Abstract

The U.S. Geological Survey and U.S. Army Corps of Engineers collected high-resolution multibeam sonar data during 2016–18 to compute stage-area and stage-capacity tables for the U.S. part of Koocanusa Reservoir in Lincoln County, northwestern Montana. Koocanusa Reservoir is a transboundary reservoir extending about 48 miles from Libby Dam upstream to the U.S. international boundary with Canada and another 42 miles within Canada to near Wardner, British Columbia. The upstream extent of the reservoir within Canada, where much of the sedimentation was previously documented, was not included in this study. Previously developed stage-area and stage-capacity tables were developed for the entire reservoir and could not be directly compared to the stage-area and stage-capacity tables from this study. Two discrete stage-area and stage-capacity values from the original survey (unknown survey date prior to 1980) were available for parts of the reservoir within the United States at the normal full-pool and normal minimum-pool elevations (2,459 and 2,287 U.S. survey feet above the National Geodetic Vertical Datum of 1929, respectively). At the normal full-pool elevation, the stage-area relation resulted in a 0.06-percent increase in surface-water acreage. Conversely, a 0.03-percent decrease in storage capacity at the normal full-pool elevation occurred. At the normal-minimum-pool elevation, the stage-area relation showed a 1.21-percent decrease in surface water from 14,487 to 14,314 acres. The usable storage capacity, defined as the volume of water between the normal full-pool and normal minimum-pool elevations, decreased by 0.39 percent (15,353 acre-feet). Results from this study indicate that a relatively minimal amount of sedimentation has occurred since initial filling in Koocanusa Reservoir for parts of the reservoir within the United States. Updated stage-area and stage-capacity tables for the entire reservoir will require additional bathymetric and topographic surveys for the parts of Koocanusa Reservoir within Canada.

Introduction

Reservoirs formed by dams are continuously refilled by natural river systems and are subject to sedimentation from upstream sources. Over time, reservoirs fill with sediment and require updated surveys to account for sedimentation and decreased storage capacity. Periodic bathymetric (elevation of the Earth surface beneath a body of water) and topographic surveys monitor the relation between stage (water-surface elevation), surface area, and the resulting volumetric storage capacity. Sedimentation in a reservoir generally originates from two sources, including the natural inflowing river system tributaries and sediment delivered from bank erosion along the reservoir shoreline. The trapping efficiency for course sediment (cobbles and gravel) is nearly 100 percent in most reservoirs, with only a small fraction of suspended sediment (fine-grain) moving through the reservoir (Brune, 1953).

Koocanusa Reservoir is a transboundary reservoir in southeastern British Columbia, Canada, and Lincoln County, northwestern Montana created by the impoundment of the Kootenai River by Libby Dam (fig. 1). Koocanusa Reservoir was constructed from 1966 to 1972 with storage of water beginning on March 21, 1972, after the U.S. Army Corps of Engineers (USACE) completed construction of Libby Dam (fig. 2). Because Koocanusa Reservoir is the most upstream reservoir in the Kootenai River drainage basin, the reservoir receives all upstream water and sediment from the unregulated Kootenai River (spelled Kootenay River for those segments within Canada). An initial stage-capacity relation was developed after the dam was constructed and was originally developed using single-beam sonar survey methods (J. Moen, U.S. Army Corps of Engineers, written commun., 2020). With advancements in survey technology, notably multibeam sonar echosounder systems, more complete bathymetric surveys are now possible. Full-coverage surveys increase the accuracy of reservoir stage-capacity relations by minimizing the interpolated areas required with single-beam surveys.

Libby Dam is a high head dam with a structural height of 422 feet (ft) and a hydraulic head of 366 ft (U.S. Army Corps of Engineers, 1983). The part of Koocanusa Reservoir within Lincoln County, Montana extends about 48 miles (mi) from Libby Dam upstream to the international boundary with Canada. Koocanusa Reservoir extends another 42 mi within Canada to near Wardner, British Columbia (Columbia Basin Inter-Agency Committee, 1965; fig. 1).

Water stored in Koocanusa Reservoir primarily is used for flood risk management and power production within operating strategies that allow for downstream flow augmentation for Endangered Species Act-listed species in the Kootenai and mainstem Columbia Rivers, as well as for irrigation and recreation (U.S. Army Corps of Engineers, 1983). The total storage in Koocanusa Reservoir is the volume of the reservoir from the maximum controllable level (2,459 U.S. survey feet [sft]) and above the minimum elevation in the reservoir (2,090 sft).[1] Total storage in Koocanusa Reservoir is accomplished when the stage is at the top of the spillway control, 2,461 sft, but that elevation rarely is reached because of the maximum stage of 2,459 sft permitted by the Columbia River Treaty (J. Moen, U.S. Army Corps of Engineers, written commun., 2020). An unusually high flow period in 2012 resulted in the operation of Koocanusa Reservoir to a maximum elevation of 2,461 sft, which British Columbia and United States both agreed upon. Maximum permitted storage capacity is defined using a normal full-pool elevation of 2,459 sft (table 1). Previously developed stage-capacity relations indicate a total storage capacity of 5,869,393 acre-feet and a surface area of 46,456 acres at a stage of 2,459 sft (U.S. Army Corps of Engineers, 2016). Conservation storage, also referred to as usable storage, is defined as the volume of water impounded between the normal full-pool and normal minimum-pool elevations (2,459 sft and 2,287 sft, respectively) for useful purposes such as municipal water supply, power generation, or irrigation (U.S. Army Corps of Engineers, 2016; table 1). The total surface area of Koocanusa Reservoir at the normal minimum-pool elevation (2,287 sft) is 14,487 acres with a storage capacity of 889,925 acre-feet (U.S. Army Corps of Engineers, 2016). Dead storage is defined as the volume of water in the reservoir below the minimum-pool elevation, which is the minimum operational elevation at the bottom of the sluice gate at 2,201.35 sft (U.S. Army Corps of Engineers, 1983; table 1). The dead storage volume is 120,528 acre-feet. The minimum dead storage elevation is 2,090 sft and represents zero storage and the deepest point in the reservoir (U.S. Army Corps of Engineers, 2016).

