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Bathymetric Surveys of Lake Arthur and Raccoon Lake, Pennsylvania, June 2007

Data Series 357

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

Cover photograph:
Photograph of Lake Arthur.
Photograph by C.D. Hittle, U.S. Geological Survey.

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Conversion Factors

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)
acre	0.004047	square kilometer (km^2)
	Volume	
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Bathymetric Surveys of Lake Arthur and Raccoon Lake, Pennsylvania, June 2007

By Clinton D. Hittle and A. Thomas Ruby III

Abstract

In spring of 2007, bathymetric surveys of two Pennsylvania State Park lakes were performed to collect accurate data sets of lake-bed elevations and to develop methods and techniques to conduct similar surveys across the state. The lake-bed elevations and associated geographical position data can be merged with land-surface elevations acquired through Light Detection and Ranging (LIDAR) techniques. Lake Arthur in Butler County and Raccoon Lake in Beaver County were selected for this initial data-collection activity. In order to establish accurate water-surface elevations during the surveys, benchmarks referenced to NAVD 88 were established on land at each lake by use of differential global positioning system (DGPS) surveys. Bathymetric data were collected using a single beam, 210 kilohertz (kHz) echo sounder and were coupled with the DGPS position data utilizing a computer software package. Transects of depth data were acquired at predetermined intervals on each lake, and the shoreline was delineated using a laser range finder and compass module. Final X, Y, Z coordinates of the geographic positions and lake-bed elevations were referenced to NAD 83 and NAVD 88 and are available to create bathymetric maps of the lakes.

Introduction

Throughout Pennsylvania, there is an existing need to collect accurate geo-referenced bathymetric data of lakes and reservoirs. These bathymetric data can be combined with Light Detection and Ranging (LIDAR) land-surface-elevation data to produce seamless elevation maps. Until recently, the use of conventional surveying and fathometer methods made conducting highly accurate bathymetric surveys of lakes and reservoirs time consuming. Recent advancements in equipment, data-collection techniques, computer software, and differential global positioning systems (DGPS) make it possible to produce accurate digital products of lake-bed elevations within a shorter time frame.

In 2007, the U.S. Geological Survey (USGS) and the Pennsylvania Department of Conservation and Natural Resources (DCNR), Bureau of Topographic and Geologic Survey (T&GS), began a cooperative effort to collect lake-bed elevation (bathymetric) data within water bodies of the Commonwealth of Pennsylvania. Of primary interest are the lakes and reservoirs within the system of Pennsylvania State Parks. The objectives of the data-collection effort were to 1) acquire accurate geo-referenced bathymetry data, 2) quality assure the collected data points, and 3) deliver a digital lake-bed-elevation product of geo-referenced X, Y, Z points.

The initial areas of data collection were selected not only to provide data but to perform instrumentation operation and performance checks and to develop a standard and efficient data-collection and manipulation method for future bathymetric studies.

