RECLAMATION

Managing Water in the West

Technical Report No. SRH-2014-16

2013 Lake Tschida (Heart Butte Reservoir) Sedimentation Survey

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

September 2014

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The Bureau of Reclamation's (Reclamation) Sedimentation and River Hydraulics (Sedimentation) Group of the Technical Service Center (TSC) prepared and published this report. Ron Ferrari of Reclamation's Sedimentation Group conducted the bathymetry survey of the reservoir in July 2013 and completed the data processing to generate the reservoir topography and area-capacity information presented in this report. Kent Collins of the Sedimentation Group and Christopher Murray the Great Plains Regional Office performed the technical peer review of this document.

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The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Reclamation Report

This report was produced by the Bureau of Reclamation's Sedimentation and River Hydraulics Group (Mail Code 86-68240), PO Box 25007, Denver, Colorado 80225-0007, www.usbr.gov/pmts/sediment/.

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2013 Lake Tschida (Heart Butte Reservoir) Sedimentation Survey

prepared by

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Technical Service Center
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14. ABSTRACT

Reclamation surveyed Lake Tschida (Heart Butte Reservoir) in July 2013 to develop updated reservoir topography and compute the present storage-elevation relationship (area-capacity tables). The bathymetric survey, conducted near water surface elevation 2,064 (project datum in feet), used sonic depth recording equipment interfaced with a real-time kinematic (RTK) global positioning system (GPS) that provided continuous sounding positions throughout the underwater portion of the reservoir covered by the survey vessel. The above-water topography was developed by digitizing the reservoir water's edge from aerial photographs collected by the United States Department of Agriculture (USDA) and digital bare earth Interferometric Synthetic Aperture Radar (IFSAR) data.

As of July 2013, at top of conservation pool elevation 2,064.5, the reservoir surface area was 3,142 acres with a capacity of 65,091 acre-feet. At maximum reservoir elevation 2,119.5 the reservoir surface area was 11,214 acres with a capacity of 435,123 acre-feet. Since 1949 dam closure, a total capacity change of 10,953 acre-feet below elevation 2,064.5 was measured, equal to an average annual loss of 169.0 acre-feet. The capacity change is due to sediment deposition and methodology differences between the surveys.

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Technical Report No. SRH-2014-16

2013 Lake Tschida (Heart Butte Reservoir) Sedimentation Survey

Heart Butte Dam
North Dakota

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Introduction

Heart Butte Dam and Lake Tschida, also known as Heart Butte Reservoir, are part of the Heart Butte Unit of the Pick-Sloan Missouri Basin Program that provides storage capacity for irrigation and benefits for flood control, recreation, fish and wildlife. The reservoir and dam, located in Grant County on the Heart River downstream of E.A. Patterson Reservoir, are 18.4 miles south of Glen Ullin and 14.8 miles north of Elgin, North Dakota (Figure 1). Reclamation's Dakota Area Office administers and operates this facility. The recreational facilities are operated by Tri-Cities Joint Job Development Authority. At elevation 2,065.5 the reservoir length is around 12.9 miles with an average width of 0.4 miles. The drainage area above Heart Butte Dam is 1,710 square miles (mi^2) with 400 mi^2 of drainage contributing to by E.A. Patterson Reservoir leaving 1,310 mi^2 as sediment contributing. During planning, no space for sediment accumulation was allocated within the reservoir.

The homogeneous earthfill structure was constructed between 1948 and 1949, becoming operational in October 1949, Figure 2. Heart Butte Dam has the following dimensions:

Structural height[1]	142 feet	Hydraulic height	118 feet
Crest length	1,850 feet	Crest elevation[2]	2,124 feet
Top width	40 feet		

There is an uncontrolled concrete glory hole spillway located through the right abutment of the dam with crest elevation 2,064.5. The design discharge capacity is 5,700 cubic feet per second (cfs) at reservoir elevation 2,118.2. An auxiliary spillway structure is located 1.5 miles south of the dam and just west of Highway 49. The uncontrolled spillway has a width of 2,685 feet, crest elevation 2,109.0, and a design maximum discharge of 200,260 cfs.

The outlet works structure is a high pressure, gate-controlled, concrete conduit located through the right abutment of the dam. There are two 4- by 5-foot gates with one for regulating and the other for emergency use. The intake, with crest elevation 2,030.0, has a discharge capacity of 700 cfs.

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[1] The definition of such terms as "top width, "structural height," etc. may be found in manuals such as Reclamation's *Design of Small Dams* and *Guide for Preparation of Standing Operating Procedures for Dams and Reservoirs*, or ASCE's *Nomenclature for Hydraulics.*

[2] Elevations in feet. Unless noted all elevations based on the original Project datum established during construction of Heart Butte Dam. This study measured the Project datum 0.2 feet lower than National Geodetic Vertical Datum of 1929 (NGVD29) and 1.7 feet lower than the North American Vertical Dam of 1988 (NAVD88).

