Abstract

The U.S. Geological Survey (USGS), in cooperation with the Shoshone-Bannock Tribes, surveyed the bathymetry and selected above-water sections of Blackfoot Reservoir, Caribou County, Idaho, in 2011. Reservoir operators manage releases from Government Dam on Blackfoot Reservoir based on a stage-capacity relation developed about the time of dam construction in the early 1900s. Reservoir operation directly affects the amount of water that is available for irrigation of agricultural land on the Fort Hall Indian Reservation and surrounding areas. The USGS surveyed the below-water sections of the reservoir using a multibeam echosounder and real-time kinematic global positioning system (RTK-GPS) equipment at full reservoir pool in June 2011, covering elevations from 6,090 to 6,119 feet (ft) above the North American Vertical Datum of 1988 (NAVD 88). The USGS used data from a light detection and ranging (LiDAR) survey performed in 2000–2001 to map reservoir bathymetry from 6,116 to 6,124 ft NAVD 88, which was mostly in depths too shallow to measure with the multibeam echosounder, and most of the above-water section of the reservoir (above 6,124 ft NAVD 88). Selected points and bank erosional features were surveyed by the USGS using RTK-GPS and a total station at low reservoir pool in September 2011 to supplement and verify the LiDAR data. The stage-capacity relation was revised and presented in a tabular format. The data sets show a 2.0-percent decrease in capacity from the original survey, due to sedimentation or differences in accuracy between surveys. A 1.3-percent error also was detected in the previously used capacity table and measured water-level elevation because of a questionable reference elevation at monitoring stations near Government Dam. Reservoir capacity in 2011 at design maximum pool of 6,124 ft above NAVD 88 was 333,500 acre-ft.

Introduction

Blackfoot Reservoir is an 18,000-acre lake located about 15 mi north of Soda Springs, Caribou County, in southeastern Idaho (fig. 1). The reservoir was formed in 1909–10, after the completion of Government Dam on the Blackfoot River, and primarily is used now (2012) for irrigation supply and recreation. Reservoir releases are managed by the Bureau of Indian Affairs (BIA) based on a stage-capacity relation developed in 1933 using water-surface elevations (stages) referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29). The reservoir supplies irrigation water for about 50,000 acres of agricultural land near Pocatello and on the Fort Hall Indian Reservation. Elevation of the reservoir bottom ranges from 6,090 to 6,124 ft above the North American Vertical Datum of 1988 (NAVD 88), and the reservoir holds 333,500 acre-ft of water at full pool elevation (6,124 ft above NAVD 88). Drainage area to the reservoir is 581 mi^2 (Harenberg and others, 1989). The U.S. Geological Survey (USGS) operated a non-recording stage-monitoring station on the northern end of the reservoir near the dam from 1912 to 1925 and from 1929 to 1989 (USGS station 13065000). The BIA and Idaho Power Company also have operated stage-monitoring stations in the reservoir near the dam over various time periods.

The USGS surveyed the bathymetry of Blackfoot Reservoir in 2011 to determine temporal changes due to sedimentation and other factors, and to improve the overall accuracy of the stage-capacity table. Bathymetric surveys of high accuracy and resolution are possible through advances in instrumentation, notably multibeam echosounders (MBESs). An MBES coupled with real-time kinematic global positioning systems (RTK-GPS) has advantages over traditional techniques for surveying reservoir bathymetry, such as single-beam echosounders, acoustic Doppler profilers, or soundings, because they can provide more coverage of the reservoir bed and real-time data corrections. The topography (above-water) of the reservoir, which could not be measured with the MBES, was surveyed by Horizons, Inc., in 2000 using terrestrial light detection and ranging (LiDAR), and verified in selected areas by USGS in 2011 using RTK-GPS surveying equipment.

Wind is a factor that is not accounted for in a typical bathymetric or terrestrial survey, but it can influence an observer's perception of reservoir capacity and operations. Wind moving across a reservoir can cause the water surface to be sloped, resulting in increased stage on one end of the reservoir. For example, if wind causes high stage near the dam at Blackfoot Reservoir, reservoir managers may release water under the assumption that the stage at the dam is constant across the reservoir. In this case, the current storage in the reservoir would be overestimated, and too much water may be released. The USGS evaluated this phenomenon through wind and stage monitoring in May–November 2011.

Previous Investigations

The original stage-capacity table for Blackfoot Reservoir was developed in 1933 using data from topographic maps that were made about the time of construction of Government Dam (David Bollinger, Bureau of Indian Affairs, written commun., 2012). Selected elevations and capacities from the 1933 stage-capacity table are published in U.S. Geological Survey (1956) and in various USGS Annual Water Data Reports from 1912 through 1989 (Harenberg and others, 1989). Horizons, Inc., surveyed the above-water section of the reservoir in autumn 2000, when stages were about 6,116 ft above NAVD 88, using terrestrial LiDAR equipment resulting in a point spacing of 14 × 7 ft. Horizons, Inc., provided the LiDAR data to Dowl HKM in March 2001, who used the data to prepare a map of the exposed reservoir pool with 2-ft contour intervals from 6,116 to 6,124 ft above NAVD 88 (Gary Elwell, Dowl HKM, written commun., 2004). No parts of the reservoir below 6,116 ft were surveyed during this study. Dowl HKM noted a 2-percent decrease in reservoir capacity from 1933 to 2000 in the range of surveyed elevations (Gary Elwell, Dowl HKM, written commun., 2004).

The U.S. Army Corps of Engineers rebuilt the spillway at Government Dam in 1984, and the spillway crest elevation was raised 2 ft from 6,122.5 to 6,124.5 ft NAVD 88 (reported as 6,118.5–6,120.5 ft NGVD 29) (Gary Elwell, Dowl HKM, written commun., 2004). Dowl HKM noted a discrepancy in the reported spillway crest elevation during their 2000–2001 study. Project personnel observed water spilling over the spillway crest when the reservoir pool elevation was measured at 6,124.41 ft NAVD 88 (reported as 6,120.41 ft NGVD 29), and determined that the true spillway elevation must be closer to 6,124.0 ft NAVD 88 (reported as 6,120.0 ft NGVD 29). The USGS verified the spillway elevation as near 6,124.0 ft NAVD 88 (6,120.0 ft NGVD 29) during the 2011 study using RTK-GPS surveying equipment. The spillway is slightly sloped with highest elevations on the northern side (6,124.2 ft NAVD 88), and lowest elevations on the southern side (6,124.0 ft NAVD 88).