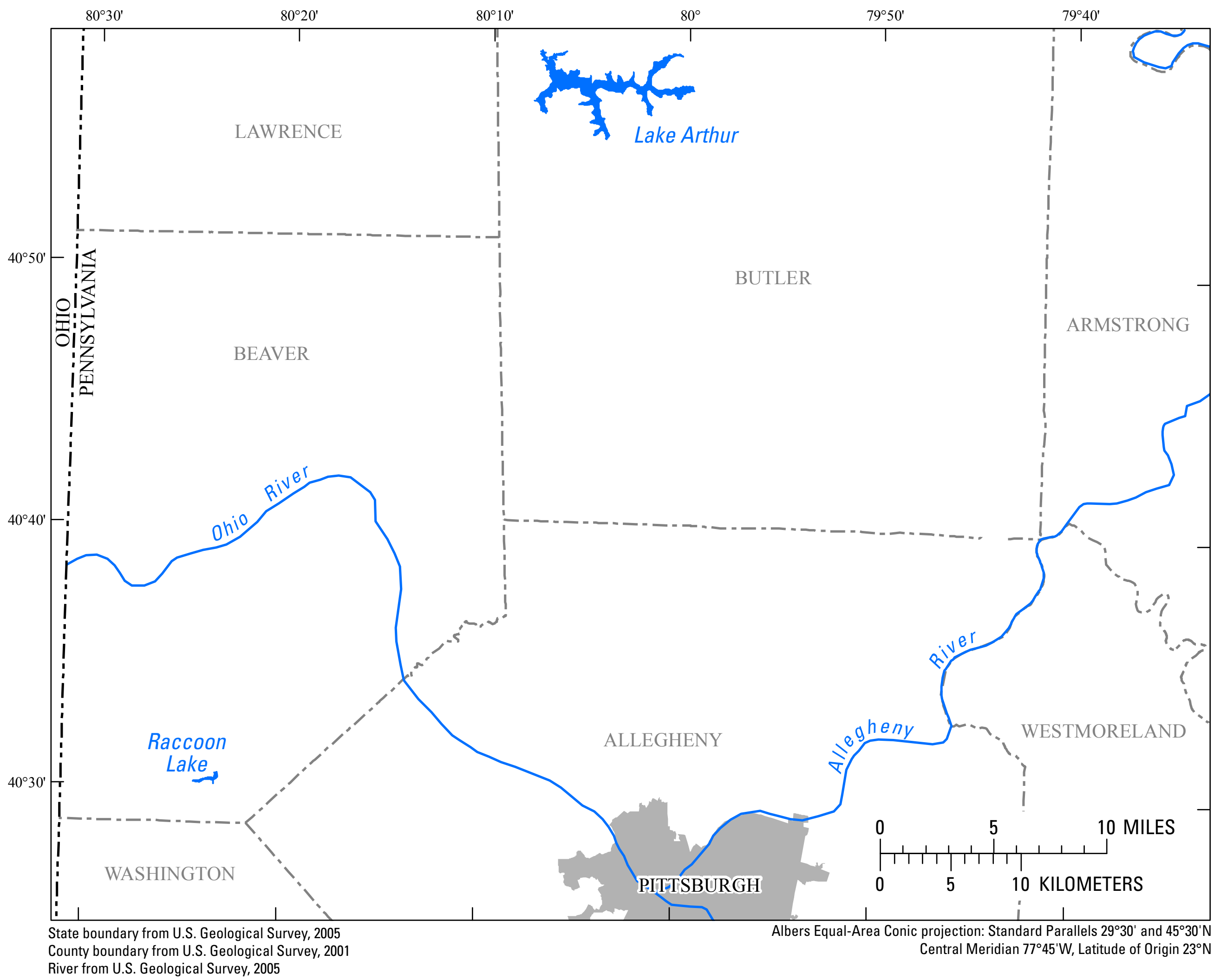
Purpose and Scope

This report presents the bathymetric data collected at two State Park lakes in the spring of 2007 and briefly summarizes the methods and equipment used to collect, manipulate, and quality assure these data. The data are provided in electronic format (appendix) and may be downloaded for further study or may be incorporated into various Geographic Information System (GIS) applications.

Study Area

The areas for initial study were Lake Arthur in Moraine State Park, Pa., and Raccoon Lake within Raccoon Creek State Park, Pa. (fig. 1).

Lake Arthur is a 3,225-acre lake constructed in 1969 on Muddy Creek within Butler County, Pa. Lake Arthur has a usable capacity of about 37,000 acre-feet and has a complex shoreline composed of several tributary arms. The dam is a gated spillway type, and uses for the lake include boating, sailing, canoeing, swimming, and fishing along with low-flow augmentation (Pennsylvania Department of Conservation and Natural Resources, 2008a).



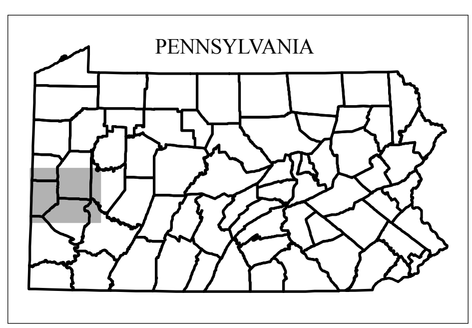


Figure 1. Study area and location of the lakes surveyed.

Raccoon Lake, constructed on Traverse Creek in 1948, is in Beaver County, Pa. The body of water is 101 acres in size with a gated spillway dam and has similar recreational and low-flow purposes as Lake Arthur (Pennsylvania Department of Conservation and Natural Resources, 2008b).

Methods of Investigation

The primary tasks performed to complete the project included office preparation, field operations, data manipulation, and quality assurance. The following sections describe the general methods used as well as customized methods used for these two specific surveys.

