UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Monitoring of Thermal Activity in the Northern Part of Yellowstone National Park and Vicinity: Part 1-February 1985- June 1988

by

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ABSTRACT

We report on studies of thermal activity in the Gardner River and Norris Geyser Basins in Yellowstone National Park, as well as in the Corwin Springs Known Geothermal Resource Area north of the Park. This activity was monitored by the measurement of stream discharge and chloride concentration and the calculation of chloride flux.

The discharge and chloride flux from Norris Geyser Basin, as measured in Tantalus Creek, varies greatly as a function of time. The increase in both seems to be related to an increase in discharge of a water of high chloride concentration, and may be the result of variations in thermal output from Norris Geyser Basin.

Of the chloride flux measured at the Gardner River gauging station, approximately 75 % originates from Hot River, and 15 % from Mammoth Outflow. The remaining 10 % is contributed by upstream sources and by possible underflow from Mammoth Hot Springs. The chloride flux in the Gardner River shows sizable variations from month to month over the 40 months of measurement.

Although the discharge from La Duke Hot Spring varied seasonally, the chloride concentration remained constant, resulting in an increase of chloride flux with increased discharge. We have observed this phenomenon at other hot spring systems in the Park.

We have been monitoring water level and chloride concentration in the Miller thermal well located 1 km from La Duke Hot Spring, as measures of the variations in the shallow hydrologic system. Although significant changes in water level have occurred, the chloride concentration of the Miller well water has been constant for the past 18 months.

INTRODUCTION

Monitoring of the thermal activity in Yellowstone National Park is being carried out 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, as well as to relate these variations to other geochemical and geophysical phenomena in order to gain knowledge of the mechanics of the geothermal system. Fornier et al. (1976) used the chloride flux in river water to determine the mass and heat flux of hot spring waters into the Yellowstone and Madison Rivers, including Norris and Mammoth systems, and Norton and Friedman (1985) utilized chloride flux measurements to determine thermal activity out of the four major river drainage basins of the Park. In the latter paper the authors showed that the chloride flux in the rivers and streams is about 94% from geothermal sources and the remainder from precipitation, rock weathering, and human contribution. In the case of streams issuing directly from thermal areas, essentially all of the chloride is from geothermal sources. More recently, Friedman et al (1988) used the same method to determine the thermal activity in southwest Yellowstone National Park which is adjacent to Island Park Geothermal Area.

In this paper we report on the first phase of a long-term monitoring study of thermal activity in the Gardner River drainage basin in the northern part of the Park which relates to the Mammoth Hot Springs thermal area, Norris Geyser Basin, and the Corwin Springs Known Geothermal Resource Area (KGRA). The principal area of hot spring discharge in the KGRA is at La Duke Hot Spring. The locations of these features are shown in figures 1 and 2.

Norris Geyser Basin is located near the southern limit of the Gardner River drainage basin and is considered to be on a major fault extending northward to the Mammoth Hot Springs thermal area, and possibly continuing north outside the Park into the Corwin Springs KGRA.

One reason for the initiation of this study was to satisfy the requirements under two Congressional Acts. The first requires the Secretary of the Interior to monitor significant thermal features within the National Park System (Federal Register,1987). The second is the requirement of the U.S. Geological Survey to respond to current legislation in Senate Bill 1889 (Congressional Record-Senate,1987). This bill amends the Geothermal Steam Act of 1970 to provide that *the U.S. Geological Survey in consultation with the National Park Service shall conduct a study of the impact of present and potential geothermal development in the vicinity of Yellowstone National Park on the thermal features within Yellowstone National Park. The area to be studied shall include the lands within the Corwin Springs*

Known Geothermal Resource Area.

The Draft Environmental Impact Statement issued by Montana Department of Health and Environmental Sciences (1988) delineates the issues related to the development of geothermal resources by the Church Universal and Triumphant in Park County, Montana. Of particular concern is the impact that pumping of the thermal water in the vicinity of La Duke Hot Spring by the Church could have on the thermal features at Mammoth Hot Springs. One of the important issues is the use of the water rights of the La Duke Hot Spring by the Church and how it might impact the thermal features at Mammoth Hot Springs. A report by Sonderegger (1987) addresses the possible impact based on the known and inferred geologic structures that interconnect the two systems. In addition, under the water laws of the State of Montana there is no limit to the number of geothermal wells pumping less than 100 gallons per minute that can be drilled in this area. The progress report presented here addresses some of the monitoring requirements under Public Law L.99-591, provides data for the studies required under Melcher amendment to the Geothermal Steam Act (S.1889), and provides data needed for a better understanding of the geothermal system.

EXPERIMENTAL METHODS

Discharge of streams and springs was measured by either reading the height of water in a weir of standard design, and referring to tables to convert water-height to discharge, or by reading a staff gauge placed in the stream and converting these readings to discharge by the use of a rating table. These rating tables were generated by calculating discharges using velocity measurements in the usual manner, and relating these discharges to the water height as measured by the staff gauge.

Samples for the measurement of chloride concentration were filtered through a 5 micrometer filter immediately after they were collected. The chloride measurements were carried out in the National Water Quality Analysis Laboratory of the U.S.G.S. Water Resources Division in Denver. A series of standard waters of known chloride concentration were analyzed together with every group of 20 to 40 samples collected in the field, and all analyses were normalized to these gravimetric standards. Using this protocol, the chloride analyses are accurate to 2 % of the true chloride values.

Chloride flux is the product of discharge and chloride concentration. Instantaneous chloride flux is reported in grams of chloride per second, while integrated monthly and annual chloride flux is reported in grams of chloride per month or year, and represents the total amount of chloride, in grams, that is discharged by the feature during that interval of time.

RESULTS

The results are shown in tables 1-9 and figures 1 to 9. Each site will be discussed separately.

La Duke Hot Spring

Although this spring is located on National Forest land, the discharge occurs out of a concrete spring box that is located on the highway right-of-way. The discharge of this spring declined from 52 to 4 gallons per minute (gpm) when a thermal well located 728 feet (220 m) S.W. of the spring was pumped at 400 gpm(Hydrometrics, 1986) .A 90° "V" notch weir was emplaced in September 1986 adjacent to the culvert that carries the spring discharge under the highway. This weir was destroyed by vandals during the winter of 1987, and a new weir (60° "V" notch) was installed on September 1987. The weir site was upgraded in September 1988 by the removal of material from the area immediately behind the weir plate.

The results of the discharge and chloride measurements are given in table 1 and in figure 3. The concentration of chloride remained constant during the two years of measurement. Inasmuch as the discharge increased during the spring of 1988, peaking in early July, the chloride flux increased in proportion to the discharge . There appears to be a seasonal variation of the flow of La Duke Hot Spring, which does not affect its chloride concentration.

Miller Well

The Miller Well is located on the Miller property 8.4 km north of Gardiner, Montana on Highway 89 about 100 m east of the Yellowstone River. It is located approximately 1 km south of La Duke Hot Spring, and contains thermal water (table 2) similar in chemical composition to that of La Duke. The well is 58 m deep and is being pumped from a depth of 55 m. The use of this well, which has been graciously granted to us for long-term study by the owners, allows the monitoring of a number of parameters related to the underground thermal waters in the area. The well has been continuously pumped at a rate of 1 1/2 gpm for the past 8 years and is still being pumped at this rate. The depth-to-water in the well fluctuates with time (see table 3). The elevated temperature of the well water, measured at the land surface by a thermocouple and recorder, has remained constant at 26.5° C, indicating the connection of the well with a thermal source. A temperature profile run in September 1988 indicates that a maximum temperature of 25.5° C occurred at a depth of 40 m (M.L. Sorey, personal communication, 1988). Another temperature profile will be measured.

The data are given in table 3 and figure 4. Note that the chloride concentration remained constant during the sampling period.

Hot River

Hot River, also known as Boiling River, is a thermal stream that is considered to drain the Mammoth Hot Springs system. It issues from the ground at about 47° C at a location 50 m from its confluence with the Gardner River. Our data show that approximately 80% of the chloride contributed to the Gardner River from the Mammoth Hot Springs system exits via Hot River

Conn et al (1988) reported that A.M. Pitt of the U.S. Geological Survey discovered several years ago that a large amount of water from the Gardner River flowed into a sinkhole about 500 m upstream from the location where the Hot River exits from the ground. This water from the sinkhole mixes with thermal water underground and has been observed in the thermal stream that can be seen through skylights in the travertine to flow toward the Hot River. Measurements of water temperature and electrical conductivity show that the water in these skylights has the same temperature and conductivity as Hot River. There is a small travertine-depositing hot spring, about 200 meters upstream from, and about 20 meters vertically above, Hot River. Conn, et al (1988) have suggested that this spring may have the same chemical composition as Hot River before its dilution with Gardner River water via the sinkhole. Recent measurements by these authors showed that, at the time of measurement, about 30% of the flow of Hot River was contributed by this inflow from the Gardner River.

A staff gauge was installed in January 1987 on Hot River near the place where it issues from the ground. Three velocity-meter measurements were made to develop a stage-discharge rating for this site.

The data are presented in table 4, and in figure 5. Significant variations in discharge, chloride concentration, and calculated chloride flux were observed. Periods of increased discharge during the winter were accompanied by corresponding decreases in chloride concentration. This indicates a dilution of Hot River by snow melt, or by increased inflow from the Gardner River through the sinkhole. However for the period of record reported here calculated values of discharge and chloride flux generally increased by a factor of 1.5.

This can be the result of either the inflow of stored chloride by melt-water, or to chloride contributed by the Gardner River via the sinkhole.

Allen and Day (1935) stated that the composition of Hot River resembled that of Mammoth water, but was more dilute. They also commented on the fact that the temperature of Hot River was lowest when the water was most dilute, and suggested that this was caused by dilution of Hot River with surface melt water and precipitation. They were unaware of the existance of the sinkhole.

