U.S. Department of the Interior
U.S. Geological Survey

Prepared in cooperation with the
Dolores Water Conservancy District

Scientific Investigations Map 3203

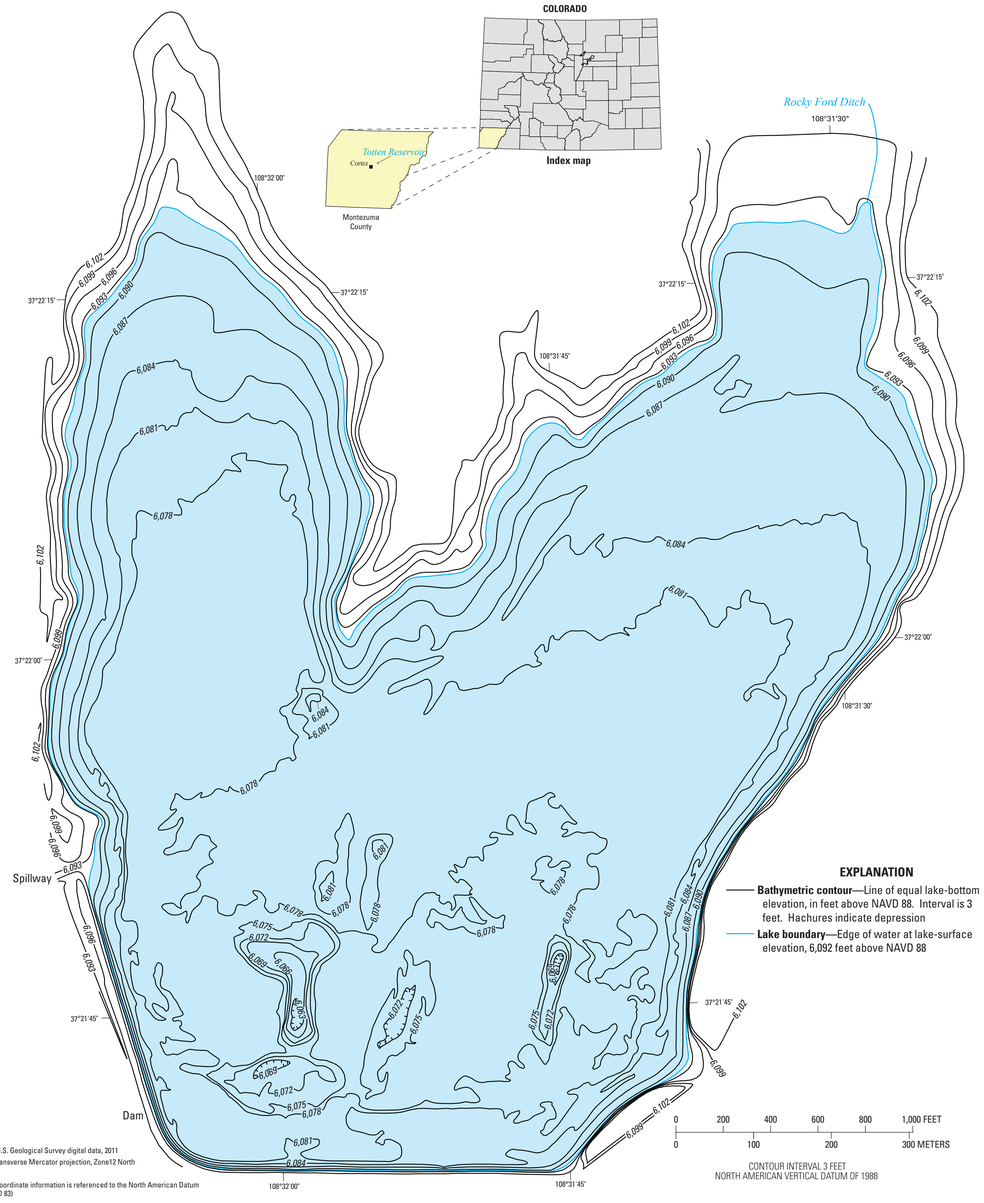

Figure 1. Bathyetric contours of Totten Reservoir, Montezuma County, Colorado, 2011 (not for navigational use).

