ARROWROCK RESERVOIR

1997 SEDIMENTATION SURVEY

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13. ABSTRACT ***(Maximum 200 words)***

The Bureau of Reclamation (Reclamation) surveyed Arrowrock Reservoir in October of 1987 and June 1997 to develop a topographic map and compute a present storage-elevation relationship (area-capacity tables). The data were used to calculate reservoir capacity lost due to sediment accumulation since dam closure in 1915. The 1987 aerial data were collected near reservoir elevation 3,028 feet. The 1997 underwater survey was conducted to complete topography of the reservoir and to measure changes that had occurred, due to sediment deposition, since 1987. The underwater survey used sonic depth recording equipment interfaced with a global positioning system (GPS) that gave continuous sounding positions throughout the underwater portion of the reservoir. The new topographic map of Arrowrock Reservoir was developed from the combined 1987 aerial and 1997 underwater measured topography.

As of June 1997, at top of active conservation elevation (feet) 3,216.0, the surface area was 3,141 acres with a total capacity of 272,224 acre-feet. Since initial filling in 1915, about 19,376 acre-feet of sediment have accumulated in Arrowrock Reservoir below elevation 3,216.0, resulting in a 6.64 percent loss in reservoir volume. Since 1915, the estimated average annual rate of reservoir capacity lost to sediment accumulation is 235.4 acre-feet

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ARROWROCK RESERVOIR

1997 SEDIMENTATION SURVEY

by

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Water Resources Services
Technical Service Center
Denver, Colorado

August 1998

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The Bureau of Reclamation's (Reclamation) Sedimentation and River Hydraulics Group of the Technical Service Center (TSC) prepared and published this report. Ronald Ferrari of the TSC conducted the hydrographic survey with assistance from Mr. Charlie (Pete) Swan and Mr. James Dean of the Pacific Northwest Region. Ronald Ferrari completed the data processing needed to generate the new topographic map and area-capacity tables. Sharon Nuanes of the TSC completed the final map development. Cassie Klumpp of the TSC performed the technical peer review of this documentation.

U.S. Department of the Interior
Mission Statement

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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INTRODUCTION

Arrowrock Dam, one of five principal features of the Boise Project, is located in Elmore County about 15 miles east of Boise, Idaho and about 4 miles below the confluence of the North and South Forks of the Boise River (fig. 1). Additional principal features are Anderson Ranch Dam, Black Canyon Dam, Boise River Diversion Dam, Cascade Dam, and Deadwood Dam. Lucky Peak Dam, built by the Corps of Engineers, is located about 1 mile upstream from the Boise River Diversion Dam and backs water up to Arrowrock Dam. Arrowrock Dam and Reservoir are owned and operated by Reclamation with the principal purpose to furnish irrigation water.

Arrowrock Dam construction was completed in 1916 with first storage in February 1915. The dam was repaired and raised an additional 5 feet from 1935 through 1937. The dam is a thick arch concrete structure whose dimensions are (fig. 2):

• Hydraulic height[1]	257 feet	• Structural height	350 feet
• Top width	16 feet	• Crest length	1,150 feet
• Crest elevation	3,216.0 feet	• Top of parapet wall	3,219.75 feet

The drainage area above Arrowrock Dam is 2,210 square miles, of which a calculated 1,597 square miles contributed sediment inflow during the study period. Sediments from the remaining drainage area are trapped by Anderson Ranch Reservoir and Dam that have a drainage area of 980 square miles and began water storage in December 1945. The basin ranges from elevation (feet)[2] 3,216, top of dam, to about 10,000 feet. Arrowrock Reservoir has an average width of 0.2 miles with a length, at elevation 3,216, of around 23.5 miles that includes the North and South Forks of the Boise River.

Arrowrock Dam's spillway, located in a granite cut at the right side of the dam, is a side-channel type structure controlled by 6 structural steel drum gates that are 62 feet long and 6 feet high, and separated by 6-foot piers. The spillway chute channel, about 800 feet long, is a concrete lined trapezoidal section that discharges into the tailwater formed by Luck Peak Reservoir. The spillway crest is at elevation 3,210.0 with top of gates at elevation 3,216.0. The spillway provides a maximum discharge of 40,000 cubic feet per second (ft^3/s) at maximum reservoir water surface elevation 3,219.75.

The outlet works consists of 25 outlets through the dam that are located in 3 tiers. These outlets have an original maximum discharge of 28,600 ft^3/s at reservoir water surface elevation 3,210.0. However, operation restrictions, as described in the current Arrowrock Dam standard operating procedures, have been placed on the outlets, have reduced the maximum discharge capacity allowed. The lower tier consists of five sluice outlets with a centerline elevation of 2,967.0. Each sluice outlet is 60 inches in diameter and controlled by 5- by 5-foot high-pressure gates. The middle tier consists of 10 outlets with a centerline elevation of 3,018.0.

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[1]The definitions of such terms as "hydraulic height," "structural height," etc. may be found in manuals such as Reclamation's *Design of Small Dams* and *Guide for Preparation of Standing Operating Procedures for Dams and Reservoirs*, or ASCE's *Nomenclature for Hydraulics*.

[2]Elevation levels are shown in feet.

Seven of these outlets are 52-inches in diameter with the other 3 tapering from 52- to 72-inch diameter. The upper tier consists of ten 52-inch diameter outlets with a centerline elevation of 3,105.0. The upper and middle outlets are primarily for irrigation and river releases controlled by 58-inch Ensign balanced valves installed at the upstream face of the dam.

SUMMARY AND CONCLUSIONS

This Reclamation report presents the 1997 results of the survey of Arrowrock Reservoir. The primary objectives of the survey were to gather data needed to:

- develop reservoir topography
- compute area-capacity relationships
- estimate storage depletion caused by sediment deposition since dam closure

Standard land surveying methods were used to establish the horizontal and vertical control points for the aerial survey that was flown in October 1987 around reservoir water surface elevation 3028. The aerial survey analysis was conducted by Reclamation's Mid-Pacific Region with the purpose of developing an area-capacity table of Arrowrock Reservoir. The average end area method was used to calculate the reservoir area and resulting volume by interpolating cross sections at 200-foot spacing throughout the reservoir. The survey measured a surface area of 3,138 acres and a storage capacity of 280,526 acre-feet at reservoir elevation 3,216.0. The study assumed a reservoir capacity of 5,430 acre-feet at elevation 3,028.0. This capacity came from the 1949 Arrowrock capacity tables and assumed no volume change due to sediment inflow.

The 1997 underwater survey was conducted to complete the reservoir topography below elevation 3,028 and to measure changes due to sediment deposition, above elevation 3,028, since the 1987 aerial survey. The horizontal control established for the aerial survey was also used for the June 1997 hydrographic survey. The bathymetric survey was run using sonic depth recording equipment interfaced with a differential global positioning system (DGPS) capable of determining sounding locations within the reservoir. The system continuously recorded depth and horizontal coordinates of the survey boat, as it was navigated along grid lines covering Arrowrock Reservoir. The positioning system provided information to allow the boat operator to maintain course along these grid lines. The grid lines were set up and run to concentrate the data collection in the channel sections of the grid lines. Water surface elevations recorded by a Reclamation gauge during the time of collection were used to convert the sonic depth measurements to true reservoir bottom elevations.

1997 Arrowrock Reservoir surface areas at predetermined contour intervals were generated by a computer graphics program using the collected reservoir data. The new reservoir topographic map is a combination of the 1987 aerial and 1997 underwater-measured topography, but was predominantly developed by the 1987 aerial data. The 1997 underwater collection provided data not covered by the aerial survey and in the river channel sections of the reservoir that had changed due to sediment deposition since 1987. The 1997 area and capacity tables were produced by a computer program that uses measured contour surface

areas and a curve-fitting technique to compute area and capacity at prescribed elevation increments (Bureau of Reclamation 1985).

Table 1 contains a summary of the Arrowrock Reservoir's watershed characteristics for the 1997 survey. The 1997 survey determined that the reservoir has a storage capacity of 272,224 acre-feet and a surface area of 3,141 acres at reservoir elevation 3,216.0 feet. Since closure in 1915, the reservoir had an estimated volume change of 19,376 acre-feet below reservoir elevation 3,216.0. This volume represents a 6.6 percent loss in capacity and an average annual loss of 235.4 acre-feet per year.

RESERVOIR OPERATIONS

Arrowrock Reservoir is primarily an irrigation facility, but operates in conjunction with Anderson Ranch and Lucky Peak Reservoirs to provide flood control. The July 1997 area-capacity tables show 272,224 acre-feet of total storage below elevation 3,216.0. The 1997 survey measured a minimum elevation of 2,987.4 which is around 20 feet above the five sluice outlets of the dam.

The Arrowrock Reservoir inflow and end-of-month stage records in table 1, operation period October 1947 through June 1997, show the inflow and annual fluctuation since the last reservoir survey in 1947. The average inflow into the reservoir for this operation period was 1,799,300 acre-feet per year. Extreme storage fluctuations of Arrowrock Reservoir ranged from an elevation of 2,969.0 in 1987, when there was no usable content, to the maximum recorded elevation of 3,219.1 in 1948 (table 1). The records show that in most years the reservoir fills to the near-full reservoir elevation of 3,216 and annually, while supplying irrigation water downstream, drops 100 to 200 feet in elevation. Records also show that, prior to the 1954 construction of Lucky Peak Reservoir, 50 percent of the years the sluice gates were operated wide open from a few days to a few months at a time. This allowed the natural flow to pass through the reservoir flushing a portion of the accumulated sediment downstream toward the dam and through the sluice gates. The 1947 sedimentation study estimated 1,300 acre-feet of the reservoir sediment was removed by sluicing from 1915 through 1947.

