

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

SEDIMENTATION SURVEY
OF
ARROWROCK RESERVIOR
BOISE PROJECT, IDAHO

Sedimentation Section Report

HYDROLOGY DIVISION



BRANCH OF PROJECT PLANNING
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By

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Sedimentation Section
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Introduction

This report presents the results of an investigation of reservoir sedimentation in Arrowrock Reservoir on the Boise River, near Boise, Idaho. Certain data relative to sedimentation below Arrowrock Dam are also presented. The objective of the investigation was to determine the effect of sedimentation on the above reservoir and on the design, operation, and useful life on proposed reservoirs to be built by the Bureau of Reclamation, United States Department of the Interior; also the data obtained were to be used in flood control studies by the Forest Service, United States Department of Agriculture in evaluating the effects of erosion in the Boise National Forest. The investigation was carried out by the Sedimentation Section, Hydrology Division, Branch of Project Planning, Bureau of Reclamation, United States Department of the Interior, Denver, Colorado, in cooperation with the Intermountain Forest and Range Experiment Station, Forest Service, United States Department of Agriculture, Ogden, Utah, and the Portland District, Corps of Engineers, Department of the Army, Portland, Oregon, at the request of the Director, Intermountain Forest and Range Experiment Station, Ogden, Utah, and as part of the authorized program of the Bureau of Reclamation for obtaining required data for use as outlined above. The investigation was made under the authority of the Reclamation Act of 1902 and amendments thereto and under the Flood Control Act of June 22, 1946 (Public Law No. 738) as subsequently amended. Field investigations began August 18, 1947, and were finished December 5, 1947.

Acknowledgments

The Intermountain Forest and Range Experiment Station, United States Forest Service, Department of Agriculture, Ogden, Utah, under the direction of Mr. Reed Bailey, furnished excellent cooperation throughout the entire investigation, furnishing both office and field personnel, equipment and services. Volume weight and mechanical analyses of the sediment samples were made under the direction of Mr. Joe S. Adair, Geologist of the above office. Other services and valuable data pertaining to land cover, land use, soil groups, and erosion in Arrowrock drainage-area and sediment studies below Arrowrock Dam were furnished by Messrs. Henry Lobenstein and Marvin Rosa, United States Forest Service, Ogden, Utah.

Additional field personnel for the investigation was furnished by Colonel O. E. Walsh, District Engineer, Department of the Army, Portland District, Portland, Oregon.

Valuable data, including the original reservoir maps, boring logs, and services were furnished by Mr. George Carter, District Manager, Bureau of Reclamation, Boise, Idaho; also Purchasing Agents of his office, Messrs. A. S. Leicher and Nelson, were particularly helpful in

expediting the procurement of urgently needed equipment and supplies. Mr. William Ballard, Superintendent of Arrowrock Dam, furnished gage records and other services.

Mr. I. J. Matthews, District Manager, Bureau of Reclamation, Casper, Wyoming, assisted in the investigations by loan of personnel.

Acknowledgment is also made to Mr. R. J. Newell, Regional Director, Region 1, Bureau of Reclamation, Boise, Idaho, and his staff for their cooperation in the review of this report. Valuable assistance was received from Messrs. Thomas Maddock, Jr., and Whitney Borland, Head and Assistant Head, respectively, Sedimentation Section, Hydrology Division, Bureau of Reclamation, Denver, Colorado. Rainfall and temperature records were obtained from the United States Weather Bureau and stream-flow data were furnished by the United States Geological Survey.

Purpose and Scope

The purpose of this investigation was to obtain basic data necessary for estimating the rates of sedimentation in reservoirs proposed for construction by the Bureau of Reclamation in mountainous areas similar to the Boise drainage-basin, to provide similar data needed by the United States Engineers, and to obtain quantitative data needed by the Forest Service for evaluating the effects of erosion in certain drainage-areas of the Boise National Forest. In addition to obtaining information for estimating the quantity of sediment that would be expected to reach the proposed reservoirs, studies were made to estimate the probable distribution of the sediment that would occur within proposed reservoirs. These data will also provide a measure of the probable future useful life of reservoirs based on the capacity of the reservoirs with relation to the sizes and types of their drainage-areas. The development of new area-capacity curves or charts of Arrowrock Reservoir was not a purpose of this survey.

Advance information relative to the probable or expected rates of sedimentation should assist personnel engaged in the design of structures and thus increase the usefulness of these projects. It may also provide information which will justify upstream measures of control, due to the economic effects of sedimentation, if such measures will reduce the rates of sediment production.

Location (Figure 1, Page 23)

Arrowrock Reservoir is located in Section 13, T. 3 N., R. 4 E., Sections 1 and 2, 7-12, 14-19, 22-26, and 36, T. 3 N., R. 5 E., Sections 31-34, T. 3 N., R. 6 E., and Sections 28-33, T. 4 N., R. 3 E., Elmore and Boise Counties, Idaho.

Arrowrock Dam is 22 miles east of Boise, Idaho, by road and 15 miles airline.

The dam is on the Boise River and impounds water on, in addition to the above river, the South Fork of the Boise River, Rattlesnake, Willow, Cottonwood, Grouse and other small creeks.

The drainage-area includes part of Camas County in addition to parts of Elmore and Boise Counties.

Ownership

The lake and dam are owned by the United States Government and operated by the Bureau of Reclamation, Department of the Interior. The canal and drainage systems pertaining thereto are operated by Boise Project Board of Control.

Purpose Served

The water impounded by Arrowrock Dam is used to irrigate approximately 150,000 acres of Boise Valley land, whose principal crops are alfalfa, clover and pasture, grain, potatoes, sugar beets, peaches and prunes, truck and seed crops.

Description of the Dam

The dam is a rubble concrete arch gravity structure. (Figure 3(a), Page 30). The radius of the upstream face is 669.5 feet, measured at the parapet, and the height of the dam is 353.5 feet above the streambed. The crest width is 15.5 feet and carries a 16-foot roadway along its top length of approximately 1,150 feet. The maximum width at the base is 223 feet. The upstream face of the dam is nearly vertical.

Through the dam there are 10 upper balanced valve outlets, each 52 inches in diameter at elevation 3105.0. There are also 7 lower valve outlets each 52 inches in diameter at elevation 3018.0. In addition to the above outlets the dam has 5 sluice outlets, each 60 inches in diameter at elevation 2967.0. (The elevations above are the centerlines of the openings.) (Figure 3(b), Page 30)

The spillway is of the side-channel type and is located in a granite cut at the north side of the dam. The crest of the spillway is controlled by six, structural steel, drum gates, each 62 feet long and 6 feet high, separated by 6-foot piers. The maximum capacity of the spillway is 40,000 second-feet. Its normal capacity is 15,000 second-feet. The lip of the movable crest of the spillway is elevation 3216.0.

The dam was sufficiently completed on February 21, 1915, to permit storage to begin on this date; however, the final completion of the dam was in 1916. The dam as described above includes the 5-foot raise in height which was accomplished in 1937.

Description of the Lake^{1/}

The area of the lake at crest stage is 3,089 acres. Its original capacity was 279,250 acre-feet and its present capacity is 271,550 acre-feet. The loss of capacity due to sedimentation is 7,700 acre-feet.

The capacity figures above should be considered as volumes, since bank storage which is significant in this area is not included. A capacity chart based on inflow and outflow records, and thus including bank storage shows the reservoir to have a larger capacity than the volumetric amount obtained by this survey. This chart based on inflow and outflow records will continue to be used by the Boise Board of Control for the distribution of water below Arrowrock Dam.

The length of the lake measured along the thalweg from the dam to the confluence of the South Fork of the Boise River and the Main Arm of the Boise River is 4.12 miles. From this confluence to the head of the lake on the South Fork the distance is 10.73 miles and from the confluence of the two streams to the head of the lake, on the Main Arm of the Boise River, the distance is 8.64 miles, or the total length of the lake including these two major arms is 23.49 miles.

The width of the lake in comparison with the height of the dam is narrow, averaging about $1/4$ mile in width at the dam; about $1/2$ mile upstream it broadens out to about $1/2$ mile in width for a distance of about 1 mile, where it again becomes about $1/4$ mile in width. Below the confluence on the Main Arm and the South Fork of the Boise Rivers it broadens again, to a width of about $3/4$ mile, above this confluence it narrows to about $1/4$ mile in width and at about 6- $1/2$ miles above the dam it again expands to $3/4$ mile in width. Above the mouth of Cottonwood Creek it ranges from $1/4$ mile in width to about 250 feet in width near the head of backwater.

The South Fork Arm of the lake is also narrow ranging from 1,472 feet near its mouth to 222 feet in width near its head.

The other tributaries are quite narrow, with steep gradients averaging more than 150 feet fall per mile.

The slopes of the valley sides of the lake and the lake basin are very steep, making it difficult and laborious for survey personnel, with equipment, to climb the slopes. The maximum depth of the lake, measured

^{1/}At crest elevation 3216.0 determined by this survey.

near the dam, during this survey was 239 feet and the depth near the confluence of its major arms was 184 feet (at crest stage).

Description of the Drainage-area

Area. The area of the drainage-area is 2,170 square miles, not including the 41.4 square miles of drainage-area above Little Camas Reservoir, which is diverted from the drainage-area into the Long Tom Reservoir by a canal and thus would contribute only a negligible amount of sediment to the reservoir.

General characteristics. The drainage-area of Arrowrock Reservoir may be divided into two major parts. The north part is drained by the North and Middle Forks of the Boise River. This area is about 830 square miles. The south or larger part is drained by the South Fork of the Boise River. Its area is over 1,000 square miles. The other principal tributaries are Rattlesnake Creek and Willow Creek which drain into the South Fork and Cottonwood Creek which drains into the main arm of Boise River and Grouse Creek which empties into the reservoir just above Arrowrock Dam.

Geology. The bedrock of about 90 percent of Arrowrock's 2,170 square miles of drainage-area consists mainly of granite and related rock types, designated as the Idaho Batholith. This rock is coarse-grained, hard and igneous, cut by dikes, jointed and faulted. The next largest group of rocks consists of basalt which covers an area of over 230 square miles. The basalt is exposed on the south side of the reservoir from Grouse Creek to the junction of the main tributaries of the lake; above the junction the basalt appears on both sides of the South Fork of the Boise River and continues along this stream to the mouth of Lime Creek. In general, the larger quantity of basaltic flows appear on the north side of the South Fork above Rattlesnake Creek, except opposite the mouth of Fall Creek where the greater portion lies on the south side of this stream. This basalt, Snake River variety, is denser and finer grained than the Batholith. Some of the basaltic flows, or an area of about 10 square miles, have been classified as recent. (United States Geologic Map of Idaho, 1940 Edition with revisions.) Alluvial deposits were noted in about 1 percent of the drainage-area. These were located near the headwaters of the Middle and the South Forks of the Boise River. A small amount of silicic volcanic rocks was observed, their location was near the head of Willow Creek. In the east portion of the drainage-area, near the headwaters of Little Smoky Creek, there is a small area of carboniferous sedimentary rocks which are bordered on the north by basaltic rocks of the Columbia River type.

Topography. The topography of the Boise River drainage-area above Arrowrock Dam is rugged and mountainous, ranging from about 10,000 feet at its headwaters to 3,216 feet at spillway crest. Timber covers the higher mountainous areas, except where it is destroyed by burns and

removed by logging operation. The lower areas are covered with only desert vegetation except near the head of the lake, and above it, along the stream channels. Extensive lava flows have left portions of the area barren.

