PREPARED IN COOPERATION WITH THE
U.S. ENVIRONMENTAL PROTECTION AGENCY

WATER-RESOURCES INVESTIGATIONS REPORT 96-4027
Watts, Kenneth R., 1996, Bathymetric surface and storage capacity of Terrace Reservoir, Conejos County, Colorado, July–August 1994

Abstract

Sediments deposited in Terrace Reservoir contain large concentrations of trace metals. A study was done by the U.S. Geological Survey, in cooperation with the U.S. Environmental Protection Agency, to map the current (1994) bathymetric (bottom) surface to estimate the current storage capacity of Terrace Reservoir and the volume of sediment deposited in the reservoir during 1981–94. A better understanding of the bathymetric surface and changes in that surface caused by deposition of trace-metal-enriched sediments will allow the U.S. Environmental Protection Agency to choose appropriate remediation plans for Terrace Reservoir. The 1994 bathymetric-surface map of Terrace Reservoir was machine contoured from 21,944 depth soundings. Depth soundings were made with an echo sounder during July and August 1994. A storage-capacity table of the reservoir was estimated from the 1994 bathymetric-surface map. Comparison of the July–August 1994 storage capacity with estimated 1981 storage capacity indicated a decrease in storage capacity of about 580 acre-feet, below a stage of 8,545 feet. Average annual deposition of sediments in Terrace Reservoir during 1981–94, below a stage of 8,545 feet, was assumed to equal the average annual decrease in storage capacity and was an estimated 41 acre-feet. The thickness of sediment deposited in Terrace Reservoir during 1981–94, below a stage of 8,545 feet, averaged about 2.7 feet.

INTRODUCTION

Sediment deposited in Terrace Reservoir, Conejos County, Colorado, contains large concentrations of trace metals (A.J. Horowitz and others, U.S. Geological Survey, written commun., 1995). The volume of trace-metal-bearing sediment stored in Terrace Reservoir had not been determined previously. However, the bathymetric surface was mapped from aerial photographs taken when the reservoir was drained for maintenance in 1981, and the storage capacity was estimated from that map (Davis Engineering Services, Inc., 1981).

Sources of trace metals in the Alamosa River Basin, upstream from Terrace Reservoir, include outcrops of mineralized rocks and mined areas. Mining of gold in the Alamosa River Basin began with the discovery of gold at Summitville in 1870. The Summitville Mine was operated as a large-tonnage, open-pit, heap-leach gold mine during 1986–92. On December 6, 1992, the operators of the Summitville Mine declared bankruptcy and abandoned the site, and the U.S. Environmental Protection Agency (EPA) assumed operation of the site and increased water-treatment capacity at the site to minimize discharge of low-quality water to the Wightman Fork, a tributary of the Alamosa River (fig. 1). Mining activities have affected concentrations of trace metals in surface water in the basin. Comparison of pre-1985 and post-1985 data indicate that pH decreased and concentrations of dissolved and total or total-recoverable trace metals (copper, iron, and possibly zinc) increased in the Alamosa River downstream from its confluence with the Wightman Fork (Cain, 1995).

Detailed studies of the water quality, limnology, sediment deposition and geochemistry, and movement of metals into, within, and through Terrace Reservoir began in 1994 by the U.S. Geological Survey, in cooperation with the EPA (Cain, 1995). A current definition of the bathymetric surface and of the volume of trace-metal-bearing sediments deposited in the reservoir can be used by the EPA in selection of appropriate actions for remediation of Terrace Reservoir. This report presents the results from a study that was done to map the current (July–August 1994) configuration of the bathymetric surface to estimate the current storage capacity of Terrace Reservoir and the volume of sediment deposited in Terrace Reservoir during 1981–94. Field work for the study was done in July and August 1994.

Location and Description of Terrace Reservoir

Terrace Reservoir is located in Conejos County, Colorado, about 16 mi south-southwest of Monte Vista and about 12 mi downstream from the confluence of the Alamosa River and the Wightman Fork (fig. 1). Water released from Terrace Reservoir is used to irrigate about 45,000 acres of farmland in the San Luis Valley of south-central Colorado (U.S. Environmental Protection Agency, 1993).