From the observations quoted by Allen and Day (1935) and from Fournier (personal communication, 1989) the discharge and chloride of Hot River has not changed greatly from 1883 to the present.

Mammoth Outflow

Mammoth Outflow is the informal name that we have given to the thermal stream that drains the Mammoth Terraces. It flows past the housing units and enters the Gardner River 200 m above the footbridge. The footbridge is about 1 km above the confluence of the Hot River with the Gardner River. Approximately 10% of the chloride flux from Mammoth Hot Springs exits via this stream.

Sampling and discharge measurements were begun in September 1986. The original staff-gauge site was located adjacent to the employee housing area in Mammoth. This site was replaced by a weir installed in September 1988 near the helicopter pad, downstream from the initial site. Results obtained for the original site are given in table 5 and figure 6.

The chloride concentration was constant with time, but the discharge, and therefore chloride flux, was highly variable. The discharge peaked during the winter, suggesting that snow melt may have increased the flow, but without affecting the chloride concentration, similar to the effect found for La Duke Hot Spring. However the timing of the discharge peaks are out of phase at the two sites. This can be attributed to the fact that snow melted constantly during the winter at Mammoth Hot Springs, but only in the springtime in the vicinity of La Duke.

Mammoth Hot Springs

The total chloride flux from the Mammoth Hot Springs system can best be found by measuring the difference in chloride flux in the Gardner River above and below Mammoth Hot Springs. Gauging and sampling have only recently been initiated above the system to supplement the measurements already being made below it. Another method of estimating the chloride flux from the Mammoth Hot Springs system is to compare the sum of the fluxes from Mammoth Outflow and Hot River with the flux in the Gardner River below the system. On the three days that this was done, the results indicate that about 90% of the chloride from Mammoth Hot Springs exits via Hot River and Mammoth Outflow.

Allan and Day (1935) measured the discharge from 6 weirs placed on streams that exited various portions of the Mammoth Hot Springs. These measurements were carried out from November 1928 through August 1932, and showed that the discharge varied both seasonally and long-term. On the basis of the constancy of temperature of the of the springs irrespective of the amount of discharge, they ruled out the effect of long-term drought on the the discharge of the springs. We take issue with their conclusions, and a manuscript is in preparation explaining our explanation of the observed data.

Tantalus Creek

Tantalus Creek is the surface drainage of Norris Geyser Basin. A weir was constructed on the creek in September 1987 about 1 km downstream from Porcelain Basin and about 1/2 km from its confluence with the Gibbon River. The data from this site are given in table 6 and figure 7. The discharge and chloride from this stream fluctuates greatly with time. Although the chloride flux varies directly with the discharge, the relationship between the two, shown in figure 5C, is not simple. The chloride flux increases with flow at a rate greater than would be expected if the increased flow was the result of either dilution with precipitation runoff, or was from water having a constant chloride concentration. This may result from an addition to the normal stream flow by water of a high chloride concentration, such as might originate from geyser eruptions of Echinus Geyser in theBack Basin, and Blue Geyser in Porcelain Basin, or from increased thermal activity in the Norris Geyser Basin. We plan to continuously measure and telemeter the discharge data for Tantalus Creek in order to relate the discharge to geyser activity.

Gardner River

An automated station, established for the purpose of measuring stream flow many years ago and later abandoned, was reactivated in 1985 (figure 1). Sampling the river for chloride at this site revealed that the chloride concentration varied from point to point across the river. We then investigated the uniformity across the river at various sites downstream(see table 7), and found that the chloride concentration in the river at the Mac Minn Bench site was essentially the same as that in both sides of the river at sites further downstream. Therefore the MacMinn Bench site was chosen for collecting samples of the Gardner River for this work.

The data are presented in table 8 and figure 8. The data from this river shows the normal effects of spring runoff with respect to discharge and chloride concentration. The chloride flux, however is fairly constant with time.

The chloride in the Gardner River, as measured on three separate days, is contributed mainly by Mammoth Hot Springs (see table 9). The sum of the fluxes from Mammoth Outflow and Hot River account for about 90 % of the chloride flux measured in the Gardner River. The balance of 10% is contributed by a number of sources, including underflow from Mammoth Hot Springs, as well as upstream sources. From a chloride survey of these upstream sources shown in table 10, it is evident that Obsidian Creek is the major source of this upstream chloride.

Integrating the instantaneous chloride flux values, it is possible to calculate monthly and yearly flux values. It is then possible to compare monthly chloride flux at base flow from year to year. The integrated monthly chloride flux data for the Gardner River from March 1985 through June 1988 is as shown in figure 9.

CONCLUSIONS

La Duke Hot Springs

Chloride concentrations remained constant for the two years of measurement. Discharge increased from 95 gpm to a peak of 140 gpm in the spring. There appears to be a seasonal effect on the discharge of this spring which does not affect its chloride concentration.

Miller Well

The chloride concentration has been constant for the 18 months of sampling. The depth-to-water in the well fluctuates with time. There is insufficient data to relate the changes in depth-to-water of this well to changes in discharge of the adjacent La Duke Hot Springs.

Hot River

Discharge has been variable from 16 to 38 cfs over the 18 months of record, with an increase during the winter. The chloride concentration varies inversely with the discharge. However the chloride flux varies directly with discharge. This can be the result of either the inflow of stored chloride by melt-water, or to additional chloride contributed by Gardner River inflow via the sinkhole. About 75% of the chloride in the the Gardner River near its confluence with the Yellowstone comes from Hot River.

Mammoth Outflow

Approximately 15% of the chloride in the Gardner River originates from Mammoth Outflow. The chloride concentration is constant with time, but the discharge and therefore chloride flux is highly variable. The discharge peaked during the winter, suggesting that the snow that melts during the winter may have influenced the discharge, but not the chloride concentration, similiar to the effect found for La Duke. This can be the result of the fact that the snow melts constantly during the winter at Mammoth Hot Springs, but only during springtime at La Duke. The constancy of chloride concentration during periods of increased spring flow was not anticipated, and the reasons for this phenomena are not known. We have observed this phenomenon at a number of other thermal systems in the Park (see Friedman et al, 1988).

Mammoth Hot Springs

Although the preponderance of the chloride leaving Mammoth Hot Springs exits via the Hot River and Mammoth Outflow, an unknown amount may leave by underflow into the Gardner River, and we will be measuring this in the future.

Tantalus Creek

Allen and Day (1935) reported discharge measurements from 1.4 to 4.4 cfs. measured occasionally from 1927 to 1930. The discharge from this thermal stream that drains Norris Geyser Basin has been observed by us to fluctuate from 2.5 to 5 cfs. Evidence from a high water mark on the weir indicates that a value as high as 9 cfs was reached during the spring of 1988. The chloride concentration is also variable, and the chloride flux increases with flow at a rate greater than would be expected if the increased flow was the result of either dilution with precipitation runoff, or from additional discharge of water of the same chloride concentration. This effect could result from from an addition to the normal water flow by water of a high chloride concentration, such as might arise from geyser eruptions in the Norris Geyser Basin.

Gardner River

About 90% of the chloride in the Gardner River is contributed by Hot River and Mammoth Outflow. The balance is from a number of sources, including underflow from Mammoth Hot Springs, as well as from sources upstream, such as Obsidian Creek.

The chloride flux was fairly constant from March 1985 to July 1988 with the exceptions of the spring runoff periods. Although the integrated monthly chloride flux varies greatly from month-to-month, the annual integrated flux for the full two years of measurement (1986-87) was constant to 2.5%, well within the errors of measurement. During the winter of 1987-8 the integrated chloride flux was significantly lower than that of the previous two winters.

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REFERENCES

Allen, E.T., and Day, A.L. (1935) Hot springs of the Yellowstone National Park. Carnagie Institute of Washington. Report number 466

Congressional Record-Senate (1987), S-166673, Sec. 10(a)

Conn, P.J., Hudgins, J.A., and Hamilton, W.L.(1988) The source of Hot River. abstract, *Sixth Annual Yellowstone Physical Science Symposium. 6 Sept 1988*, Mammoth, Yellowstone National Park, WY.

Draft environmental impact statement (1988) Church Universal and Triumphant, Park County. Montana Department of Health and Environmental Sciences, 152 pp.

Federal Register (1975) Geological Survey, Corwin Springs, Montana, Known Geothermal Resources Area, vol. 40 no. 141, July 22, 1975

Federal Register (1987) Part 111, Dept. of Interior, National Park Service Significant thermal features within units of the National Park System; Notice. v. 52, No. 148, Par 2(b)

Friedman, I., Norton, D.R., and Hutchinson, R.A. (1988) Monitoring of thermal activity in southwest Yellowstone National Park. U.S.Geol. Survey Open File Report 88-532

Leonard,R.B., Brosten, T.M., and Midtlyng, N.A.(1978) Selected data from thermal-spring areas, South West Montana. U.S. Geol. Survey Open File Report 78-438

Norton, D.N., and Friedman,I (1985) Chloride Flux out of Yellowstone National Park. J. *Volcanol. Geotherm. Res. 26*, 231-250

Hydrometrics (1986) Aquifer testing and evaluation of a geothermal well at Royal Teton Ranch near Corwin Springs, Montana.A report prepared by Hydrometrics, Helena, Montana to the Royal Teton Ranch, Corwin Springs, Montana,41 pp

Sonderegger, J.L. (1987) Informal report to State of Montana Agencies concerning Potential effects of production from a geothermal well located near La Duke Hot Spring. Montana Bureau of Mines and Geology, Butte, MT.