Purpose and Scope

To document sedimentation, this study presents updated stage-area and stage-capacity tables for parts of Koocanusa Reservoir within the United States. The USACE and U.S. Geological Survey (USGS) collected full-coverage, high-resolution multibeam sonar data of Koocanusa Reservoir bathymetry during 2016–18 (Fosness and Dudunake, 2021). Previous light detection and ranging (or lidar) topography data collected near Libby Dam in 2010 and additional lidar data collected in 2019 throughout Lincoln County, Montana, provided data above the water surface. The bathymetry and lidar data covered Koocanusa Reservoir (within the United States) below the normal full-pool elevation. This report presents the results from this study by establishing updated stage-area and stage-capacity relations for Koocanusa Reservoir in Lincoln County, Montana. This study quantified changes in storage capacity compared to the original and most recent stage-area and stage-capacity tables (U.S. Army Corps of Engineers, 2016; J. Moen, U.S. Army Corps of Engineers, written commun., 2020).

Methods

Bathymetry data were collected by the USACE during 2016–17 and USGS in 2018 for that part of Koocanusa Reservoir within Lincoln County, Montana. 2010 and 2019 lidar topography data were combined with bathymetry data to create a digital elevation model (DEM) of Koocanusa Reservoir. Updated stage-area and stage-capacity relations were developed using the DEM and compiled in tabular format.

Horizontal and Vertical Positional Control

Reservoir sedimentation studies require horizontal and vertical positional control to reference the bathymetric survey. Although the official Montana State Plane coordinate system uses international feet for horizontal control and U.S. survey feet (sft) for vertical control, all datasets were consistent with USACE surveys using U.S. survey feet for both horizontal and vertical control. Modern survey equipment generally uses the North American Vertical Datum of 1988 (NAVD 88), bathymetric and lidar survey data were collected and referenced to that vertical datum. Geoid model 2012A (GEOID12A) was the most current geoid model at the time of the survey; therefore, it was used to produce the final orthometric heights (elevations) (Fosness and Dudunake, 2021). The National Geodetic Vertical Datum of 1929 (NGVD 29) is an older vertical datum but is still used by the USACE to reference reservoir stage. NGVD 29 elevation was converted to NAVD 88 using the National Geodetic Survey Coordinate Conversion and Transformation Tool VERTCON (Milbert, 1999). NGVD 29 was the vertical datum used during the dam construction and is still the current referenced datum. However, modern survey equipment uses NAVD 88; therefore, this study used and referenced all datums to NAVD 88 (referenced to Geoid12A). Previous stage-area and stage-capacity relations reference NGVD 29 elevations; therefore, NGVD 29 elevations also are referenced in this study.

[1] All elevations, except where otherwise noted, are in U.S. survey feet referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29). One U.S. Survey foot is equal to 1.000002 international foot.

Suitable horizontal and vertical positional control was not available in most of the study area; therefore, several temporary benchmarks were established, occupied, and processed to establish the final benchmark coordinates (table 2). Static survey methods used to establish benchmarks within the study area were required for receiving real-time kinematic position corrections to the survey vessel (Rydlund and Densmore, 2012). A temporary benchmark generally was established every 5 to 7 mi throughout the study area to minimize orthometric height error and signal latency associated with atmospheric changes over long distances (fig. 2).

Static benchmark solutions were post-processed using the Online Positioning User Service (OPUS) projects maintained by the National Geodetic Survey (National Geodetic Survey, 2020). Horizontal post-processed coordinates acquired by the USACE did not change substantially; therefore, no horizontal corrections were applied to the final dataset. The vertical post-processed elevations were updated with a vertical shift applied to the final USACE bathymetry data. Minimal differences were found between the horizontal and vertical coordinates used during the USGS bathymetric surveys and post-processed coordinates; therefore, no horizontal or vertical shifts were required for the 2018 bathymetry data. Estimated 95-percent confidence intervals were determined for the horizontal and vertical precision of observations to maintain quality control of the positional accuracy (table 2).

