# Hydrographic and Sedimentation Survey of Kajakai Reservoir, Afghanistan

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1608-M

*Prepared in cooperation with the Ministry of Agriculture and Irrigation, Water and Soil Survey Department of Afghanistan under the auspices of the United States Agency for International Development*

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*By* DON C. PERKINS *and* J. K. CULBERTSON

CONTRIBUTIONS TO THE HYDROLOGY OF ASIA AND OCEANIA

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*Sediment deposition in Kajakai Reservoir on Helmand River 1953 to 1968, determined using underwater mapping techniques*

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# HYDROGRAPHIC AND SEDIMENTATION SURVEY OF KAJAKAI RESERVOIR, AFGHANISTAN

By Don C. Perkins and J. K. Culbertson

ABSTRACT

A hydrographic and sedimentation survey of Band-e Kajakai (Kajakai Reservoir) on the Daryā-ye Hīrmand (Helmand River) was carried out during the period September through December 1968. Underwater mapping techniques were used to determine the reservoir capacity as of 1968. Sediment range lines were established and monumented to facilitate future sedimentation surveys. Afghanistan engineers and technicians were trained to carry out future reservoir surveys.

Samples were obtained of the reservoir bed and in the river upstream from the reservoir. Virtually no sediments coarser than about 0.063 millimeter were found on the reservoir bed surface. The median diameter of sands being transported into the reservoir ranged from 0.040 to 0.110 millimeter. The average annual rate of sedimentation was 7,800 acre-feet. Assuming an average density of 50 pounds per cubic foot (800 kilograms per cubic meter), the estimated average sediment inflow to the reservoir was about 8,500,000 tons (7,700,000 metric tons) per year.

The decrease in capacity at spillway elevation for the period 1953 to 1968 due to sediment deposition was 7.8 percent, or 117,700 acre-feet. Redefinition of several contours above the fill area resulted in an increase in capacity at spillway elevation of 13,600 acre-feet; thus, the net change in capacity was 7.0 percent, or 104,800 acre-feet.

Based on current data and an estimated rate of compaction of deposited sediment, the assumption of no appreciable change in hydrologic conditions in the drainage area, the leading edge of the principal delta will reach the irrigation outlet in 40–45 years.

It is recommended that a resurvey of sediment range lines be made during the period 1973–75.

## INTRODUCTION

Storage of water behind Kajakai Dam on the Daryā-ye Hīrmand (Helmand River) (fig. 1) began in January 1953. A reconnaissance survey of Band-e Kajakai (Kajakai Reservoir) was made in May 1967 to observe generally the magnitude and extent of sediment deposition that occurred during the first 14 years of storage. Sediment deposition appeared to be significant, and recommendations were made that a more comprehensive sedimentation survey be carried out.

The Agency for International Development (USAID), an agency of the Government of the United States of America, and the Ministry of Agriculture and Irrigation (MAI), an agency of the Royal Government of Afghanistan (RGA), signed an agreement to conduct a hydrographic and sedimentation survey of Kajakai Reservoir. A survey was carried out during the period September through December 1968. The results of the survey are presented in this report.

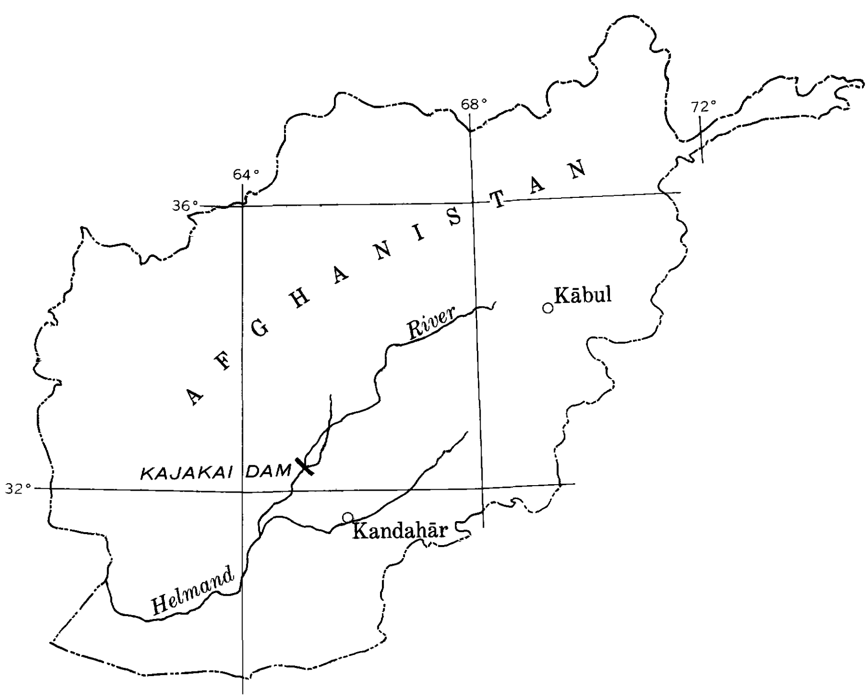


FIGURE 1.—Sketch map of Afghanistan showing location of Kajakai Dam on Helmand River.

## PURPOSE OF SURVEY

The objectives of the survey were (1) to define the current stage-capacity relation, (2) to determine the rate of sedimentation since closure in 1953, (3) to establish sediment range lines in order to simplify future sedimentation surveys, and (4) to train Afghan engineers and technicians in the techniques and procedures used in the survey.

## ACKNOWLEDGMENTS

Accomplishment of the hydrographic and sedimentation survey of Kajaki Reservoir in the relatively short period of time allotted was the result of cooperative efforts of several organizations and many individuals. Planning and execution of the survey was done by U.S. Geological Survey engineers of the Surface Water Research Project, NAD, USAID, in cooperation with the Water and Soils Survey Department (WSSD) of MAI. USAID and RGA provided funding. The following engineers and technicians worked on the project:

USAID: A. O. Westfall, Project Chief; D. C. Perkins and J. K. Culbertson, consultants; Vincent Piro and Dallas Childers, Jr., field engineers.

WSSD: Abdul Jadar Haidari, Mirza Mohammad Mushtaq, Anwar Lodin, engineers; M. Asif, Najibullah, M. Omer, Rahmanudin, Wali Mohamadi, Nazar M., Abdul Aziz, technicians.

PEACE CORPS: Patrick Molinari, Forrest Garrison, Joseph Goss, volunteers.

Individual and personal thanks go to Messrs. Jumma Mohammadi, President, WSSD; Marion Patten, Gordon V. Potter, Drew Mills, and Elonzo B. Grantham, Jr., of USAID; and Governor Safi, President, Helmand-Arghandab Valley Authority (HAVA), for their efforts and cooperation before and throughout the survey.

## LOCATION AND DESCRIPTION OF RESERVOIR

Construction of Kajakai Dam was completed in November 1952, and the gates were closed January 1953. The reservoir is about 90 miles (145 km) upstream from Lashkar Gāh on the Helmand River. The dam is earth-fill construction and rises 85 meters above the riverbed to a crest elevation of 1,050.0 m. Water is stored primarily to furnish irrigation water to the lower Helmand River valley. The elevation of the irrigation outlet is about 968 m. Future plans for water use include installation of hydroelectric units to provide power for the Helmand-Arghandab Valley Region (HAVR).

Original capacity of the reservoir was 1,495,000 acre-feet at a spillway elevation of 1,033.5 m and a capacity of 2,300,000 acre-feet at elevation 1,045 m. Original zero storage elevation was 965.0 m. The reservoir extends about 28 miles (49,000 m thalweg distance) upstream from Kajakai Dam. Full-capacity widths of the reservoir vary considerably from a minimum of about 200 m in the "narrows" to about 2,400 m at several points. Figure 2 is a sketch map showing the water-surface contour at an elevation of about 1,015 m. Also shown in figure 2 are approximate locations of permanent sediment range lines set up as a result of the 1968 survey.

## HYDROGRAPHIC SURVEY

A comparative summary of the initial capacities, the 1968 capacities, change in capacities, and percent change in capacities at 5-m increments of elevation are given in table 1. The 1968 capacity is given in table 2.

The hydrographic survey determined locations of current underwater contours as described in the following sections. New contours were drawn on prints of the original topographic maps produced by the 1953 Fairchild Surveys. Areas within each contour were planimetered and capacities between contours computed as shown in the example at the bottom of table 1.

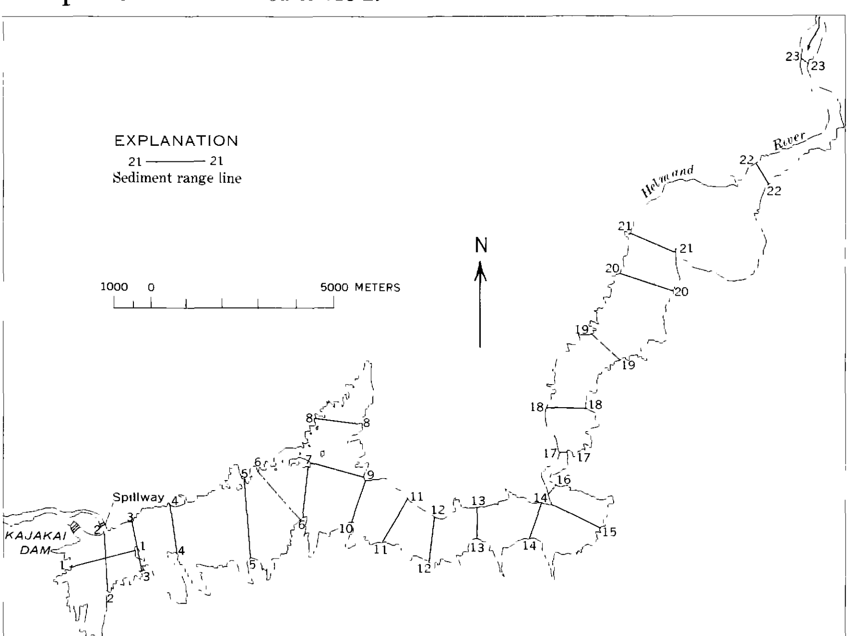


FIGURE 2.—Sketch map of Kajakai Reservoir showing location of sediment range lines.

TABLE 1.—*Comparative summary, original and 1968 surveys*

| Elevation (meters) | Capacity, in thousands of acre-feet | | Change in capacity in thousands of acre-feet (15 yr) | Percent loss in capacity |
|---|---|---|---|---|
| | 1953 | 1968 | | |
| 1,035 | 1,587.0 | 1,479.1 | 107.9 | 6.8 |
| 1,033.5 [1] | 1,495.0 | 1,390.9 | 104.8 | 7.0 |
| 1,030 | 1,294.0 | 1,185.3 | 108.7 | 8.4 |
| 1,025 | 1,039.0 | 931.6 | 107.4 | 10.3 |
| 1,020 | 824.0 | 723.9 | 100.1 | 12.1 |
| 1,015 | 644.0 | 554.3 | 89.7 | 13.9 |
| 1,010 | 489.0 | 422.0 | 67.0 | 13.7 |
| 1,005 | 364.0 | 321.2 | 42.8 | 11.8 |
| 1,000 | 266.0 | 242.5 | 23.5 | 8.8 |
| 995 | 186.0 | 175.0 | 11.0 | 5.9 |
| 990 | 123.0 | 117.7 | 5.3 | 4.3 |
| 985 | 73.0 | 70.8 | 2.2 | 3.0 |
| 980 | 35.0 | 34.2 | 0.8 | 2.3 |
| 975 | 13.3 | 10.5 | 2.8 | 21.1 |
| 970 | 2.7 | 1.2 | 1.5 | 55.6 |
| 968 | | 0 | | |
| 965 | 0 | | | |

[1] Spillway elevation.

*Example of volume computation:*

Given:

A = area of 1,005-m contour = 26,681,000 sq m

B = area of 1,000-m contour = 21,672,000 sq m

Find:

V = volume, in acre-feet, between elev 1,000 and 1,005 m

$$= \frac{A+B}{2} \times 5 \div 1{,}233.49 \text{ (cubic meters per acre-foot)}$$

$$= \frac{26{,}681{,}000 + 21{,}672{,}000}{2} \times 5 \div 1{,}233.49$$

$$= \frac{48{,}353{,}000}{2} \times 5 \div 1{,}233.49 = \underline{98{,}000} \text{ acre-feet}$$

TABLE 2.—*Capacity of Kajakai Reservoir, 1968, in thousands of acre-feet*

| Elevation (meters) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 960 | | | | | | | | | 0 | 0.5 |
| 970 | 1.2 | 2.1 | 3.5 | 5.3 | 7.6 | 10.5 | 14.0 | 18.1 | 22.8 | 28.2 |
| 980 | 34.2 | 40.7 | 47.6 | 54.9 | 62.6 | 70.8 | 79.4 | 88.4 | 97.8 | 107.6 |
| 990 | 117.7 | 128.2 | 139.2 | 150.7 | 162.7 | 175.0 | 187.7 | 200.9 | 214.4 | 228.3 |
| 1,000 | 242.5 | 257.1 | 272.2 | 287.9 | 304.2 | 321.2 | 339.1 | 358.0 | 378.0 | 399.3 |
| 1,010 | 422.0 | 446.0 | 471.3 | 497.9 | 525.8 | 554.3 | 584.3 | 615.9 | 649.7 | 685.7 |
| 1,020 | 723.9 | 763.4 | 803.9 | 845.4 | 887.9 | 931.6 | 977.2 | 1,024.9 | 1,075.2 | 1,128.3 |
| 1,030 | 1,185.3 | 1,243.9 | 1,302.7 | 1,361.5 | 1,420.3 | 1,479.1 | | | | |

Discrepancies in segments of some contours shown on the 1953 topographic map were revealed during the 1968 hydrographic survey. They are readily apparent in figures 16–18, and others, which show the reservoir bottom in some areas to be lower in 1968 than in 1953, although subjected to sediment deposit for many years. Locations of some contours above the water surface at the time of the survey were refined on the basis of levels run from the water surface to sediment range-line monuments. As a result of the refinement in location of some contours, capacity in several reaches of the reservoir was found to be greater than initially indicated. (See figs. 16–18.)

Sediment range lines were established to aid in future sedimentation monitoring surveys. Permanent concrete monuments were located at both ends of each range line. These monuments were painted white and numbered according to the range lines. Each monument was located by triangulation. Azimuths from monument to monument were determined and are given in table 3 for rapid location of range lines in future surveys.