White, D.E., Hem, J.D., and Waring, C.A. (1963) Data of geochemistry, sixth ed., Chapter F. Chemical composition of subsurface waters. U.S. Geol. Survey Prof. Paper 440F, p F1-F67

White, D.E., Fournier, R.O., Muffler, L.P.J., and Truesdell, A.H. (1975) Physical results of research drilling in thermal areas of Yellowstone National Park, Wyoming. U.S. Geol. Survey Prof. Paper 892

Table 1
La Duke Hot Spring

Sample number	Date	date number	Chloride ppm	Weir reading inchs	Chloride flux g/s	Discharge gpm
A-713LD	4-Sep-86	247	45.4	4.45*	.272	95
B-716LD	10-Jan-87	375	45.5	4.5*	.281	98
1108LD	11-Feb-87	407	46.9			
1124LD	12-Mar-87	436	46.6			
1153LD	13-Apr-87	468	46.8			
1195LD	12-May-87	497	46.9			
1196LD	14-May-87	499	47.0			
1235LD	9-Jun-87	525	46.2			
1310LD	17-Jul-87	563	46.4			
1360LD	31-Jul-87	577	46.0			
1312LD	17-Aug-87	594	46.0			
745LD	6-Sep-87	614	46.4	5.7	.284	101[3]
1351LD	11-Sep-87	619	47.3			
1385LD	11-Oct-87	649	46.4			
1392LD	5-Nov-87	674	44.1	5.60	.270	96
1401LD	12-Nov-87	681	44.8	5.90	.310	110
	8-Dec-87	707		5.80		105
1416LD	10-Dec-87	709	44.6	5.60	.270	96
	15-Dec-87	714		5.70		101
	23-Dec-87	722		5.50		92
1446LD	29-Dec-87	728	44.2	5.80	.293	105
	5-Jan-88	735		5.80		105
1435LD	15-Jan-88	745	44.6	5.70	.284	101
	21-Jan-88	751		5.70		102
1454LD	27-Jan-88	757	44.5	6.00	.323	115
	3-Feb-88	764		6.10		119
783LD	12-Feb-88	773	44.5	5.80	.290	105
1505LD	13-Feb-88	774	44.2	5.90	.307	110
	17-Feb-88	778		5.80		105
	25-Feb-88	786		6.00		115
	2-Mar-88	792		5.80		105
1496LD	8-Mar-88	798	45.1	5.80	.299	105
	10-Mar-88	800		5.80		105
1494LD	15-Mar-88	805	44.4	5.80	.294	105
	16-Mar-88	806		5.90		110
	22-Mar-88	812		5.80		105
	31-Mar-88	821		5.90		110
	7-Apr-88	828		6.00		115
1540LD	12-Apr-88	833	45.0	6.00	.330	115
	14-Apr-88	835		6.00		115
	22-Apr-88	843		6.00		115
	28-Apr-88	849		6.00		115
1541LD	4-May-88	855	44.7	6.10	.336	119
	11-May-88	862		6.10		119
1567LD	12-May-88	863	44.9	6.10	.340	119
	19-May-88	870		6.20		124
	25-May-88	876		6.30		129
	2-Jun-88	884		6.30		129
1611LD	7-Jun-88	889	44.8	6.40	.380	135
	8-Jun-88	890		6.30		129
1597LD	14-Jun-88	896	44.8	6.40	.380	135
	14-Jun-88	896		6.40		135
	16-Jun-88	898		6.40		135
	24-Jun-88	906		6.40		135
	29-Jun-88	911		6.50		140
	5-Jul-88	917		6.50		140
	7-Jul-88	919		6.50		140
1633LD	10-Jul-88	922		6.50		140
	13-Jul-88	925		6.40		135

[3] The first two weir readings were made on a 90° weir. The remainder on a 60° weir. No readings of the weir were made from February through August 1987.

Table 2

Chemical Analysis of selected thermal features

Constituent	Miller Well[4]	La Duke Hot Spring[5]	La Duke Hot Spring[6]	Mammoth Hot Springs[7]	Hot River[8]
Ca	72	320	342	272	205
Mg	85	58	63	68	54
Na	310	230	240	129	105
K	30	23	23	69	41
Fe	0.014	0.16	0.14	0.06	—
Al	—	<.001	<0.1	0.2	—
SiO_2	59	49	—	55	52
Li	0.140	0.24	—	2.3	—
NH_4	—	0.24	—	—	—
HCO_3	360	300	278	667	530
SO_4	980	1200	1340	501	393
Cl	37	45	51	170	122
F	1.7	3.6	3.8	2.4	—
NO_3	—	0	—	—	—
B	0.650	0.46	—	4.3	—
H_2S	—	0.1	—	2.6	—
As	0.014	—	—	—	—
Ba	0.027	—	—	—	—
Pb	0.010	—	—	—	—
Mn	0.021	—	—	—	—
Sr	1.4	—	—	—	—
Zn	0.010	—	—	—	—
Sp. Cond.[9]	2210	2460	2540	2220	—
pH	8.6	6.5	6.7	6.6	—
Temp.[10]	25.5	65	57	72	—

[4] Miller Well analysis, 1983 by U.S.G.S., W.R.D. Central Lab., Lab. I.D. 3228901

[5] La Duke analysis, 1975 listed on p. 46 of Leonard et al. (1978)

[6] La Duke analysis, 1986, Appendix 3, Hydrometrics, 1986

[7] Mammoth analysis, 1955, listed on p. 54 of White, et al. (1963), except SiO_2 for which the value from White et al (1975) was used.

[8] Hot River analysis Allen And Day (1935), table 76

[9] Specific Conductivity in micromhos/cm^2

[10] Temperature in degrees Celcius

Table 3

Miller Well

Sample. number	Date	Date number	Chloride ppm	Depth to water,ft
717MW	10-Jan-87	375	35.3	
1107MW	11-Feb-87	407	35.2	
1123MW	10-Mar-87	434	34.8	
1150MW	13-Apr-87	468	36.0	
1192MW	14-May-87	499	38.4	
1232MW	9-Jun-87	525	36.2	
1311MW	10-Aug-87	587	34.9	
1350MW	10-Aug-87	587	34.5	
A-719MW	5-Sep-87	613	36.5	
748MW	6-Sep-87	614	35.6	
1383MW	11-Oct-87	649	35.5	
1391MW	5-Nov-87	674	33.8	41.85
1400MW	12-Nov-87	681	33.9	
1415MW	10-Dec-87	709	34.1	34.84
1445MW	29-Dec-87	728	33.8	
1432MW	15-Jan-88	745	34.2	
1453MW	27-Jan-88	757	33.6	34.92
784MW	12-Feb-88	773	33.7	
1506MW	13-Feb-88	774	33.5	
1495 MW	8-Mar-88	798	34.7	40.23
1493MW	15-Mar-88	805	34.6	
1535MW	12-Apr-88	833	34.4	
1537MW	4-May-88	855	34.6	
1556MW	14-May-88	865	34.8	
1596MW	14-Jun-88	896	35.4	
1610MW	7-Jun-88	889	35.5	

Table 4

Hot River

Sample number	Date	Date number	Chloride ppm	Gauge reading,ft	Discharge cfs	Chloride flux, g/s
A-717BR	4-Sep-86	612	122.4			
B-719BR	15-Jan-87	745	134.2	1.22	17.6	66.87
1121BR	29-Jan-87	759	133.5	1.20	16.0	60.48
1109BR	4-Feb-87	765	132.7	1.21	16.8	63.13
1110BR	12-Feb-87	773	134.2	1.20	16.0	60.79
1111BR	20-Feb-87	781	135.7	1.22	17.6	67.64
1112BR	26-Feb-87	787	143.6	1.19	15.3	62.20
1113BR	6-Mar-87	795	132.2	1.24	19.2	71.89
1114BR	13-Mar-87	802	135.8	1.26	21.0	80.77
708BR	21-Mar-87	810	133.3	1.25	21.1	79.65
1171BR	1-Apr-87	821	137.8	1.24	19.2	74.89
1158BR	10-Apr-87	830	137.4	1.24	19.2	74.69
1159BR	16-Apr-87	836	132.3	1.25	20.1	75.32
1160BR	21-Apr-87	841	137.4	1.26	21.0	81.69
1161BR	29-Apr-87	849	125.9	1.30	25.0	89.15
1239BR	6-May-87	856	127.7	1.30	25.0	90.38
1270BR	12-May-87	862	122.1	1.32	27.2	94.01
1229BR	27-May-87	877	120.0	1.31	26.1	88.70
1226BR	2-Jun-87	883	118.8	1.32	27.2	91.47
1262BR	11-Jun-87	892	119.1	1.32	27.2	91.69
1263BR	19-Jun-87	900	123.4	1.30	25.0	87.37
1264BR	23-Jun-87	904	121.2	1.29	23.9	82.01
1265BR	2-Jul-87	913	119.5	1.30	25.0	84.62
1298BR	8-Jul-87	919	123.0	1.30	25.0	87.09
1299BR	17-Jul-87	928	123.6	1.30	25.0	87.50
1300BR	23-Jul-87	934	123.5	1.31	26.1	91.28
1301BR	31-Jul-87	942	124.2	1.31	26.1	91.79
1313BR	7-Aug-87	949	124.8	1.31	26.1	92.21
1314BR	12-Aug-87	954	123.0	1.32	27.2	94.75
1315BR	19-Aug-87	961	124.6	1.34	29.6	104.4
1316BR	28-Aug-87	970	124.3	1.32	27.2	95.72
736BR	3-Sep-87	976	120.8	1.32	27.2	93.04
1353BR	9-Sep-87	982	121.7	1.33	28.3	97.50
1354BR	19-Sep-87	992	120.4	1.34	29.6	100.9
1355BR	23-Sep-87	996	123.2	1.32	27.2	94.91
1223BR	30-Sep-87	1003	121.9	1.32	27.2	93.86
1386BR	6-Oct-87	1009	122.3	1.32	27.2	94.16
1387BR	23-Oct-87	1026	130.1	1.32	27.2	100.2
1402BR	5-Nov-87	1039	126.9	1.32	27.2	97.74
1403BR	3-Dec-87	1067	126.8	1.32	27.2	97.66
1417BR	6-Jan-88	1101	131.9	1.30	25.0	93.38
1437BR	5-Feb-88	1131	138.5	1.28	22.9	89.81
785BR	12-Feb-88	1138	140.7	1.25	20.1	80.05
1438BR	21-Feb-88	1147	135.1	1.26	21.0	80.34
1497BR	14-Mar-88	1169	126.3	1.32	27.2	97.25
1498BR	28-Mar-88	1183	121.6	1.34	29.6	101.9
1568BR	16-May-88	1232	100.5	1.40	37.7	107.3
1569BR	24-May-88	1240	101.0	1.40	37.7	107.8
1600BR	23-Jun-88	1270	105.1	1.40	37.7	112.2