Climate. The climate in this area is such that the winters are long, there is much snow, and below-zero temperatures are not uncommon. Roads are frequently blocked with snow. A distinct change can be noted in driving from the dam to Boise, Idaho, it appears while traversing this distance that you have driven several hundred miles south. In the summer the days are warm and the nights are cool, frost could be expected almost every night in the higher altitudes.

Rainfall. (1) The mean annual rainfall at Arrowrock over a period of 28 years is 18.53 inches, very little of which falls during the summers which are usually dry.

Inflow. (2) The inflow into the reservoir from the Boise River at Twin Springs averaged per year 303,290 acre-feet and the inflow from the South Fork at Lennox averaged 698,986 acre-feet or the total for the two major tributaries at the above points averaged 1,502,276 acre-feet per year.

The outflow below Arrowrock Dam at Dowling Ranch yearly average was 1,615,997 acre-feet, which is 113,721 acre-feet more than that measured at Twin Springs and Lennox. This additional outflow evidently came from minor tributaries, below the gaging stations at Lennox and Twin Springs, on which meager records were made. Records made of the inflow on two of these small tributaries for the calendar year 1939 shows the inflow from Cottonwood Creek to be 7,140 acre-feet and from Grouse Creek to be 2,320 acre-feet. The drainage-area between Dowling Ranch and Arrowrock Dam is about 13.5 square miles. (Average outflow and inflow measurements for the two major stations above are based on U.S.G.S. records for 33 years.) (Location of gaging stations shown in Figure 1.)

Land cover. The major types of land cover in the Boise drainage-area are tabulated below: The area described includes the 41.4 square miles of drainage-area above Little Camas Reservoir and also the 13 square miles of drainage-area below Arrowrock Dam to Dowling Ranch gage. (Data were furnished by the United States Forest Service and compiled from Boise and Sawtooth National Forest Timber and Grazing Surveys, supplemented by 1939 field survey.)

Cover (type)	Middle and North Fork (acres)	South Fork (acres)	Arrowrock Tributaries (acres)	Total (acres)
Sagebrush	7,910	196,610	61,760	266,280
Browse	32,340	82,550	31,270	146,160
Grassland	36,470	65,410	47,450	149,330
Annual Weeds	170	--	--	170
Perennial Forbs	120	12,110	5,710	17,940
Meadow	--	620	--	620
Conifer, protection	298,850	201,790	18,260	518,900
Conifer, commercial	143,180	88,850	22,390	254,420
Conifer, cut-over	2,430	--	--	2,430
Conifer, burn	2,430	1,730	--	4,160
Broadleaf trees	--	4,410	--	4,410
Barren	8,820	24,920	--	33,740
Water area	720	3,990	3,180	7,890
Cultivated	--	14,410	2,760	17,170
TOTAL	533,440	697,400	192,780	1,423,620

Land uses. The major types of land uses in the Boise drainage-area are tabulated below: The area described is the same as that used for land cover above.

Land use	North and Middle Fork (acres)	South Fork (acres)	Arrowrock Tributaries (acres)	Total (acres)
Grazing	522,320	669,100	186,220	1,377,640
Commercial timber ^{1/}	139,270	72,980	34,500	246,750
Reserves	10,160	9,740	--	19,900
Re-seeding	240	160	620	1,020
Irrigated farming	--	5,110	460	5,570
Dry farming	--	9,300	2,300	11,600
Mining claims ^{1/}	760	2,690	180	3,630
Water surface	720	3,990	3,180	7,890
TOTAL	533,440	697,400	192,780	1,423,620

^{1/} The acreages also used for grazing, included in total grazing.

Soils. The soils of Arrowrock drainage-area are tabulated below: This table does not include the soils in the 13 square miles of Boise drainage-area below Arrowrock Dam used in the two preceeding tables on land cover and use.

	Middle and North Fork	South Fork	Arrowrock Tributaries	Total
	(square mile)	(square mile)	(square mile)	(sq. mi.)
<u>Residual Granite</u>				
1. Deep	200.9	137.3	67.3	405.5
2. Moderate	109.9	495.7 ^{1/}	105.9	711.5
3. Shallow	343.4	309.8	80.5	733.7
4. Stony	156.1	74.4	12.5	243.0
<u>Residual Basalt</u>				
1. Moderate	--	55.4	21.4	76.8
<u>Alluvium</u>				
1. Deep	22.1	10.9	3.4	36.4
<u>Windblown</u>	--	--	5.2	5.2
<u>TOTAL</u>	<u>832.4</u>	<u>1,083.5</u>	<u>296.2</u>	<u>2,212.1</u>

^{1/}Includes 119 square miles of residual rhyolite, moderately deep soil, mainly in South Fork.

Erosion. The extent of the erosion in the Boise drainage-area as observed in 1939 is tabulated below: The erosion table includes the same area as used in the preceding table for the soil groups.

	Middle and North Fork	South Fork	Arrowrock Tributaries	Total
	(square mile)	(square mile)	(square mile)	(sq. mi.)
Slight	273.3	283.1	75.5	631.9
Moderate	329.9	653.1	135.2	1,118.2
Moderate-severe	62.3	62.0	66.9	191.2
Severe	10.8	10.8	3.3	24.9
Geologic	156.1	74.5	15.3	245.9
<u>TOTAL</u>	<u>832.4</u>	<u>1,083.5</u>	<u>296.2</u>	<u>2,212.1</u>

History of Survey

The survey of Arrowrock Reservoir was made during the period August 18 to December 5, 1947, by the Sedimentation Section, Hydrology Division, Branch of Project Planning, Bureau of Reclamation, United States Department of the Interior in cooperation with the Flood Control Section, Intermountain Forest and Range Experiment Station, Forest Service, United States Department of Agriculture. Assistance was also furnished by the Portland District Engineers Office, Department of the Army.

The personnel of the party consisted of Louis M. Seavy, Chief, Zach A. Elkin, Dale W. Henry, Argel I. Duncan (Bureau of Reclamation) and Joe S. Adair, Assistant Chief, Byron Thurmond, Richard Payne, Walter A. Marker, John L. Murray, Bud H. Classen (Forest Service) and Lorne H. MacDonell and Paul V. Livingston (Engineer Corps).

(The participation of the entire above personnel was not continuous for the duration of the survey due to agencies having need for them on other jobs which were carried out concurrently with this survey.)

The field work was initiated by chaining and checking a baseline 5,120 feet long, located on the right or north side of the lake, beginning about 6,000 feet above the dam and extending upstream. This work was followed by the establishment of a triangulation system consisting of 175 stations. This triangulation control was checked by tying in General Land Office section corners, and by chaining a checkline between two or more triangulation stations on each of the six planetable sheets used in connecting the systems. Additional checks were made as each range was established or profiled. The crest contour of the reservoir, elevation 3,216.0 was mapped on the above planetable sheets at a scale of 1 inch to 500 feet. The length of the shoreline is 52 miles. Original and present capacities and silt volume were determined by the range method(3). Soundings were taken on 71 ranges and sediment measurements were made on 58 ranges. The mean of the sediment measurements made on the range above and the range below the intermediary range was used on ranges having no sediment measurements. Triangulation stations and range ends were marked with iron pipe to provide a basis for future re-surveys.

The elevation of the lake bottom on the ranges at the time of this survey was obtained by the use of the portable type 808J Fathometer mounted on a boat, kept on line by a transit-man, and cut-in at 20-second intervals by a planetable-man, see Figure 12, Page 39. Sufficient checks of the depths of water obtained by the fathometer were made by a lead line to verify the accuracy of the fathograms. Figure 13, Page 40, is a fathogram showing soundings on Range 67. At each of the 9 fixes, the boat's location was established on planetable sheet.

Since the stage of the lake varied from elevation 3,183.4 to elevation 3,077.4 during this survey or from 32.6 feet below crest to 133.6 feet below crest it was necessary to supplement the fathograms at each end of the ranges by land surveying, which was done in the conventional method by using the transit, rod and level or alidade and rod. This latter method was also used for running profiles on the upper ranges of the major arms and tributaries (from Cottonwood Creek upstream on the main arm and from R-70 upstream on the South Fork of the Boise River). (See map of Reservoir, Pages 26 and 29.)

No significant differences were noted between the profiles obtained by the conventional method and those obtained by the use of the fathometer where they overlapped and such profiles were intentionally overlapped for

a check. This check was convenient to accomplish as the lake stage was much lower when the land portion was rodded than when the water portion was sounded.

Sediment measurements on the upper ranges were made by using a soil auger concurrently with the running of the profiles; however, in the lower and deeper portion of the lake the time element was such that the sediment measurements were made separately from the soundings. They were taken from a raft (Figure 11, Page 38) anchored on the range, by using 3/4-inch sectional iron or aluminum pipe. There was welded on the bottom end of this pipe a 1-inch carpenter's bit. This pipe with bit was lowered into the water and sediment through a 12- by 13-inch hole in the center of the raft by means of a meter winch, rope, block and tackle and "dog." Since the original channel bottom of the lake was hard (well compacted), usually gravel or cobble stone, little difficulty was entertained in recognizing the original bottom. The pipe moved readily through the sediment which had been deposited since the construction of the dam; however, when the pipe was being lowered into the sediment it was necessary occasionally to give the bit a few turns to penetrate through a banded layer of sand, after which it would sink easily through the softer sediment down to the next sand layer, etc., until the hard or compacted bottom was reached. After this measurement was taken the raft was moved out on the range to the next site for a new sediment measurement by the use of a boat and outboard motor, re-anchored and the process continued. The horizontal locations of the sediment measurements were determined by use of the transit, or sextant.

The elevation of the original bottom just above the dam obtained by the above method of boring agreed with the elevations shown in the original boring logs made by the Bureau before the construction of the dam. Although the elevation of the stream channel (with the exception of data in the boring logs) was not shown on the original map the elevation of the old flood plain was shown. This information provided a check for the sediment measurements made on ranges, except for those in the old streambed and since the streambed usually averaged only 2 to 3 feet deeper than the flood plain measurements shown on the map, such data served as a rough check for those measurements also. The sediment spud (3) developed by the Division of Research, United States Soil Conservation Service, Washington, was experimented with on several ranges throughout the reservoir in an attempt to use it to measure the sediment but because of the laminated layers of sand it failed to penetrate to the old soil horizon or to the original channel bottom; so the soil auger and the 3/4-inch pipe with bit had to be used throughout the survey. These layers of sand are believed to have been formed by the annual or more frequent drawdowns of the reservoir which permitted a strong enough current to carry coarse sand into even the lower portions of the reservoir.

Distribution of Sediment

Because of the varying stages of the lake and the steep gradients of the tributaries there has been considerable re-distribution of the

sediment, especially in the upper reaches. This redistribution was visible during the course of this survey, for the channels on the upper portion of the arms which were filled with sediment when the triangulation stations were erected, were practically washed clean except for sediment sticking to the sides and deposited at bends, by the time the profiles were run. As the ranges below the head of backwater were sounded and sediment measurements made after this redistribution occurred, the sediment which was measured there included that which at high stages had lain in the upper reaches. This redistribution of sediment occurred on the main arm as far downstream as Range 20 and on the South Fork down to Range 69.

The variation of the thickness of sediment in Arrowrock Reservoir is presented graphically in Figure 4, Page 31, which shows both the present and the 1915 longitudinal profiles of the thalweg of the main arm and tributaries of the lake.

