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Storage Capacity and Sedimentation of Loch Lomond Reservoir, Santa Cruz, California, 1998

By Kelly R. McPherson *and* Jerry G. Harmon

U.S. Geological Survey Water-Resources Investigations
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FIGURES

TABLE

CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Volume	
acre-foot (acre-ft)	1,233	cubic meter
acre-foot (acre-ft)	0.32585	million gallons
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second

Vertical Datum: In this report, "sea level" refers tot he National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Abbreviations:

GIS	geographic information system
GPS	global positioning system
USGS	U.S. Geological Survey

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ABSTRACT

In 1998, a bathymetric survey was done to determine the storage capacity and the loss of capacity owing to sedimentation of Loch Lomond Reservoir in Santa Cruz County, California. Results of the survey indicate that the maximum capacity of the reservoir is 8,991 acre-feet in November 1998. The results of previous investigations indicate that storage capacity of the reservoir is less than 8,991 acre-feet. The storage capacity determined from those investigations probably were underestimated because of limitations of the methods and the equipment used.

The volume of sedimentation in a reservoir is considered equal to the decrease in storage capacity. To determine sedimentation in Loch Lomond Reservoir, change in storage capacity was estimated for an upstream reach of the reservoir. The change in storage capacity was determined by comparing a 1998 thalweg profile (valley floor) of the reservoir with thalweg profiles from previous investigations; results of the comparison indicate that sedimentation is occurring in the upstream reach. Cross sections for 1998 and 1982 were compared to determine the magnitude of sedimentation in the upstream reach of the reservoir. Results of the comparison, which were determined from changes in the cross-sectional areas, indicate that the capacity of the reservoir decreased by 55 acre-feet.

INTRODUCTION

Loch Lomond Reservoir, an impoundment of Newell Creek, is in the Santa Cruz Mountains, California (fig. 1). The reservoir, which is owned by the city of Santa Cruz, was developed in the late 1950's. The reservoir opened for public recreation in 1963, at which time it became a source of water supply for the city of Santa Cruz. Water managers for the city of Santa Cruz periodically measure storage capacity to determine if any sedimentation has occurred, allowing water managers to take timely and appropriate actions. Sedimentation has been observed by park rangers and city water managers at the inflow of Newell Creek for many years. Sediment deposition has occurred in the lower reach of the reservoir because of landslides and in the upstream reach because of inflow from Newell Creek (Fogelman and Johnson, 1985). To determine the storage capacity of the reservoir in 1998 and changes in sedimentation, the U.S. Geological Survey (USGS), in cooperation with the city of Santa Cruz, completed a bathymetric survey of the reservoir.

Purpose and Scope

The purpose of this report is to document the storage capacity of Loch Lomond Reservoir in 1998. This report presents the storage capacity of the reservoir for elevations at multiple stages (2-foot intervals) and data on the magnitude of sediment deposition in the upstream reach of the reservoir. Background information for this report was obtained

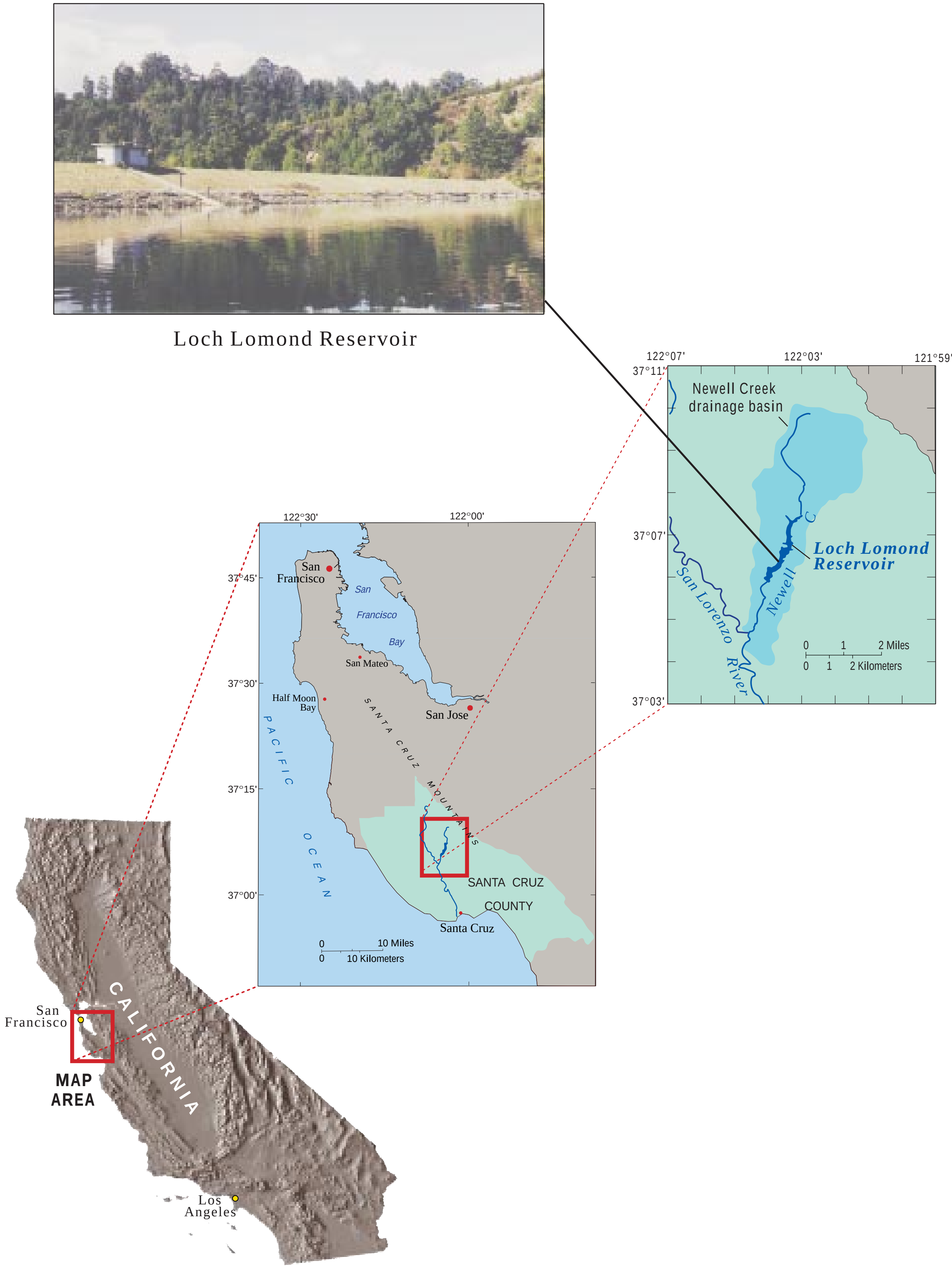


Figure 1. Location of Loch Lomond Reservoir, Santa Cruz County, California.

from reports by Brown (1973) and Fogelman and Johnson (1985).

The scope of the study included a bathymetric survey done using global positioning system (GPS) and depth-sounding equipment. Data were collected from about 27,000 locations. The data, which consist of both horizontal (GPS) and vertical (depth sounding) data, were combined with existing topographic data to develop a detailed topographic map of the reservoir. The method and equipment used for the 1998 bathymetric survey provided a more detailed survey than the previous surveys. The results of the 1998 survey will be useful for future studies of the reservoir because of the repeatability of the survey.