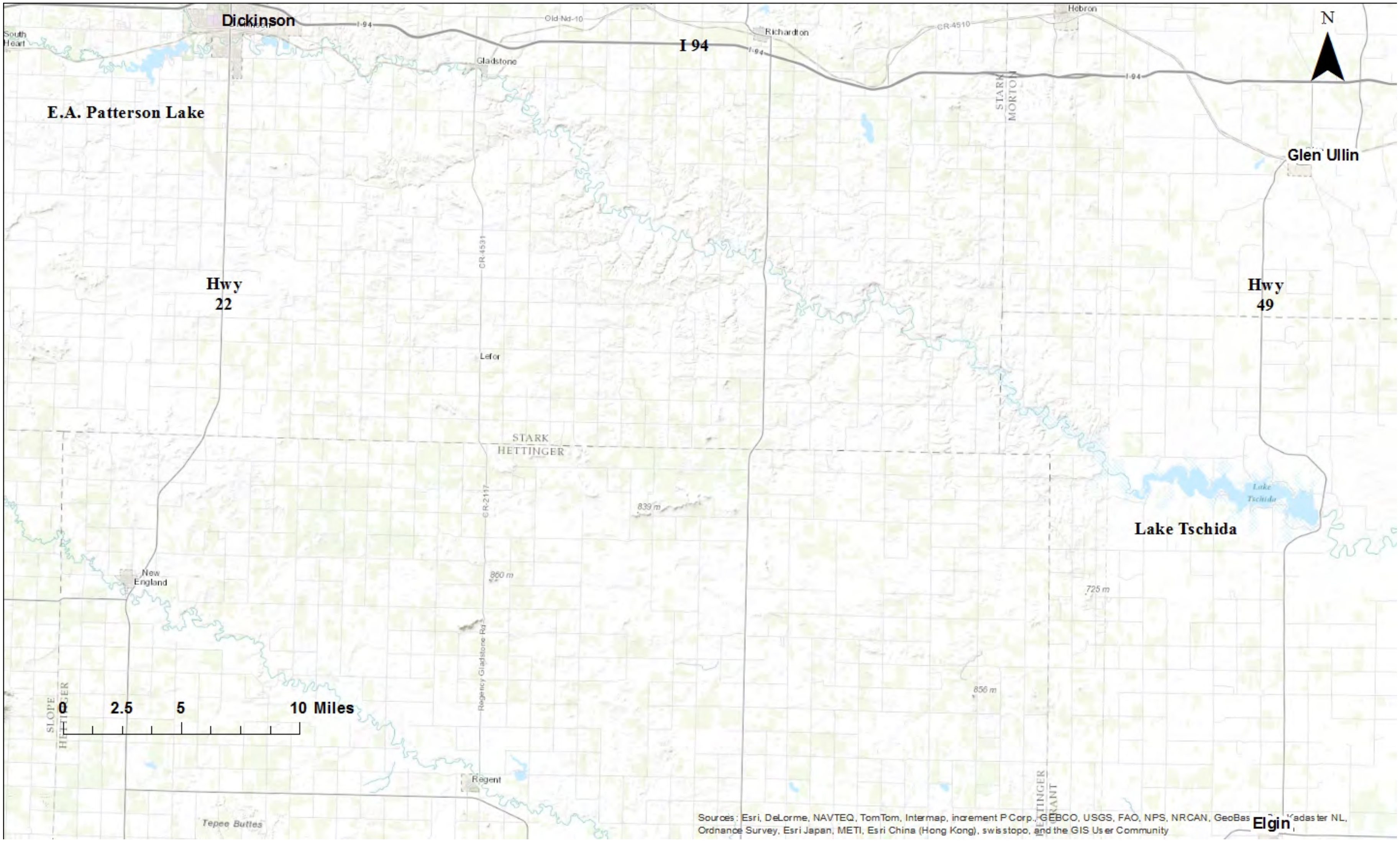

Figure 1 - Lake Tschida and Heart Butte Dam location map, North Dakota.

Figure 2 - Heart Butte Dam and uncontrolled concrete glory hole spillway.

Figure 3 - Uncontrolled concrete glory hole spillway at water surface elevation 2,064.

1992 Survey Summary

Reclamation surveyed Heart Butte Reservoir (Lake Tschida) in 1992 to monitor changes after 42.9 years of reservoir operations. A survey of 20 range lines was conducted to represent the change of the entire reservoir. Much of the reservoir and tributary ranges were surveyed from the summer of 1992 through the spring of 1993. Some data were gathered by drilling through ice cover and probing the channel bottom during the winter. The reservoir surface areas were computed by the Width Adjustment Method that entails computing the revised contour areas between two ranges by applying an adjustment factor to each of the original segmental contour areas between adjacent ranges. The adjustment factor is determined as the ratio of the new average width to the original average width for both the upstream and downstream ranges at a specified contour. The reservoir subdivided into segments using the sedimentation range lines to delineate the limit of each segment boundary. Segment contour areas for each elevation were determined by digitizing the segment contours on the original topography. For any given contour elevation, the original segment area was multiplied by the adjustment factor to obtain the 1992 surface area for that elevation. The total surface area at a given contour elevation was computed as the summation of all segment areas at that elevation. More information on the Width Adjustment Method is available within the Erosion and Sedimentation Manual (Ferrari and Collins, 2006). The computed capacity of the reservoir from the 1992 survey was 67,146 acre-feet with a surface area of 3,299 acres at elevation 2,064.5 feet. Since the reservoir's initial filling in October 1949, it was estimated that 8,898 acre-feet of sediment have settled in the reservoir by 1992. The average annual rate of sediment accumulation below the spillway crest elevation was 207.4 acre-feet (Bureau of Reclamation, 1994).

Control Survey Data Information

Prior to the 2013 bathymetric survey, a control network was established using the on-line positioning user service (OPUS) and RTK GPS to set the horizontal and vertical control points near Heart Butte Dam. OPUS, operated by the National Geodetic Survey (NGS), allows users to submit GPS data files that are processed with known point data to determine positions relative to the national control network. The OPUS generated coordinates were used to determine position and vertical difference between NAVD88, recorded water surface elevations, and the monument points.

The horizontal control was established in North Dakota state plane South coordinates tied to NAD83 (2011) in US Survey Feet (feet). The vertical control, tied to the Reclamation’s project vertical datum and NAVD88, was computed using the Geoid model 2012A (GEOID12A). RTK GPS water surface measurements collected during the bathymetric survey, tied to NAVD88, were around 1.7 feet higher than the water surface gage measurement. Unless noted, all elevation computations within this report are referenced to Reclamation's project datum that this study determined is 0.2 feet lower than NGVD29 and 1.7 feet lower than NAVD88 (GEOID12A). The developed reservoir topography elevations were tied to NAVD88 (GEOID12A). The computed surface area values from the 2013 reservoir topography were shifted down 1.7 feet to match the project vertical datum and were used for development of the 2013 surface areas and capacity values.