HYDROGRAPHIC SURVEY EQUIPMENT AND METHOD

The hydrographic survey equipment was mounted in the cabin of a 24-foot trihull aluminum vessel equipped with twin in-board motors. The hydrographic system contained on the survey vessel consisted of a global positioning system (GPS) receiver with a built-in radio and an omnidirectional antenna, a depth sounder, a helmsman display for navigation, a plotter, a computer, and hydrographic system software for collecting underwater data. Power to the equipment was supplied by an on-board generator.

The shore equipment included a second GPS receiver with a built-in radio and an omnidirectional antenna. The GPS receiver and antenna were mounted on a survey tripod over a known datum point. To obtain the maximum radio transmission range, known datum points with clear line-of-sight to the survey boat were selected. The power for the shore unit was provided by a 12-volt battery.

GPS Technology and Equipment

The hydrographic positioning system used at Arrowrock Reservoir was Navigation Satellite Timing and Ranging (NAVSTAR) GPS, an all-weather, radio-based, satellite navigation system that enables users to accurately determine three-dimensional position. The NAVSTAR system's primary mission is to provide passive global positioning and navigation for land-, air-, and sea-based strategic and tactical forces and is operated and maintained by the Department of Defense (DOD). The GPS receiver measures the distances between the satellites and itself and determines the receiver's position from intersections of the multiple-range vectors. Distances are determined by accurately measuring the time a signal pulse takes to travel from the satellite to the receiver.

The NAVSTAR system consists of three segments:

- The space segment is a network of 24 satellites maintained in a precise orbit about 10,900 nautical miles above the earth, each completing an orbit every 12 hours.

- The ground control segment tracks the satellites, determining their precise orbits. Periodically, the ground control segment transmits correction and other system data to all the satellites, and the data are then retransmitted to the user segment.

- The user segment includes the GPS receivers which measure the broadcasts from the satellites and calculate the position of the receivers.

The GPS receivers use the satellites as reference points for triangulating their position on earth. The position is calculated from distance measurements to the satellites that are determined by how long a radio signal takes to reach the receiver from the satellite. To calculate the receiver's position on earth, the satellite distance and the satellite's position in space are needed. The satellites transmit signals to the GPS receivers for distance measurements along with the data messages about their exact orbital location and operational status. The satellites transmit two "L" band frequencies (called L1 and L2) for the distance measurement signal. At least four satellite observations are required to mathematically solve for the four unknown receiver parameters (latitude, longitude, altitude, and time); the time unknown is caused by the clock error between the expensive satellite atomic clocks and the imperfect clocks in the GPS receivers. For hydrographic surveying of the altitude, Arrowrock's water surface elevation parameter was known, which realistically meant only three satellite observations were needed to track the survey vessel. During the Arrowrock Reservoir survey, the best six available satellites were used for position calculations.

The GPS receiver's absolute position is not as accurate as it appears in theory because of the function of range measurement precision and the geometric position of the satellites. Precision is affected by several factors--time, because of the clock differences, and atmospheric delays caused by the effect on the radio signal of the ionosphere. Geometric dilution of precision (GDOP) describes the geometrical uncertainty and is a function of the relative geometry of the satellites and the user. Generally, the closer together in angle two satellites are from the

receiver, the greater the GDOP. GDOP is broken into components: position dilution of precision (x,y,z) (PDOP), and horizontal dilution of precision (x,y) (HDOP). The components are based only on the geometry of the satellites. The PDOP and HDOP were monitored during the Arrowrock Reservoir Survey, and for the majority of the time they were less than 3, which is within the acceptable limits of horizontal accuracy for Class 1 and 2 level surveys (Corps of Engineers 1991).

An additional and larger error source in GPS collection is caused by false signal projection, called selective availability (S/A). The DOD implements S/A to discourage the use of the satellite system as a guidance tool by hostile forces. Positions determined by a single receiver when S/A is active can have errors of up to 100 meters.

A method of collection to resolve or cancel the inherent errors of GPS (satellite position or S/A, clock differences, atmospheric delay, etc.) is called differential GPS (DGPS). DGPS was used during the Arrowrock Reservoir survey to determine positions of the moving survey vessel in real time. DGPS determines the position of one receiver in reference to another and is a method of increasing position accuracies by eliminating or minimizing the uncertainties. Differential positioning is not concerned with the absolute position of each unit but with the relative difference between the positions of two units, which are simultaneously observing the same satellites. The inherent errors are mostly canceled because the satellite transmission is essentially the same at both receivers.

At a known geographical benchmark, one GPS receiver is programmed with the known coordinates and stationed over that geographical benchmark. This receiver, known as the master or reference unit, remains over the known benchmark, monitors the movement of the satellites, and calculates its apparent geographical position by direct reception from the satellites. The inherent errors in the satellite position are determined relative to the master receiver's programmed position, and the necessary corrections or differences are transmitted to the mobile GPS receiver on the survey vessel. For the Arrowrock Reservoir survey, position corrections were determined by the master receiver and transmitted via an ultra-high frequency (UHF) radio link every 3 seconds to the survey vessel mobile receiver. The survey vessel's GPS receiver used the corrections along with the satellite information it received to determine the vessel's differential location. Using DGPS resulted in positional accuracies of 1 to 2 meters for the moving vessel compared to positional accuracies of 100 meters with a single receiver.

The Technical Service Center (TSC) mobile and reference GPS units are identical in construction and consist of a 6-channel L1 coarse acquisition (C/A) code continuous parallel-tracking receiver, an internal modem, and a UHF radio transceiver. The differential corrections from the reference station to the mobile station are transmitted using the industry standard Radio Technical Commission for Maritime Services (RTCM) message protocol via the UHF radio link. The programming to the mobile or reference GPS unit is accomplished by entering necessary information via a notebook computer. The TSC's GPS system has the capability of establishing or confirming the land base control points by using notebook computers for logging data and postprocessing software. The GPS collection system has the capability to collect data in 1927 or 1983 North American Datums (NAD) in the surveyed

area's state plane coordinate system's zone. For Arrowrock Reservoir, the data were collected in Idaho's 1927 NAD west state plane zone. The 1997 developed contours had to be shifted slightly to match the digitized U.S. Geological Survey (USGS) quad features.

Survey Method and Equipment

The Arrowrock Reservoir hydrographic survey collection was conducted June 16 through June 19, 1997. The water surface, collected in 15-minute increments, varied between elevations 3,211.4 and 3,214.9, where at the time, the reservoir was spilling. The bathymetric survey was run using sonic depth recording equipment interfaced with a DGPS capable of determining sounding locations within the reservoir. The survey system software continuously recorded reservoir depths and horizontal coordinates as the survey boat moved across closely spaced grid lines covering the reservoir area. Most of the transects (grid lines) were run in a perpendicular direction to the original river thalweg at 300-foot spacing. The survey vessel's guidance system gave directions to the boat operator to assist in maintaining course along these predetermined lines. During each run, the depth and position data were recorded on the notebook computer hard drive for subsequent processing. A graphic plotter was used in the field to track the boat and ensure adequate coverage during the collection process.

The topography of the Boise River drainage area above Arrowrock Dam is rugged and mountainous with the reservoir having very steep slopes and the upper area very narrow with steep bank conditions. These conditions make it difficult for surveying mainly when you consider the original survey was conducted by standard land survey techniques. The 1987 aerial survey needed extensive horizontal and vertical control requiring a helicopter to gain access to many of the control points. The 1987 aerial collection was conducted when the reservoir was nearly empty, about elevation 3028, which allowed mapping of the majority of the reservoir area. The 1947 sedimentation study (Reclamation 1948) observed a redistribution of sediment during the course of the survey where the channel sediments in the upper arms of the reservoir were flushed downstream into the lower reservoir. Due to these conditions the 1997 survey focused the underwater collection in the channel portions of the reservoir using the aerial data to map the steep side slopes of the reservoir. This assumed no change of the steep side slopes of the reservoir since 1987. The 1997 hydrographic survey ran transects of the channel portions of the reservoir from Arrowrock Dam upstream into the North and South Forks of the Boise River. The collection ended in the upstream area of the north and south forks of the reservoir when a comparison of the 1997 collected depths with the 1987 depths found no significant change.

To keep the 1997 control work to a minimum the hydrographic survey started with three 1987 established control points that were accessible and located in the lower portions of the reservoir. Three temporary points were established in June of 1997, using the 1987 control, to provide the needed shore datums to survey the channel areas of the north and south forks of the river. A listing of the 1987 control points used during the 1997 hydrographic survey control is shown below.