TABLE 3.—*Azimuth of monuments and sediment range lines*

[Monument numbers indicated by R denote right-bank location, and L, denote left bank. Right and left bank determined by facing downstream]

| Monument occupied | Monument observed | Azimuth of monument observed | Remarks |
|---|---|---|---|
| F2X | Orientation | 0°00′ | F2X at lookout point near tower. Orientation point near north end dam. |
| | 1L1 | 208°33′ | |
| | 2L | 158°49′ | |
| | 3L | 121°04′ | |
| | 4L | 102°19′ | |
| | 1L2 | 100°47′ | On island, under water above elev 1,020.0. |
| | 6L | 84°07′ | |
| | 9R | 77°17′ | |
| | 11R | 81°42′ | |
| | 13L | 89°46′ | Same as F11X. |
| 1L1 | F2X | 28°33′ | Backsight. |
| | Line 1–1 | 75°58′ | |
| | 2L | 136°21′ | |
| | 3R | 54°24′ | |
| | 3L | 96°14′ | |
| | 4R | 85°05′ | |
| | 5L | 86°17′ | |
| | 5R | 61°17′ | |
| | 7R | 65°35′ | |
| 2L | F2X | 338°49′ | Do. |
| | 1L | 316°22′ | |
| | Line 2–2 | 353°58′ | |
| 3L | F2X | 301°02′ | Do. |
| | 1L1 | 276°14′ | |
| | 1L | 348°30′ | |
| | Line 3–3 | 348°32′ | |
| | 2R | 316°52′ | |

TABLE 3.—*Azimuth of monuments and sediment range lines*—Continued

[Monument numbers indicated by R denote right-bank location, and L. denote left bank. Right and left bank determined by facing downstream]

| Monument occupied | Monument observed | Azimuth of monument observed | Remarks |
|---|---|---|---|
| 4L | F2X | 282°19′ | Backsight. |
| | Line 4–4 | 351°02′ | |
| | 3R | 314°02′ | |
| | 2R | 290°47′ | |
| | 1L | 265°05′ | |
| | 5L | 88°11′ | |
| | 5R | 36°35′ | |
| | 6R | 27°40′ | |
| | 1L | 284°54′ | |
| 5R | 4L | 216°35′ | Do. |
| | Line 5–5 | 174°57′ | |
| | 6L | 127°30′ | |
| | 8L | 63°40′ | |
| 6L | 5R | 307°30′ | Do. |
| | 8L | 27°09′ | |
| | Line 6–6 | 316°02′ | |
| | Line 6–7 | 5°25′ | |
| | 9 | 56°24′ | |
| | 11R | 76°37′ | |
| 8L | 6L | 207°09′ | Do. |
| | Line 8–8 | 272°22′ | |
| | 7 | 227°08′ | |
| 9 | 6L | 236°24′ | Do. |
| | Line 9–7 | 285°15′ | |
| | Line 9–10 | 197°30′ | |
| | 11R | 111°35′ | |
| | 12R | 114°26′ | |
| | 5R | 271°40′ | |
| 11L | 10 | 307°20′ | Do. |
| | Line 11–11 | 210°00′ | |
| | 7 | 318°27′ | |
| | 9 | 347°38′ | |
| | 12R | 61°52′ | |
| 12R | 10 | 263°16′ | Do. |
| | 6L | 266°30′ | |
| | Line 12–12 | 185°02′ | |
| | 7 | 290°33′ | |
| | 9 | 294°26′ | |
| | 13L | 126°22′ | Same as F11X. |
| 13L | 12R | 306°22′ | Backsight. |
| | Line 13–13 | 0° 00′ | |
| | 11R | 302° 55′ | |
| | 5R | 285° 46′ | |
| | 7 | 294° 41′ | |
| | 9 | 299° 00′ | |
| | 6R | 290° 20′ | |
| | 14R | 53° 30′ | |
| 14L | 13R | 233° 30′ | Backsight F10X to F11X. |
| | Line 14–14 | 198° 07′ | Across lower end of narrows. |
| | Line 14–15 | 115° 44′ | |
| | Line 14–16 | 40° 04′ | |
| | 11L | 252° 57′ | |

TABLE 3.—*Azimuth of monuments and sediment range lines*—Continued

[Monuments numbers indicated by R denote right-bank location, and L, denote left bank. Right and left bank determined by facing downstream]

| Monument occupied | Monument observed | Azimuth of monument observed | Remarks |
|---|---|---|---|
| 17R | Orientation | 90° 05′ | 17R monument is at upper end of narrows. Orientation is 17L. |
| | Line 17–17 | 90° 05′ | |
| | 21L | 29° 01′ | |
| | 18R | 31° 04′ | |
| | 19R | 12° 25′ | |
| | 20R | 13° 25′ | |
| | 20L | 38° 58′ | |
| 18R | 17R | 211° 04′ | Backsight. |
| | Line 18–18 | 270° 05′ | |
| | 19R | 0°20′ | |
| | 20R | 7°18′ | |
| | 21L | 28°24′ | |
| | 21R | 13°16′ | |
| 19R | 17L | 188°42′ | |
| | Line 19–19 | 132°00′ | Do. |
| | 20R | 15°15′ | |
| | 20L | 69°31′ | |
| | 19R | 180°20′ | |
| | 17R | 192°25′ | |
| | 18L | 207°58′ | |
| 20R | 17L | 191°02′ | Do. |
| | Line 20–20 | 108°05′ | |
| | 19R | 195°15′ | |
| | 21L | 74°14′ | |
| | 19L | 166°15′ | |
| | 18R | 187°18′ | |
| 21L | 17L | 207°16′ | Do. |
| | 20R | 254°14′ | |
| | 19L | 199°35′ | |
| | 19R | 225°49′ | |
| | 17R | 209°01′ | |
| | 18L | 218°23′ | |
| | Line 21–22 | 293°04′ | |
| | 22R | 39°27′ | |
| 22R | 21L | 219°27′ | Do. |
| | Line 22–22 | 146°05′ | 3,320 m upstream of 21. |
| 23L | Line 23–23 | 306°42′ | |

In order to facilitate future resurveys of Kajakai Reservoir, the reservoir has been divided into separate reaches defined by range lines. The reaches are delineated by adjacent range lines, or between a range line and the end of a definite arm of the reservoir. For instance, that portion of the reservoir between the dam and range line 2–2 constitutes a single reach, and that portion between range lines 2–2 and 3–3 constitutes a second reach. Capacity was determined for each reach. The sum of the capacities in all reaches equals the total reservoir capacity. Table 4 gives the areas for each contour and the incremental capacity in acre-feet between contours for each reach. The incremental capacities are added to give the total capacity within the reach. Also given in this table are coefficients to be applied to resurvey data in order to compute changes in capacity. Coefficients vary for each contour interval and between reaches.

The coefficients are empirical and have the dimension acre-feet per square meters. The coefficient simply relates the average area between contours (contour interval) of the range line cross sections to capacity in acre-feet in that reach for the same contour interval. Cross-section areas of sediment range lines are given in table 5. For example, the capacity in acre-feet between elevation 1,005 and 1,010 in the reach 3–3 to 4–4 may be computed by multiplying the average area in square meters between elevations 1,005 and 1,010 of cross sections 3–3 and 4–4 by the coefficient 1.25. Using the data from table 5, and the coefficient from table 4 for the reach 3–3 to 4–4, the capacity in acre-feet is

$$\text{Capacity} = \frac{3930+5950}{2} \times 1.25 = 6{,}180 \text{ acre-feet.}$$

Therefore, in future surveys the only base data necessary to collect, in order to compute a reasonably correct change in storage, will be cross-section areas of each sediment range line.

TABLE 4.—*Summary of 1968 Kajakai Reservoir reach data*

| Elevation (meters) | Area (thousands of sq m) | Capacity (thousands of ac-ft) | Coefficient | Area (thousands of sq m) | Capacity (thousands of ac-ft) | Coefficient | Area (thousands of sq m) | Capacity (thousands of ac-ft) | Coefficient | Area (thousands of sq m) | Capacity (thousands of ac-ft) | Coefficient |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Reach dam to 2–2 | | | Reach 2–2 to 3–3 | | | Reach 3–3 to 4–4 | | | Reach 4–4 to 5–5 | | |
| 968 | 0 | | | 0 | | | 0 | | | 0 | | |
| | | 0.25 | 1.07 | | 0.24 | 1.39 | | 0.57 | 1.06 | | 0.09 | 0.189 |
| 970 | 154 | | | 150 | | | 352 | | | 56 | | |
| | | 1.05 | .689 | | .98 | .694 | | 2.23 | 1.14 | | 4.43 | 2.75 |
| 975 | 367 | | | 336 | | | 748 | | | 2,128 | | |
| | | 1.70 | .676 | | 1.51 | .615 | | 3.18 | .896 | | 9.77 | 1.75 |
| 980 | 471 | | | 410 | | | 823 | | | 2,695 | | |
| | | 2.16 | .698 | | 1.77 | .584 | | 3.60 | .926 | | 11.37 | 1.86 |
| 985 | 596 | | | 464 | | | 952 | | | 2,913 | | |
| | | 2.75 | .732 | | 2.04 | .592 | | 4.07 | 1.02 | | 12.18 | 1.94 |
| 990 | 762 | | | 541 | | | 1,054 | | | 3,094 | | |
| | | 3.55 | .782 | | 2.39 | .600 | | 4.54 | 1.07 | | 12.99 | 1.99 |
| 995 | 991 | | | 638 | | | 1,188 | | | 3,313 | | |
| | | 4.60 | .914 | | 2.98 | .693 | | 5.07 | 1.15 | | 13.82 | 2.01 |
| 1,000 | 1,280 | | | 833 | | | 1,314 | | | 3,505 | | |
| | | 5.78 | 1.05 | | 3.62 | .783 | | 5.58 | 1.20 | | 14.58 | 2.02 |
| 1,005 | 1,573 | | | 951 | | | 1,439 | | | 3,687 | | |
| | | 7.04 | 1.19 | | 4.13 | .840 | | 6.18 | 1.25 | | 15.33 | 2.01 |
| 1,010 | 1,900 | | | 1,088 | | | 1,610 | | | 3,877 | | |
| | | 8.46 | 1.20 | | 4.68 | .821 | | 6.91 | 1.24 | | 16.18 | 1.96 |
| 1,015 | 2,276 | | | 1,220 | | | 1,798 | | | 4,107 | | |
| | | 9.96 | 1.32 | | 5.33 | .872 | | 7.73 | 1.31 | | 17.27 | 2.02 |
| 1,020 | 2,638 | | | 1,413 | | | 2,018 | | | 4,413 | | |
| | | 11.50 | 1.38 | | 6.11 | .825 | | 8.79 | 1.28 | | 18.44 | 2.07 |
| 1,025 | 3,034 | | | 1,604 | | | 2,320 | | | 4,687 | | |
| | | 13.30 | 1.32 | | 6.72 | .752 | | 9.92 | 1.26 | | 19.56 | 2.05 |
| 1,030 | 3,529 | | | 1,715 | | | 2,576 | | | 4,965 | | |
| | | 10.77 | 1.50 | | 5.06 | .79 | | 7.63 | 1.34 | | 14.47 | 2.12 |
| 1,033.5 | | | | | | | | | | | | |
| | | 4.62 | ------- | | 2.17 | ------- | | 3.27 | ------- | | 6.20 | ------- |
| 1,035 | 4,064 | | | 1,850 | | | 2,802 | | | 5,234 | | |
| Total | | 87.49 | | | 49.73 | | | 79.27 | | | 186.68 | |
| | Reach 5 5 to 6–7 | | | Reach 6-7 to 9–10 | | | Reach 8–8 to end | | | Reach 8–8 to 9–7 | | |
| 968 | | | | | | | | | | | | |
| 970 | 0 | | | | | | | | | | | |
| | | 0.65 | 2.07 | | | | | | | | | |
| 975 | 320 | | | 0 | | | | | | | | |
| | | 4.58 | 1.13 | | 1.96 | 1.78 | | | | | | |
| 980 | 1,939 | | | 968 | | | | | | | | |
| | | 8.30 | 1.50 | | 4.79 | 1.41 | | | | | | |
| 985 | 2,170 | | | 1,394 | | | | | | 0 | | |
| | | 9.40 | 1.48 | | 6.16 | 1.23 | | | | | 0.12 | 0.018 |
| 990 | 2,468 | | | 1,646 | | | | | | 60 | | |
| | | 10.52 | 1.56 | | 7.00 | 1.31 | | | | | .71 | .499 |
| 995 | 2,721 | | | 1,808 | | | 0 | | | 293 | | |
| | | 11.42 | 1.60 | | 7.60 | 1.34 | | | | | 1.86 | 1.05 |
| 1,000 | 2,912 | | | 1,940 | | | 2 | | | 628 | | |
| | | 12.17 | 1.64 | | 8.13 | 1.41 | | 0.20 | 0.188 | | 3.16 | 1.19 |
| 1,005 | 3,093 | | | 2,072 | | | 98 | | | 933 | | |
| | | 12.89 | 1.67 | | 8.63 | 1.47 | | .79 | .276 | | 4.45 | 1.10 |
| 1,010 | 3,265 | | | 2,188 | | | 294 | | | 1,262 | | |
| | | 13.63 | 1.70 | | 9.12 | 1.50 | | 2.30 | .548 | | 6.18 | 1.14 |
| 1,015 | 3,460 | | | 2,310 | | | 840 | | | 1,787 | | |
| | | 14.35 | 1.68 | | 9.59 | 1.48 | | 4.41 | .833 | | 7.98 | 1.24 |
| 1,020 | 3,621 | | | 2,420 | | | 1,338 | | | 2,149 | | |
| | | 15.32 | 1.71 | | 10.06 | 1.50 | | 6.80 | 1.08 | | 9.56 | 1.35 |
| 1,025 | 3,938 | | | 2,542 | | | 2,016 | | | 2,567 | | |
| | | 16.48 | 1.76 | | 10.56 | 1.54 | | 10.84 | 1.36 | | 10.98 | 1.38 |
| 1,030 | 4,194 | | | 2,669 | | | 3,331 | | | 2,850 | | |
| | | 12.18 | 1.86 | | 7.74 | 1.61 | | 9.90 | 1.60 | | 8.35 | 1.44 |
| 1,033.5 | | | | | | | | | | | | |
| | | 5.22 | ------- | | 3.32 | ------- | | 4.24 | ------- | | 3.58 | ------- |
| 1,035 | 4,390 | | | 2,784 | | | 3,649 | | | 3,036 | | |
| Total | | 147.11 | | | 94.66 | | | 39.48 | | | 56.93 | |