Since the stream currents, due to drawdown of the lake, had cleared the sediment from the center of the streams in the upper reaches of the tributaries before they were measured, this graph fails to depict the deposition in these areas, which occur as previously mentioned on the sides of the stream and on the inside of the bends in the stream. However due to the steep sides of the lake most of the sediment consists of bottom-set laminated beds except near the heads of the tributaries. In the lower reaches, particularly from the dam to the confluence of the major arms the sediment has filled the original channel and extends over the old flood plain. The maximum measured depth of sediment in the old stream channel was on Range 5, where it was 26 feet. On Range 1, approximately 150 feet above the dam, the sediment was 22 feet deep. The sediment depth in the channel of the main body of the lake between the dam and Range 15 averaged 19 feet. The surface of the sediment over this area was fairly level and uniform, indicating little recent bottom current. On the South Fork of the Boise River between Range 60 and 66 the average sediment depth in the channel was of greater depth averaging 20.7 feet. Alluvial fans were deposited at the mouths of the tributaries. The fan at the mouth of Irish Creek, a small tributary entering the lake from the north about 5 miles above the dam, depicts these deposits. See Figure 6, Page 33.

Sediment deposits in the small tributaries, the channel section of which has been re-deposited further downstream, is illustrated by Figure 7, Page 34, showing deposits on Cottonwood Creek with exposed edges recently cut away.

Sediment deposits on the old flood plain are shown in Figures 8 and 9(a), Pages 35 and 36.

Figure 9(b), Page 36, shows small delta deposits, laid down at various stages of the lake, in Cinch Creek, a small tributary entering the lake from the north about 1 mile above the dam.

Sand deltas on the sides of the streams were noted near the head of backwater. In Figure 10(a), Page 37, men are shown making sediment measurements, with a soil auger, in a sand delta.

Approximately 5,000 acre-feet of sediment was deposited in the main arm of the Boise River. About one-half of this amount was deposited below its junction with the South Fork of the Boise River, Figure 10(b), Page 37.

About 2,400 acre-feet of sediment was deposited in the South Fork Arm of the lake above Range 60, or slightly more than the amount measured in the main arm above their junction. The graph, Figure 4, Page 31, indicates considerably more sediment in the channel of the South Fork than in the main arm; this amount was almost compensated for in the main arm by more sediment being deposited on the sides of the channel and on the old flood plain, which was more developed than the flood plain on the South Fork. The steeper gradient of the main arm also tended to scour out and re-deposit downstream a good percent of its channel portion of sediment.

The most sediment measured in a tributary arm was in Grouse Creek which contained slightly more than 200 acre-feet of sediment above Range 50.

Lateral distribution of sediment is shown by typical cross-sections. Ranges 3, 22, 30, 41, 46, 66 and 76, Figure 5, Page 32.

Tabulated below is the distribution of sediments by tributaries. The proportions of fine and coarse sediments were determined by use of field measurements taken on adjacent ranges for computation of the distribution of sizes of sediment in each segment. The average volume weight used per cubic foot in the tabulation below was 54.7 pounds for fine material and 94.3 pounds for coarse material. The average volume weight per cubic foot for the total quantity of sediment was 73 pounds.

Arrowrock Reservoir Sediments

	Fine fractions		Coarse fractions		Total	
	Ac-ft.	Tons	Ac-ft.	Tons	Ac-ft.	Tons
Boise River, above junction with S.F.	1,272	1,515,422	847	1,739,611	2,119	3,255,033
Boise River, below junction with S.F.	1,615	1,924,063	1,265	2,598,120	2,880	4,522,183
South Fork, includ- ing Rattlesnake and Willow Creeks	1,192	1,420,113	1,275	2,618,659	2,467	4,038,772
Grouse Creek	60	71,482	146	299,862	206	371,344
Cottonwood Creek	22	26,210	11	22,592	33	48,802
TOTALS	4,161	4,957,290	3,544	7,278,844	7,705	12,236,134

Volume weight and mechanical analyses. Eighteen sediment samples were taken in Arrowrock Reservoir at selected locations and depths for the purpose of obtaining the volume weight and the gradation in size of the sediment. The size of each sample taken was 8 inches in length and 1-1/2 inches in diameter. They were obtained by means of a pipe sediment sampler, having a check valve near its upper end and threaded at its lower end for attaching sample containers. A rope was attached to the sampler for obtaining underwater samples. Data pertaining to these sediment samples are tabulated on the following page.

Analysis of observed densities. An analysis of observed densities is illustrated by use of a graph, see Figure 14, Page 41. Sample data from Guernsey Reservoir, North Platte River, Wyoming, obtained in 1947 were used in addition to Arrowrock Reservoir sample data. The sediment samples for this analysis were divided into sand, silt, and clay fractions. Clay included particles less than 0.005 mm, silt particles between 0.005 and 0.05, and sand all material larger than 0.05 mm. Most of the samples follow a curve showing distinctly an increase in weight with increasing sand content. The dry weight of these sediment samples, having a high percent of silt and clay ranges from 10 to 30 pounds per cubic foot less than the weight per cubic foot shown in Report No. 9 "Density of Sediments Deposited in Reservoirs" (4).

Sluicing of Arrowrock Reservoir

In addition to the sediment that may have passed through the dam by way of the upper and middle outlets (see Page 30) and through the spillway, consideration should be given to the large quantity of sediment that may have been discharged through the bottom outlets or sluice gates.

Personnel observing sluicing operations below Arrowrock Dam noted considerable sediment passing through the sluice gates and entering the stream below the dam. Below is a table showing the periods sluicing was effected.

Record of Sluicing Arrowrock Reservoir (5)

<u>Year</u>	<u>Period</u>	<u>Number days</u>	<u>Average discharge second-feet</u>
1919	Sept 13-17, Sept 20 to Oct 1	17	576
1920	Sept 13 to Oct 10	28	721
1922	Sept 19 to Oct 22	34	701
1924	Aug 19 to Oct 15	58	439
1926	Sept 16 to Oct 16	31	518
1928	Oct 8 to Oct 21	14	704
1929	Oct 20 to Oct 31	12	608
1931	Oct 13 to Nov 7	26	548
1933	Oct 16 to Oct 30	15	597
1934	Oct 14 to Oct 24	11	569
1935	Oct 22 to Oct 25	4	566
1937	Oct 10 to Oct 25	16	607
1941	Oct 16 to Oct 17	2	845
1942	Oct 17 to Oct 18	2	800

Sediment Sample Data of Arrowrock Reservoir

Boise River, Idaho

Sample No.	Range	Station	Elevation	Date sampled	Volume weight (lb/cu ft)	Mechanical Analyses										
						Percent of grade sizes										
						5 mm	3-5 mm	2-3 mm	1-2 mm	.5-1 mm	.25- mm	.10- mm	.05- mm	.005- mm	0- mm	
1	60	4+50	3,048	10-15-47	53.9	-	-	-	-	0.3	0.5	21.0	12.9	49.2	16.0	
2	60	8+65	3,049	10-15-47	87.9	-	-	-	-	0.7	14.0	71.2	7.5	5.6	1.0	
3	13	4+59	3,026	10-23-47	60.4	-	-	-	0.2	0.4	0.7	54.0	16.0	20.7	8.0	
4	1	6+07	2,975	10-23-47	44.2	-	-	-	0.5	2.0	2.1	3.1	2.3	38.0	52.0	
5	17	6+95	3,032	10-17-47	102.2	0.2	0.7	2.2	6.7	23.4	34.1	25.9	1.9	3.9	1.0	
6	5	20+09	2,987	11-6-47	64.2	-	0.3	1.7	5.9	17.6	18.1	14.5	2.2	23.0	16.7	
7	20	21+80	3,066	11-20-47	52.7	-	-	-	0.1	0.4	0.8	5.3	4.7	46.7	32.0	
8	79	2+77	3,161	11-24-47	61.5	-	-	-	-	0.1	1.0	8.5	11.2	63.2	16.0	
9	47	2+59	3,186	11-26-47	85.2	6.2	9.5	18.8	25.1	20.5	7.3	8.0	1.4	1.9	1.3	
10	29	2+14	3,207	12-4-47	47.7	-	-	-	0.1	0.6	1.0	11.9	23.9	50.5	12.0	
11	84	0+09	3,215	11-26-47	57.9	-	0.3	0.4	0.6	0.8	1.0	11.9	14.7	55.4	14.9	
12	83	0+44	3,200	11-26-47	52.3	-	-	-	0.5	1.2	1.3	13.3	11.2	55.5	17.0	
13	81	1+25	3,204	11-25-47	58.8	-	-	-	0.2	0.4	0.8	25.8	20.4	39.4	13.0	
14	80	0+51	3,199	11-25-47	57.3	-	-	-	0.1	0.4	0.5	16.2	15.9	53.9	13.0	
15	80	1+10	3,169	11-25-47	48.3	-	-	-	0.9	3.5	5.7	16.6	7.4	52.4	13.5	
16	82	2+00	3,182	11-26-47	112.5	0.4	0.3	8.6	37.3	19.0	6.1	19.4	3.9	3.2	1.8	
17	19	1+00	3,195	12-5-47	85.9	18.3	26.3	24.1	11.1	7.2	2.8	4.3	1.6	3.4	0.9	
18	21	6+58	3,133	12-5-47	52.1	0.5	0.2	0.5	0.6	0.9	1.4	11.7	5.2	45.4	33.6	

The average discharge for the above period, 270 days, was 605 cubic feet per second or a total discharge of 323,953 acre-feet of sediment-laden water. Unfortunately no sediment sampling was made of the water at the time of the above sluicing for computation of the quantity of sediment removed from the reservoir; however, estimates below indicate that approximately 1,300 acre-feet of sediment may have been removed during the above period by sluicing.

A rough estimate of the quantity of sediment removed from the reservoir during these sluicing periods could be obtained by estimating the volume of the material that might be scoured out above the dam. From the table above, the five sluice gates, each 5 feet in diameter, were opened during fourteen periods and the periods between sluicing operations ranged from 1 to 4 years. The average time the gates were opened during each period was 19 days. Original survey data shows that 22 acres were submerged and that there were 132 acre-feet of storage when the lake stage was at the centerline of the sluice gates or at elevation 2967. 1947 survey data, obtained 5 years since the last sluicing operations were made, shows the top of the sediment at Range 1, just above the dam to be at elevation 2976.7, indicating that not only the 132 acre-feet of storage is lost but that sediment has taken away many additional acre-feet above the centerline of the sluice gates.

An estimate of the sediment removed by sluicing was made by using data in (5) Table 17, Discharge and Sediment Loads in the Boise River Drainage-basin.

Table 17

Sediment Loads Above and Below Arrowrock Dam, Boise River, 1939-40

Period	Station above <u>1/</u> Arrowrock Dam			Boise River <u>2/</u> below Arrowrock Dam		
	Suspended <u>3/</u>	Total <u>4/</u>	Total <u>5/</u>	Suspended <u>3/</u>	Total <u>4/</u>	Total <u>6/</u>
	(Tons)	(Tons)	(Ac-ft)	(Tons)	(Tons)	(Ac-ft)
Jan - June 1939:	80,600	103,000	52	13,000	26,000	24
July - Dec 1939:	1,860	2,700	1.4	5,130	10,300	10
Jan - June 1940:	97,400	133,000	68	27,500	27,500	25
Total	179,860	238,700	122	45,730	64,000	59

1/ Boise River at Twin Springs, Cottonwood Creek, and Grouse Creek. Not including sediment from South Fork of Boise River and tributaries.

2/ Dowling Ranch gage. (See Figure 1, Page 23, for location of gaging stations.)

3/ Table 8, Page 27 (5).