Terrace Reservoir is impounded behind an earth-fill dam that was completed across the Alamosa River Canyon during 1912. The sides of the reservoir are rocky and steep. The crest of the overflow spillway of Terrace Reservoir is at an approximate altitude of 8,571 ft above NGVD of 1929. At maximum stage (8,571 ft above NGVD of 1929), the reservoir is about 14,000 ft long; ranges from a few feet to about 1,500 ft wide; and has a surface area of about 299 acres. The storage capacity of Terrace Reservoir at maximum stage was reportedly about 15,182 acre-ft in 1981 (Davis Engineering Services, Inc., 1981). Based on high-water marks, reservoir stage generally is less than about 8,564 ft above NGVD of 1929.

The storage and release of water from Terrace Reservoir for irrigation affects the distribution of sediments within the reservoir. During the fall through late spring, when water is stored for later release, sediments are deposited in the upstream one-third of the reservoir. During the summer, when water is released for irrigation, reservoir stage drops rapidly and much of the sediment, which previously was deposited in the upstream one-third of the reservoir, is transported to and deposited in the downstream two-thirds of the reservoir. Between June 28 and August 12, 1994, the reservoir stage dropped about 30 ft and much of the sediment in the upstream one-third of the reservoir was eroded and transported farther downstream in the reservoir.

Data Collection

The bathymetric surface of Terrace Reservoir was surveyed during July and August 1994, using an echo sounder (ODECO TDS–1000) mounted on a boat. Soundings were made on a fixed time interval while the boat traveled at a relatively constant speed of about 2 to 3 mi/h. The location of each sounding was computed from the distance and azimuth from a known position on the shore (navigation station) to a target mounted on the boat about 6 ft above the echo sounder's transducer. Distance and azimuth were determined with a HYDRO2 navigation system. Distance from the navigation station to the target was measured using an infrared range finder. Azimuth from the navigation station to the target was measured with an electronic surveying instrument (total data station). Data from the echo sounder, the range finder, and the total data station were stored and processed in the field on a laptop computer, using a hydrographic-surveying software package (Coastal Oceanographics, 1994). [The use of trade, product, industry, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.]

Each sounding depth (depth to reservoir bottom) was converted to a bottom altitude by subtracting the sounding depth from the reservoir stage. Reservoir stage was determined twice daily, using temporary staff gages. When necessary, the stage was interpolated to estimate the stage at the time the depth sounding was made. Temporary staff gages were used because the stage recorder for the reservoir was inoperative during July and August 1994. Datum for the temporary staff gages was a mark on the crest of the overflow spillway of Terrace Reservoir (BM–1, fig. 2), which is approximately 8,571 ft above NGVD of 1929.

Soundings were not made in the upstream one-third of the reservoir, upstream from navigation station TP–6 (fig. 2), because the boat was difficult to handle in the shallow and relatively narrow channel. Because no soundings were made west of navigation station TP–6, the bathymetric surface of the reservoir upstream from TP–6 and above a stage of about 8,550 ft was not surveyed. Soundings in the middle one-third of the reservoir, between navigation stations TP–6 and TP–4, were made on July 1, 1994, when reservoir stage was 8,559.1 ft, and in the lower one-third of the reservoir, downstream from navigation station TP–4, during August 10–12, 1994, when reservoir stage was between 8,533.8 and 8,534.0 ft. Traces along which soundings were taken are shown in figure 2. Horizontal coordinates of the depth soundings used in this report are given as easting (distance east) and northing (distance north) from the datum that was used for a previous (1981) survey of the bathymetric surface of Terrace Reservoir (Davis Engineering Services, Inc., 1981). The locations of two prominent features (BM–1 and HUB–1, fig. 2) were used to register the coordinate locations from this survey with the coordinate locations from the survey by Davis Engineering Services, Inc. (1981). BM–1 (fig. 2) is a mark on the crest of the overflow spillway adjacent to the north wingwall. HUB–1 (fig. 2) is a 2-ft-long iron rod, near a boulder on a prominent point of rock, north of the east end of the earth-fill dam. After editing to remove spurious and duplicate data points, a total of 21,944 bottom altitudes were used to define the July–August 1994 bathymetric surface of Terrace Reservoir.

Acknowledgments

The following individuals and organizations are acknowledged for providing information and access to private property. Paul Prickett of the Terrace Reservoir Irrigation Company provided unpublished stage measurements for the reservoir, and the Terrace Reservoir Irrigation Company allowed access to the reservoir for the bathymetric survey. Davis Engineering Services, Inc., of Del Norte, Colorado, provided a base-stable copy of the 1981 bathymetric-surface map and a copy of the 1981 storage-capacity table for Terrace Reservoir. The State Engineer's Office, Irrigation Division 3, Alamosa, Colorado, provided data on monthly storage in the reservoir. David S. Mueller, U.S. Geological Survey, provided training in use of the navigation system and hydrographic software.