Office Preparation

Initially, the USGS obtained permission from DCNR State Park Managers and staff for reservoir access and field reconnaissance of the study areas. Aerial photographs of the lakes and surrounding areas were acquired and geo-referenced for incorporation into the navigation-support software. The geo-referenced digital images of the lakes were used to establish the transects to be navigated during the surveys. The transects were generated within HYPACK™ (a navigation software package capable of collecting bathymetric and geographic-position data) and were spaced at intervals necessary to accumulate a data set. For the surveys on Raccoon Lake and Lake Arthur, the transects were spaced between 100 and 250 ft apart. The transect lines were used to guide the boat during the survey and to improve overall boat navigation. The number and location of transects were determined by lake complexities such as geometry, alignment, and irregularities of the lake shore and features such as islands and confluence points of tributaries. In general, complex lake characteristics require more transects to define them. Equipment used in the survey was assembled and tested to verify proper operation before being deployed in the field. Research indicated that DGPS reference marks were needed because of the lack of existing benchmarks in the survey areas.

Field Operation—Equipment

The equipment used in the surveys is categorized between the land-survey elements and the boat-survey elements.

Land-Survey Elements:

- Two outside vertical staff (OVS) gages incremented to hundredths of a foot.
- Four DGPS receivers with antennas (to establish reference marks).
- DGPS data-processing software.
- A digital level instrument and associated rod to run vertical surveys between reference marks and the OVS gages.

Boat-Survey Elements:

- A boat of sufficient size to accommodate a crew of three people with an enclosed work area to protect the equipment from the elements.
- An echo sounder and transducer with an appropriate frequency for the depth of the lake. In this survey, a 210 kilohertz (kHz) ODOM™ transducer and a Navisound™ 210 Reson echo sounder were utilized. The Navisound™ 210 Reson echo sounder had a depth range from 0.6 to 600 m (Reson Inc., 2005).
- A Trimble™ DGPS system along with a differential correction service from Omni Star™.
- A laptop computer with the HYPACK™ software package installed. HYPACK™ is a navigation software package that was used to integrate the lake-bed depths along with the DGPS horizontal position data and also to display the location of the boat on a geo-referenced aerial photo of the lake for navigation purposes.
- A monitor installed specifically for the boat operator to view the HYPACK™ display. This allows the boat operator to maintain a proper heading related to the pre-defined transects while maintaining safe operation of the boat.
- A laser range finder to compute distance measurements accompanied with a compass module enabling determination of accurate azimuths and delineation of the shoreline.

Field Operation—Methods

The staff required to carry out the field operation consisted of two teams. The first team was the survey crew that established the reference marks used to define the water-surface elevation of the lakes in NAVD 88. This team also installed the OVS gages. The second team was the boat crew that consisted of three persons: boat operator, equipment operator, and the operator of the laser range finder.

One OVS gage was installed at a location around each lake to correlate the lake bathymetry with the water surface during the time of data collection. The location was at a boat ramp for easy access by the boat crew.

Reference marks were established on the shore of each lake utilizing DGPS techniques and referenced to NAVD 88 (fig. 2). An optical level survey from each reference mark to the OVS gage (at Raccoon Lake) and to the surface-water

Figure 2. Differential global positioning survey used to establish reference marks near the lake shore.

streamflow-gaging station (at Lake Arthur) defined the lake elevations for the bathymetric-survey data-collection periods.

The equipment setup on the boat consisted of the ODOM ™ transducer mounted on the starboard side with the DGPS mounted directly above the transducer. The depth of the transducer in the water was measured and was entered into HYPACK™ as an offset. The operator of the laser range finder would make the edge measurements from above the transducer position to correlate the lake shore with the boat position (fig. 3).

Data collection at each lake followed the predetermined transect lines created in HYPACK™ to ensure complete coverage of the lake. At the start of the bathymetric survey, the boat operator held the boat stationary on one side of the plan line near the shore.

The echo sounder and DGPS were started, and depths and position data were simultaneously recorded within HYPACK™. The operator of the laser range finder measured and recorded the distance and azimuth reading to the shoreline edge of water, shouting “mark” for the equipment operator to mark the edge in HYPACK™. Subsequently, a distance and bearing were entered to define the shoreline point. The boat operator then proceeded across the lake, following the predetermined transect line to the opposite end of the transect. During the survey, the equipment operator took detailed notes to assist in field and office processing. As the boat made its approach to the shoreline, the boat was stopped, held in position, and steadied to allow the operator of the laser range finder and equipment operator to mark the ending shoreline location. The recording was stopped, and the crew proceeded to the next unfinished transect to repeat the process. After the collection of data at all predetermined transects, any gaps in data were identified, and additional transects were run to complete the data acquisition at each lake. The completed transects and shoreline points collected during the Lake Arthur and Raccoon Lake surveys are shown on figures 4 and 5, respectively.