Although all the surveyed bathymetry data were acquired while referencing NAVD 88, all elevations were converted to reference NGVD 29 for comparison and consistency with USACE data. The National Geodetic Survey Coordinate Conversion and Transformation Tool VERTCON application produced an NGVD 29 elevation from a NAVD 88 input allowing for the difference to serve as the offset between the two datums (Milbert, 1999). The VERTCON-computed conversion from NGVD 29 to NAVD 88 was plus (+) 3.841 feet (± 0.034 ft). Overall, the horizontal and vertical precision of observations defined by the 95-percent confidence interval ranged from 0.009 to 0.154 ft, suggesting that the use of temporary benchmarks was fit for the purposes of this study. The coordinates for each benchmark are provided in local geographic and projected coordinates (table 2).

Bathymetry

USACE and USGS bathymetric surveys were collected during late summer (July–September), coinciding with high reservoir water-surface elevation. Bathymetric data collection methods generally were consistent with USACE and USGS surveys. Each survey used a multibeam sonar coupled with an inertial navigations system. A complete description of the spatial reference, equipment, processing methods, quality assessment, and quality control is described in the metadata in the associated data release (Fosness and Dudunake, 2021). The USACE used an R2 Sonic and Reason SeaBat 7125 SV2 multibeam sonar in 2016 and 2017, respectively. The USACE collected bathymetry data from the international boundary to near Boulder Creek in 2016 and Boulder Creek to Tweed Creek in 2017. Additional bathymetry data were collected during high reservoir stage conditions in 2016 at Bristow Creek. Bathymetry data generally were collected at an elevation of about 2,449 sft (about 10 sft below the normal full-pool elevation). In all, the USACE surveyed about 26.5 mi during 2016 and 2017 (fig. 2). In 2018, personnel from the USGS Oregon and Idaho Water Science Centers used a Norbit compact integrated wideband multibeam sonar with integrated inertial navigation system to acquire bathymetry data from Tweed Creek to Libby Dam. Collectively, about 24.6 mi of bathymetry data were collected by the USGS. In total, the USACE and USGS surveyed 48 mi of Koocanusa Reservoir within the United States. The 42-mi part of Koocanusa Reservoir within Canada was not surveyed as part of this study.

Quality Assurance and Quality Control

Prior to USACE and USGS data-collection efforts, a patch test was done to correct any misalignment between the multibeam sonar and inertial navigation system. A patch test determines timing and physical offsets caused by latency and angular offsets to roll, pitch, and yaw between the multibeam sonar and the inertial navigation system. Any angular offsets found in the patch test were applied to the post-processed bathymetry data. To ensure that accurate depths were recorded with the multibeam sonar, a bar check was completed prior to USACE and USGS data-collection efforts. The process for a bar check includes using a plate that is offset below the survey vessel by a measured distance. The depth determined by the multibeam sonar was compared to the measured depth to verify that proper depths were recorded.

In-place speed of sound in water must be determined at the sonar to accurately determine depths acquired. Because speed of sound in water varies through time and space in a lake or reservoir, sound velocity profiles were collected 3–5 times per day to capture changes in the speed of sound in water due to variable water temperatures within the thermocline. Moreover, a sound velocity probe was integrated with the multibeam sonar to provide real-time sound velocity data near the water surface. Sound velocity data were applied to bathymetry data during routine post-processing steps that included removing erroneous data spikes and other false returns.

Lidar

Two lidar datasets were used in this study to complete areas of missing data between the normal full-pool elevation and bathymetry data. Lidar data were collected within select reaches of the Columbia River drainage basin in 2010 including near Libby Dam (OCM Partners, 2021). In 2019, the State of Montana Department of Natural Resources and Conservation contracted Aero-Graphics to acquire, process, and deliver lidar data and derivative products that adhere to USGS specifications (Heidemann, 2018; Montana State Library, 2021). Neither the 2010 nor the 2019 lidar penetrated the water surface, so topography data were only available for areas above the water-surface elevation at the time of lidar data collection. Lidar data collected in 2010 (dates unknown within that year) provided additional topography data for elevations above 2,413 sft (NAVD 88). The extent of the 2010 lidar data was only available for the area within about 1 mi from Libby Dam. The 2019 lidar data coverage included the entire part of Koocanusa Reservoir within Lincoln County, Montana. The water-surface elevation during the 2019 lidar data collection was variable and ranged from about 2,445 sft in the lower part of the reservoir to about 2,454 sft in the area near the international boundary. Because the extent of the bathymetry did not overlap the lidar data, except in a few locations, those areas needed to be interpolated to the normal full-pool elevation of 2,459 sft.

Interpolated Areas

The combination of multibeam sonar and lidar data provided nearly 100 percent coverage within the surveyed area; however, the survey vessel was unable to safely navigate shallow areas near the shoreline and tributaries of Koocanusa Reservoir resulting in missing bathymetry data. Additionally, lidar data were available only for areas above the water surface at the time of lidar data collection. To resolve the data voids, a routine was used to estimate an interpolated surface between bathymetry and lidar data. The Esri ArcMap tool "Topo to Raster" in the Spatial Analyst toolbox (Esri, 2020) estimated a hydrologically correct surface from point-cloud elevation data. Using this tool allowed for an estimated surface that represents areas of missing data better than a straight-line interpolation (Fosness and Dudunake, 2021).

