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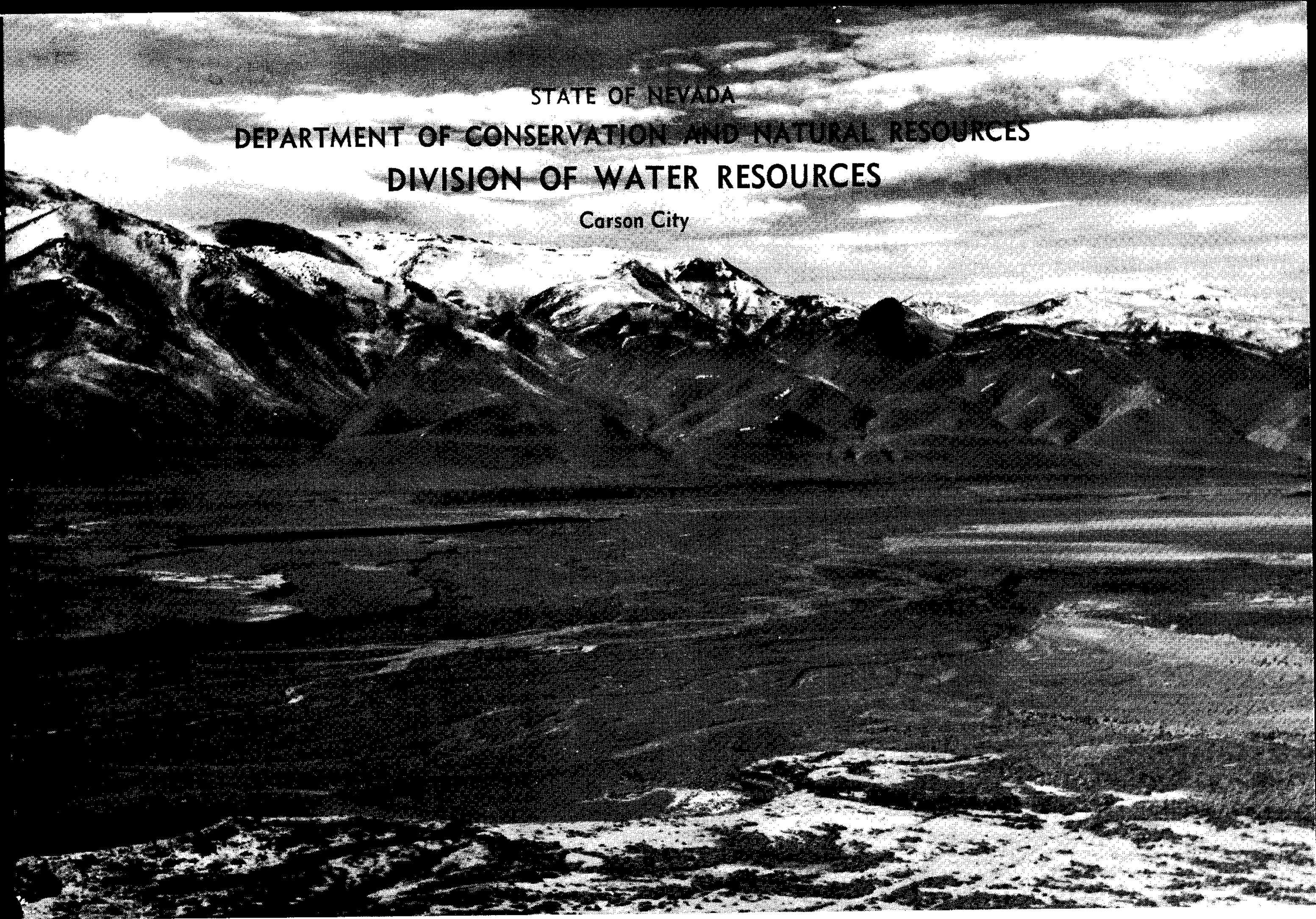

Terminal reach of the Truckee River.

# WATER RESOURCES – INFORMATION SERIES

## REPORT 18

## RUNOFF, EROSION, AND SOLUTES IN THE LOWER TRUCKEE RIVER, NEVADA, DURING 1969

By

P. A. GLANCY, A. S. VAN DENBURGH,

and

S. M. BORN

Prepared cooperatively by the Geological Survey
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Aftermath of 1969 runoff in the lower Truckee River.

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WATER RESOURCES BULLETIN
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# RUNOFF, EROSION, AND SOLUTES IN THE LOWER TRUCKEE RIVER, NEVADA, DURING 1969[1]

*P. A. Glancy, A. S. Van Denburgh, and S. M. Born*[2]

ABSTRACT. The Truckee River heads in the Sierra Nevada at Lake Tahoe, and terminates in Pyramid Lake. During the 1969 water year, flow about 9 miles upstream from the mouth (974,000 acre-ft) was almost four times the long-term average, due mainly to heavy winter rains and spring snowmelt. A short period of low-altitude rainfall produced the highest concentrations of suspended sediment, whereas a much longer subsequent period of snowmelt yielded a much greater total quantity of material. The upper 90 percent of the basin yielded about 260 acre-feet (630,000 tons) of sediment at the Nixon gage, whereas an estimated 2,800 acre-feet (6.8 million tons) was contributed by erosion of about 200 acres of river bank below the gage. Solute content at the gage ranged from 80 to 450 mg/l, dominated by calcium, sodium, and bicarbonate, plus silica in the most dilute snowmelt and chloride in the most concentrated low flows. Solute load totaled about 130,000 tons, of which the principal constituents in Pyramid Lake–sodium plus equivalent bicarbonate and chloride–amounted to almost 40,000 tons. The total solute load during a year of average flow may be 45,000-55,000 tons, including 18,000-22,000 tons of principal lake constituents.
(KEY TERMS: bank erosion; channel erosion; sediment transport; flood water; streamflow; runoff; sediment yield; water chemistry; seasonal variation of streamflow and water quality; Pyramid Lake; solute loads; stream-gradient disequilibrium; lower Truckee River basin; suspended-sediment particle size; Nevada)

## INTRODUCTION

### *Purpose and Scope*

Runoff in the Truckee River basin was much greater than average during water year 1969 (Oct. 1, 1968-Sept. 30, 1969). This paper describes the seasonal and areal character of streamflow, erosion, fluvial sediment movement, and solute transport during the unusual year, and relates these factors to physical characteristics of the basin, variations in climate, and the storage, release, and diversion of water.