When setting the control network a monument stamped "Bureau of Reclamation" and "2121.542" was used as the base for the 2013 survey, Figure 4. The monument was located downstream of the dam within the fenced area of the dam tender's property, Figure 5. During the 2013 survey the regional office informed the bathymetric crew the actual elevation of the monument was elevation 2,121.471. The OPUS computed coordinates for the base monument are:

East	**1,639,269.691**
North	**341,341.135**
Elevation	**2,123.172 (NAVD88/GEOID12A)**
Project Elevation	**<u>2,121.471</u>**
Difference	**1.701**

During the survey RTK GPS water surface measurements tied to NAVD88 were compared to the water surface gage readings that are maintained by Reclamation. The average difference for only those water surface measurements collected in calm conditions was 1.7 feet. Using the Corp of Engineer's program CORPSCON, an elevation difference of 1.52 was computed between NAVD88 and NGVD29 at the base station. At E.A. Patterson Reservoir, more than 45 river miles upstream, the CORPSCON computed elevation difference was 1.77 feet. Reclamation documents indicate that the structure designs were tied to mean sea level, but the 2013 survey determined the project vertical datum was around 0.2 feet lower than NGVD29, the implied sea level during construction. For computational purposes the project or construction vertical datum of 1.7 feet below NAVD88 was used for this study. From this GPS base a second Reclamation monument in the area and the top of dam were measured. The measurements on the dam were taken on the center line of the road near the right abutment, but were not used to determine the elevation difference due to changes over time resulting from road development. The second Reclamation monument had the following RTK GPS measured coordinates:

East	**1,639,267.590**
North	**341,393.325**
Elevation	**2,121.427 (NAVD88/GEOID12A)**

Figure 4 - Bureau of Reclamation stamped "2121.542."

Figure 5 **- Bureau of Reclamation monument located downstream of dam along fence line.**

Reservoir Operations

Heart Butte Dam is a multipurpose feature of the Missouri River Basin Project whose primarily purpose is providing water storage capacity for irrigation, flood control, recreation, fish, and wildlife. The July 2013 total capacity was 435,123 acre-feet below elevation 2,119.5. The minimum bottom elevation measured during the 2013 survey was 2,008.6. The following values are from the July 2013 capacity table:

222,427 acre-feet of surcharge pool storage between elevation 2,094.5 and 2,119.5.
147,605 acre-feet of flood control storage between elevation 2,064.5 and 2,094.5.
60,763 acre-feet of active conservation storage between elevation 2,030.0 and 2,064.5.
4,328 acre-feet of dead pool storage below elevation 2,030.0.

End-of-month stage records for Lake Tschida in Table 1 show the annual fluctuation for operation water years 1950 through 2013. The average inflow during this period was 86,050 acre-feet with the highest measured being 306,872 acre-feet in 1982. Table 1 shows reservoir level fluctuations have ranged from a maximum elevation of 2,086.2 in 1952 and since than a minimum elevation of 2,049.0 in 1992.

Hydrographic Survey, Equipment, and Method of Collection

Bathymetric Survey Equipment

The bathymetric survey equipment was mounted on an aluminum vessel with the transducer and GPS unit located over the side, Figure 6. The hydrographic system included a GPS receiver with a built-in radio, a depth sounder, a helmsman display for navigation, a computer, and hydrographic system software for collecting the underwater data. On-board batteries powered all the equipment. The shore equipment included a second GPS receiver with an external radio. The shore GPS receiver and antenna were mounted on survey tripods over a known datum point and powered by a 12-volt battery.

Figure 6 - Survey vessel for reservoir mapping with mounted transducer on side (Lake Sumner-New Mexico, March 2013)

The Sedimentation Group uses RTK GPS with the major benefit being precise heights measured in real time to monitor water surface elevation changes. The RTK GPS system employs two receivers that track the same satellites simultaneously just like with differential GPS. The basic outputs from a RTK receiver are precise 3-D coordinates in latitude, longitude, and height with accuracies on the order of 2 centimeters horizontally and 3 centimeters vertically. The output is on the GPS WGS-84 datum that the hydrographic collection software converted into North Dakota’s state plane south coordinates, NAD83, in US Feet (feet).

The Lake Tschida bathymetric survey was conducted from July 17-20, 2013 near water surface elevations 2,064.0. The bathymetric survey used sonic depth recording equipment interfaced with RTK GPS that measured the sounding locations within the reservoir covered by the survey vessel. The survey system software continuously recorded reservoir depths and horizontal coordinates as the survey boat moved along grid lines established to cover the reservoir. Shoreline data were also collected as the vessel traversed to each grid line and as it returned to port each day. The survey vessel's guidance system provided directions to the boat operator to assist in maintaining a course along the predetermined lines. As each line was traversed, the depth and position data were recorded on the laptop computer hard drive for subsequent processing, resulting in point data at one second intervals. The water surface elevations at the dam from Reclamation gage records and RTK GPS measurements were used to convert the sonic depth measurements to lake-bottom elevations tied to the project vertical datum and NAVD88 that is 1.7 feet higher. Final processing of the July 2013 bathymetric data resulted in around 82,400 points, Figures 7 through 11.

The underwater data were collected using a depth sounder at 200 kHz calibrated by adjusting the speed of sound through the water column which varies with density, salinity, temperature, turbidity, and other conditions. The data were digitally transmitted to the computer collection system through RS-232 serial ports. The depth sounder produced digital charts of the measured depths and when the charted depths indicated a difference from the computer recorded bottom depths, the computer data files were modified during the analysis. Additional information on collection and analysis procedures is outlined in Chapter 9 of the *Erosion and Sedimentation Manual* (Ferrari and Collins, 2006).

Above-Water Data

Aerial Photography

The 2013 survey of Lake Tschida focused on the collection of the bathymetric or underwater data that were accessible by the survey vessel, requiring acquisition of the best available above water data to complete the topographic development. During processing, orthographic aerial photos collected over several years near full water surface elevation 2,064 were downloaded from the USDA data web site and used to develop a breakline to represent full reservoir conditions (USDA, 2010). This full reservoir contour was developed by digitizing the water's edge from the aerial image and assigning an elevation to it. That contour was then used during the 2013 reservoir contour development. The water surface elevation assigned to this contour was elevation 2,066.0 (NAVD88) to represent the water surface to just below the spillway crest elevation 2,066.2 (NAVD88).

Aerial IFSAR

IFSAR digital bare earth data were obtained in North Dakota's state plane, south zone in NAD83 with vertical elevations tied to NAVD88 in feet. IFSAR airborne technology enables mapping of large areas quickly and efficiently, resulting in detailed information at a much lower cost than other technologies such as low altitude detailed aerial photogrammetry and LiDAR. The IFSAR data at Lake Tschida were collected in May 2007 near reservoir water surface elevation 2,062 (NAVD88). The IFSAR data provided detailed topographic images around the reservoir body with reported accuracies of 2 meters horizontally and 1 meter vertically in areas of unobstructed flat ground (Intermap, 2011). The reservoir coverage was obtained in raster format, from which 1-foot contours were developed and used as breaklines during topographic development.