Table 5

Mammoth Outflow

Sample number	Date	Date number	Chloride ppm	Discharge cfs	Chloride flux, g/s
A-715MO	4-Sep-86	612	171.7	2.83	13.8
B-722MO	15-Jan-87	745	171.4	3.74	18.2
1122MO	30-Jan-87	760	170.5		
1115MO	4-Feb-87	765	168.9		
1116MO	12-Feb-87	773	171.7		
1117MO	20-Feb-87	781	167.6		
1120MO	26-Feb-87	787	169.8	3.25	15.6
1118MO	6-Mar-87	795	169.4		
1119MO	13-Mar-87	802	171.8		
707MO	20-Mar-87	809	176.7		
1170MO	1-Apr-87	821	172.0		
1162MO	10-Apr-87	830	171.1		
1163MO	17-Apr-87	837	174.0		
1231MO	21-Apr-87	841	168.9		
1164MO	1-May-87	851	172.1		
1227MO	12-May-87	862	176.7		
1181MO	21-May-87	871	172.9		
1225MO	30-May-87	880	170.0		
1230MO	5-Jun-87	886	169.4		
1266MO	10-Jun-87	891	169.8		
1267MO	19-Jun-87	900	171.2		
1269MO	25-Jun-87	906	173.2	2.98	14.6
1165MO	3-Jul-87	914	171.8		
1302MO	9-Jul-87	920	173.3		
1303MO	15-Jul-87	926	171.9		
1304MO	24-Jul-87	935	170.2		
1305MO	30-Jul-87	941	173.1		
1317MO	4-Aug-87	946	173.2		
1318MO	12-Aug-87	954	170.0		
1319MO	21-Aug-87	963	171.0		
1320MO	27-Aug-87	969	170.0	1.38	6.6
739MO	3-Sep-87	976	170.4	2.03	9.8
1357MO	12-Sep-87	985	171.3		
1358MO	19-Sep-87	992	171.2		
1268MO	9-Oct-87	1012	171.7		
1389MO	23-Oct-87	1026	172.3		
1404MO	6-Nov-87	1040	171.0		
1405MO	4-Dec-87	1068	171.5		
1418MO	6-Jan-88	1101	171.2		
1439MO	5-Feb-88	1131	171.8		
786MO	12-Feb-88	1138	170.3		
1440MO	26-Feb-88	1152	170.0		
1499MO	18-Mar-88	1173	164.0		
1500MO	1-Apr-88	1187	166.6		
1545MO	15-Apr-88	1201	166.2		
1546MO	29-Apr-88	1215	164.3		
1547MO	13-May-88	1229	164.8		
1571MO	19-May-88	1235	165.7		
1572MO	27-May-88	1243	166.9		
1573MO	3-Jun-88	1250	166.0		
1601MO	10-Jun-88	1257	168.0		
1602MO	17-Jun-88	1264	168.2		
1603MO	24-Jun-88	1271	167.7		

Table 6

Tantalus Creek

Sample number	Date	Date number	Chloride ppm	Weir reading,in	Discharge cfs	Chloride flux, g/s
751TC	7-Sep-87	250	548	7.1	3.0	47.0
1387TC	8-Jan-88	373	484	7.5	3.3	45.3
808TC	14-Feb-88	410	501	10.1	5.2	73.8
1388TC	7-Mar-88	432	494	9.8	5.0	69.5
1389TC	14-Apr-88	470	402	6.2	2.5	28.6
1390TC	16-May-88	502	504	8.3	3.9	55.5
1391TC	1-Jun-88	518	498	9.4	4.7	65.6
1671TC	20-Jun-88	537	556	8.0	3.7	58.8

Table 7

Homogeneity of chloride in Gardner River sampling sites on 15 February, 1988

Sample number	Time	Location	Distance km	Chloride Concentration ppm[5] triplicate analysis			Av	Standard deviation percent
566	1115	Near confluence with Yellowstone River	0.1	37.7	37.7	37.3	37.6	0.6
564	1145	Footbridge, east side	1.5	36.6	37.2	37.1	37.0	0.9
565	1150	Footbridge, west side		38.0	37.7	37.4	37.7	0.8
561	1200	Lower bridge, north side	2.3	36.7	36.2	36.5	36.5	0.7
562	1205	Lower bridge, south side		36.2	36.6	37.4	36.7	1.7
563	1210	Mac Minn Bench, east side	3.8	36.2	36.7	36.6	36.5	0.7
558	1620	Upper bridge, north side	4.4	34.9	33.7	34.6	34.4	1.8
559	1625	Upper bridge, middle		34.8	35.2	34.6	34.9	0.9
560	1630	Upper bridge, south side		37.5	38.1	37.7	37.8	0.8
		Automated gauging site	4.5					

[5] Sample collections for chloride analysis were made at the Mac Minn Bench site.

Table 8

Gardner River

Sample number	Date	Date number	Chloride ppm	Gauge reading,ft	Discharge cfs	Chloride flux, g/s	
						total	thermal
543Ga	22-Feb-85	53	38.2	1.98	104	112	110
545Ga	8-Mar-85	67	44.6	1.98	104	131	129
547Ga	14-Mar-85	73	40.6	1.92	92	106	104
572Ga	2-Apr-95	92	37.8	2.03	115	123	121
584Ga	18-Apr-85	108	18.4	2.48	241	126	121
573Ga	26-Apr-85	116	32.5	2.14	140	129	126
574Ga	5-May-85	125	12.3	2.73	340	118	112
608Ga	14-May-85	134	12.5	2.71	331	117	111
609Ga	24-May-85	144	6.3	3.32	669	119	106
610Ga	30-May-85	150	7.8	3.18	578	127	115
597Ga	5-Jun-85	156	9.3	2.96	451	118	109
611Ga	6-Jun-85	157	7.6	3.24	616	132	120
612Ga	13-Jun-85	164	9.9	2.88	410	115	107
613Ga	21-Jun-85	172	12.5	2.67	314	111	105
644Ga	27-Jun-85	178	15.1	2.53	259	111	106
651Ga	5-Jul-85	186	17.9	2.38	207	105	101
633Ga	11-Jul-85	192	19.0	2.32	189	102	98
652Ga	13-Jul-85	194	20.0	2.34	195	110	107
653Ga	18-Jul-85	199	20.6	2.28	177	103	100
654Ga	24-Jul-85	205	20.7	2.28	177	104	100
655Ga	30-Jul-85	211	21.7	2.25	169	104	100
692Ga	3-Aug-85	215	21.5	2.26	171	104	101
693Ga	15-Aug-85	227	26.0	2.15	142	105	102
641Ga	19-Aug-85	231	26.8	2.13	137	104	101
694Ga	22-Aug-85	234	27.1	2.12	135	104	101
695Ga	30-Aug-85	242	29.0	2.08	125	103	100
611Ga	2-Sep-85	245	24.3	2.15	142	98	95
696Ga	11-Sep-85	254	27.9	2.13	137	108	106
697Ga	27-Sep-85	270	28.8	2.11	132	108	105
713Ga	11-Oct-85	284	36.2	2.10	132	135	133
714Ga	22-Oct-85	295	28.3	2.12	138	111	108
651Ga	5-Nov-85	309	29.7	2.09	129	109	106
737Ga	7-Nov-85	311	33.9	2.02	107	103	101
738Ga	30-Dec-85	364	43.5	2.01	103	127	125
739Ga	14-Jan-86	379	39.1	2.01	103	114	112
763Ga	5-Feb-86	401	37.1	1.95	84	88	87
740Ga	6-Feb-86	402	40.2	1.97	90	102	101
796Ga	13-Mar-86	437	38.7	2.03	110	121	118
797Ga	18-Mar-86	442	40.8	2.01	103	119	117
824Ga	19-Mar-86	443	39.0	2.02	107	118	116
798Ga	2-Apr-86	457	28.1	2.16	150	119	116
799Ga	15-Apr-86	470	23.5	2.27	184	122	119
851Ga	30-Apr-86	485	21.0	2.29	191	114	110
800Ga	3-May-86	488	13.3	2.79	383	144	137
801Ga	21-May-86	506	10.3	3.01	490	143	133