Description of Study Area

Loch Lomond Reservoir, located 9 miles north of Santa Cruz, is about 2.5 miles long with a maximum width of about 1,500 feet. The elevation of the spillway is 577.5 feet above sea level. Newell Creek flows into San Lorenzo River 2 miles downstream from Loch Lomond Dam and extends 3 miles upstream of the upper end of the reservoir.

The climate in Santa Cruz County is characterized as a Mediterranean climate with wet, mild winters and warm, dry summers. Annual rainfall in Santa Cruz averages about 29 inches between November and March, but ranges from a minimum of 14 inches (1975–76) to a maximum of 53 inches (1982–83) (City of Santa Cruz, 1996). Rainfall in the Santa Cruz Mountains upstream of Loch Lomond Reservoir averages about 50 inches per year. The most intense winter storms produce rapid runoff that causes erosion on the steep-sided canyons within the drainage basin; the highest elevation in the basin is more than 2,300 feet above sea level. Vegetation in the study area primarily consists of redwoods and occasional flat areas of chaparral, as shown in figure 2.

The geology of the area primarily consists of interbedded layers of sandstone, siltstone, and shale of Tertiary age (Brown, 1973). These materials decompose into soil that is easily transported. For a more detailed geology of Santa Cruz County, see Brabb (1960) and Cummings and others (1962).

Previous Investigations and Limitations

Three investigations were done on Loch Lomond Reservoir prior to the 1998 investigation. The first investigation, which was in conjunction with the construction of the dam prior to its completion in 1960, used aerial photographs to develop a topographic map of the reservoir (Brown, 1973). The accuracy of the map was estimated to be plus or minus 3 feet; this accuracy was based on prominent surface features on the reservoir bed. Because of the limited accuracy of this method and because elevations between data

Figure 2. Vegetation typical in the area of Loch Lomond Reservoir, Santa Cruz County, California.

points could only be interpolated, estimates of storage capacity can vary considerably. The results of the 1960 investigation indicated that the storage capacity of the reservoir was about 8,600 acre-feet (Brown, 1973).

A second investigation, which was done in 1971, was based on aerial photographs and on depth soundings made at selected intervals of the reservoir (Brown, 1973). The method used during the 1971 investigation to determine sediment deposition was based on an estimated trap efficiency of sediment of about 95 percent and the presence of a thin layer of fine sediment deposited throughout the reservoir. The results of this investigation indicated that the storage capacity of the reservoir decreased by 46 acre-feet between 1960 and 1971. Although this investigation provided a more detailed definition of the reservoir bed surface, the change in storage capacity between 1960 and 1971 investigations was based on sedimentation deposition rather than on a method that directly calculates capacity.

In 1982, a third investigation of the reservoir was done to determine the storage capacity and sediment deposition of the reservoir. Depths measured across 35 ranges (cross sections) and ground surveys (Fogelman and Johnson, 1985) were used to estimate storage capacity and sediment deposition. The results of the 1982 investigation indicated that the storage capacity of Loch Lomond Reservoir was about 8,800 acre-feet. This increase in the estimated storage capacity probably was not due to an actual change in capacity but to more accurate estimates resulting from the more detailed survey. Although this investigation was more detailed than the investigations of 1960 and 1971, the method used for the 1982 investigation also had limitations. Data from the cross sections surveyed in 1982 provided a better definition of the reservoir bed than data from the previous investigations, but there were still unknown variances in the reservoir bed between each of the sections. To reduce errors in interpolation between the cross-section data, cross sections were located where bank changes were significant. Small changes in the elevation of the reservoir bed, however, affect the storage capacity.

Acknowledgments

Randal L. Dinehart, U.S. Geological Survey, provided the equipment used for this 1998 survey; he also aided in the operation of the equipment and developed the methodology for the survey. Both the design of the equipment and the method used for the survey, which had been tested by Dinehart prior to the 1998 survey, significantly shortened the amount of time and personnel needed to complete the bathymetric survey.

The authors thank the park staff at Loch Lomond Reservoir for providing us with easy access to the reservoir during the survey.

STORAGE CAPACITY

Data Collection

The topography of Loch Lomond Reservoir was surveyed on November 4 and 5, 1998, from a moving boat using electronic depth-sounding equipment in conjunction with GPS and an automatic data recorder (fig. 3). The equipment included a Sonar Lite depth

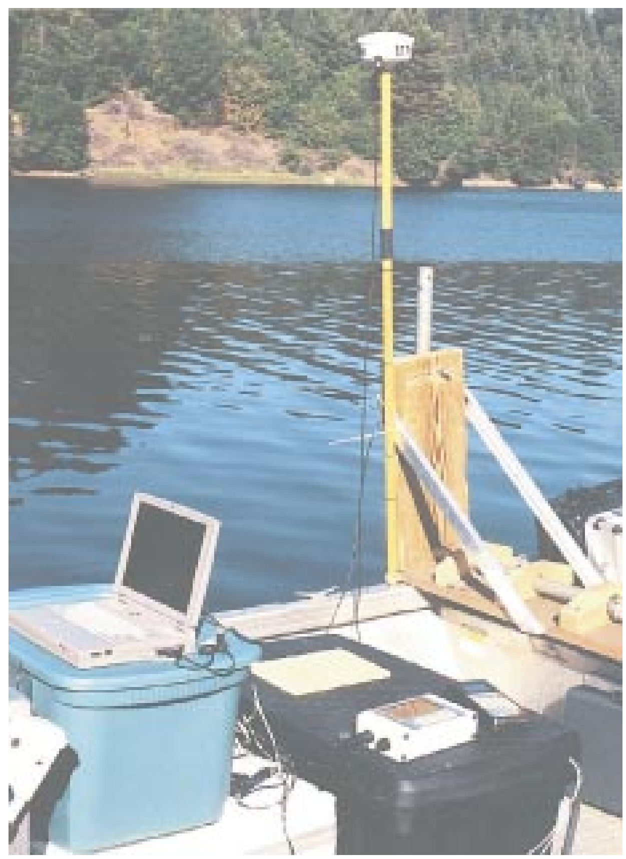


Figure 3. Depth-sounding equipment and global positioning system (GPS) used to survey the topography of Loch Lomond Reservoir in Santa Cruz County, California.

