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

Prepared in cooperation with the
Lower Brule Sioux Tribe

Scientific Investigations Map 3307
Sheet 2 of 2

Base from U.S. Department of Agriculture, National Agriculture Imagery Program (NAIP), 2012
Universal Transverse Mercator projection, zone 14

Figure 5. Lines of equal water depth in nearshore areas of Lake Sharpe adjacent to the community of Lower Brule, 2013.

DATA PROCESSING AND INTERPRETATION

Once the data collection effort was completed, data editing was necessary to remove erroneous data points and apply water-surface elevations. Bathymetric data can be affected by anything that happens to be in the water column below the depth transducer. HYPACK® software has a data editing module that allows the user to remove erroneous data points caused by submerged vegetation or timber, fish, bubbles (from waves or the motor), or rock/cobble on an otherwise smooth bottom. Submerged vegetation was present in many parts of the surveyed area, and sometimes in large patches. In some areas, part of the echosounder signal was able to penetrate through the vegetation so that some of the returns were actually from the lake bottom. In other areas, the vegetation was very thick, and the signal did not reach the bottom. In areas of thick vegetation, the edited data has gaps where the erroneous vegetation returns were removed.

The boat-based data from the echosounder is produced at a high frequency (as many as 20 pulses per second). This results in very closely spaced data points when the boat travels at the slow speeds typically used during the survey. Individual data points commonly were less than 0.2 foot apart along the transect. This high frequency of data collection would be useful when traveling at higher speeds or in areas with a steep and rapidly changing bottom terrain. However, the bottom within the study area was generally very smooth, and the shallow depths commonly encountered required a relatively slow travel speed. This resulted in a very dense dataset with many redundant data points. The HYPACK® software allows the user to select a subset of the data, based on a desired distance between points or when the depth change between adjacent points exceeds a user-defined threshold. This capability was used on the boat-based data collected on the regular transects to provide a dataset of a more manageable size. The maps of water depth and bottom elevation described in the next section were developed from the edited subset of the original data.

DEVELOPMENT OF MAPS

Although lakes such as Lake Sharpe might sometimes be assumed to have a flat water surface, data points collected at the water surface throughout the surveyed area and during each day of data collection indicated a decrease in water-surface elevation in the downstream direction. The change in water surface throughout the study area was approximately 1 foot. Although dam releases for hydropower generation upstream at Oahe Dam and downstream at Big Bend Dam typically followed a diurnal cycle during data collection (Darin Larson, Civil Engineer, U.S. Army Corps of Engineers, written commun., 2014), the study area appears to be far enough away from the dams to allow at least some of the diurnal cycle changes to be attenuated. Because of the changing water surface throughout the study area, lines of equal water depth will not be parallel to elevation contours of the reservoir bottom. Therefore, separate maps for water depth and bottom elevation were developed for the nearshore areas of the study area.

WATER-DEPTH MAP

The boat-based data were exported into a spreadsheet and subsequently loaded into a geographical information system software, ArcGIS (Esri, 2014). Within ArcGIS, each data point could be plotted on-screen and labeled with its corresponding water depth (distance from water surface to lake bottom). By interpolating water depth between points and from one transect to the next, lines of equal water depth were manually digitized for 2, 3, 3.5, 4, and 5 feet deep. A few transects had data points of depths greater than 5 feet, so segments of these lines of equal depth also were digitized where adequate data were available. Lines of equal depth for the nearshore area adjacent to Lower Brule (fig. 5) and for the study area (fig. 6) indicate that 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.

BOTTOM-ELEVATION MAP

The contour map of the elevation of the lake bottom in nearshore areas of Lake Sharpe was developed in a manner similar to that used for the water-depth map, but with the wading-based data collected near shore included. For the bottom-elevation map, contours were manually digitized for elevations of 1,419; 1,418; 1,417; and 1,416 feet above the North American Vertical Datum of 1988. Some transects had data points at lower elevations, so segments of these elevation contours also were digitized where adequate data were available (fig. 7).

ACCURACY ASSESSMENT OF DATA AND MAPS

Each physical measurement has two components: the number representing the estimated value of the property being measured, and the degree of uncertainty associated with that measurement. The analyses of uncertainty associated with the data and the maps derived from the data are described in this section.