Table 8, continued

Sample number	Date	Date number	Chloride ppm	Gauge reading	Discharge cfs	Chloride flux, g/s total	thermal
843Ga	27-May-86	512	6.1	3.58	834	144	128
844Ga	4-Jun-86	520	4.2	4.24	1354	159	133
890Ga	9-Jun-86	525	6.3	4.13	1258	223	198
876Ga	20-Jun-86	536	6.3	3.40	715	128	114
877Ga	27-Jun-86	543	8.8	2.98	475	118	108
878Ga	3-Jul-86	549	11.8	2.74	343	115	108
921Ga	9-Jul-86	555	11.5	2.76	352	115	108
922Ga	17-Jul-86	563	14.6	2.55	267	110	105
923Ga	22-Jul-86	568	16.5	2.43	224	105	100
935Ga	22-Jul-86	568	16.7	2.41	217	103	98
924Ga	27-Jul-86	573	16.7	2.45	231	109	105
964Ga	5-Aug-86	582	20.1	2.29	178	101	98
965Ga	13-Aug-86	590	21.4	2.25	166	101	97
966Ga	21-Aug-86	598	19.8	2.37	204	114	110
967Ga	29-Aug-86	606	24.3	2.20	150	103	100
982Ga	2-Sep-86	610	24.3	2.24	160	110	107
1001Ga	15-Sep-86	623	25.1	2.19	153	109	106
1002Ga	1-Oct-86	639	25.2	2.17	153	109	106
1003Ga	16-Oct-86	654	30.2	2.11	132	113	110
1040Ga	22-Oct-86	660	29.1	2.12	132	109	106
1027Ga	30-Oct-86	668	29.3	2.12	135	112	109
1028Ga	18-Nov-86	687	29.7	2.11	126	106	103
1047Ga	4-Dec-86	703	44.2	1.98	93	117	115
1057Ga	12-Dec-86	711	40.3	2.03	110	126	123
1070Ga	14-Jan-87	744	37.4	2.03	110	116	114
1080Ga	20-Feb-87	781	51.0	2.04	114	165	162
1103Ga	25-Feb-87	786	41.1	2.00	100	116	114
1081Ga	13-Mar-87	802	39.7	2.00	100	112	110
1146Ga	10-Apr-87	830	39.9	2.01	103	116	114
1131Ga	17-Apr-87	837	32.6	2.21	166	153	150
1132Ga	23-Apr-87	843	27.6	2.32	200	156	152
1133Ga	5-May-87	855	16.9	2.47	252	121	116
1180Ga	18-May-87	868	14.0	2.69	339	134	128
1199Ga	20-May-87	870	12.9	2.68	335	122	116
1277Ga	21-May-87	871	15.8	2.54	278	124	119
1182Ga	28-May-87	878	14.7	2.64	318	132	126
1183Ga	5-Jun-87	886	17.5	2.43	238	118	113
1211Ga	11-Jun-87	892	21.7	2.47	252	155	150
1213Ga	25-Jun-87	906	23.3	2.20	163	108	104
1271Ga	30-Jun-87	911	25.9	2.17	153	112	109
1214Ga	3-Jul-87	914	26.6	2.14	144	108	106
1248Ga	9-Jul-87	920	23.1	2.24	175	114	111
1249Ga	15-Jul-87	926	28.1	2.12	138	110	107
1250Ga	24-Jul-87	935	26.7	2.15	147	111	108
1251Ga	31-Jul-87	942	28.0	2.07	123	98	95
1286Ga	4-Aug-87	946	29.1	2.07	123	101	99
1328Ga	11-Aug-87	953	32.3	2.06	120	110	107
Sample	Date	Date	Chloride	Gauge	Discharge	Chloride flux, g/s	

Table 8, continued

number	number	ppm	reading	cfs	total	thermal
1287Ga12-Aug-87	954	30.9	2.07	123	108	105
1288Ga21-Aug-87	963	32.6	2.04	114	105	103
1289Ga27-Aug-87	969	32.3	2.07	123	113	110
1338Ga 2-Sep-87	975	34.2	2.03	110	107	104
742Ga 3-Sep-87	976	35.2	2.04	114	114	111
1339Ga11-Sep-87	984	34.9	2.03	110	109	107
1340Ga18-Sep-87	991	35.3	2.01	103	103	101
1386Ga25-Sep-87	998	37.5	2.01	103	109	107
1364Ga30-Sep-87	1003	40.0	2.01	103	117	115
1341Ga 9-Oct-87	1012	35.8	2.00	100	101	99
1372Ga23-Oct-87	1026	42.4	1.93	78	93	92
1387Ga4-Nov-87	1038	37.9	1.99	84	98	96
1224Ga4-Dec-87	1068	38.9	1.95	84	93	91
1448Ga15-Dec-87	1079	47.3	1.93	78	104	103
1411Ga6-Jan-88	1101	42.8	1.85	55	67	66
1441Ga27-Jan-88	1122	42.6	1.94	81	97	96
1423Ga 5-Feb-88	1131	43.0	1.98	93	114	112
1424Ga26-Feb-88	1152	45.7	1.98	93	121	119
1501Ga8-Mar-88	1163	47.4	1.93	78	104	103
1485Ga18-Mar-88	1173	50.1	2.05	117	166	164
1486Ga 1-Apr-88	1187	36.7	1.95	84	87	86
1518Ga15-Apr-88	1201	34.8	2.07	123	121	119
1519Ga29-Apr-88	1215	27.2	2.17	153	118	115
1521Ga4-May-88	1220	28.7	2.13	141	115	112
1520Ga13-May-88	1229	14.9	2.60	302	127	121
1554Ga19-May-88	1235	12.3	2.88	425	148	140
1555Ga27-May-88	1243	8.9	3.34	677	171	157
1556Ga 3-Jun-88	1250	12.2	2.81	392	135	128
1606Ga 7-Jun-88	1254	12.5	3.14	560	198	187
1584Ga10-Jun-88	1257	11.9	2.85	411	138	130
1585Ga17-Jun-88	1264	14.0	2.58	294	117	111
586Ga24-Jun-88	1271	16.8	2.46	248	118	113

Table 9

Sources of chloride flux contributed to the Gardner River

Sample number	Date	Location	Discharge cfs	Chloride ppm	Chloride flux g/s	Percent of Gardner River flux
715	4 -Sep-86	MO[6]	2.83	172	14	13
722B	15 -Jan -87	MO	3.74	171	18	17
739	3-Sep-87	MO	2.03	170	9.8	9
717	4-Sep-86	HR[7]	21.2	122	74	73
719B	15-Jan-87	HR	17.6	134	67	58
726	3-Sep-87	HR	27.2	121	93	82
982	4-Sep-86	Ga[8]	146	24	101	
928B	15-Jan-87	Ga	91	42	116	
942	3-Sep-87	Ga	114	35	114	
	4-Sep-86	MO + HR			88	87
	15-Jan-87	MO + HR			85	73
	3-Sep-87	MO + HR			103	90