### *Hydrogeographic Setting*

The Truckee River heads high in the Sierra Nevada of eastern California and far western Nevada. The mainstem begins at the outlet of Lake Tahoe and terminates in closed-basin Pyramid Lake, about 115 miles downstream (60 miles to the northeast) and 2,435 feet lower (Fig. 1). Most of the river's perennial streamflow originates in the Sierra Nevada; however, several smaller mountain ranges, hills, and intervening valleys also contribute flow during part

[1]Paper No. 72104 of the *Water Resources Bulletin.* Discussions are open until June 1, 1973.
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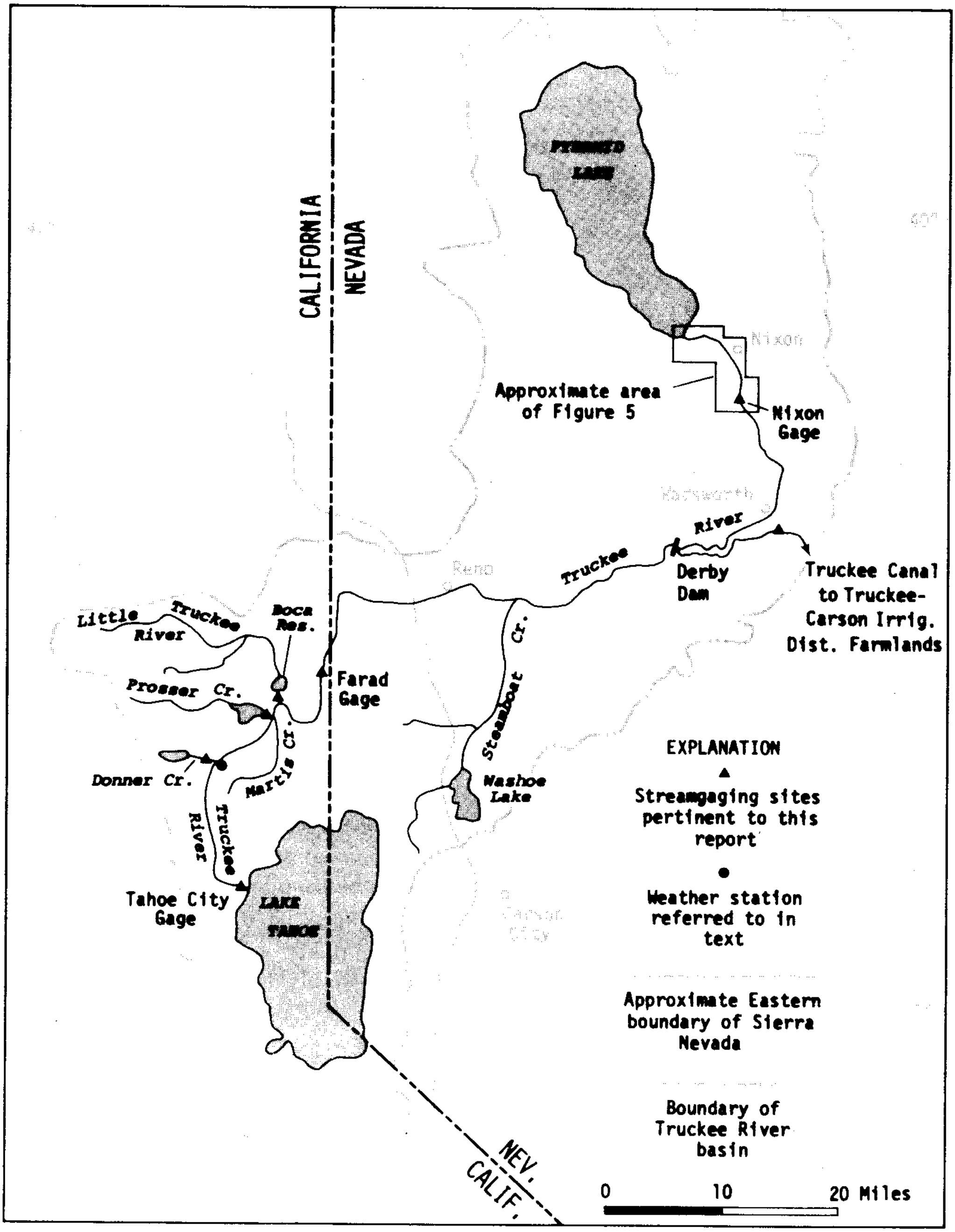



Fig. 1. Map of Truckee River basin, showing principal hydrologic features.

or all of the year. Total area tributary to the river upstream from Pyramid Lake, including the Lake Tahoe basin, is about 1,960 square miles. The main perennially flowing tributaries and some hydrologic and geographic features of the river basin are shown in Figure 1.

Lake Tahoe overflowed naturally into the Truckee River before the arrival of pioneer settlers in the area. However, the lake outlet was dammed by man during the latter part of the 19th century, and outflow is now regulated according to complex water-management procedures. Surface outflows from Donner Lake, Prosser Creek Reservoir, and Boca Reservoir are also man-controlled (Fig. 1). Derby Dam (Fig. 1) allows transbasin diversion of Truckee River flow, mainly to Lahontan Reservoir and the Newlands Irrigation Project in the adjacent Carson River drainage. Three small diversion dams, Numana, Siphon and Marble Bluff (approximate locations shown in Fig. 5), were constructed in the lower Truckee drainage basin [U.S. Bur. of Indian Affairs, 1959]. Today, only Numana Dam, the oldest, remains. It is about 3 airline miles upstream from Nixon, and is used solely to divert streamflow for irrigation. The other two dams, which were downstream from Nixon, failed during floods in the 1950's, as documented by the U.S. Bureau of Indian Affairs [1959, pp. 6-9]. The hydrologic influence exercised by these two structures has been largely obliterated during subsequent high flows.

Figure 1 does not show structures completed since the 1969 water year. Stampede Dam on the Little Truckee River and Martis Creek Dam are now operational [1972], and the feasibility of constructing Marble Bluff Dam, near the river mouth, is being evaluated [Malmstrom, 1971]. These structures did not influence 1969 runoff conditions but they will affect or be affected by future runoff.

Evaporation of water from Lake Tahoe and Pyramid Lake accounted for most of the natural water losses from the Truckee River basin prior to man's settlement of the area. The lakes' surface levels were probably more or less at equilibrium, although they fluctuated seasonally and over the long term in response to changing climatic conditions.

Mankind's development of the river system has caused several notable changes: (1) by law, the level of Lake Tahoe is regulated by controlling releases to the Truckee River; (2) these releases, as well as those from other downstream reservoirs, tend to stabilize river flow by attenuating flood peaks and amplifying seasonal low flows; and (3) the combined effects of man's intrabasin streamflow consumption and transbasin diversion at Derby Dam have markedly reduced the amount of water reaching Pyramid Lake.

Pyramid Lake's surface elevation was about 3,865 feet in 1905, when transbasin diversion of river flow through the Truckee Canal began [Harding, 1965, p. 94]; in February and March 1967, lake-surface elevation was at an all-time historic low of about 3,784 feet—a net decline of about 80 feet in 64 years. As a result, the shoreline receded, thereby lengthening the river channel and channel characteristics changed markedly. During periods of low flow, the Truckee at and near its mouth is largely confined to a braided meandering channel, which is steadily degrading to keep pace with the net decline of lake level. In times of exceptionally high flow, however, the entire alluvial flood plain is inundated by the swollen river. During these times of high discharge, the flood plain is extended laterally by undercutting, with subsequent failure of river banks. Thus, the most readily apparent stream-channel changes include fluctuating gradients, a progressive net downcutting, severe lateral bank erosion during high-streamflow periods, and changes in channel width-depth relations caused by the heavy sediment loads associated with the aforementioned changes.

### *Sources of Data*

The U.S. Geological Survey has collected streamflow records on the Truckee River and some of its tributary streams and lakes for several decades. In addition, streamflow and lake levels have been measured at several locations in the river basin by the Truckee-Carson Irrigation District and the office of the Federal Watermaster. Cumulatively, these records document nearly a century of hydrologic history, although periods of record for many of the sites cover only fragments of this long time span. Much of this information is available in numerous basic-data publications of the U.S. Geological Survey, in a hydrologic reconnaissance report by Van Denburgh and others (in press), and in an excellent publication by S. T. Harding [1965].