TABLE 4.—*Summary of 1968 Kajakai Reservoir reach data*—Continued

| Elevation (meters) | Area (thousands of sq m) | Capacity (thousands of ac-ft) | Coefficient | Area (thousands of sq m) | Capacity (thousands of ac-ft) | Coefficient | Area (thousands of sq m) | Capacity (thousands of ac-ft) | Coefficient | Area (thousands of sq m) | Capacity (thousands of ac-ft) | Coefficient |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Reach 9-10 to 11-11 | | | Reach 11-11 to 12-12 | | | Reach 12-12 to 13-13 | | | Reach 13-13 to 14-14 | | |
| 968 | | | | | | | | | | | | |
| 970 | | | | | | | | | | | | |
| 975 | 0 | | | | | | | | | | | |
| | | 0.96 | 3.51 | | | | | | | | | |
| 980 | 477 | | | 0 | | | 0 | | | | | |
| | | 2.83 | .976 | | 1.53 | 1.01 | | 0.28 | 1.71 | | | |
| 985 | 918 | | | 756 | | | 137 | | | 0 | | |
| | | 4.17 | .793 | | 3.92 | .915 | | 1.75 | .917 | | 0.34 | 0.869 |
| 990 | 1,140 | | | 1,179 | | | 726 | | | 170 | | |
| | | 4.96 | .895 | | 5.02 | 1.01 | | 3.22 | 1.02 | | 2.19 | 1.76 |
| 995 | 1,305 | | | 1,299 | | | 864 | | | 973 | | |
| | | 5.52 | .956 | | 5.44 | .978 | | 3.75 | .944 | | 4.17 | 1.41 |
| 1,000 | 1,416 | | | 1,384 | | | 985 | | | 1,148 | | |
| | | 5.96 | 1.01 | | 5.72 | .957 | | 4.27 | .961 | | 5.07 | 1.60 |
| 1,005 | 1,523 | | | 1,440 | | | 1,120 | | | 1,352 | | |
| | | 6.36 | 1.05 | | 5.95 | .951 | | 4.78 | 1.01 | | 5.98 | 1.70 |
| 1,010 | 1,614 | | | 1,495 | | | 1,237 | | | 1,596 | | |
| | | 6.73 | 1.08 | | 6.14 | .948 | | 5.20 | 1.03 | | 6.83 | 1.63 |
| 1,015 | 1,708 | | | 1,537 | | | 1,326 | | | 1,773 | | |
| | | 7.13 | 1.11 | | 6.32 | .925 | | 5.66 | 1.05 | | 7.43 | 1.64 |
| 1,020 | 1,810 | | | 1,581 | | | 1,468 | | | 1,894 | | |
| | | 7.56 | 1.15 | | 6.53 | .923 | | 6.18 | 1.09 | | 7.86 | 1.63 |
| 1,025 | 1,918 | | | 1,639 | | | 1,580 | | | 1,983 | | |
| | | 7.98 | 1.19 | | 6.75 | .922 | | 6.72 | 1.13 | | 8.27 | 1.64 |
| 1,030 | 2,019 | | | 1,690 | | | 1,733 | | | 2,098 | | |
| | | 5.88 | 1.21 | | 4.86 | .928 | | 5.16 | 1.24 | | 6.13 | 1.75 |
| 1,033.5 | -------- | | | -------- | | | -------- | | | -------- | | |
| | | 2.52 | ------- | | 2.08 | ------- | | 2.21 | ------- | | 2.63 | ------- |
| 1,035 | 2,125 | | | 1,738 | | | 1,903 | | | 2,223 | | |
| Total | | 68.56 | | | 60.26 | | | 49.18 | | | 56.90 | |
| | Reach 14-14 to 14-15 | | | Reach 14-15 to 14-16 | | | Reach 14-16 to 17-17 | | | Reach 17-17 to 18-18 | | |
| 968 | | | | | | | | | | | | |
| 970 | | | | | | | | | | | | |
| 975 | | | | | | | | | | | | |
| 980 | | | | | | | | | | | | |
| 985 | | | | | | | | | | | | |
| 990 | 0 | | | | | | | | | | | |
| | | 0.23 | 1.23 | | | | | | | | | |
| 995 | 111 | | | | | | | | | | | |
| | | 1.22 | .792 | | | | | | | | | |
| 1,000 | 490 | | | 0 | | | 0 | | | 0 | | |
| | | 3.54 | 1.76 | | 0.78 | 1.95 | | 0.08 | ------- | | 0.04 | ------- |
| 1,005 | 1,256 | | | 383 | | | 40 | | | 22 | | |
| | | 5.60 | 1.91 | | 2.62 | .952 | | .59 | 0.601 | | 1.69 | 1.14 |
| 1,010 | 1,507 | | | 908 | | | 251 | | | 810 | | |
| | | 6.49 | 1.19 | | 3.88 | .982 | | 1.06 | .856 | | 3.84 | 1.54 |
| 1,015 | 1,692 | | | 1,004 | | | 274 | | | 1,082 | | |
| | | 7.09 | 1.18 | | 4.23 | .975 | | 1.16 | .881 | | 4.87 | 1.71 |
| 1,020 | 1,805 | | | 1,084 | | | 298 | | | 1,320 | | |
| | | 7.52 | 1.20 | | 4.58 | 1.01 | | 1.26 | .891 | | 5.79 | 1.92 |
| 1,025 | 1,908 | | | 1,174 | | | 323 | | | 1,538 | | |
| | | 7.93 | 1.22 | | 4.96 | 1.06 | | 1.35 | .915 | | 6.69 | 2.09 |
| 1,030 | 2,005 | | | 1,272 | | | 344 | | | 1,763 | | |
| | | 5.83 | 1.27 | | 3.74 | 1.11 | | 1.01 | .931 | | 5.41 | 1.49 |
| 1,033.5 | -------- | | | -------- | | | -------- | | | -------- | | |
| | | 2.50 | ------- | | 1.60 | ------- | | .43 | | | 2.32 | |
| 1,035 | 2,106 | | | 1,362 | | | 371 | | | 2,050 | | |
| Total | | 47.95 | | | 26.38 | | | 6.95 | | | 30.65 | |

TABLE 4.—*Summary of 1968 Kajakai Reservoir reach data*—Continued

| Elevation (meters) | Reach 18-18 to 19-19: Area (thousands of sq m) | Capacity (thousands of ac-ft) | Coefficient | Reach 19-19 to 20-20: Area (thousands of sq m) | Capacity (thousands of ac-ft) | Coefficient | Reach 20-20 to 21-21: Area (thousands of sq m) | Capacity (thousands of ac-ft) | Coefficient | Reach 21-21 to 22-22: Area (thousands of sq m) | Capacity (thousands of ac-ft) | Coefficient |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 968 | | | | | | | | | | | | |
| 970 | | | | | | | | | | | | |
| 975 | | | | | | | | | | | | |
| 980 | | | | | | | | | | | | |
| 985 | | | | | | | | | | | | |
| 990 | | | | | | | | | | | | |
| 995 | | | | | | | | | | | | |
| 1,000 | | | | | | | | | | | | |
| 1,005 | 0 | | | 0 | | | 0 | | | | | |
| | | 3.68 | 1.58 | | 4.04 | 3.32 | | 0.07 | ------ | | | |
| 1,010 | 1,817 | | | 1,997 | | | 34 | | | 0 | | |
| | | 7.85 | 1.70 | | 10.25 | 2.20 | | 3.29 | 1.16 | | 3.32 | 4.43 |
| 1,015 | 2,055 | | | 3,059 | | | 1,588 | | | 1,638 | | |
| | | 8.91 | 1.76 | | 13.38 | 2.09 | | 6.69 | .956 | | 16.45 | 4.74 |
| 1,020 | 2,342 | | | 3,542 | | | 1,713 | | | 6,480 | | |
| | | 10.07 | 1.51 | | 15.38 | 2.09 | | 7.19 | .954 | | 28.19 | 6.33 |
| 1,025 | 2,628 | | | 4,055 | | | 1,834 | | | 7,427 | | |
| | | 11.39 | 1.85 | | 17.55 | 2.09 | | 7.65 | .928 | | 31.11 | 5.90 |
| 1,030 | 2,994 | | | 4,603 | | | 1,940 | | | 7,921 | | |
| | | 9.20 | 1.53 | | 13.88 | 2.12 | | 5.73 | .936 | | 23.12 | 6.18 |
| 1,033.5 | ------ | | | ------ | | | ------ | | | ------ | | |
| | | 3.94 | ------ | | 5.95 | ------ | | 2.46 | ------ | | 9.91 | ------ |
| 1,035 | 3,490 | | | 5,176 | | | 2,101 | | | 8,377 | | |
| Total | | 55.04 | | | 80.43 | | | 33.08 | | | 112.10 | |

| Elevation (meters) | Reach 22-22 to 23-23: Area (thousands of sq m) | Capacity (thousands of ac-ft) | Coefficient | Reach 23-23 to end: Area (thousands of sq m) | Capacity (thousands of ac-ft) | Coefficient |
|---|---|---|---|---|---|---|
| 968 | | | | | | |
| 970 | | | | | | |
| 975 | | | | | | |
| 980 | | | | | | |
| 985 | | | | | | |
| 990 | | | | | | |
| 995 | | | | | | |
| 1,000 | | | | | | |
| 1,005 | | | | | | |
| 1,010 | | | | | | |
| 1,015 | 0 | | | 0 | | |
| | | 1.61 | 8.27 | | 0.05 | ------ |
| 1,020 | 796 | | | 25 | | |
| | | 4.48 | 3.31 | | 10.53 | 24.0 |
| 1,025 | 1,416 | | | 5,169 | | |
| | | 6.44 | 2.53 | | 30.50 | 22.8 |
| 1,030 | 1,720 | | | 9,881 | | |
| | | 5.44 | 2.69 | | 34.19 | 27.4 |
| 1,033.5 | ------ | | | ------ | | |
| | | 2.33 | ------ | | 14.66 | ------ |
| 1,035 | 2,112 | | | 14,221 | | |
| Total | | 20.30 | | | 89.93 | |

TABLE 5.—*Cross-section area of sediment range lines, in square meters*

| Elevation (meters) | Sediment range lines | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2–2 | 3–3 | 4–4 | 5–5 | 6–7 | 8–8 | 9–7 | 9–10 | 11–11 | 12–12 | 13–13 |
| 968 | 0 | 0 | 0 | | | | | | | | |
| | 233 | 116 | 961 | 0 | | | | | | | |
| 970 | | | | | | | | | | | |
| | 1,530 | 1,310 | 2,600 | 627 | 0 | | | 0 | | | |
| 975 | | | | | | | | | | | |
| | 2,510 | 2,400 | 4,700 | 6,460 | 1,640 | | 0 | 550 | 0 | 0 | |
| 980 | | | | | | | | | | | |
| | 3,100 | 2,960 | 4,800 | 7,400 | 3,690 | | 30 | 3,090 | 2,720 | 329 | 0 |
| 985 | | | | | | | | | | | |
| | 3,760 | 3,120 | 4,830 | 7,710 | 5,020 | | 1,390 | 4,970 | 5,560 | 3,020 | 795 |
| 990 | | | | | | | | | | | |
| | 4,540 | 3,430 | 5,030 | 8,060 | 5,440 | 0 | 2,860 | 5,290 | 5,780 | 4,200 | 2,130 |
| 995 | | | | | | | | | | | |
| | 5,040 | 3,560 | 5,290 | 8,470 | 5,820 | 62 | 3,480 | 5,480 | 6,060 | 5,070 | 2,870 |
| 1,000 | | | | | | | | | | | |
| | 5,490 | 3,750 | 5,540 | 8,870 | 5,930 | 1,080 | 4,230 | 5,600 | 6,180 | 5,790 | 3,090 |
| 1,005 | | | | | | | | | | | |
| | 5,920 | 3,930 | 5,950 | 9,340 | 6,100 | 2,880 | 5,220 | 5,670 | 6,400 | 6,120 | 3,330 |
| 1,010 | | | | | | | | | | | |
| | 7,080 | 4,310 | 6,830 | 9,660 | 6,400 | 4,190 | 6,670 | 5,760 | 6,680 | 6,290 | 3,800 |
| 1,015 | | | | | | | | | | | |
| | 7,540 | 4,710 | 7,080 | 10,030 | 7,060 | 5,300 | 7,560 | 5,890 | 6,900 | 6,760 | 3,990 |
| 1,020 | | | | | | | | | | | |
| | 8,360 | 6,460 | 7,260 | 10,600 | 7,350 | 6,300 | 7,830 | 6,040 | 7,120 | 7,020 | 4,330 |
| 1,025 | | | | | | | | | | | |
| | 10,050 | 7,830 | 7,910 | 11,130 | 7,590 | 7,960 | 7,920 | 6,080 | 7,310 | 7,340 | 4,570 |
| 1,030 | | | | | | | | | | | |
| | 7,200 | 5,610 | 5,800 | 7,870 | 5,230 | 6,190 | 5,360 | 4,420 | 5,250 | 5,230 | 3,100 |
| 1,033.5 | | | | | | | | | | | |
| Total 1968 | 72,350 | 53,500 | 74,580 | 106,230 | 67,270 | 33,960 | 52,550 | 58,840 | 65,960 | 57,170 | 32,000 |

| Elevation (meters) | Sediment range lines | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 14–14 | 14–15 | 14–16 | 17–17 | 18–18 | 19–19 | 20–20 | 21–21 | 22–22 | 23–23 |
| 968 | | | | | | | | | | |
| 970 | | | | | | | | | | |
| 975 | | | | | | | | | | |
| 980 | | | | | | | | | | |
| 985 | | | | | | | | | | |
| | 0 | | | | | | | | | |
| 990 | | | | | | | | | | |
| | 358 | | | | | | | | | |
| 995 | | | | | | | | | | |
| | 3,070 | 0 | | | | | | | | |
| 1,000 | | | | | | | | | | |
| | 3,230 | 797 | 0 | 0 | 0 | 0 | | | | |
| 1,005 | | | | | | | | | | |
| | 3,690 | 4,250 | 1,250 | 720 | 2,230 | 2,430 | 0 | 0 | | |
| 1,010 | | | | | | | | | | |
| | 4,570 | 6,290 | 1,600 | 880 | 4,090 | 5,120 | 4,190 | 1,500 | 0 | |
| 1,015 | | | | | | | | | | |
| | 5,060 | 6,990 | 1,690 | 940 | 4,750 | 5,380 | 7,440 | 6,550 | 390 | 0 |
| 1,020 | | | | | | | | | | |
| | 5,330 | 7,240 | 1,820 | 1,000 | 5,030 | 6,280 | 8,440 | 6,630 | 2,270 | 438 |
| 1,025 | | | | | | | | | | |
| | 5,510 | 7,460 | 1,900 | 1,060 | 5,250 | 7,060 | 9,690 | 6,800 | 3,740 | 1,340 |
| 1,030 | | | | | | | | | | |
| | 3,890 | 5,320 | 1,390 | 780 | 6,500 | 5,500 | 7,560 | 4,690 | 2,790 | 1,250 |
| 1,033.5 | | | | | | | | | | |
| Total 1968 | 34,708 | 38,350 | 9,650 | 5,380 | 27,850 | 31,770 | 37,320 | 26,170 | 9,190 | 3,030 |

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## HORIZONTAL CONTROL

A topographic map compiled by Fairchild Aerial Surveys, Inc., U.S.A., using stereophotogrametric methods was used as the base map. The scale of this map was 1:50,000, with a contour interval of 5 meters. The original Fairchild triangulation stations were plotted on the map.

Prior to the 1968 hydrographic survey, the U.S. Bureau of Reclamation of Helmand-Arghandab Valley Region (HAVR) recovered and placed flags on the Fairchild triangulation stations that were above the reservoir level. The bearing of the lines between triangulation stations were available for the 1968 survey. The azimuth of lines as computed from the bearings are given in table 6.