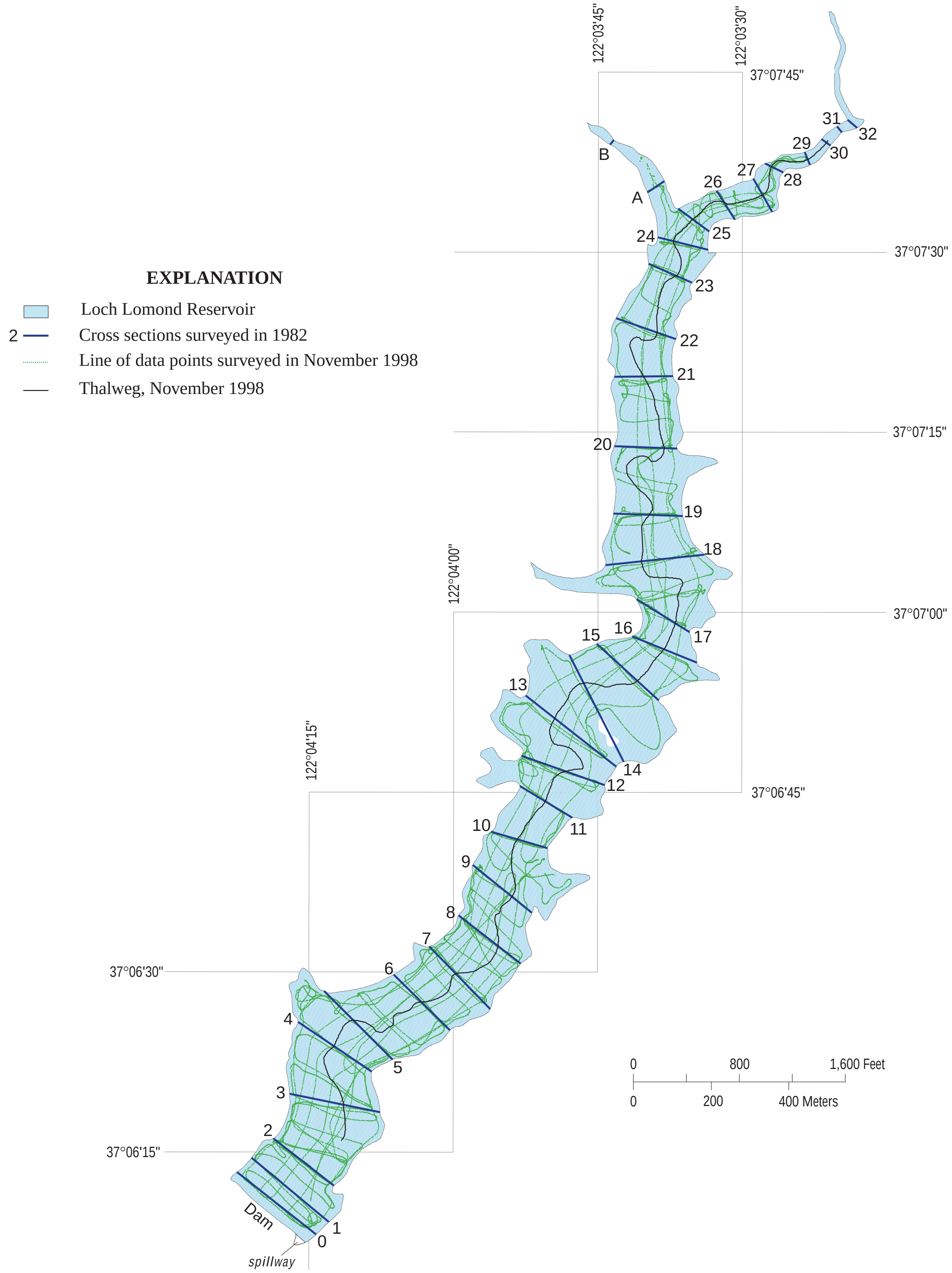
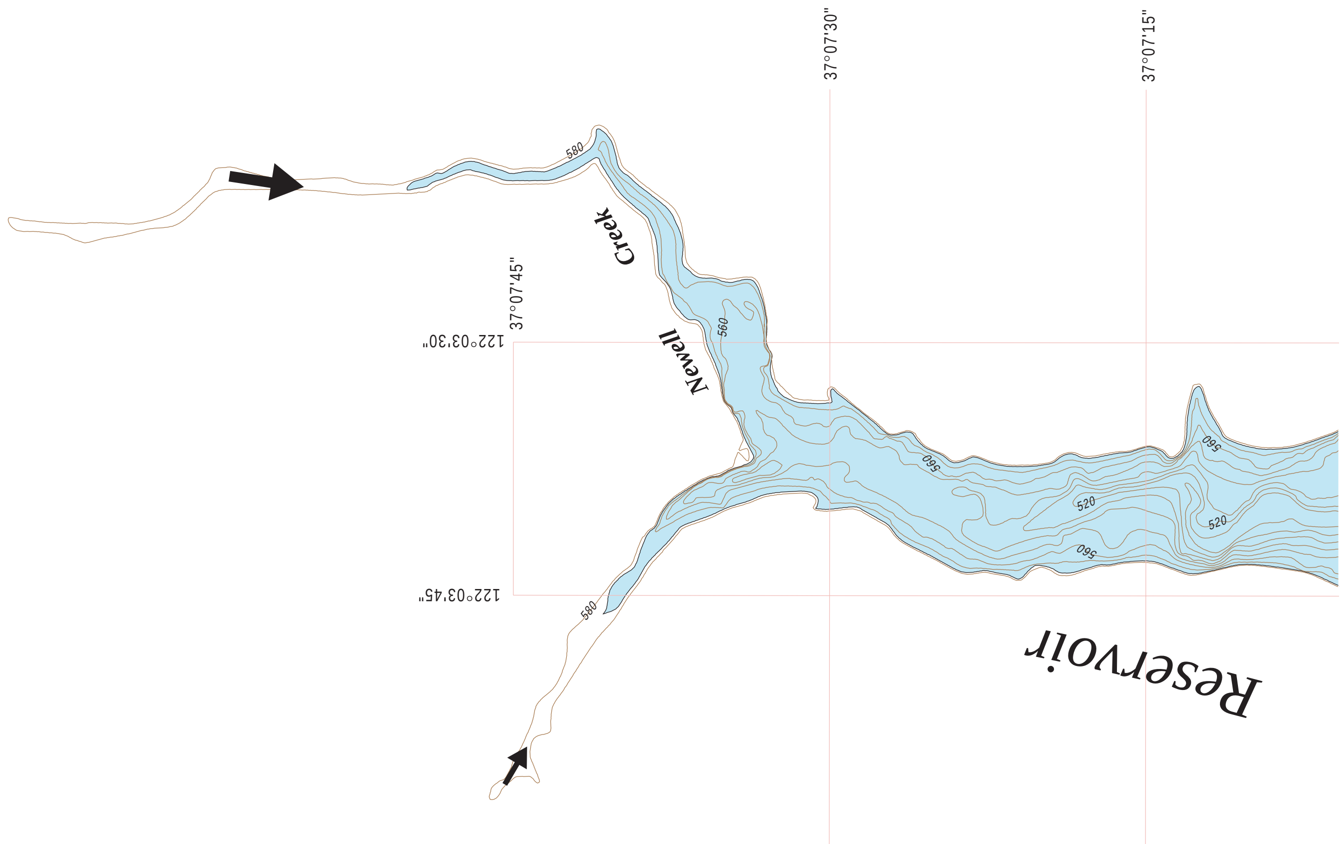


Figure 4. Location of data points measured for depth from a moving boat on Loch Lomond Reservoir, Santa Cruz County, California.