The U.S. Geological Survey has also collected periodic suspended-sediment samples from the Truckee River at the streamflow gaging station about 4 miles upstream from Nixon, Nev. (hereafter referred to as the Nixon gage) since the beginning of the 1963 water year, in cooperation with the U.S. Bureau of Reclamation. Additional samples were collected during water year 1969 to assist Stephen M. Born in describing erosion characteristics of the river as part of his investigation of the Truckee River delta [Born, 1970; Born and Ritter, 1970]. Water samples were also collected during the 1969 water year by the Geological Survey at the Nixon gage to provide information regarding variation in the river's dissolved-solids load during the year.

Aerial photographs covering the lowermost few miles of the river were obtained immediately prior to the beginning of the 1969 water year, and again after the water year, to enable a quantitative evaluation of lateral riverbank erosion during the year.

## STREAMFLOW

Truckee River flow during 1969 at the Nixon gage, about 9 miles upstream from Pyramid Lake, was 974,000 acre-feet. Average annual flow, determined from records of the Federal Watermaster for the river below Numana Dam, plus the diversion at the dam, during 1929-57, and Geological Survey data for the river above the dam during 1958-69, was 251,000 acre-feet. During the 41-year period of record, only the runoff in water year 1952 (1,040,000 acre-ft) exceeded the flow in 1969. In contrast, the minimum annual runoff of record was only 13,000 acre-feet (1931).

The surface level of Pyramid Lake rose about 8 feet between January and July of 1969 because of the unusually great inflow from the Truckee River.

Table 1, a summary of 1969 hydrologic data collected at the Nixon gage, groups the records into eight periods of varying streamflow conditions. Conditions of temperature and precipitation recorded near Truckee, Calif., are representative of those in the upper drainage basin where most of the runoff originated.

Table 2 summarizes high-flow conditions at the Nixon gage during 1958-69, and shows the following noteworthy contrasts: (1) the total annual flow of 1969 exceeded the next highest annual flow during this period by more than 1½ times, although, (2) the peak instantaneous discharge of 1969 was exceeded three times during the 12-year period (by over 2½ times in 1963); and (3) sustained high flow [rates exceeding 3,000 cfs (cubic feet per second)] occurred 23 percent of the time–more than 1½ times longer than the next highest year (1967). These sustained high flows are significant with regard to erosion, as discussed later.

Table 3 provides a generalized description of weather conditions and runoff characteristics in the Truckee River basin during the water year. In summary, the heavy runoff year comprised an early period of low flow, a short period of minor low-altitude flooding caused by rainfall, moderate to heavy flows from low-altitude snowmelt and storage releases, a prolonged period of sustained high flows caused by combined high-altitude snowmelt and storage releases, and a return to late-season low flows. These varying streamflow conditions, as well as

TABLE 1. Summary of Precipitation and Air Temperature at Truckee, Calif., and Hydrologic and Water Quality Conditions for Truckee River Near Nixon, Nev., Water Year 1969
(Precipitation and air temperature for National Weather Service station at Truckee Ranger Station)

| PERIOD NUMBER | PERIOD | TOTAL PRECIPITATION (in) | AVERAGE AIR TEMPERATURE (°C) | AVERAGE DISCHARGE (cfs) | TOTAL ACRE-FEET | ESTIMATED AVERAGE SUSPENDED-SEDIMENT CONCENTRATION (mg/l) | ESTIMATED TOTAL TONNAGE OF SUSPENDED SEDIMENT | AVERAGE SPECIFIC CONDUCTANCE (micromhos per cm at 25°C) | TOTAL TONNAGE OF SOLUTES[1] | TONNAGE OF SODIUM PLUS EQUIVALENT BICARBONATE AND CHLORIDE[1,2] |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 10-1 to 12-21 | 8.45 | 2.0 | 44 | 7,200 | 14 | 140 | 690 | 4,000 | 1,800 |
| 2 | 12-22 to 1-19 | 8.43 | -3.5 | 480 | 27,500 | 40 | 1,500 | 300 | 7,200 | 2,500 |
| 3 | 1-20 to 1-31 | 15.47 | -5.5 | 2,530 | 60,300 | 1,200 | 100,000 | 240 | 13,000 | 4,300 |
| 4 | 2-1 to 2-28 | 9.57 | -5.0 | 1,630 | 90,600 | 210 | 26,000 | 180 | 15,000 | 4,700 |
| 5 | 3-1 to 3-31 | 1.56 | -1.0 | 2,200 | 135,000 | 350 | 65,000 | 140 | 18,000 | 5,100 |
| 6 | 4-1 to 6-30 | 5.23 | 8.5 | 3,440 | 620,000 | 450 | 380,000 | 110 | 68,000 | 17,000 |
| 7 | 7-1 to 7-31 | .90 | 16.0 | 430 | 26,300 | 81 | 2,900 | 210 | 4,900 | 1,700 |
| 8 | 8-1 to 9-30 | .10 | 14.5 | 50 | 6,000 | 19 | 150 | 660 | 3,200 | 1,300 |
| | ENTIRE YEAR | 49.79 | 6.0 | 1,340 | 974,000 | 430 | 570,000 | 144 | 133,000 | 39,000 |

1. With bicarbonate multiplied by 0.492 to make results comparable with "residue on evaporation" values.

2. Tonnages are based on combined milligram-per-liter concentrations calculated as follows: sodium and chloride are totaled along with an amount of bicarbonate that is equivalent (on a reacting-value basis) to the amount by which sodium exceeds chloride; that is, me/l (milliequivalents per liter) $HCO_3$ = me/l Na - me/l Cl.

TABLE 2. Summary of Truckee River Flow at the Nixon Gage, Water Years 1958-69

| WATER | PEAK INSTANTANEOUS DISCHARGE | | ANNUAL FLOW | PERCENTAGE OF YEAR THAT AVERAGE DAILY DISCHARGE EXCEEDED: | | |
|---|---|---|---|---|---|---|
| YEAR | cfs | DATE | (acre-feet) | 3,000 cfs | 4,000 cfs | 5,000 cfs |
| 1958 | 5,160 | MAY 21 | 521,000 | 13 | 6.0 | 0.6 |
| 1959 | 726 | FEB. 17 | 24,500 | 0 | 0 | 0 |
| 1960 | 1,560 | FEB. 9 | 25,300 | 0 | 0 | 0 |
| 1961 | 417 | Aug. 25 | 18,200 | 0 | 0 | 0 |
| 1962 | 920 | MAY 9, 10 | 47,000 | 0 | 0 | 0 |
| 1963 | 14,000 | FEB. 2 | 320,000 | 2.5 | 0.8 | 0.5 |
| 1964 | 615 | NOV. 15 | 42,100 | 0 | 0 | 0 |
| 1965 | 9,950 | DEC. 24 | 437,000 | 2.2 | 1.6 | 1.4 |
| 1966 | 1,660 | DEC. 7 | 153,000 | 0 | 0 | 0 |
| 1967 | 6,360 | MAY 22 | 640,000 | 15 | 6.0 | 0.8 |
| 1968 | 2,210 | FEB. 24 | 241,000 | 0 | 0 | 0 |
| 1969 | 5,320 | JAN. 26 | 974,000 | 23 | 3.8 | 0 |