Bathymetry of Totten Reservoir, Montezuma County, Colorado, 2011

By
Michael S. Kohn
2012

ABSTRACT

In order to better characterize the water supply capacity of Totten Reservoir, Montezuma County, Colorado, the U.S. Geological Survey, in cooperation with the Dolores Water Conservancy District, conducted a bathymetric survey of Totten Reservoir. The study was performed in June 2011 using a man-operated boat-mounted multibeam echo sounder integrated with a global positioning system and a terrestrial real-time kinematic global positioning system. The two collected datasets were merged and imported into geographic information system software. A bathymetric map of the reservoir was generated in addition to plots for the stage-area and the stage-volume relations.

INTRODUCTION

Totten Reservoir is owned and operated by the Dolores Water Conservancy District (DWCD), and water from the reservoir is used for recreation and irrigation of agricultural land. Because the storage capacity of Totten Reservoir is not documented and storage capacity information would aid water-resources managers in their operation of the reservoir during periods of drought and (or) high demand, the U.S. Geological Survey (USGS), in cooperation with the DWCD, conducted a bathymetric study of Totten Reservoir to determine the stage-surface area and stage-volume relations of the reservoir. This report provides water managers with a better understanding of available water supply in the reservoir and, should another bathymetric survey be conducted in the future, a dataset that also could be used to determine sedimentation infill rate and the useful lifespan of the reservoir. This report supports one of the USGS strategic directions of water supply by providing information related to the water census of the United States.

PURPOSE AND SCOPE

This report presents the results of the bathymetric evaluation of Totten Reservoir. The report contains a description of the data collection and analytical methods used to survey the reservoir and to develop datasets which aid water managers. A bathymetric map of the reservoir is presented with plots for the stage-area and the stage-volume relations.

DESCRIPTION OF STUDY AREA

Totten Reservoir is located in southwestern Colorado at 37°21'39" N. latitude and 108°32'06" W. longitude in central Montezuma County, just northeast of the town of Cortez (U.S. Geological Survey, 2011). Totten Reservoir is a man-made lake created by the impoundment of Rocky Ford Ditch (Holdren and Nelson, 1998). Construction of the dam was completed in 1965 (Holdren and Nelson, 1998). The reservoir has a mean depth of 13.7 feet (ft) and maximum depth of 21 ft with a surface area of 241 acres (ac) (Holdren and Nelson, 1998). A hydrologic study of the reservoir revealed the average annual surface runoff and average annual groundwater inflows to the reservoir are approximately 183 acre-feet (ac-ft) and 223 ac-ft, respectively (Bureau of Reclamation, 1988).

The water rights in the reservoir are owned by the DWCD; however, recreational activities are permitted on the reservoir as Totten Reservoir is home to Totten Reservoir State Wildlife Area. Downstream from Totten Reservoir approximately 0.2 miles (mi), Rocky Ford Ditch flows into Simon Draw, a branch of McElmo Creek, a tributary of the San Juan River which feeds the Colorado River (U.S. Geological Survey, 2011).

BATHYMETRIC MEASUREMENT AND STORAGE ANALYSIS

The USGS performed a bathymetric survey of Totten Reservoir using a man-operated boat-mounted multibeam echo sounder integrated with a global positioning system (GPS) and a terrestrial real-time kinematic (RTK) GPS in June 2011. For the purposes of this report, data collected from both the boat-mounted multibeam echo sounder and terrestrial RTK GPS will be considered bathymetric data. The multi-beam echo sounder collected data at lake depths of approximately 3 feet and greater, whereas a terrestrial topographic survey was performed with the RTK GPS in shallow areas near the shore not navigable by boat to the elevation of the top of the dam plus about 2 to 3 additional feet.