4/ Total loads from reliable estimates, Pages 22 to 24, (5)

1939 (Twin Springs	60-80 percent
(Dowling Ranch	50 percent
(Grouse and Cottonwood	100 percent
1940 (Twin Springs	50-70 percent
(Dowling Ranch	100 percent
(Grouse and Cottonwood	100 percent

5/ At 90 pounds per cubic foot, Page 41 (5), for sand samples (70 samples by USGS in drainage).

6/ At 50 pounds per cubic foot, Page 41 (5). For silt samples (Nos. 42, 44, 53, by USGS in Arrowrock). (94.3 pounds per cubic foot was obtained for sand, using five samples obtained in 1947 and 54.7 pounds per cubic foot was the average volume weight obtained from thirteen samples of fine material taken in 1947, see Pages 13 and 14 of this report.)

In the right-hand column of the above table it is shown that 34 acre-feet of sediment was transported below Arrowrock Dam in 1939 and that the sediment transported from January through June 1940, was 25 acre-feet or only 1 acre-foot more than for the same period in 1939. Since the water flow from January through June 1939 was 75 percent of the amount of water for the calendar year 1939, the relationship of the quantity of sediment to the amount of water was almost the same for the last half of the year as that for the first half of the year.

The runoff at this station, Dowling Ranch, for 1939 was 77.6 percent of the average runoff during the 37.6 years life of Arrowrock Dam and since no sluicing operations were made from October 25, 1937, until October 1941 and from October 18, 1942, to date of 1947 survey, it is believed that the sediment rate determined for 1939, for outflow below Arrowrock Dam could be applied from the time storage began above Arrowrock until 2 years after sluicing operations ceased, 1915 to 1945, to estimate the quantity of sediment removed by sluicing operations. Then $34 \text{ acre-feet} \div 77.6 \times 100 \times 30 \text{ years}$ equals 1,314 acre-feet, the quantity of sediment probably removed by sluicing. This would indicate that the water removed during the fourteen sluicing periods contained sediment averaging 4,000 ppm, less what sediment may have been passed through the dam by means of other outlets. This estimate is believed to be low since no suspended load sediment measurements were made during sluicing operations.

A check on this estimate was made by measuring the acre-feet of sediment above the centerline of the sluice gates between the dam and Range 6 or to a point 8,330 feet upstream from the dam. This check indicates that probably 63 acre-feet of sediment could have been removed during each of the 5 years which have elapsed since sluicing operation ceased, which further indicates that the above estimate of 1,314 acre-feet of sediment removed by sluicing is low; as $27 \text{ years (1915 to 1942)} \times 63 \text{ acre-feet} = 1,701 \text{ acre-feet}$. A table and a duplication of part of Figure 4, which is shown in Figure 15, Page 42, illustrates how this quantity of sediment was determined.

1,300 acre-feet should be considered as a conservative estimate of the sediment removed by sluicing since the sampling at Dowling Ranch gaging station was done from January 1939 to July 1940 and sluicing was omitted during the period October 25, 1937, to October 16, 1941. The sediment concentration should have been greater during and shortly after sluicing operations.

Figure 16, Page 43, shows sediment deposit in the Boise River above Diversion Dam^{1/}. Although much of this may have been contributed by Moore Creek, (for location see Figure 1, Page 23) a considerable portion

^{1/} Results of sedimentation studies above Diversion Dam were presented to the writer by Mr. Marvin Rose, Hydrologist, United States Forest Service.

of this sediment may have been sluiced from Arrowrock Reservoir. Sedimentation investigations by the Forest Service indicate that Diversion Dam filled 15.74 acre-feet from January 17 to September 11, 1939, and 91.19 acre-feet from April 3 to September 24, 1947. The increase in filling in 1947 over that of 1939 may have been due to the installation of flashboards in June 1947 and the increased dredging operations on Moore Creek.

STATISTICAL SUMMARY

Arrowrock Reservoir

	: Quantity	: Unit
<u>Age</u> ^{1/}	32.64	Years
<u>Watershed</u> ^{2/}		
Total area	2,170	Sq mi
<u>Reservoir</u>		
Area at crest stage.	3,089	Acres
Original storage capacity.	279,250	Ac-ft
Present storage capacity	271,550	Ac-ft
Original storage per square mile drainage-area	123.7	Ac-ft
Present storage per square mile drainage-area.	125.1	Ac-ft
<u>Sedimentation</u> ^{3/}		
Total sediment	7,700	Ac-ft
Accumulation per year average.	235.9	Ac-ft
Accumulation per year per 100 square miles drainage-area	10.87	Ac-ft
Accumulation per year per acre of drainage-area,	7.40	Cu ft
or using 73 pounds as the average weight of sediment.	0.27	Tons
<u>Depletion of storage</u>		
Loss of original capacity per year	0.085	Percent
Loss of original capacity to date of survey.	2.76	Percent

^{1/} Date storage began: February 21, 1915. Date of this survey: August 18 to December 5, 1947.

^{2/} Does not include the 41.4 miles of drainage-area above Little Camas Reservoir.

^{3/} Does not include sediment removed by sluicing. (This volume of sediment estimated to be 1,300 acre-feet, see Pages 13-18 for method of estimating this amount of sediment.)

Sediment Rates Arrowrock Reservoir V.S. Anderson Ranch Reservoir

An estimate of the sediment reduction in Arrowrock Reservoir due to the construction of Anderson Ranch Dam and also an estimate of the amount of sediment to be deposited in Anderson Ranch Reservoir is listed below:

Accumulation of sediment in Arrowrock Reservoir from 1915-1947	7,700 acre-feet
Sediment removed by sluicing to 1947.	<u>1,300</u> acre-feet
Total sediment from drainage-area (2,170 square miles) in 32.64 years.	9,000 acre-feet
Total sediment from South Fork drainage-area (1,260 square miles or 58 percent) in 32.64 years.	5,220 acre-feet
Estimated volume of sediment from South Fork drainage- area above Anderson Ranch Dam = 74 percent of 5,220 acre-feet (based on size of drainage-area above Anderson Ranch Dam (935 square miles)) compared to area of drainage-area between this dam and junction of South Fork with the Boise River (325 square miles) minus 10 percent (estimating that the trap efficiency of Anderson Ranch Dam is 90 percent)	3,475 acre-feet
for 32.64 years or annual reduction	= 106 acre-feet

Then the reduction of sediment accumulation in Arrowrock Reservoir due to the construction of Anderson Ranch Dam is 39 percent, or the expected annual sediment deposition in Anderson Ranch Reservoir based on the above deduction is about 100 acre-feet.

Since it was pointed out earlier in this report that the 1,300 acre-feet of sediment estimated to be removed by sluicing was probably a conservative figure, it would be reasonable to assume that the annual sediment accumulation in Anderson Ranch Reservoir would be slightly more than 100 acre-feet annually and that the annual amount of sediment that will now be deposited in Arrowrock Reservoir will be about 170 acre-feet.

This estimate is based on the assumption that there will be little scour in the channel below Anderson Ranch Dam. It is believed that the regulated releases of water from the Anderson Ranch Dam will be incapable of moving an appreciable quantity of the coarse material of which the stream-bed consists.

Summary

The cost of Arrowrock Reservoir was \$4,750,000. Sedimentation, as determined by this investigation, has reduced its storage volume by 2.76 percent or its loss in original value due to sedimentation is \$131,000. Considerable more loss would have occurred except for effective sluicing operations; also this loss when based on cost of present construction is much greater.

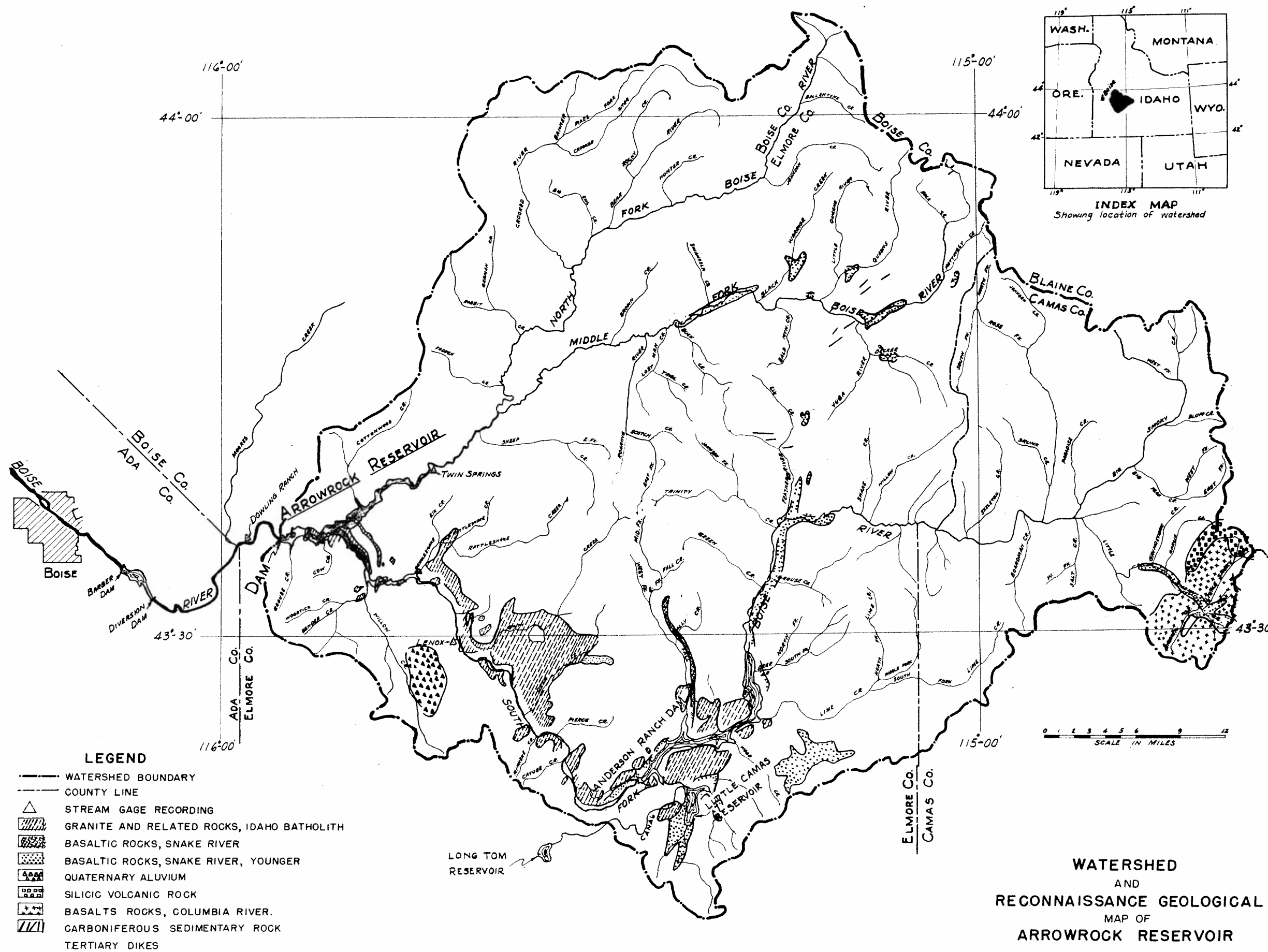
Although future sluicing operations are not contemplated due to possible downstream damage to fish and to the proposed Lucky Peak Dam, the silting rate, with the existing drainage-area use would be much less due to the construction of Anderson Ranch Dam on the South Fork of the Boise River. This investigation indicates that about 10 percent more sediment was derived from this source than from the Boise River.