Digital Elevation Model and Minimum and Maximum Pool Elevation Contours

Geographic information system software was used to process, analyze, and compile bathymetry and topography data. Post-processed bathymetry data were published in a compressed point-cloud format (Fosness and Dudunake, 2021). The bathymetry, lidar, and interpolated area datasets were combined to generate a surface raster DEM (fig. 2). The DEM shows the pre-reservoir Kootenai River and tributary channels now submerged by Koocanusa Reservoir. Normal full-pool and normal minimum-pool elevation contours were generated and represent the maximum and minimum usable storage capacity in Koocanusa Reservoir (table 1). DEM and elevation contours are published in Fosness and Dudunake (2021).

Stage-Area and Stage-Capacity Table Development

To develop relations between reservoir stage, surface area, and storage capacity, all available bathymetry, lidar, and interpolated area datasets were combined to create a seamless surface representation. A 10-ft triangulated irregular network (TIN) surface raster grid was created to represent all elevations in Koocanusa Reservoir below the normal full-pool elevation for the development of stage-area and stage-capacity relations. Using the Esri ArcMap "Storage Capacity" tool in the Spatial Analyst toolbox, a stage-area and stage-capacity table was created using the surface raster (Esri, 2020). The Storage Capacity tool generated a table of water-surface elevations (stage) and corresponding storage capacities that describe the relation used to determine the volume of water at variable water-surface elevations (stage). Stage-area and stage-capacity were computed at 1-ft intervals for the U.S. part of Koocanusa Reservoir for elevations ranging from the minimum-pool elevation (2,201.35 sft) to the normal full-pool elevation (2,459 sft; Fosness and Dudunake, 2021).

Stage-Area and Stage-Capacity Tables

Stage-area and stage-capacity tables were updated from zero storage (2,090 sft) to the normal full-pool elevation (2,459 sft) of Koocanusa Reservoir for areas within the United States. The revised stage-area table describes the water-surface area in acres for each increment in water-surface elevation. Similarly, the stage-capacity table describes the volume of storage capacity at each increment in water-surface elevation. The area and capacity of dead storage was computed from zero storage (2,090 sft) to the minimal operational storage (2,201.35 sft). Dead storage is the area and volume of water that cannot be regulated by Libby Dam. The minimal operational storage was computed from the minimal operational stage (2,201.35 sft) to the beginning of conservation storage at the normal minimum-pool elevation (2,287 sft). The conservation storage was computed beginning at the normal minimum-pool elevation to the normal full-pool elevation (2,459 sft; table 3). Stage-area and stage-capacity data are also available in the data release at 1-ft increments (Fosness and Dudunake, 2021).

To compute stage-area and stage-capacity changes over time, the updated relations were compared to USACE stage-area (fig. 3) and stage-capacity (fig. 4) relations. The USACE 2012 stage-area and stage-capacity curves (fig. 3 and 4, respectively) include the entire Koocanusa Reservoir, whereas the USGS and USACE survey data (2016–18) were only for parts within the United States. Because the 2012 stage-area and stage-capacity tables were for the entire reservoir, those data could not be directly compared to the stage-area and stage-capacity tables from this study. Two discrete stage-area and stage-capacity values from the original survey (unknown survey date prior to 1980) were available for parts of the reservoir within the United States at the normal full-pool and normal minimum-pool elevations (table 4; J. Moen, U.S. Army Corps of Engineers, written commun., 2020). At the normal full-pool elevation, the stage-area relation resulted in a 0.06-percent increase in surface-water acreage from 28,994 acres to 29,011 acres (table 4). Conversely, the storage capacity at the normal full-pool elevation decreased (0.03 percent) within the surveyed area. At the normal minimum-pool elevation, the stage-area decreased (1.21 percent) from 14,487 acres to 14,314 acres (table 4). The total usable storage capacity, defined as the volume of water from 2,287 to 2,459 sft, decreased by 0.39 percent or 15,353 acre-feet (table 4).

The computed stage-area and stage-capacity changes over time assumed that each stage-area and stage-capacity table is accurate without uncertainty. The uncertainty of the original stage-area and stage-capacity tables is unknown (J. Moen, U.S. Army Corps of Engineers, written commun., 2020). The uncertainty of the current stage-area and stage-capacity tables was minimized by combining multibeam sonar and lidar data to provide nearly 100 percent coverage within the surveyed area, resulting in minimal amount of interpolation required within the study area. An unmeasurable difference in stage-area and stage-capacity estimates may be attributed to using different survey methods to develop the stage-area and stage-capacity tables. Considering the unmeasurable differences, the changes over time for stage-area (+0.06 percent) and stage-capacity (-0.03 percent) at the normal full-pool elevation suggest minimal sedimentation for parts of Koocanusa Reservoir within the United States. Updated stage-area and stage-capacity tables for the entire reservoir will require additional bathymetric and topographic surveys for the part of Koocanusa Reservoir within Canada.