Point number	North	East	Elevation
101	701095.50	456656.78	3255.94
103	706226.60	459852.96	3228.70
104	703082.73	465451.93	3245.63

The 1997 underwater data were collected by a depth sounder that was calibrated by lowering a deflector plate below the boat by cables with known depths marked by beads. The depth sounder was calibrated by adjusting the speed of sound, which can vary with density, salinity, temperature, turbidity, and other conditions. The collected data were digitally transmitted to the computer collection system via a RS-232 port. The depth sounder also produces an analog hard-copy chart of the measured depths. These graphed analog charts were printed for all survey lines as the data were collected and recorded by the computer. The charts were analyzed during postprocessing, and when the analog charted depths indicated a difference from the recorded computer bottom depths, the computer data files were modified. The analog charts were also used to determine the steep side slopes of the data files which were removed from the underwater data set. The water surface elevations at the dam, recorded by a Reclamation gauge at 15-minute intervals, were used to convert the sonic depth measurements to true lake-bottom elevations.

RESERVOIR AREA AND CAPACITY

Topography Development

Using ARC/INFO the topography of Arrowrock Reservoir was developed from the combined 1987 aerial and 1997 underwater data. ARC/INFO is a software package for development and analysis of geographic information system (GIS) layers and development of interactive GIS applications (ESRI 1992). GIS technology provides a means of organizing and interpreting large data sets. The new topography was predominantly developed by the 1987 aerial data. The 1997 underwater collection provided data in the channel sections of the reservoir not covered by the aerial collection and in the reservoir areas that changed due to sediment deposition since 1987.

Using ARCEDIT the underwater and aerial data layers were plotted. Using the select and delete commands the 1987 aerial data points of the reservoir channel sections that were overlapped by the 1997 underwater channel section data were removed. Removal of the overlapping 1987 channel data generated present reservoir condition topography. This data set was used to compute present reservoir capacity.

During contour development, interpolated data points wre used because there were inadequate aerial data points for developing complete upper contours at Arrowrock Dam and at the vertical wall of Lambing Creek. The 1987 aerial analysis measured cross sections at 200-foot spacings starting at the upstream face of the dam. This was adequate for area computations, but lacked necessary data points to cause complete upper contour closure. At elevation 3,216.0, the 1987 cross section aerial analysis measured a surface area of 3,140 acres and the 1997 study measured a surface area of 3,141 acres with the interpolated data points. The

interpolated data points resulted in a complete contour that was closer with an insignificant change to the area computation. Appending the edited aerial and underwater data sets gave a total of 16,191 coordinate points for contour development as illustrated on figure 3. The combined collected data ranged from elevation 2,987.3 to elevation 3,490.8. The data were collected in the Idaho west zone state plane coordinates in NAD 1927. A slight shift in the contour data was required to match with the USGS quad map features.

The contours of the reservoir were developed by digitizing a boundary around the edge of the combined data set that covered the reservoir area. The digitized polygon enclosing the data set was assigned an elevation of no data and was used to perform a clip of Arrowrock Reservoir such that interpolation was not allowed to occur outside of this boundary. This clip was performed using the hardclip option of the ARC/INFO CREATETIN command.

Contours for the reservoir were computed from the combined data set using the triangular irregular network (TIN) surface modeling package within ARC/INFO. A TIN is a set of adjacent, non-overlapping triangles computed from irregularly spaced points with x,y coordinates and z values. TIN was designed to deal with continuous data such as elevations. The TIN software uses a method known as Delaunay's criteria for triangulation where triangles are formed between all data points within the polygon clip. The method requires that a circle drawn through the three nodes of a triangle will contain no other point, meaning that sample points are connected to their nearest neighbors to form triangles using all collected data. This method preserves all collected survey points. Elevation contours are then interpolated along the triangle elements. The TIN method is discussed in greater detail in ARC/INFO V7.0.2 *ARC Command References* (ESRI 1992).

The linear interpolation option of the ARC/INFO TINCONTOUR command was used to interpolate contours from the Arrowrock Reservoir TIN. In addition, the contours were generalized by weeding out vertices along the contours. This generalization process improved the presentability of the resulting contours by removing very small variations in the contour lines. This generalization had no bearing on the computation of surface areas and volumes for Arrowrock Reservoir since the areas were calculated from the developed TIN.

ARC/INFO V7.0.2 GIS software was used to digitize the USGS quad features such as the dam, roads and portions of reservoir contour elevation 3,216.0. The digitized features were transformed to Idaho's NAD 1927 west state plane coordinates using the ARC/INFO PROJECT command. Using ARCEDIT, the 1997 developed contours and the digitized USGS feature layers were plotted. The resulting plot found that the 1997 developed contours did not line up with the USGS digitized features. To match the USGS quad layer with the 1997 contour layers required shifting the 1997 contours about 90 feet to the west and 195 feet to the south. This shift to line up the features did not affect the computed surface areas and resulting reservoir volume since the 1987 aerial and 1997 underwater data were collected with the same control system. The contour topography at 10-foot intervals is presented on figures 4 through 10 (drawing numbers 3-D-2227 through 3-D-2233). The contour topography on these maps was drawn as developed without any shifting of the 1987 and 1997 collected data. The USGS features on the maps were shifted about 90 feet to the east and 195 feet to the north to line up with the 1997 Arrowrock Reservoir contours.

Development of 1997 Contour Areas

The 1997 contour surface areas for Arrowrock Reservoir were computed at 5-foot increments, from elevations 2,988.0 to 3,225.0, using the Arrowrock Reservoir TIN discussed above. The 1997 survey measured the minimum reservoir elevation at 2,987.3 feet. These calculations were performed using the ARC/INFO VOLUME command. This command computes areas at user-specified elevations directly from the TIN and takes into consideration all regions of equal elevation.

1997 Storage Capacity

The storage-elevation relationships based on the measured surface areas were developed using the area-capacity computer program ACAP85 (Bureau of Reclamation 1985). Surface areas at 5-foot contour intervals from minimum reservoir elevation 2,987.3 to elevation 3,225.0 were used as the control parameters for computing the Arrowrock Reservoir capacity. The program can compute an area and capacity at elevation increments of 0.01- to 1.0-foot by linear interpolation between the given contour surface areas. The program begins by testing the initial capacity equation over successive intervals to ensure that the equation fits within an allowable error limit. The error limit was set at 0.000001 for Arrowrock Reservoir. The capacity equation is then used over the full range of intervals fitting within this allowable error limit. For the first interval at which the initial allowable error limit is exceeded, a new capacity equation (integrated from basic area curve over that interval) is utilized until it exceeds the error limit. Thus, the capacity curve is defined by a series of curves, each fitting a certain region of data. Final area equations are derived by differentiating the capacity equations, which are of second order polynomial form:

$$y = a_1 + a_2x + a_3x^2$$

where:

y = capacity
x = elevation above a reference base
a_1 = intercept
a_2 and a_3 = coefficients

Results of the 1997 Arrowrock Reservoir area and capacity computations are listed in table 1. A separate set of 1997 area and capacity tables has been published for the 0.01-, 0.1-, and 1-foot elevation increments (Bureau of Reclamation 1997). A description of the computations and coefficients output from the ACAP85 program is included with these tables. Both the original and 1997 area-capacity curves are plotted on figure 5. As of June 1997, at elevation 3,216.0, the surface area was 3,141 acres with a total capacity of 272,224 acre-feet.

SEDIMENT ANALYSES

Figure 11 is a plot of Arrowrock Reservoir's original area data versus the 1997 measured areas. This illustrates the difference between the original and the 1997 measured surface

areas. At elevation 3,216.0, the 1997 survey measured a 1.6 percent larger surface area of 3,141 acres compared to the original measured surface area of 3,089 acres. This difference could be attributed to shore line erosion, but the area plots are a near-mirror image of each other possibly indicating an elevation datum difference between the surveys. Review of available literature did not find any reference to either of these conditions.

The topography of the drainage area above Arrowrock Dam is rugged and mountainous with the slopes of the valley sides of the reservoir being very steep. These types of conditions make it very difficult for surveying. It is assumed that the 1915 surface areas were measured by standard plane table survey techniques. For the 1987 aerial survey a helicopter was used to gain access to many of the control points. It is the general conclusion by this study that the resulting surface area difference of the two surveys was mainly attributed to the accuracy difference between the two methods of collection.

One of the purposes of the 1997 survey was to measure the reservoir volume lost due to sediment contribution since dam closure in 1915 and since the last reservoir sedimentation survey in 1947. The 1947 sedimentation survey of Arrowrock Reservoir indicated that the original, 1915, measured capacity at elevation 3,216.0 was 279,250 acre-feet with the 1947 measured capacity being 271,550 acre-feet. The 1947 operation capacity at elevation 3,216.0 was reported as 286,500 acre-feet which was calculated from inflow-outflow records. The 14,950 acre-feet difference between the 1947 measured and operating capacity was attributed to significant bank storage. For the purpose of the 1997 study it was assumed the capacity difference is more due to the method and accuracy of the different surveys than bank storage. From the 1915 inflow and outflow records the original operation capacity at elevation 3,211.0 was reported as 276,500 acre-feet. In 1935, the dam was raised to elevation 3,216.0. For the purpose of calculating 1997 sediment deposition the original capacity was projected to be 291,600 acre-feet at elevation 3,216.0.

Since Arrowrock Dam closure in February 1915, the measured total volume change at reservoir elevation 3,216.0 was estimated to be 19,376 acre-feet. The estimated average annual rate of capacity lost for this time period (82.3 years) was 235.4 acre-feet per year. The storage loss in terms of percent of original storage capacity was 6.64 percent. Table 1 contains the Arrowrock Reservoir sediment accumulation and water storage data based on the 1997 resurvey.

