Figure 1. Location of 7-mile reach of Lake Sharpe shoreline surveyed in study area near Lower Brule, South Dakota, in 2013.

Figure 2. Locations of planned regular and oblique transects in nearshore areas of Lake Sharpe in the study area, 2013.

ABSTRACT

Shoreline erosion rates along Lake Sharpe, a Missouri River reservoir, near the community of Lower Brule, South Dakota, were studied previously during 2011–12 by the U.S. Geological Survey, the Lower Brule Sioux Tribe, and Oglala Lakota College. The rapid shoreline retreat has caused many detrimental effects along the shoreline of Lake Sharpe, including losses of cultural sites, recreation access points, wildlife habitat, irrigated cropland, and landmass. The Lower Brule Sioux Tribe is considering options to reduce or stop erosion. One such option for consideration is the placement of discontinuous rock breakwater structures in shallow water to reduce wave action at shore. Information on the depth of water and stability characteristics of bottom material in nearshore areas of Lake Sharpe is needed by the Lower Brule Sioux Tribe to develop structural mitigation alternatives. To help address this need, a bathymetric survey of nearshore areas of Lake Sharpe near Lower Brule, South Dakota, was completed in 2013 by the U.S. Geological Survey in cooperation with the Lower Brule Sioux Tribe.

HYPACK® hydrographic survey software was used to plan data collection transects for a 7-mile reach of Lake Sharpe shoreline near Lower Brule, South Dakota. Regular data collection transects and oblique transects were planned to allow for quality-assurance/quality-control comparisons.

Two methods of data collection were used in the bathymetric survey: (1) measurement from a boat using bathymetric instrumentation where water was more than 2 feet deep, and (2) wading using Real-Time Kinematic Global Navigation Satellite System equipment on shore and where water was shallower than 2 feet deep. A dual frequency, 24- or 200-kilohertz narrow beam, depth transducer was used in conjunction with a Teledyne Odom CV100 dual frequency echosounder for boat-based data collection. In water too shallow for boat navigation, the elevation and nature of the reservoir bottom were mapped using Real-Time Kinematic Global Navigation Satellite System equipment.

Once the data collection effort was completed, data editing was performed in HYPACK® to remove erroneous data points and to apply water-surface elevations. Maps were developed separately for water depth and bottom elevation for the study area. Lines of equal water depth for 2, 3, 3.5, 4, and 5 feet from the water surface to the lake bottom were mapped in nearshore areas of Lake Sharpe. Overall, water depths stay shallow for quite a distance from shore. In the 288 transects that crossed a 2 foot depth line, this depth occurred an average of 88 feet from shore. Similarly, in the 317 transects that crossed a 3 foot depth line, this did not occur until an average of 343 feet from shore. Elevation contours of the lake bottom were mapped primarily for elevations ranging from 1,419 to 1,416 feet above North American Vertical Datum of 1988.

Horizontal errors of the Real-Time Kinematic Global Navigation Satellite System equipment for the study area are essentially inconsequential because water depth and bottom elevation were determined to change relatively slowly. The estimated vertical error associated with the Real-Time Kinematic Global Navigation Satellite System equipment for the study area ranges from 0.6 to 0.9 inch. This vertical error is small relative to the accuracy of the bathymetric data.

Accuracy assessments of the data collected for this study were computed according to the National Standard for Spatial Data Accuracy. The maps showing the lines of equal water depth and elevation contours of the lake bottom are able to support a 1-foot contour interval at National Standards for Spatial Data Accuracy vertical accuracy standards, which require a vertical root mean squared error of 0.30 foot or better and a fundamental vertical accuracy calculated at the 95-percent confidence level of 0.60 foot or better.

INTRODUCTION

Shoreline erosion along a 7-mile reach of Lake Sharpe, near the community of Lower Brule, South Dakota, was studied previously during 2011–12 by the U.S. Geological Survey, the Lower Brule Sioux Tribe, and Oglala Lakota College (Neitzert and others, 2012). Lake Sharpe is a reservoir on the Missouri River created by the construction of Big Bend Dam and operated today by the U.S. Army Corps of Engineers. The loss of land area associated with this erosion has caused many detrimental effects in the nearshore areas of Lake Sharpe, including the losses of cultural sites, recreation access points, wildlife habitat, and irrigated cropland and landmass. Water treatment costs at the Lower Brule Rural Water System have risen due to increased sediment found in water from Lake Sharpe, and sedimentation around the intake structure has necessitated extending the intake farther into Lake Sharpe (Jim MacCauley, Program Manager, Lower Brule Rural Water System, oral commun., 2014). Of special concern is the rapid advance of the shoreline toward the municipal wastewater lagoons (fig. 1) located southeast of Lower Brule, S. Dak.