TABLE 6.—*Azimuths to triangulation stations*

[Based on the Fairchild Survey. Positions originate at F2X (at tower observation point) and are carried through the triangulation net on the assumed azimuth of 130°00′ for the line F2X to F4X. Vertical datum is 1,051.79 m below station F2X elev 1,051.79 m. (See fig. 3)]

| Station occupied | Station observed | Azimuth |
|---|---|---|
| F1X | F2X | 09°13′14″ |
| | F4X | 92°25′09″ |
| | Cut in peak | 140°30′36″ |
| Cut in peak | F1X | 320°30′36″ |
| | F2X | 344°13′11″ |
| | F4X | 44°30′55″ |
| F2X | F3X | 85°18′12″ |
| | F4X | 130°00′00″ |
| | Cut in peak | 164°13′11″ |
| | F1X | 189°13′14″ |
| F4X | Cut in peak | 224°30′55″ |
| | F1X | 272°25′09″ |
| | F2X | 310°00′00″ |
| | F3X | 347°49′40″ |
| | F5X | 11°49′12″ |
| | F6X | 46°49′39″ |
| F3X | F7X | 43°53′21″ |
| | F5X | 104°47′21″ |
| | F4X | 167°49′40″ |
| | F2X | 265°18′12″ |
| F5X | F3X | 284°47′21″ |
| | F7X | 21°02′11″ |
| | F6X | 144°43′07″ |
| | F4X | 191°49′12″ |
| | F3X | 284°47′21″ |
| F6X | F4X | 226°49′39″ |
| | F5X | 324°43′07″ |
| | F7X | 01°21′28″ |
| | F8X | 39°12′59″ |
| | F9X | 65°40′51″ |

TABLE 6.—*Azimuths to triangulation stations*—Continued

| Station occupied | Station observed | Azimuth |
|---|---|---|
| F7X | F17X | 36°46′01″ |
| | F8X | 106°17′51″ |
| | F9X | 137°42′26″ |
| | F6X | 181°21′28″ |
| | F5X | 201°02′11″ |
| | F3X | 223°53′21″ |
| F8X | F7X | 286°17′51″ |
| | F17X | 01°54′59″ |
| | F18X | 33°39′29″ |
| | F10X | 97°19′14″ |
| | F11X | 124°10′27″ |
| | F9X | 180°13′05″ |
| | F6X | 219°12′59″ |
| | F7X | 286°17′51″ |
| F9X | F6X | 245°40′51″ |
| | F7X | 317°42′26″ |
| | F8X | 00°13′05″ |
| | F11X | 84°04′37″ |
| F17X | F18X | 97°50′02″ |
| | F10X | 139°53′08″ |
| | F8X | 181°54′59″ |
| | F7X | 216°46′01″ |
| F11X | F9X | 264°04′37″ |
| | F8X | 304°10′27″ |
| | F10X | 53°30′32″ |
| | F12X | 101°32′40″ |
| F12X | F11X | 281°32′40″ |
| | F10X | 314°54′02″ |
| | F13X | 346°17′56″ |
| | F14X | 25°21′28″ |
| F10X | F11X | 233°30′32″ |
| | F8X | 277°19′14″ |
| | F17X | 319°53′08″ |
| | F18X | 340°33′09″ |
| | F16X | 22°57′47″ |
| | F13X | 76°40′42″ |
| | F12X | 134°54′02″ |
| | F11X | 233°30′32″ |
| F18X | F19X | 29°51′45″ |
| | F16X | 124°09′50″ |
| | F10X | 160°33′09″ |
| | F8X | 213°39′29″ |
| | F17X | 277°50′02″ |
| F19X | F21X | 66°56′17″ |
| | F20X | 123°33′59′ |
| | F16X | 171°12′53″ |
| | F18X | 209°51′45″ |

TABLE 6.—*Azimuths to triangulation stations*—Continued

| Station occupied | Station observed | Azimuth |
|---|---|---|
| F16X | F19X | 351°12′53″ |
| | F20X | 36°39′02″ |
| | F15X | 84°10′25″ |
| | F14X | 112°26′21″ |
| | F13X | 173°20′41″ |
| | F10X | 202°57′47″ |
| | F18X | 304°09′50″ |
| | F19X | 351°12′53″ |
| F13X | F14X | 60°09′19″ |
| | F12X | 166°17′56″ |
| | F10X | 256°40′42″ |
| | F16X | 353°20′41″ |
| F14X | F12X | 205°21′28″ |
| | F13X | 240°09′19″ |
| | F16X | 292°26′21″ |
| | F15X | 16°06′59″ |
| F21X | F24X | 63°52′50″ |
| | F22X | 109°59′00″ |
| | F20X | 175°02′35″ |
| | F19X | 246°56′17″ |
| F20X | F21X | 355°02′35″ |
| | F22X | 51°43′08″ |
| | F15X | 168°13′12″ |
| | F16X | 216°39′02″ |
| | F19X | 303°33′59″ |
| | F21X | 355°02′35″ |
| F15X | F14X | 196°06′59″ |
| | F16X | 264°10′25″ |
| | F20X | 348°13′12″ |
| | F22X | 23°25′51″ |
| F22X | F15X | 203°26′51″ |
| | F20X | 231°43′08″ |
| | F21X | 289°59′00″ |
| | F24X | 341°34′41″ |
| | F23X | 23°10′03″ |
| F24X | F25X | 05°09′59″ |
| | F23X | 68°45′21″ |
| | F22X | 161°34′41″ |
| | F21X | 243°52′50″ |
| F25X | F27X | 44°07′21″ |
| | F23X | 121°15′21″ |
| | F24X | 185°09′59″ |
| F23X | F22X | 203°10′03″ |
| | F24X | 248°45′21″ |
| | F25X | 301°15′21″ |
| | F27X | 06°06′56″ |
| F27X | F23X | 186°06′56″ |
| | F25X | 224°07′21″ |
| | F29X | 359°08′39″ |
| | F28X | 22°07′33″ |
| F28X | F27X | 202°07′33″ |
| | F29X | 247°42′49″ |
| | F31X | 357°43′12″ |
| | F30X | 37°14′07″ |

TABLE 6.—*Azimuths to triangulation stations*—Continued

| Station occupied | Station observed | Azimuth |
|---|---|---|
| F29X | F31X | 20°07′57″ |
| | F28X | 67°42′49″ |
| | F27X | 179°08′39″ |
| F31X | F30X | 128°47′33″ |
| | F28X | 177°43′12″ |
| | F29X | 200°07′57″ |
| F30X | F28X | 217°14′07″ |
| | F31X | 308°47′33″ |

A new triangulation net was established at the approximate high-water elevation and tied to the Fairchild triangulation net (fig. 3). The new triangulation net was necessary in order to establish a horizontal reference system with which to correlate the 1968 survey with the Fairchild base map.

The new triangulation station network and the lines, or courses, to be sounded were plotted on an overlay of the base map. The azimuths of the lines to be sounded were determined from the overlay and recorded for use in the field.

The horizontal location of the boat in which the sonic sounder was mounted was determined by a transitman located on shore directing the boat operator, by two-way radio, on the predetermined azimuth. A standard navigational sextant (fig. 4) was used to fix the position of the boat on the line being sounded (fig. 5).

The fathometer chart was marked by the sextant operator pressing the remote control switch mounted on the sextant (fig. 6).

The notekeeper recorded the angle observed by the sextant operator and a fix number on the field notes (fig. 7). The fix numbers were also recorded on the fathometer chart (fig. 6). The distance from shore was estimated and recorded for the first and last sextant angle observed.

An alternate method using two transits to locate the position of the boat was used (fig. 8). The sextant operator assumed the duties of the second transitman. The transit was located on shore to observe intersecting angles over the entire length of the line being sounded. It was necessary to establish temporary triangulation stations for this purpose when the intersecting angles could not be observed over the entire length of the line being sounded from the previously established triangulation stations.

Two-way radios were used by the first transitman to direct the boat operator along the selected course. The second transitman and notekeeper in the boat were in radio communication; however, a different frequency was used to prevent confusing the commands given by the two transitmen, boat operator and fathometer operator-notekeeper.

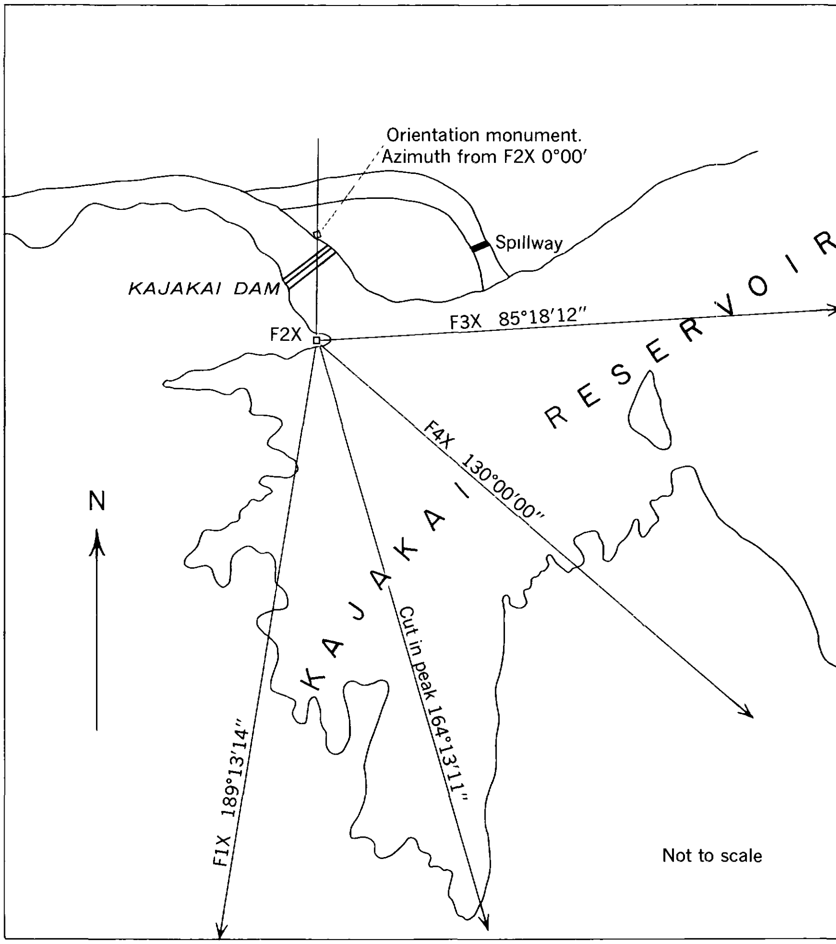



FIGURE 3.—Sketch map of Kajakai Reservoir showing azimuth from F2X (triangulation station 1953 Fairchild survey) to orientation monument established for 1968 hydrographic and sedimentation survey.

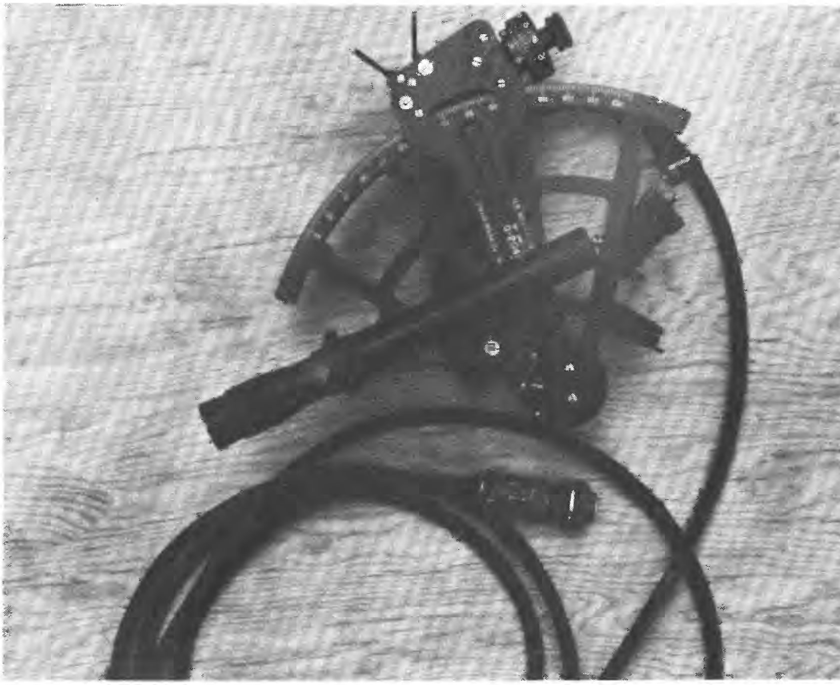


FIGURE 4.—Standard navigational sextant.

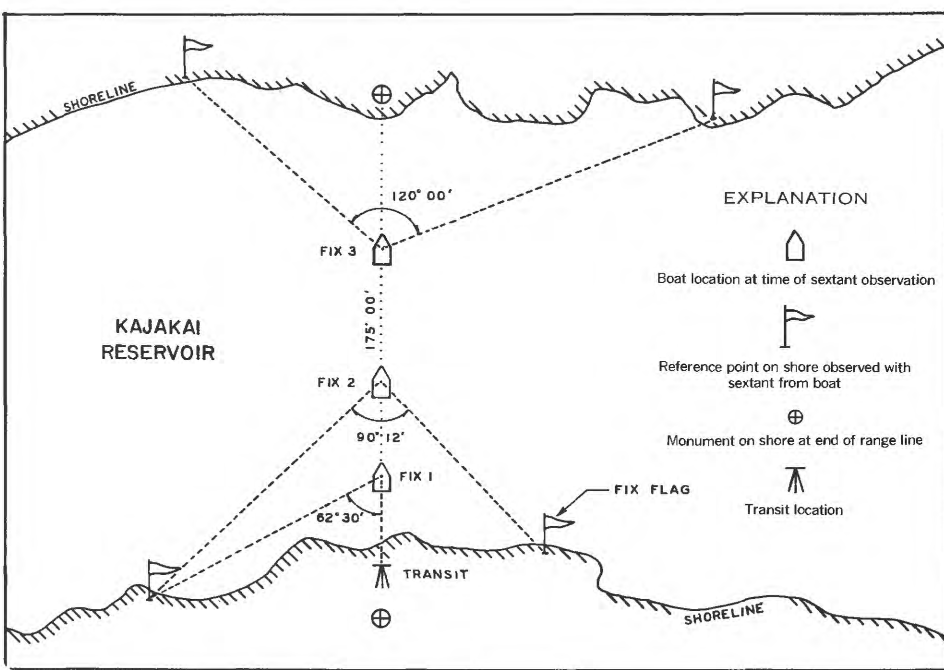



FIGURE 5.—Sketch map illustrating position fix by sextant.

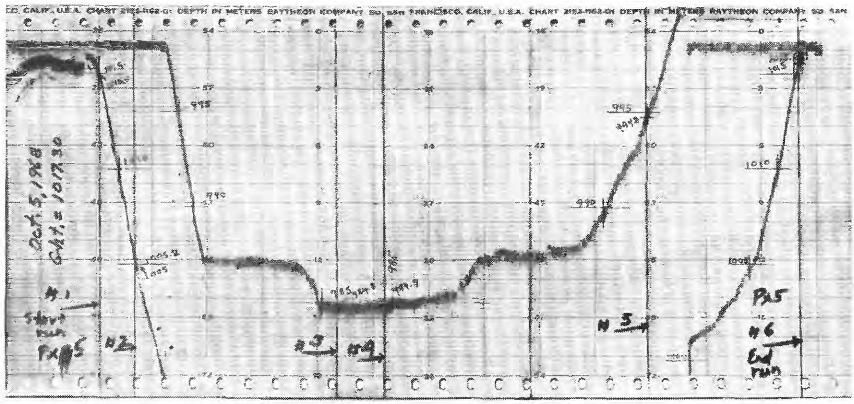



FIGURE 6.—Fathometer chart for sediment range line 12–12 cross section.