Data Manipulation

Raw bathymetry data were processed within HYPACK™ to filter (1) multiple-return acoustic signals in shallow water, (2) corrupt GPS signals, and (3) redundant areas along the banks caused by equipment limitations. The raw data were viewed (fig. 6) and edited (fig. 7). Carefully examining each transect, the data were filtered within HYPACK™ using all supporting note documentation and quality-assurance data (paper copies of the analog signal). After finalizing the raw data, it was saved as edited data. The edited data were then

Figure 3. Laser range finder and compass module operated from the transducer and differential global position system location to define the shoreline.

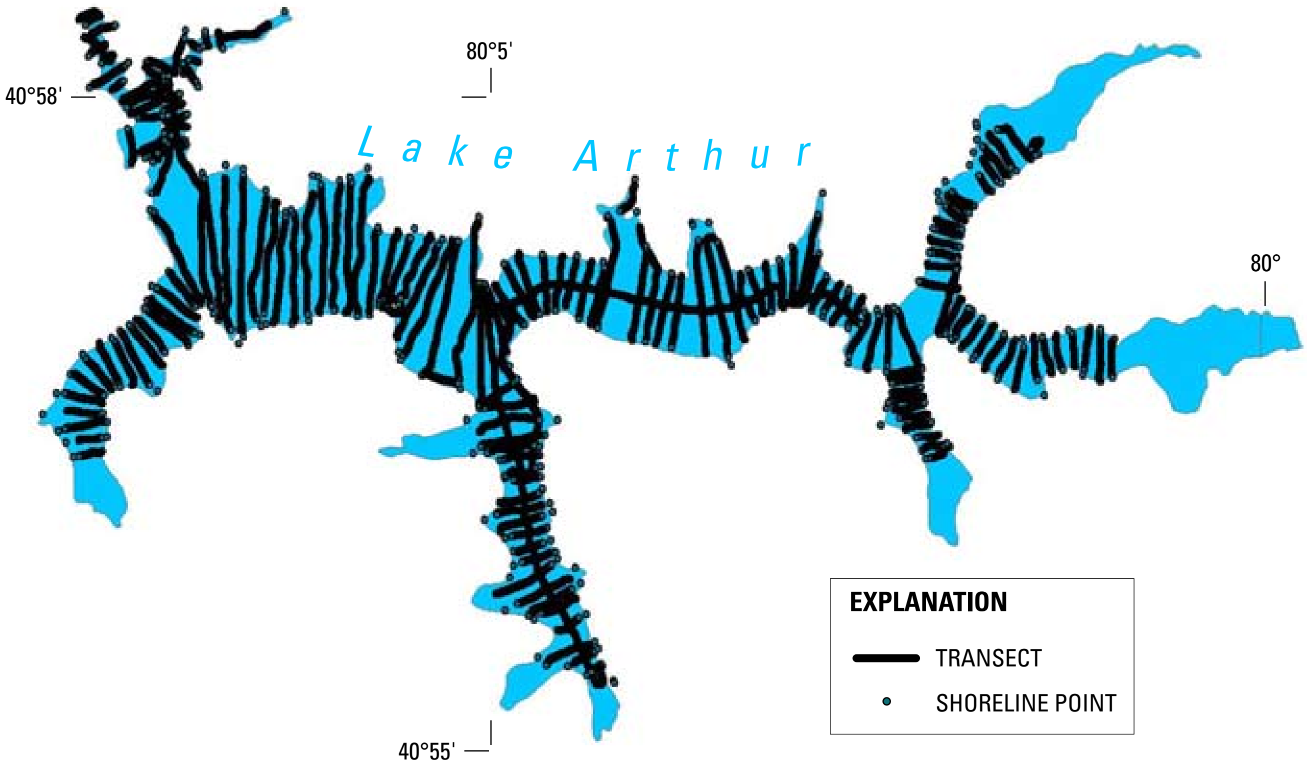


Figure 4. Transects and shoreline points collected during the Lake Arthur bathymetric survey. In areas with no transects or points, the lake was either to shallow or off limits to boating.