Summary

The U.S. Geological Survey and U.S. Army Corps of Engineers collected high-resolution multibeam sonar data during 2016–18 to compute stage-area and stage-capacity tables for Koocanusa Reservoir in Lincoln County, northwestern Montana. Koocanusa Reservoir is a transboundary reservoir extending about 48 miles from Libby Dam upstream to the U.S. international boundary with Canada and another 42 miles within Canada to near Wardner, British Columbia. The upstream extent of the reservoir within Canada, where much of the sedimentation was previously documented, was not included in this study.

This study used a combination of multibeam sonar and light detection and ranging (or lidar) data and provided nearly 100 percent coverage within the surveyed area, resulting in a minimal amount of interpolation required within the study area. The original stage-area and stage-capacity tables were developed using single-beam survey data; therefore, an unmeasurable difference in stage-area and stage-capacity estimates may be attributed to different survey methods.

Previously developed stage-area and stage-capacity tables were developed for the entire reservoir and could not be directly compared to the stage-area and stage-capacity from this study. Two discrete stage-area and stage-capacity values from the original survey (unknown survey date prior to 1980) were available for parts of the reservoir within the United States at the normal full pool and normal minimum pool. Results from the current study (2016–18) indicated that a relatively minimal amount of sedimentation has occurred for parts of Koocanusa Reservoir within the United States. A decrease (0.03 percent) in storage capacity at the normal full-pool elevation was measured, and the usable storage (from 2,287 to 2,459 feet) decreased by 0.39 percent (15,353 acre-feet). Additional bathymetric and topographic surveys for the part of Koocanusa Reservoir within Canada are needed to update stage-area and stage-capacity tables for the entire reservoir.

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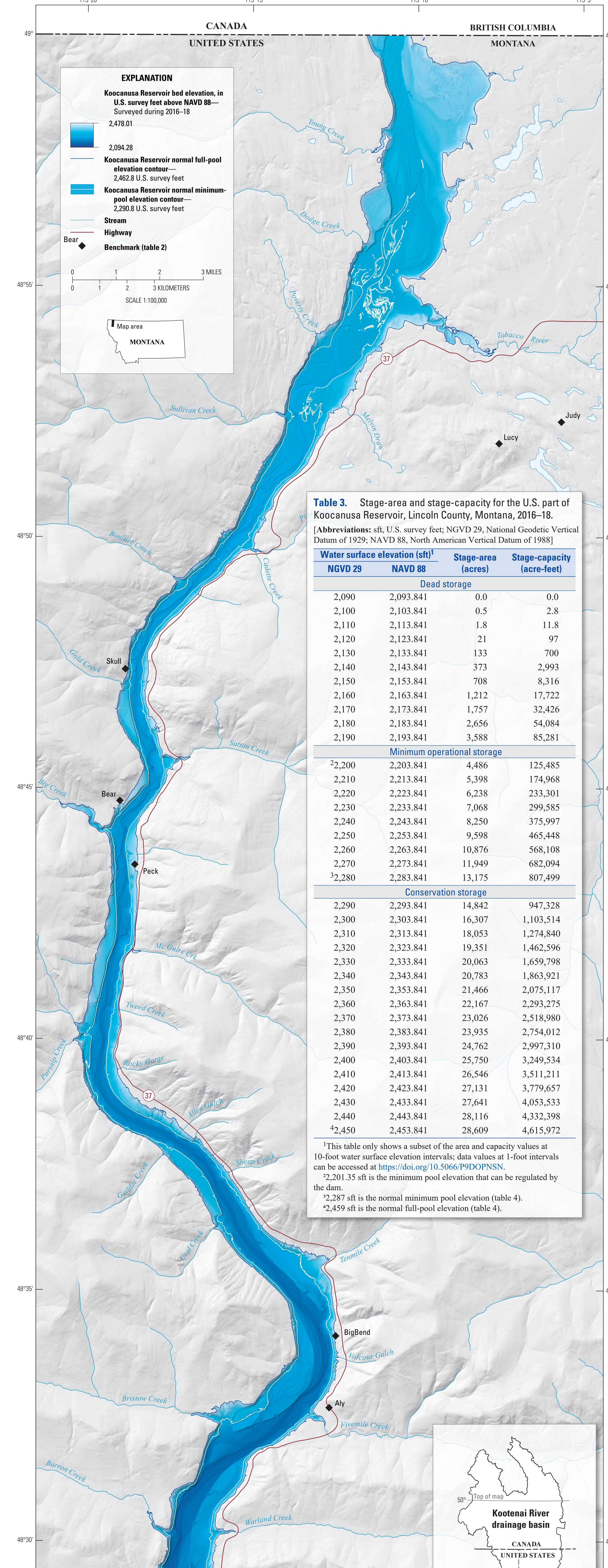

Table 3. Stage-area and stage-capacity for the U.S. part of Koocanusa Reservoir, Lincoln County, Montana, 2016–18.