37°07'30"
37°07'15"
37°07'45"
122°03'30"
122°03'45"
Newell
Creek
Reservoir
580
560
520

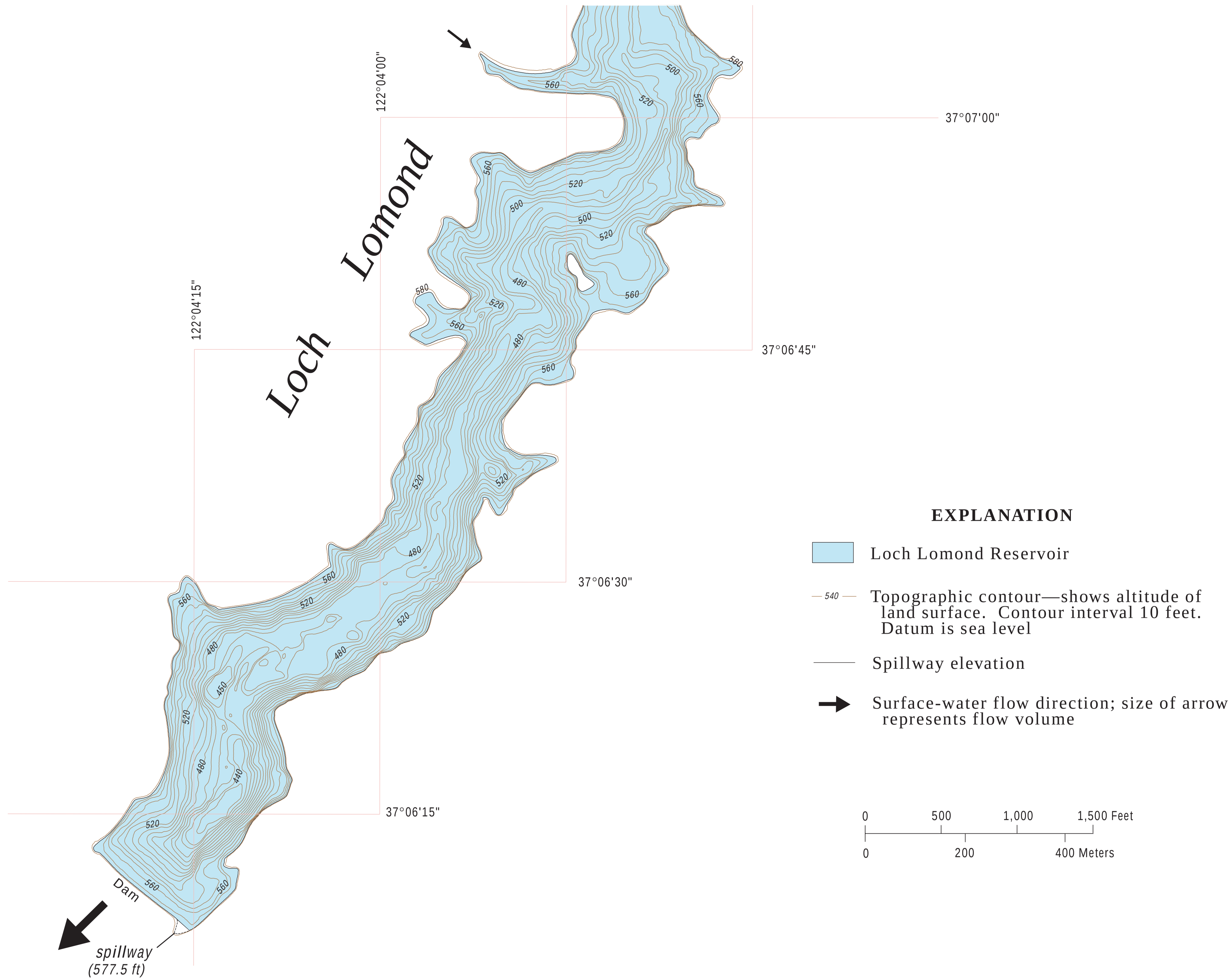


Figure 5. Elevation of reservoir bed produced from November 1998 bathymetric survey of Loch Lomond Reservoir, Santa Cruz County, California.

sounder and a PRO XR Differential GPS receiver. The equipment was tested at another reservoir prior to the survey of Loch Lomond Reservoir and was tested again on Loch Lomond Reservoir just prior to the start of the survey. The 1998 survey was limited to what could be done by boat, which in turn was limited to areas with enough clearance for the equipment (depths less than 2 feet could not be measured). Shoreline and bank elevations, which were based on field assumptions, were assumed to have changed only minimally except at the inflow channels.

GPS was used to determine the latitude and longitude for each depth measurement. Measurements were made by receiving and recording radio signals sent by GPS satellites. A public broadcast GPS base station, or control station, operated by the Coast Guard was used during the 1998 survey giving a 0.7-meter horizontal resolution with updated corrections every 5 seconds (Randal Dinehart, U.S. Geological Survey, oral commun., 1998).

Sounding equipment was used to measure depth from a transducer (probe) to the bed of the reservoir. Depths recorded by the sounder, which has resolution of 0.002 meter for a maximum range of 50 meters, were measured at a fixed distance below the water surface. The recorded depths and the constant value of the depth sounder were subtracted from the water-surface elevation to obtain elevations of the reservoir bed. The depths were synchronized with the GPS data to determine the location of the probe as the boat traversed across the reservoir.

During the 2 days of the survey, the elevation of the water surface (stage) of the reservoir was high (573.5 feet above sea level and only 4 feet below the spillway). Inflows to and outflow from the dam was low (about 5 ft^3/s) and the weather was mild which provided a flat water surface for the duration of the survey. Reproducing some of the data to match the 1982 survey was easily done because most of the steel stakes that marked the 1982 survey sections were still in place. Additionally, attempts were made to match the 1982 survey at sites where no steel stakes were found by surveying from an existing stake to an approximate location of the cross section on the opposite reservoir bank. Some of the shallow areas, however, could not be surveyed because the boat could not be maneuvered in the shallow water. Using the method of surveying described at the beginning of this section, we were able to define areas that cannot be defined by traditional methods of cross-section surveying. Latitude and longitude and depth were recorded for about 27,000 data points (fig. 4).

Because of differences in accuracy among the surveys, differences in estimated maximum capacity calculated for each survey would be expected even if no deposition had occurred. The accuracy of the 1998 survey is assumed to be greater than that of previous surveys because more data were collected during the 1998 survey.

Data from the 1998 survey were used to produce a topographic map of Loch Lomond Reservoir with more detail than previous topographic maps. The addition of GPS mapping linked to depth-sounding equipment has greatly increased the possibility of survey repeatability for future surveys.

Data Conversion

Reservoir bed elevations calculated from the 1998 survey data and elevations determined from USGS 7.5-minute topographic maps were combined to produce a detailed topographic map of Loch Lomond Reservoir.

First, raw data from the data recorder were stored in ASCII-file format and imported into a spreadsheet program. Because GPS and the depth sounder do not collect data on the same time interval, data were extracted only for those locations with both horizontal (GPS) and vertical (depth sounding) coinciding measurements. The extracted measurements were imported into a geographic information system (GIS) and then a grid or rasterized file was created using a method of triangulation for an irregular network. The grid was then generated into a contour map using the GIS software package.

General topographic features of the area were used to establish contours for the reservoir bed elevations of areas between the data point locations and along the shoreline. These features were determined using the GIS to combine the 1998 topographic map with the features from field observations and from the 1982 contour map by Fogelman and Johnson (1985). Elevations greater than 570 feet above sea level were obtained from the topographic maps. The edited map (fig. 5) was used to calculate the area of the reservoir bed and the capacity of the reservoir using the GIS.

