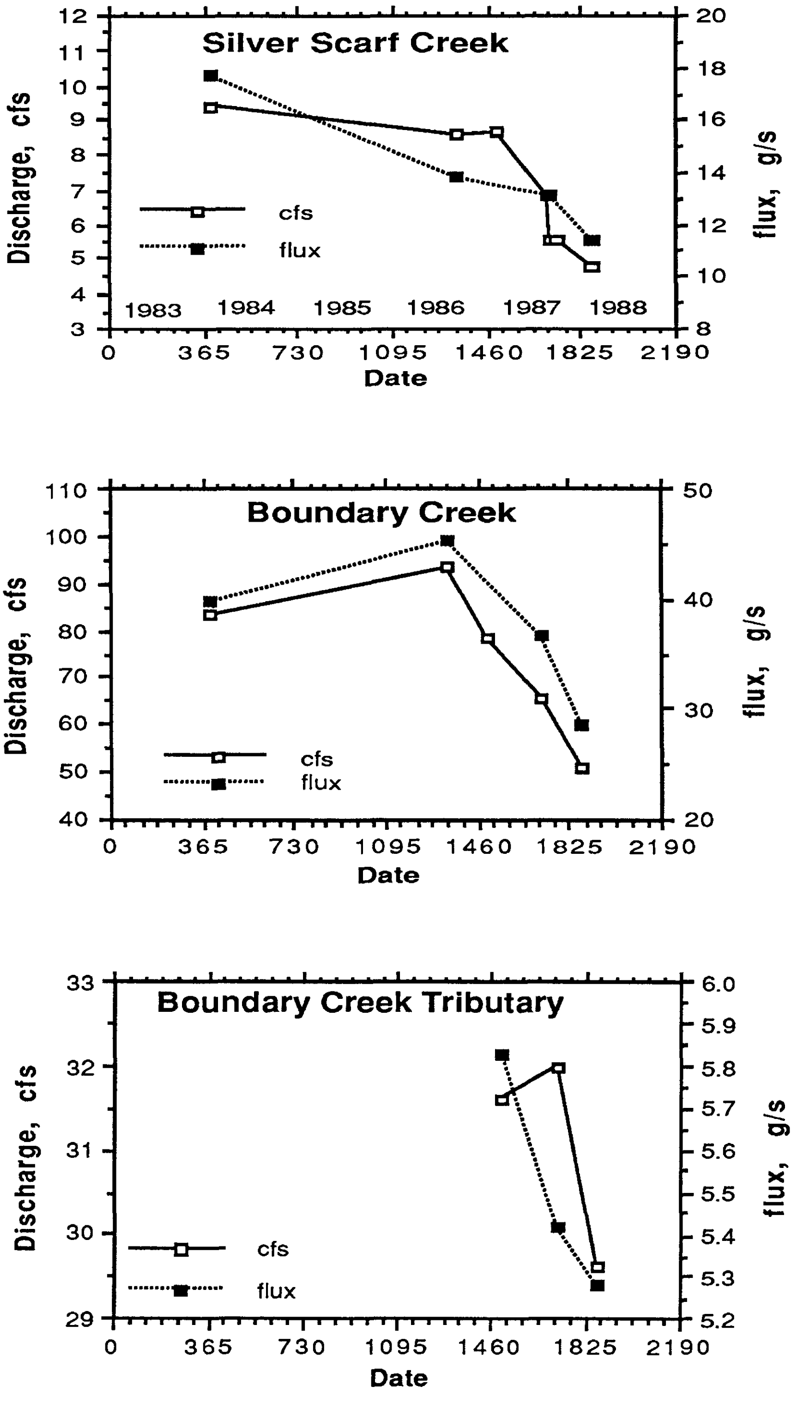


Figure 10. Plot of discharge and chloride flux for weirs 4, 5, 6, 7 located at the Middle Boundary Creek Thermal Area



11. Plot of discharge and chloride flux measured at staff gauges on major streams in the Boundary Creek drainage

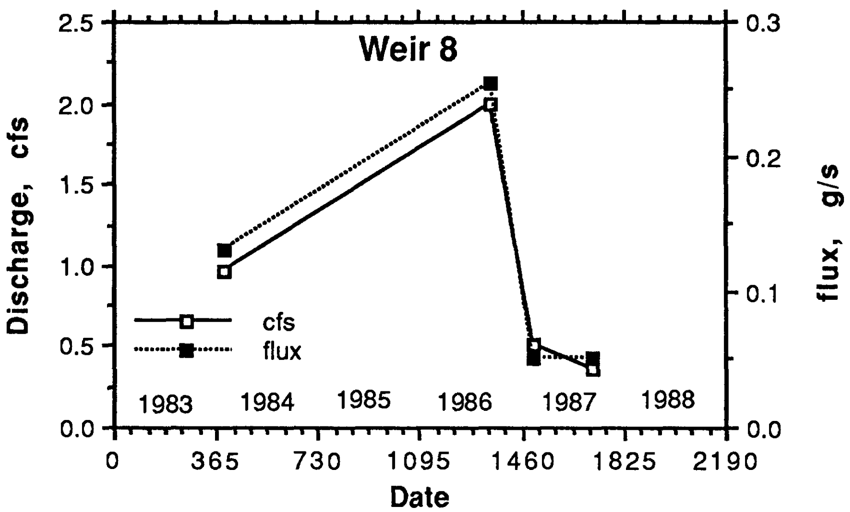


Figure 12
Plot of discharge and chloride flux for weir 8.