The sediment computation values must be questioned due to all the interpolation of reservoir capacity and sluicing of reservoir sediments, but the resulting value of 235.4 acre-feet per year appears reasonable when compared to previous studies and other reservoirs in the region. It must be noted that all the annual sediment accumulation values in table 1 do not account for reservoir sediment that has been removed due to sluicing operations. The 1947 sediment survey of Arrowrock Reservoir gave a conservative estimate of 1,300 acre-feet of sediment that had been sluiced from the reservoir. If this value was considered in the 1947 study then the estimated average annual rate of sediment inflow would have been 276.1 acre-feet. The sediment trapping affect of Anderson Ranch reduced this annual value to 230.2 acre-feet, but as stated previously all the interpolations affect the actual sediment computation values. A resurvey of Arrowrock Reservoir should be considered in the future if major sediment inflow

events are observed, or if the average annual rate of sediment accumulation requires further clarification.

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RESERVOIR SEDIMENT
DATA SUMMARY

Arrowrock Reservoir
NAME OF RESERVOIR

1
DATA SHEET NO.

DAM

1. OWNER Bureau of Reclamation	2. STREAM Boise River	3. STATE Idaho
4. SEC. 13 TWP. 3 N RANGE 4 E	5. NEAREST P.O. Boise	6. COUNTY Elmore
7. LAT 43° 35' 39" LONG 115° 55' 20"	8. TOP OF DAM ELEVATION 3219.75[1]	9. SPILLWAY CREST EL 3210.0[2]

RESERVOIR

10. STORAGE ALLOCATION	11. ELEVATION TOP OF POOL	12. ORIGINAL SURFACE AREA, AC	13. ORIGINAL CAPACITY, AF	14. GROSS STORAGE ACRE- FEET	15. DATE STORAGE BEGAN
a. SURCHARGE					
b. FLOOD CONTROL					
c. POWER					2/15
d. WATER SUPPLY					
e. IRRIGATION					16. DATE NORMAL OPERATION BEGAN
f. CONSERVATION	3216.0	3089	286,500	286,500	
g. DEAD					2/15

17. LENGTH OF RESERVOIR 23.5[3] MILES — AVG. WIDTH OF RESERVOIR 0.2 MILES

BASIN

18. TOTAL DRAINAGE AREA 2,210 SQUARE MILES		22. MEAN ANNUAL PRECIPITATION	11.7[4] INCHES
19. NET SEDIMENT CONTRIBUTING AREA 1,597[5] SQUARE MILES		23. MEAN ANNUAL RUNOFF	14.6[6] INCHES
20. LENGTH 66 MILES	AV. WIDTH 33 MILES	24. MEAN ANNUAL RUNOFF	1,717,100[7] ACRE-FEET
21. MAX. ELEVATION 10000	MIN. ELEVATION 3216	25. ANNUAL TEMP. MEAN 52°F RANGE -23°F to 108°F[8]	

SURVEY DATA

26. DATE OF SURVEY	27. PER. YRS.	28. ACCL. YRS.	29. TYPE OF SURVEY	30. NO. OF RANGES OR INTERVAL	31. SURFACE AREA, AC.	32. CAPACITY ACRE-FEET	33. C/I RATIO AF/AF
2/15			Contour	20-ft	3,089	291,600[9]	.17
10/47	32.6	32.6	Range	71	3,089	286,500[9]	.17
6/97	49.7	82.3	Contour (D)	10-ft	3,141	272,224[10]	.16

26. DATE OF SURVEY	34. PERIOD ANNUAL PRECIP.	35. PERIOD WATER INFLOW, ACRE FEET			WATER INFLOW TO DATE, AF	
		a. MEAN ANN.	b. MAX. ANN.	c. TOTAL	a. MEAN ANN.	b. TOTAL
10/47	18.53	1,572,509	3,006,000	51,892,823	1,572,509	51,892,823
6/97	11.7[4]	1,799,300[11]	3,107,800	89,423,890	1,717,100	141,316,713

26. DATE OF SURVEY	37. PERIOD CAPACITY LOSS, ACRE-FEET			38. TOTAL SEDIMENT DEPOSITS TO DATE, AF		
	a. TOTAL	b. AV. ANN.	c. /MI.^{2}-YR.	a. TOTAL	b. AV. ANNUAL	c. /MI.^{2}-YR.
10/47	7,700[12]	235.9	.11	7,700	235.9	.11
6/97	14,276[13]	230.2	.14	19,376[14]	235.4	.15

26. DATE OF SURVEY	39. AV. DRY WT. (#/FT^3)	40. SED. DEP. TONS/MI.^{2}-YR.		41. STORAGE LOSS, PCT.		42. SEDIMENT INFLOW, PPM	
		a. PERIOD	b. TOTAL TO DATE	a. AV. ANNUAL	b. TOTAL TO DATE	a. PER.	b. TOT.
10/47	73	173.3	173.3	0.0869	2.84	174	174
6/97				0.0807[14]	6.64[14]		

26. DATE OF SURVEY	43. DEPTH DESIGNATION RANGE BY RESERVOIR ELEVATION											
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION											

26. DATE OF SURVEY	44. REACH DESIGNATION PERCENT OF TOTAL ORIGINAL LENGTH OF RESERVOIR														
	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-105	105-110	110-115	115-120	120-125
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN REACH DESIGNATION														

Table 1. - Reservoir sediment data summary (page 1 of 2).

45. RANGE IN RESERVOIR OPERATION[11]

YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF	YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF
1948	3,219.1	3,089	1,572,900	1949	3,219	3,056	1,492,850
1950	3,219	3,057	1,816,940	1951	3,218	3,048	1,797,780
1952	3,216	3,071	2,553,240	1953	3,216	3,087	1,898,980
1954	3,219	3,058	1,907,430	1955	3,217	3,068	1,166,880
1956	3,217	3,045	2,213,570	1957	3,217	3,070	1,976,870
1958	3,217	3,068	2,204,260	1959	3,214	3,030	1,382,600
1960	3,217.0	2,993.0	1,591,300	1961	3,217.0	2,993.0	1,235,080
1962	3,211.5	3,031.0	1,447,110	1963	3,217.8	3,035.9	1,606,100
1964	3,216.4	3,060.2	1,606,200	1965	3,216.8	3,108.7	3,107,800
1966	3,214.9	3,021.9	1,300,700	1967	3,206.4	3,019.7	1,378,500
1968	3,214.2	3,006.0	1,336,100	1969	3,215.6	3,023.8	2,163,500
1970	3,216.0	3,067.8	2,053,600	1971	3,216.8	3,009.1	2,904,800
1972	3,216.2	3,063.4	2,659,500	1973	3,214.7	3,024.5	1,331,400
1974	3,213.4	3,106.0	2,714,800	1975	3,213.7	3,101.5	2,257,200
1976	3,213.3	3,061.1	1,871,600	1977	3,185.0	2,994.0	912,600
1978	3,213.1	3,071.8	1,672,200	1979	3,213.7	3,181.0	1,080,600
1980	3,215.8	3,120.6	1,737,100	1981	3,216.4	3,085.2	1,254,800
1982	3,217.2	3,108.5	2,714,900	1983	3,215.3	3,094.8	2,796,900
1984	3,216.7	3,112.8	2,582,670	1985	3,205.7	3,085.5	1,492,680
1986	3,216.0	3,148.4	2,462,560	1987	3,199.7	2,969.0	1,129,570
1988	3,181.8	3,000.0	994,330	1989	3,188.2	3,025.4	1,444,930
1990	3,172.7	3,068.0	1,160,000[12]	1991	3,198.9	3,055.7	1,079,460
1992	3,160.4	3,040.6	777,570	1993	3,213.2	3,103.2	1,470,800
1994	3,198.7	3,044.1	1,007,870	1995	3,215.6	3,077.8	1,848,000[11]
1996	3,215.3	3,099.0	2,539,930	1997	3,215	3,111	2,714,830[11]

46. ELEVATION - AREA - CAPACITY DATA FOR **1997 CAPACITY**[13]

ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
2987.3	0	0	3000	7.7	21	3010	40.1	263
3020	70.9	814	3030	156.3	1,957	3040	202.0	3,740
3050	265.8	6,071	3060	402.6	9,464	3070	554.5	14,149
3080	702.5	20,472	3090	869.6	28,339	3100	1,045.1	37,912
3110	1,204.0	49,160	3120	1,358.8	61,962	3130	1,531.9	76,383
3140	1,694.8	92,540	3150	1,853.0	110,295	3160	2,022.6	129,683
3170	2,195.7	150,750	3180	2,374.7	173,605	3190	2,561.2	198,282
3200	2,775.2	224,962	3210	2,998.1	253,815	3216	3,141	272,224
3220	3,248.0	285,003						