Methods

Field data were collected at various times from May 29 to November 30, 2011. The USGS collected stage data at three locations and wind data at one location. Reservoir bathymetry was measured using MBES equipment on June 6–24, 2011, at maximum pool (average 6,124.0 ft NAVD 88), and selected ground elevations were measured using RTK-GPS and a total station on September 26–30, 2011, at minimum pool for the year (average 6,119.3 ft NAVD 88).

Stage and Wind Monitoring

The USGS installed three stage-monitoring stations and one wind monitoring station on Blackfoot Reservoir in May and June 2011 (fig. 1). The stage and wind monitoring station (USGS station 13065000) on the northern end of the reservoir near Government Dam was installed on May 27, 2011. Station equipment included a Sutron ACCUBAR® bubbler pressure sensor to measure reservoir stage, a Vaisala WINDCAP® sonic anemometer to measure wind speed and direction, and a Sutron SatLink2 datalogger to record and transmit data. Data were recorded every 15 minutes and transmitted through satellite telemetry every hour. The anemometer stored instantaneous and 12-minute average readings of wind speed and direction. Average wind readings were used for the analysis unless an anomaly was detected, such as an erroneous reading resulting from a leaf or bird obstructing one of the sensors. In this case, the instantaneous readings were used in place of the average readings if they were reasonable and did not appear to be outliers. Stage data from the northern station from May 27 to November 30, 2011, are published in U.S. Geological Survey (2011).

The other two stage-monitoring stations were installed on the eastern and southern sides of the reservoir on June 21, 2011. The two additional stations were compared with the stage and wind monitoring data at the northern station to determine whether wind causes enough slope in the reservoir's water surface to warrant consideration of wind in reservoir operation. The stations were equipped with two In-Situ Level TROLL® 500 vented pressure transducers mounted on a weighted platform on the reservoir bed. The vented cables extended to the water surface to a buoy, and the cable ends were housed in a locked case attached to the top of the buoy, enabling USGS personnel to periodically download data from the transducers. Stage at all three monitoring stations was referenced to a staff plate or other stable reference point installed near each station. Reference points on each staff plate were surveyed during the ground RTK-GPS survey to tie sensor readings into a common datum for comparison. Stage sensors were reset to the staff plate reading at each visit. Corrections for sensor drift or malfunction were applied as needed by pro-rating over time depending on the cause and magnitude of the correction.

Bathymetric Survey

USGS personnel determined that a full-coverage MBES bathymetric survey for the reservoir was not required to create a stage-capacity table that would accurately represent the true capacity of the reservoir. Wilson and Richards (2006) stated that a planned line interval of approximately 1 percent of the longitudinal length of the reservoir is suitable for defining a bathymetric surface. The spacing of MBES survey lines used for the Blackfoot Reservoir survey was 500 ft, which is approximately 0.6 percent of the longitudinal length of the reservoir (fig. 2). This smaller spacing better defined some of the more complex bathymetric features around the islands and shorelines. A 2-ft interval contour map created from the LiDAR data was used to create the boundary extent for the bathymetric survey. The LiDAR survey (2000) was conducted at a stage of 6,116 ft NAVD 88, which is 8 ft below full pool. This data set provided spatial data in parts of the reservoir that would normally have been below water (6,116–6,124 ft NAVD 88). Due to depth constraints, most parts of the reservoir in this elevation range were unmeasurable by the MBES system. The MBES survey was planned to include all areas less than around 6,116 ft and include overlap of the MBES and LiDAR data above 6,116 ft NAVD 88 wherever possible.

Horizontal and Vertical Control

Horizontal and vertical control for the bathymetric survey was established by setting three temporary benchmarks on two islands located within the reservoir. A National Geodetic Survey-designated benchmark "Gray GPS", located about 7 mi east of the center of the reservoir, was used to survey and verify the temporary benchmarks. Two benchmarks were established on the reservoir to be used as daily set-up locations for the bathymetric survey, and a third was used as a daily coordinate check benchmark. Two benchmarks were established on Long Island and one benchmark was established on Split Island (fig. 2).

Data Collection and Processing

The equipment used to conduct the bathymetric survey included an Odom Hydrographic Systems ES-3 multibeam echosounder; an International Industries™ DSM-10 TSS dynamic motion reference unit (roll, pitch, yaw); and an Odom DIGIBAR-Pro profiling sound velocimeter to provide continuous near-surface sound velocity data. A Hemisphere™ VS110 heading and position receiver using two GPS antennas mounted over the echo sounder transducer provided a precise heading. A more detailed description of the equipment used for the bathymetric survey is described in Fosness (in press). Horizontal and vertical positioning was accomplished using an RTK-GPS receiver mounted directly above the MBES and radio linked to a static base-station receiver using a GPS antenna positioned over one of the three temporary benchmarks. The elevation for the reservoir-bottom was calculated in real-time, so a water-surface measurement was not necessary for the bathymetric survey.

Bathymetry data were collected using HYPACK® software's HYSWEEP® software (HYPACK, Inc., 2011). The raw data were post-processed to remove erroneous data caused by macrophyte growth and false echo returns. An algorithm called the Combined Uncertainty Bathymetric Estimator (CUBE) was built into the HYSWEEP® software suite. The CUBE method is a robust statistical filtering approach that incorporated both data points and the total propagated uncertainty of each component of the MBES to determine the estimate for position and elevation within a gridded surface. The CUBE results from the Blackfoot Reservoir bathymetry were output to a 3×3 ft gridded surface that defined the Easting (X), Northing (Y), and elevation (Z) in ASCII format. In some areas, a CUBE estimate could not be resolved in the software. In those areas, the data were reduced to the median value and output to a 3×3 ft gridded surface.