[6] Mammoth Outflow

[7] Hot River

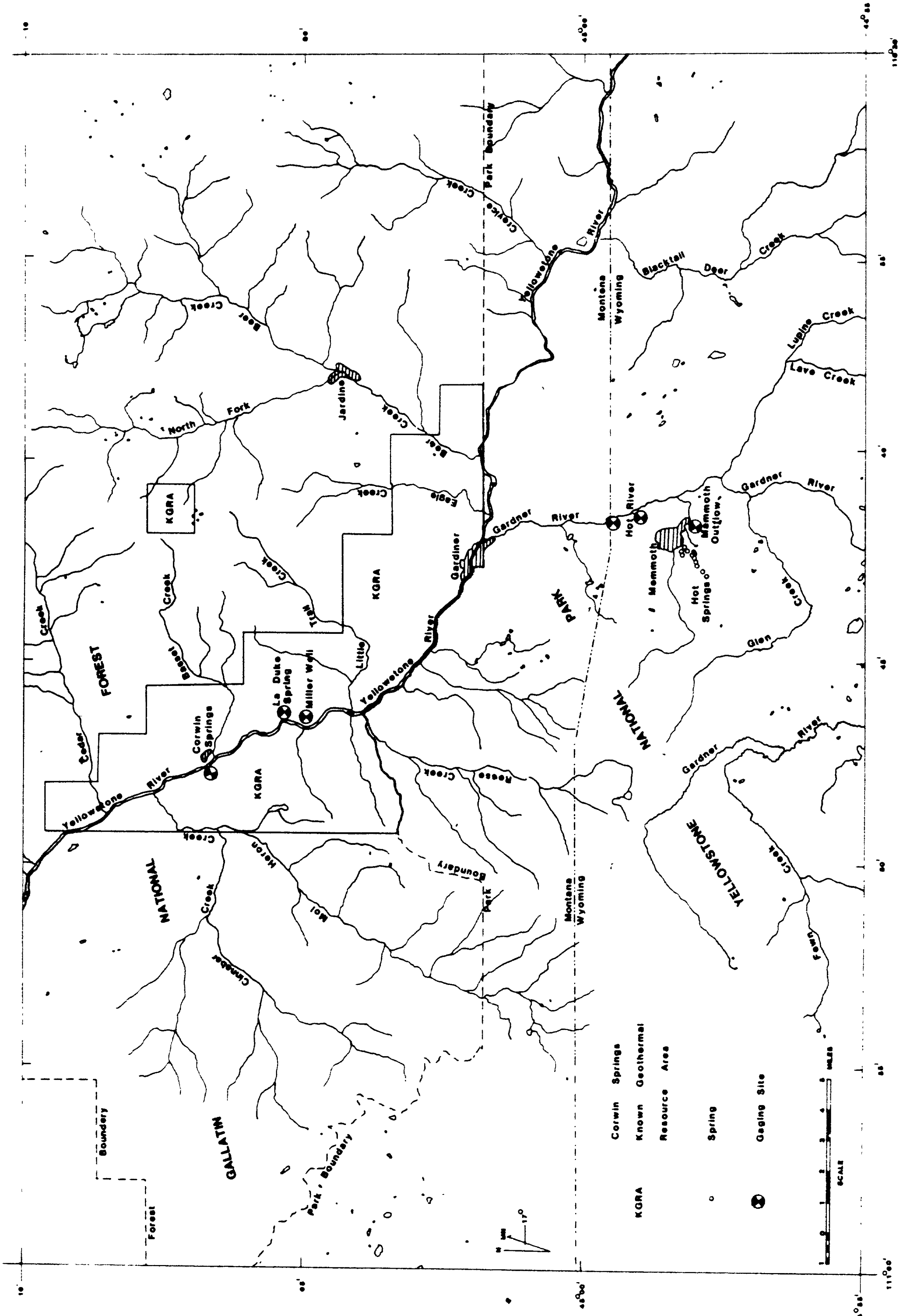
[8] Gardner River

Table 10

Survey of chloride in Upper Gardner River drainage

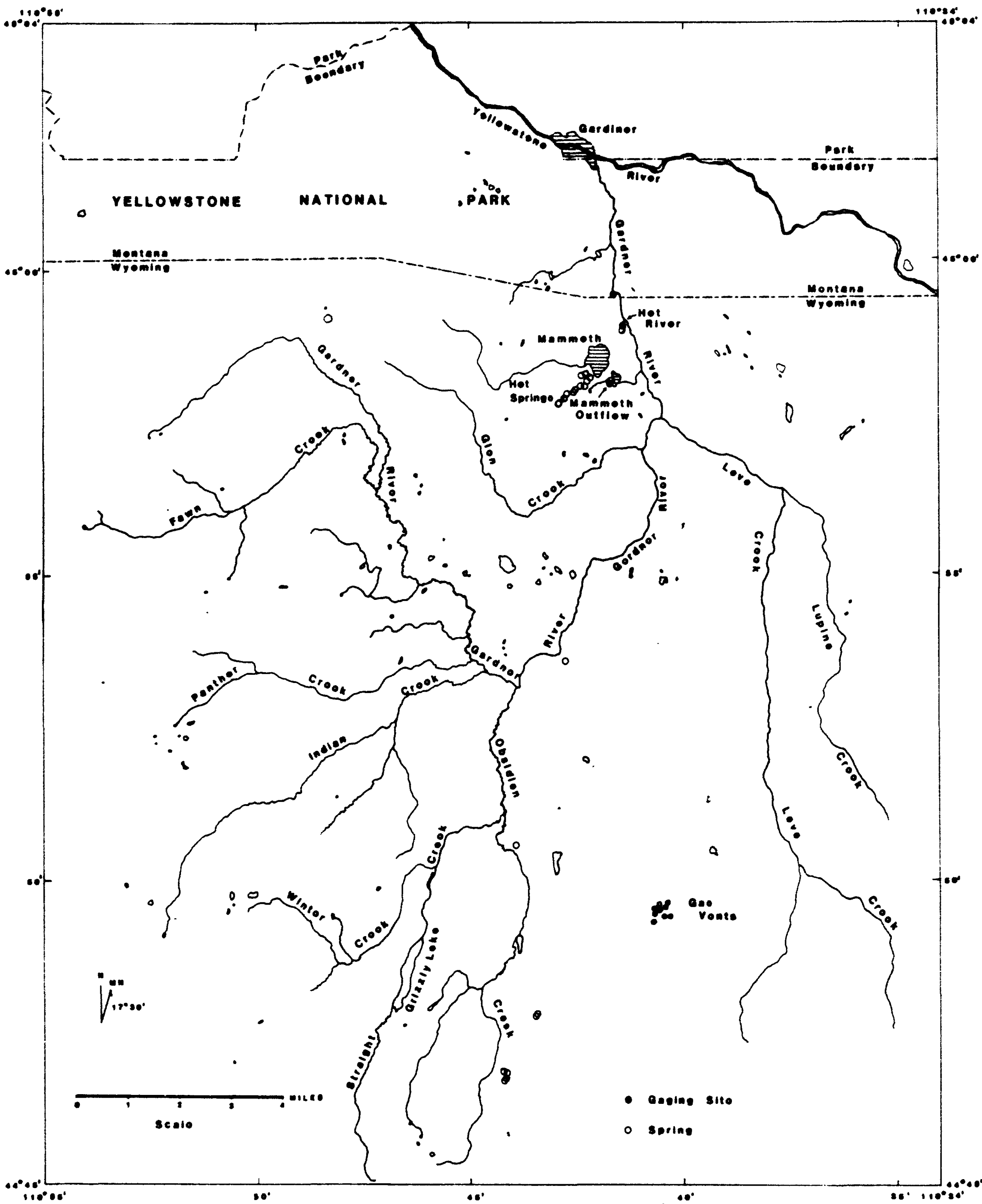
Sample number	Date	Location		Chloride ppm	Conductivity µmhos
73	26-Jul-82	Lava Creek	Picnic area	0.8	80
27	24-Jan-83			1.0	84
326	13-Apr-83			1.0	102
58	27-Jul-82	Gardner River	Sheepeater Canyon Bridge (S.E. of Mammoth Hot Spr.)	2.1	1330
117	1-Aug-82	Gardner River	Seven Mile Bridge	4.9	136
307	13-Apr-83		(Indian Creek Campground)	8.2	282
306	13-Apr-83	Indian Creek	above confluence with Obsidian Creek	1.0	318
305	13-Apr-83	Obsidian Creek	above confluence with Indian Creek	17.5	245
304	13-Apr-83	Obsidian Creek	400 m downstream from Clearwater Springs	231	2240
114	1-Aug-82	Glen Creek	Near junction Grand Loop	1.9	195
308	13-Apr-83		Road and Bunsen Peak Rd.	1.2	199

Figure 1



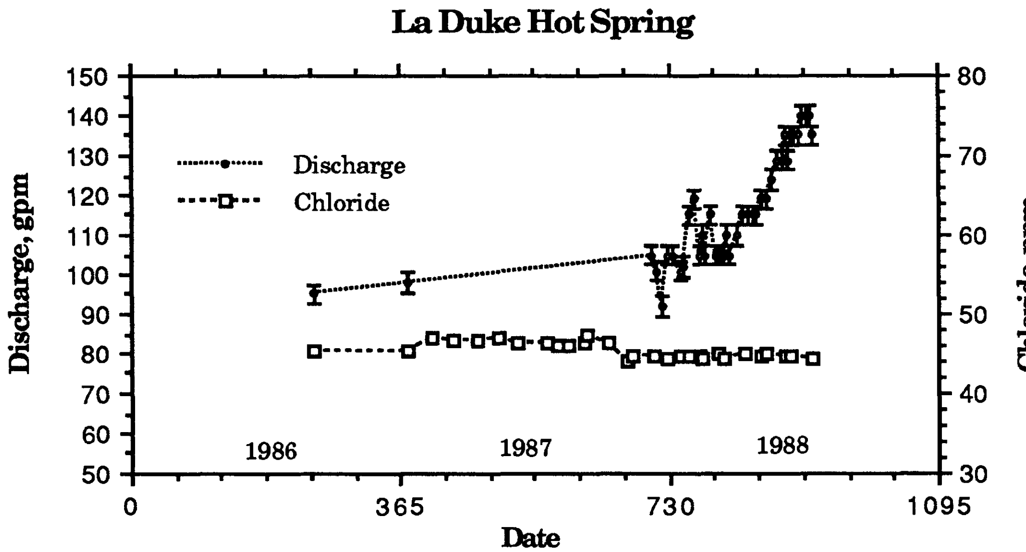
Yellowstone River drainage basin in the vicinity of Corwin Springs Geothermal Area

Figure 2



Gardner River Drainage Area

Figure 3


La Duke Hot Spring
Discharge
Chloride
Discharge, gpm
Chloride, ppm
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140
130
120
110
100
90
80
70
60
50
80
70
60
50
40
30
1986
1987
1988
0
365
730
1095
Date

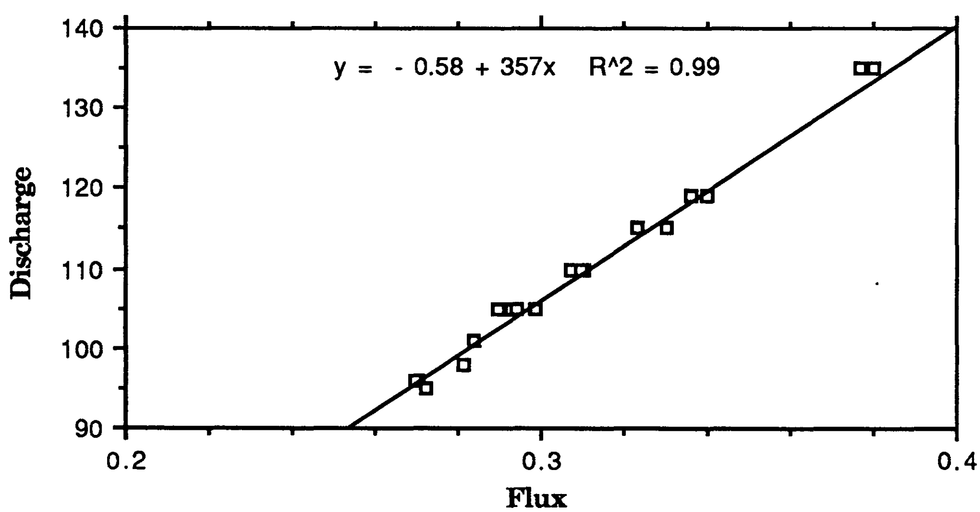
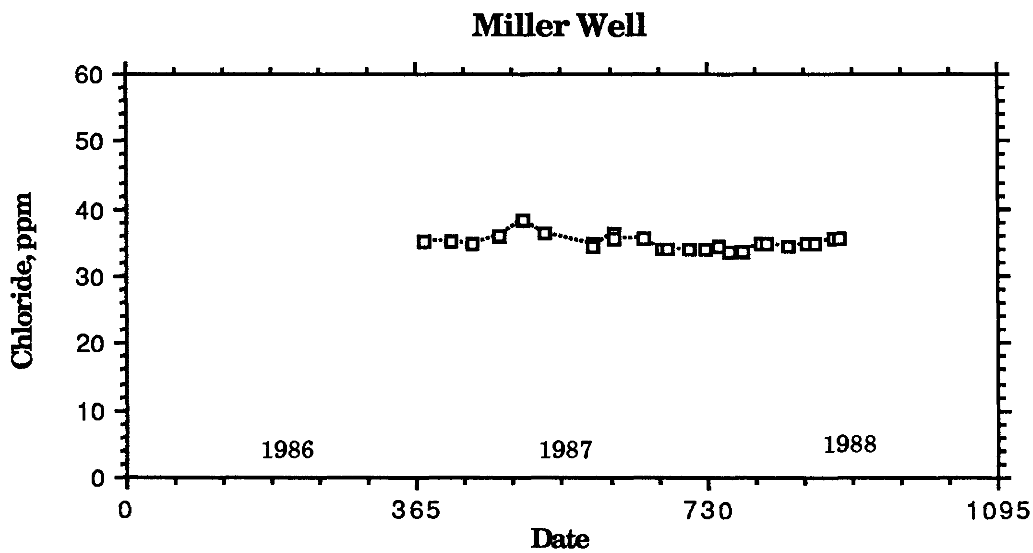