Coordinating the time of the first and last fix marked on the fathometer chart and the observation of the intersecting angle by the second transitman was accomplished by the fathometer operator giving the command by radio. The intermediate fix marks on the chart were made by the fathometer operator on command from the second transitman. The intersecting angles observed by the second transitman were transmitted by radio to the notekeeper-fathometer operator to record on the field notes (fig. 9).

Figures 10 through 13 are photographs of other phases of fieldwork.

## VERTICAL CONTROL

A continuous water-level recorder installed at the outlet tower provided a continuous record of the reservoir level. The water surface was determined by levels from selected Fairchild triangulation stations and compared with the level recorded at the outlet tower to determine the slope throughout the reservoir. The slope of the reservoir water surface was determined to be negligible between sediment range line 21–21 and the tower. Corrections were applied to compensate for water-surface slope upstream from this range line.

Lake: Kajakai

Date: Sept. 20, 1968

Location: ⊼ at 5R

Gage: 1018.40

Sheet 12 of 22 sheets

| Line azimuth | Fix | Sextant angle | Target | Distance to/from shore | Elevation at fix | Contour locations at proportioned distance between sextant fixes |
|---|---|---|---|---|---|---|
| 5R to 5L | 1 | 44°59' | 6L-5L | 2 m | 1016.2 | |
| 175°00' | 2 | 60°56' | 10L-5L | | 998.9 | 1015/.07 1010/.21 1005/.34 1000/.94 |
| | 3 | 63°00' | 10L-5L | | 975.8 | 995/.29 990/.33 985/.44 980/.53 |
| | 4 | 75°00' | 5R-9 | | 974.3 | 975/.38 |
| | 5 | 67°00' | 5R-9 | | 975.4 | 975/.52 |
| | 6 | 58°53' | 5R-6R | 3 m | 1016.7 | 980/.07 985/.10 990/.51 995/.70 |
| | | | | | | 1000/.78 1005/.86 1010/.92 1015/.99 |

FIGURE 7.—Example of field notes and office compilation sheet for determination of position fix by sextant.

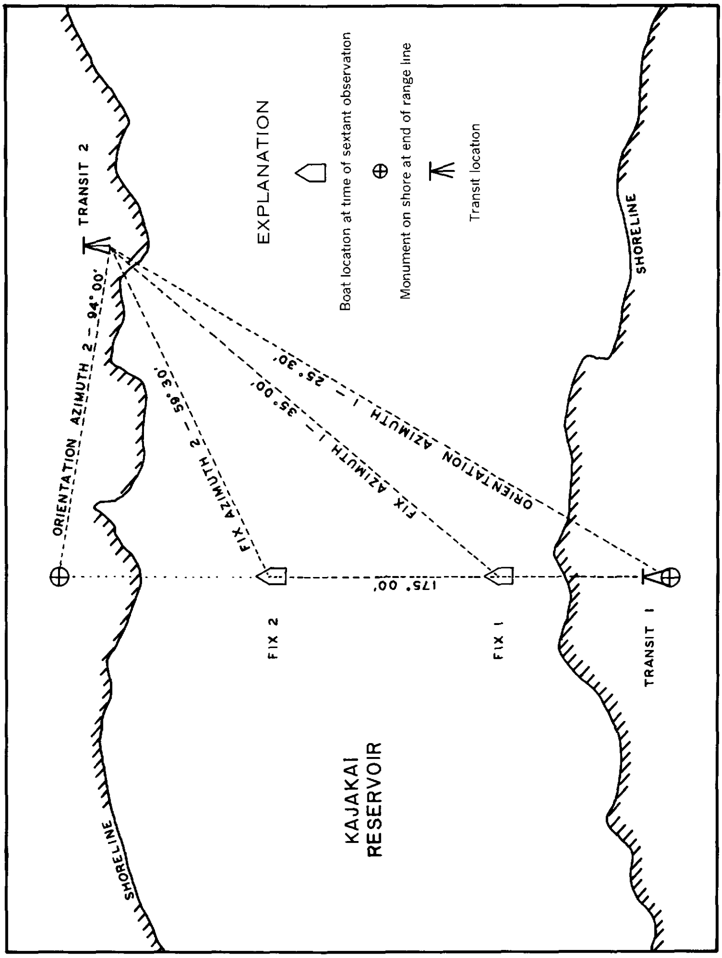



FIGURE 8.—Sketch map illustrating position fix by 2-transit method.

Lake: Kajakai  Date: Sept. 20, 1968

Location: ⊼ No. 2 at 4L  Gage: 1018.40  Sheet 12 of 22 sheets

| Line azimuth | Fix | Azimuth to fix | Distance to/from shore meters | Elevation at fix meters | Contour locations at proportioned distance between sextant fixes |
|---|---|---|---|---|---|
| 5R to 5L | 1 | 40°28' | 2 | 1016.2 | |
| 175°00' | 2 | 42°00' | | 998.9 | 1015/.07 1010/.21 1005/.34 1000/.94 |
| | 3 | 44°00' | | 975.8 | 995/.29 990/.33 985/.44 980/.53 |
| | 4 | 57°00' | | 974.3 | 975/.38 |
| | 5 | 70°00' | | 975.4 | 975/.52 |
| | 6 | 84°32' | 3 | 1016.7 | 980/.07 985/.10 990/.51 995/.70 |
| | | | | | 1000/.78 1005/.86 1010/.92 1015/.99 |

FIGURE 9.—Example of field notes and office compilation sheet for determination of position fix by 2-transit method.

FIGURE 10.—Transitman directing boat on a given azimuth.

FIGURE 11.—Boat with fathometer crew beginning sounder run.

FIGURE 12.—Triangulation transitman at F2X.

FIGURE 13.—Survey crew receiving training in transit operation.

## OFFICE PROCEDURE

The Fairchild maps were photographically transferred to a matte surface stable-base film. An overlay drafted on stable-base film was prepared for each map sheet.

The new triangulation net, location of the flags and sounding lines were plotted on the overlay. The fix locations on the sounding lines, as indicated in the field notes as sextant angles between targets (fig. 7) were plotted on the overlay by using a two-arm protractor. This method of horizontal positioning is based on the assumption that the boat is in line at the time the sextant angles are observed.

Errors in the observed angles or in the plotting of the angles were usually apparent when the proportionate distance between plotted fix locations were compared with the fix locations indicated on the fathometer chart. Minor variations in the proportionate distances were acceptable and were considered due to minor variations in boat speed.

Compilation of the data recorded on the fathometer chart was accomplished in three steps.

*Step 1.* The chart (fig. 6) was visually inspected to determine if the zero setting as indicated on the chart remained in the correct position and if the fathometer operator switched to the correct depth range without a loss of record and maintained the gain control at the proper level. The field notes were correlated with the fathometer chart and notations made on the chart indicating the reservoir level at the time the soundings were obtained, and the date the soundings were made.

*Step 2.* The depths indicated on the chart were converted to elevations by using a graphical sliding scale placed on the chart in a position to relate the gage height at the time the soundings were made to the zero depth as indicated on the chart. The depth indicated by the chart record was converted to elevation by the sliding scale.

The elevation at each fix mark and the position of each contour elevation to be transferred to the map were noted on the fathometer chart.

*Step 3.* The elevations at each fix and the contour locations at proportionate distances between fixes were recorded on the field note sheet.

A variable scale, or a 10-point divider, was used to determine the contour locations at proportionate distances between fixes. The data recorded opposite fix 2 (figs. 7, 9), 1015/.07, 1010/.21, 1005/.34, 1000/.94, indicated that the 1,015-m contour was located 0.07 of the distance between fix 1 and fix 2 and the 1,010-, 1,005-, and 1,000-m contours were at the proportional distances between fix 1 and fix 2 of 0.21, 0.34, and 0.94, respectively.

The proportionate distance between fixes, determined from the recorder chart for each contour location, was transferred to the overlay.

Where more definition of the under-water contours was required, additional lines to be sounded were plotted on the overlay and the azimuth determined.

## SEDIMENTATION

One of the objectives of the survey was to establish permanent sediment range lines which could be resurveyed at any later date to determine future rates of sediment deposition. Location of range lines was based on probable representativeness of the cross sections to the reach upstream and downstream. Cross-section areas of these range lines are related to capacity in adjacent reaches. Cross sections of all sediment range lines are shown in figures 14 through 24.

Figure 25 shows the relation between the original streambed, or thalweg, profile and the 1968 profile as determined by this survey. Locations of sediment range lines are indicated. Range lines were established uplake only to the point where the current and original streambed elevations coincided. This point was determined to be at about elevation 1,025 m and about 45,000 m thalweg distance from the dam.

Depths of deposited material reached a maximum at about range line 14–16 (fig. 21) where the average depth of sediment in the cross section was 18.5 m. The leading edge of the deposition was at cross section 11–11 (fig. 19). The most active area of deposition was in the delta area formed where the river enters the reservoir. Position of this active delta is governed by reservoir elevation and river discharge. The rate of movement of the delta becomes more rapid when the reservoir elevation is low and river discharge is high. During that period of the year when river discharge becomes significantly greater than releases, the reservoir elevation rises rapidly, and the delta movement into the lake slows as more deposition occurs at the higher elevations upstream. As the elevation of the reservoir drops, a part of the sediment deposited in the upstream reaches is carried further into the reservoir. The two small deltas at elevations 1,010 and 1,015 m (fig. 25) are the relatively recent effects of the latter phenomena.

Movement of the leading edge of the deposit, in that reach between range lines 12–12 and 14–15, will not advance appreciably until the secondary deltas between range lines 19–19 and 21–21 are moved to range line 14–15. This may occur rapidly if the water level in the reservoir is drawn down to an elevation of 1,005 m or less for 2 or more years in succession. However, if the minimum reservior elevation is not drawn down below about 1,015 m for a number of years, delta encroachment to the narrows will be slower because the sediments would be deposited as berms in the upstream river channel between range line 21–21 and some point upstream of where the current profiles coincide.

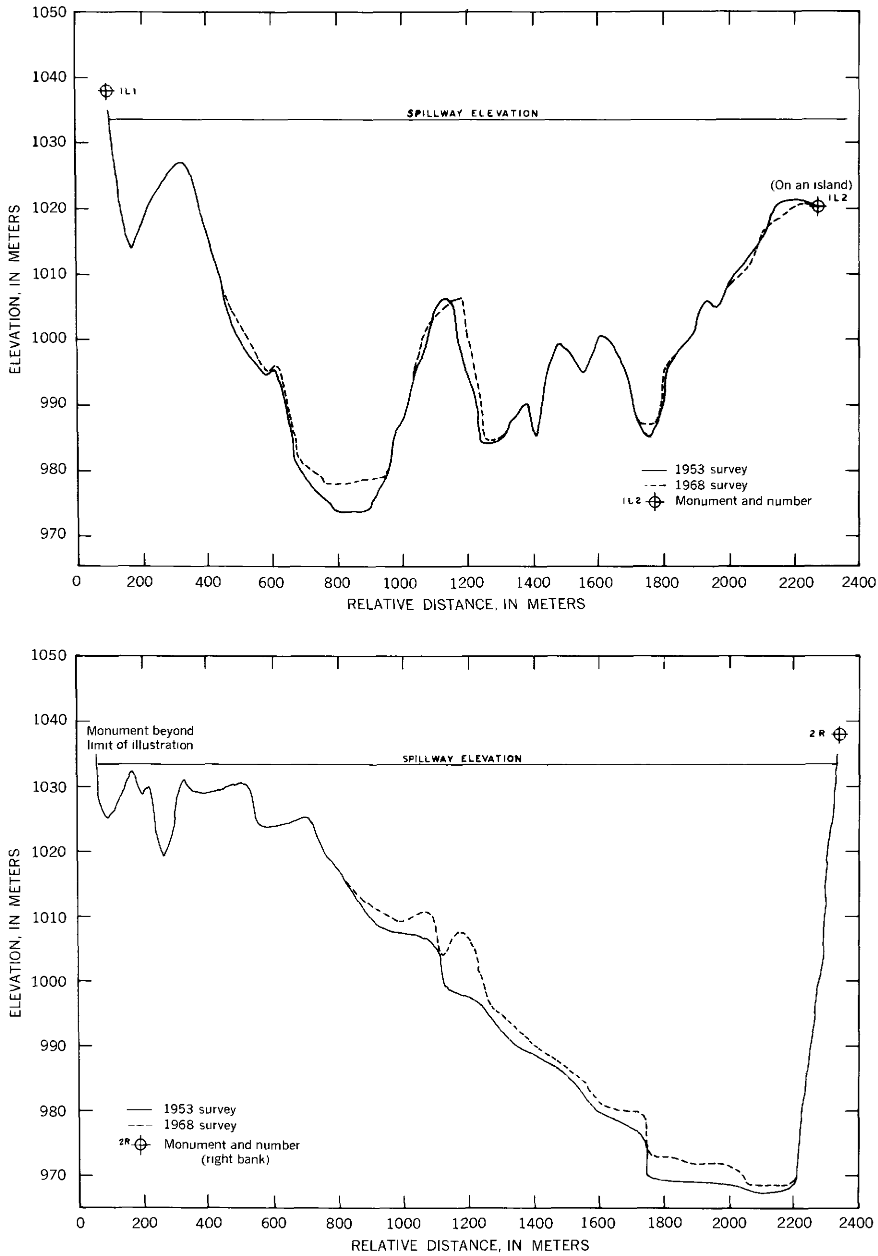



FIGURE 14.—Cross sections of sediment range lines 1–1 and 2–2, Kajakai Reservoir.