Ground Survey

Elevations of major erosional bank surfaces and reference points near monitoring stations were measured on September 26–30, 2011 (fig. 2). The ground survey was used to verify that the Dowl HKM LiDAR data set from 2000 to 2001 properly represented major erosional banks and other features that could affect the capacity-table calculation. USGS personnel used a survey-grade RTK-GPS, in conjunction with a Trimble VX total spatial station to collect ground-survey data. The RTK-GPS and Trimble VX total spatial station system provide a combined accuracy of 0.039 ft horizontally and 0.072 ft vertically (Trimble Navigation Limited, 2003, 2010), and has built-in constraints to exclude any data collected outside of the desired accuracy limits. The RTK-GPS data were collected using the 2009 Geoid model (Roman and others, 2010) to derive NAVD 88 elevations, and post-processed in Trimble Business Center software (Trimble Navigation Limited, 2011). The ground-survey data were referenced to the National Geodetic Survey's Continuously Operating Reference Station (CORS) network (Snay and Soler, 2008) by establishing accurate base-station locations using the Static Online Positioning User Service (OPUS-S) (Weston and others, 2007). The survey data used the same spatial reference as the bathymetric and LiDAR data: State Plane Idaho East Zone referenced by the North American Datum of 1983 and NAVD 88.

Quality Control and Quality Assurance

Static observations were collected daily at the RTK-GPS base station to ensure accuracy within the survey and provide quality assurance to the horizontal and vertical positioning established for each of the temporary benchmarks. The National Geodetic Survey's OPUS-S was used to post-process the static data for each day of surveying. Daily benchmark checks were made to ensure the RTK-GPS was properly set up and that the coordinates matched those established at the temporary benchmarks.

Physical offsets were measured for each of the MBES components and entered into the software to ensure proper translation for the MBES data solutions. A patch test was conducted for the multibeam system prior to the start of the survey to ensure that the physical offsets were correctly aligned for latency, pitch, roll, and yaw according to the National Oceanic and Atmospheric Administration (2012). The physical offset measurements, the results of the patch test, and uncertainty estimates for each component of the MBES were entered into the total propagated uncertainty (TPU) editor module built into HYPACK®. The TPU module quantifies all sources of error in the survey by accounting for the settings, field conditions, physical offsets, and patch test results.

The CUBE module also was used to output an uncertainty estimate for each 3×3 ft gridded cell. The CUBE module utilized the TPU editor to account for the uncertainty associated with each component used for the MBES survey. The estimated mean uncertainty for the bathymetric survey was approximately 0.21 ft.

The MBES and 2000–2001 LiDAR data overlapped between elevations 6,116–6,119 ft, allowing a comparison between methods and detection of changes in parts of the reservoir (areas with black dots in fig. 2). More than 48,000 points were available for a comparison between data sets made using a 6-ft grid. The reported vertical accuracy of the LiDAR survey was ±0.7 ft (Horizons, Inc., written commun., 2001). On average, the MBES elevations were 0.95 ft lower than the LiDAR elevations in areas where data sets overlapped. Thirty-four percent of the comparison points matched within the combined uncertainty, calculated as the square root of the sum of square errors, of the MBES survey (0.21 ft) and LiDAR survey (0.7 ft), which was 0.73 ft.

The 2011 ground survey data confirm that the LiDAR data were collected in the presence of the major erosional banks, and the LiDAR data does represent the vertical nature of the erosional banks within the limits of the LiDAR data density. The RTK-GPS ground survey elevations were on average 0.8 ft lower than the LiDAR elevations in areas where comparisons were possible. This difference is just slightly higher than the combined uncertainty (0.704 ft) of the RTK-GPS ground survey (0.072 ft) and LiDAR survey (0.7 ft). Some of the differences may have been due to varying benchmarks or control points used to establish vertical and horizontal control and true differences in location and elevation of comparison points. Overall, however, the LiDAR data are considered to be good quality and were used along with USGS-collected data sets to create a revised stage-capacity table.