Sediment production from Arrowrock's drainage-area is very low in comparison to other areas of similar size in the United States. This low rate is believed due to land cover, land use, restricted grazing, hard shallow soils, and the type of precipitation on the drainage-basin.

These studies indicate that in a channel-type reservoir with steep gradient and sides, and having frequent drawdowns, the major sediment deposition may be expected to be found in the old stream channels, at mouths of tributaries, and on the old flood plain. When reservoir stream gradients are steep, similar to those of Arrowrock's, the sediment load deposited at the mouths of most of the tributaries is considerably higher in elevation than the lower elevations of the reservoir, which has frequently been allotted as sediment storage space.

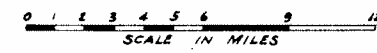
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- (1) Climatological Data, Idaho Section, Weather Bureau, United States Department of Commerce.
- (2) Water Supply Paper 903, Surface Water Supply of the United States, Snake River Basin, Geological Survey, United States Department of the Interior.
- (3) Eakin, H. M., Silting of Reservoirs, United States Department of Agriculture, Technical Bulletin 524, 1936. Revised by Mr. Carl B. Brown, 1939.
- (4) Lane, E. W. and Koelzer, V. A. Report No. 9, Density of Sediment Deposited in Reservoirs, a study of methods used in measurement and analysis of sediment loads in streams, cooperated in by United States Department of the Interior, Army, Agriculture, the Tennessee Valley Authority and the Iowa Institute of Hydraulic Research.
- (5) Love, S. K. and Benedict, P. C. Discharge and Sediment Loads in the Boise River Drainage-Basin, Idaho, 1939-1940, Geological Survey, United States Department of the Interior.

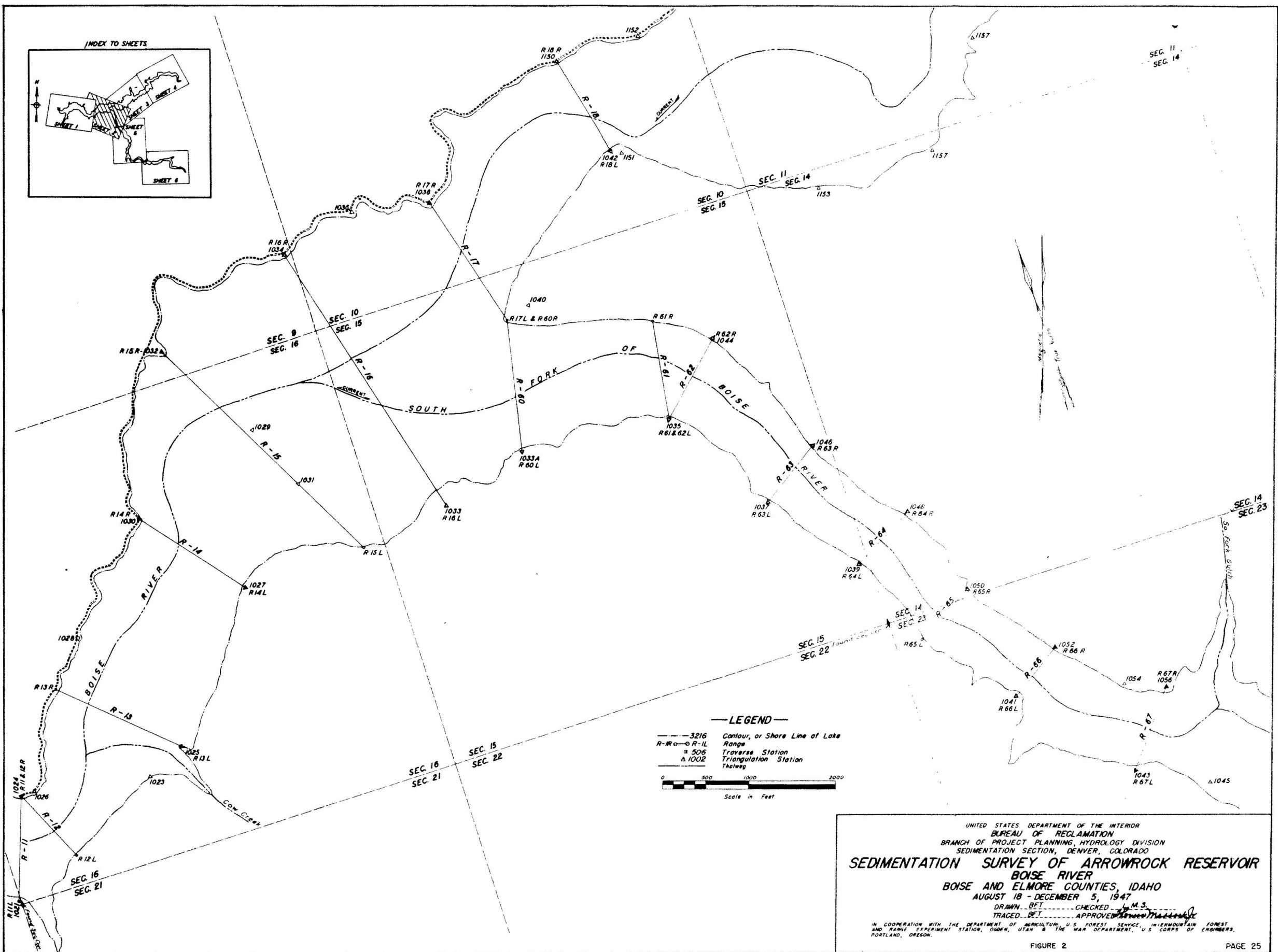
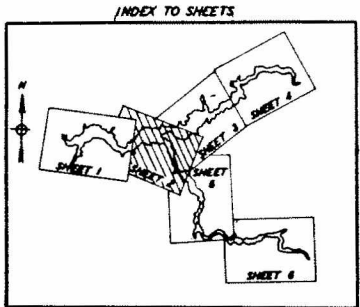


LEGEND

- WATERSHED BOUNDARY
- - - COUNTY LINE
- ▲ STREAM GAGE RECORDING
- [Hatched Box] GRANITE AND RELATED ROCKS, IDAHO BATHOLITH
- [Dotted Box] BASALTIC ROCKS, SNAKE RIVER
- [Cross-hatched Box] BASALTIC ROCKS, SNAKE RIVER, YOUNGER
- [Stippled Box] QUATERNARY ALUVIUM
- [Box with 'S'] SILICIC VOLCANIC ROCK
- [Box with 'B'] BASALTS ROCKS, COLUMBIA RIVER.
- [Box with 'C'] CARBONIFEROUS SEDIMENTARY ROCK
- [Box with 'D'] TERTIARY DIKES



**WATERSHED
AND
RECONNAISSANCE GEOLOGICAL
MAP OF
ARROWROCK RESERVOIR**



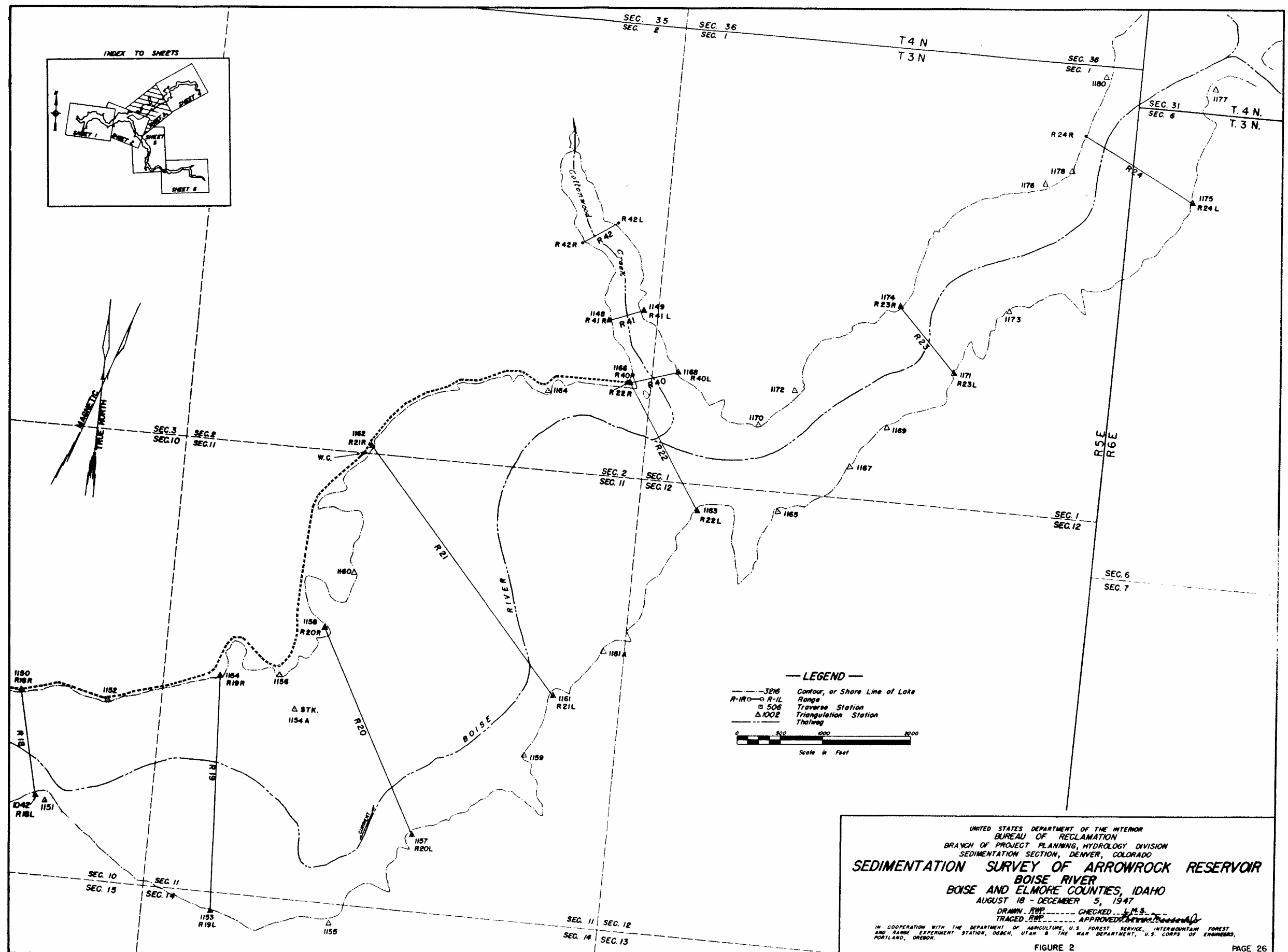
UNITED STATES DEPARTMENT OF THE INTERIOR
 BUREAU OF RECLAMATION
 BRANCH OF PROJECT PLANNING, HYDROLOGY DIVISION
 SEDIMENTATION SECTION, DENVER, COLORADO