y = - 0.58 + 357x R^2 = 0.99
140
130
120
110
100
90
Discharge
0.2
0.3
0.4
Flux

Figure 4


Miller Well
Chloride, ppm
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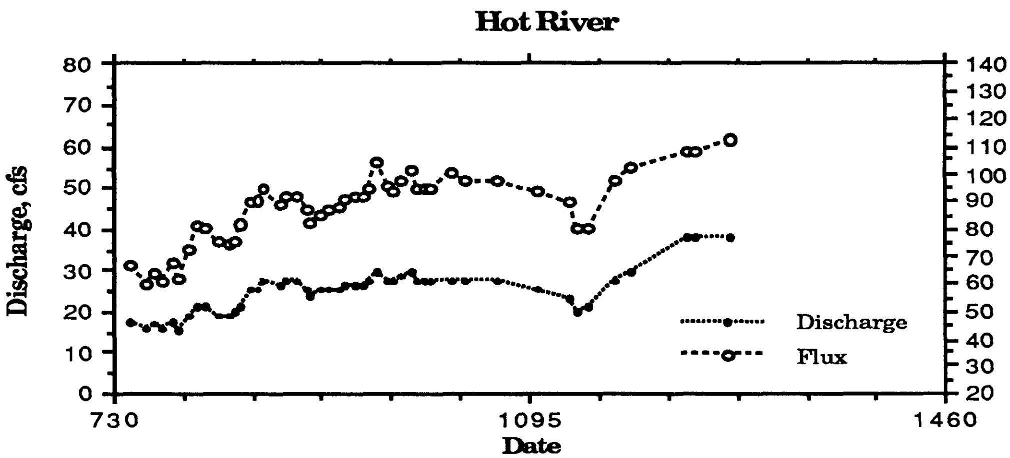
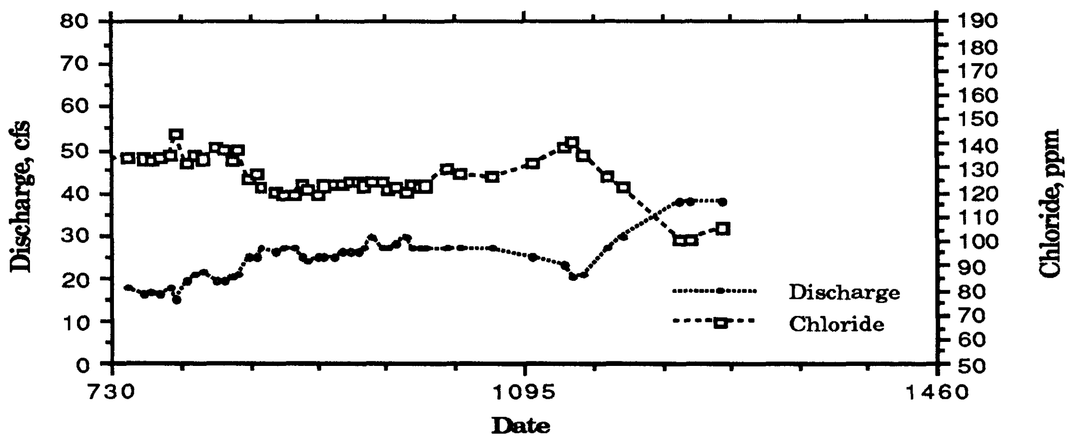
40
30
20
10
0
1986
1987
1988
0
365
730
1095
Date