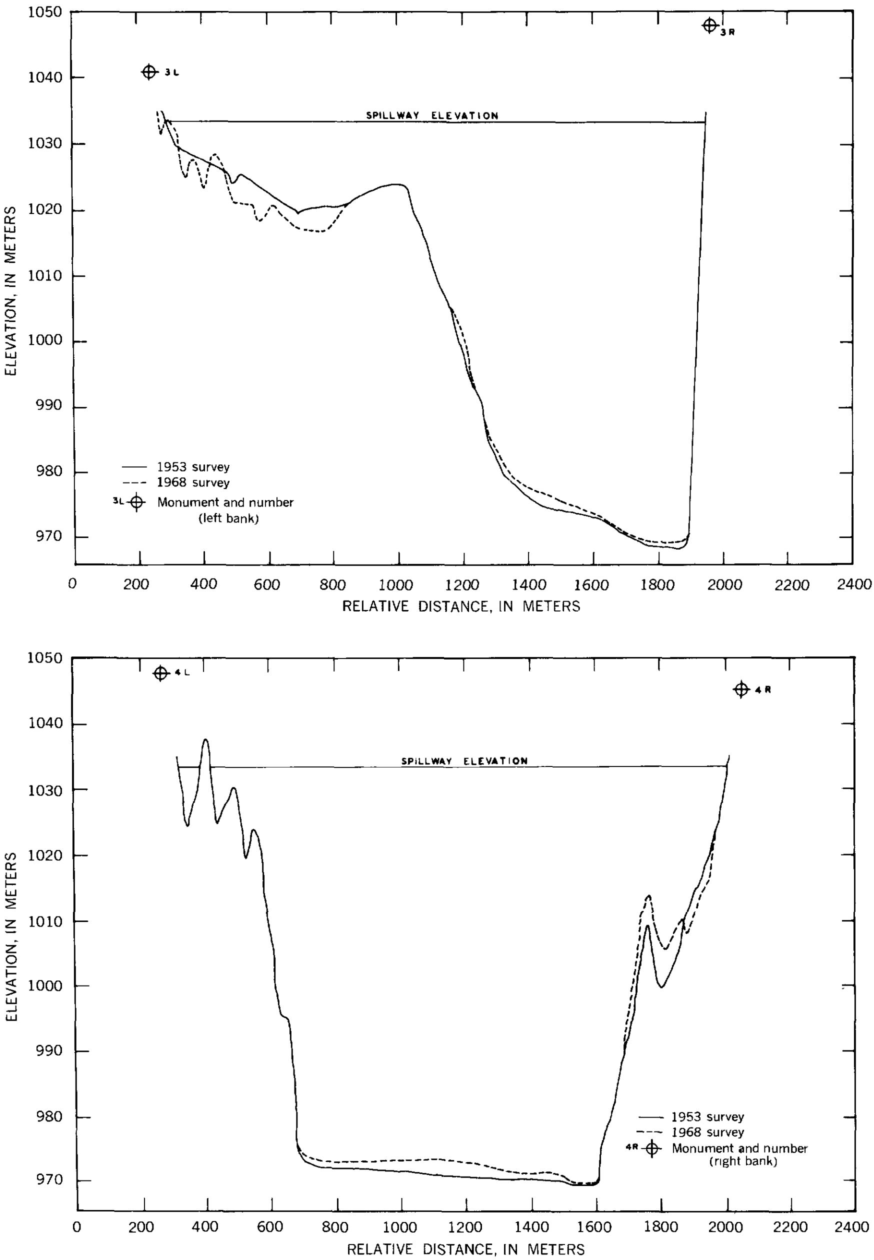
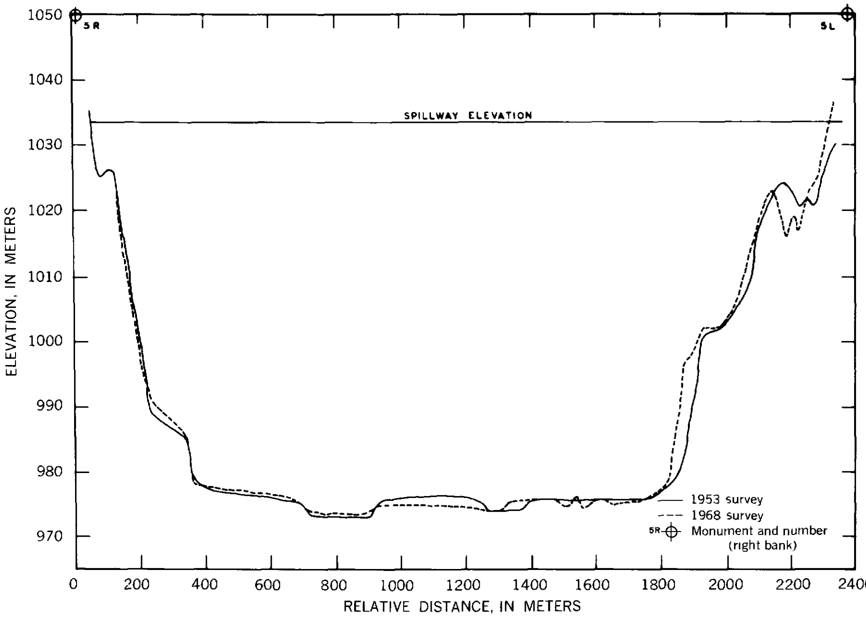



FIGURE 15.—Cross sections of sediment range lines 3–3 and 4–4, Kajakai Reservoir.



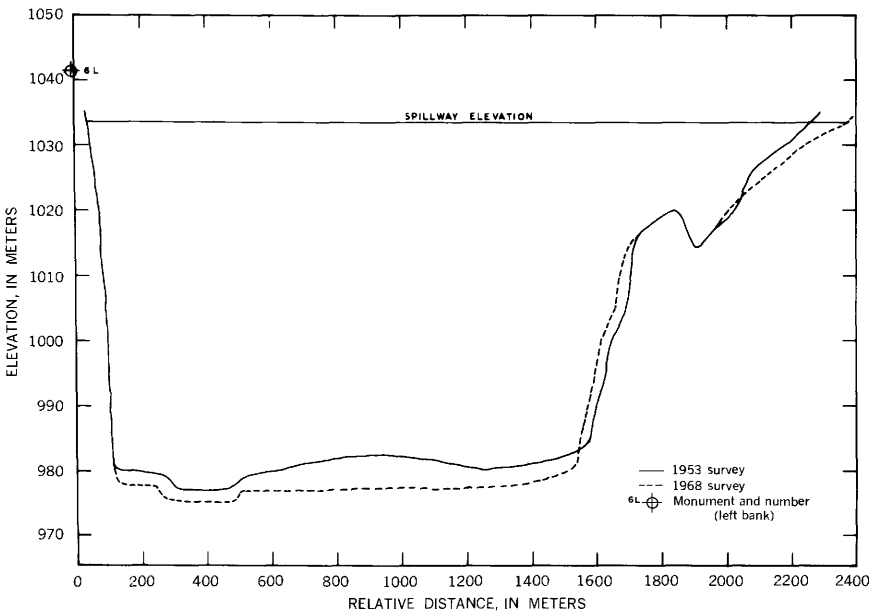
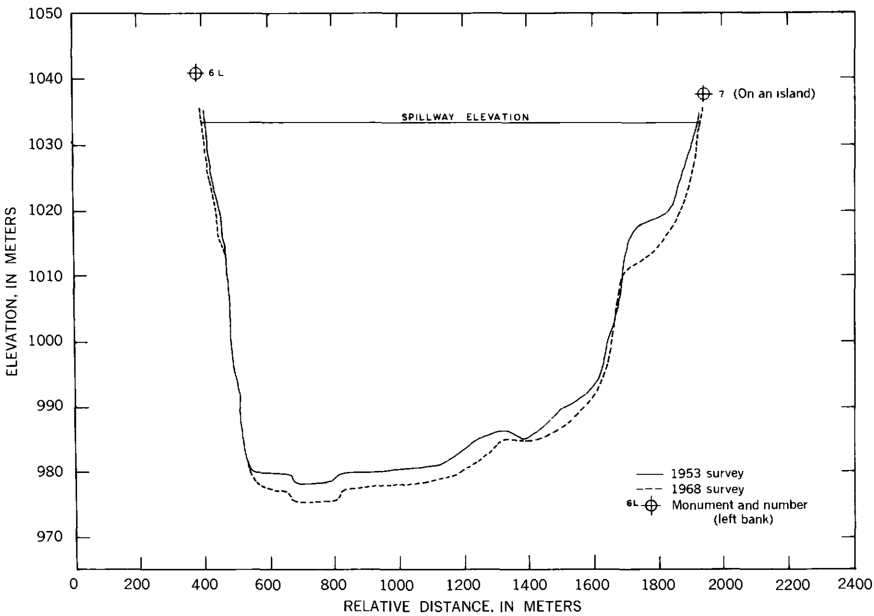




FIGURE 16.—Cross sections of sediment range lines 5–5 and 6–6, Kajakai Reservoir.



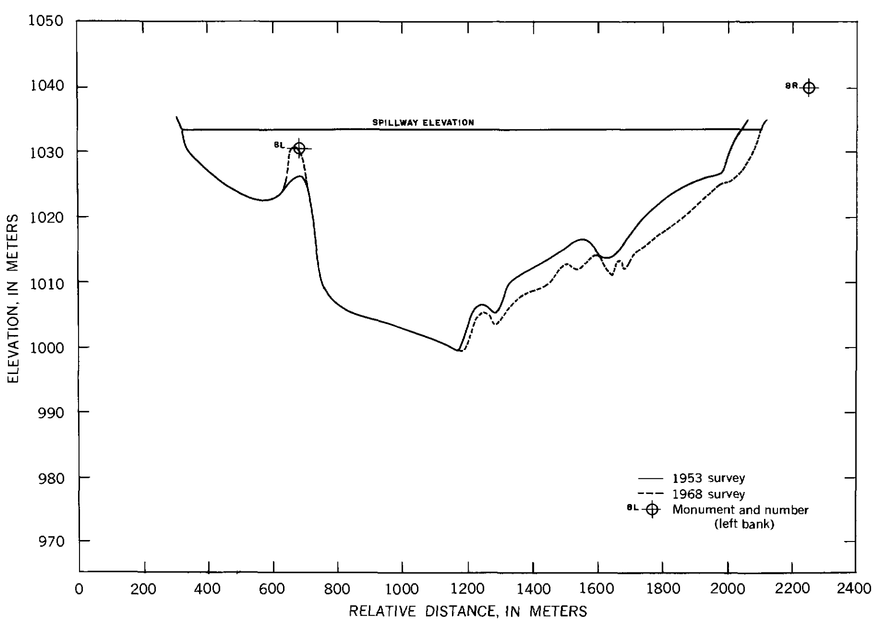




FIGURE 17.—Cross sections of sediment range lines 6–7 and 8–8, Kajakai Reservoir.

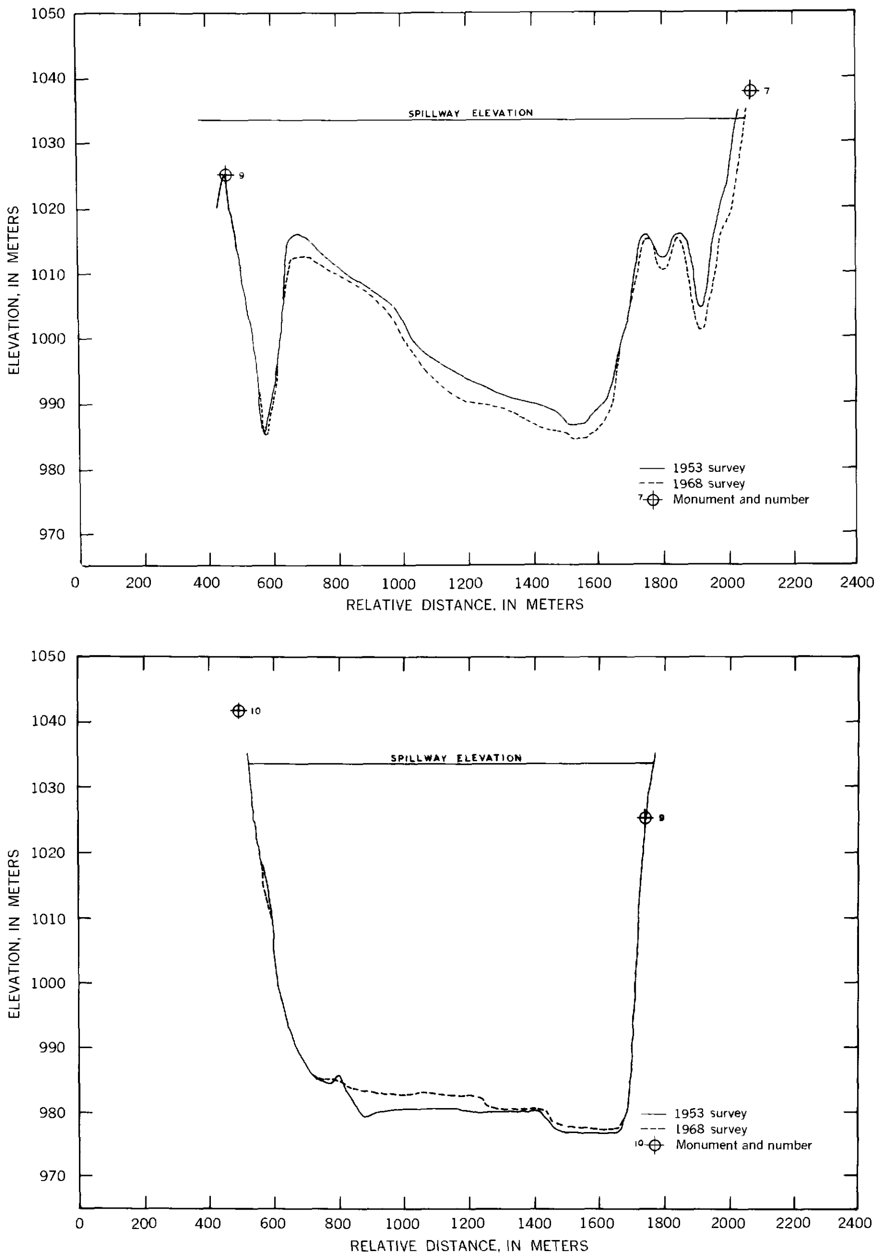



FIGURE 18.—Cross sections of sediment range lines 9–7, and 9–10, Kajakai Reservoir.