47. REMARKS AND REFERENCES

[1] Top parapet wall is elevation 3219.75. Roadway elevation is 3216.0. Dam raised 5-feet in 1935.
[2] Top of gates elevation is 3216.0. Spillway sill elevation is 3210.0.
[3] Length main arm = 12.8 miles, length of South Fork arm = 10.7 miles.
[4] Bureau of Reclamation Project Data Book, 1981. Reported value for all of Boise Project.
[5] Represents loss of contributing area since dam closure, 12/45, at Anderson Ranch with total drainage of 980 mi^2.
[6] Net contributing area of 1597 mi^2 = 2210 mi^2 - 980 mi^2 (51.5 yrs/82.3 yrs).
[7] Calculated using mean annual runoff value of 1,717,100 AF, item 24, 1915-1997.
[8] Computed annual inflows from 1915 through 6/97.
[9] The original calculated volume at el. 3216 was 279,550 AF which did not include bank storage. Based on 1915 inflow-outflow records the original operating capacity, at el. 3211, was reported as 276,500 AF. Dam raised 5-ft in 1935. For sediment computations, the original operating capacity, at el. 3216, was projected to be 291,600 AF. 1947 survey measured capacity reported as 271,550 AF at El. 3216. The operation capacity reported as 286,500 AF, based on 1935 inflow - outflow records. The difference attributed to significant bank storage.
[10] Surface area & capacity at el. 3216.0 computed by ACAP program using 1987 aerial and 1997 underwater survey data.
[11] Inflow values in acre-feet and maximum and minimum elevations in feet by water year from 2/15 through 6/97. Inflow estimated for 1990 and 1995 due to missing monthly records. Years with whole elevation values in item 45 were estimated from reservoir content records. 1960 through 1996 from USGS water records.
[12] The 1947 sediment survey assume a original capacity of 279,250 AF and 1947 capacity of 271,550 AF at El. 3216.0. Volume does not include 1,300 AF of sediment estimated to have been removed by sluicing.
[13] Difference of capacity 1935 (286,500 AF) & 1997 (272,224 AF). Average value for 62 years of operation. Question as to true original capacity. 1915 inflow - outflow records measured capacity as 276,500 AF at el. 3211. Projected 1915 reservoir capacity as 291,600 AF, at el. 3216.0. Assume portion of capacity difference due to accuracy difference of two surveys.
[14] Capacities computed by Reclamation's ACAP computer program.

48. AGENCY MAKING SURVEY Bureau of Reclamation
49. AGENCY SUPPLYING DATA Bureau of Reclamation | DATE May 1998

Table 1. - Reservoir sediment data summary (page 2 of 2).

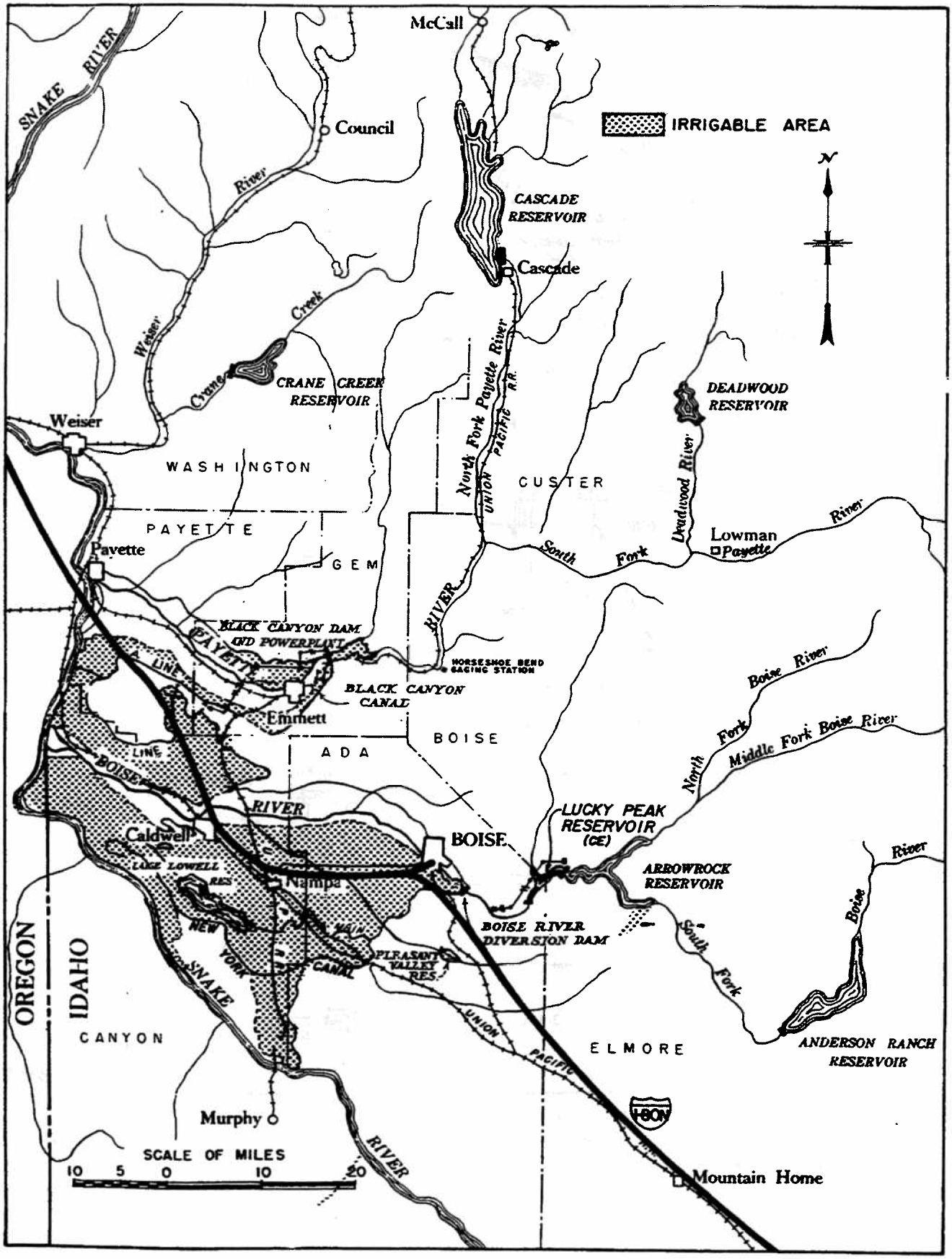


Figure 1. - Arrowrock Reservoir location map.

Space intentionally left blank due to security concerns

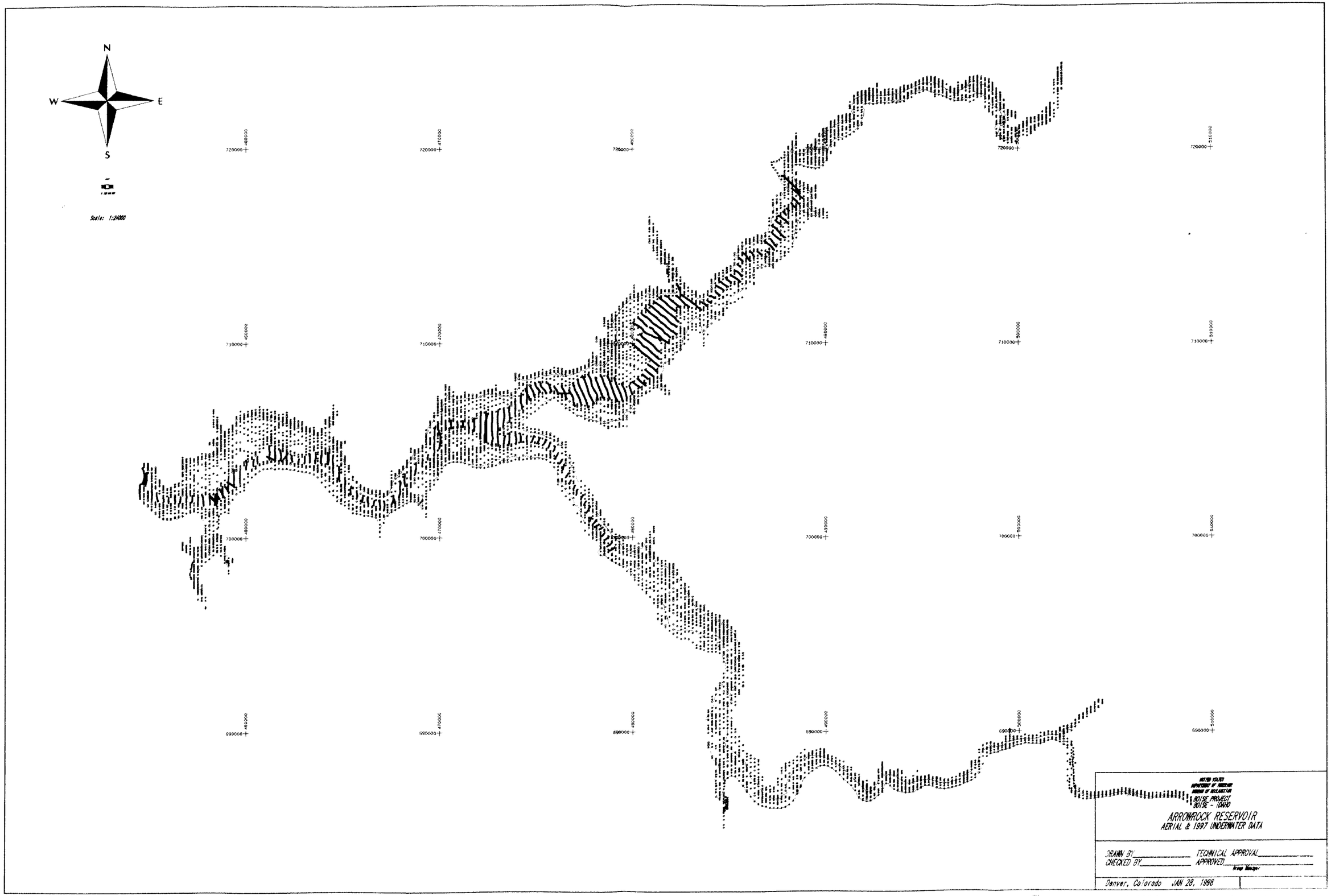


Figure 3. - Arrowrock 1997 underwater data points.