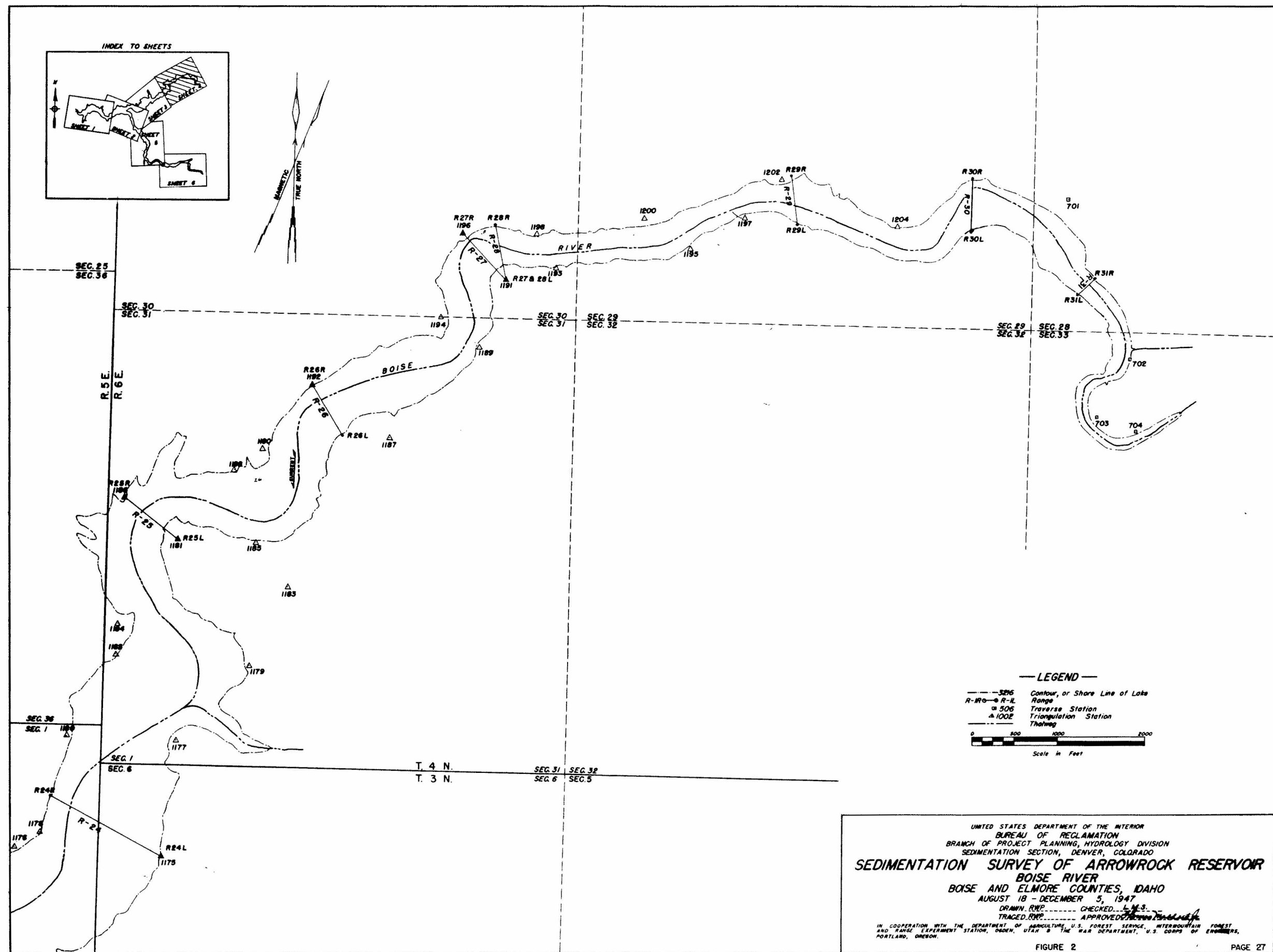
SEDIMENTATION SURVEY OF ARROWROCK RESERVOIR
BOISE RIVER
BOISE AND ELMORE COUNTIES, IDAHO
 AUGUST 18 - DECEMBER 5, 1947

DRAWN BY BET CHECKED BY M.S.
 TRACED BY BET APPROVED BY *[Signature]*

IN COOPERATION WITH THE DEPARTMENT OF AGRICULTURE, U.S. FOREST SERVICE, INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION, OGDEN, UTAH & THE WAR DEPARTMENT, U.S. CORPS OF ENGINEERS, PORTLAND, OREGON.

FIGURE 2 PAGE 25





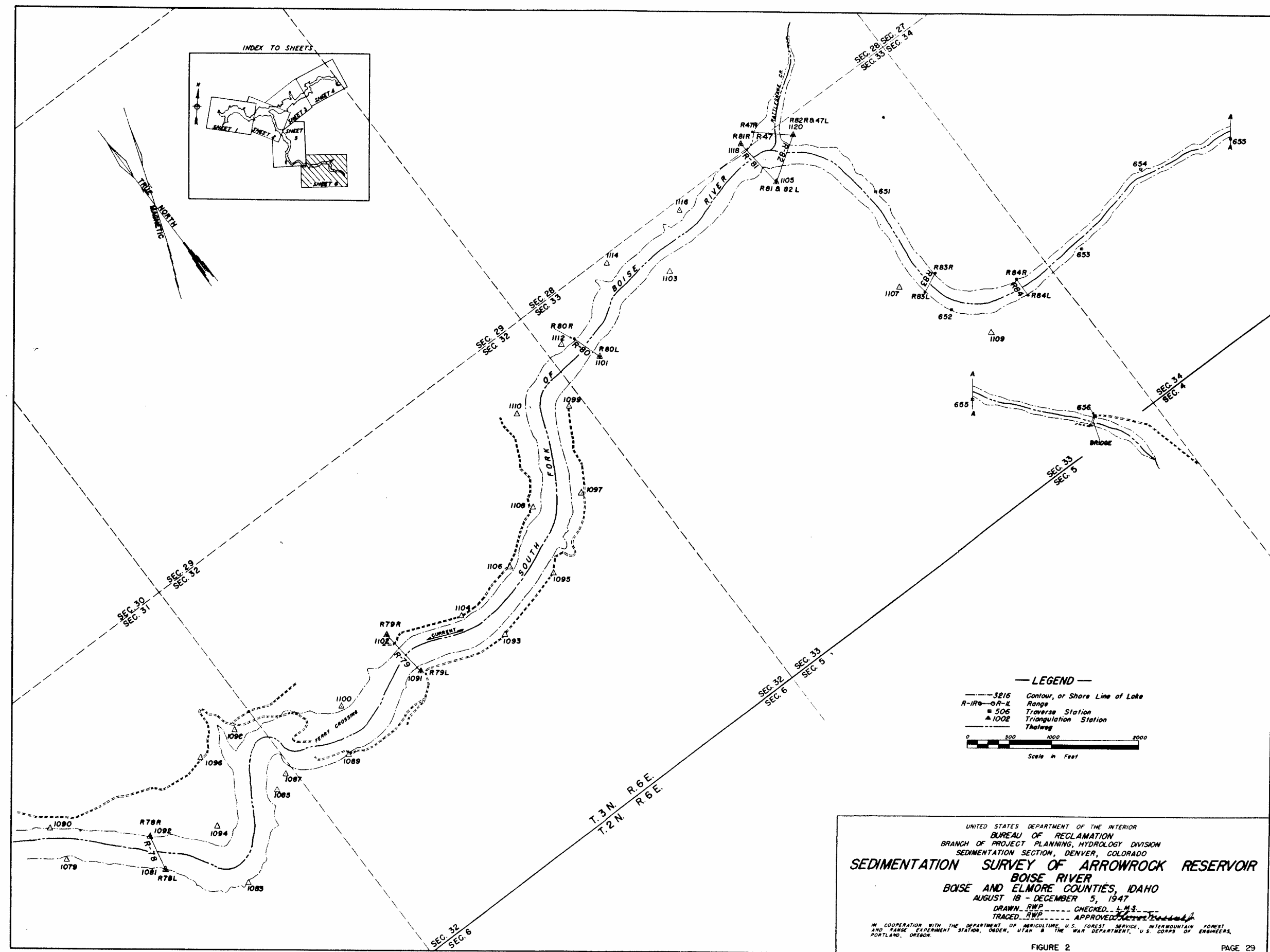
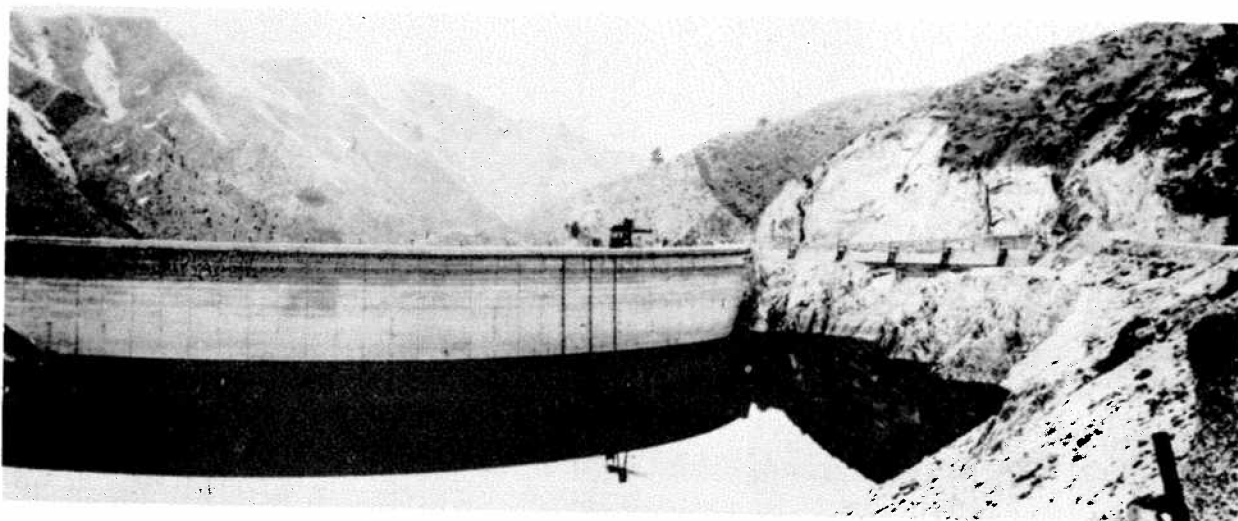


FIGURE 2



(a) Upstream view.