BATHYMETRIC SURFACE

The altitude and configuration of the bathymetric surface of Terrace Reservoir during July–August 1994 (fig. 3) were machine contoured, using ARC/INFO (Environmental Systems Research Institute, Inc., 1994). Selected machine-drawn contours were revised because of insufficient data spacing in some areas and because of inherent limitations of the contouring program. The coordinates used on the 1994 bathymetric-surface map (fig. 3) are in feet east (easting) and feet north (northing) of the datum that was used by Davis Engineering Services, Inc. (1981). Although the coordinate system is based on the State-Plane Coordinate System for southern Colorado, the locations have not been determined precisely. Therefore, the local coordinate system used by Davis Engineering Services, Inc. (1981), was maintained for comparative purposes. Because no new data were collected in the upstream one-third of the reservoir west of TP–6 (fig. 3), the 1994 bathymetric surface was not contoured in this area. Contours also are not shown where altitude of the surface is greater than 8,550 ft in the lower two-thirds of the reservoir because little data were collected when the stage of the reservoir was greater than 8,550 ft. Changes in the configuration of the bathymetric surface between altitudes of 8,550 and 8,571 ft have not been determined. However, substantial quantities of sediments are not likely to accumulate above an altitude of about 8,550 ft in the upstream one-third of the reservoir west of TP–6 (fig. 3) because of erosion during periods when the reservoir stage drops rapidly and in the downstream two-thirds of the reservoir because the sides of the reservoir are very steep.

The 1981 and 1994 bathymetric-surface maps were similar in most areas. Differences between the bathymetric surfaces, in part, quantified the accumulation of sediments in the reservoir between 1981 and 1994 and also indicated some areas in which errors in contouring probably resulted from insufficient data. Some differences between the 1981 and 1994 bathymetric-surface maps also resulted from the types of data used to prepare the maps. The 1981 bathymetric-surface map (Davis Engineering Service, Inc., 1981) was prepared from aerial photographs taken when the reservoir was drained for maintenance and essentially constituted a continuous data set. The 1994 bathymetric-surface map was prepared from a finite number of depth soundings (21,944) and constituted a discontinuous data set. Differences between the 1981 and 1994 bathymetric-surface maps also might have resulted from errors in determining locations of the navigation stations and soundings and in the measurement of depth and reservoir stage. The use of different contouring methods also could introduce differences because the methods are interpretive.

Errors in depth measurement probably resulted from the vertical motion of the boat due to waves or changes in velocity of the boat, but likely would have a mean error of zero and range from about –0.5 to 0.5 ft. Errors in sounding locations are likely to have resulted from slight errors in the measurement of the azimuth from the navigation station to the target mounted above the transducer of the echo sounder. Errors in measuring the azimuth probably were less than 1 degree. At a distance of 1,000 ft, an error of 1 degree in the azimuth would result in an error in location of the sounding of about 17.5 ft. Although the accuracy of sounding locations cannot be determined with the available data, it was assumed likely location errors were less than 1 to 2 ft. Errors in stage measurement included measurement of the stage on the temporary staff gages (–0.05 to 0.05 ft) and datum error (–0.02 to 0.02 ft) and are not a substantial source of error.

STORAGE CAPACITY

The storage capacity of Terrace Reservoir during July–August 1994 (table 1) was estimated from the 1994 bathymetric-surface map (fig. 3), using ARC/INFO. Although the storage capacity of Terrace Reservoir during 1981 (table 1) was reported by Davis Engineering Services, Inc. (1981), for purposes of comparison, the 1981 storage capacity was estimated from the digitized 1981 bathymetric-surface map, using ARC/INFO.

