Chemical Quality of Surface Water in the Flaming Gorge Reservoir Area, Wyoming and Utah

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2009-C

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By R. J. MADISON *and* K. M. WADDELL

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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CHEMICAL QUALITY OF SURFACE WATER IN THE FLAMING GORGE RESERVOIR AREA, WYOMING AND UTAH

By R. J. MADISON and K. M. WADDELL

ABSTRACT

Construction of Flaming Gorge Dam on the Green River by the U.S. Bureau of Reclamation started in 1959, and storage began in November 1962. A reconnaissance study was made during the period 1966–68 to determine the effects of the reservoir on the chemical quality of the effluent water and to describe the quality of the impounded water and inflowing water.

The major inflow to the reservoir is from the Green River, which contributes an average of 81 percent of the water and 59 percent of the inflow load of dissolved solids. Together, Blacks Fork and Henrys Fork contribute an average of about 16 percent of the water and about 23 percent of the dissolved-solids load, whereas minor tributaries contribute approximately 3 percent of the total inflow water to the reservoir, but about 18 percent of the total incoming load of dissolved solids.

The concentration of dissolved solids in the reservoir in October 1966 was about 150 mg/l (milligrams per liter) greater than the concentration of the 1962–66 inflow and in September 1968 about 95 mg/l greater than the concentration of the 1962–68 inflow. The increased concentration is due mostly to leaching of minerals from the reservoir bottom. For the 1963–68 water years, about 1.2 million tons of dissolved solids was leached from inundated areas. The major observable difference between the chemical composition of the inflow during 1963–66 and that of the reservoir in 1966 is an increase in the percentage of sulfate and a decrease in the percentage of bicarbonate. Impoundment of water in Flaming Gorge Reservoir during the 1963–68 water years caused the concentration of dissolved solids in the river system to increase by 130 mg/l, or about 32 percent over what would have occurred without the reservoir. Evaporation accounted for an increase of 15 mg/l, and leaching accounted for an increase of 115 mg/l.

INTRODUCTION

Flaming Gorge Reservoir, on the Green River in Wyoming and Utah (fig. 1), has a usable capacity of 3.75 million acre-feet (excluding 0.4 million acre-feet of dead storage capacity) and is about 90 miles long The lower part of the reservoir, which fills Red Canyon and Flaming Gorge, is very narrow and deep; at the dam, the total depth of water when the reservoir is full (water-surface elevation 6,040 ft above mean sea level) exceeds 400 feet. The upper sections of the reservoir, upstream from Flaming Gorge, are much more shallow, spread out to a considerably greater width, and lie mostly in a desert plateau area. Construction of the dam by the U.S. Bureau of Reclamation started in 1959, and storage in the reservoir began in November 1962.

Flaming Gorge Reservoir is a major part of the Colorado River Storage Project, which is a long-range, basinwide program to de-

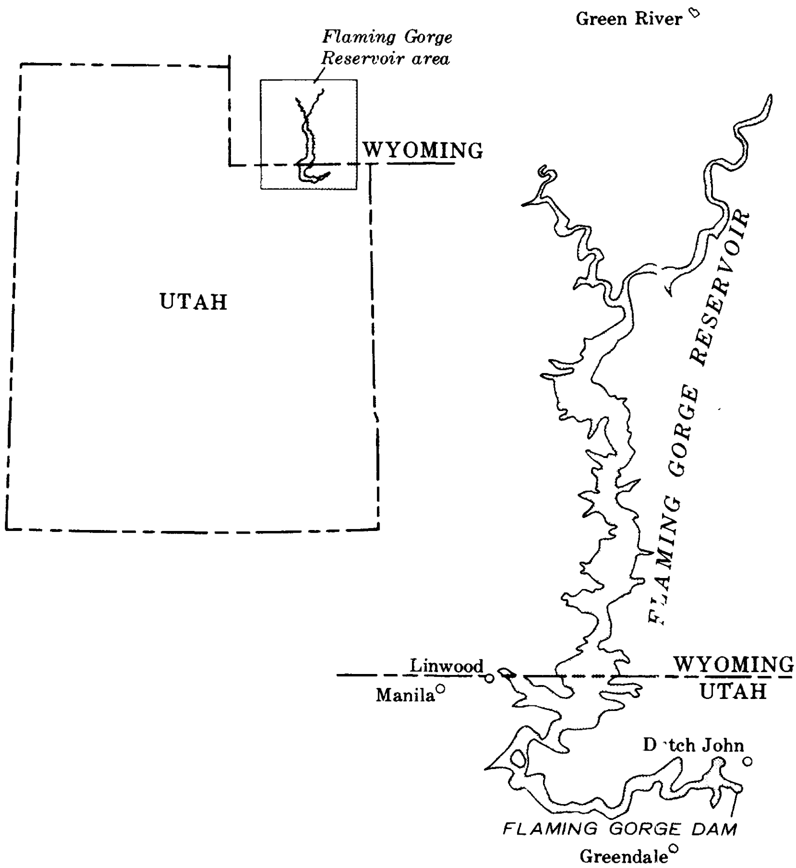


FIGURE 1.—Location of report area.

velop the water resources of the Upper Colorado River system. The reservoir stores water to meet downstream commitments and allows fuller use of the remaining water in upstream valleys.

The effects on water quality of impoundment by dams are important in evaluating present water-quality conditions and in predicting future conditions. Water storage usually results in increased concentrations of some dissolved ions, both because the ions are dissolved from soluble minerals inundated by reservoir water and because water is lost from the reservoir by evaporation. Storage of water also provides conditions suitable for precipitation of carbonate, thereby decreasing the dissolved calcium and bicarbonate ion concentrations. Evaluation of the chemical quality of stored water and the suitability of the water for its intended use will be valuable in establishing criteria useful to water management.

This reconnaissance resulted from participation by the U.S. Geological Survey in continuing studies of the quality of water of the Colorado River Basin. These studies are reported biennially in progress reports on "Quality of Water in the Colorado River Basin" that are prepared by the U.S. Department of the Interior for Congress. In one report (U.S. Dept. of Interior, 1967) the Geological Survey prepared a statement on accretion of water and dissolved solids in the Green River as it flowed unregulated through the Flaming Gorge Reservoir area. The present report evaluates data collected for the purpose of determining chemical changes that occurred as the result of water impoundment after closure of the dam. It presents a brief discussion of the quality of the inflow waters (figs. 2, 3), describes the quality of the impounded waters (pl. 1), and shows the effects of the reservoir on the effluent water (figs. 4–8).

Water-quality samples were collected at the surface, bottom, and seven intermediate points from each of six sites in the reservoir (1–6, pl. 1) in October 1966 and in September 1968. The sampling sites were selected to be representative of the entire main body of the reservoir, to allow an estimate of the load of dissolved solids in the reservoir, and to show chemical changes. Two sites (7, 8) in the main body of the reservoir, two sites (9, 10) in the upper reaches of Blacks Fork Arm, and three sites (11–13) in the upper reaches of Green River Arm were sampled in September 1967. Some additional data are available from samples collected from two sites (1, 6) by the U.S. Bureau of Reclamation in March 1967. Data on the influent and effluent waters were obtained at stream-sampling sites which had been previously established as a part of the Geological Survey's basic-data collection programs (pl. 1). The basic data utilized for this report are tabulated in a separate basic-data release (Madison, 1970).

INFLOW TO RESERVOIR

Continuous records of streamflow and water quality are available for the major inflow to Flaming Gorge Reservoir and for the outflow from the reservoir area for a 6-year period (1956–62) prior to closure of Flaming Gorge Dam. Figure 2 shows that the Green River contributes an average of 81 percent of the inflow water and 59 percent of the inflow load of dissolved solids.