(b) Downstream view

Arrowrock Dam

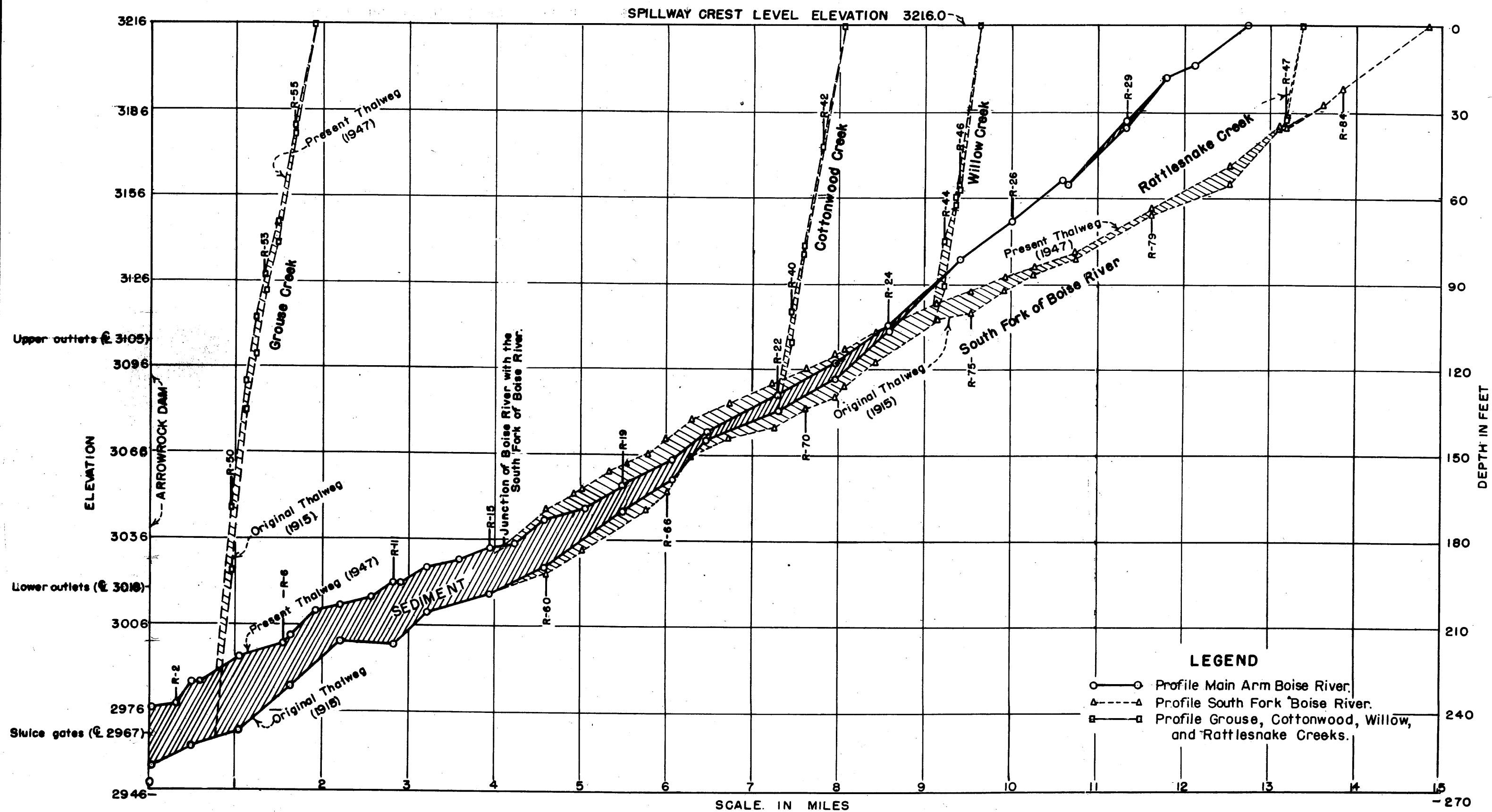


FIGURE 4-- LONGITUDINAL PROFILE-PRESENT AND ORIGINAL THALWEGS, BOISE RIVER AND TRIBUTARIES, ARROWROCK RESERVOIR

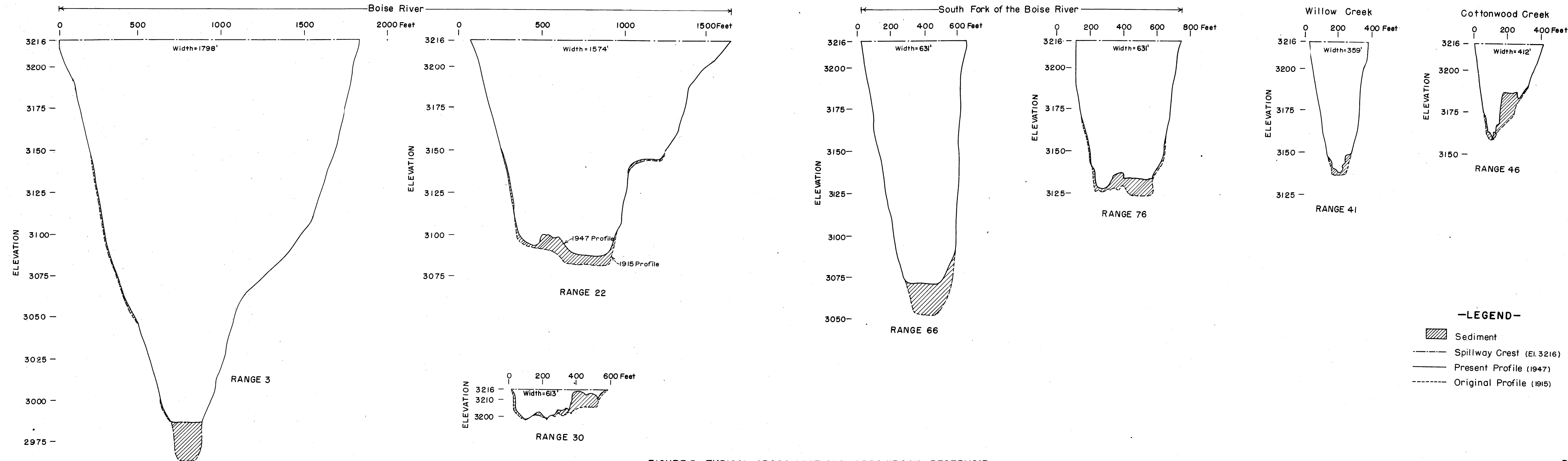


FIGURE 5-TYPICAL CROSS SECTIONS-ARROWROCK RESERVOIR



(a) Downstream view.



(b) Upstream view.

Alluvial fan at the mouth of
Irish Creek.



(a) Sediment being redistributed downstream, after drawdown of lake. Note height and lamination of sediment.



(b) Upstream view, showing redistribution of sediment.

Sediment deposits near mouth of Cottonwood Creek.



(a) Exposed mud flat, near
sedimentation range No. 25,
view looking upstream.



(b) Mud flat opposite Trail
Creek, between ranges
24 and 25.

Exposed mud flats Boise River.



(a) Exposed sediment; note drying cracks; location - between ranges 21 and 22.



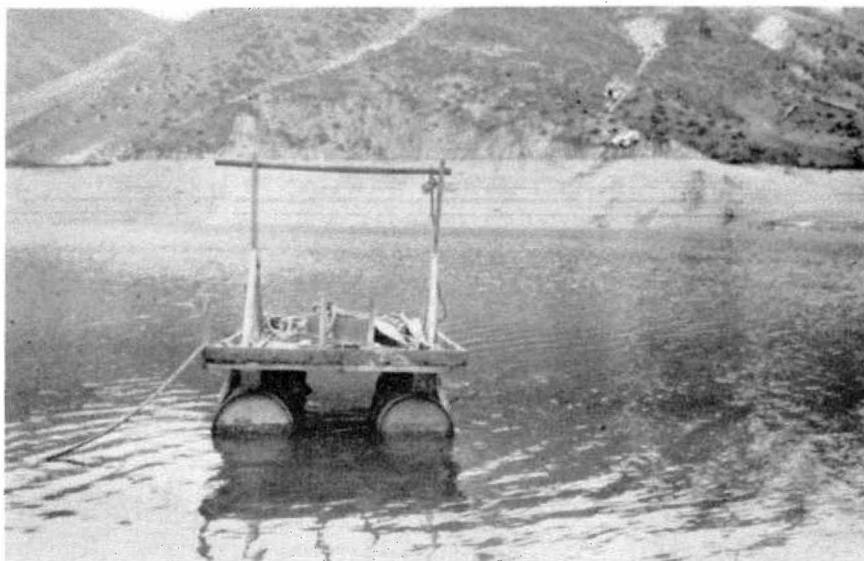
(b) Sediment deposits in Cinch Creek.



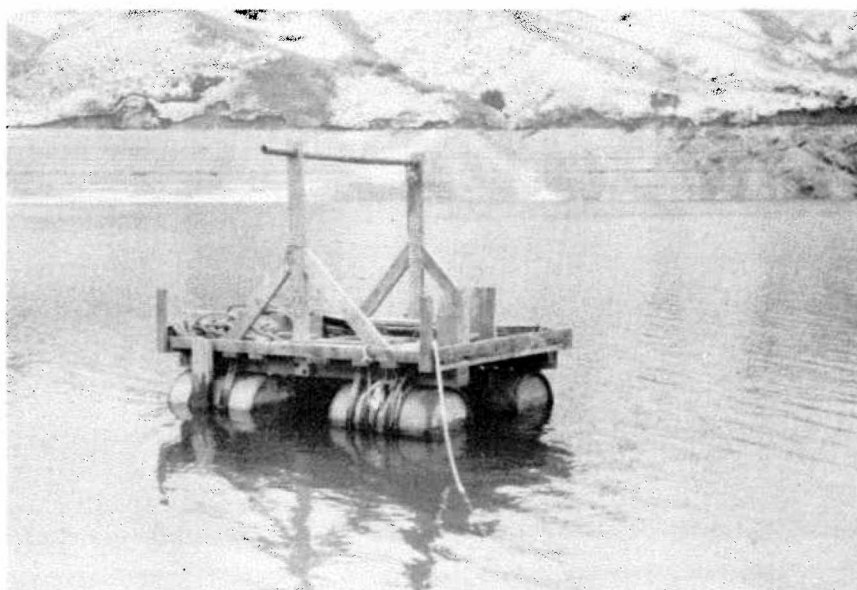
(a) Taking borings in sand delta on range 31, near head of backwater, Boise River.



(b) Confluence of Boise River and South Fork of Boise River.



(a) End view.

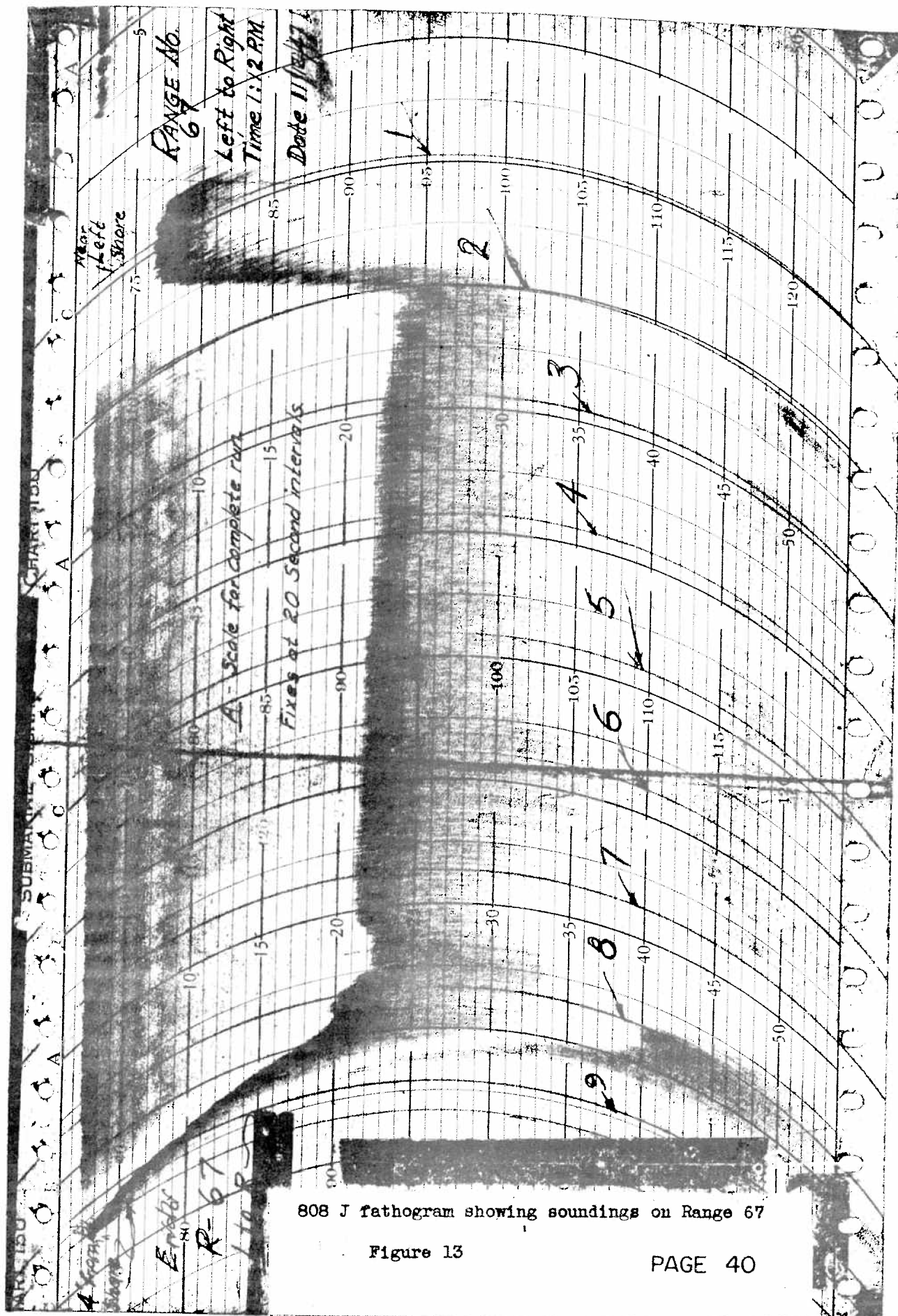


(b) Side view.