Figure 5


Hot River
Discharge, cfs
Flux, g/s
Date
Discharge
Flux
730
1095
1460


Discharge, cfs
Chloride, ppm
Date
Discharge
Chloride
730
1095
1460

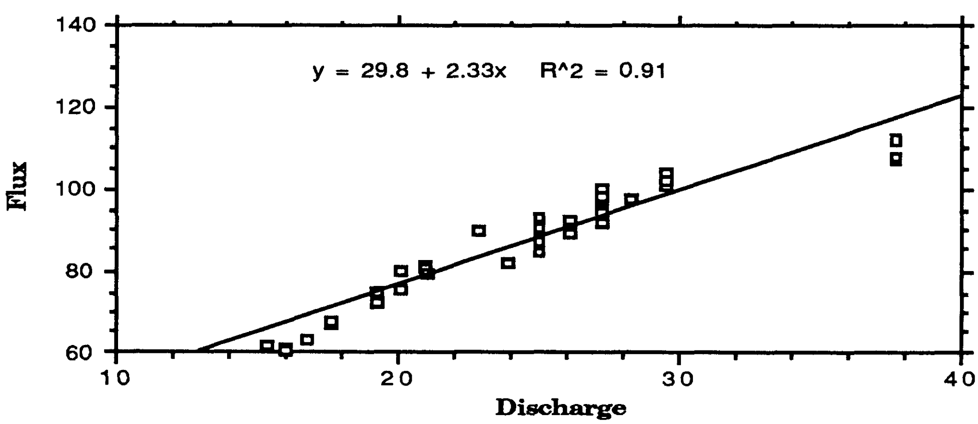

y = 29.8 + 2.33x R^2 = 0.91
Flux
Discharge

Figure 6

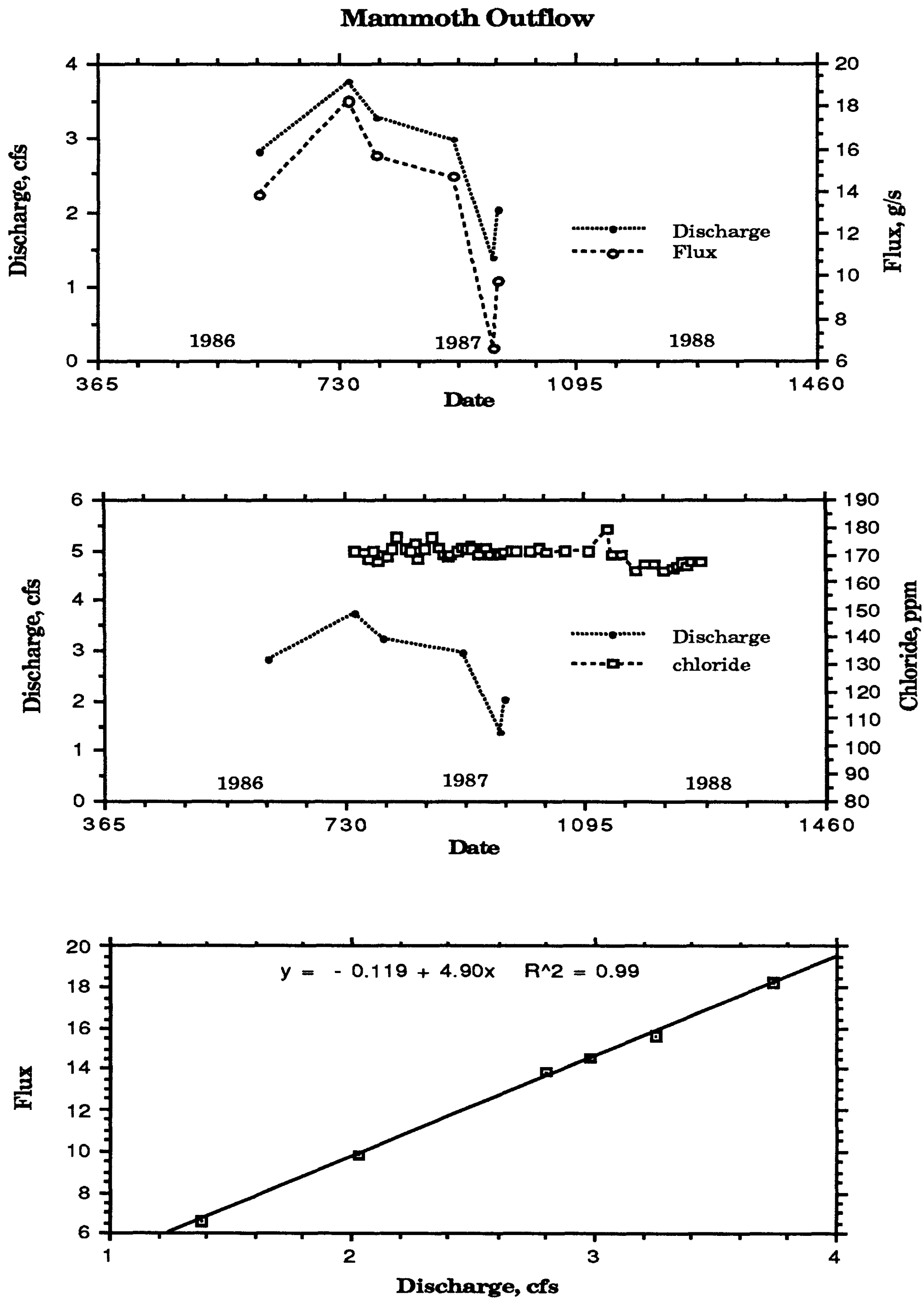
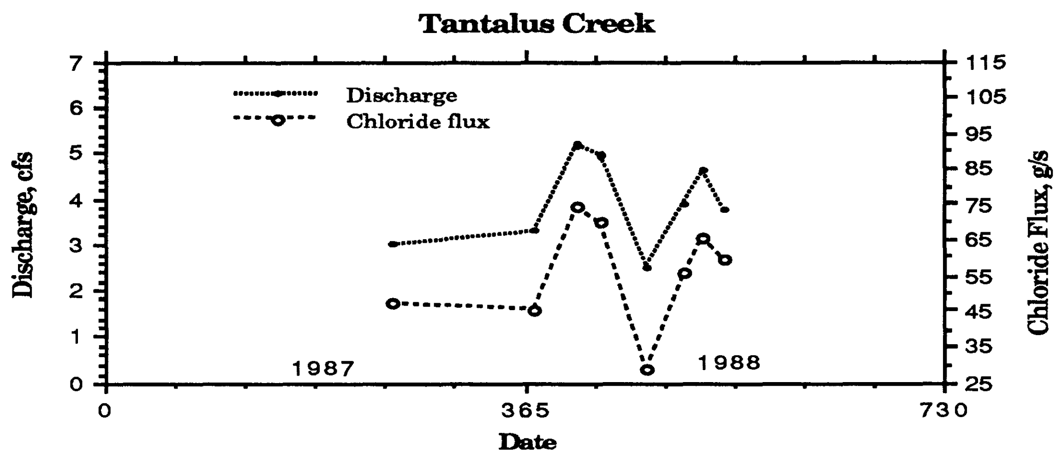
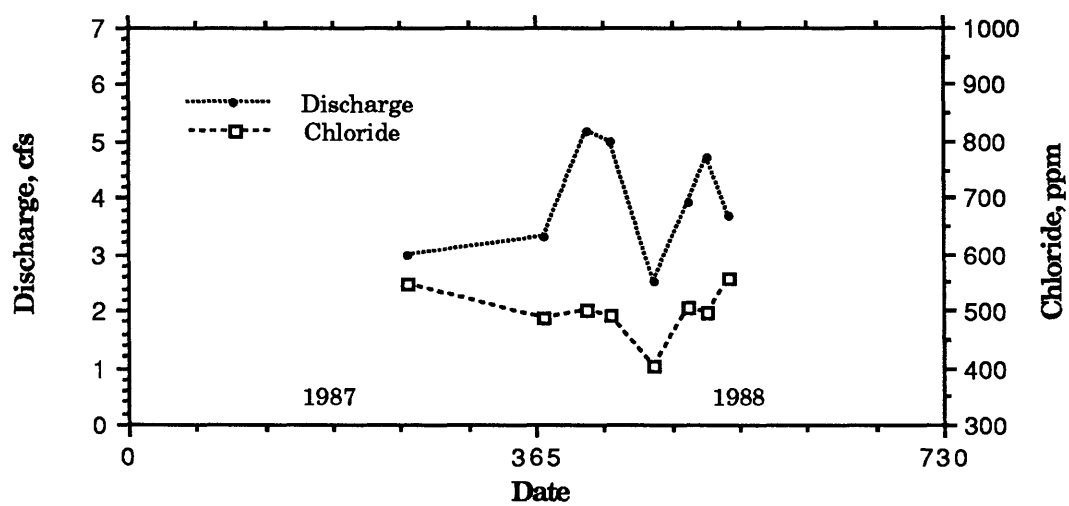
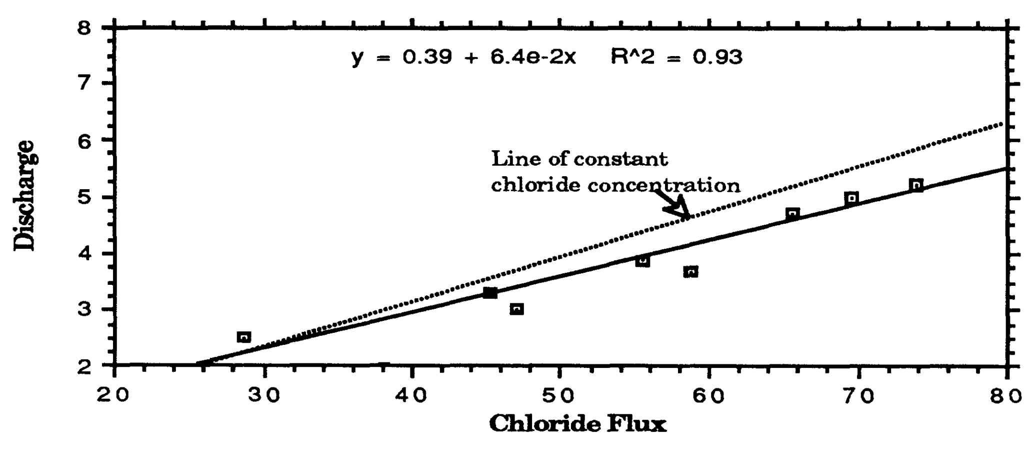

Mammoth Outflow
Discharge, cfs
Flux, g/s
Discharge
Flux
1986
1987
1988
365
730
1095
1460
Date
Discharge, cfs
Chloride, ppm
Discharge
chloride
1986
1987
1988
365
730
1095
1460
Date
y = - 0.119 + 4.90x R^2 = 0.99
Flux
Discharge, cfs

Figure 7

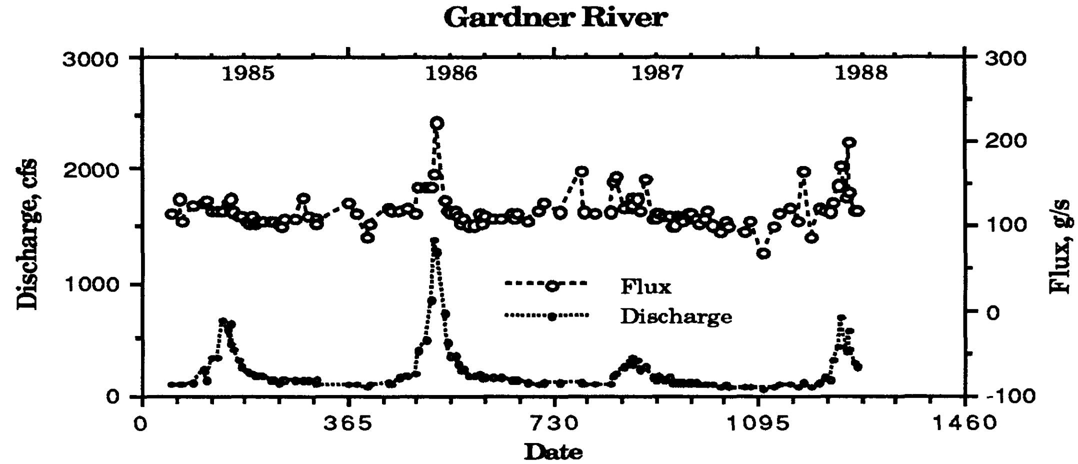


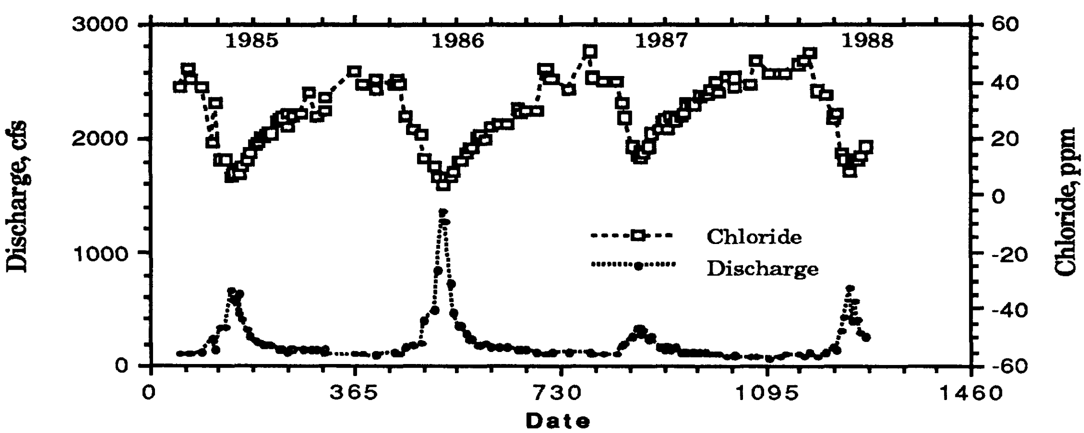


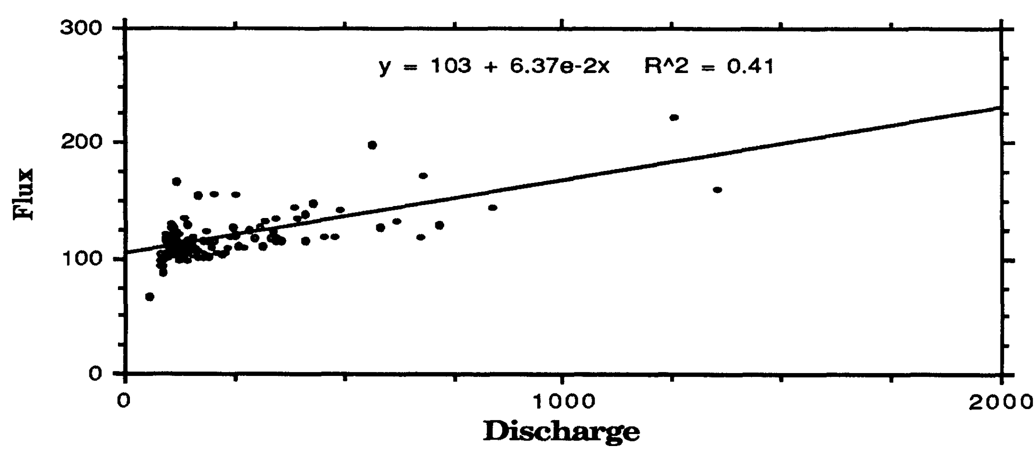


Gardner River Drainage Area

Figure 8







Gardner River Drainage Area

Figure 9

Gardner River
Monthly Integrated Chloride Flux