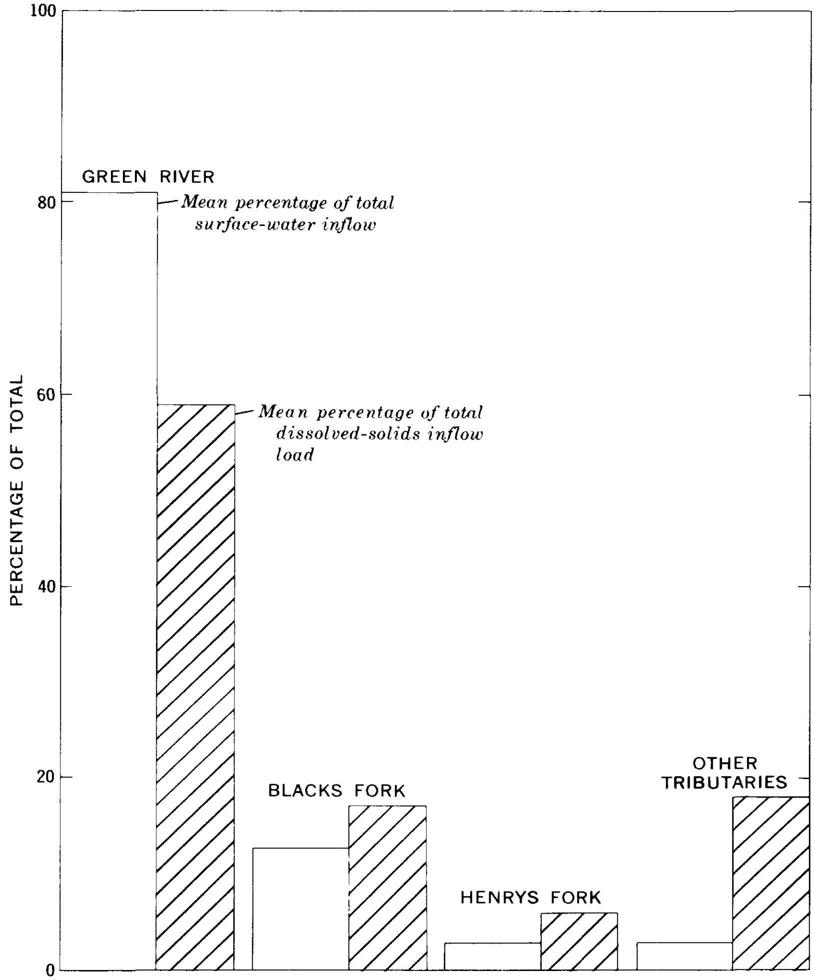


FIGURE 2.—Relative contribution of water and of dissolved-solids load to Flaming Gorge Reservoir from streams.

Blacks Fork and Henrys Fork discharge more-concentrated water (fig. 3): their combined inflow contributes an average of about 16 percent of the water, but about 23 percent of the dissolved-solids load. During the high-runoff period, most of the major inflowing streams yield a calcium bicarbonate type water. During the low-runoff period, the water is mostly of the calcium sulfate type.

Other minor tributaries contribute approximately 3 percent of the total inflow to the reservoir, but about 18 percent of the total incoming load of dissolved solids. The streams draining into the upper part of the reservoir above Henrys Fork are mostly intermittent; they drain semiarid desert plateau areas which contain abundant quantities of soluble minerals. The total amount of water these streams contribute is small, but they contain high concentrations of dissolved solids. Sodium and sulfate are the predominant dissolved ions. Carter, Cart, and Sheep Creeks, which drain into the lower section of the reservoir from mountainous areas, contribute larger amounts of water, but are more dilute. They contain primarily calcium bicarbonate type water.

During a high-flow period in June 1967, the discharge of the minor tributaries was measured and water-quality samples collected. These data are summarized in table 1.

TABLE 1.—*Discharge and water-quality data for minor tributaries to Flaming Gorge Reservoir area*

Map location (pl. 1)	Stream	Date of collection	Discharge (cfs)	Dissolved solids (mg/l)	Predominate cation	Predominate anion
B	Bitter Creek	6–26–67	66.3	1,040	Na	SO_4
C	Little Firehole Canyon	6–13–67	.1	5,310	Na	SO_4
D	Middle Firehole Canyon	6–13–67	<.1	3.100	Na	SO_4
E	Sage Creek	6–13–67	1.5	1,510	Mg	SO_4
G	Summers Dry Creek	6–13–67	28.7	381	Na	HCO_3
H	Currant Creek	6–12–67	2.9	566	Ca	SO_4
I	Upper Marsh Creek	6–12–67	.1	961	Na	HCO_3
J	Middle Marsh Creek	6–12–67	.1	999	Na	SO_4
K	Spring Creek	6–12–67	.6	1,080	Na	SO_4
M	Birch Spring Draw	6–13–67	18	2,340	Na	SO_4
N	Sheep Creek	6–13–67	26.4	290	Ca	SO_4
P	Carter Creek	6–14–67	300	42	Ca	HCO_3
Q	Dutch John Draw	6–12–67	.1	518	Ca	HCO_3
R	Cart Creek	6–12–67	46.8	60	Ca	HCO_3

CHEMICAL QUALITY OF WATER IN THE RESERVOIR

Data are insufficient to define completely the annual limnological cycle for Flaming Gorge Reservoir. The data shown on plate 1, however, give some indication of the movement of water through the reservoir. Chemical-quality conditions in the reservoir in the fall of 1966 and 1968 are also shown on plate 1. The less concentrated spring and summer runoff is shown near the surface

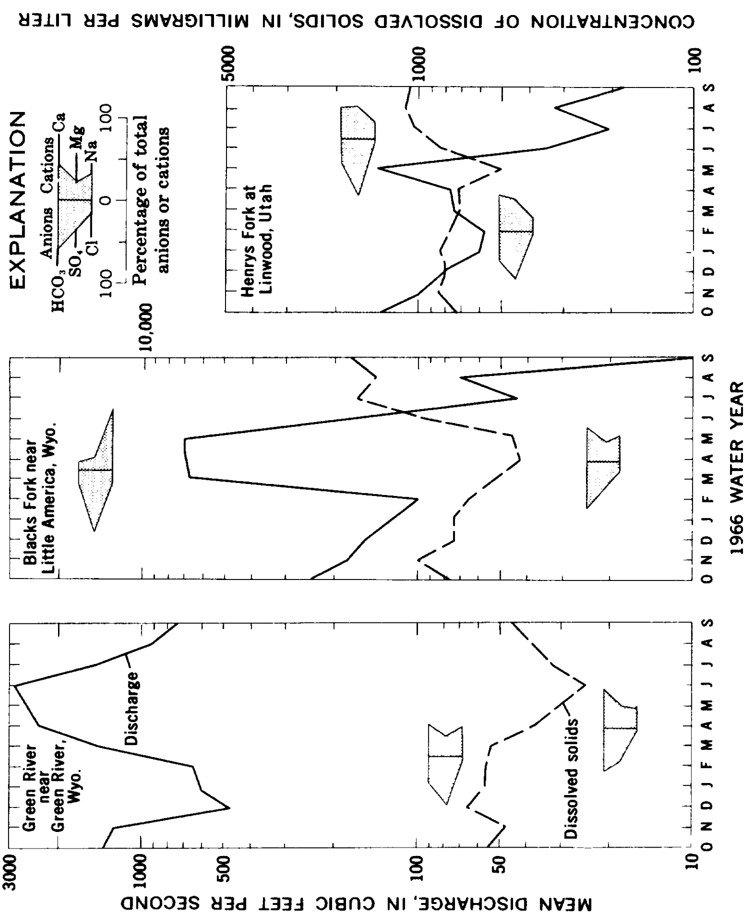


FIGURE 3.—Representative monthly mean discharge and concentration of dissolved solids for major tributaries to Flaming Gorge Reservoir and chemical composition for maximum and minimum concentrations (1966 water year).

at the lower end of the reservoir. The profile on plate 1 which represents the reservoir in the spring of 1967 shows the more concentrated water from the previous winter occupying the lower end of the reservoir.