[**Abbreviations:** sft, U.S. survey feet; NGVD 29, National Geodetic Vertical Datum of 1929; NAVD 88, North American Vertical Datum of 1988]

Water surface elevation (sft)[1]		Stage-area (acres)	Stage-capacity (acre-feet)
NGVD 29	NAVD 88		
Dead storage			
2,090	2,093.841	0.0	0.0
2,100	2,103.841	0.5	2.8
2,110	2,113.841	1.8	11.8
2,120	2,123.841	21	97
2,130	2,133.841	133	700
2,140	2,143.841	373	2,993
2,150	2,153.841	708	8,316
2,160	2,163.841	1,212	17,722
2,170	2,173.841	1,757	32,426
2,180	2,183.841	2,656	54,084
2,190	2,193.841	3,588	85,281
Minimum operational storage			
[2]2,200	2,203.841	4,486	125,485
2,210	2,213.841	5,398	174,968
2,220	2,223.841	6,238	233,301
2,230	2,233.841	7,068	299,585
2,240	2,243.841	8,250	375,997
2,250	2,253.841	9,598	465,448
2,260	2,263.841	10,876	568,108
2,270	2,273.841	11,949	682,094
[3]2,280	2,283.841	13,175	807,499
Conservation storage			
2,290	2,293.841	14,842	947,328
2,300	2,303.841	16,307	1,103,514
2,310	2,313.841	18,053	1,274,840
2,320	2,323.841	19,351	1,462,596
2,330	2,333.841	20,063	1,659,798
2,340	2,343.841	20,783	1,863,921
2,350	2,353.841	21,466	2,075,117
2,360	2,363.841	22,167	2,293,275
2,370	2,373.841	23,026	2,518,980
2,380	2,383.841	23,935	2,754,012
2,390	2,393.841	24,762	2,997,310
2,400	2,403.841	25,750	3,249,534
2,410	2,413.841	26,546	3,511,211
2,420	2,423.841	27,131	3,779,657
2,430	2,433.841	27,641	4,053,533
2,440	2,443.841	28,116	4,332,398
[4]2,450	2,453.841	28,609	4,615,972

[1]This table only shows a subset of the area and capacity values at 10-foot water surface elevation intervals; data values at 1-foot intervals can be accessed at https://doi.org/10.5066/P9DOPNSN.

[2]2,201.35 sft is the minimum pool elevation that can be regulated by the dam.

[3]2,287 sft is the normal minimum pool elevation (table 4).

[4]2,459 sft is the normal full-pool elevation (table 4).

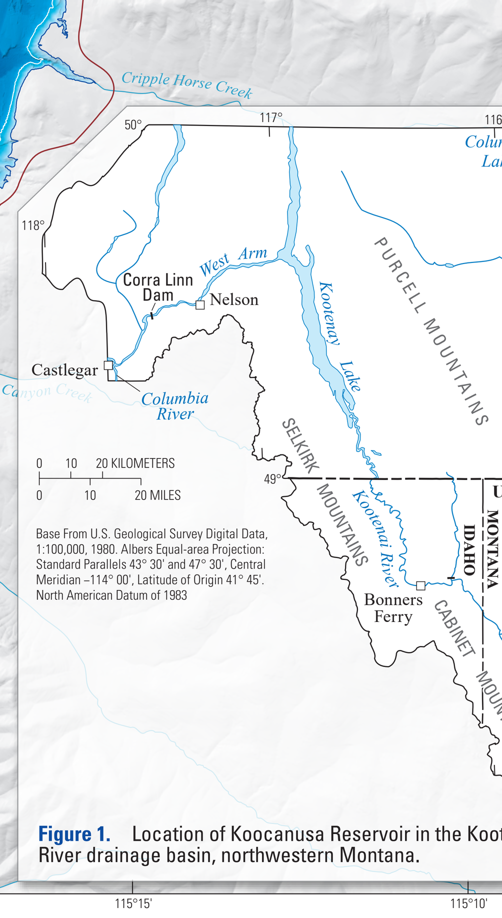

Figure 1. Location of Koocanusa Reservoir in the Kootenai River drainage basin, northwestern Montana.

Base from U.S. Geological Survey 10-meter digital elevation data
Montana Lambert Conformal Conic projection, Standard Parallels 45° and 49°, Central Meridian −109° 30', Latitude of Origin 44° 15'
North American Datum of 1983, North American Vertical Datum of 1988 (NAVD 88)

Bathymetry data from Fosness and Dudunake, 2021. Available at https://doi.org/10.5066/P9DOPNSN
NOT INTENDED FOR NAVIGATIONAL USE

Figure 2. Digital elevation model and normal full-pool and normal minimum-pool elevation contours, the U.S. part of Koocanusa Reservoir, Lincoln County, Montana, 2016–18.