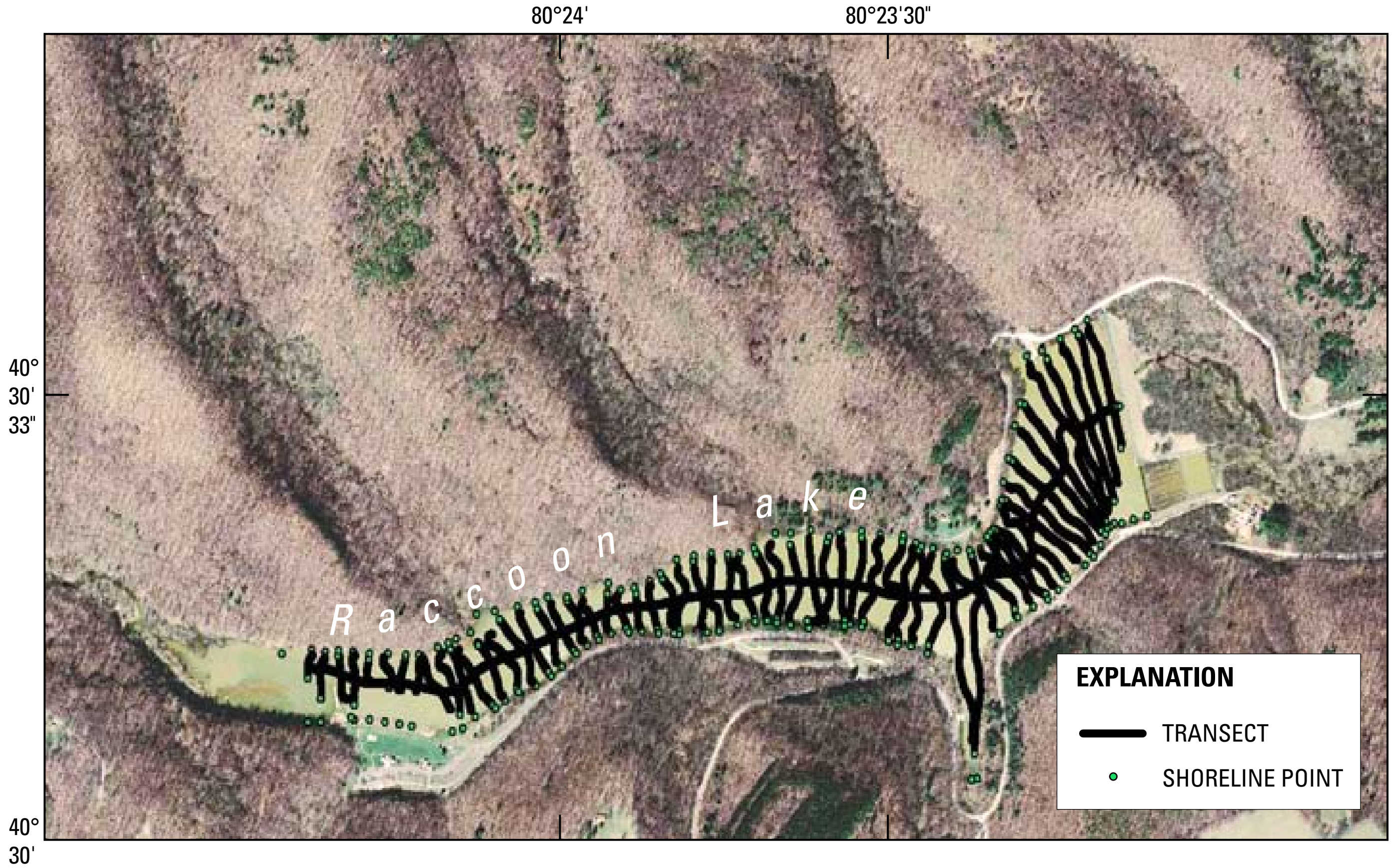


Figure 5. Transects and shoreline points collected during the Raccoon Lake bathymetric survey. In areas with no transects or points, the lake was either to shallow or off limits to boating.