TABLE 3. A Generalized Summary of Runoff Conditions in the Truckee River Basin During the 1969 Water Year

| PERIOD | GENERAL WEATHER CONDITIONS | DOMINANT RUNOFF CHARACTERISTICS |
|---|---|---|
| Oct. 1-Dec. 21 | Dry with short periods of minor precipitation | Seasonal low flows[1] |
| Dec. 22 | --- | Sharp increase in flow at Nixon gage because of reduced diversions through Derby Canal |
| Late Dec.-Jan. 17 | Periods of snowfall; beginning of snowpack accumulation at high altitudes | No change |
| Jan. 18-21 | Heavy basin-wide rainfall | Snowpack absorbed rain at high altitudes. Heavy runoff at low and middle altitudes, with appreciable overland flow and channel flushing |
| Jan. 22-24 | Cessation of rainfall and rapidly falling temperatures | Receding flood runoff |
| Jan. 25-26 | Warming temperatures, renewed rainfall | Renewed low-altitude runoff and localized small tributary flooding in lower parts of the basin |
| Jan. 27-mid March | All significant precipitation as snow; unusually heavy accumulations at high altitudes | Recession of late Jan. flooding, but generally high flows maintained by low- to medium- altitude snowmelt and increased reservoir releases |
| Late March-June | Some snowfall, with snowpack in mountains about 200% of average by April 1.[2] High-altitude melting beginning in April, with maximum melt during June. Periods of heavy rainfall during June | Heavy streamflow caused by contributions from uncontrolled small tributaries, combined with large lake and reservoir releases to accomodate heavy snowmelt inflow. Flooding of Truckee River near Tahoe City caused by rains[3] |
| Early July | Hot weather. Generally dry | Receding snowmelt runoff |
| Late July-Sept. | Warm to hot weather. Generally dry | Return to stable low-flow conditions |

1. U. S. Geol. Survey, 1970, p. 112-138.
2. U. S. Soil Conservation Service, 1969, p. 1.
3. U. S. Corps of Engineers, 1971, p. 13.

sediment-transport patterns and changes in dissolved-solids load, form the basis for the eight periods shown in Table 1.

Figure 2 shows the seasonal variation in streamflow, along with information on the timing of precipitation. Table 4 summarizes the combined effects of controlled releases from upper-basin storage facilities and uncontrolled runoff above the Geological Survey gaging station on the Truckee River at Farad, Calif. The total drainage area above the Farad gage is 932 square miles, of which 747 square miles is upstream from the outlets of Lake Tahoe, Donner Lake, Prosser Reservoir, and Boca Reservoir. The Farad gage records streamflow from most of the high-altitude Sierra Nevada drainage tributary to the Truckee River. Thus, the Farad data plus

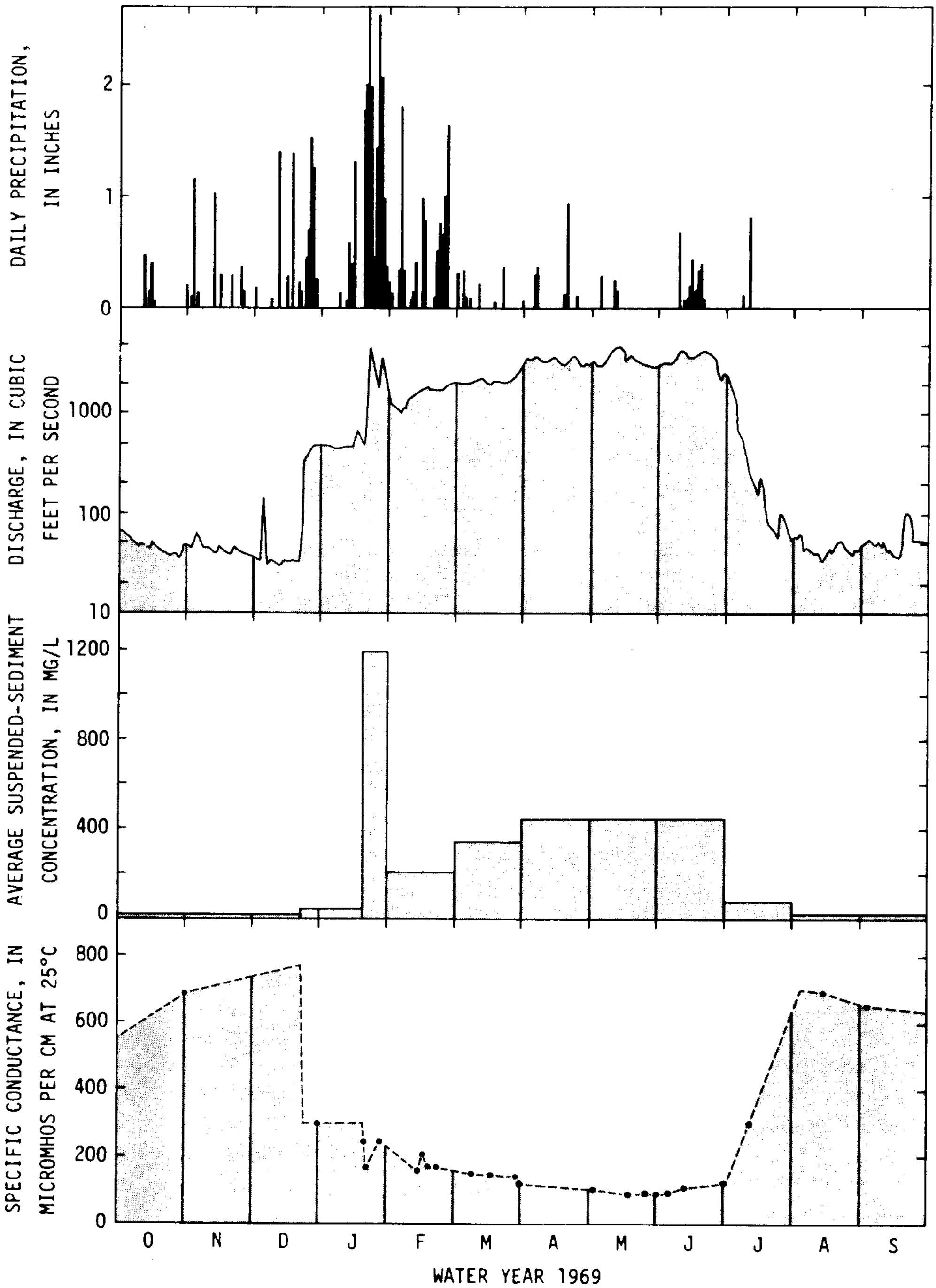



Fig. 2. Precipitation at Truckee, Calif., and streamflow, suspended-sediment concentration, and specific conductance for Truckee River near Nixon, water year 1969. Precipitation data from published records of National Weather Service for gage at Truckee Ranger Station, Calif.