The weighted-average concentration of dissolved solids in the inflow to the reservoir is calculated as 400 mg/l (milligrams per liter) for the period from closure (November 1962) until September 1966 and as 410 mg/l from closure until September 1968. The weighted-average concentration of dissolved solids in the reservoir was 550 mg/l in October 1966 and 505 mg/l in September 1968. Hence the concentration of dissolved solids in the reservoir in October 1966 was about 150 mg/l greater than the concentration of the 1962–66 inflow and in September 1968 about 95 mg/l greater than the concentration of the 1962–68 inflow. Although some of the increased concentration can be attributed to evaporation, most is the result of leaching of minerals from the reservoir bottom.

The chemical composition of water in the reservoir at any particular time is determined by the amount and type of minerals that (1) enter as inflow, (2) are leached from inundated areas, (3) are chemically precipitated from solution, and (4) leave the reservoir in the outflow. The concentration of dissolved minerals will be affected by volume changes resulting from evaporation in addition to these four factors. Comparison of the chemical-composition diagrams on plate 1 for the weighted-average inflow to the reservoir for the period 1963–66 with that for the water in the reservoir in October 1966 shows the net change that took place.

The major observable difference between the chemical composition of the inflow during 1963–66 and that of the reservoir in 1966 is an increase in the percentage of sulfate and a decrease in the percentage of bicarbonate (percentage of milliequivalents per liter). The water entering the reservoir as inflow during the 1963–66 water years contained equal percentages of sulfate and bicarbonate ions (each about 47 percent of the total anions). The water in the reservoir on October 1, 1966, contained about 34 percent bicarbonate and about 57 percent sulfate. The percentage of the other ions changed little. The change in the relative amounts of bicarbonate and sulfate in solution is the result of leaching of gypsum ($CaSO_4 \cdot 2H_2O$) and other soluble evaporites from the inundated areas and of precipitation of calcium carbonate ($CaCO_3$). The percentage of calcium ions did not change appreciably because some of the gain in calcium as the result of leaching was compensated by a loss of calcium through precipitation.

The net effects of leaching and chemical precipitation on the dissolved load in the reservoir are shown in table 2. Except for bicarbonate, there was a net load gain for all the major constituents.

TABLE 2.—*Changes in load, in millions of tons, of dissolved ions in Flaming Gorge Reservoir for the period October 1962–September 1966*

Ion	(1) Total inflow load	(2) Total outflow load	(3) Theoretical load stored in reservoir (1–2)	(4) Calculated load in reservoir Oct. 1, 1966	Gain (+) or loss (–) of dissolved ions (3–4)
Ca + Mg (as $CaCO_3$)	2.15	1.47	0.68	1.02	+0.34
Na	.43	.33	.10	.21	+.11
HCO_3	1.75	.98	.77	.62	–.15
SO_4	1.38	1.16	.22	.81	+.59
Cl	.15	.11	.04	.08	+.04

The chemical composition of the water in the main reservoir, although different from that of the inflow, is very uniform. The dissolved-solids concentration shows a definite increase with depth, but the percentage of individual ions is essentially the same throughout the major portion of the reservoir (pl. 1). In the extreme upper reaches of the reservoir, where the inflow from Blacks Fork and Green River enters, some variation in chemical composition occurs (pl. 1) as the inflow mixes with the main body of water in the reservoir. The data shown for the estuary areas represent only one set of samples collected in September 1967. Additional data are needed to define better the movement of inflow into and through the reservoir and the changes in chemical composition that take place during this movement.

The calculated load of dissolved solids in the reservoir in October 1966 was about 1,850,000 tons. This figure was computed by using the chemical-quality data from the vertical sampling lines at sites 1–6 together with area-capacity curves. To determine initial leaching and storage, the theoretical load in October 1966 was also computed, using inflow and outflow data. The theoretical load (net amount of dissolved solids contributed to the reservoir from runoff) was 1,050,000 tons. The difference of 800,000 tons between the calculated load and the theoretical load represents the estimated net amount of dissolved solids added by leaching during the first 4 years after closure of the reservoir.

In September 1968, the calculated load of dissolved solids in the reservoir was about 1,500,000 tons. The theoretical load or the total amount of dissolved solids that should have been in the reservoir as the result of inflow and outflow from October 1966 to September 1968 and storage in October 1966 was about 1,100,000 tons. Thus, in the 2-year period 1966–68, the amount of dissolved solids leached from the inundated area was about 400,000 tons, or one-half the amount leached in the previous 4-year period. On the basis of these calculations, it would appear that the rate of leaching did not decrease significantly over the first 6 years that the reservoir was closed. If it is assumed that all the dissolved solids added to the river system were due to solution of gypsum ($CaSO_4 \cdot 2H_2O$), the 1,200,000 tons of dissolved load leached during the 1963–68 water years would be equivalent to a layer of gypsum about 8½ inches thick spread over an area of 1 square mile. The average rate of leaching would be equivalent to the solution of about 1½ inches of gypsum per year from the 1 square mile area.

The data used to arrive at the figures pertaining to inflow and outflow loads are not seasonally continuous, and they cover only a relatively short period of time (1957–68). The chemical quality of the major inflowing tributaries (Green River at Green River, Wyo., Blacks Fork at Little America, Wyo., and Henrys Fork at Linwood, Utah) was measured from 1952, but the flow near Greendale (outflow point from the reservoir since closure) was observed only from 1957. Thus, the relationship used to determine unmeasured inflow is not precise, and the above figures should be considered as estimates only.

EFFECT OF THE RESERVOIR ON WATER QUALITY AND FLOW OF THE GREEN RIVER

COMPOSITION AND CONCENTRATION OF DISSOLVED SOLIDS

SEASONAL VARIATION

The 1957 water year was representative of average flow and chemical-quality conditions of the Green River near Greendale prior to closure of Flaming Gorge Dam. During the 1957 water year, the monthly weighted-average concentrations of dissolved solids near Greendale ranged from about 280 mg/l during high-flow periods to about 680 mg/l during low-flow periods. The chemical composition (percentage of milliequivalents per liter) ranged from the calcium sodium sulfate type during low-flow periods to a calcium bicarbonate type during high flows (fig. 4). After closure of the dam, the concentration of dissolved solids and the chemical composition were essentially constant throughout the year, with only slight seasonal variation. The concentration of dissolved solids during the 1967 water year ranged from 540 mg/l during high-flow periods to about 620 mg/l dur-