Because the computations indicated that the storage capacity of the reservoir was greater in 1998 than in 1982, an analysis was done to determine if the results of the two surveys could be compared solely on

Table 1. Storage capacity for water-surface elevations (stage) at 2-foot intervals to the maximum capacity of Loch Lomond Reservoir, Santa Cruz County, California, November 1998

[Water surface elevation is in feet above sea level. Storage capacity is in acre-feet]

Water surface elevation	Storage capacity	Water surface elevation	Storage capacity	Water surface elevation	Storage capacity	Water surface elevation	Storage capacity
577.5[1]	8,991	542	4,120	504	1,340	466	148
577	8,900	540	3,920	502	1,250	464	120
576	8,730	538	3,730	500	1,160	462	99
574	8,400	536	3,550	498	1,070	460	81
572	8,070	534	3,370	496	991	458	68
570	7,750	532	3,200	494	912	456	56
568	7,440	530	3,030	492	836	454	46
566	7,140	528	2,870	490	763	452	39
564	6,840	526	2,710	488	694	450	32
562	6,550	524	2,560	486	628	448	27
560	6,270	522	2,420	484	565	446	22
558	6,000	520	2,280	482	506	444	18
556	5,730	518	2,150	480	449	442	14
554	5,470	516	2,020	478	397	440	10
552	5,230	514	1,890	476	348	438	7
550	4,990	512	1,770	474	301	436	5
548	4,760	510	1,660	472	258	434	3
546	4,530	508	1,550	470	217	432	1
544	4,320	506	1,440	468	181	430	0

[1]Maximum capacity.

the basis of capacity. To determine if there were any consistencies between the two surveys, we compared capacities at multiple stages for a part of the reservoir where the least amount of sedimentation likely was occurring and where the 1982 data matched the data collected in 1998. The results of this comparison indicate that the capacities between the sections did not match because the reservoir bed was better defined during the 1998 survey.

Capacity

The storage capacity of Loch Lomond Reservoir was determined for various water-surface elevations (stage). Using data from the 1998 bathymetric survey, capacity was calculated for 2-foot stage intervals to the maximum capacity of the reservoir (a stage of 577.5 feet; table 1). The estimated maximum capacity of the reservoir in November 1998 was 8,991 acre-feet.

SEDIMENTATION

The results of an analysis of the capacity of Loch Lomond Reservoir indicated that its capacity was larger in 1998 than in 1982, and therefore no sedimentation had occurred. However, field observations indicated that sedimentation had occurred. Therefore, additional analyses were done using thalweg and cross-section profiles to show changes in sedimentation between 1998 and 1982.

Thalweg Profiles

The thalweg profiles show the elevation of the valley floor from the entrance channel of the reservoir to the lowest point of the reservoir. The 1998 thalweg profiles were compared with the profiles from previous surveys to show changes in sedimentation.

A comparison of the 1982 thalweg profile with the 1960 profile indicates that the elevation of the valley floor in upstream reach of the reservoir was higher in 1982 than it was in 1960 indicating that sediment deposition occurred between 1960 and 1982 (Fogelman and Johnson, 1985). A similar comparison was made between the 1971 thalweg profile and the 1960 profile; the results of the comparison indicated that sediment deposition was occurring in the upstream reach of the reservoir. A comparison of the 1998 thalweg profile with the 1982 profile indicates that the thalweg was higher in the upstream reach in 1998 than in 1982, indicating continuing sediment deposition between 1982 and 1998 (fig. 6).

Cross-Section Profiles

Cross-section profiles for 1982 and 1998 were compared to show changes in sedimentation (fig. 7). The results of the comparisons are as follows:

- Cross sections 4, 5, 7, 9, 11, 15, 17,19, and 20 indicate that the 1998 surveyed cross sections may not have been in precisely the same location as the sections surveyed in 1982, as indicated by the somewhat mismatched bank shape and slope. The bank elevations would not have changed between 1982 and 1998 or would have changed only minimally. Thalweg elevations for these sections indicate that no sedimentation has occurred.
- Cross sections 1, 8, 12, and 21 show significant bank mismatch indicating that these sections clearly are not in the same location as the sections in the earlier survey.
- Cross section 2 indicates that only about 1 percent of the cross-sectional area of sediment deposition has occurred near the deepest part of the reservoir.
- Cross section 13 indicates there was some lateral change but that no sedimentation occurred.
- Cross section 18 indicates that a small amount of sedimentation, approximately 4 percent of the cross-sectional area, has occurred on a ledge formation of the section, but that no sedimentation has occurred in the remaining area of the cross section.
- Cross sections 3, 6, 10, 14, and 16 indicate a good match and that no sedimentation has occurred.
- Cross sections 22–28, which are in the upstream reach of the reservoir, show a good match to the 1982 survey and indicate that sedimentation has occurred.

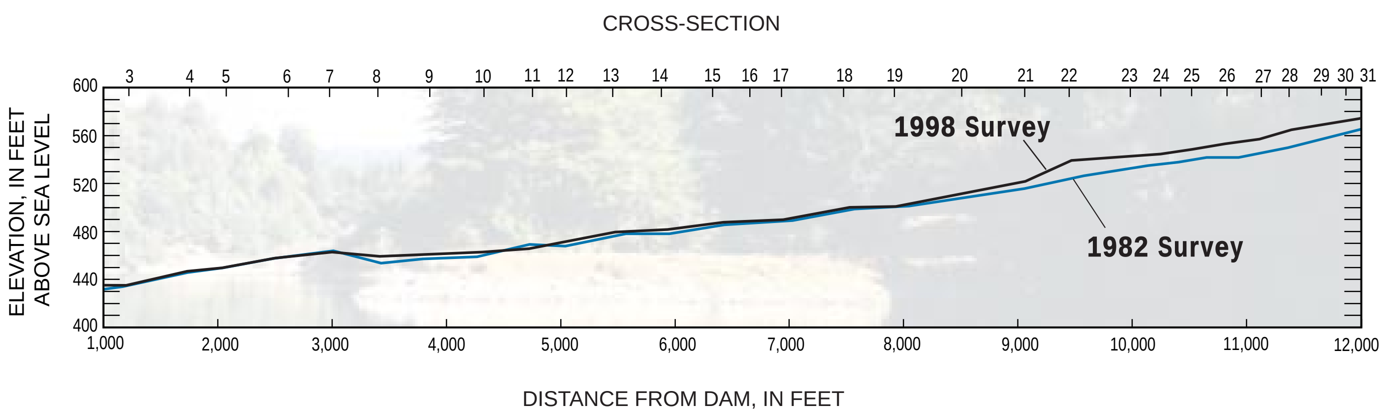


Figure 6. Thalweg profiles showing valley floor elevations of Loch Lomond Reservoir, Santa Cruz County, California, 1982 and 1998.