TABLE 4. Truckee River Flow at Farad, Calif., During Water Year 1969, as Affected by Weather and Controlled Upstream Storage Releases, and Relation to Flow at Nixon Gage and in Truckee Canal

| | | FLOW AT FARAD | | | | |
|---|---|---|---|---|---|---|
| PERIOD NUMBER | PERIOD | ACRE-FEET | PERCENTAGE DERIVED FROM CONTROLLED RELEASES UPSTREAM | REMARKS | FLOW AT NIXON GAGE, AS PERCENTAGE OF FLOW AT FARAD | FLOW AT TRUCKEE CANAL NEAR WADSWORTH[1], AS PERCENTAGE OF FLOW AT FARAD |
| 1 | Oct. 1-Dec. 21 | 68,100 | 82 | Dry weather; low flows augmented by storage releases. | 11 | 109 |
| 2 | Dec. 22-Jan. 19 | 25,300 | 74 | Some snow and rain; continued low flows and steady storage releases. | 110 | 159 |
| 3 | Jan. 20-Jan. 31 | 36,400 | 52 | Heavy rain, local runoff; reduced release from Lake Tahoe, increased releases from Donner, Prosser, and Boca Reservoirs. | 170 | .1 |
| 4 | February | 84,800 | 90 | Increased releases from lake Tahoe, steady releases from Donner, Prosser, and Boca Reservoirs. | 110 | .8 |
| 5 | March | 133,000 | 89 | High Releases from Lake Tahoe and Prosser Reservoir, steady releases from Donner and Boca Reservoirs; some low-altitude snowmelt. | 100 | 1 |
| 6 | April-June | 651,000 | 69 | Generally heavy storage releases; heavy high-altitude snowmelt and rainfall. | 95 | 5 |
| 7 | July | 52,300 | 63 | Diminishing high-altitude snowmelt; generally decreased storage releases. | 50 | 20 |
| 8 | Aug.-Sept. | 65,600 | 80 | Dry weather; low flows augmented by storage releases | 9 | 27 |
| | TOTAL (rounded) | 1,116,000 | 74 | | 88 | 15 |

1. Indicates quantity of water leaving Truckee River Basin via canal; annual net diversion totaled 171,000 acre-feet.

information on man-controlled upstream storage releases characterize high-altitude runoff in the Truckee River basin.

## EROSION AND SEDIMENT TRANSPORT

The heavy runoff during the 1969 water year caused extensive erosion in the Truckee River basin. Table 1 summarizes estimated suspended-sediment loads during the year at the Nixon gage, according to periods of differing streamflow. The cumulative annual suspended-sediment load passing the gage was estimated at about 570,000 tons. This estimate was made from a family of sediment-rating curves based on 35 depth-integrated suspended-sediment samples collected during the water year [U.S. Geol. Survey, 1970, pp. 210-211]. The curves and analytical results are believed to be reasonable approximations, because about 80 percent of the samples were collected during the periods of high streamflow, when sediment transport was greatest. Sediment bedload (unmeasured by the suspended-sediment sampling) is assumed to have been about 10 percent of the suspended-sediment load [Lane and Borland, 1951; Sheppard, 1965, Table 1], or about 60,000 tons. Therefore, the total sediment load passing the gage is estimated at about 630,000 tons for the water year. The total load would be equivalent to upstream erosion of about 420,000 cu yd (cubic yards) of material, assuming an average in-place sediment density of about 1.5 tons per cu yd (110 lbs per cu ft). The sediment originated upstream from the Nixon gage and mainly downstream from the major storage reservoirs, or from about 1,210 square miles of the basin. Therefore, the net annual sediment-yield rate from above the Nixon gage was about 520 tons (350 cu yd) per square mile. More than 99 percent of the estimated load passed the Nixon gage between January 19 and July 10 —only about 47 percent of the year.

Suspended-sediment concentrations were greatest during January 20-31. The maximum concentration measured was 2,400 mg/l (milligrams per liter) on January 20. The peak measured instantaneous load of the year, equivalent to 24,200 tons per day, also occurred during this period, on January 21 [U.S. Geol. Survey, 1970, p. 210]. These peak measured concentrations and loads are about three times greater than any of those measured later during the period of sustained high flows. Figure 3 shows average suspended-sediment loads at the Nixon gage for the eight periods listed in Table 1; average daily loads for January 20-31 are about twice those for the period April 1-June 30, whereas the relationship between average daily water discharges during the two periods is reversed. High streamflow during January 20-31 was caused mainly by rainfall and subsequent rapid overland runoff that produced high sediment concentrations and loads for a relatively short time. In contrast, the sustained high streamflow of February 1 through June 30, particularly in April, May, and June, did not involve the intense overland runoff throughout the area, although large quantities of sediment were continually scoured from stream channels. Therefore, the persistent channel scouring of February 1-June 30, although more areally restricted and less intense than the overland runoff and accompanying sheet and rill erosion of January 20-31, caused almost five times as much sediment to be moved past the Nixon gage (Table 1). Relatively insignificant quantities of sediment were derived from above the gage during October 1-January 19 and July 1-September 30 (Fig. 3 and Table 1).

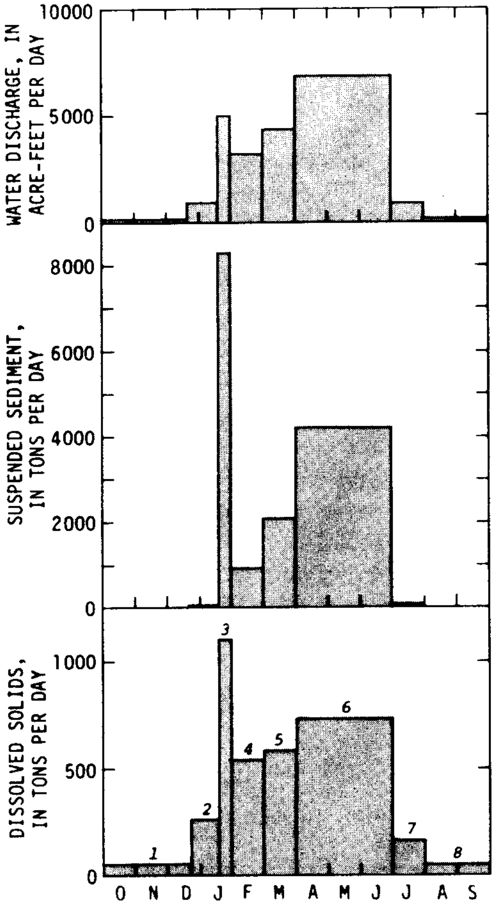



Fig. 3. Streamflow, suspended-sediment load, and solute load carried by Truckee River near Nixon during water year 1969. Numbers correspond with periods listed in Table 1.

Differences in the particle-size distribution of suspended sediment passing the Nixon gage are shown in Figure 4 [data from U.S. Geol. Survey, 1970, pp. 210-211]. Two distinct groups of plots are evident: one group for samples collected during January 20-27, and the other for the period February 18 to June 12. The January group represents predominantly finer-grained material eroded by rainfall runoff that involved an appreciable amount of intensive, short-duration overland flow (sheet and rill erosion) and minor tributary flushing. The resultant turbid water-sediment mixture was hastily flushed into and through the main river channel. The sediment load was further augmented by main-channel erosion of coarser-grained material, and the combined load passed the Nixon gage with the overall particle-size distribution shown in Figure 4.

The group of samples collected between February 18 and June 12 were noticeably coarser-grained than the January group (Fig. 4). These later transported sediments were derived during periods of sustained high flow marked by continuous releases of clear water from upstream storage facilities. Their generally coarser-grained character is thought to result from the dominance of channel erosion over sheet and rill erosion during the sustained high flow. Main-channel erosion is believed to involve generally coarser-grained sediments than those derived from overland flow. Certainly the spring snowmelt involved some sheet and rill erosion, but the products are believed masked by the dominance of channel erosion.

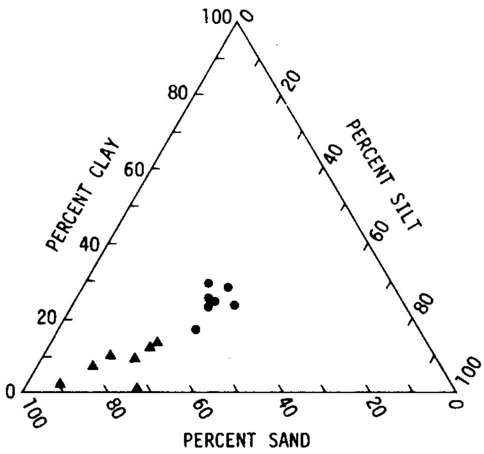



Fig. 4. Particle-size distribution of suspended-sediment samples collected Jan. 20-27, 1969 (circles) and Feb. 18-June 12, 1969 (triangles).