BATHYMETRIC MEASUREMENTS USED IN DATA COLLECTION

Bathymetric data from the multibeam echo sounder were collected June 6–8, 2011, using a Teledyne Odom Hydrographic ES3PT–M integrated multibeam echo sounder and motion sensor (Teledyne Odom Hydrographic, Inc., 2011) equipped with a Trimble SPS461 GPS receiver using procedures described in Wilson and Richards (2006). The vertical and horizontal precision of the multibeam echo sounder GPS as rated by the manufacturer are ±0.065 ft and ±0.032 ft, respectively (Trimble Navigation Limited, 2009b). The multibeam echo sounder has a swath width of 120 degrees capable of collecting data to depths of 197 ft. The echo sounder collects 240 data points at a sample frequency of 12 hertz (Hz); however, this varies with depth. The GPS generates position data at a rate of 5 Hz and navigational data at a rate of 1 Hz. A Teledyne Odom Hydrographic Real Time Appliance (RTA) was used for data synchronization of all aforementioned instruments resulting in a data string recorded at 1 Hz. The bathymetry data from the multibeam echo sounder were compiled and stored using the hydrographic survey software, HYPACK 2010 from HYPACK, Inc. (HYPACK, Inc., 2010).

The multibeam echo sounder emits a pulse at a frequency of 240 kilohertz, which is reflected off the lake bed and detected by the receiver. The velocity of the pulse is affected by the lake temperature and salinity. For Totten Reservoir, a freshwater lake, the effect of salinity was assumed to be negligible (U.S. Army Corps of Engineers, 2002). Velocity profiles of Totten Reservoir were recorded using a Teledyne Odom Hydrographic Digibar-Pro velocity meter throughout the study and were used to correct the data during post-processing (Teledyne Odom Hydrographic, Inc., 2001). Calibration points were obtained with the RTK GPS while the multibeam echo sounder was simultaneously recording to confirm the results.

The dam, principle outlet structure, and spillway also were surveyed using the RTK GPS. The terrestrial topographic survey was performed June 6–9, 2011, with a Trimble R8 GNSS RTK GPS receiver, a Trimble HPB450 radio modem, and a Trimble TSC2 controller. The vertical and horizontal precision of the RTK GPS as rated by the manufacturer are ±0.066 ft and ±0.033 ft, respectively (Trimble Navigation Limited, 2009a). The RTK GPS setup consisted of a base station, which included a receiver and radio, and a rover which consisted of a receiver and controller. The base station was located at a fixed position on the east end of the dam and receives information from satellites and transmits data to the rover's receiver via the radio. The base station also continuously records its position. The rover communicates with the base station and is used to collect and record individual data points throughout the study area based on the position of the base station.

The daily water-surface elevation was determined from the RTK GPS survey-data points. The RTK GPS dataset included more than 6,000 data points obtained over the course of the study on the shoreline and in the shallow areas of the lake that were not navigable by boat. The shoreline was surveyed from a lake depth of 3 ft to 2–3 ft above the top of the dam.

All survey data were collected with a common coordinate system, geoid, ellipsoid, and datum. The coordinate system used was Universal Transverse Mercator (UTM), zone 12 north, the horizontal datum was North American Datum 1983 (NAD 83), and the vertical datum was North American Vertical Datum 1988 (NAVD 88), Geoid 03, ellipsoid World Geodetic System 1984 (WGS 84). Data from the base station collected throughout the study were submitted to the National Geodetic Survey's Online Positioning User Service (OPUS) Web site for processing (*http://www.ngs.noaa.gov/OPUS/*, accessed October 19, 2011). All survey data were recomputed to reflect the OPUS solution correction.

POST PROCESSING AND DATA ANALYSIS

The motion sensor in the multibeam sonar records the instrument's motion in terms of pitch, roll, and heave. Pitch is the alternating rise and fall of the boat's bow and stern, roll is rotation of the boat about its main axis, heave is the vertical rise and fall of the entire vessel, and yaw is the rotation of the sonar from the boat's main axis. The ambient offsets of pitch, roll, and yaw were corrected using a calibration test, otherwise known as a patch test, as the instrument was not installed exactly vertical and in line with the boat's main axis. From the patch test, the pitch offset angle was determined to be -15.5 degrees, the roll 1.0 degree, and the yaw 5.5 degrees.