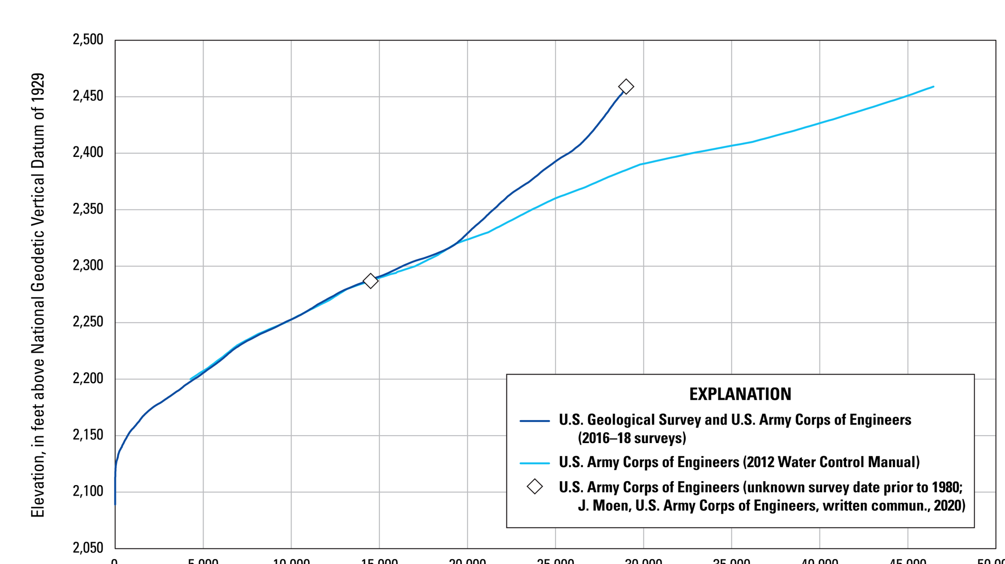

Figure 3. Stage-area curve showing the relation between the water-surface elevation and area, Koocanusa Reservoir, Lincoln County, Montana. U.S. Army Corps of Engineers (USACE) 2012 Water Control Manual included all of Koocanusa Reservoir, whereas U.S. Geological Survey and USACE surveys during 2016–18 only included that part of Koocanusa Reservoir within the United States. USACE original survey (unknown survey date prior to 1980) included two discrete stage-area values to compare to the 2016–18 surveys.

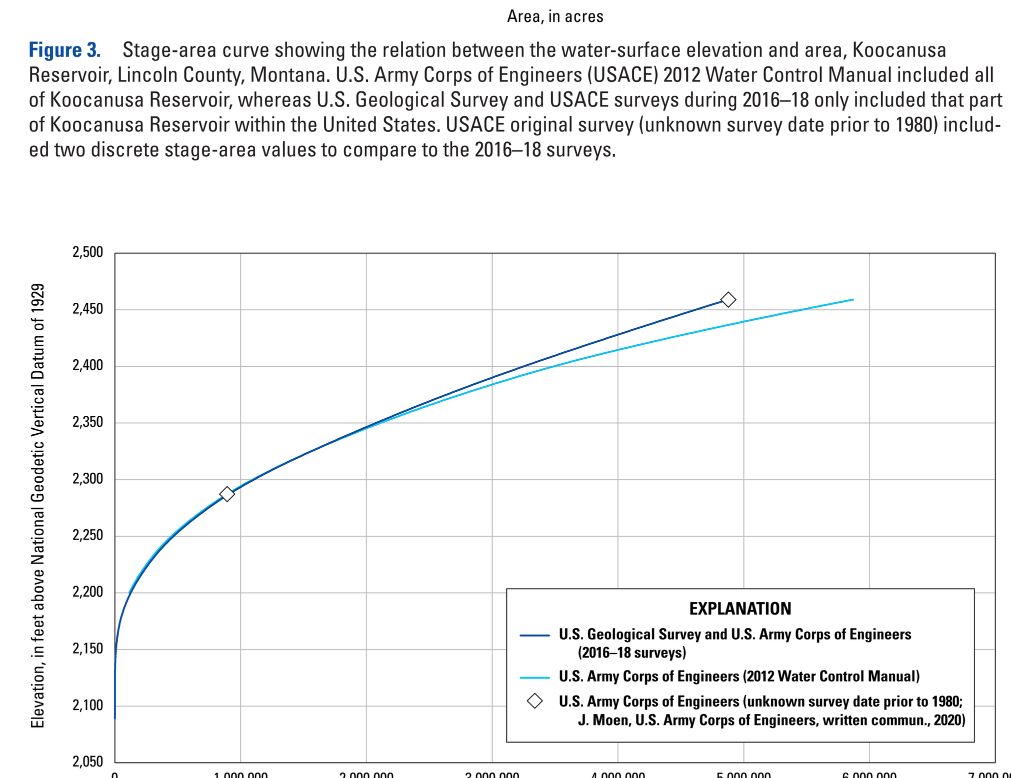

Figure 4. Stage-capacity curve showing the relation between the water-surface elevation and storage capacity, Koocanusa Reservoir, Lincoln County, Montana. U.S. Army Corps of Engineers (USACE) 2012 Water Control Manual included all of Koocanusa Reservoir, whereas U.S. Geological Survey and USACE surveys during 2016–18 only included that part of Koocanusa Reservoir within the United States. USACE original survey (unknown survey date prior to 1980) included two discrete stage-capacity values to compare to the 2016–18 surveys.

Table 1. Notable elevations for Libby Dam and the U.S. part of Koocanusa Reservoir, Lincoln County, Montana.