The difference between the 1981 reported and estimated storage capacity of Terrace Reservoir at a stage of 8,545 ft (table 1), calculated as the reported 1981 storage capacity minus the estimated 1981 storage capacity, was –130 acre-ft. The 1981 estimated storage capacity was about 1.5 percent larger than the 1981 reported storage capacity. The difference between the 1981 and the 1994 estimated storage capacity of Terrace Reservoir at a stage of 8,545 ft (table 1), calculated as 1981 estimated minus 1994 estimated storage capacity, was 580 acre-ft. The 1994 estimated storage capacity was about 6.7 percent smaller than the 1981 estimated storage capacity and was assumed equivalent to the cumulative deposition of sediments in Terrace Reservoir during 1981–94. Although the estimated change in storage capacity during 1981–94 was assumed to approximate the cumulative 1981–94 deposition of sediment, the difference in storage capacity also includes errors in data collection, in contouring the bathymetric data, and in calculating the storage capacity from the bathymetric surface. The average annual decrease in storage capacity of Terrace Reservoir at a stage of 8,545 ft, during 1981–94, was less than or equal to about 41 acre-ft, or an annual decrease of about 0.5 percent of the estimated 1981 storage capacity at a stage of 8,545 ft (table 1). Although sediment deposition was not assumed to be of uniform thickness within the reservoir at a stage of 8,545 ft, the ratio of cumulative decrease in storage capacity of the reservoir (580 acre-ft) to the estimated 1981 surface area of the reservoir (215 acres) was about 2.7 ft and was assumed to be equivalent to the average thickness of sediment deposited in Terrace Reservoir during 1981–94.

A preliminary review of the differences between the digitized 1981 bathymetric-surface map (Davis Engineering Services, Inc., 1981) and the 1994 bathymetric-surface map (fig. 3) showed an irregular pattern of positive differences (deposition) and negative differences (erosion). Most of the positive difference (deposition) was in the middle one-third of the reservoir between 1,500 and 6,000 ft easting. An apparent irregular pattern of positive and negative differences in the downstream one-third of the reservoir was assumed to primarily result from data and contouring errors.

REFERENCES CITED

Cain, Doug, 1995, Factors affecting surface-water quality in the Alamosa River Basin, south-central Colorado [abs.], *in* Posey, H.H., Pendelton, J.A., and Van Zyl, Dirk, eds., Proceedings—Summitville Forum '95, Jan. 17–20, 1995, Fort Collins, Colo.: Colorado Geological Survey Special Publication 38, p. 159.

Coastal Oceanographics, 1994, Hypack—Version 4.16 users manual: Durham, Conn., 247 p.

Davis Engineering Services, Inc., 1981, Capacity survey of the Terrace Reservoir: Del Norte, Colo., 3 sheets, scale 1:2,400.

Environmental Systems Research Institute, Inc., 1994, ARC/INFO—Version 7.0.2: Redlands, Calif.

King, T.V.V., ed., 1995, Environmental considerations of active and abandoned mined lands—Lessons from Summitville, Colorado: U.S. Geological Survey Bulletin 2220, 38 p.

U.S. Environmental Protection Agency, 1993, Summitville mining site "Background" fact sheet, January 1993.

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
acre	4,047	square meter
acre-foot (acre-ft)	1,233	cubic meter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
mile per hour (mi/h)	1.609	kilometer per hour

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.

Table 1. Storage capacity of Terrace Reservoir, 1981 and 1994

Altitude of water surface (feet)	1981 reported [1] Surface area (acres)	1981 reported [1] Storage capacity (acre-feet)	1981 estimated [2] Surface area (acres)	1981 estimated [2] Storage capacity (acre-feet)	Difference between 1981 reported and 1981 estimated storage capacity (acre-feet)	1994 estimated [3] Surface area (acres)	1994 estimated [3] Storage capacity (acre-feet)	Difference[4] between 1981 and 1994 estimated storage capacity (acre-feet)
8,450	0.7	1.0	0.8	1.9	–0.9	0.7	1.7	0.2
8,455	2.7	9.4	2.6	10.4	–1.0	4.0	13.5	–3.1
8,460	7.0	33.5	7.1	34.6	–1.1	8.5	44.8	–10.2
8,465	14.7	87.7	14.6	88.7	–1.0	14.6	102	–13.3
8,470	20.8	176	21.3	178	–2.0	20.6	190	–12.0
8,475	22.3	284	29.4	306	–22.0	26.2	308	–2.0
8,480	37.4	434	38.8	476	–42.0	33.3	457	19.0
8,485	49.5	651	49.9	698	–47.0	43.0	647	51.0
8,490	58.8	921	60.0	972	–51.0	49.2	878	94.0
8,495	71.1	1,250	74.0	1,310	–60.0	65.0	1,160	150
8,500	94.0	1,660	96.2	1,730	–70.0	88.1	1,550	180
8,505	108	2,160	112	2,250	–90.0	106	2,030	220
8,510	126	2,750	127	2,850	–100	120	2,600	250
8,515	136	3,400	137	3,510	–110	130	3,220	290
8,520	145	4,110	147	4,220	–110	139	3,890	330
8,525	159	4,870	161	4,990	–120	150	4,610	380
8,530	172	5,700	172	5,820	–120	162	5,390	430
8,535	183	6,590	184	6,710	–120	174	6,240	470
8,540	197	7,540	198	7,660	–120	187	7,140	520
8,545	211	8,560	215	8,690	–130	200	8,110	580