The post processing of the multibeam echo sounder bathymetry data was performed using HYPACK 2011 from HYPACK, Inc. (HYPACK, Inc., 2011). All the data were filtered using the automated search and filter tool. Then, manual filtering was performed on the multibeam echo sounder bathymetry data to edit any spikes or inconsistencies the automated filter overlooked. Once all the data were filtered, the data were separated by the observation day. The multibeam echo sounder bathymetry data were interpolated onto a grid, with individual grid cells having sides of 6.56 ft, by computing the average depth in each cell and positioning the mean at the cell center.

The daily mean water surface elevation was computed from the gage height recorded at the gage located near the outlet structure. The multibeam echo sounder bathymetry data, which initially used the water-surface elevation as a datum, were converted to elevation (NAVD 88) using the daily mean water-surface elevation. The result was one dataset with a common horizontal and vertical datum (NAD 83 and NAVD 88).

The bathymetry dataset was imported into Environmental Systems Research Institute (ESRI) ArcMap 9.3.1 (Environmental Systems Research Institute, Inc., 2010) so the elevation contours and reservoir area and volume could be determined from the lake bottom to approximately 2–3 ft above the top of dam. Once the 6.56-ft grid was created using HYPACK 2011, it was merged with the RTK GPS dataset in ArcMap by generating a triangulated irregular network (TIN) from both datasets. The TIN was then converted to a 6.56-ft horizontal grid, and using the contour tool in ArcMap, contours at intervals of 3 ft were produced. The areas and volumes at various elevations were computed using the surface volume tool in ArcMap (figs. 1–3, and table 1).

In figure 1, some of the upper contours are not continuous; this is mainly due to the spillway not allowing for the continuation of the contours as the spillway invert is below the elevation of the top of the dam. However, at the northeast end of the reservoir, near the inlet, sufficient data were not collected to resolve the contours causing the breaks. Where breaks in contours occurred, it was assumed the areas and volumes above that point were computed as if a vertical wall existed at that point. That assumption provided better results than using a high resolution digital elevation model. When comparing the 10-meter digital elevation model (DEM) (Gesch and others, 2002) at the reservoir with the data collected, it appeared that the DEM did not provide sufficient accuracy to improve the dataset collected for this report. Therefore, no DEM was used to supplement the dataset and the results of this report were generated only from field data.

BATHYMETRY OF TOTTEN RESERVOIR

From the RTK GPS data, the top of the dam was approximately 6,100 ft above NAVD 88, the spillway invert was 6,094 ft above NAVD 88, and full-pool elevation was 6,092 ft above NAVD 88. The invert elevation of the main outlet is approximately 6,076 ft above NAVD 88 (Ken Curtis, Dolores Water Conservancy District, written commun., Jan. 4, 2011). At the spillway elevation, the surface area of the lake is 243 ac and the volume is 2,940 ac-ft, of which, 42 ac-ft is in the dead pool. The minimum elevation of the reservoir is located 33 ft below the spillway elevation. As shown in figure 3, the volume increases very rapidly with depth initially, but at elevations greater than 6,078 ft above NAVD 88, the stage-volume curve is approximately linear.

SUMMARY

A better understanding of available water supply aids water managers in their operation of reservoirs during periods of drought and (or) high demand, and, should another bathymetric survey be conducted in the future, provides a dataset that also could be used to determine sedimentation infill rate and the useful lifespan of the reservoir. The U.S. Geological Survey, in cooperation with Dolores Water Conservancy District, carried out a bathymetry study of Totten Reservoir, Montezuma County, Colorado, from June 6–9, 2011. The study was performed using a man-operated boat-mounted multibeam echo sounder integrated with GPS navigation and RTK GPS. The vertical and horizontal precision of the multibeam echo sounder GPS as rated by the manufacturer are ±0.065 feet and ±0.032 feet, respectively. The vertical and horizontal precision of the RTK GPS as rated by the manufacturer are ±0.066 feet and ±0.033 feet, respectively. From the RTK GPS survey, the top of dam was approximately 6,100 feet above North American Vertical Datum 1988 (NAVD 88) and the spillway invert was 6,094 feet above NAVD 88. The two collected datasets were merged and imported into geographic information system software. The results of the study include a stage-surface area and stage-volume relations and bathymetric map. At the spillway elevation, the surface area of the lake is 243 acres and the volume is 2,940 acre-feet.