Horizontal accuracy of the boat- and wading-based data is dependent on the horizontal accuracy of the RTK GNSS equipment and the surveying methodology used in data collection. Holding the rover rod and base tripod plumb ensures that the GNSS antenna is directly above the point being measured. A birds-eye level mounted to the base tripod and each rover rod helps to minimize horizontal errors because of the GNSS antenna being out of plumb. Horizontal accuracy of the GNSS equipment being used in RTK mode is specified by the manufacturer as 0.3937 inch (10 millimeters) plus 1 part per million times the baseline length (Topcon Positioning Systems, 2007). The data points farthest away from the GNSS base station (that is, the data points at the southern end of the study area) are approximately 24,813 feet away, for which the 1 part per million increase in horizontal error equates to 0.3 inch. The manufacturer's estimated horizontal error associated with the RTK GNSS equipment over the study area ranges from 0.4 to 0.7 inch (fig. 8). Horizontal errors of this magnitude are essentially inconsequential because changes in water depth and bottom elevation were found to be very gradual. No steep drop-offs were evident in the study area. Horizontal errors of the base coordinates are expected to be within 0.05 foot based on OPUS peak-to-peak root mean squared errors. The peak-to-peak root mean squared error is the difference between the three baseline solutions computed by OPUS (National Geodetic Survey, 2014b).

Proper equipment and surveying methods can help to minimize vertical errors associated with the GNSS equipment. Using a fixed-height tripod at the RTK GNSS base station and fixed-height rover poles largely eliminates errors associated with incorrectly measured antenna height. Vertical errors specified by the GNSS manufacturer used in RTK mode are 0.5906 inch (15 millimeters) plus one part per million times the baseline length (Topcon Positioning Systems, 2007). The data points farthest away from the GNSS base (that is, the data points at the southern end of the study area) are approximately 24,813 feet away, for which the 1 part per million increase in horizontal error equates to 0.3 inch. The manufacturer's estimated vertical error associated with the RTK GNSS equipment over the study area ranges from 0.6 to 0.9 inch (fig. 9). This vertical error is small relative to the accuracy of the bathymetry data, as discussed in the following paragraphs.

Accuracy assessments of the data collected for this study were computed according to the National Standard for Spatial Data Accuracy (NSSDA; Federal Geographic Data Committee, 1998). This standard is mathematically robust and well-suited to large datasets. The data are compared to an independent dataset to compute the vertical root mean squared error ($RMSE_z$) using equation 1:

$$RMSE_z = \frac{\sum_{i=1}^{n}(Z_{data_i} - Z_{check_i})}{n} \quad (1)$$

where

$RMSE_z$ is the vertical root mean square error,
Z_{data_i} is the vertical coordinate of the *i*th check point in the dataset,
Z_{check_i} is the vertical coordinate of the *i*th check point in the independent dataset,
i is an integer from 1 to *n*, and
n is the number of points being checked.

Assuming the errors are normally distributed, vertical accuracy at the 95-percent confidence level (A_z) is then computed from the $RMSE_z$ value using equation 2:

$$A_z = 1.960 \times RMSE_z \quad (2)$$

where

A_z is the fundamental vertical accuracy calculated at the 95-percent confidence level.

For this study, boat- and wading-based data from the regular transects were considered the primary dataset, whereas the boat- and wading-based data from the oblique transects were considered the independent dataset. The boat-based data from the regular transects were compared with the boat-based data from the oblique transects where lines intersected to evaluate the repeatability of the echosounder data at various depths over the study area. Using ArcGIS software (Esri, 2014), any boat-based data point from an oblique transect that was within a selection distance of a boat-based data point from a regular transect was identified and their elevations compared. Points within 0.33 feet of each other were assumed to be coincident (Wilson and Richards, 2006). This criterion was met by 119 point pairs, giving an $RMSE_z$ value of 0.228 feet and an A_z value of 0.448 feet (table 2).