The most interesting aspect of erosion involves the Truckee River downstream from the Nixon gage. No perennial tributaries feed this terminal reach, and no data are available regarding sediment transport to the main channel from ephemeral tributaries. Figure 5 shows the areas of greatest lateral streambank erosion during water year 1969. Estimated quantities of erosion at the locations shown in Figure 5 are tabulated in Table 5. Cumulatively,

TABLE 5. Estimates of Channel Erosion from Major Source Areas Along the Truckee River Downstream from the Nixon Gage

| EROSION SITE[1] | ESTIMATED AREA ERODED (acres) | ESTIMATED AVERAGE THICKNESS (feet)[2] | ESTIMATED VOLUME ERODED (acre-feet) |
|---|---|---|---|
| SEVERAL SMALL AREAS[3] | a 15 | 10 | 150 |
| A | b 2 | 15 | 30 |
| B | b 34 | 10 | 340 |
| C | b 5 | 20 | 100 |
| D | b 26 | 25 | 650 |
| E | c 12 | 40 | 480 |
| F | c 60 | 10 | 600 |
| G | c 18 | 10 | 180 |
| H | c 28 | 10 | 280 |
| TOTAL (rounded) | 200 | -- | 2,800 |

1. Approximate locations shown in figure 5.
2. Field estimates using bank heights measured by P. A. Glancy in spring of 1970.
3. Throughout 2-mile reach upstream from Nixon Bridge.
a. Field estimates by P. A. Glancy in spring of 1970, with assistance by local landowners.
b. Area determined by Bureau of Indian Affairs and furnished by J. W. Long (written commun., 1970).
c. Area determined by S. M. Born using 1968 and 1969 aerial photographs.

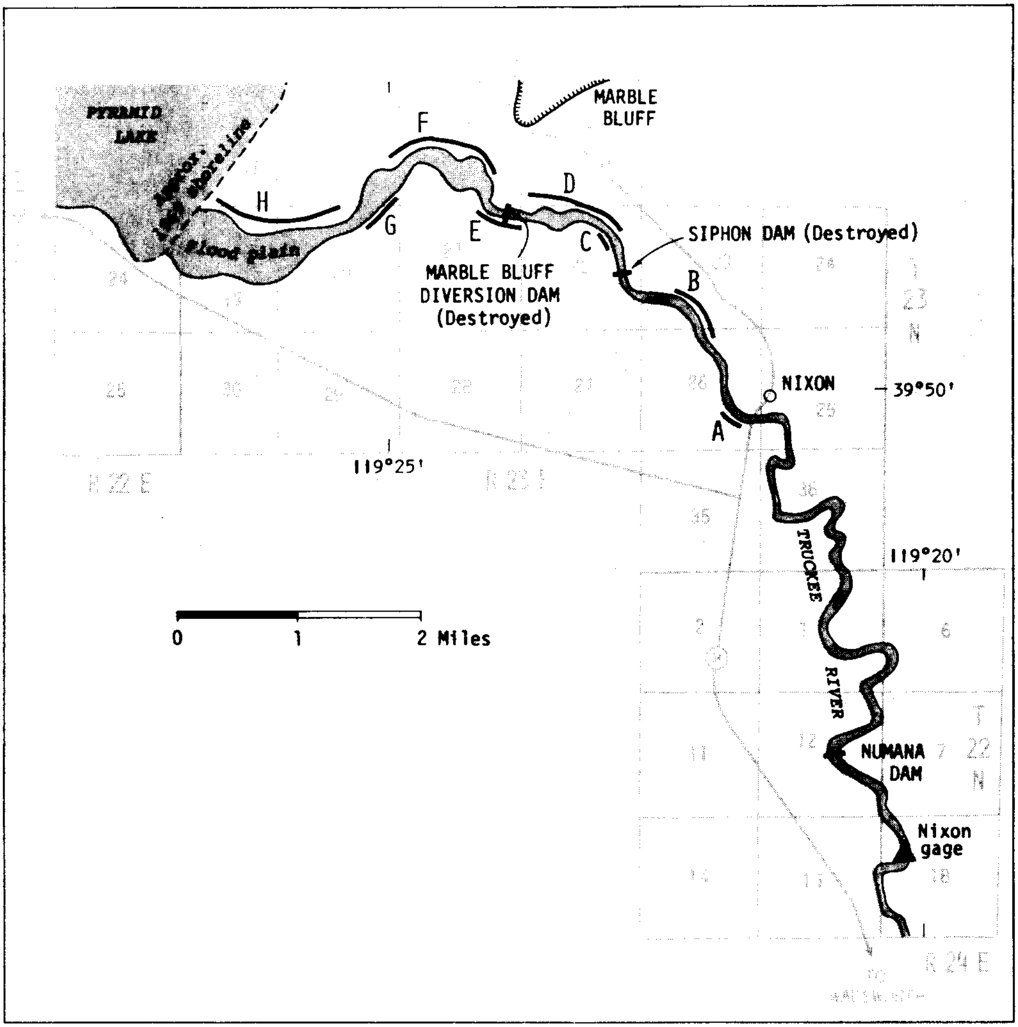



Fig. 5. Map of Nixon and vicinity, showing principal areas of 1969 bank erosion (not true to scale) along the Truckee River (letters correspond to those in Table 5).