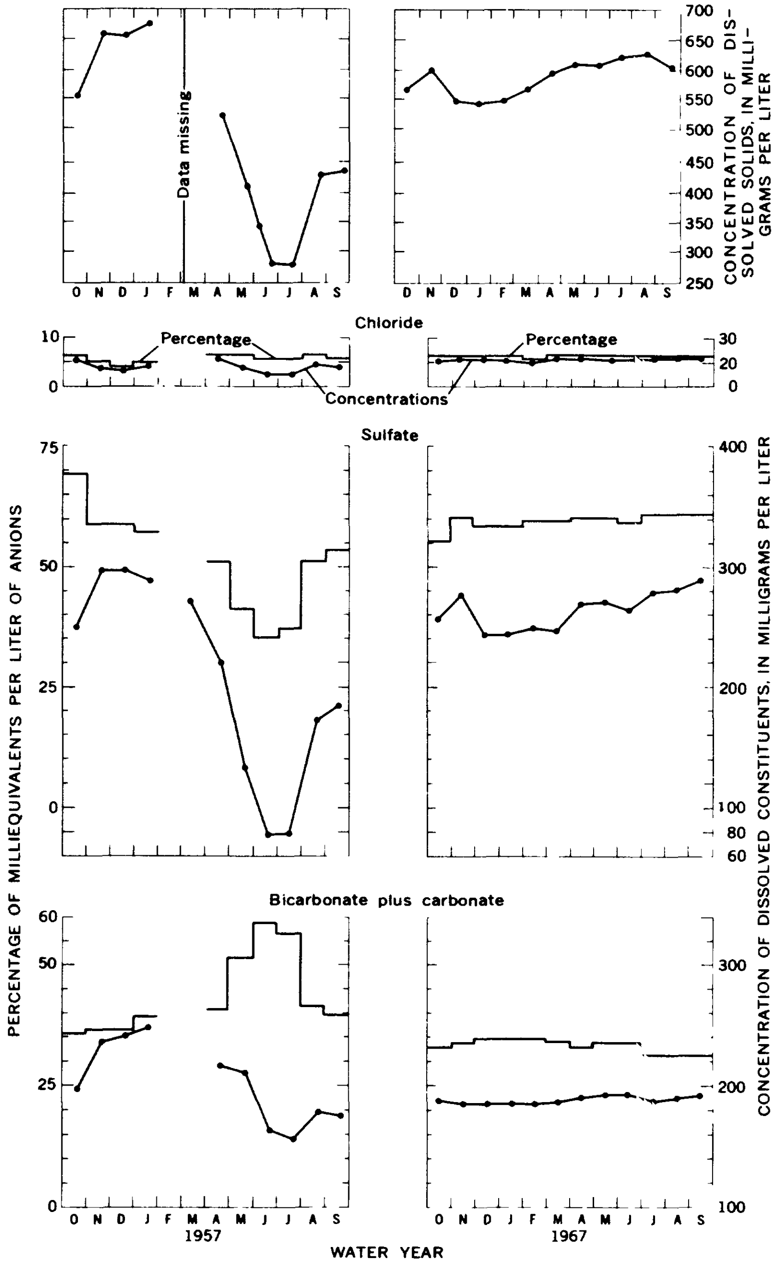


FIGURE 4.—Typical seasonal variation in chemical composition and in concentration of dissolved solids for Green River near Greendale before and after closure of Flaming Gorge Dam.

ing low-flow periods, and the chemical composition was of a calcium sodium sulfate type throughout the water year.

ANNUAL VARIATION

Figure 5 and table 3 illustrate the effects of the reservoir on the annual minimum, maximum, and weighted-average concentrations of dissolved solids in Green River near Greendale before and after closure of Flaming Gorge Dam. The overall effect of the reservoir was to increase the average concentration of dissolved solids and decrease the difference between extremes.

The concentrations of all major constituents increased in the water near Greendale after closure of the dam (fig. 6), with

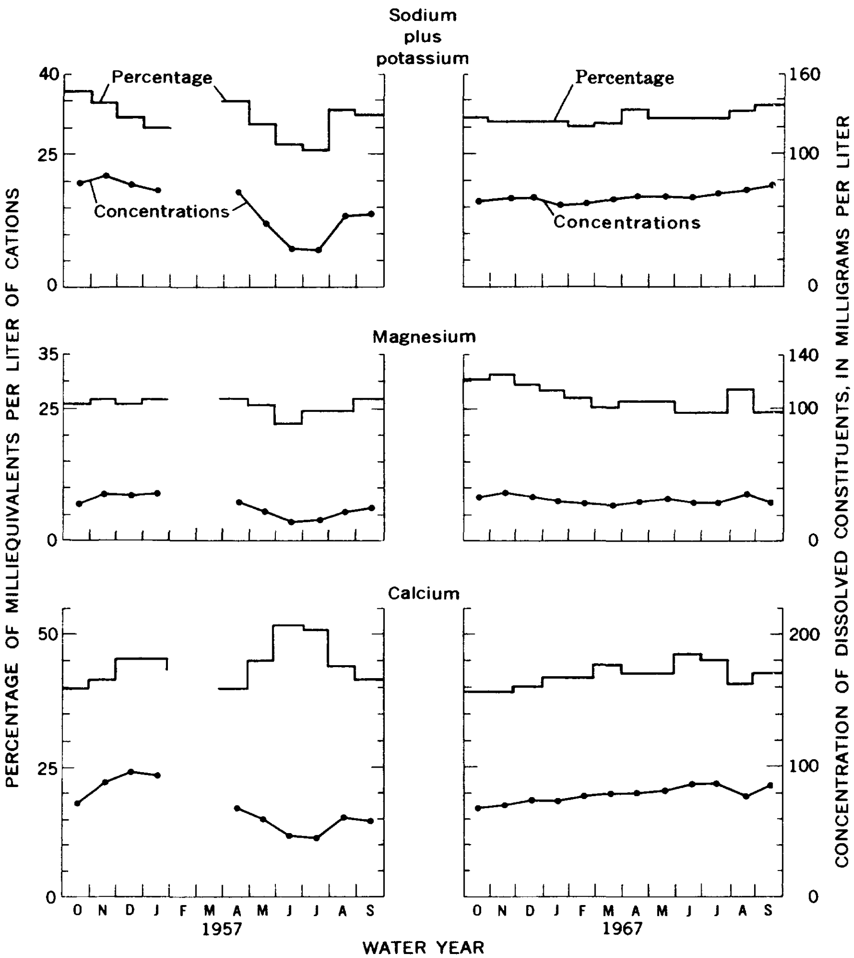


FIGURE 4.—Continued.