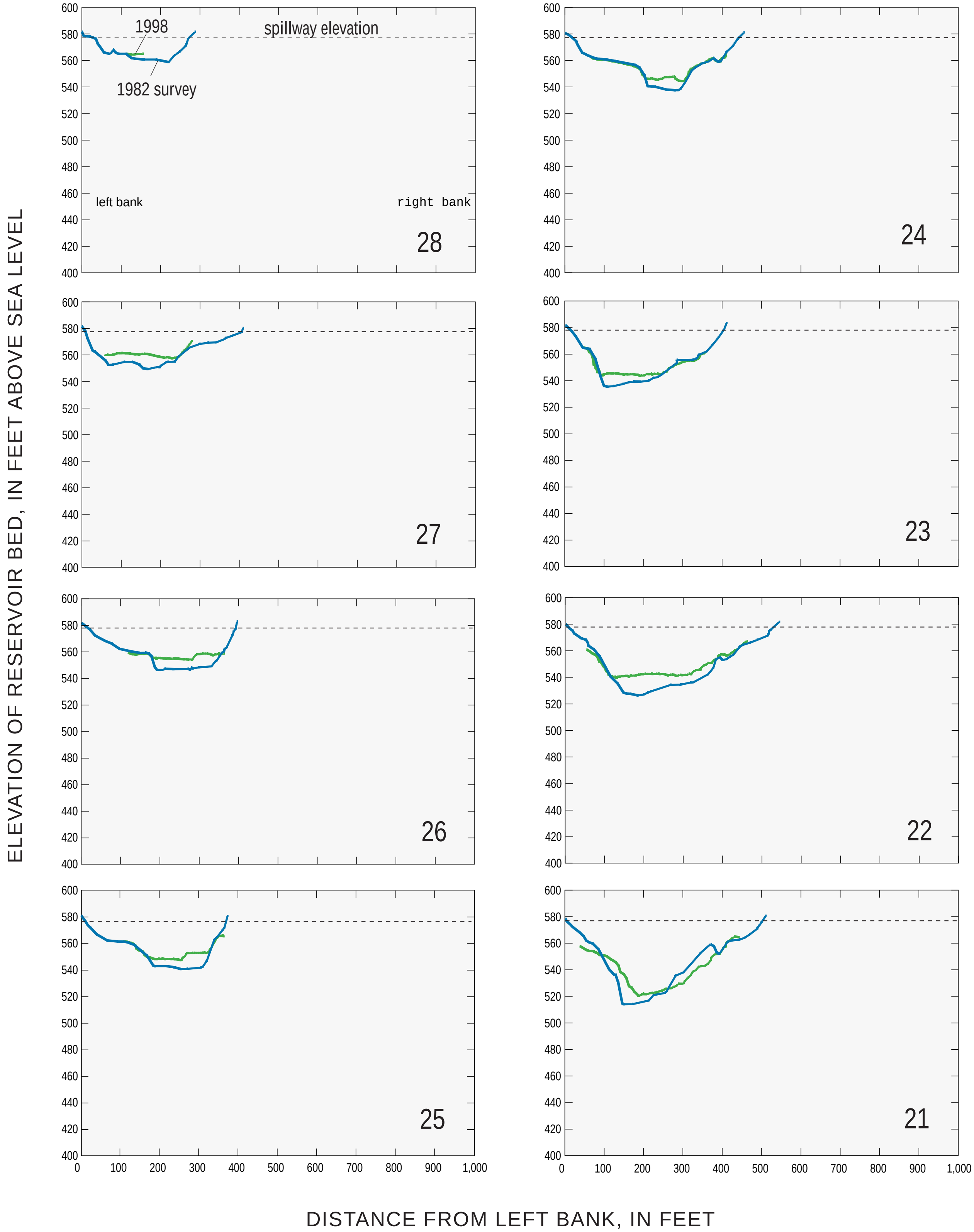


Figure 7. Changes in elevation of the bed of Loch Lomond Reservoir, Santa Cruz County, California, 1998 and 1982. See figure 4 for location of cross sections.

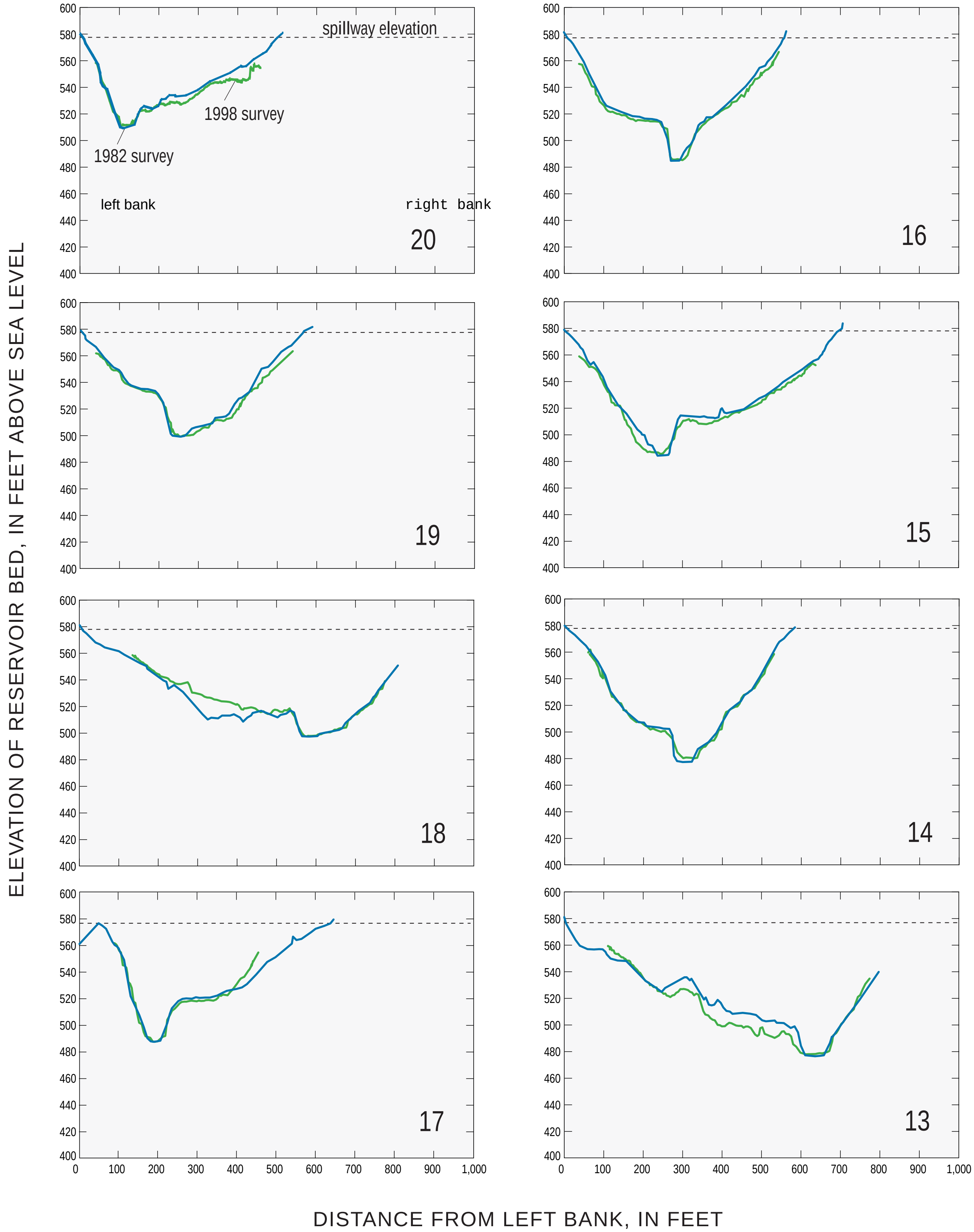
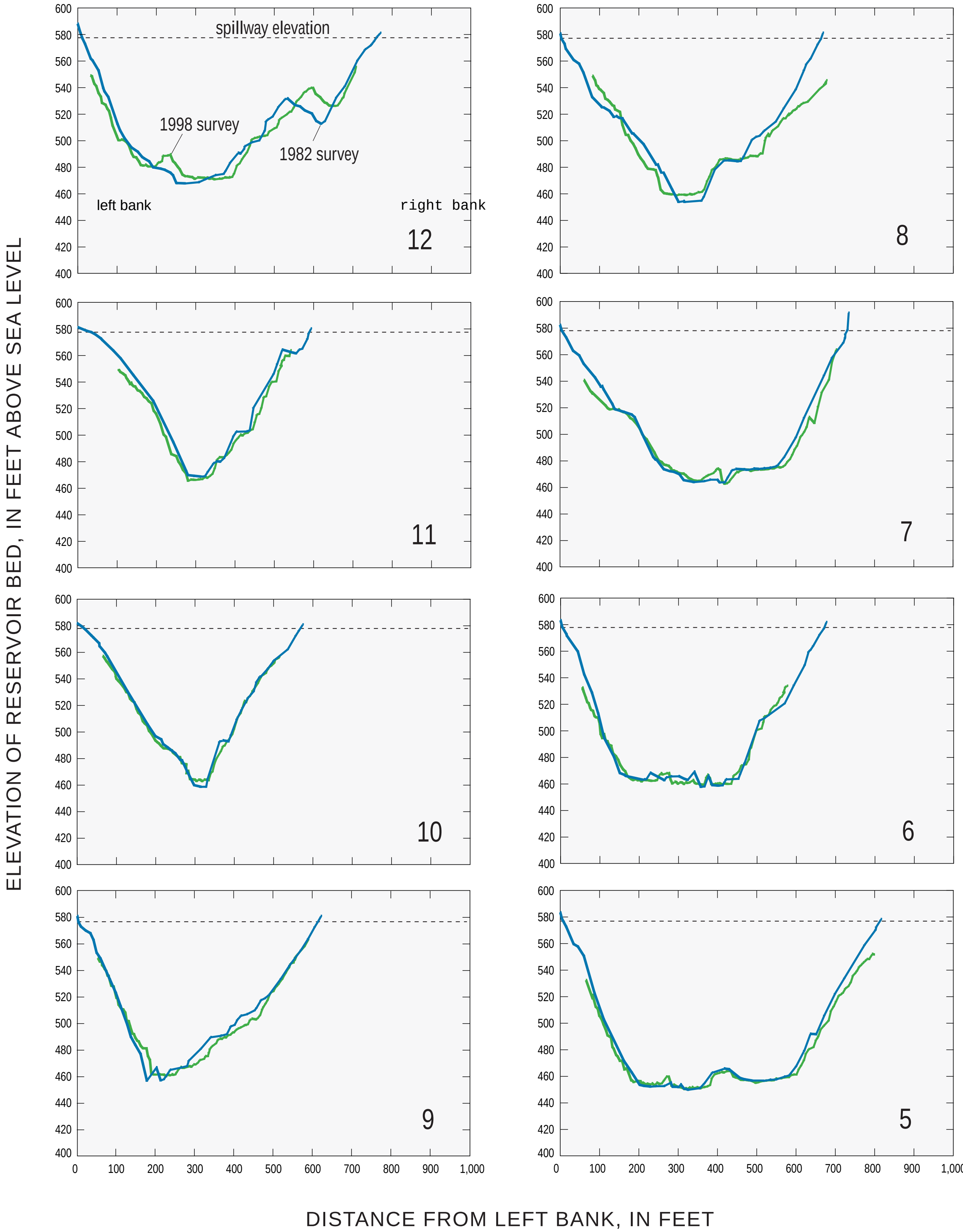