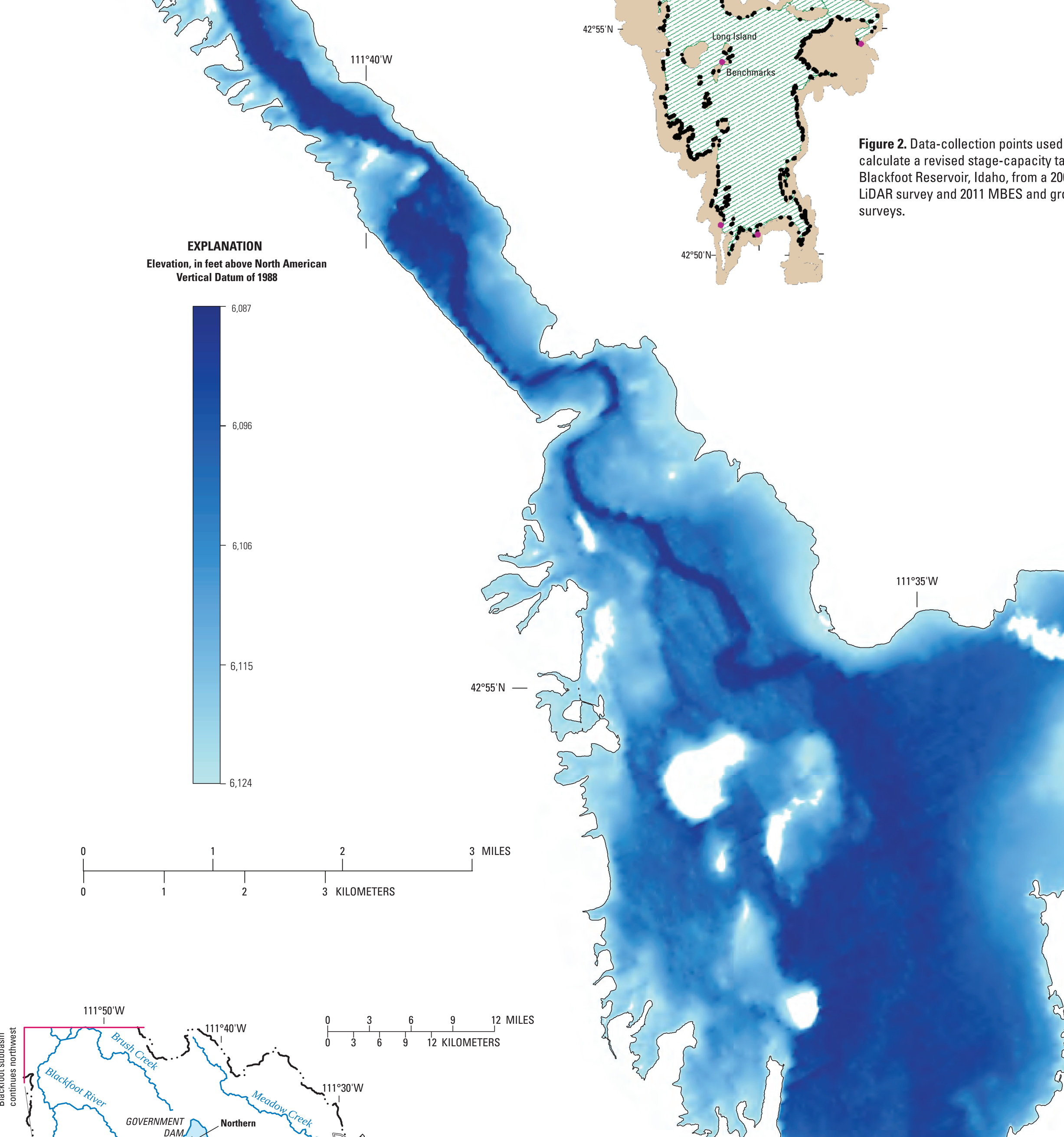

Figure 5. Bathymetric surface elevations in Blackfoot Reservoir, Idaho, 2011. A historical river channel visible in the northern half of the reservoir and its absence in the southern and eastern parts of the reservoir indicates some sedimentation.

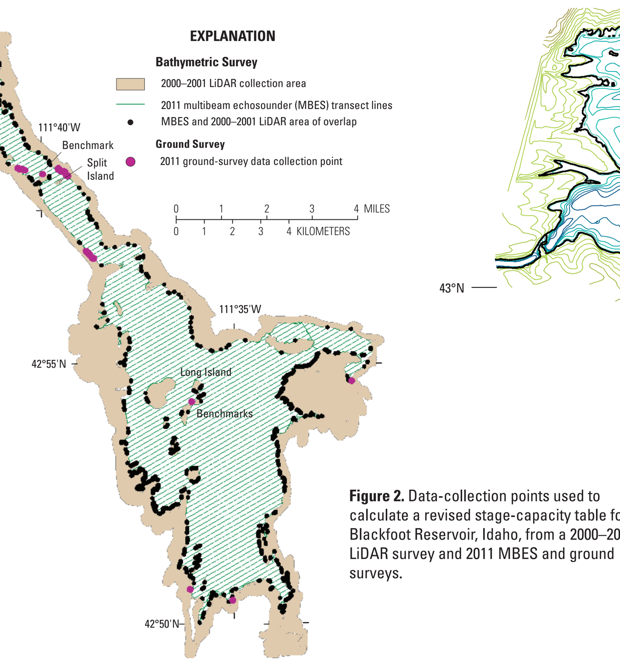

Figure 2. Data-collection points used to calculate a revised stage-capacity table for Blackfoot Reservoir, Idaho, from a 2000–2001 LiDAR survey and 2011 MBES and ground surveys.