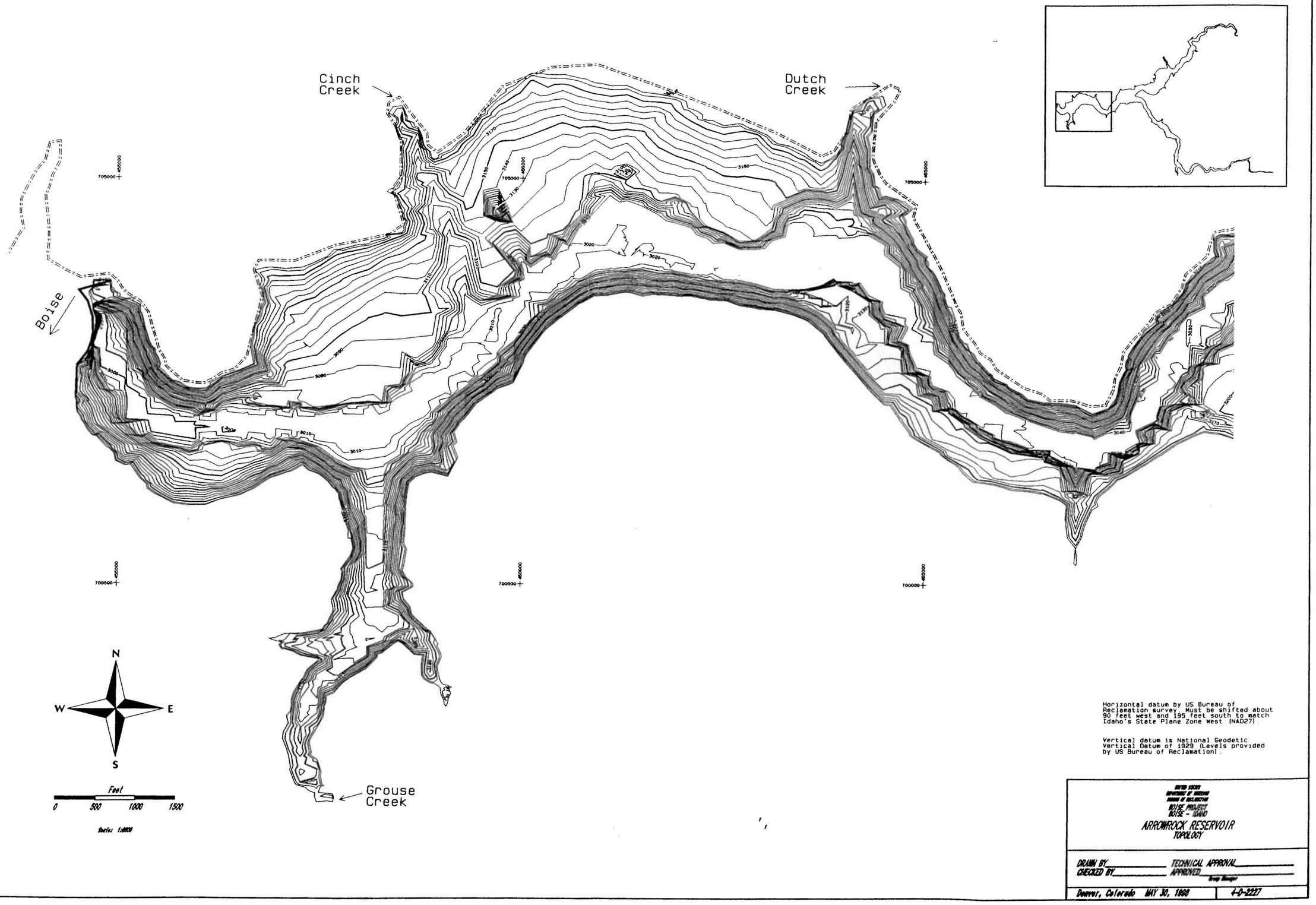
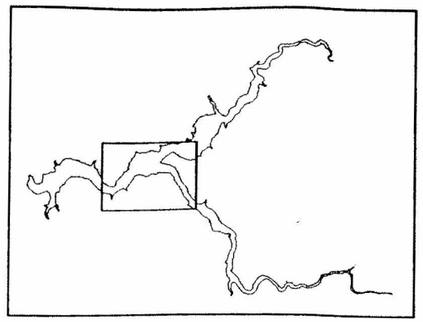


Figure 4. - Arrowrock Reservoir topographic map, No. 3-D-2227.



Horizontal datum by US Bureau of Reclamation survey. Must be shifted about 90 feet west and 195 feet south to match Idaho's State Plane Zone West (NAD27).

Vertical datum is National Geodetic Vertical Datum of 1929 (Levels provided by US Bureau of Reclamation).

UNITED STATES
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BOISE PROJECT
BOISE - IDAHO

ARROWROCK RESERVOIR
TOPOLOGY

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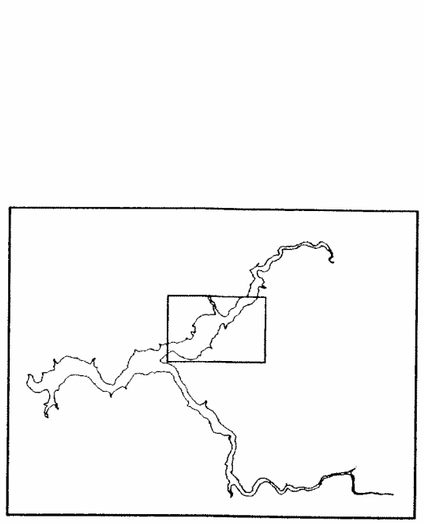
CHECKED BY_____ APPROVED_____
Area Manager

Denver, Colorado MAY 30, 1968 | 4-D-2228

Figure 5. - Arrowrock Reservoir topographic map, No. 3-D-2228.



Cottonwood Creek

North Fork Boise River

N
W E
S

Feet
0 500 1000 1500

Scale: 1:6000

Horizontal datum by US Bureau of Reclamation survey. Must be shifted about 90 feet west and 195 feet south to match Idaho's State Plane Zone West (NAD27).

Vertical datum is National Geodetic Vertical Datum of 1929 (Levels provided by US Bureau of Reclamation).

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CHECKED BY _____ APPROVED _____
Group Manager

Denver, Colorado MAY 30, 1968 | 4-D-2229

Figure 6. - Arrowrock Reservoir topographic map, No. 3-D-2229.