[1]Davis Engineering Services, Inc. (1981).
[2]Surface area and storage capacity estimated from digitized map of the bathymetric surface of Davis Engineering Services, Inc. (1981), using ARC/INFO.
[3]Area and cumulative capacity estimated from 1994 bathymetric surface, using ARC/INFO.
[4]Difference calculated as 1981 estimated storage capacity minus 1994 estimated storage capacity

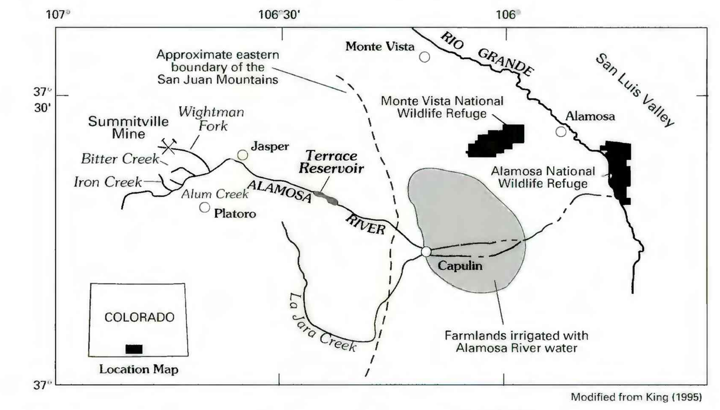

Figure 1. Location of Terrace Reservoir.

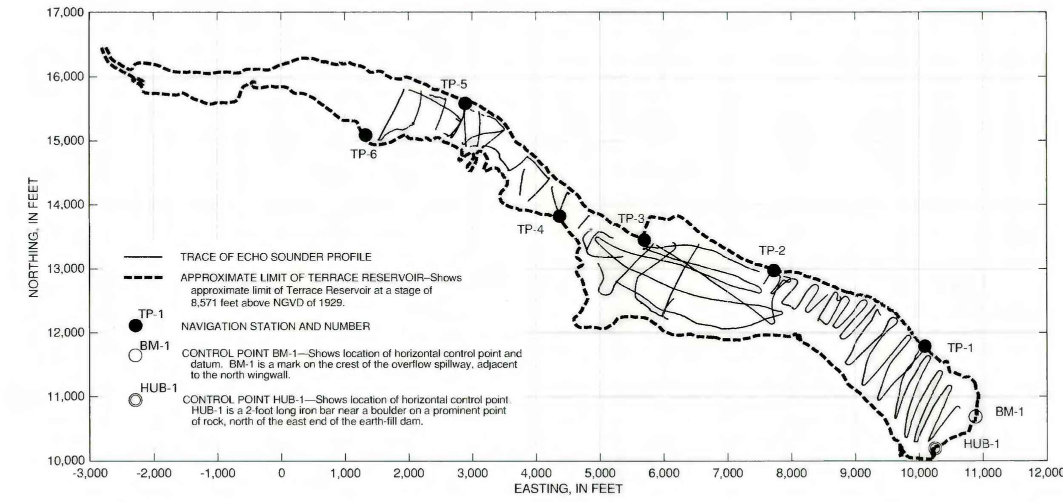

Figure 2. Locations of navigation stations, traces of echo sounder profiles, and approximate limit of Terrace Reservoir.

[BM–1, a mark on the crest of the overflow spillway adjacent to the north wingwall, is a horizontal control point and datum. HUB–1, a 2-foot-long iron rod near a boulder on a prominent point of rock north of the east end of the earth-fill dam, is a horizontal control point. Easting is the distance east of the arbitrary meridian and northing is the distance north of the arbitrary baseline that was used in the 1981 bathymetric-surface map (Davis Engineering, Inc., 1981).]