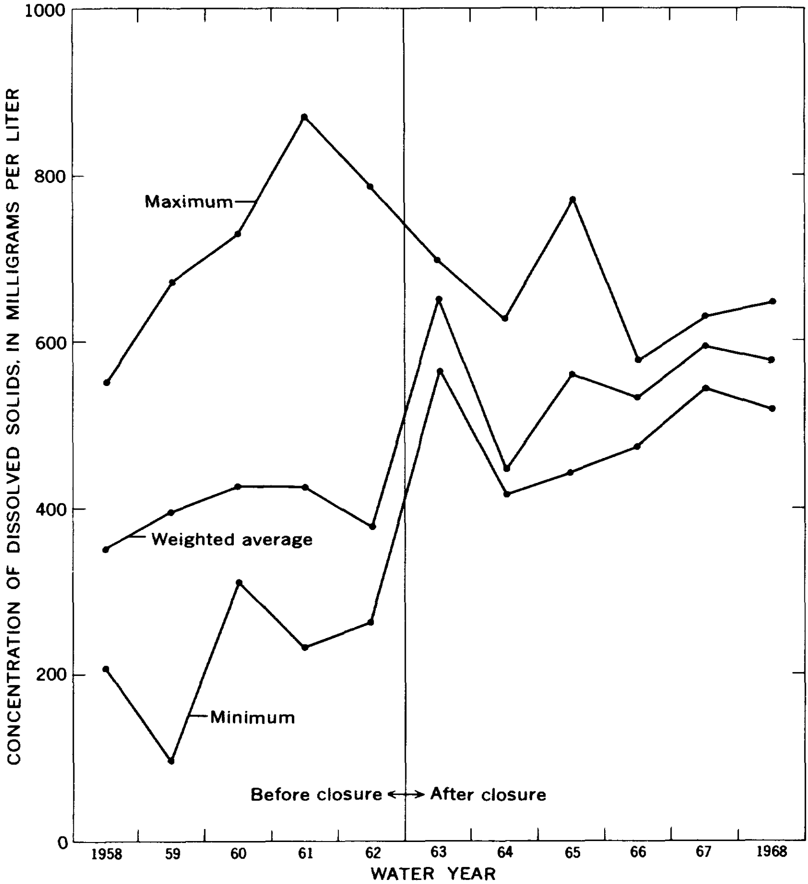


FIGURE 5.—Annual maximum, minimum, and weighted-average concentration of dissolved solids of Green River near Greendale before and after closure of Flaming Gorge Dam.

sulfate having the most pronounced increase. The percentage composition (in milliequivalents per liter) of calcium, magnesium, sodium, and chloride remained about the same after closure. The percentage of bicarbonate decreased, however, while that of sulfate increased. These changes in composition are due to the chemical changes in the reservoir.

RELATIVE EFFECTS OF EVAPORATION AND LEACHING

During the 1963–68 water years, approximately 400,000 acre-feet of water was lost from the river system owing to evaporation. All the evaporative loss was not attributable to the reservoir, however, because some loss would have occurred under natural conditions without the reservoir. The weighted-average concen-

TABLE 3.—*Variation of concentration of dissolved solids, in Green River near Greendale before and after closure of Flaming Gorge Dam*

Period	Before closure					After closure					
Water year	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968
Mean discharge (thousands of acre-feet)	1,310	1,576	973	781	2,919	170	1,258	1,437	1,189	2,162	2,530
Dissolved-solids concentration:											
Annual maximum (mg/l)	551	671	729	866	784	700	623	773	578	630	649
Annual minimum (mg/l)	204	98	316	236	262	564	419	442	471	543	517
Range (mg/l)	347	573	413	629	522	136	204	331	107	87	132
Ratio of maximum to minimum	2.7	6.8	2.3	3.7	3.0	1.2	1.5	1.7	1.2	1.2	1.3

tration of dissolved solids that would have been present at Green River near Greendale during the 1963–68 water years without the reservoir was 410 mg/l. Evaporation alone would have caused the concentration to increase to 425 mg/l; that is, concentration by evaporation would have caused only about a 15-mg/l increase in the system. The actual weighted-average concentration of dissolved solids during the 1963–68 water years for the river system, which includes the water stored in the reservoir and water released, was 540 mg/l. Leaching, therefore, accounted for an increase of 115 mg/l. The combined increase in concentration of dissolved solids due to evaporation and leaching was 130 mg/l, or 32 percent more than the theoretical weighted average. It must be emphasized that these figures pertain to the effect of the reservoir on the river system and should not be confused with the figures given in the section "Chemical Quality of Water in Flaming Gorge Reservoir," which pertain only to the water stored in the reservoir as of a given date.

DISSOLVED LOAD

Although there was an accumulative net gain of 1,200,000 tons of dissolved solids in the Green River system during the 1963–68 water years (fig. 7), this gain in dissolved load is entirely in water stored in the reservoir. At the end of the 1968 water year, the amount of dissolved load that had passed Greendale was about 250,000 tons less than that which would have occurred during the 1963–68 water years without the reservoir.

FLOW REGIME

The effect of Flaming Gorge Reservoir on the flow of the Green River below the reservoir can be seen in figure 8. The slope change of the curve is due to streamflow depletion at Green River

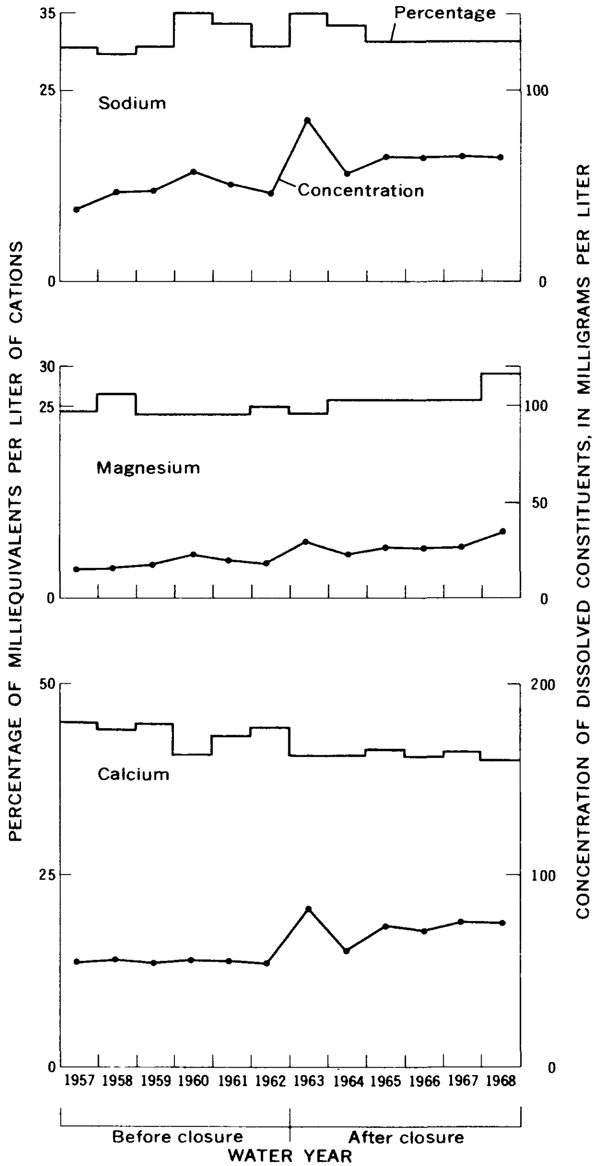


FIGURE 6.—Annual weighted-average percentage composition and concentration of major dissolved constituents of Green River near Greendale before and after closure of Flaming Gorge Dam.

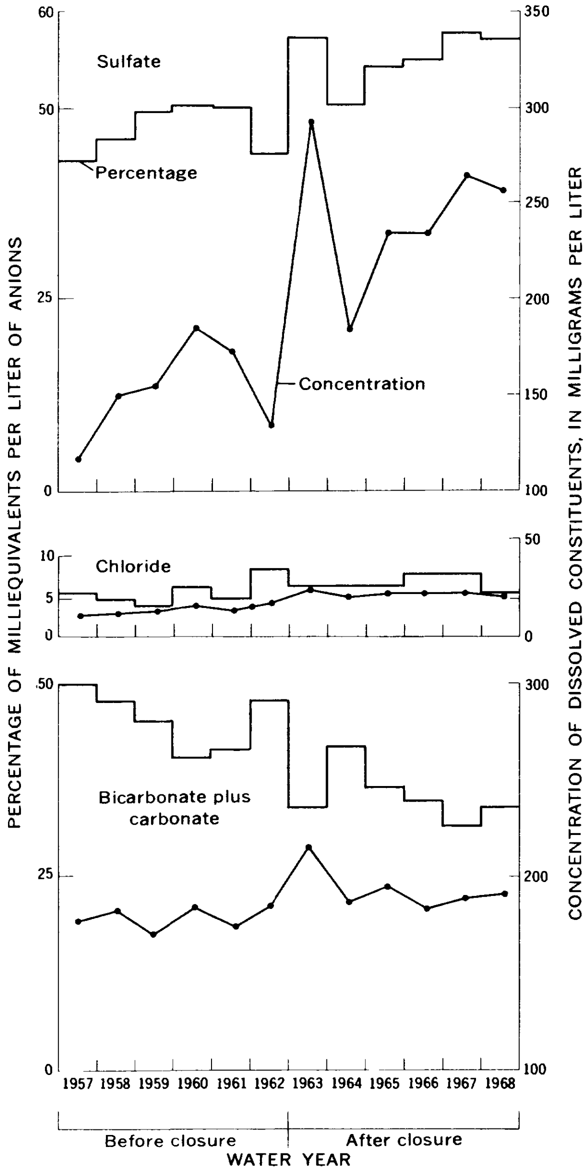


FIGURE 6.—Continued.