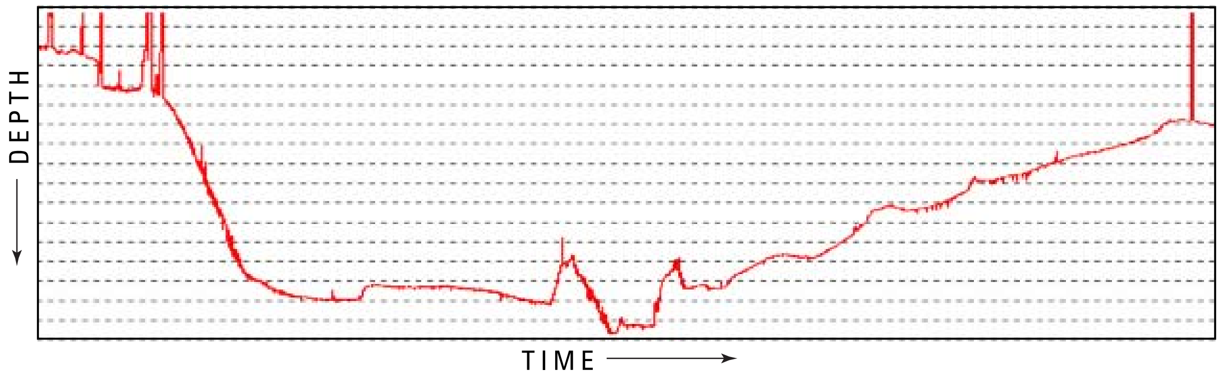


Figure 6. A generalized example of a raw graph of the relation between depth (vertical axis) and time (horizontal axis) collected and displayed in HYPACK™.

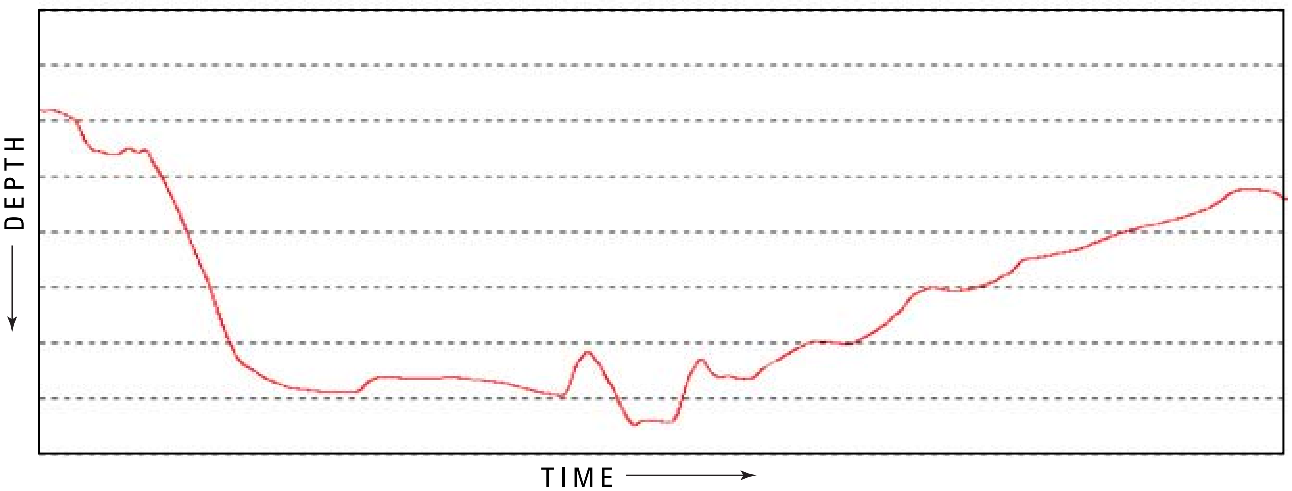


Figure 7. A generalized example of an edited graph of the relation between depth (vertical axis) and time (horizontal axis) displayed in HYPACK™. Erroneous data shown as spikes in figure 6 were removed, and the data were smoothed.

exported into X, Y, Z coordinates to complete the final product. The position and depth data (X, Y, Z coordinates) can be used for the production of bathymetric maps using various GIS applications. A data file containing the edited data is available in the appendix.

Quality Assurance

A complete analysis of the accuracy of the vertical (elevation) and horizontal (geographic position) data was beyond the scope of this data-collection effort. Equipment and procedures used in the collection of the bathymetric data set were mimicked where possible from bathymetric surveys previously performed by the USGS (Wilson and Richards, 2006).