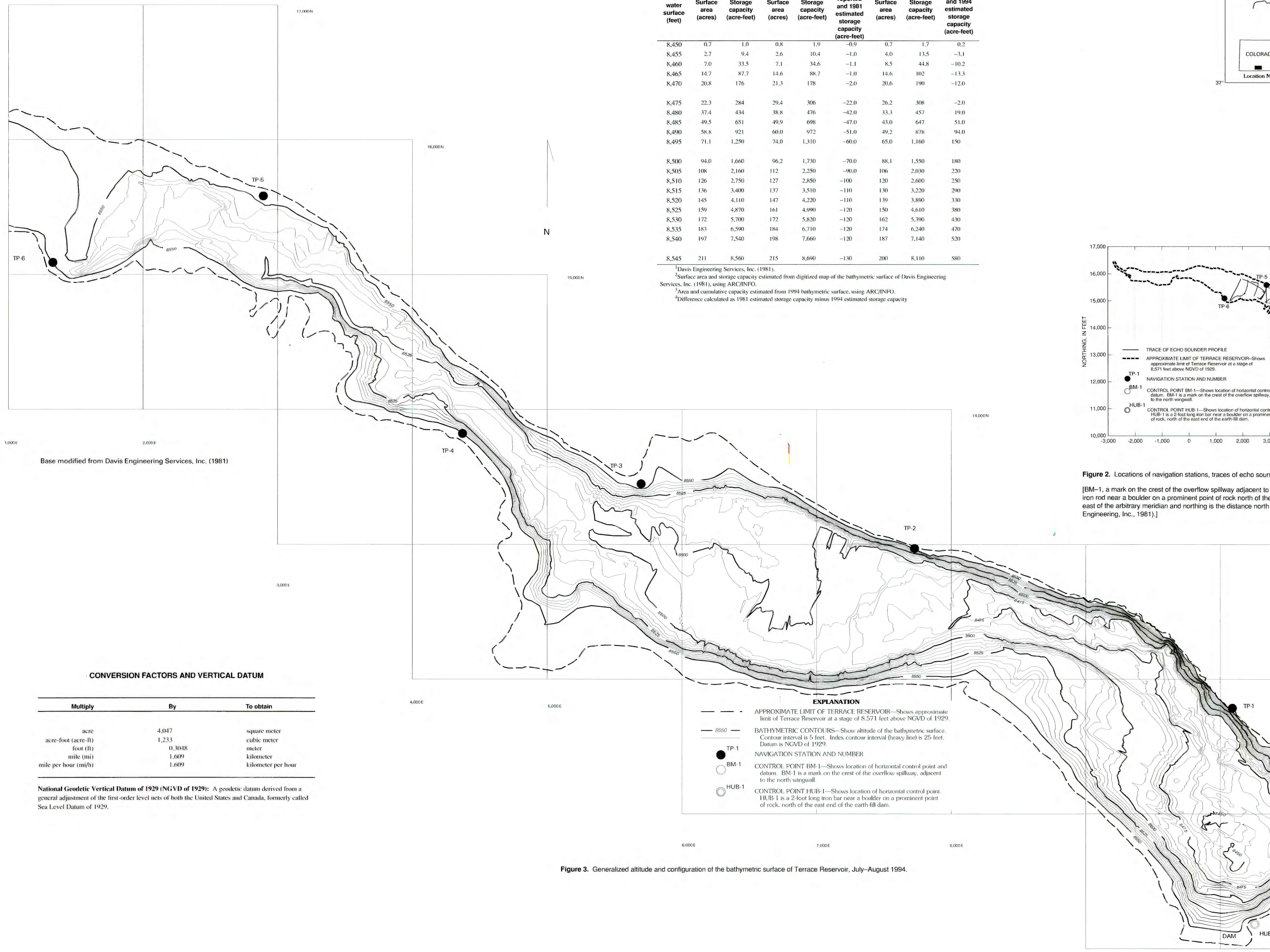

Figure 3. Generalized altitude and configuration of the bathymetric surface of Terrace Reservoir, July–August 1994.

SCALE 1:4,800
0 1,000 2,000 3,000 4,000 FEET
0 1,000 METERS

BATHYMETRIC SURFACE AND STORAGE CAPACITY OF TERRACE RESERVOIR, CONEJOS COUNTY, COLORADO, JULY–AUGUST 1994

By
Kenneth R. Watts

1996