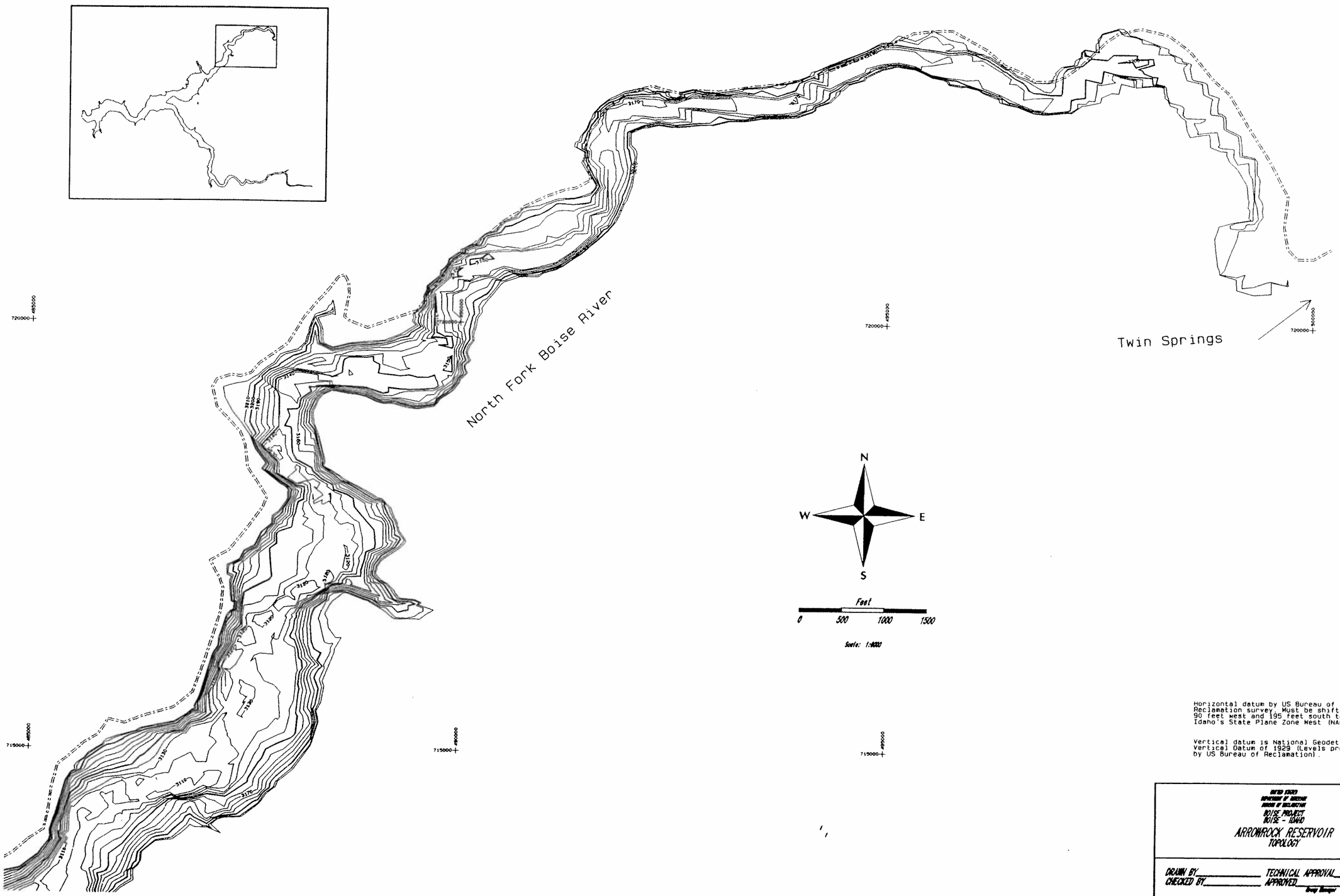


Figure 7. - Arrowrock Reservoir topographic map, No. 3-D-2230.

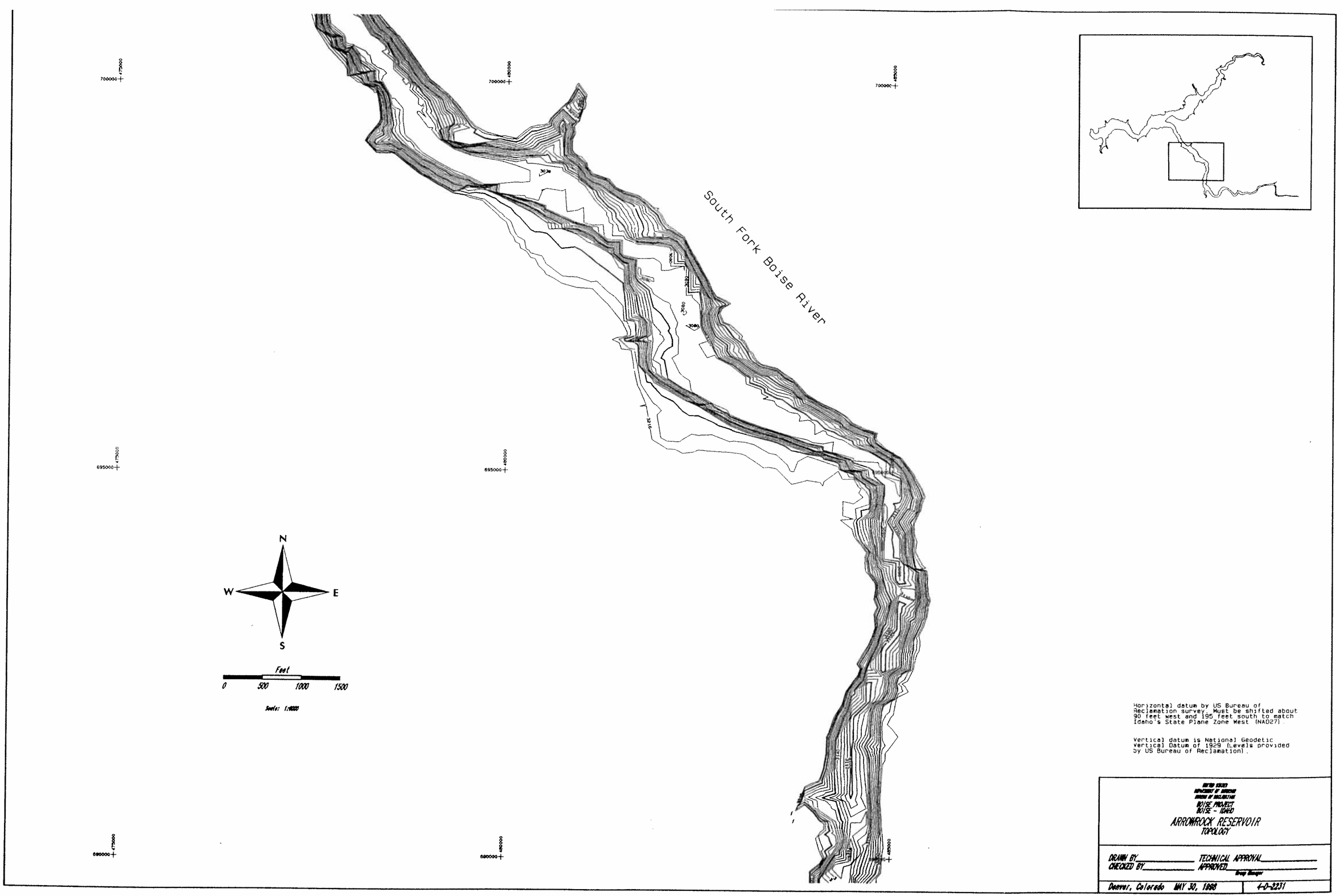
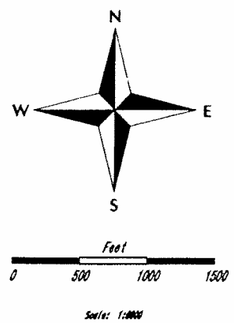
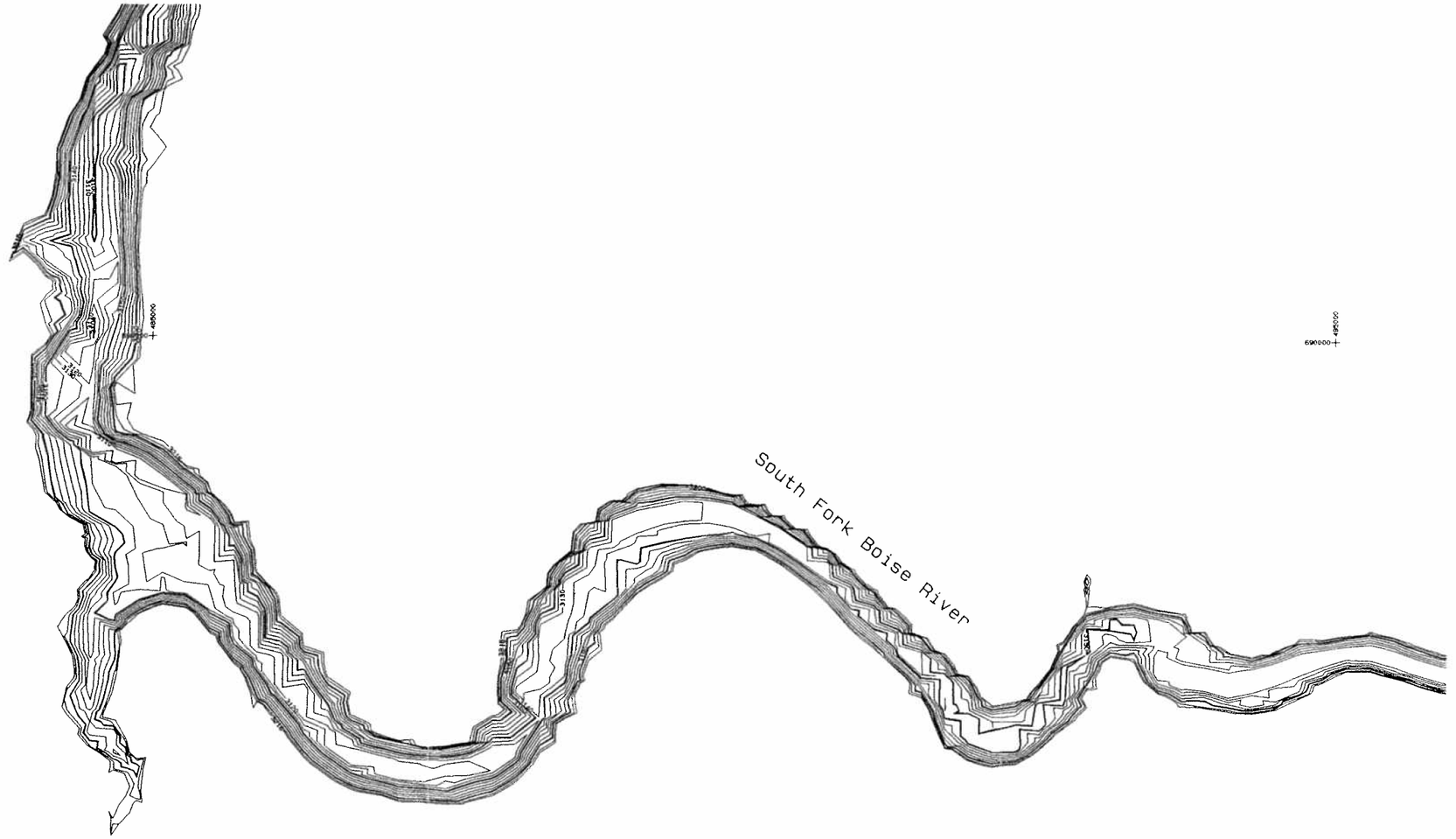
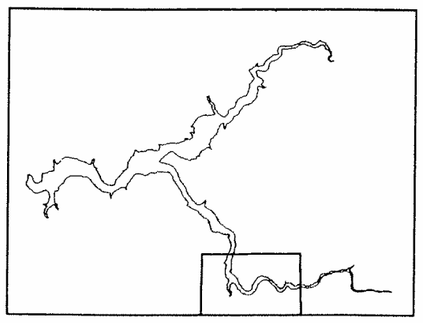


Figure 8. - Arrowrock Reservoir topographic map, No. 3-D-2231.