The Lower Brule Sioux Tribe is considering options that would reduce or stop erosion and perhaps mitigate some of the habitat that has already been lost. One option being considered is the placement of discontinuous rock breakwater structures in shallow water to reduce wave action at the shore and potentially allow a plant margin to establish. The calmer water between these structures and shore also may provide backwater habitat. Information on the depth of water and stability characteristics of bottom material in nearshore areas of Lake Sharpe is needed by the Lower Brule Sioux Tribe to determine the proper placement of breakwater structures and estimate the quantity of material required for construction of breakwater structures. To help address this need, a bathymetric survey of nearshore areas of Lake Sharpe near Lower Brule, South Dakota, was completed in 2013 by the U.S. Geological Survey in cooperation with the Lower Brule Sioux Tribe.

SURVEY PREPARATION

HYPACK® hydrographic survey software was used (HYPACK, Inc., 2013) to plan data collection activities. Data collection transects were planned for nearshore areas in a 7-mile reach of Lake Sharpe shoreline in the study area near Lower Brule, S. Dak. (fig. 2). Regular data collection transects were laid out approximately perpendicular to shore and 100 feet apart. Oblique transects were laid out approximately 1,000 feet apart and oriented at roughly 45 degrees from regular transects to allow for quality-assurance/quality-control comparisons. This resulted in a total of 318 regular transects and 31 oblique transects. Because nearshore depths were unknown before the bathymetric survey, the required length of the regular transects also was unknown to achieve water depths of at least 5 feet. Regular transects typically were planned with a 400-foot length, but a second segment was added to most transects to extend them to approximately 800 feet. This allowed some regular transects to be angled to avoid crossing adjacent transects and achieve better data coverage (fig. 2). The intent was to collect data on regular transects from the shore outward into the lake a minimum of 400 feet, or farther if required until water was at least 5 feet deep. One additional transect was planned, which ran approximately parallel to shore in water about 3 to 4 feet deep. It is hoped that data from this parallel transect can be used in conjunction with future geophysical studies of the area.

Vertical and horizontal control for data collection was from a reference point established for use in a previous study (Neitzert and others, 2012). A 4.75-hour static Global Navigation Satellite System (GNSS) occupation on a nearby Bureau of Land Management cadastral disk (with no known published coordinates, but determined to be located at latitude 44°07'49.64693" North, longitude 99°34'45.65437" West) was processed using the Online Positioning User Service (OPUS; National Geodetic Survey, 2014a). Using the cadastral disk as a base, a 5-minute Real-Time Kinematic (RTK) occupation was completed to establish the coordinates of a punch point in the end of a length of rebar driven into the ground near a concrete pad. At the next site visit, the cadastral disk was found to have been destroyed, so the rebar was used as control for the bathymetric survey for this study and is referred to as the base station (fig. 2). Additional OPUS occupations were made during data collection to ensure that the rebar had not moved.

DATA COLLECTION METHODS

Two methods of data collection were used in the bathymetric survey. From July 29 to August 7, 2013, boat-based data were collected using bathymetry instrumentation where water was more than 2 feet deep. From August 12 to 15, wading-based data were collected using Real-Time Kinematic Global Navigation Satellite System (RTK GNSS) equipment on shore and in water about 2 feet deep or shallower. Boat-based data collection also used RTK GNSS for navigation and determination of the water-surface elevation. The RTK GNSS is a global positioning method where a stationary receiver (known as a base station) uses a radio to send out real-time differential correction signals to one or more mobile receivers (known as rovers). The GNSS surveying methods used to support this study met the criteria for a Level IV GNSS survey (Rydlund and Densmore, 2012). The data collection procedures and equipment used are described in the following subsections.

BOAT-BASED DATA COLLECTION

A 17½-foot, flat-bottom aluminum boat was used for boat-based data collection activities. This hull shape has a shallow draft that allows the vessel to travel in shallow water. Because boat-based data collection is substantially faster than wading-based data collection, it was preferable to use the boat on as much of any given data transect as was practical. A mount was attached near the front of the boat and used to deploy a Teledyne ODOM OTSBB 200/24-4-20 (over-the-side, broadband, dual-frequency [200-kilohertz and 4-degree beam width or 24-kilohertz and 20-degree beam width]) depth transducer in an Airmar M-42 housing and the RTK GNSS receiver used for guidance. The 4-degree beam width provides a smaller "footprint" on the reservoir bottom than the 20-degree beam, and can provide more accurate depths, especially in steep areas. The 200-kilohertz and 4-degree beam width were used for data collection on the regular and oblique transects. Data streams from the 200-kilohertz, 4-degree beam and the 24-kilohertz, 20-degree beam were collected on the parallel transect. The transducer was used in conjunction with a Teledyne Odom CV100 dual-frequency echosounder, which was connected to a laptop running HYPACK® software. The RTK GNSS receiver provided a very accurate horizontal location (within an inch) for each depth data point, and allows HYPACK® to display the position of the vessel relative to data transects. This allows the boat operator to adjust travel direction and maintain position on the data transects. During data collection, an effort was made to keep the transducer within 10 feet on either side of data transects; however, this was not always possible. In some locations, the boat was navigated around weedbeds, whereas in other locations, data needed to be collected far beyond the end of the data transect to reach water depths of 5 feet (fig. 3). In addition to horizontal location, the RTK GNSS connected to the echosounder also recorded water-surface elevation for each depth data point. These water-surface elevation data were averaged by transect and used with depth and antenna offset (distance between the GNSS antenna and the water surface) to determine the elevation of the lake bottom.