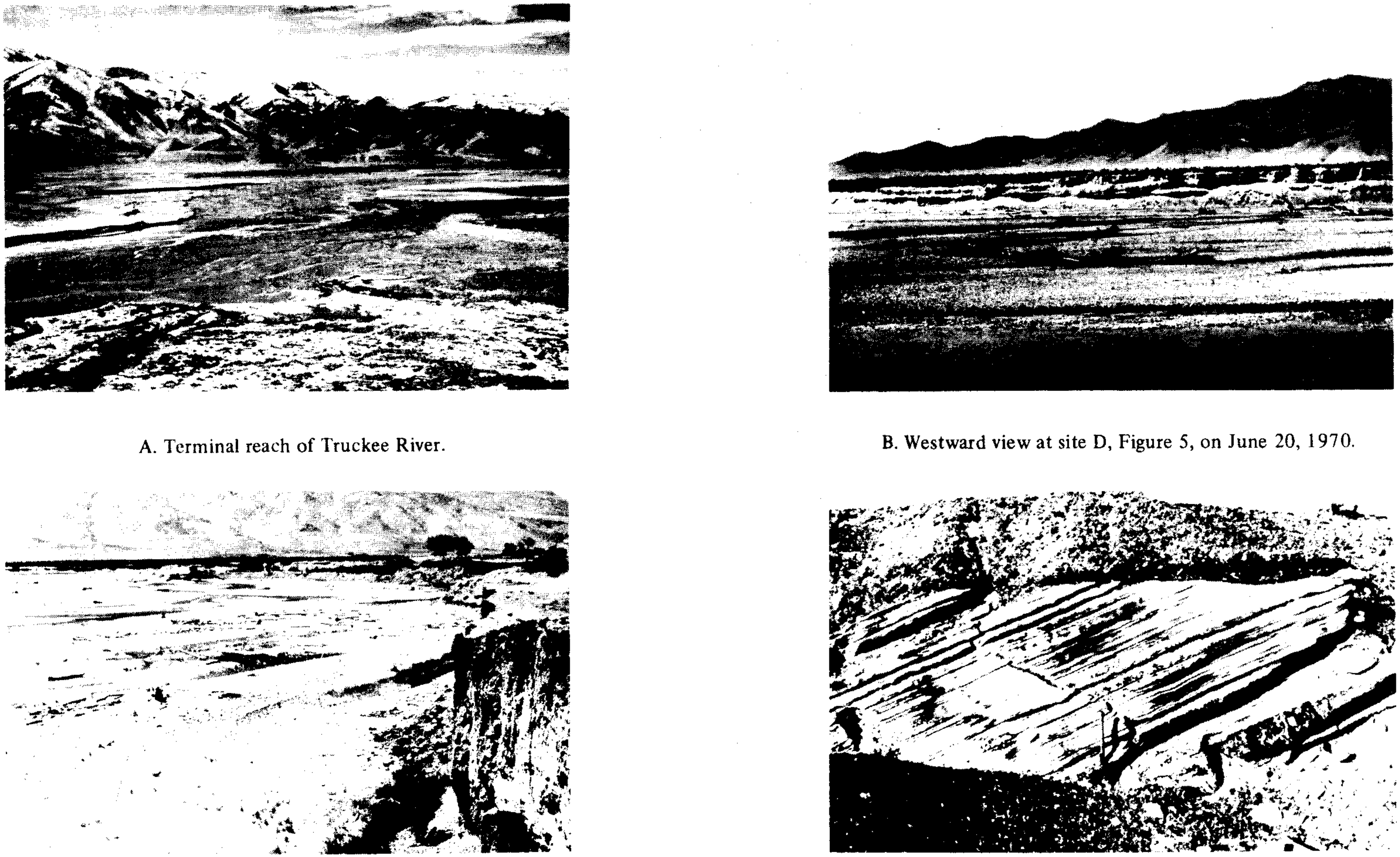
the estimated lateral streambank erosion thus accounted for is about 2,800 acre-feet, or 4,500,000 cu yd (more than 10 times the amount of sediment estimated to have passed the Nixon gage). That volume is equivalent to about 6,800,000 tons, if the same unit weight of 1.5 tons per cu yd (about 110 lbs. per cu ft) is assumed for the in-place deposits as was assumed for materials eroded above the Nixon gage. The amount of erosion below the Nixon gage estimated from the lateral channel cutting is probably a conservative estimate of the overall erosion that occurred in that part of the river system because only the most obvious areas of lateral streambank erosion (generally greater than 1 acre) were considered. Also, no accounting was possible for (1) eroded quantities furnished to the main channel from the ephemeral downstream tributaries that are known to have contributed sediment during the heavy rains of late January, or (2) main channel downcutting of the terminal river reaches that probably occurred because of channel adjustments caused by the net long-term base-level drop of Pyramid Lake.

Examination of aerial photographs of the river between Nixon and Pyramid Lake taken in 1938, 1954, 1965, and 1969 shows progressive lateral channel cutting along both banks. This lateral erosion creates a widening flood plain that is continually rescoured during subsequent high-flow periods. The photographs indicate that the severe lateral cutting generally began first near the delta and progressed continually upstream with time. Generally, the river reaches nearest the lake appear to have been affected the most, partly because of the longer period of time they have been severely eroding, with progressively lesser effects generally apparent upstream. This continued and progressive upstream lateral erosion has apparently been accompanied by severe vertical channel downcutting that has also steadily progressed upstream. The severely eroded terminal reach of the river channel and the acutely underfit nature of streamflow during low-flow periods are shown in Figure 6a.

The only known quantitative records of the lateral and vertical channel erosion are a few cross-section profiles taken by the U.S. Bureau of Indian Affairs [1959, appendix] at the Marble Bluff and Siphon diversion dams (Fig. 5), and some periodic longitudinal profiles of the river reach between these two dams. Those data, plus an additional set of profiles at the same locations constructed from a detailed topographic map of the area [U.S. Bur. Reclamation, 1971], suggest that: (1) more than a thousand feet of cumulative lateral erosion of the southwest river bank at the site of Marble Bluff Diversion Dam occurred between 1942 and 1970, with no evidence of significant concurrent deposition along the northeast bank; (2) progressive vertical scour of the streambed at the site of Marble Bluff Diversion Dam between 1916 and 1970 cumulatively totals about 30 feet; (3) several hundred feet of cumulative lateral erosion of the west river bank at Siphon Diversion Dam occurred between 1938 and 1970, with no evidence of significant concurrent deposition along the east bank; (4) progressive vertical scour of the streambed at the site of Siphon Dam between 1916 and 1970 cumulatively totals about 20 feet; and (5) the average stream gradient between the two dams progressively increased from about 3½ feet per mile in 1916 to about 10 feet per mile in 1970. This long-term upstream progression of vertical and lateral channel erosion is undoubtedly part of the river's response to the 80-foot lowering of the Pyramid Lake base level during the past 64 years. The available photographic evidence, the minimal quantitative data on continued river scour cited above, and the lack of visible evidence of significant point-bar deposits near the areas of severe lateral channel erosion during 1969, suggest that most of the eroded material was swept downstream to the lake or delta area. Undoubtedly, some temporary storage of alluvium occurs along the flood plain after periods of high flow, but all available evidence suggests that the quantity of these temporarily stored deposits is minor compared to the overall quantities eroded by lateral and vertical scour during the high-flow periods. Therefore, the river below Numana Dam (Fig. 5) is an alluvial system out of equilibrium with respect to streamflow and sediment-transport conditions.

In summary, the principal erosional characteristic of the lower Truckee River basin during the 1969 water year is the apparent exceptionally high rate along the lower river reaches where base-level effects are accentuated, in contrast to the lesser rates and quantities realized from the combined middle and headwater reaches.

The major causes of severe erosion along the lower river reaches during 1969 are believed to be as follows: (1) the dynamic channel changes that are occurring because of the rapid decline of lake levels and adjusting gradients during the last half century; (2) the abnormal length of time during which river flows exceeded 3,000 cfs (an arbitrary threshold of discharge apparently related to severe channel erosion along the lower river); and (3) the erosive susceptibility of loosely consolidated Quaternary deposits through which the river flows along its lower reaches (Fig. 6). These Quaternary deposits of fluvial and lacustrine origin are extremely



A. Terminal reach of Truckee River.

B. Westward view at site D, Figure 5, on June 20, 1970.

C. Southwestward view of site E, Figure 5, same date.

D. Modern terrace gravel and sand overlying foreset beds of the Holocene deltaic complex. Trenching tool is 2 ft long (from Born and Ritter, 1970, p. 1237).

**Fig. 6. Photographs showing erosion and character of alluvial streambank materials.**

variable, both laterally and vertically. They include: (1) fluvial gravel, sand, silt, and clay; (2) prodeltaic silty clay and clayey silt; (3) delta-slope clayey to sandy silt with some sand interbeds; (4) extremely variable delta-front platform deposits wherein sand and pebbly sand dominate; and (5) on-delta deposits, which, although highly variable, commonly comprise the coarser deposits (sand and gravel). The deposits are composed largely of volcanic detritus. The fine-grained sediments, in particular, exhibit a high degree of cohesion, and, when eroded by the Truckee River, form steep bluffs along the river valley (Fig. 6b and c). The late Quaternary deltaic deposits are commonly capped by several feet of fluvial sand and gravel (Fig. 6d).