In some places, the IFSAR data contradicted the water surface shoreline represented by the digitized USDA water surface contour assigned elevation 2,066.0 (NAVD88) for this study. The steeper bank slopes along the reservoir shoreline likely caused these discrepancies. The bathymetric data collected along the shoreline during the 2013 survey and the digitized USDA water surface contour representing the reservoir near spillway crest elevation 2,066.2 were sufficient to map the near shore area and all IFSAR data from elevation 2,066.0 (NAVD88) and below were removed. The IFSAR data were the most recent above water data information available and the developed 1-foot contours above elevation 2,066.0 were used to develop the 2013 reservoir topography in the upper elevations. Surface areas of the reservoir above elevation 2,066.0 developed from the IFSAR data compared very well with the original and 1992 surface areas, so the 2007 IFSAR was combined with the USDA contour and 2013 bathymetry for the total reservoir area and capacity computations. During past studies at other reservoirs, the Sedimentation Group has encountered accuracy issues with the use of the IFSAR data for surface area computations and has recommended the collection of more accurate above water data. For the 2013 study, the favorable surface area comparisons justified the use of the IFSAR data. However, if more accurate aerial data are collected in the future, they should be used for the area and capacity development.

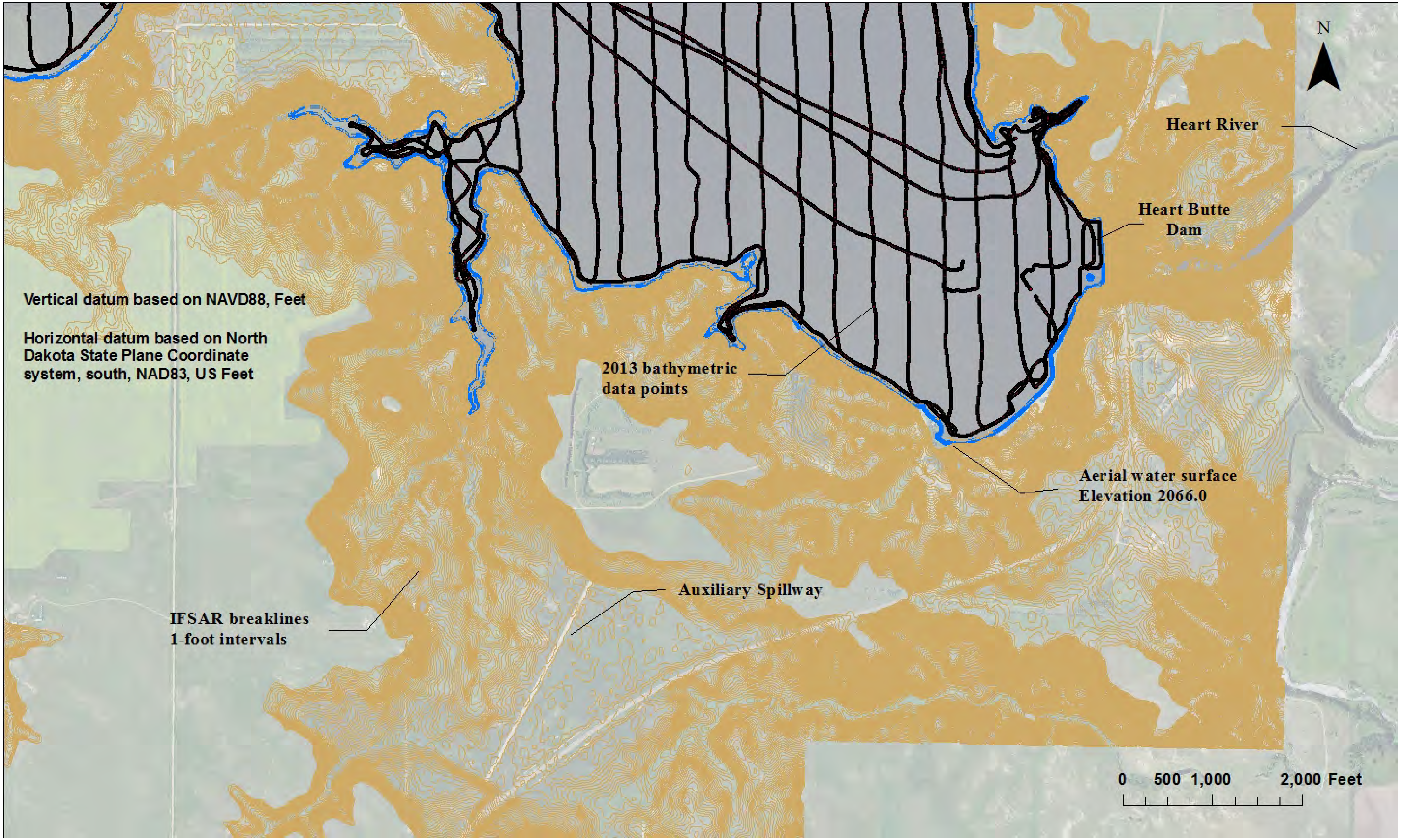

Figure 7 - Lake Tschida, 2013 bathymetric data and imported data coverages, 1 of 5 (NAVD88/GEOID12A).