WADING-BASED DATA COLLECTION

In water too shallow for boat navigation (less than 2 feet), the elevation and nature of the reservoir bottom were mapped using RTK GNSS. Wading-based data collection took place after boat-based data collection was completed. In this way, portions of transects where data had already been collected by boat could be identified, and wading-based data collection only needed to extend to (or slightly overlap) the boat-based data (fig. 3). Because the wading-based data were not collected simultaneously with boat-based data, changes in water surface elevation would mean that water depths between the two data collection methods would not be directly comparable. Windy conditions and resulting waves during wading-based data collection would have made it difficult to estimate depth accurately. To avoid these problems, depth was not recorded with bottom elevation and firmness. Wading-based data points were collected from the toe of the bank out to the approximate location where the boat data began. Once wading was completed for all transects, an additional point was collected at the top of bank for those transects that had a visible bank. Data points along the transect were variably spaced, depending on changes in slope. Points were as close as 1 foot apart in steep areas, but generally were several feet apart in flatter areas. An average of 3 seconds worth of data was stored as the elevation of the lake bottom. The bottom of the rove pole was not allowed to sink into the lake bottom, but was held at the surface of the lake bottom material. Similar to the collection of the boat-based data, an effort was made to collect wading-based data within 10 feet on either side of the data transects. However, many locations had fallen timber that made it difficult to stay near the transect, and a few areas had overhanging tree canopy that interfered with satellite signal.

At each wading-based data point, a qualitative assessment of the firmness of the bottom material was made by the surveyor, based on how much the surveyor's feet sank in the bottom material. A label indicating the degree of firmness was assigned to the point and stored with the elevation data. Labels used to describe the bottom firmness are summarized in table 1; of the 3,609 wading-based data points, most (2,704) had a firm bottom. The spatial distribution of the wading-based data points labeled with a soft bottom is shown on figure 4. Only 126 points (about 3.5 percent) had labels indicating the feet of the surveyor sank 3 or 4 inches.

Table 1. Labels used to describe bottom firmness at wading-based data points.

Label	Description
F	Firm bottom. The feet of the surveyor did not sink detectably.
S1	Soft bottom, with the feet of the surveyor sinking approximately 1 inch.
S2	Soft bottom, with the feet of the surveyor sinking approximately 2 inches.
S3	Soft bottom, with the feet of the surveyor sinking approximately 3 inches.
S4	Soft bottom, with the feet of the surveyor sinking approximately 4 inches.

QUALITY-ASSURANCE/QUALITY-CONTROL MEASURES

Quality-assurance/quality-control measures were made to ensure that the data collected were accurate, meaningful, and allowed an analysis of uncertainty. The quality-assurance/quality-control measures used in data collection are described in this section.

Following good surveying practices (Rydlund and Densmore, 2012) can help ensure accuracy of the GNSS data. A 6.562-foot (2-meter) fixed-height tripod was used at the base station to avoid antenna measurement errors. Birds-eye levels were used on the base tripod and rove poles to ensure the antennae were held plumb and vertical while collecting data. An average of three measurements was used for each wading-based data point. Data were only collected when integer ambiguities were fixed (an indicator of solution stability), and with a minimum of four common satellites between the base and rover GNSS receivers.

The accuracy of depth data output from the echosounder and transducer was verified at the beginning and end of each day of boat-based data collection by using bar checks. During a bar check, an underwater object (in this study, a perforated metal plate) is passed below the transducer at multiple known depths, which are compared to the depths output by the echosounder. When differences exist between the known and output depths, data corrections can be calculated and applied to the data. Care must be taken during bar checks to ensure that the plate stays parallel to the water surface, and its depth below the water surface can be accurately determined. Using a heavy weight, tethering the corners of the metal plate to the weight, and avoiding areas of waves or high-water velocity during bar checks were techniques used to ensure that the plate stayed parallel to the water surface. For this study, the barcheck apparatus was suspended from the boat using a brake winch with a depth gage. For each bar check, the depth gage was set to zero when the plate was held at the water surface. The depths selected for bar checks must bracket the range of depths expected during data collection. Because the water in the study area was relatively shallow and is mixed by currents and waves, wide temperature variations within the water column are not expected. Water temperature was used to select an appropriate value for the speed of sound in water (*www.engineeringtoolbox.com/sound-speed-water-d_598.html*, accessed July 29, 2013).

Another way to assure quality data is to assess the accuracy of an instrument through independent repeated measurements. A description of data quality based on comparison of repeat measurements is presented in the "Accuracy Assessment of Data and Maps" section.

Figure 3. Extent of boat- and wading-based data collected in nearshore areas of Lake Sharpe in the study area, 2013.

Figure 4. Spatial distribution of wading-based data points where a soft bottom was found.

Nearshore Bathymetric Mapping along a 7-mile Reach of Lake Sharpe Shoreline near Lower Brule, South Dakota, 2013

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