Differences in bottom elevations from boat-based and wading-based data sources were compared between the two datasets. For this comparison, the boat-based data from regular transects were again used as the primary dataset, and the wading-based data from regular transects were considered the independent dataset. Using ArcGIS software (Esri, 2014), any boat-based data point on a regular transect that was within a selection distance of a wading-based data point on a regular transect was selected for comparison. Because spacing between wading-based data points typically was larger than spacing between boat-based data points, far fewer points were available using the same selection distance of 0.33 feet used for the comparison between boat-based data on regular and oblique transects. Accordingly, the selection distance was increased in an effort to identify enough point pairs for a comparison. A 2-foot selection distance was initially tried, but less than 100 points met this distance criterion. Using a 3-foot selection distance, 347 pairs of data points were available for comparison. The mean bottom-elevation difference between paired data points from these datasets was 0.013 foot, with a median difference of 0.02 foot. Although the maximum (0.40 foot) and minimum (-0.56 foot) differences between paired elevations were large, it must be remembered that the points compared could be as much as 3 feet apart. The $RMSE_z$ value for the pairs of data points was 0.140 foot, and the A_z value was 0.247 foot (table 2). The better accuracy of these data than those used in the comparison between boat-based data from regular and oblique transects may be because the point pairs were concentrated in shallower areas near shore, where the bottom tended to be more smooth and uniform. The shallower depth would help minimize elevation differences between the datasets even though the point pairs were potentially much farther apart.

Table 2. Summary of accuracy assessments for bathymetric survey in nearshore areas of Lake Sharpe, 2013.

Primary datset	Independent dataset	Selection distance (feet)	Number of data point pairs	Vertical root mean squared error (*RMSE*$_z$) (feet)	Fundamental vertical accuracy at 95-percent confidence level (A_z)(feet)
Regular transects, boat-collected	Oblique transects, boat-collected	0.33	119	0.0228	0.448
Regular transects, boat-collected	Regular transects, wading-collected.	3	347	0.140	0.247
Lines of equal water depth	Oblique transects, boat-collected.	0.33	1,333	0.286	0.560
Bottom-elevation contours	Oblique transects, boat-collected	0.33	1,095	0.261	0.511

Additional analyses were completed to assess the accuracy of the maps of water depth and bottom elevation derived from the boat- and wading-based water-depth and bottom-elevation data for the regular transects. Comparisons were made between each set of lines or contours for the water-depth map or bottom-elevation map, respectively, and the boat- and wading-based data from oblique transects. These comparisons incorporate inaccuracies that may be introduced from the effects of data processing and interpretation. For these comparisons, the lines or contours derived from boat- and wading-based data on the regular transects provided the primary dataset, and the boat-based data from the oblique transects provided the independent dataset. Using a 0.33-foot selection distance, 1,333 point pairs were identified for comparison between the lines of equal water depth and the boat-based data on the oblique transects. The $RMSE_z$ value was 0.286 foot and the A_z value was 0.560 foot (table 2). Using a 0.33-foot selection distance, 1,095 point pairs were identified for comparison between the bottom-elevation contours and the boat-based data on oblique transects. The $RMSE_z$ value was 0.261 foot, and the A_z value was 0.511 foot. Thus, both the water-depth map (fig. 5) and the bottom-elevation map (fig. 6) are able to support a 1-foot interval using NSSDA vertical accuracy standards, which require $RMSE_z$ and A_z of 0.30 foot and 0.60 foot or better, respectively (Federal Geographic Data Committee, 1998).