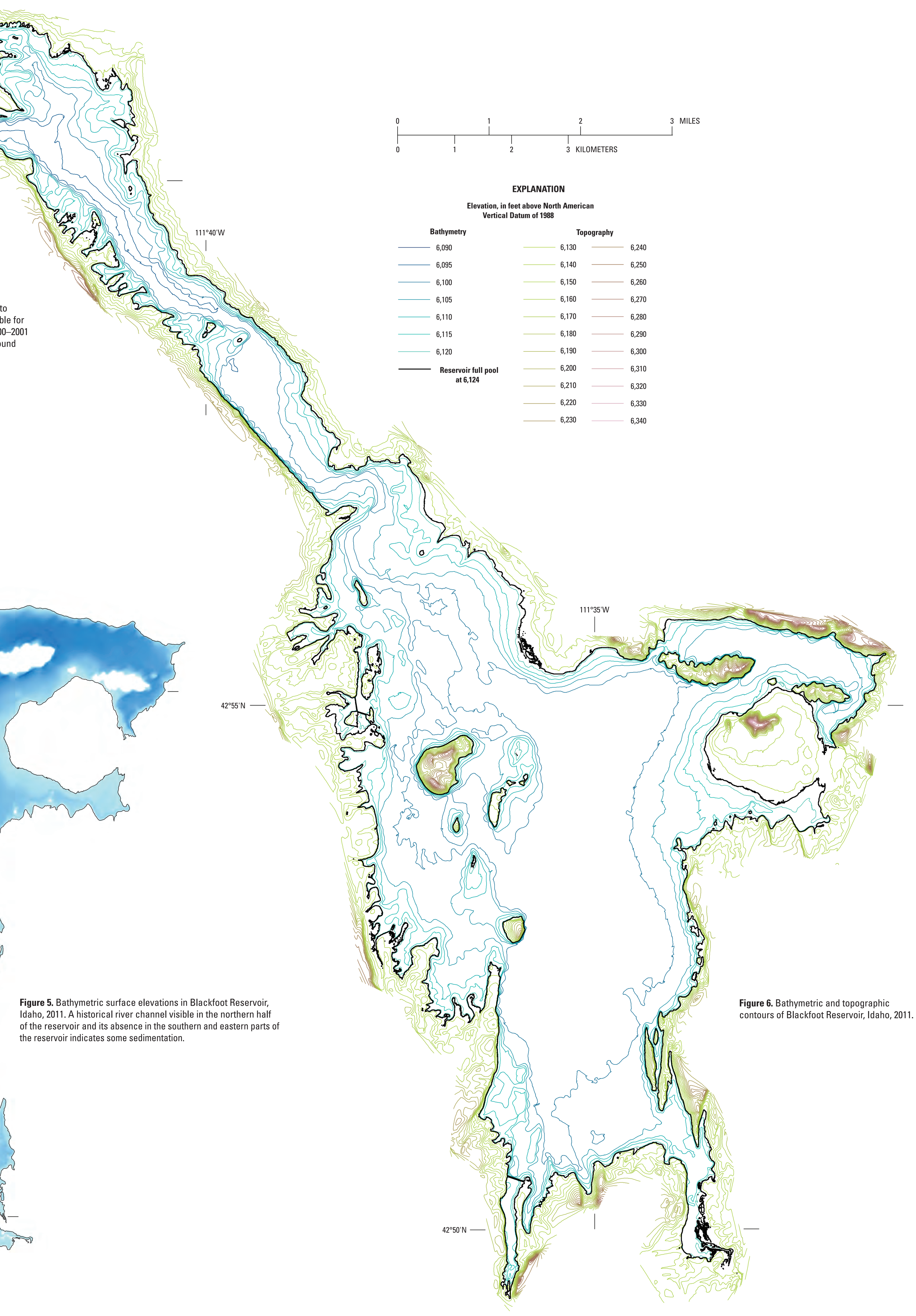

Figure 6. Bathymetric and topographic contours of Blackfoot Reservoir, Idaho, 2011.

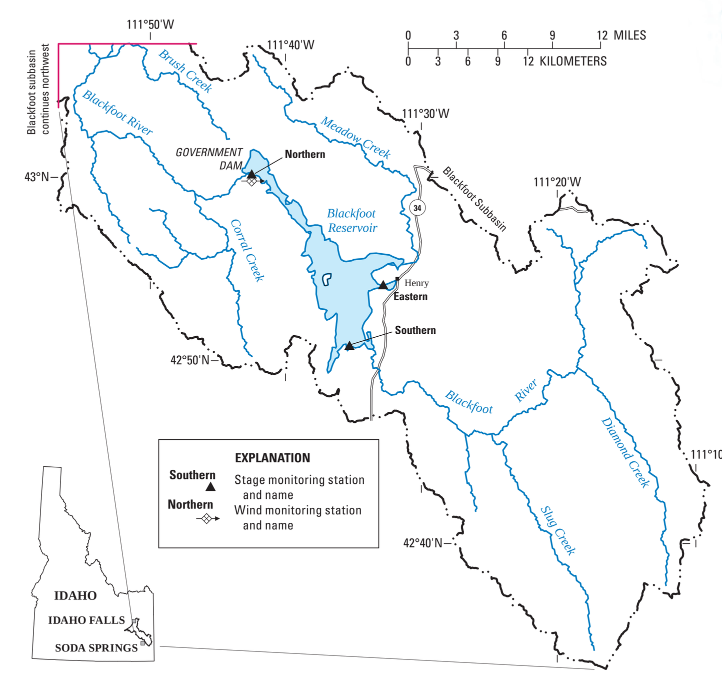

Figure 1. Location of Blackfoot Reservoir and watershed in Caribou County, Idaho.

Effect of Wind on Reservoir Surface Slope

The principal wind directions during the study were from the west (48 percent of observations), and from the south (32 percent of observations), with an overall average wind vector from the southwest (fig. 3). USGS personnel found that wind speed and direction generally do not substantially affect reservoir surface slope except during episodic events of a few hours in duration. Seven distinct events were identified during the study during days when wind speed and direction did affect reservoir surface slope. During those events, increased wind speeds from the west decreased stage at the northern station and increased stage at the eastern and southern stations. An example of such a wind event on July 19, 2011, is shown within the oval in figure 4, when a spike in wind of 24 mph from 290 degrees (west) caused stage at the northern station to decrease about 0.3 ft, and stage at the eastern and southern stations to increase 0.1 and 0.2 ft, respectively. Degree of response at the eastern and southern stations differed among events. Increased wind speeds from the south increased stage at the northern station and decreased stage at the eastern and southern stations, similar to but opposite the pattern shown in figure 4. Fluctuations occurred over several hours throughout the day, but did not result in a sustained change in reservoir surface slope. Change in stage among the stations ranged from 0.1 to 0.3 ft over the seven events.

During the study period, the average difference in stage was –0.2 ft between the northern and eastern stations, and –0.3 ft between the northern and southern stations. Some of the differences may be attributed to differences in the accuracy of the instruments used to measure stage at the eastern, southern, and northern stations. The instruments installed at the eastern and southern stations were intended to be temporary and were less accurate (accuracy ± 0.1 percent of depth; In-Situ Inc., 2010) than the instrument installed at the northern station (accuracy ± 0.02 percent of depth; Sutron Corp., 2011). At full pool elevation, a difference of 0.2–0.3 ft in reservoir surface elevation results in a difference in capacity of 1.0–1.5 percent, respectively. Reservoir capacity calculated from the average elevation of the three stations compared within 0.9 percent on average of reservoir capacity calculated from only the stage at the northern station.

As a whole, most differences in stage due to wind and gradients within the reservoir were relatively small and probably are within the measurement error of the stage-monitoring instruments and of the uncertainty of the MBES survey (0.21 ft). Therefore, reservoir operations based on stage at the northern station are considered sufficient to represent true capacity of the reservoir during the period of study.