## IMPLICATIONS OF 1969 EROSION

Some of the severe streambank erosion during 1969 reportedly damaged farm lands on the Pyramid Lake Indian Reservation [J. W. Long, U.S. Bur. of Indian Affairs, oral commun., 1970; Nevada State Journal, May 16, 1969, p. 1, and May 17, 1969, p. 6]. Successful future development and maintenance of most riparian lands along the lower river reaches probably will be subject to the steps taken to control erosion. Any design of future channel structures near the river mouth, such as the proposed Marble Bluff Dam, should consider the abnormal erosive conditions and associated river sediment-transport characteristics to guarantee the structures' hydraulic feasibility. Knowledge of the complex interplay of river, lake, and geologic controls would seem essential as a proper basis for understanding this unusual environment, and to permit proper utilization of this reach of riverside land.

## SOLUTES

During water year 1969, the dissolved-solids concentration of flow in the Truckee River at the Nixon gage is estimated to have ranged from about 80 to about 450 mg/l, on the basis of specific-conductance measurements (Fig. 2) and chemical analyses. Waters of lowest concentration contained mostly silica, calcium, sodium, and bicarbonate, whereas those of highest concentration were dominated by sodium and almost equal amounts of calcium, bicarbonate, and chloride (Fig. 7). Seasonally, the most dilute waters coincided with periods of highest flow, fed mostly by snowmelt (Figs. 2 and 8). Conversely, the highest concentrations occurred during times of lowest flow, when more than half the solute load was contributed by saline groundwater that enters the stream in the 14-mile reach above the gage.

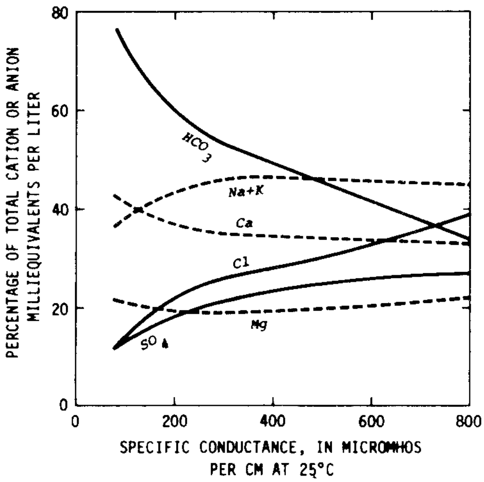



Fig. 7. Changes in the relative amounts of major ions in Truckee River near Nixon. Solid lines for negative ions; dashed lines for positive ions. Chemical symbols as follows: $HCO_3$, bicarbonate; Na, sodium; K, potassium; Ca, calcium; Cl, chloride; $SO_4$, sulfate; Mg, magnesium. Data from J. V. A. Sharp (Desert Research Institute, written commun., 1970) indicate that K contributes about 15 percent of Na + K at the lowest concentrations, and only about 5 percent at the highest concentrations.

The tonnage of salts carried by the Truckee River varied seasonally even more than the concentration of salts. The load ranged from only about 50 tons per day during periods of low flow to about 1,100 tons per day during the latter part of January (period 3, Fig. 3 and Table 1). During the 3 months of sustained high flow (April-June, period 6), the load averaged about 730 tons per day. Figure 8 shows that greater solute concentrations were associated with a given discharge during the first periods of moderate to high flow (nos. 2-4) than were present later. The reason for this difference concerns the type and timing of runoff. The first major runoff of the year tends to flush out solutes that have become available during the previous period of low flow. This was particularly true during late January 1969 (period 3, Fig. 3), when the first high flows of the season were provided by low- to medium-altitude runoff from rains (Fig. 2). This type of flow contrasts with the dilute runoff of April-June (period 6), which was generated mostly by high-altitude snowmelt.

Solutes carried past the gage totaled about 130,000 tons during the year (Table 1). Despite the low dissolved-solids concentrations during April-June, the sustained high flow during this period contributed half the total load. Conversely, though high solute concentrations were associated with low-flow periods 1 and 8, the tonnage contribution during those 4½ months was only about 5 percent of the total. The annual solute total was only one-fifth as great as the tonnage of sediment carried past the gage during the same period.

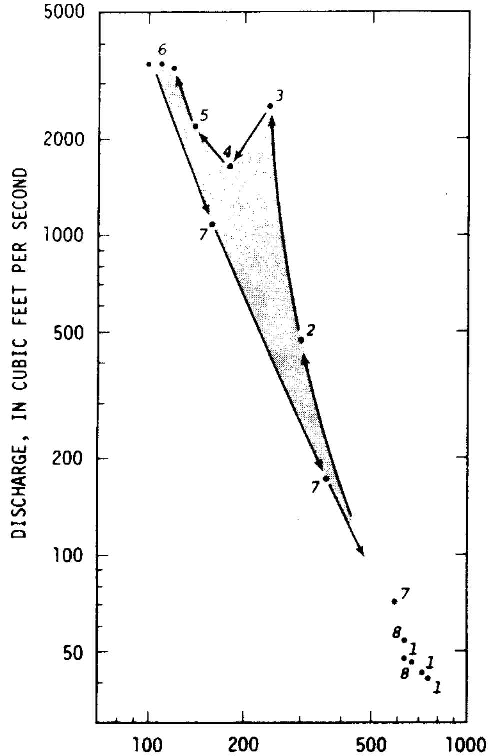



Fig. 8. Relation between specific conductance and discharge of Truckee River near Nixon during water year 1969. Numbers correspond with periods listed in Table 1. Where more than one point is shown for a single period, the period has been subdivided into time intervals of one month or less. Arrows indicate time sequence.

Pyramid Lake, which receives the flow of the Truckee River about 9 miles northwest of the Nixon gage, contains almost 5,000 mg/l of dissolved solids, dominated by sodium, bicarbonate and chloride. The quantity of sodium plus equivalent bicarbonate and chloride contributed by the Truckee River during water year 1969 was almost 40,000 tons (Table 1; see footnote 1), or about 30 percent of the total solute load passing the Nixon gage. Seasonally, sodium plus equivalent bicarbonate and chloride represented 40-45 percent of the total load during periods of low flow and high concentration, and 25-30 percent during times of high flow and low concentration.

Total flow passing the Nixon gage during water year 1969 was almost four times the long-term average, and solute quantities were similarly above normal. In water year 1970, when flow (472,000 acre-ft) was nearly twice the average, the estimated total-solute quantity carried by the river was 77,000 tons, of which 27,000 tons (35 percent) consisted of principal dissolved components of Pyramid Lake. These data for 1969 and 1970, along with other estimates, suggest that in an average year the quantity of solutes passing the gage may be

45,000-55,000 tons (average concentration, about 150 mg/l). This load includes constituents such as silica, calcium, and magnesium, which are to varying degrees unstable in a saline, alkaline, closed-lake environment. These components do not accumulate in solution over the long term, instead, they are removed by various organic and inorganic chemical reactions [Jones and Van Denburgh, 1966, pp. 443-444], and do not play a further role in the solute balance of Pyramid Lake. The net contribution of "stable" solutes that do accumulate in the lake can be approximated in terms of sodium plus equivalent bicarbonate and chloride–the principal lake components. The average annual contribution of these constituents from the river may total 18,000-22,000 tons. In contrast, the lake itself contains about 140 million tons–approximately 7,000 times the average annual income from the Truckee River alone. Expressed in another way, at present-day rates of income, solute contributions from the river would increase the tonnage in Pyramid Lake by less than 1½ percent in 100 years.

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