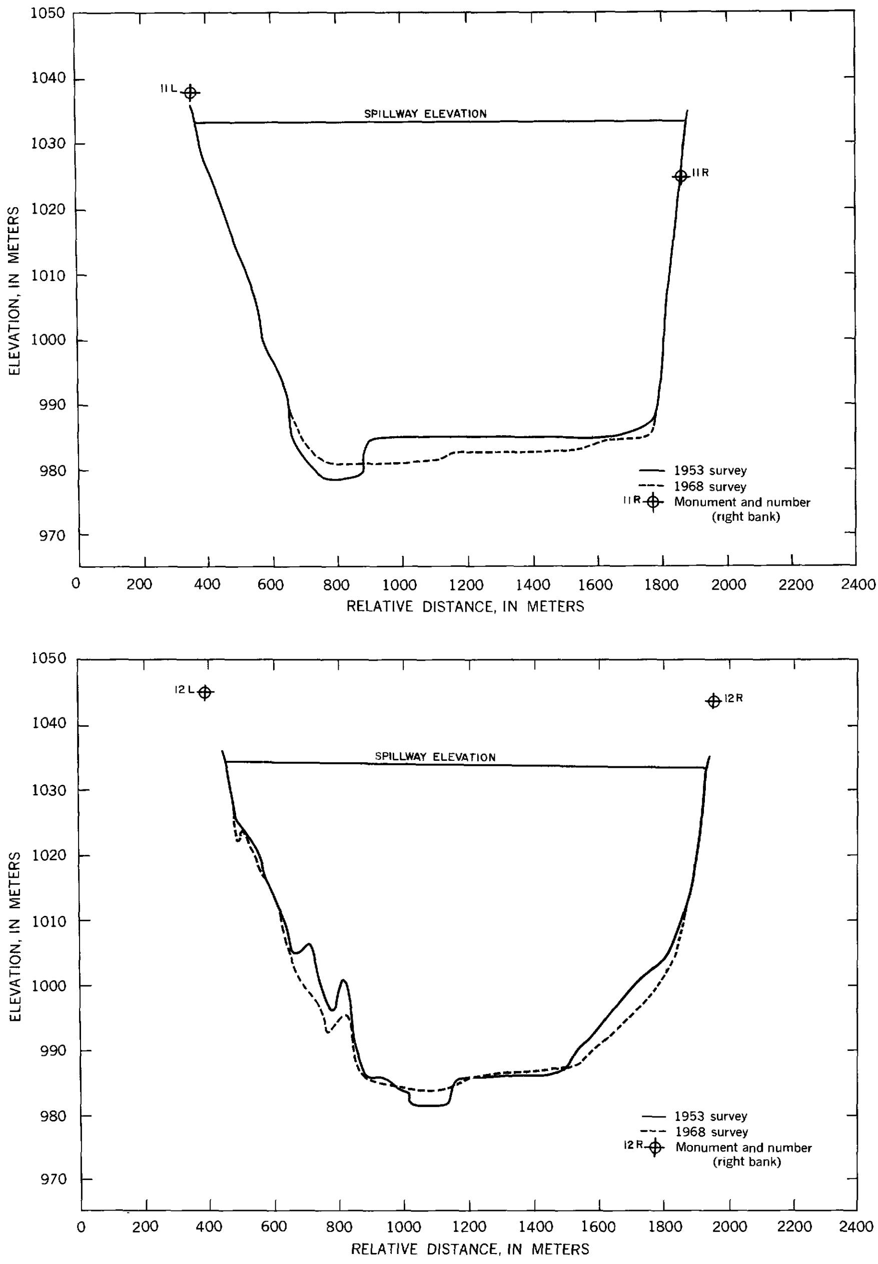



FIGURE 19.—Cross sections of sediment range lines 11–11 and 12–12, Kajakai Reservoir.

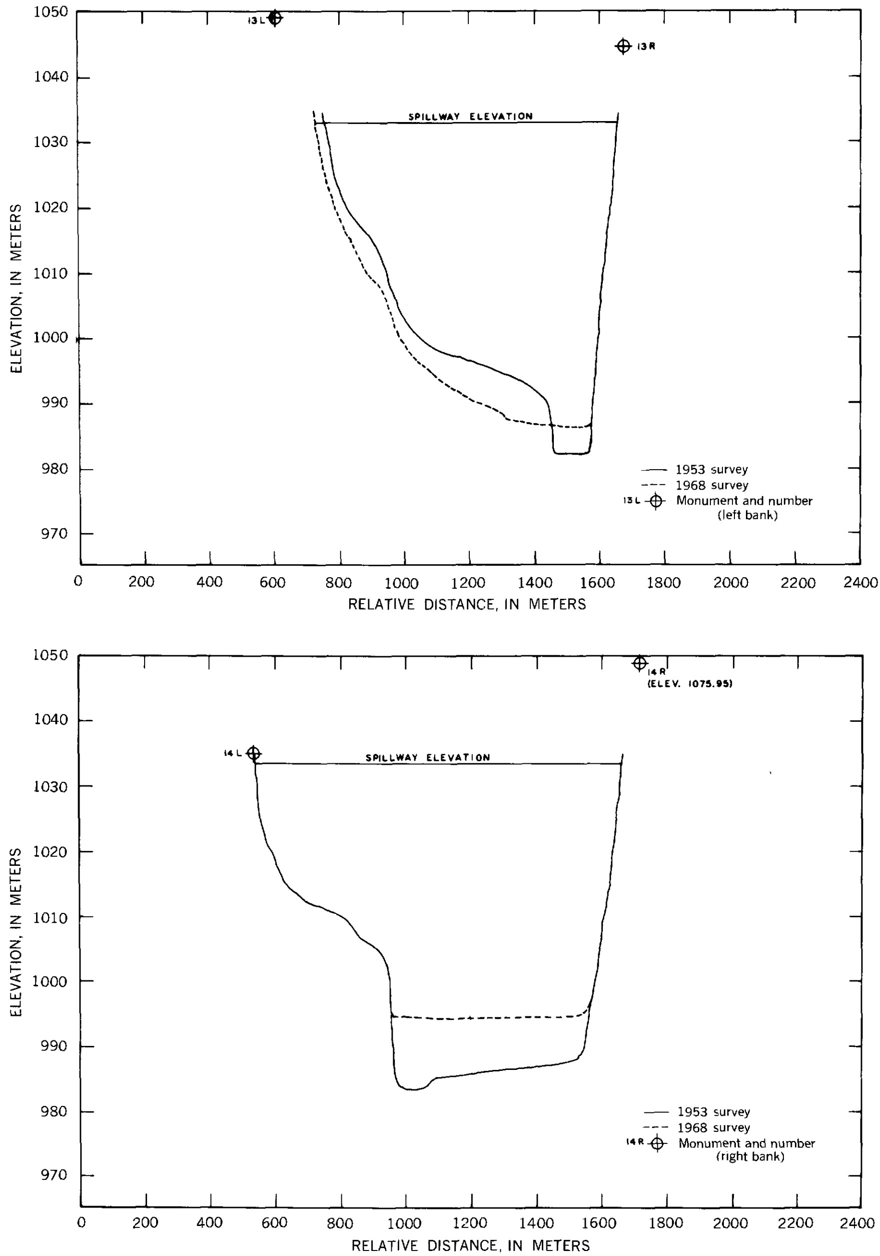



FIGURE 20.—Cross sections of sediment range lines 13–13 and 14–14, Kajakai Reservoir.

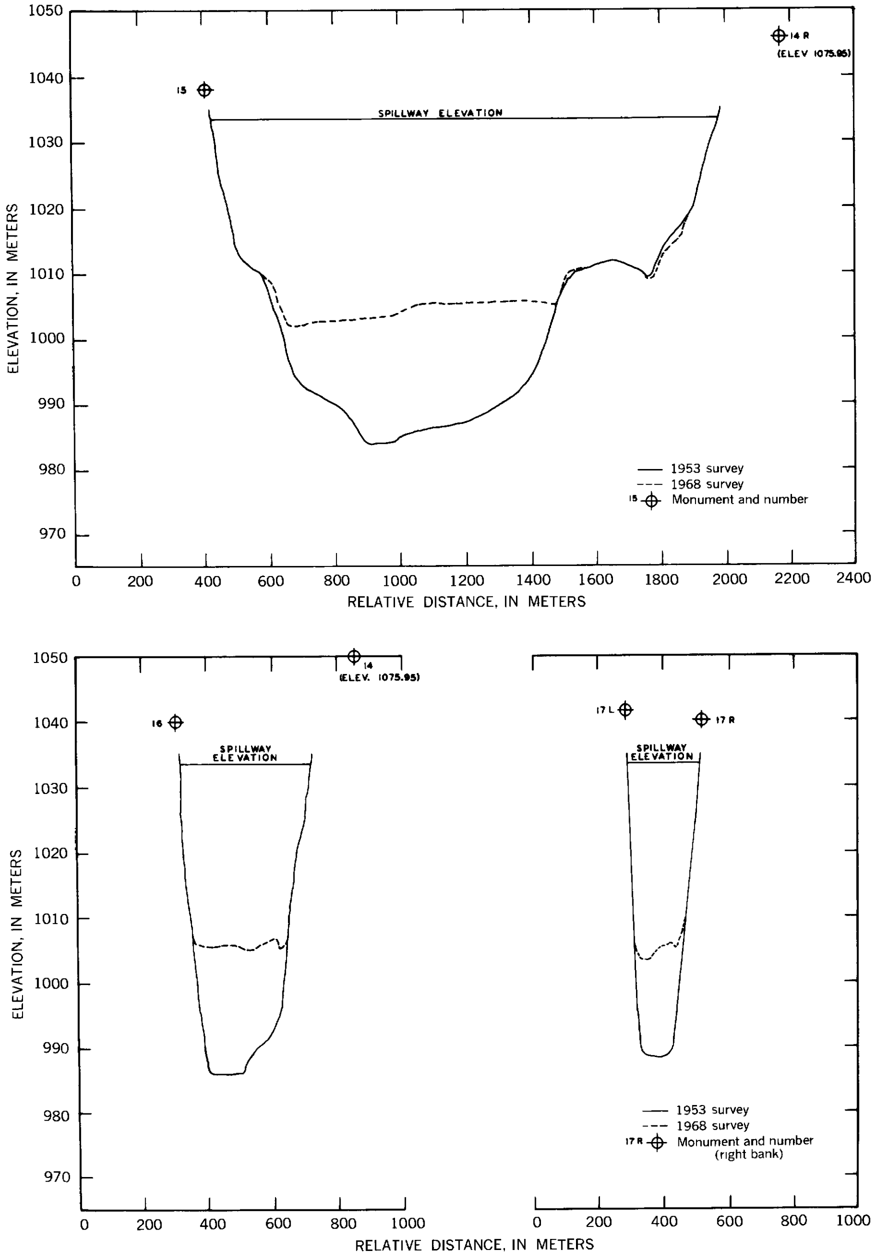
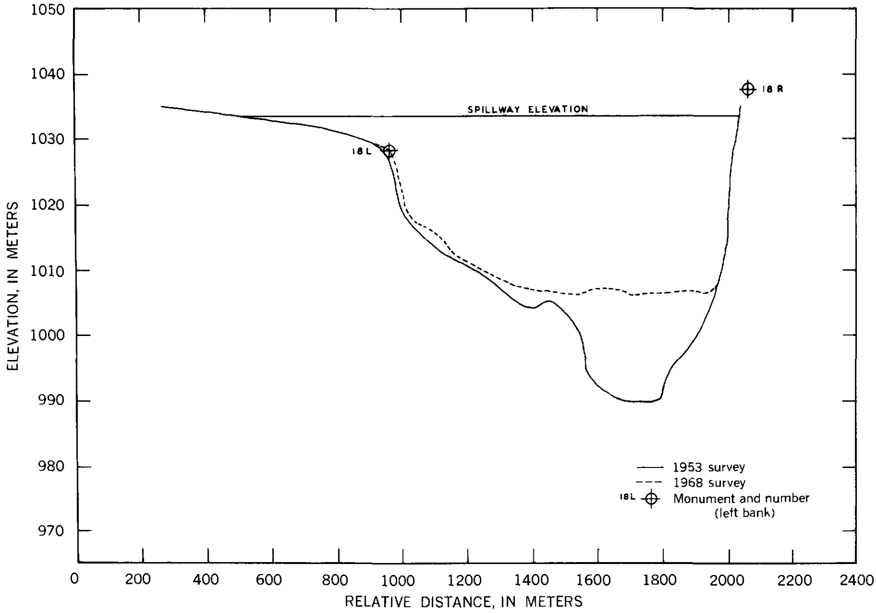



FIGURE 21.—Cross sections of sediment range lines 14–15, 14–16, and 17–17. Kajakai Reservoir.



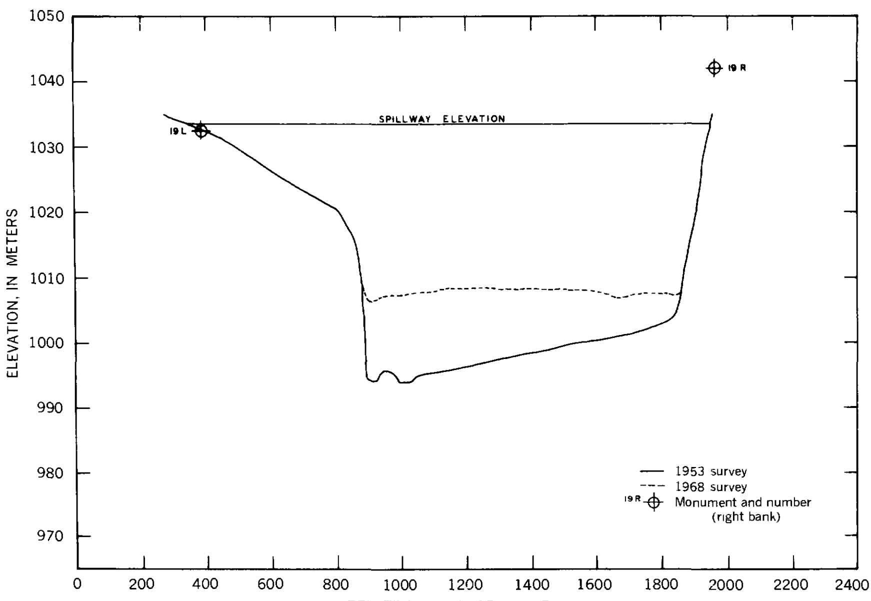




FIGURE 22.—Cross sections of sediment range lines 18–18 and 19–19, Kajakai Reservoir.

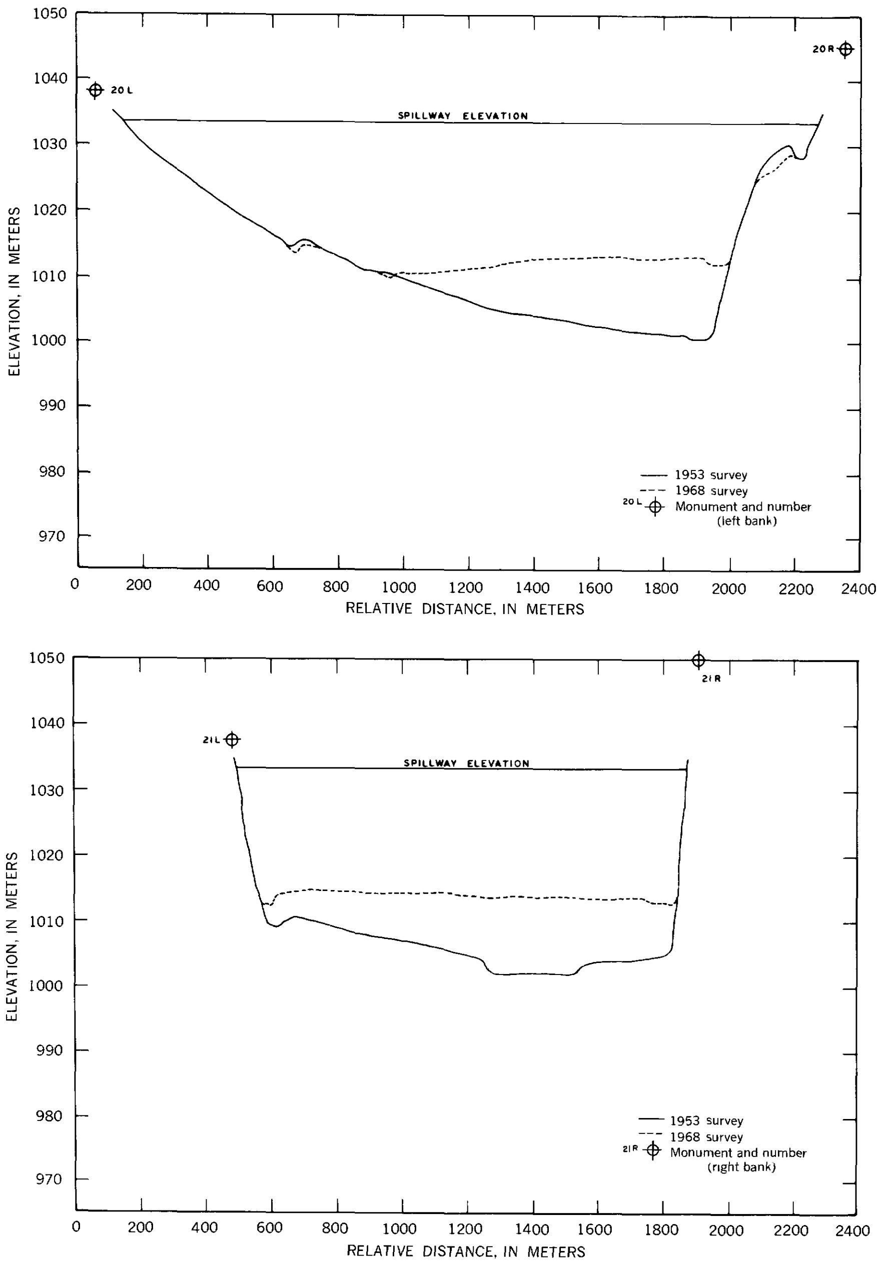



FIGURE 23.—Cross sections of sediment range lines 20–20 and 21–21, Kajakai Reservoir.