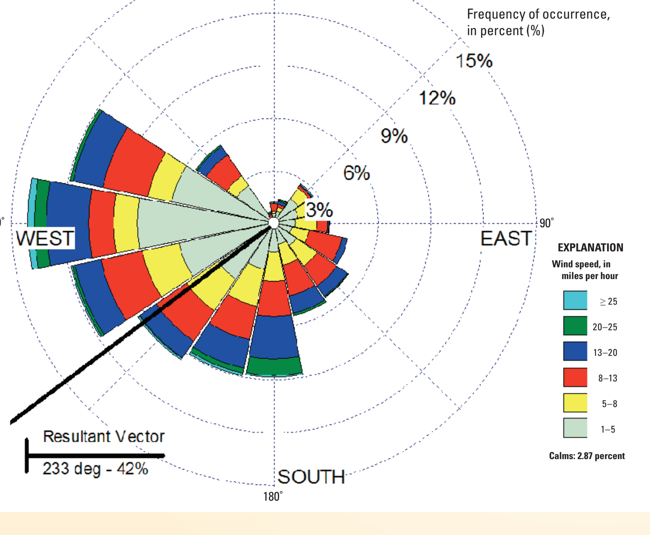

Figure 3. Distribution and frequency of wind measured at the northern monitoring station on Blackfoot Reservoir, Idaho, June 22–November 30, 2011.

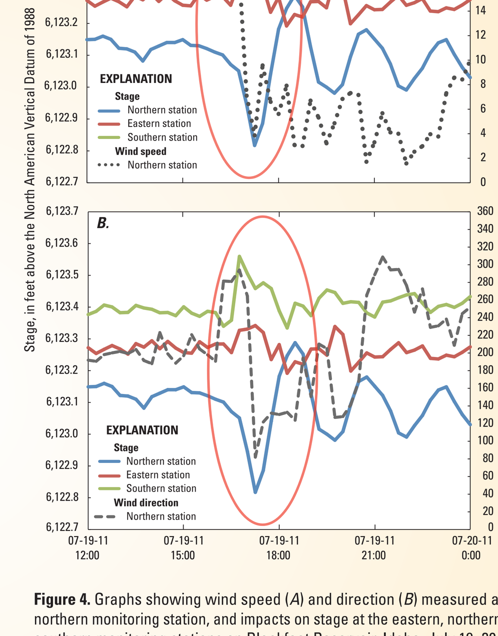

Figure 4. Graphs showing wind speed (A) and direction (B) measured at the northern monitoring station, and impacts on stage at the eastern, northern, and southern monitoring stations on Blackfoot Reservoir, Idaho, July 19–20, 2011. Oval indicates a wind event on July 19, 2011, when wind speed and direction affected reservoir slope.

Revised Stage-Capacity Relation

Geographic information system (GIS) software was used to produce a three-dimensional surface of the reservoir-bottom elevations from the bathymetric, LiDAR, and ground-survey data (fig. 5). The surface was created by combining the point measurements from the LiDAR, bathymetric, and ground surveys, and using the Natural Neighbor interpolation tool in ArcGIS™ (Environmental Systems Research Institute, Inc., 2011) to create a raster surface with a 3-ft cell size. The USGS then used ArcGIS™ to create an area and capacity table based on the raster surface showing surface area and capacity (volume) at specified elevations in 0.2-ft increments (table 1). Interpolation to 0.2 ft was desired for comparison with the stage-capacity table previously in use, although capacities at 0.8-ft intervals are more reliable because the combined uncertainty of the MBES and LiDAR surveys was 0.73 ft. The bathymetry and near-shore surface (derived from LiDAR and ground-survey data only) were contoured using ArcGIS™, and the contours were cartographically edited to create a topographic map with 5-ft contours below and 10-ft contours above 6,124 ft NAVD 88 (fig. 6). Reservoir capacity at full pool (6,124 ft NAVD 88) is 333,500 acre-ft based on 2011 bathymetric and ground survey data, and 2000–2001 LiDAR data. Reservoir capacity at minimum pool measured during the study period (6,119 ft NAVD 88) is 248,500 acre-ft (table 1).

Comparisons in capacity from the original 1933 survey, the 2000–2001 Dowl HKM study, and 2011 USGS study are shown in table 2. The comparison is limited to elevations between 6,116 and 6,124 ft NAVD 88 because reservoir elevations below 6,116 ft were not surveyed during the Dowl HKM study. Reservoir capacity in this range of elevations has decreased on average by 2.0 percent since the original survey, which supports results from the Dowl HKM study. The differences could be caused by changes in the accuracy of survey methods, and minor sedimentation in the reservoir. The bathymetric survey showed an absence of a historical river channel in the southern and eastern parts of the reservoir, which indicates some sedimentation (fig. 5). A well-defined thalweg was evident in the northern half of the reservoir indicating that little, if any, sedimentation has occurred over time in that region.

The USGS noted discrepancies in stages at monitoring stations near Government Dam operated by the USGS and other agencies. The Idaho Power Company monitoring station is referenced to the U.S. Army Corps of Engineers benchmark called "BDR-5" located on a hill north of Government Dam above the spillway, which was assumed to have an elevation of 6,161.79 ft NAVD 88 (reported as 6,157.79 ft NGVD 29 in a 1989 USGS station description) (Mark Kolowith, Idaho Power Company, written commun., 2012). The BIA monitoring station is referenced to a finished floor elevation at the BIA dam pump house. The USGS station was temporarily referenced upon installation to the same finished floor elevation as the BIA station. When the USGS surveyed reference marks in September 2011 using RTK-GPS, USGS station elevations were then referenced to benchmarks established during the MBES survey. The stage at the USGS station based on the 2011 RTK-GPS survey decreased 0.40 ft after the survey correction. After the correction was applied to the USGS station, the BIA and Idaho Power monitoring stations measured an average 0.23 ft lower and 0.52 ft higher, respectively, than the USGS station during the 2011 study period. The USGS surveyed the U.S. Army Corps of Engineers "BDR-5" benchmark in May 2012 and found that the previous elevation used was about 0.48 ft too high, which explains most of the discrepancy between the stages measured at the Idaho Power and USGS monitoring stations. The BIA station has been used as the principal data source for managing reservoir operation from 1989 to 2011. An error of –0.23 ft in stage results in an average 1.3 percent underestimation of reservoir capacity in both the old and revised stage-capacity table over the elevation range of 6,116–6,124 ft above NAVD 88. The stages and stage-capacity table described herein are based on the elevations measured at the 2011 USGS monitoring station with applied corrections.