[**Abbreviations and symbols:** sft, U.S. survey foot; ft, feet; NGVD 29, National Geodetic Vertical Datum of 1929 (also referred to as mean sea level); NAVD 88, North American Vertical Datum of 1988; USACE, U.S. Army Corps of Engineers; ≈, approximately equal to; ±, plus or minus]

Reference	Elevation (sft)		Comments and reference
	NGVD 29	NAVD 88[1]	
Top of dam elevation	2,472.5	2,476.341	(USACE, 1983); lidar data verified NAVD88 elevation (±0.15 ft) (Aero-Graphics, Inc., 2021)
Maximum spillway elevation	2,461	2,464.841	Max elevation through spillway (USACE, 1983; plate 2)
Normal full-pool elevation	2,459	2,462.841	Full-pool, conservation elevation (USACE, 1983)
Minimum spillway elevation	2,405	2,408.841	Top of spillway (USACE, 1983; plate 2)
Normal minimum-pool elevation	2,287	2,290.841	Active management storage (USACE, 1983)
Minimum selective withdrawal elevation	2,222	2,225.841	22 gates; 10.3 ft per gate; ≈227 ft (USACE, 1975; plate 4)
Minimum operational elevation	2,201.35	2,205.191	Minimum pool elevation (dead storage); (USACE, 1983; plate 2)

[1]NGVD 29 elevation was converted to NAVD 88 using the National Geodetic Survey Coordinate Conversion and Transformation Tool. NGVD 29 was the vertical datum during the dam construction, and is still the current referenced datum. However, modern survey equipment uses NAVD 88; therefore, this study used and referenced all datums to NAVD 88. NAVD 88 elevations are referenced to Geoid model 2012A.

Table 2. Horizontal and vertical control benchmarks for the U.S. part of Koocanusa Reservoir, Lincoln County, Montana, 2016–18.

[**Elevation:** Computed using Geoid model 2012A. **Date of observation:** mm-dd-yyyy, month-day-year. **Abbreviations and symbol:** NAD 83, North American Datum of 1983; dd, decimal degrees; sft, U.S. survey feet; 95%, 95-percent confidence interval]

Benchmark name	Local geographic coordinates NAD 83 (2011) (Epoch:2010.000)			Montana State Plane coordinates NAD 83 (2011)			Horizontal precision of observation (sft, 95%)	Vertical precision of observation (sft, 95%)	Date of observation (mm-dd-yyyy)
	Latitude (dd)	Longitude (dd)	Ellipsoid height (sft)	Easting (sft)	Northing (sft)	Elevation (sft)			
Bear	48.745853962	−115.315651681	2,570.395	566,773.185	1,691,189.145	2,621.199	0.154	0.154	08-01-2017
Judy	48.871819023	−115.094404017	3,109.118	623,286.637	1,733,140.726	3,161.408	0.026	0.045	07-25-2017
Lucy	48.864644154	−115.125732622	4,013.217	615,578.535	1,731,069.471	4,065.291	0.019	0.039	09-08-2017
Skull	48.789577398	−115.313162275	2,663.204	568,554.792	1,707,050.865	2,713.997	0.450	0.450	09-09-2017
Peck	48.724667387	−115.308044236	2,419.402	568,030.849	1,683,345.713	2,470.084	0.009	0.009	08-07-2018
BigBend	48.568350859	−115.206590350	2,402.197	588,299.757	1,624,679.833	2,453.140	0.031	0.039	08-28-2018
Aly	48.544495190	−115.209769461	2,636.337	586,898.481	1,616,057.763	2,687.385	0.039	0.071	07-21-2016
McGillivray	48.483056984	−115.298092539	2,436.094	563,908.280	1,595,280.493	2,487.728	0.035	0.047	08-28-2018
LPCP-3-RESET	48.413414515	−115.318146603	2,426.800	557,174.090	1,570,310.838	2,478.816	0.024	0.025	08-30-2018

Table 4. Stage-area and stage-capacity comparison, and absolute differences, the U.S. part of Koocanusa Reservoir, Lincoln County, Montana, original survey (unknown survey date prior to 1980) and current surveys (2016–18 surveys).

[**Abbreviations and symbol:** sft, U.S. survey foot; NGVD 29, National Geodetic Vertical Datum of 1929; USACE, U.S. Army Corps of Engineers; %, percent]

Reference	Stage-area (acres)		Stage-capacity (acre-feet)	
	Total, full-pool elevation (2,459 sft above NGVD 29)	Usable, minimum pool elevation (2,287 sft above NGVD 29)	Total, full-pool elevation (2,459 sft above NGVD 29)	Usable, minimum to full-pool elevation (2,287 to 2,459 sft above NGVD 29)
Original survey (unknown survey date prior to 1980)[1]	28,994	14,487	4,877,175	3,987,251
Current surveys (2016–18 surveys)	29,011	14,314	4,875,497	3,971,898
Difference	+0.06%	−1.21%	−0.03%	−0.39%

[1]J. Moen, U.S. Army Corps of Engineers, written commun., 2020

Bathymetric Map, Surface Area, and Stage-Capacity for the U.S. Part of Koocanusa Reservoir, Lincoln County, Montana, 2016–18

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