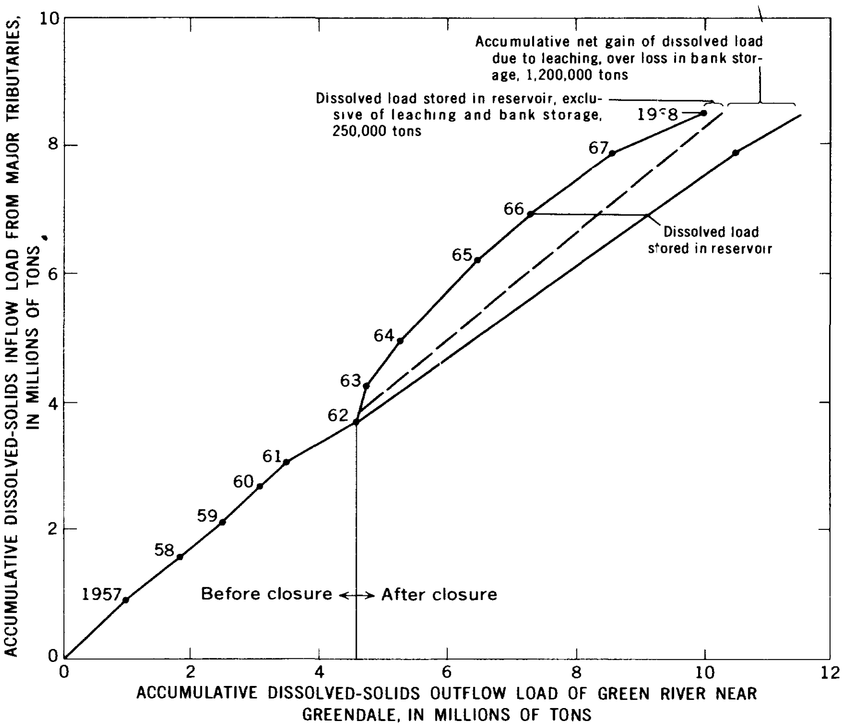


FIGURE 7.—Relationship of dissolved-solids inflow load from major tributaries to outflow load of Green River near Greendale before and after closure of Flaming Gorge Dam.

near Greendale effected by closure of Flaming Gorge Dam in November 1962. Most of the depletion is due to upstream storage in the reservoir. The accumulative depletion near Greendale during the 1963–68 water years was approximately 2,800,000 acre-feet. At the end of the 1968 water year, 2,160,000 acre-feet (rounded) was stored in the reservoir; thus 640,000 acre-feet had been lost from the river system owing to evaporation and bank storage. The 640,000 acre-feet represents a 6.5 percent loss from the river system.

The estimated accumulative evaporation loss from the reservoir during the 1963–68 water years was about 400,000 acre-feet. Bank storage can be approximated as the difference between the total depletion loss and the evaporation loss; that is 640,000 — 400,000 = 240,000 acre-feet loss due to bank storage. Bank storage in this report is considered to be all water lost from the reservoir as a result of seepage, including any possible leakage from the reservoir drainage area. Bank storage is not all loss;

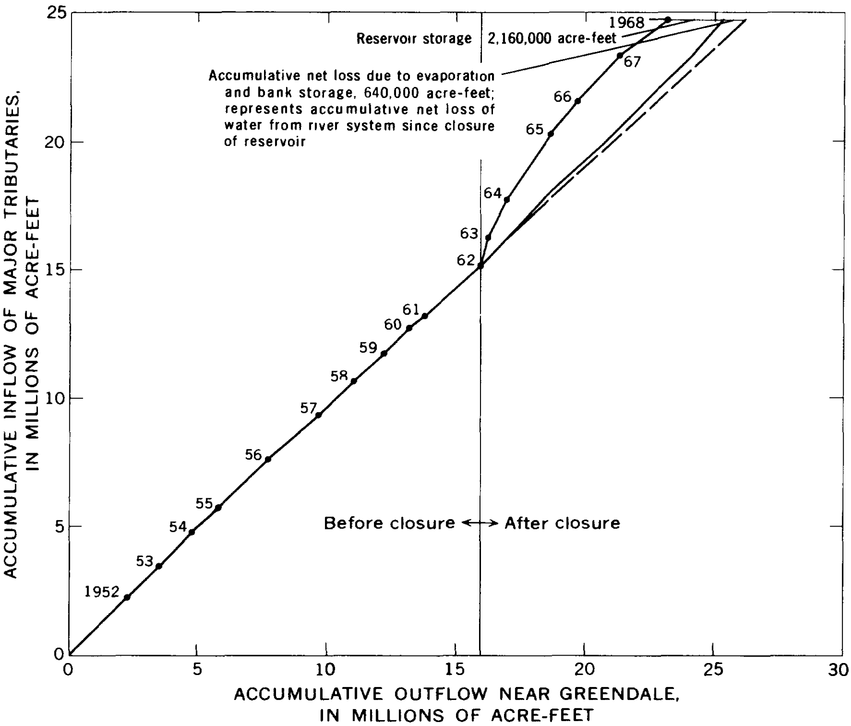


FIGURE 8.—Relationship of major tributary inflow to and outflow from the Flaming Gorge Reservoir before and after closure of Flaming Gorge Dam.

however, some is partially recoverable when the reservoir is drawn down.

NEEDS FOR ADDITIONAL STUDY

The present reconnaissance indicates a substantial increase in average concentration of dissolved solids in the Green River below Flaming Gorge Reservoir for the first 6 years after closure. Most of this increase is the result of the leaching of soluble minerals from the inundated areas, and leaching appeared to be measurably increasing the load of dissolved solids in the river system near the end of the 6-year period. Also, a comparison of inflow and outflow loads of dissolved ions indicates that some carbonate precipitation has taken place. A more detailed study of Flaming Gorge Reservoir would be desirable to determine whether the apparently rapid rate of leaching will continue and what long-term effects leaching, precipitation, and possible stratification may have on the highly utilized Colorado River system. Such studies should include the following:

1. More detailed chemical-quality and temperature profiles to define areas of change in the estuaries and the main body of the reservoir.
2. Continued monitoring of water quality in the reservoir to define further the rates of leaching and precipitation, the seasonal changes in chemical quality, and the limnological cycle of the reservoir.
3. Studies of the chemical character and quantity of solutes stored in lake-bottom sediments and in potentially inundatable soils adjacent to the reservoir.
4. Continuation of measurements of discharge and chemical quality of inflow and outflow waters.