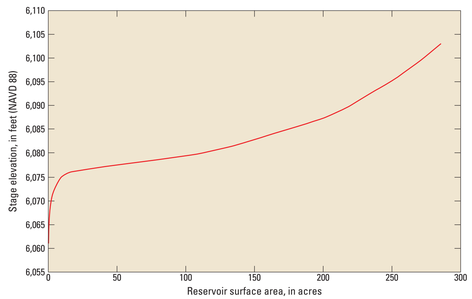

Figure 2. Stage-surface area curve of Totten Reservoir, Montezuma County, Colorado, 2011.

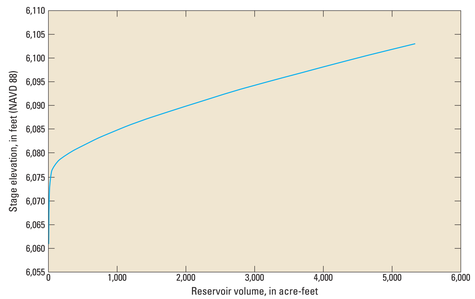

Figure 3. Stage-volume curve of Totten Reservoir, Montezuma County, Colorado, 2011.

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Publishing support provided by:
Denver Science Publishing Network
Manuscript approved for publication on February 28, 2012

For more information concerning this publication, contact:
Center Director, USGS Colorado Water Science Center
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Denver, CO 80225-0046
303-236-6900

Or visit the Colorado Water Science Center site at:
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Suggested Citation: Kohn, M.S., 2012, Bathymetry of Totten Reservoir, Montezuma County, Colorado, 2011: U.S. Geological Survey Scientific Investigations Map 3203, scale 1:290 (*http://pubs.usgs.gov/sim/3203/*).

ACKNOWLEDGMENTS

Several U.S. Geological Survey (USGS) employees helped with the data collection, including Jennifer L. Moore and Keelin R. Schaffrath. Kenneth R. Odom, now of Southern Company, Birmingham, Ala., provided help with the data collection along with assistance in organizing the data collection. Kristine L. Verdin and Barbara C. Ruddy (USGS) helped generate the map and associated graphics. The author would like to thank Paul J. Kinzel (USGS) for the onsite help and technical support he provided during the data collection and analysis, as well as comments he provided as a technical reviewer. Cory A. Williams (USGS) helped with the data collection and provided beneficial comments as a technical reviewer. The data collection was made easier by E.A. Birk of Dolores Water Conservancy District, who granted the survey crew access around the reservoir. Ken Curtis of Dolores Water Conservancy District provided previous survey information and helped to coordinate the study.

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Table 1. Stage-surface area and stage-volume relation for selected elevations of Totten Reservoir, Montezuma County, Colorado, 2011.

Stage elevation, in feet (NAVD 88)	Stage-surface area, in acres	Stage-volume, in acre-feet
6,061	0.000	0.000
6,062	0.017	0.003
6,063	0.131	0.077
6,064	0.238	0.262
6,065	0.358	0.549
6,066	0.641	1.05
6,067	0.905	1.82
6,068	1.16	2.84
6,069	1.57	4.20
6,070	2.07	6.01
6,071	2.76	8.41
6,072	3.92	11.7
6,073	5.38	16.3
6,074	7.03	22.5
6,075	9.50	30.7
6,076	15.5	42.4
6,077	35.4	66.9
6,078	63.5	116
6,079	89.5	193
6,080	112	294
6,081	128	414
6,082	140	548
6,083	152	695
6,084	162	852
6,085	173	1,020
6,086	185	1,200
6,087	197	1,390
6,088	206	1,590
6,089	213	1,800
6,090	219	2,020
6,091	225	2,240
6,092	231	2,470
6,093	237	2,700
6,094	243	2,940
6,095	249	3,190
6,096	254	3,440
6,097	259	3,700
6,098	264	3,960
6,099	269	4,220
6,100	273	4,490
6,101	277	4,770
6,102	281	5,050
6,103	286	5,330