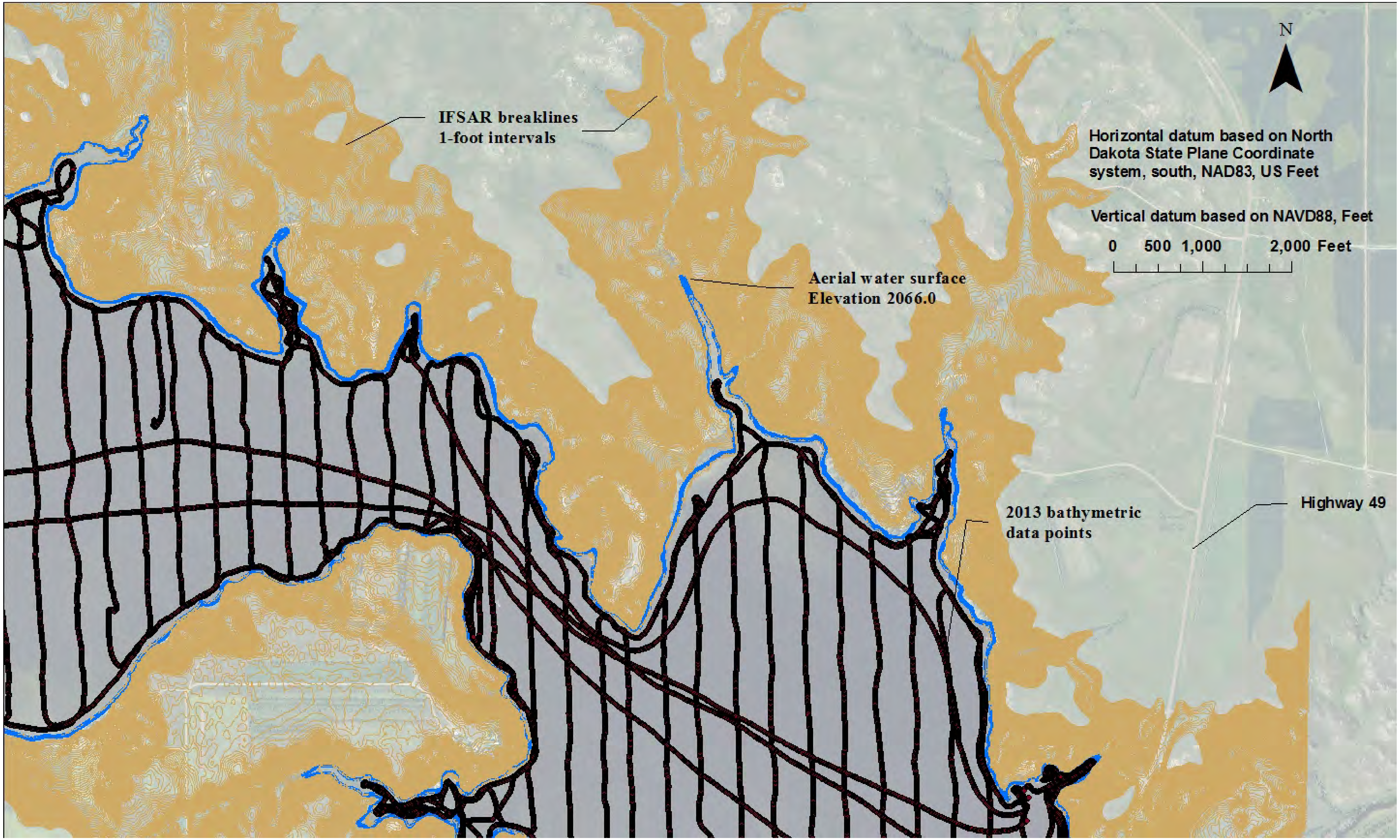

Figure 8 - P Lake Tschida, 2013 bathymetric data and imported data coverages, 2 of 5 (NAVD88/GEOID12A).

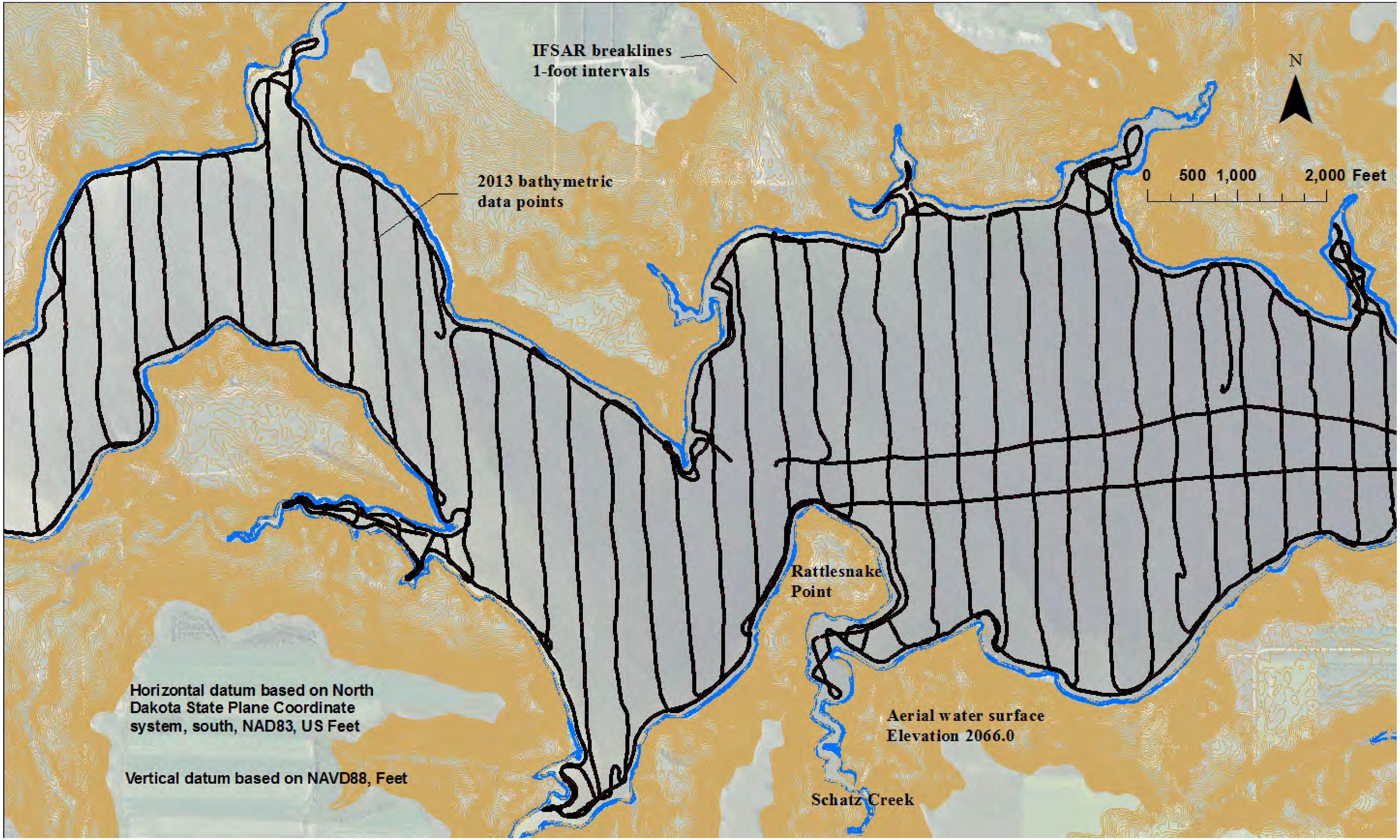

Figure 9 - Lake Tschida, 2013 bathymetric data and imported data coverages, 3 of 5 (NAVD88/GEOID12A).