SELECTED REFERENCES

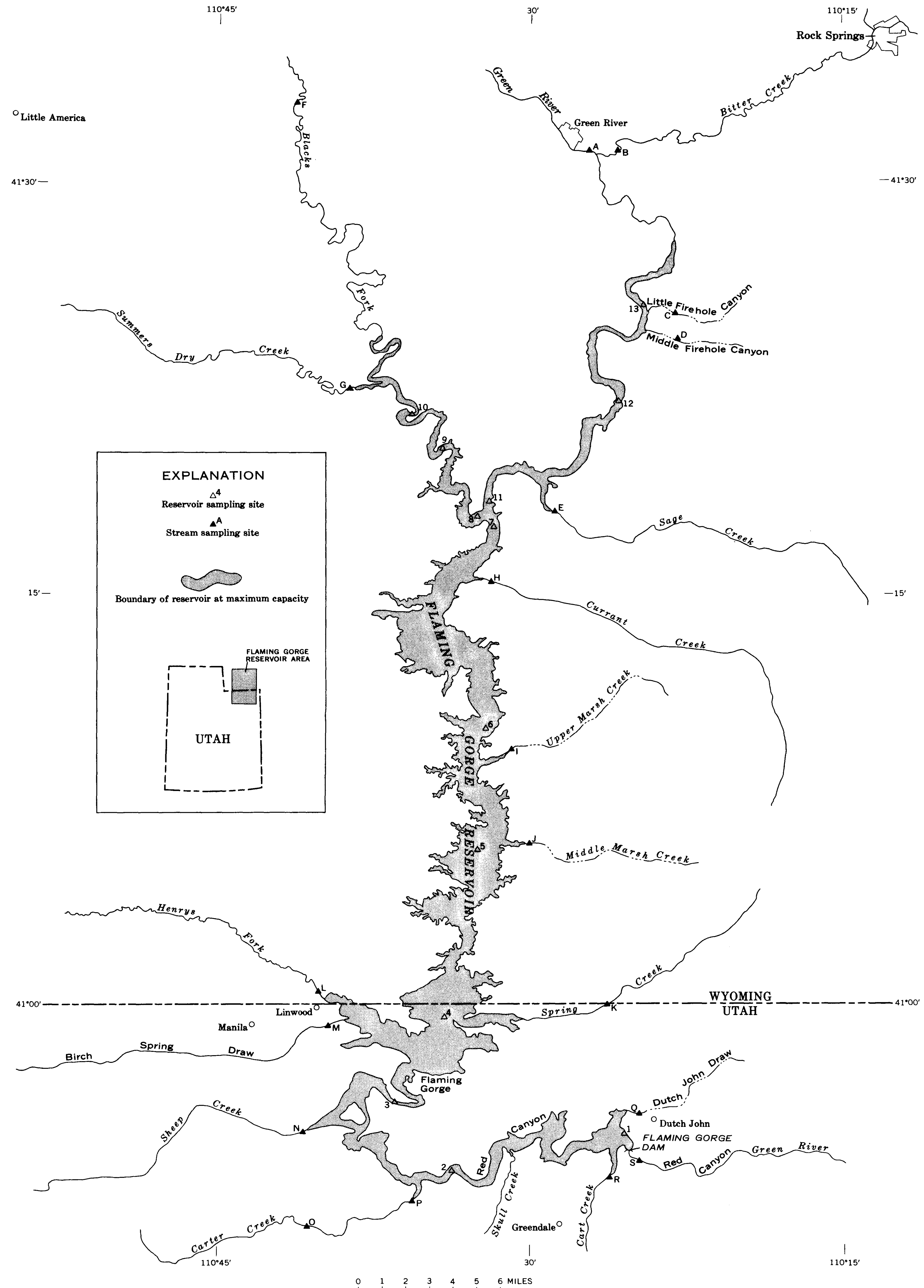
Iorns, W. V., Hembree, C. H., and Oakland, G. L., 1965, Water resources of the Upper Colorado River Basin—Technical report: U.S. Geol. Survey Prof. Paper 441, 370 p.

Madison, R. J., 1970, Water-quality data for the Flaming Gorge Reservoir area, Utah and Wyoming: U.S. Geol. Survey open-file report (duplicated as Utah Basic-Data Release 20).

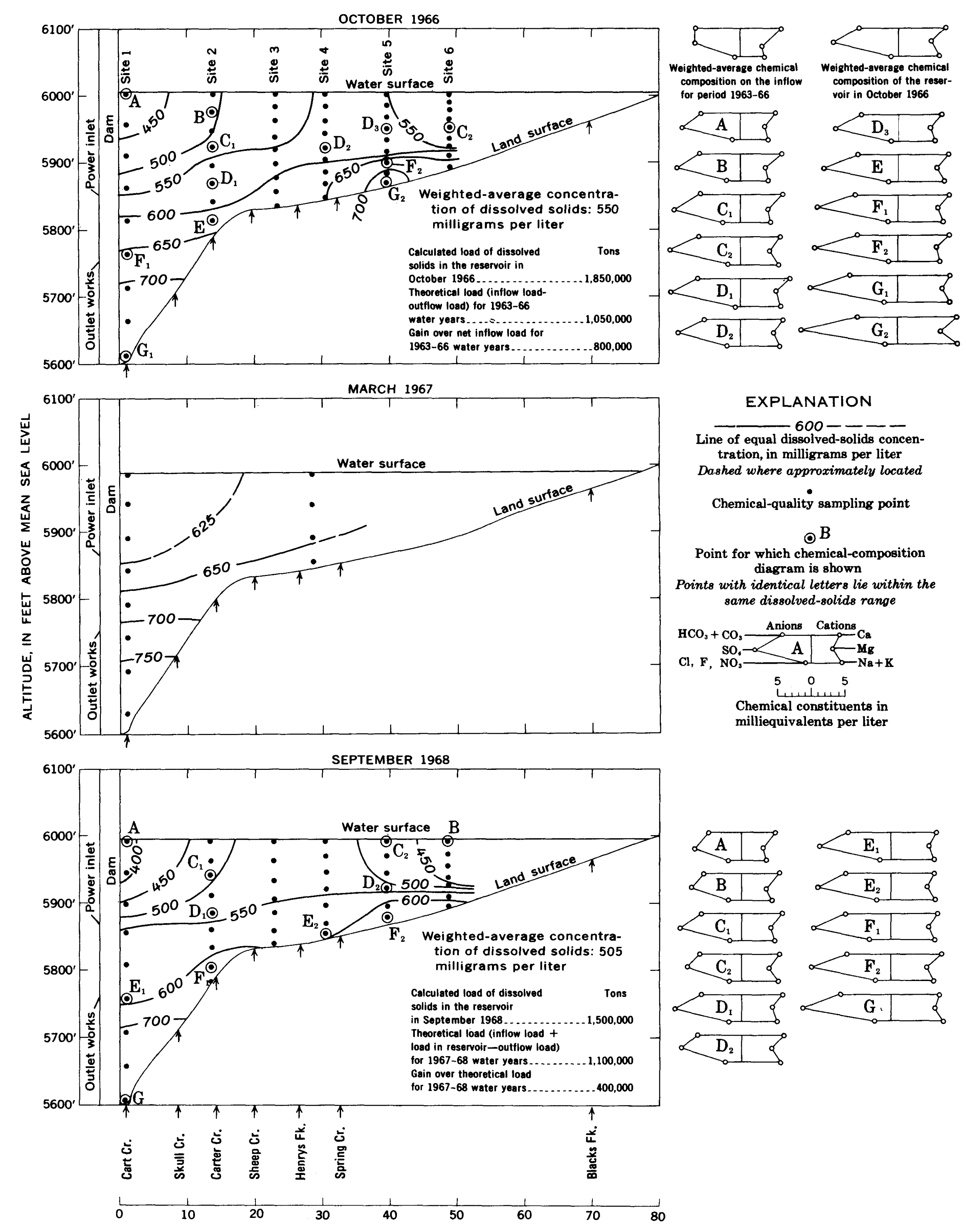
U.S. Department of Interior, 1967, Quality of water Colorado River Basin, progress report number 3, January 1967: Biennial report to the Congress.