Raft used in taking sediment
measurements (Partially dismantled)



Sounding range 18 with 808J
portable fathometer.



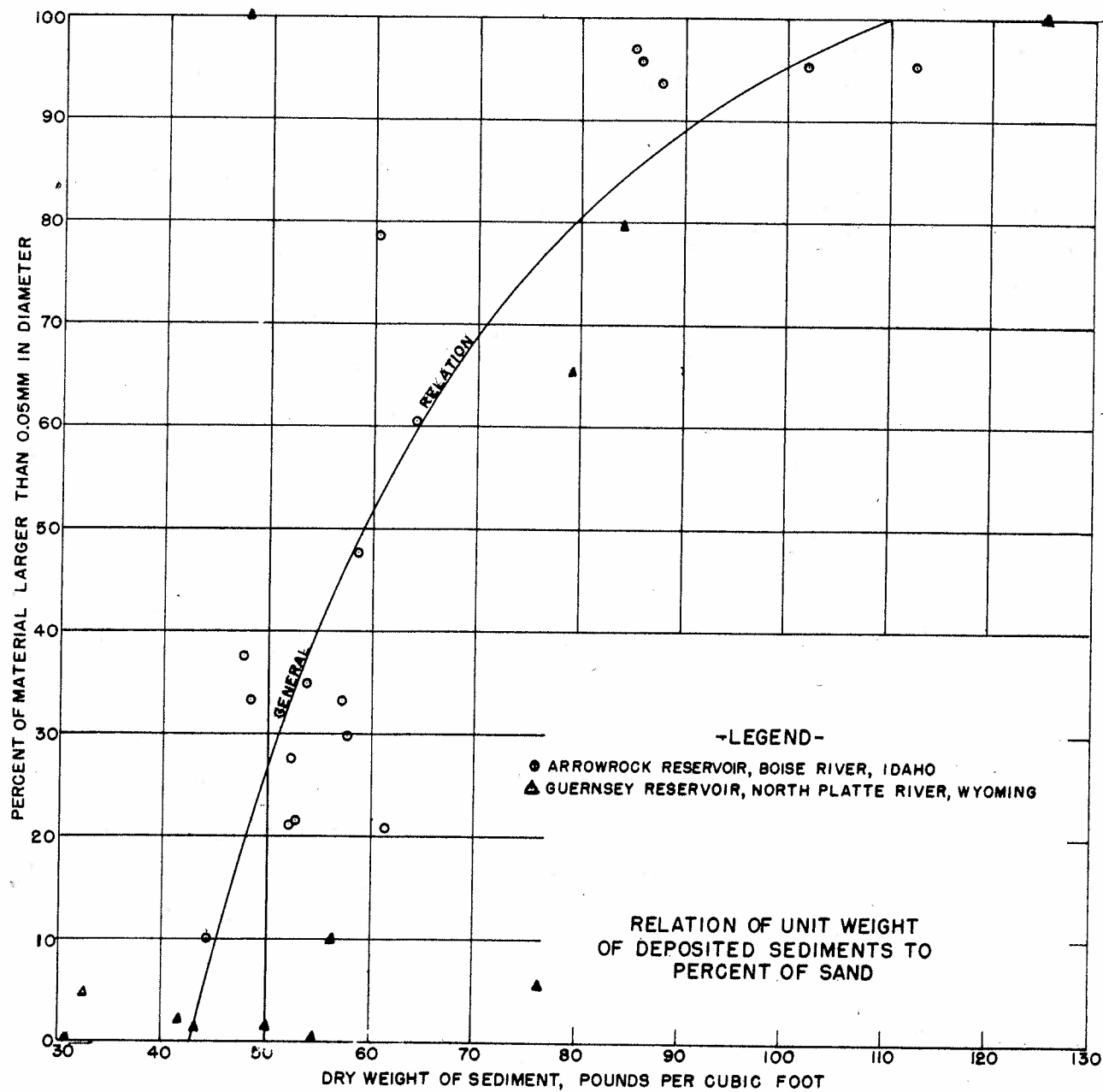


FIGURE 14

ARROWROCK RESERVOIR

COMPUTATION OF THE SEDIMENT VOLUME DEPOSITED ABOVE SLUICE GATES FROM 1942 TO 1947 THAT MIGHT HAVE BEEN SLUICED IF GATES HAD BEEN OPENED.

BOUNDING RANGES	AREA OF CROSS SECTION, SQ. FT.	DISTANCE BETWEEN RANGES, FEET	VOLUME SED. AC. FT.
DAM			
R-1	1710	230	9.03
R-2	2720	1400	71.19
R-3	2500	880	52.73
R-4	1910	550	27.84
R-5	1730	2370	99.02
R-6	0	2900	57.59

TOTAL VOLUME OF SEDIMENT THAT MIGHT HAVE BEEN SLUICED, 1942-1947, IF GATES HAD BEEN OPENED = 317.40 ACRE FEET.

∴ AVERAGE SEDIMENT THAT WOULD HAVE BEEN SLUICED PER YEAR = $317 \div 5 = 63$ ACRE FEET.

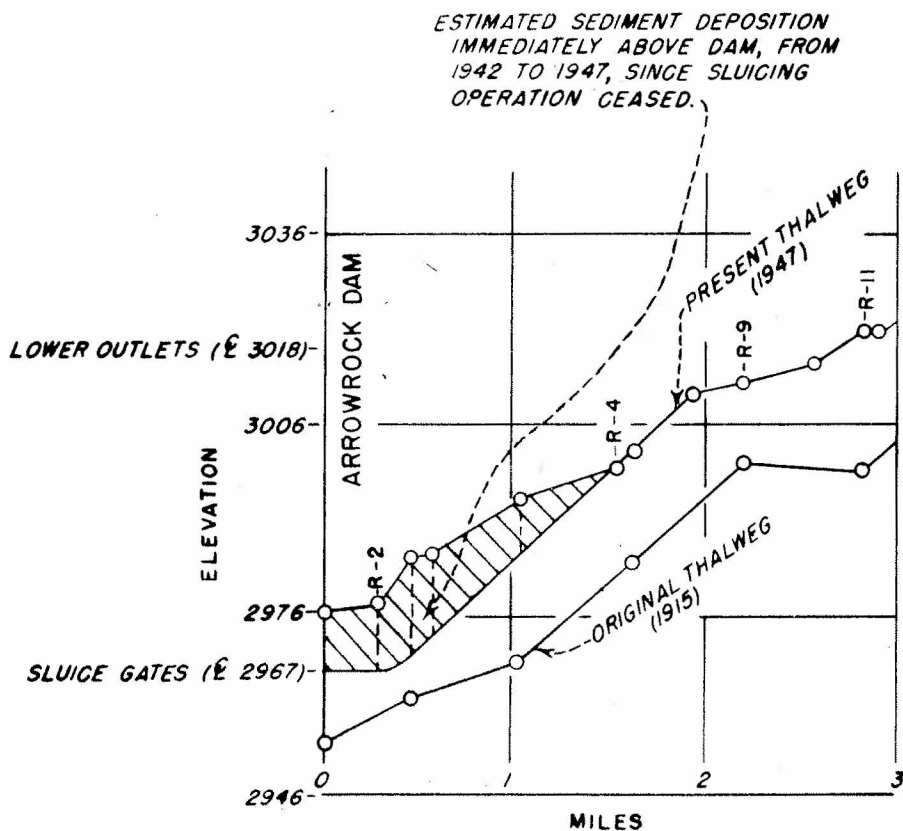
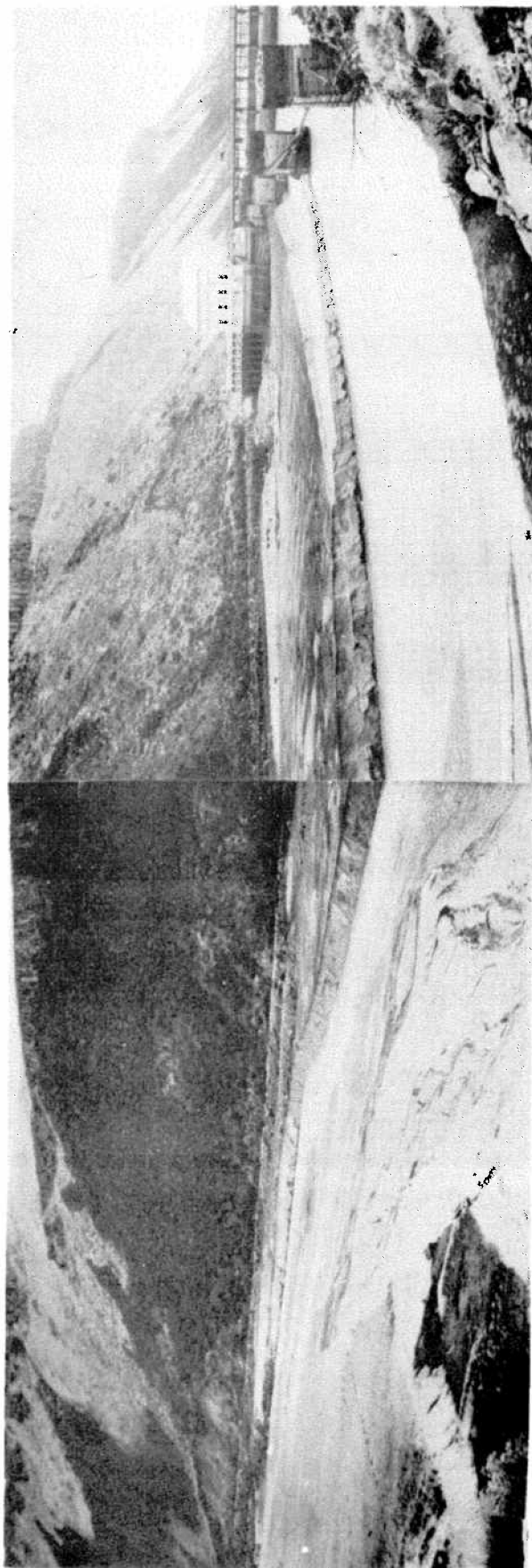


FIGURE 15



Sediment deposits on the Boise River above Diversion Dam.
(Its location is about 14 miles downstream from Arrowrock Dam.)

Figure 16