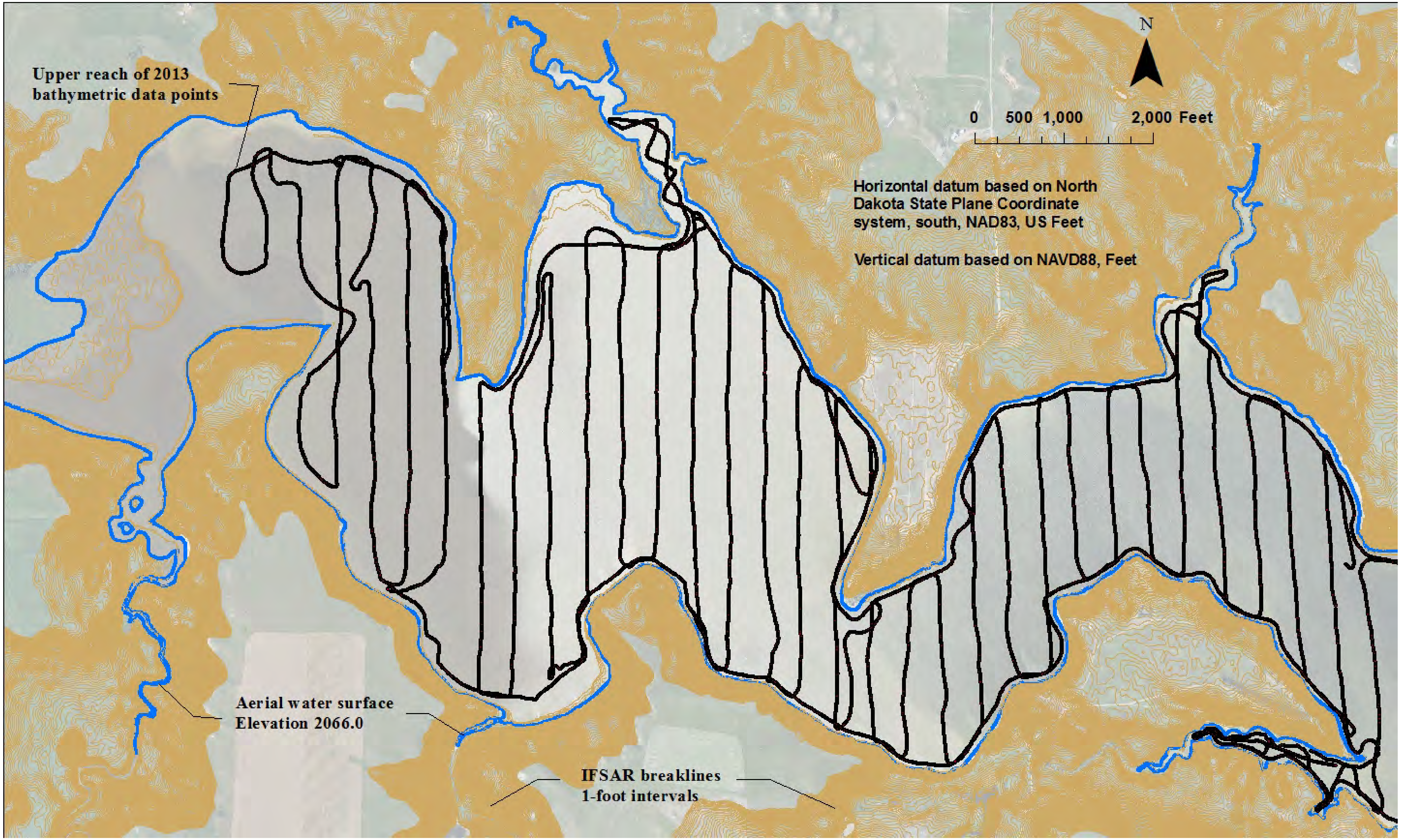

Figure 10 - Lake Tschida, 2013 bathymetric data and imported data coverages, 4 of 5 (NAVD88/GEOID12A).