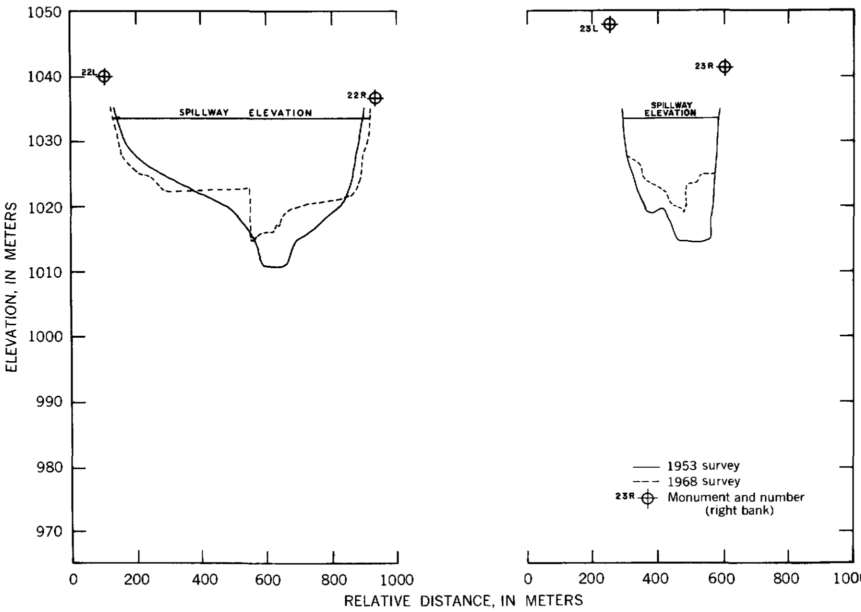



FIGURE 24.—Cross sections of sediment range lines 22–22 and 23–23, Kajakai Reservoir.

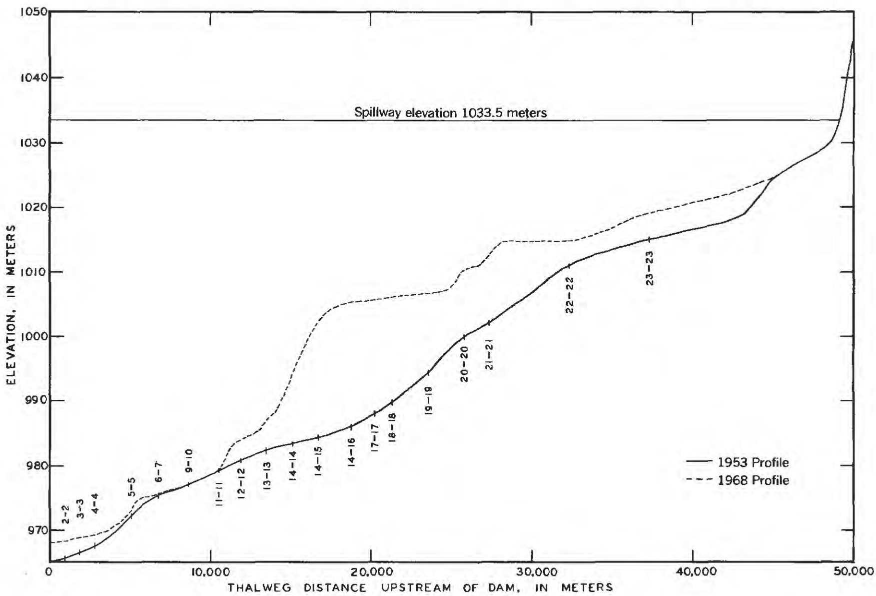



FIGURE 25.—Profile of sediment distribution along Helmand River channel through Kajakai Reservoir.

Samples of the deposited lake-bed material were obtained with a Foerst bed-material sampler. The sampler was raised and lowered by means of a U.S. B–54 sounding reel powered by a 12-volt power unit. Reel, power unit, and sampler were attached to a simple pipe crane which was mounted on the boat (fig. 26). Samples were collected throughout the reservoir, from the river at the confluence and in the river channel upstream of the reservoir. Core samples of the sediment deposits in the reservoir were not obtained because of funds and time limitations.

Samples of the lake-bed material were not analyzed for particle-size distribution other than to determine the percentage passing a 63 micron sieve. These samples were virtually all identical in composition, 99.4 percent limestone clays and silts and 0.6 percent coarser than 63 micron. Estimated density of these fine-material surface deposits was 30–50 (lb per cu ft), or 480–800 (kg per cu m). Apparently, much of this material originates from the banks of the reservoir, being sorted and washed out of the natural soils by wave action.

Samples taken from the area of the river confluence and the river channel upstream were analyzed for particle-size distribution by wet-sieve method. Results of these analyses are given in table 7.

FIGURE 26.—Foerst bed-material sampler in use.

TABLE 7.—*Particle-size analyses of bed-material samples of Helmand River*

| Location of sample | Percent finer than indicated size (microns) | | | |
|---|---|---|---|---|
| | 63 | 125 | 250 | 500 |
| Confluence with river at elev 1,015 m | 75. 3 | 98. 6 | 99. 8 | 100 |
| Do | 77. 5 | 98. 8 | 99. 9 | 100 |
| Dry sample deposited about 1,600 m upstream of range line 23–23 | 11. 6 | 93. 9 | 99. 9 | 100 |
| River channel at elev 1,026 m | 4. 2 | 63. 1 | 99. 2 | 100 |

Upstream of sediment range line 23–23, the bed of the river channel consists largely of rock and gravel with only minor deposits of sands and silts. Virtually all material finer than about 0.5 millimeter is carried in suspension into the upper reaches of the reservoir. During periods when the reservoir elevation is at, or above, spillway elevation, river discharge is also high, and most of the sands carried in suspension are deposited in the old river flood plain (fig. 27). To date, these deposits appear to be relatively insignificant in terms of reducing the useful capacity. Measurement of the volumes of sediment deposited in the reservoir area upstream from sediment range line 23–23 was not undertaken in the 1968 survey. Figure 24 is an illustration of typical cross sections in the upper reservoir reaches where berms of fine sand and clay are found in the flood-plain areas.

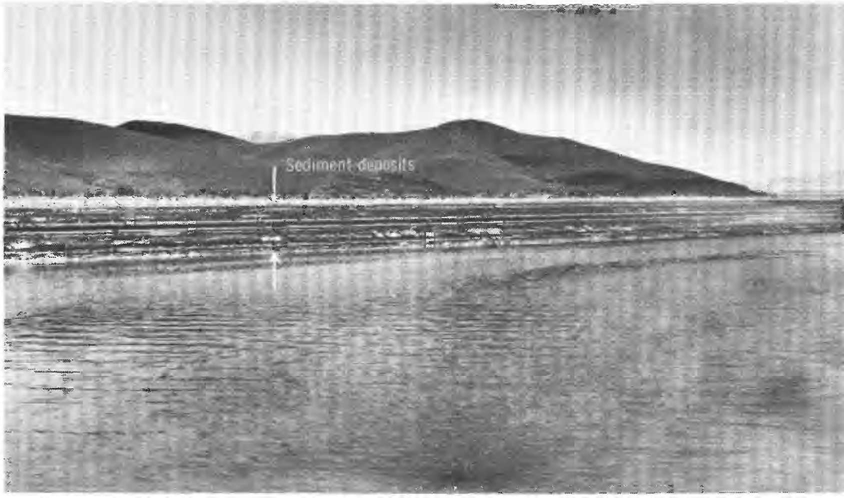



FIGURE 27.—Sediment deposited along river flood plain near range line 22–22.

## FUTURE SEDIMENTATION

As shown in table 1, the results of the 1968 survey indicated a loss in capacity of 7.0 percent at the spillway elevation 1,033.5 meters. Owing to discrepancies found in several original contours, however, this indicated loss in capacity cannot be used strictly as a loss due to sediment deposition. Refinement of original contours resulted in an increase in capacity in those reaches between range lines 5–5 and 13–13 of about 13,600 acre-feet (figs. 16–18). Applying this correction to the original capacity of 1,495,000 acre-feet at spillway elevation results in a loss due to sediment deposition of 7.8 percent, or a sediment deposition of 117,700 acre-feet during the first 15 years of storage. This was an average annual loss in capacity below spillway elevation of about 7,800 acre-feet per year. Assuming an average sediment density of 50 lb per cu ft, the average annual sediment inflow was about 8,500,000 tons per year.

A flow-duration curve (fig. 28) based on data given in table 8 shows that the average annual inflow to Kajakai Reservoir for the period 1953–1965 was 5,200,000 acre-feet. Assuming that inflow characteristics do not change appreciably over the next 15-year period, it is probable that the sediment inflow will average about 8,500,000 tons (7,700,000 metric tons) per year during that period. Future rate of change in capacity, however, may vary considerably if reservoir operation is changed, owing to an increase in rate of release for irrigation or power production, or if the timing of releases is changed. Sediment deposits will gradually become compacted over the years as more sediment is deposited over earlier deposits. Rate of compaction of sediment can be estimated only if data are available on size of the deposited material. These data are not available and cannot be obtained without core samples of the entire depth of deposit.

Samples that were obtained indicate that the greater percentage of the deposited material consists of extremely fine material at densities of 30–50 pounds per cubic foot (480–800 kg per cu m). These deposits will compact under water over the years. Also, if the water level in the reservoir were to be lowered to an elevation of 1,005 m, or lower, each year for a number of years, the fine sediments at elevations about 1,005 m would compact more rapidly because of alternate wetting and drying.

To estimate future volumes of sediment deposition based on an average annual fill rate of 7,800 acre-feet determined after 15 years might be conservative. An experiment to determine reduction in volume due to drying was performed during the survey on material sampled from the lake bed. When the samples were thoroughly dried,

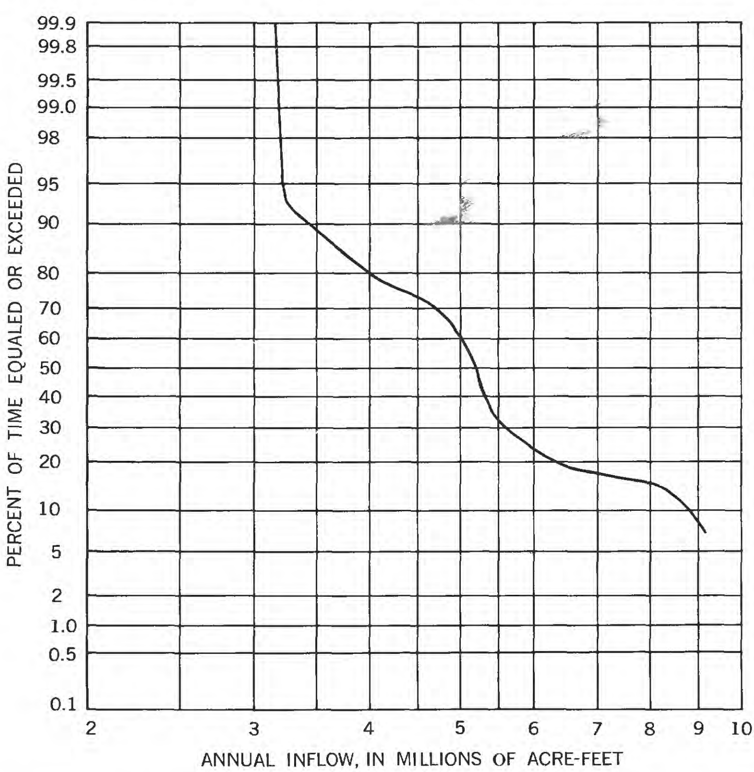



**FIGURE 28.—Flow-duration curve of annual inflow to Kajakai Reservoir, 1953–65 water years.**

TABLE 8.—*Summary of annual inflow to Kajakai Reservoir*

| Water year | Helmand River near Dehraout (acre-feet) | Tirin River at Dehraout (acre-feet) | Total (acre-feet) |
|---|---|---|---|
| 1953 | 3, 896, 000 | 260, 000 | 4, 156, 000 |
| 1954 | 4, 932, 000 | 591, 000 | 5, 523, 000 |
| 1955 | 3, 575, 000 | 221, 000 | 3, 796, 000 |
| 1956 | 5, 295, 000 | 657, 000 | 5, 952, 000 |
| 1957 | 8, 589, 000 | 470, 000 | 9, 059, 000 |
| 1958 | 4, 949, 000 | 302, 000 | 5, 251, 000 |
| 1959 | 4, 548, 000 | 455, 000 | 5, 003, 000 |
| 1960 | 4, 411, 000 | 324, 000 | 4, 735, 000 |
| 1961 | 4, 591, 000 | 544, 000 | 5, 135, 000 |
| 1962 | 2, 999, 000 | 176, 000 | 3, 175, 000 |
| 1963 | 3, 119, 000 | 182, 000 | 3, 301, 000 |
| 1964 | 4, 784, 000 | 371, 000 | 5, 155, 000 |
| 1965 | 7, 171, 000 | 704, 000 | 7, 875, 000 |
| 1966 | 3, 110, 000 | | |

the average percent reduction in volume was 53 percent. This value was used as a basis for estimating reduction in volume of deposits due to alternate wetting and drying.

Based on data that have been presented in this report, an estimated rate of compaction, and the assumption that hydrologic conditions in the reservoir drainage area do not change appreciably, the principal delta front will reach the irrigation outlet (about elev 968 m) in 40–45 years. At the end of this 40- to 45-year period, it is estimated that the reservoir capacity at spillway elevation will be reduced to about 1,200,000 acre-feet. It is recommended that a resurvey of sediment range lines be made at some time during the period 1973–75, especially if changes in reservoir operation are made during the next few years.

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