The Navisound™ 210 Reson echo sounder has an accuracy of 0.03 ft at 210 kHz (Reson Inc., 2005). A built-in bar-check utility allowed for depth verification using a correction for the speed of sound. The U.S. Army Corps of Engineers suggests performing the "bar-check" procedure to adequately calibrate a fathometer (U.S. Army Corps of Engineers, 2002). A multi-depth bar check of the echo sounder was initiated to ensure accurate depth soundings. The bar check for the surveys on Raccoon Lake and Lake Arthur were performed as follows: The equipment was set up, and the boat was held in position prior to collecting the bathymetric data. To begin the check, a 2 ft by 4 ft plate was lowered to a known depth of 6 ft below the transducer. The echo sounder displayed the depth, and if correct, a button was pressed to verify the correct speed-of-sound setting that the echo sounder uses to compute the depth. The plate was then lowered to increasing depths to continue the checking process. Finally, the plate was returned to the original 6-ft depth to verify the depth reading again. For both the Raccoon Lake and Lake Arthur surveys, the echo sounder always reported the correct depths of the bar check. The accuracy of the bar check at 6 ft was verified by use of a separate measurement utilizing a survey rod incremented to hundredths of feet. The precision of the bar checks were affected by wave action on the lake. The vertical accuracy of the echo sounder was conservatively estimated to be +/- 0.5 ft. This process was repeated each day or as needed to ensure accurate data collection. In order to minimize the effects of wave action on the accuracy of the depth data, surveys should be completed on calm water days if at all possible.

OVS gage readings were documented at the beginning and end of each survey day to determine any changes in the lake-surface elevation. For both Raccoon Lake and Lake Arthur, the elevation changes noted during the surveys by the OVS gages were less than the +/- 0.5 ft estimated accuracy of the echo sounder bar check; therefore, a stable water-surface elevation was assumed for the survey periods. The echo sounder recorded the depth data both digitally and by analog signal via a built-in thermal paper recorder that was used for comparison to the digital data during office processing.

The accuracy of the distance measurements from the transducer location to the shoreline point data was enhanced by equipment configurations and operator locations. The equipment setup on the boat was configured so that the transducer was mounted on the starboard side with the DGPS mounted directly above the transducer. The operator of the laser range finder would make the edge measurements from this position to correlate the lake shore with the boat/transducer position (fig. 3). The equipment operator was seated on the port side to offset the boat operator on the starboard side, reducing the roll of the boat during surveys.

Summary

Bathymetric surveys of Raccoon Lake in Beaver County, Pa., and Lake Arthur in Butler County, Pa., were performed by the USGS in cooperation with the DCNR to collect accurate data sets of lake-bed elevations (bathymetry) and to develop methods to help conduct similar surveys across the state. Benchmarks were established on land at each lake using DGPS surveys to determine an accurate water-surface elevation for each lake during the surveys. Bathymetric data were collected using a single beam, 210 kHz ODOM™ transducer operated by a Navisound™ echo sounder. The geographic position data were collected using a Trimble™ DGPS unit utilizing the Omni Star™ differential correction system. All data were assembled through the navigational software program HYPACK™. Within HYPACK™, transects of the depth data were acquired along predetermined intervals on each lake and displayed on a geo-referenced aerial photo. The lake shorelines were delineated using a laser range finder and compass module. Post-processing of the raw data sets eliminated erroneous spikes and smoothed the digital-data product with verification from the analog data recorded on thermal paper.

Lake-bed data are presented in X, Y, Z format with the vertical datum referenced to NAVD 88 and the horizontal position data referenced to NAD 83. LIDAR land-surface-elevation data are available for western Pennsylvania and can be merged with the lake bathymetric data to form a complete land-surface/lake-bed elevation map.

Acknowledgments

The cooperation of Obie Derr and staff at Moraine State Park, Al Wasilewski and staff at Raccoon State Park, and the DCNR, Bureau of State Parks, is gratefully acknowledged. W. Kirk Brethauer from Southwestern Pennsylvania Commission is acknowledged for supplying aerial photography and supporting GIS spatial data. Bob Glover of the USGS established the reference marks utilizing DGPS techniques. Scott Hoffman and Tom Trombley of the USGS provided the GIS support. John Fulton of the USGS trained the equipment operators in the use of HYPACK™ and echo sounder and Jamie McCoy, Megan Rogers, and Steve Nitkiewicz of the USGS assisted with data-collection activities.

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