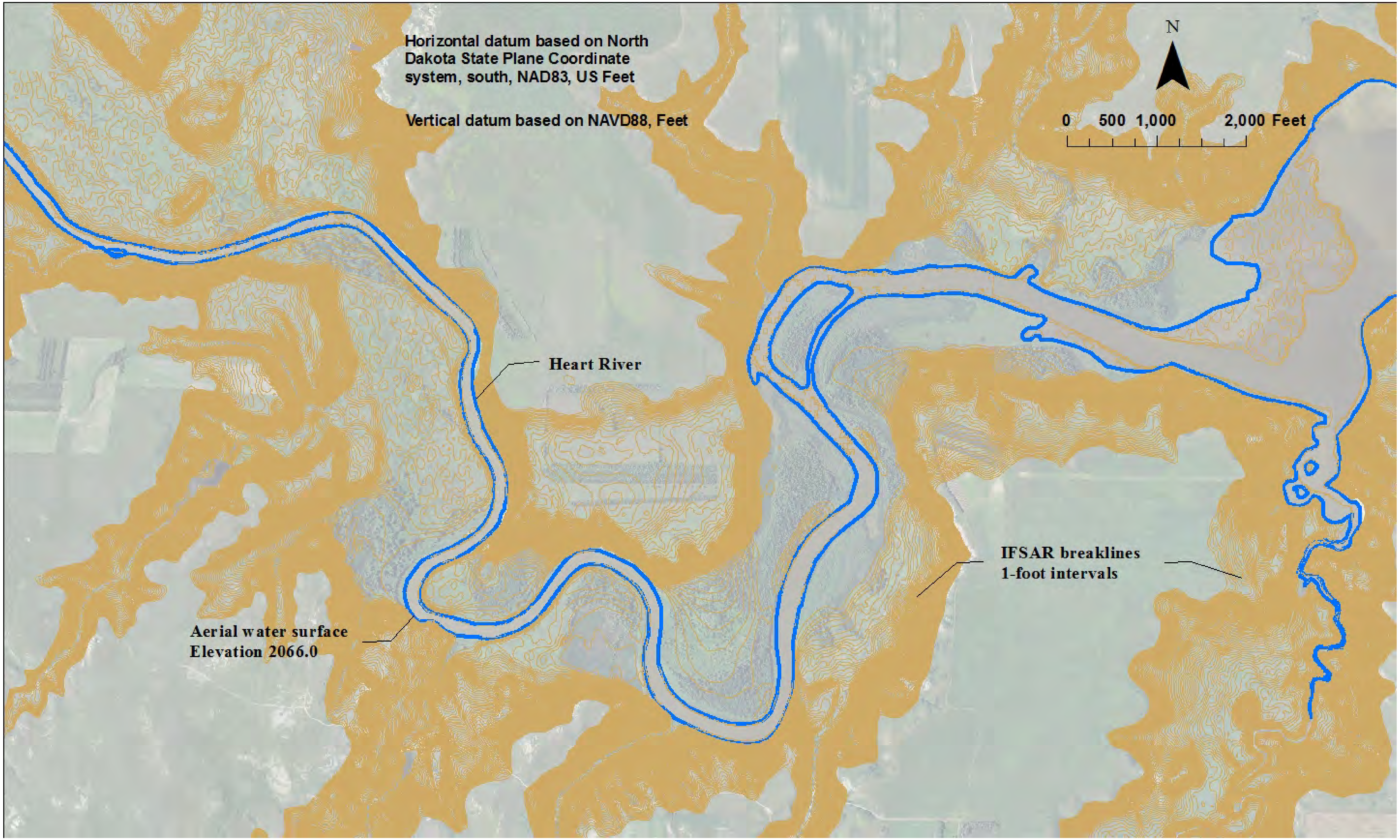

Figure 11 - Lake Tschida, 2013 bathymetric data and imported data coverages, 5 of 5 (NAVD88/GEOID12A).

Reservoir Area and Capacity

Topography Development

The 2013 Lake Tschida topographic contours were generated from several data sources that included the 2013 bathymetric survey, digitized reservoir water's edges from the USDA aerial photographs, and IFSAR data collected in 2007. Digitized breaklines projected from the above data sources were also used in areas of the reservoir not accessible during the boat survey. The breaklines were projected for the roped off area around the morning glory spillway and a few coves and inlets throughout the reservoir.

The data coverages were processed into a triangulated irregular network (TIN) that was used to develop 2-foot contours, surface areas, and volumes referenced to NAVD88 (GEOID12A). In preparation for developing the TIN, a polygon (hardclip) was created to enclose the data sets along the alignment of the dam and uncontrolled auxiliary spillway crest providing a boundary for computing the reservoir surface areas and resulting volumes. Hardclip is an ArcGIS term that represents the polygon that encloses or clips the data used to develop the topography of the study area. This polygon, not assigned an elevation, was used as a hard boundary preventing development of the 2013 TIN and contours outside of the hardclip.

Contours for Lake Tschida were developed from the TIN generated within ArcGIS. A TIN is a set of adjacent non-overlapping triangles computed from irregularly spaced points with x,y coordinates and z elevation values. A TIN is used to interpolate three-dimensional surfaces from point data to produce continuous data such as elevations. ArcGIS uses a method known as Delaunay's criteria for triangulation where triangles are formed among all data points within the polygon clip. The method requires that a circle drawn through the three nodes of a triangle will contain no other point, meaning that all the data points are connected to their nearest neighbors to form triangles, preserving all the data points. The TIN method is described in more detail in the ArcGIS user's documentation (ESRI, 2012).

The linear interpolation option of the ArcGIS *TIN* and *CONTOUR* commands was used to interpolate contours from the Lake Tschida TIN. The surface areas of the enclosed contour polygons at 2-foot increments were computed for elevations 2,010.0 through 2,120.0 (NAVD88). The minimum or zero surface area of the reservoir was elevation 2,008 (project datum or around 2,010 (NAVD88). The reservoir contour topography at 2-foot intervals is presented in Figures 12 through 27 from elevation 2,012.0 through elevation 2,130.0 (NAVD88).