Table 1. Reservoir area and capacity (volume) at specified elevations for Blackfoot Reservoir, Idaho, 2011.

[Elevations were converted from National Geodetic Vertical Datum of 1929 (NGVD 29) to North American Vertical Datum of 1988 (NAVD 88) using the National Oceanic and Atmospheric Administration VERTCON website (http://www.ngs.noaa.gov/cgi-bin/VERTCON/vert_con.prl) based on the latitude and longitude of the northern monitoring station. Conversion was 3.995 feet]

Stage or reservoir elevation (feet above NGVD 29)	Reservoir elevation (feet above NAVD 88)	Area (acres)	Capacity (acre-feet)
6,086.0	6,090.0	0.12	0.05
6,086.2	6,090.2	0.15	0.08
6,086.4	6,090.4	0.18	0.11
6,086.6	6,090.6	0.21	0.15
6,086.8	6,090.8	0.26	0.19
6,087.0	6,091.0	0.32	0.25
6,087.2	6,091.2	0.38	0.32
6,087.4	6,091.4	0.50	0.41
6,087.6	6,091.6	0.88	0.53
6,087.8	6,091.8	1.68	0.78
6,088.0	6,092.0	2.66	1.21
6,088.2	6,092.2	3.83	1.85
6,088.4	6,092.4	5.25	2.75
6,088.6	6,092.6	7.23	3.98
6,088.8	6,092.8	10.7	5.73
6,089.0	6,093.0	17.0	8.42
6,089.2	6,093.2	28.2	12.8
6,089.4	6,093.4	48.5	20.3
6,089.6	6,093.6	79.7	32.9
6,089.8	6,093.8	118	52.7
6,090.0	6,094.0	155	80.0
6,090.2	6,094.2	185	114
6,090.4	6,094.4	213	154
6,090.6	6,094.6	240	199
6,090.8	6,094.8	266	250
6,091.0	6,095.0	294	306
6,091.2	6,095.2	322	367
6,091.4	6,095.4	351	435
6,091.6	6,095.6	379	508
6,091.8	6,095.8	411	587
6,092.0	6,096.0	443	672
6,092.2	6,096.2	478	764
6,092.4	6,096.4	519	863
6,092.6	6,096.6	572	972
6,092.8	6,096.8	636	1,093
6,093.0	6,097.0	728	1,229
6,093.2	6,097.2	894	1,389
6,093.4	6,097.4	1,269	1,600
6,093.6	6,097.6	1,894	1,914
6,093.8	6,097.8	2,541	2,358
6,094.0	6,098.0	3,135	2,927
6,094.2	6,098.2	3,626	3,605
6,094.4	6,098.4	4,059	4,374
6,094.6	6,098.6	4,435	5,224
6,094.8	6,098.8	4,790	6,148
6,095.0	6,099.0	5,080	7,135
6,095.2	6,099.2	5,368	8,180
6,095.4	6,099.4	5,629	9,280
6,095.6	6,099.6	5,882	10,430
6,095.8	6,099.8	6,132	11,630
6,096.0	6,100.0	6,382	12,880
6,096.2	6,100.2	6,627	14,190
6,096.4	6,100.4	6,875	15,540
6,096.6	6,100.6	7,119	16,930
6,096.8	6,100.8	7,350	18,380
6,097.0	6,101.0	7,586	19,870
6,097.2	6,101.2	7,810	21,420
6,097.4	6,101.4	8,015	23,000
6,097.6	6,101.6	8,211	24,620
6,097.8	6,101.8	8,395	26,280
6,098.0	6,102.0	8,567	27,980
6,098.2	6,102.2	8,731	29,710
6,098.4	6,102.4	8,888	31,470
6,098.6	6,102.6	9,034	33,260
6,098.8	6,102.8	9,172	35,080
6,099.0	6,103.0	9,305	36,930
6,099.2	6,103.2	9,443	38,800
6,099.4	6,103.4	9,585	40,710
6,099.6	6,103.6	9,721	42,640
6,099.8	6,103.8	9,847	44,600
6,100.0	6,104.0	9,972	46,580
6,100.2	6,104.2	10,090	48,580

Table 1. Reservoir area and capacity (volume) at specified elevations for Blackfoot Reservoir, Idaho, 2011.—Continued

[Elevations were converted from National Geodetic Vertical Datum of 1929 (NGVD 29) to North American Vertical Datum of 1988 (NAVD 88) using the National Oceanic and Atmospheric Administration VERTCON website (http://www.ngs.noaa.gov/cgi-bin/VERTCON/vert_con.prl) based on the latitude and longitude of the northern monitoring station. Conversion was 3.995 feet]