Figure 7. Continued



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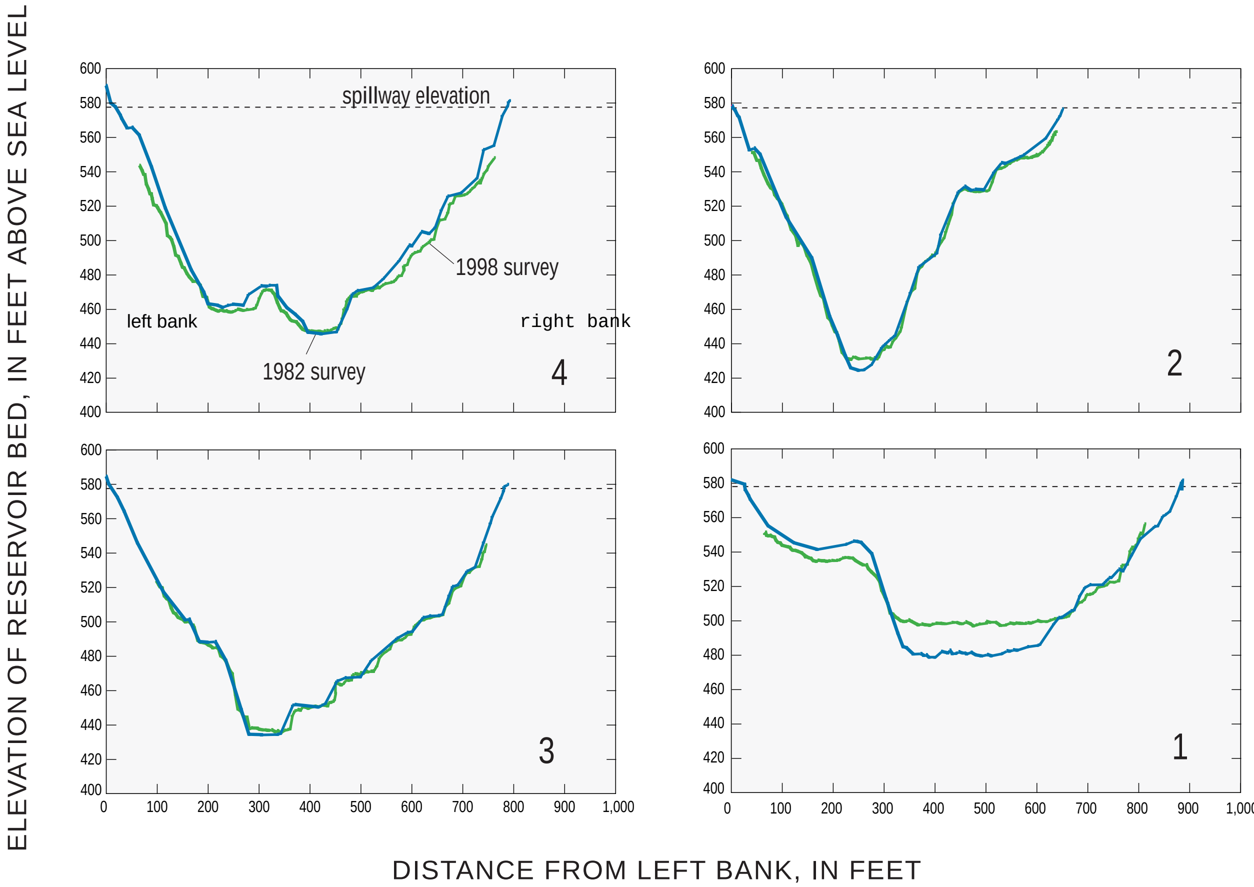

Figure 7. Continued.