——— 1969, Quality of water Colorado River Basin, progress report number 4, January 1969: Biennial report to the Congress.

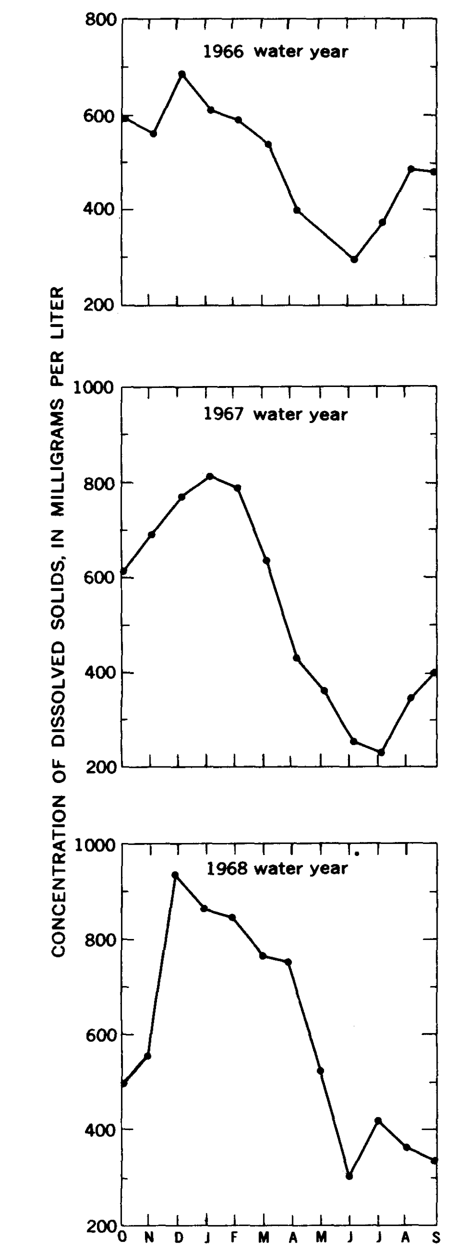
U.S. GOVERNMENT PRINTING OFFICE : 1973 O—489—405



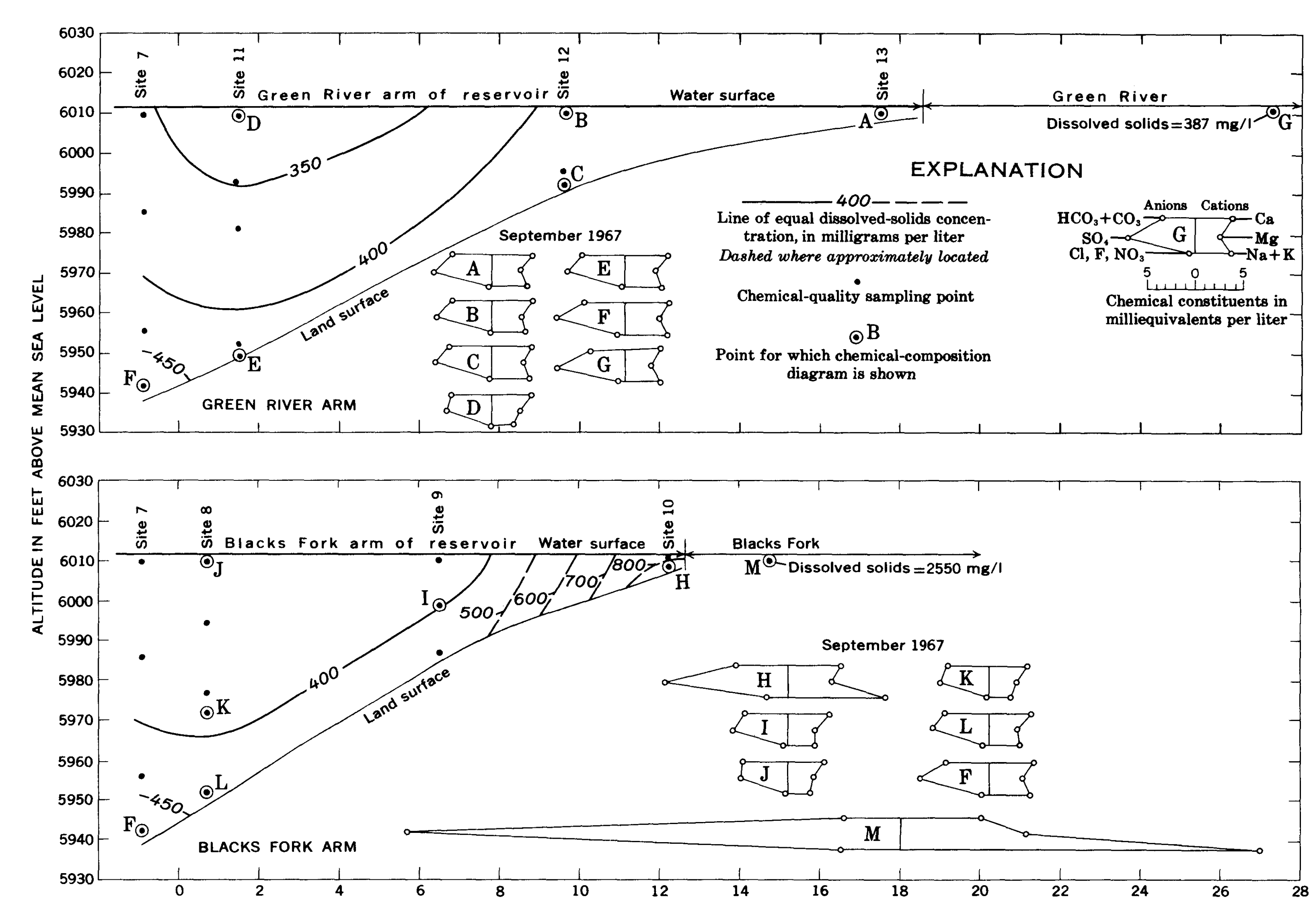
LOCATION OF SAMPLING SITES



DISTRIBUTION OF DISSOLVED SOLIDS AND CHEMICAL COMPOSITION OF WATER IN FLAMING GORGE RESERVOIR



WEIGHTED-AVERAGE CONCENTRATION OF DISSOLVED SOLIDS OF MAJOR TRIBUTARY INFLOW (GREEN RIVER, BLACKS FORK, AND HENRYS FORK)



DISTRIBUTION OF DISSOLVED SOLIDS AND CHEMICAL COMPOSITION OF WATER IN THE UPPER ARMS OF FLAMING GORGE RESERVOIR AND THE CHEMICAL COMPOSITION OF THE TRIBUTARY INFLOW

MAP SHOWING LOCATION OF SAMPLING SITES AND GRAPHS AND DIAGRAMS SHOWING DISTRIBUTION OF DISSOLVED SOLIDS AND CHEMICAL COMPOSITION OF WATER IN FLAMING GORGE RESERVOIR, WYOMING AND UTAH

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