Stage or reservoir elevation (feet above NGVD 29)	Reservoir elevation (feet above NAVD 88)	Area (acres)	Capacity (acre-feet)
6,100.4	6,104.4	10,210	50,610
6,100.6	6,104.6	10,320	52,670
6,100.8	6,104.8	10,440	54,740
6,101.0	6,105.0	10,550	56,840
6,101.2	6,105.2	10,660	58,960
6,101.4	6,105.4	10,760	61,100
6,101.6	6,105.6	10,870	63,270
6,101.8	6,105.8	10,970	65,450
6,102.0	6,106.0	11,080	67,660
6,102.2	6,106.2	11,180	69,880
6,102.4	6,106.4	11,280	72,130
6,102.6	6,106.6	11,380	74,390
6,102.8	6,106.8	11,480	76,680
6,103.0	6,107.0	11,590	78,990
6,103.2	6,107.2	11,690	81,320
6,103.4	6,107.4	11,790	83,660
6,103.6	6,107.6	11,900	86,030
6,103.8	6,107.8	11,990	88,420
6,104.0	6,108.0	12,090	90,830
6,104.2	6,108.2	12,180	93,260
6,104.4	6,108.4	12,280	95,700
6,104.6	6,108.6	12,370	98,170
6,104.8	6,108.8	12,470	100,700
6,105.0	6,109.0	12,570	103,200
6,105.2	6,109.2	12,660	105,700
6,105.4	6,109.4	12,750	108,200
6,105.6	6,109.6	12,850	110,800
6,105.8	6,109.8	12,940	113,400
6,106.0	6,110.0	13,030	116,000
6,106.2	6,110.2	13,120	118,600
6,106.4	6,110.4	13,210	121,200
6,106.6	6,110.6	13,290	123,900
6,106.8	6,110.8	13,370	126,500
6,107.0	6,111.0	13,460	129,200
6,107.2	6,111.2	13,560	131,900
6,107.4	6,111.4	13,640	134,600
6,107.6	6,111.6	13,720	137,400
6,107.8	6,111.8	13,800	140,100
6,108.0	6,112.0	13,880	142,900
6,108.2	6,112.2	13,960	145,700
6,108.4	6,112.4	14,030	148,500
6,108.6	6,112.6	14,100	151,300
6,108.8	6,112.8	14,170	154,100
6,109.0	6,113.0	14,240	156,900
6,109.2	6,113.2	14,310	159,800
6,109.4	6,113.4	14,370	162,700
6,109.6	6,113.6	14,440	165,600
6,109.8	6,113.8	14,510	168,400
6,110.0	6,114.0	14,570	171,400
6,110.2	6,114.2	14,630	174,300
6,110.4	6,114.4	14,700	177,200
6,110.6	6,114.6	14,760	180,200
6,110.8	6,114.8	14,820	183,100
6,111.0	6,115.0	14,900	186,100
6,111.2	6,115.2	14,980	189,100
6,111.4	6,115.4	15,060	192,100
6,111.6	6,115.6	15,130	195,100
6,111.8	6,115.8	15,200	198,100
6,112.0	6,116.0	15,270	201,200
6,112.2	6,116.2	15,330	204,200
6,112.4	6,116.4	15,400	207,300
6,112.6	6,116.6	15,470	210,400
6,112.8	6,116.8	15,540	213,500
6,113.0	6,117.0	15,610	216,600
6,113.2	6,117.2	15,680	219,700
6,113.4	6,117.4	15,750	222,900
6,113.6	6,117.6	15,820	226,000
6,113.8	6,117.8	15,900	229,200
6,114.0	6,118.0	15,970	232,400
6,114.2	6,118.2	16,040	235,600
6,114.4	6,118.4	16,110	238,800
6,114.6	6,118.6	16,180	242,000

Table 1. Reservoir area and capacity (volume) at specified elevations for Blackfoot Reservoir, Idaho, 2011.—Continued

[Elevations were converted from National Geodetic Vertical Datum of 1929 (NGVD 29) to North American Vertical Datum of 1988 (NAVD 88) using the National Oceanic and Atmospheric Administration VERTCON website (http://www.ngs.noaa.gov/cgi-bin/VERTCON/vert_con.prl) based on the latitude and longitude of the northern monitoring station. Conversion was 3.995 feet]

Stage or reservoir elevation (feet above NGVD 29)	Reservoir elevation (feet above NAVD 88)	Area (acres)	Capacity (acre-feet)
6,114.8	6,118.8	16,250	245,300
6,115.0	6,119.0	16,330	248,500
6,115.2	6,119.2	16,400	251,800
6,115.4	6,119.4	16,470	255,100
6,115.6	6,119.6	16,540	258,400
6,115.8	6,119.8	16,600	261,700
6,116.0	6,120.0	16,660	265,000
6,116.2	6,120.2	16,720	268,400
6,116.4	6,120.4	16,770	271,700
6,116.6	6,120.6	16,820	275,100
6,116.8	6,120.8	16,870	278,500
6,117.0	6,121.0	16,920	281,800
6,117.2	6,121.2	16,960	285,200
6,117.4	6,121.4	17,000	288,600
6,117.6	6,121.6	17,040	292,000
6,117.8	6,121.8	17,080	295,400
6,118.0	6,122.0	17,120	298,900
6,118.2	6,122.2	17,160	302,300
6,118.4	6,122.4	17,200	305,700
6,118.6	6,122.6	17,240	309,200
6,118.8	6,122.8	17,280	312,600
6,119.0	6,123.0	17,310	316,100
6,119.2	6,123.2	17,350	319,500
6,119.4	6,123.4	17,380	323,000
6,119.6	6,123.6	17,420	326,500
6,119.8	6,123.8	17,460	330,000
6,120.0	6,124.0	17,490	333,500
6,120.2	[1]6,124.2	17,530	337,000

[1] Full pool elevation is 6,124 feet NAVD 88, but stages up to 6,124.1 feet were measured at the northern station during the 2011 study. Reservoir area and capacity for a stage of 6,124.2 feet is included to bracket measured values.

Table 2. Comparison of reservoir capacity (volume) at selected elevations for 1933, 2000–2001, and 2011 surveys for Blackfoot Reservoir, Idaho.

[Reservoir elevations below 6,116 feet North American Vertical Datum of 1988 (NAVD 88) were not surveyed in the 2000–2001 HKM study. Reservoir capacity at 6,116 feet was assumed to be the same as the 1933 Bureau of Indian Affairs (BIA) table. HKM, now Dowl HKM; USGS, U.S. Geological Survey]

Stage or reservoir elevation (feet above NAVD 88)	Capacity (acre-ft)			Percentage of change in capacity, 1933–2011
	1933 BIA table	2000–01 HKM Study	2011 USGS Study	
6,116.0	205,400	205,400	201,200	-2.0
6,118.0	237,500	234,800	232,400	-2.1
6,120.0	270,600	267,100	265,000	-2.1
6,122.0	304,700	300,500	298,900	-1.9
6,124.0	339,800	334,800	333,500	-1.9
Average change				-2.0

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By
Molly S. Wood, Kenneth D. Skinner, and Ryan L. Fosness
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