Sedimentation in Upstream Reach

Typically, sedimentation first occurs near the upstream reach of a reservoir where streamflow from major tributaries flows into the reservoir. The velocity of flow decreases rapidly at the reservoir resulting in the deposition of sediment. Reservoirs, therefore, are sediment traps which, over time, decrease in storage capacity. The loss of capacity of Loch Lomond Reservoir owing to sedimentation was determined by a bathymetric survey of the reservoir. Only the cross-section profiles for the upstream reach of Loch Lomond Reservoir (between cross sections 22 and 32; fig. 8) were used to determine changes in sedimentation. These sections were used because they are located in a part of the reservoir where the greatest amount of sedimentation is occurring and because they aligned with the sections measured in 1982. The maximum capacity of the upstream reach was 450 acre-feet in 1982 (Fogelman and Johnson, 1985) and 395 acre-feet in 1998—a decrease of 55 acre-feet, which is 0.6 percent of the 1998 maximum reservoir capacity. This decrease in capacity was calculated by determining the average percentage of change, owing to sedimentation, of each of cross-sectional area in the upstream reach between the 1998 and 1982 surveys.

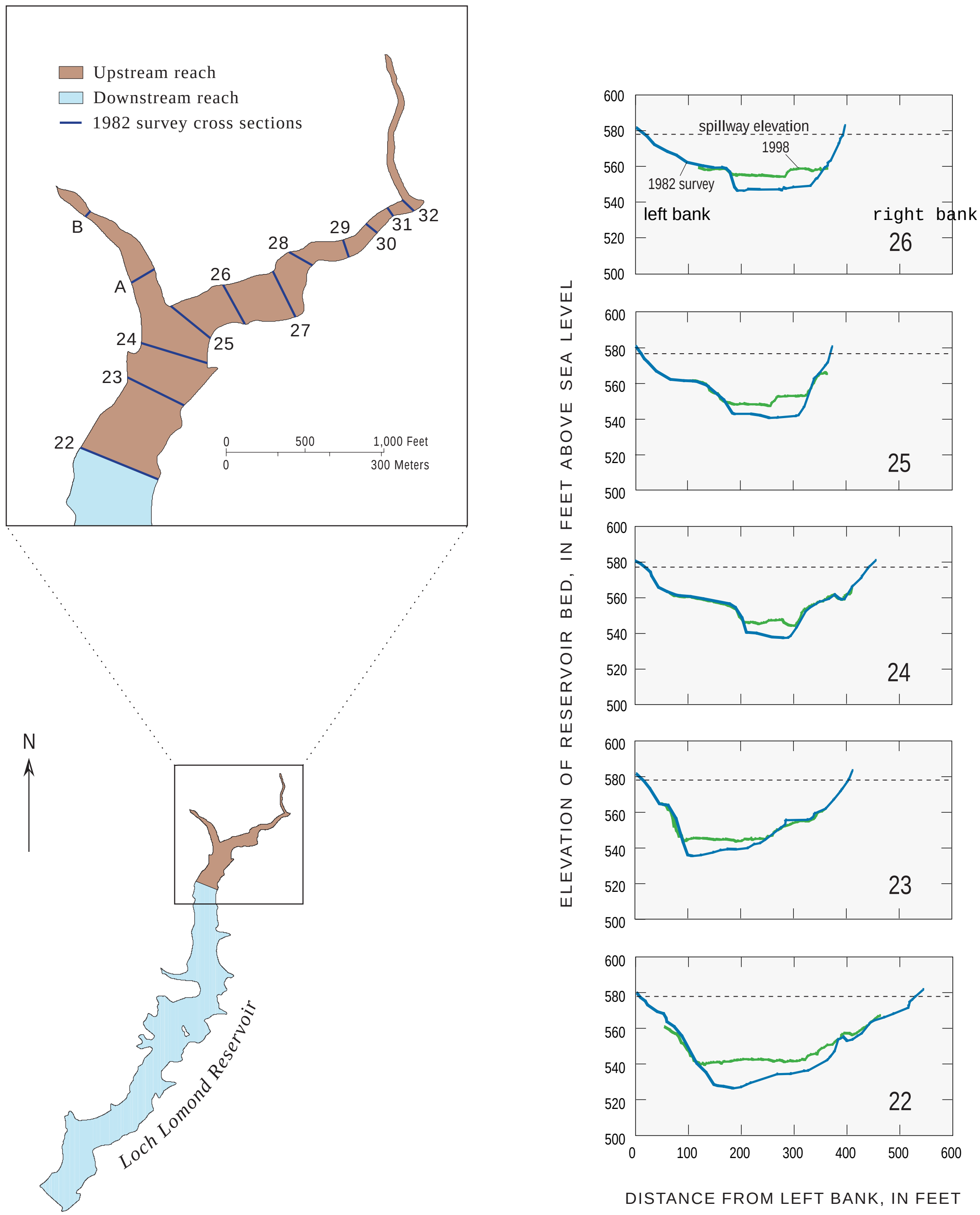

Figure 8. Location of upstream reach used for comparison of 1982 and 1998 storage capacity surveys, Santa Cruz County, California. Graphs of selected cross sections show magnitude of the differences between the 1982 and 1998 surveys of Loch Lomond Reservoir.

SUMMARY

Loch Lomond Reservoir, an impoundment of Newell Creek, is located in the Santa Cruz Mountains in Santa Cruz County, California. The reservoir is used for public recreation and for part of the water supply for the city of Santa Cruz. The reservoir is about 2.5 miles long with a maximum width of about 1,500 feet. Because reservoirs are sediment traps, the storage capacity of reservoirs decreases with time. Sediment deposition was observed by park rangers and city water managers in the upstream reach of Loch Lomond Reservoir. Sediments in the reservoir are deposited by inflow from tributaries and by landslides. Topographic surveys were used to calculate the storage capacity of the reservoir at selected intervals of stage.

The topography of Loch Lomond Reservoir was measured by boat using electronic depth-sounding equipment in conjunction with a global positioning system (GPS) to calculate storage capacity. The results of the 1998 survey, which were based on 27,000 data points, indicate that the current capacity of the reservoir is 8,991 acre-feet. Capacities also were determined for 2-foot intervals to the maximum elevation of the reservoir.

Because the accuracy of each survey method is limited and the survey methods are different, differences in total capacity calculated by any survey in comparison with another would be expected even if no deposition had occurred. The accuracy of the 1998 survey is assumed to be greater than that of previous surveys because more data were collected from a greater area of the reservoir during the 1998 survey. A comparison of elevations of the 1982 and 1998 cross sections indicates the compatibility of the methods used for the two surveys. Cross sections closely matched where little deposition was expected, and bed elevations were higher in 1998 where deposition was expected.

Results of previous investigations were compared with the results of the 1998 survey to show changes in elevations of the reservoir bed. Because limitations of the equipment and methods used for previous surveys prevented accurate calculations of the storage capacity, the results of the comparisons of thalweg profiles and cross-section profiles were used to calculate changes in elevations of the reservoir bed.

A comparison of the elevations from the 1982 and 1998 surveys, where location of the data points along the 1982 cross sections aligned, indicate that sediment deposition has occurred in the upstream reach of the reservoir. The results also indicate that between 1982 and 1998 storage capacity decreased by 55 acre-feet, which is 0.6 percent of the 1998 maximum reservoir capacity. Although the results of this study indicate that sediment deposition is relatively small in comparison to the capacity of the reservoir, the results are important because they can provide a basis for future monitoring of sedimentation in the reservoir.

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