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Base from U.S. Department of Agriculture, National Agriculture Imagery Program (NAIP), 2012
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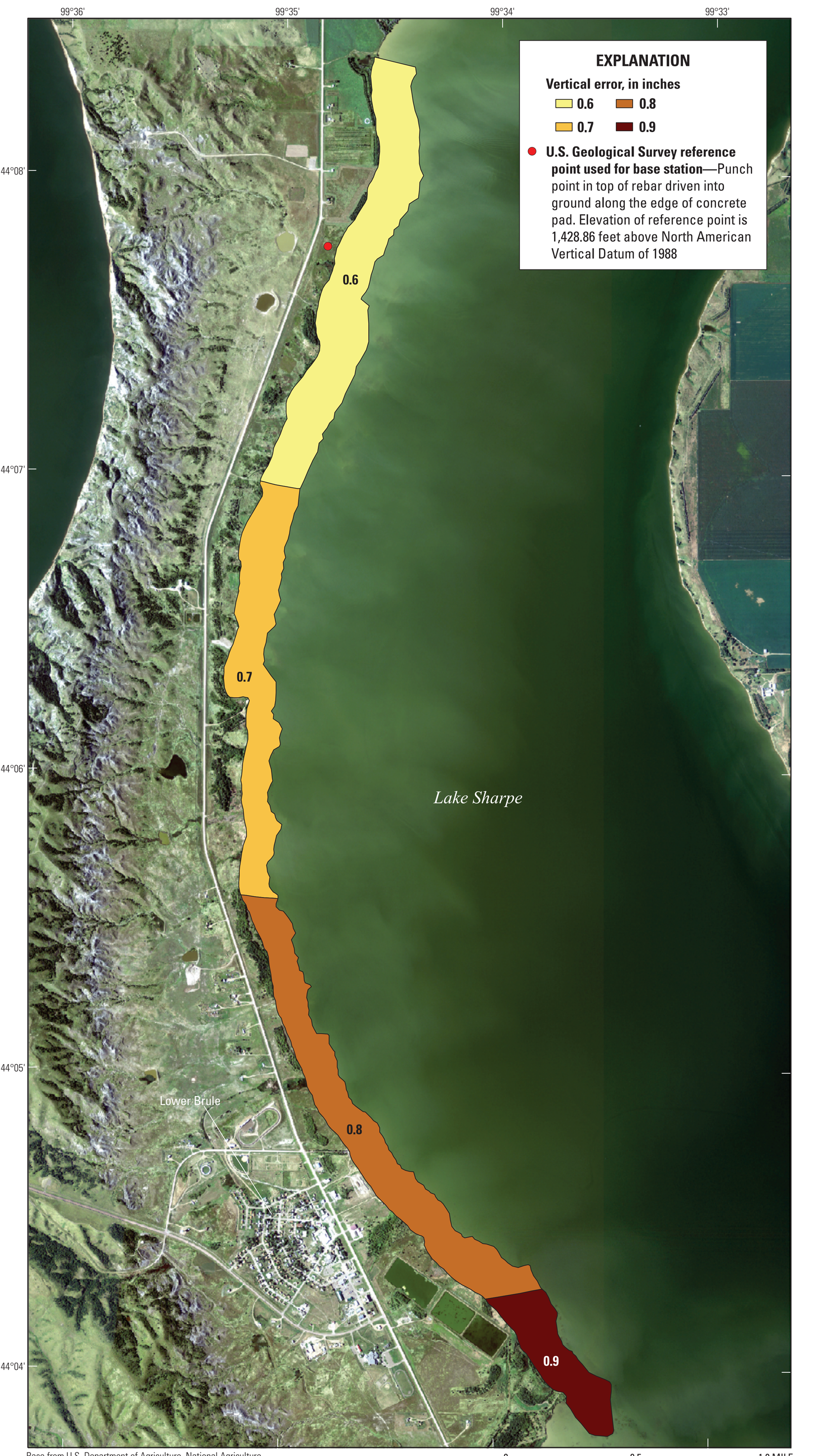
Figure 6. Lines of equal water depth in nearshore areas of Lake Sharpe in the study area, 2013.

Base from U.S. Department of Agriculture, National Agriculture Imagery Program (NAIP), 2012
Universal Transverse Mercator projection, zone 14

Figure 7. Elevation contours of the lake bottom in nearshore areas of Lake Sharpe in the study area, 2013.

Base from U.S. Department of Agriculture, National Agriculture Imagery Program (NAIP), 2012
Universal Transverse Mercator projection, zone 14

Figure 8. Estimated horizontal error for Real-Time Kinematic Global Navigation Satellite system equipment.



Base from U.S. Department of Agriculture, National Agriculture Imagery Program (NAIP), 2012
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Figure 9. Estimated vertical error for Real-Time Kinematic Global Navigation Satellite System equipment.

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

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