Horizontal datum by US Bureau of Reclamation survey. Must be shifted about 90 feet west and 195 feet south to match Idaho's State Plane Zone West (NAD27)

Vertical datum is National Geodetic Vertical Datum of 1929 (Levels provided by US Bureau of Reclamation).

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CHECKED BY _____ APPROVED _____
Group Manager

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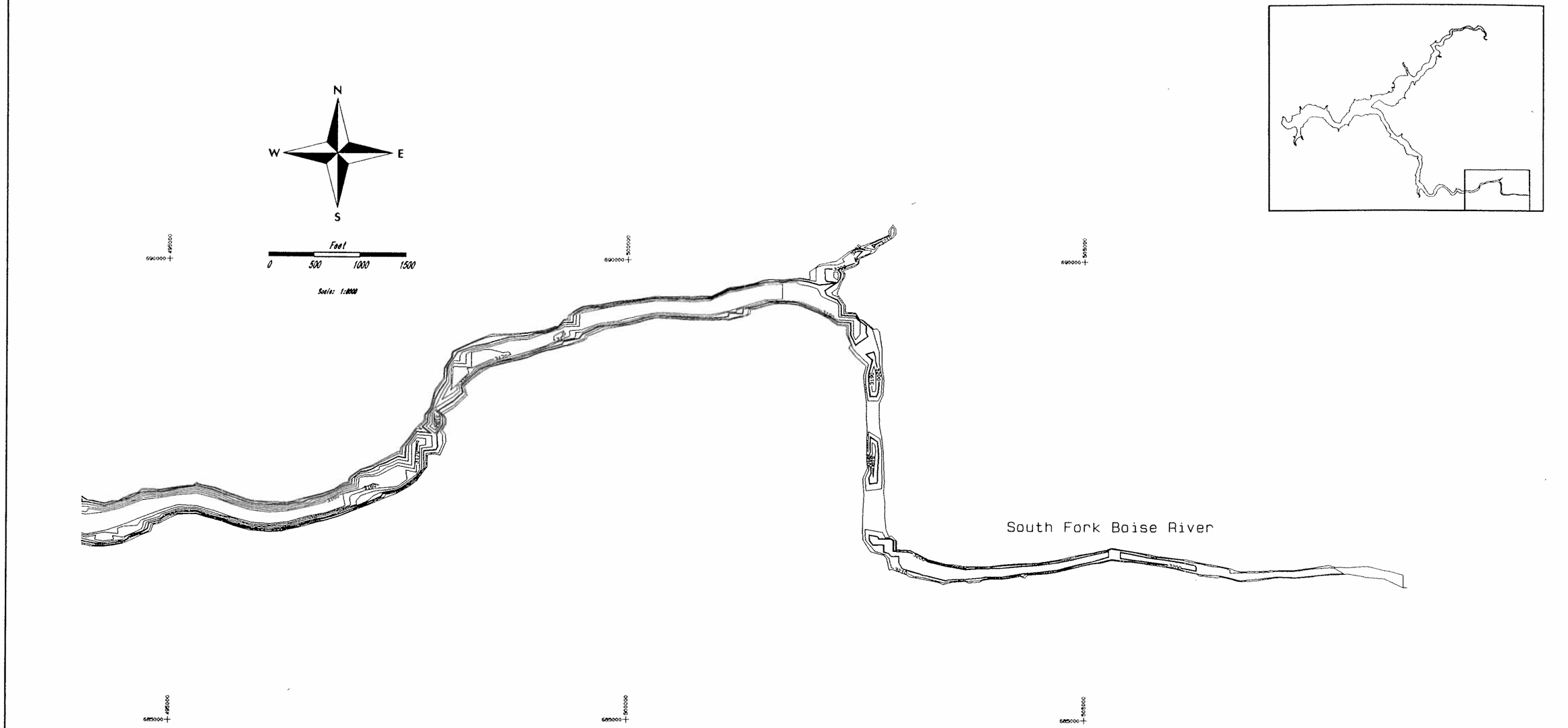
Figure 9. - Arrowrock Reservoir topographic map, No. 3-D-2232.



Horizontal datum by US Bureau of Reclamation survey. Must be shifted about 90 feet west and 195 feet south to match Idaho's State Plane Zone West (NAD27)

Vertical datum is National Geodetic Vertical Datum of 1929 (Levels provided by US Bureau of Reclamation).

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ARROWROCK RESERVOIR
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CHECKED BY _____ APPROVED _____
Group Manager

Denver, Colorado MAY 30, 1996 | 4-D-2233

Figure 10. - Arrowrock Reservoir topographic map, No. 3-D-2233.

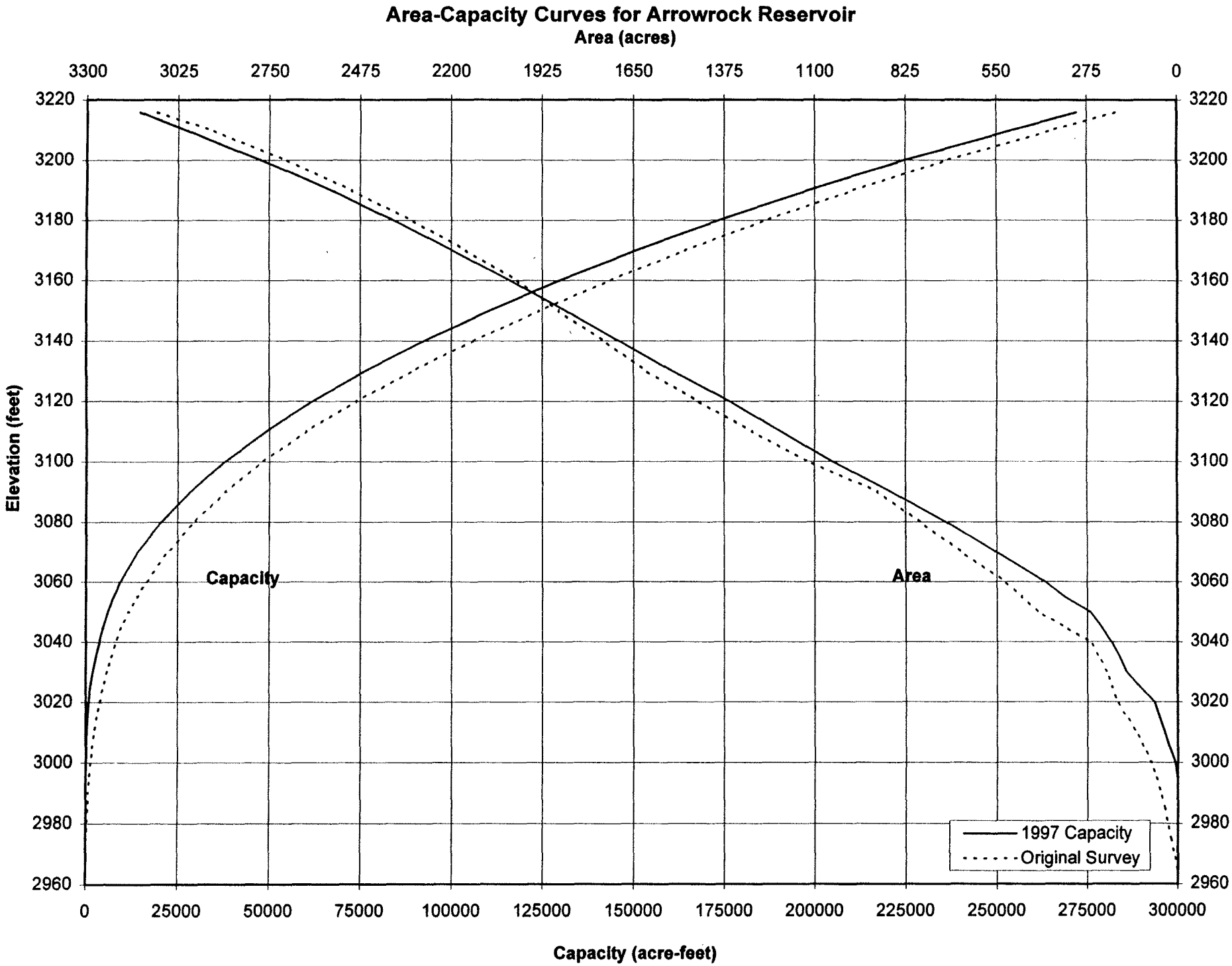

Figure 11. - 1997 area and capacity curves.

MISSION

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American Public.