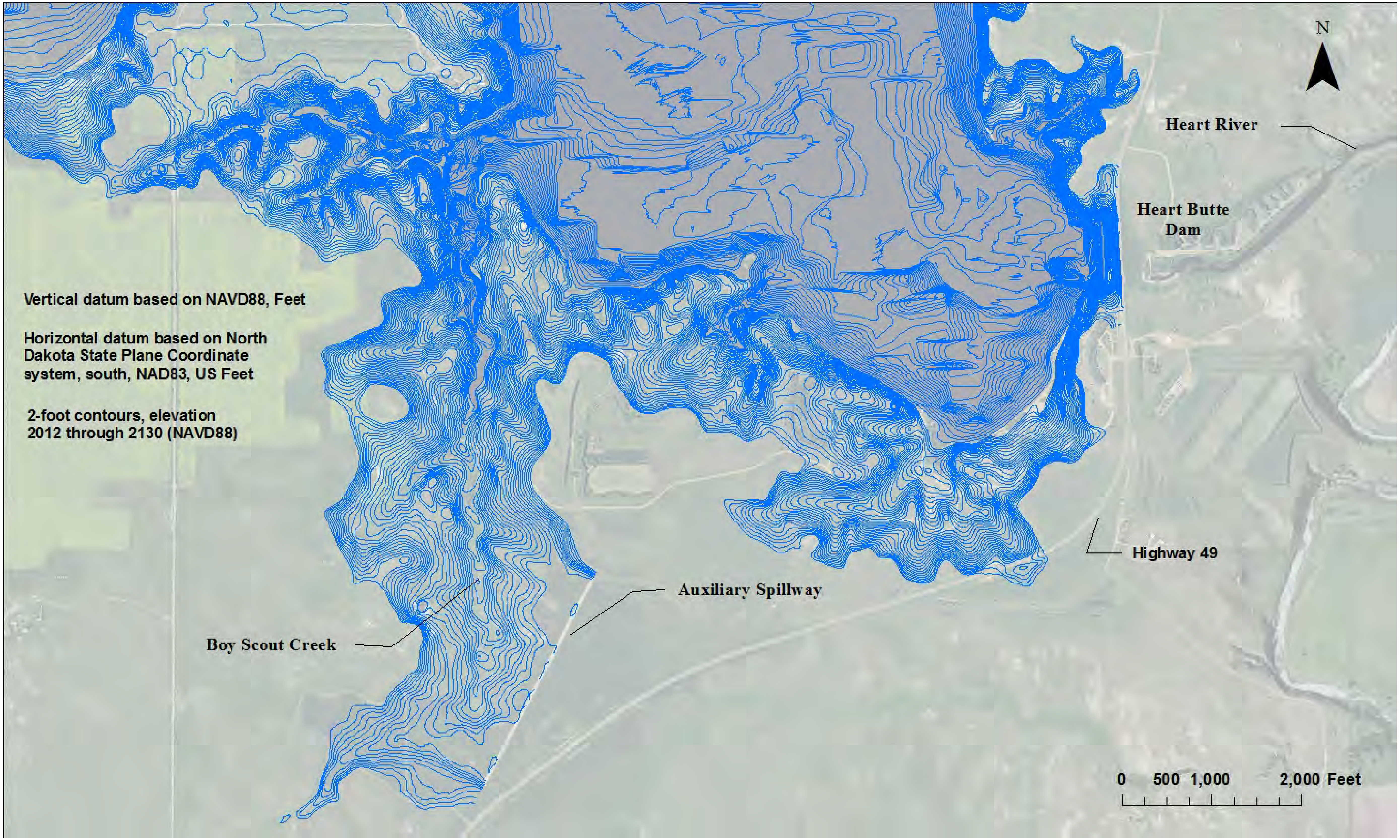

Figure 12 - Lake Tschida developed 2-foot contours from 2013 bathymetric survey and imported data coverages, 1 of 16 (NAVD88/GEOID12A).

Figure 13 - Lake Tschida developed 2-foot contours from 2013 bathymetric survey and imported data coverages, 2 of 16 (NAVD88/GEOID12A).

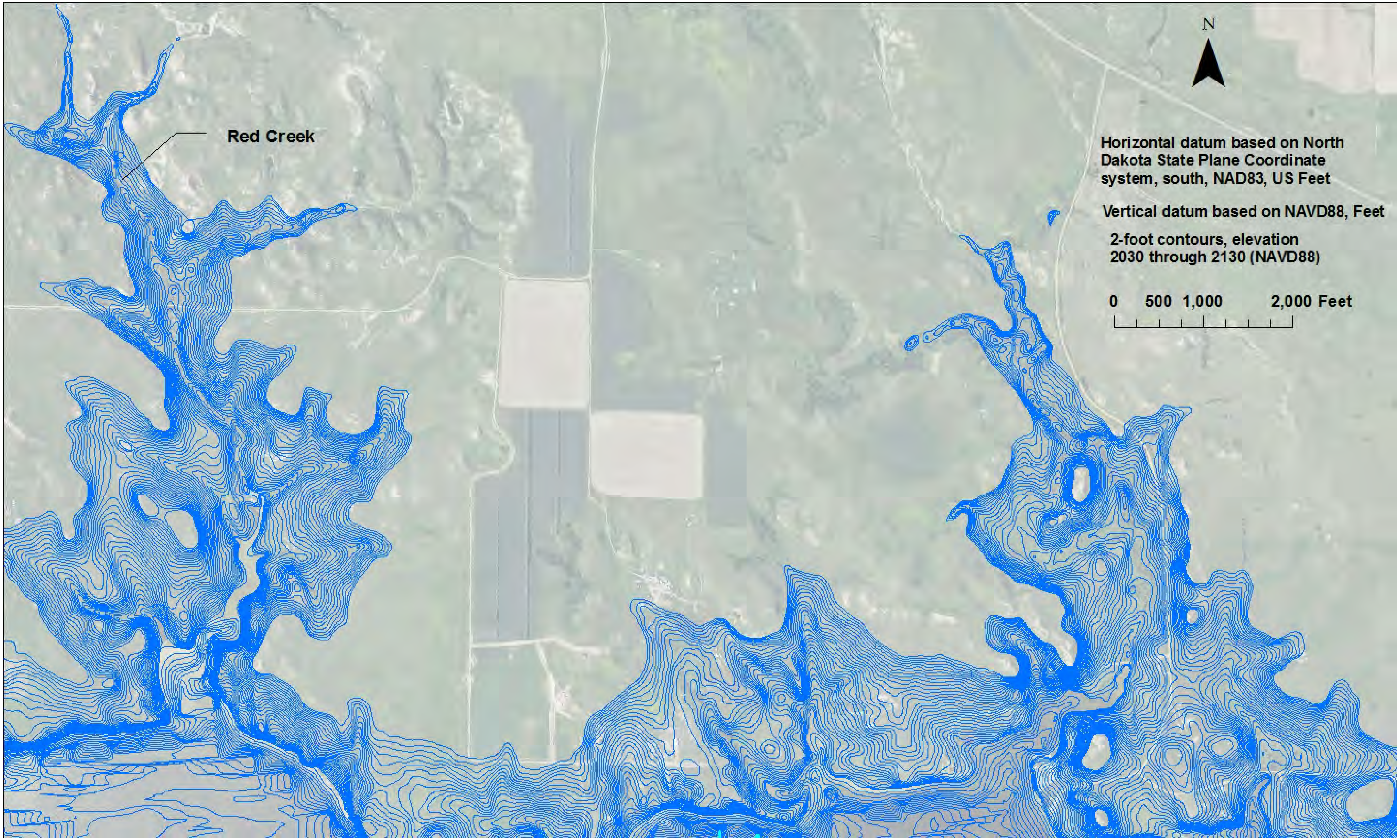

Figure 14 - Lake Tschida developed 2-foot contours from 2013 bathymetric survey and imported data coverages, 3 of 16 (NAVD88/GEOID12A).

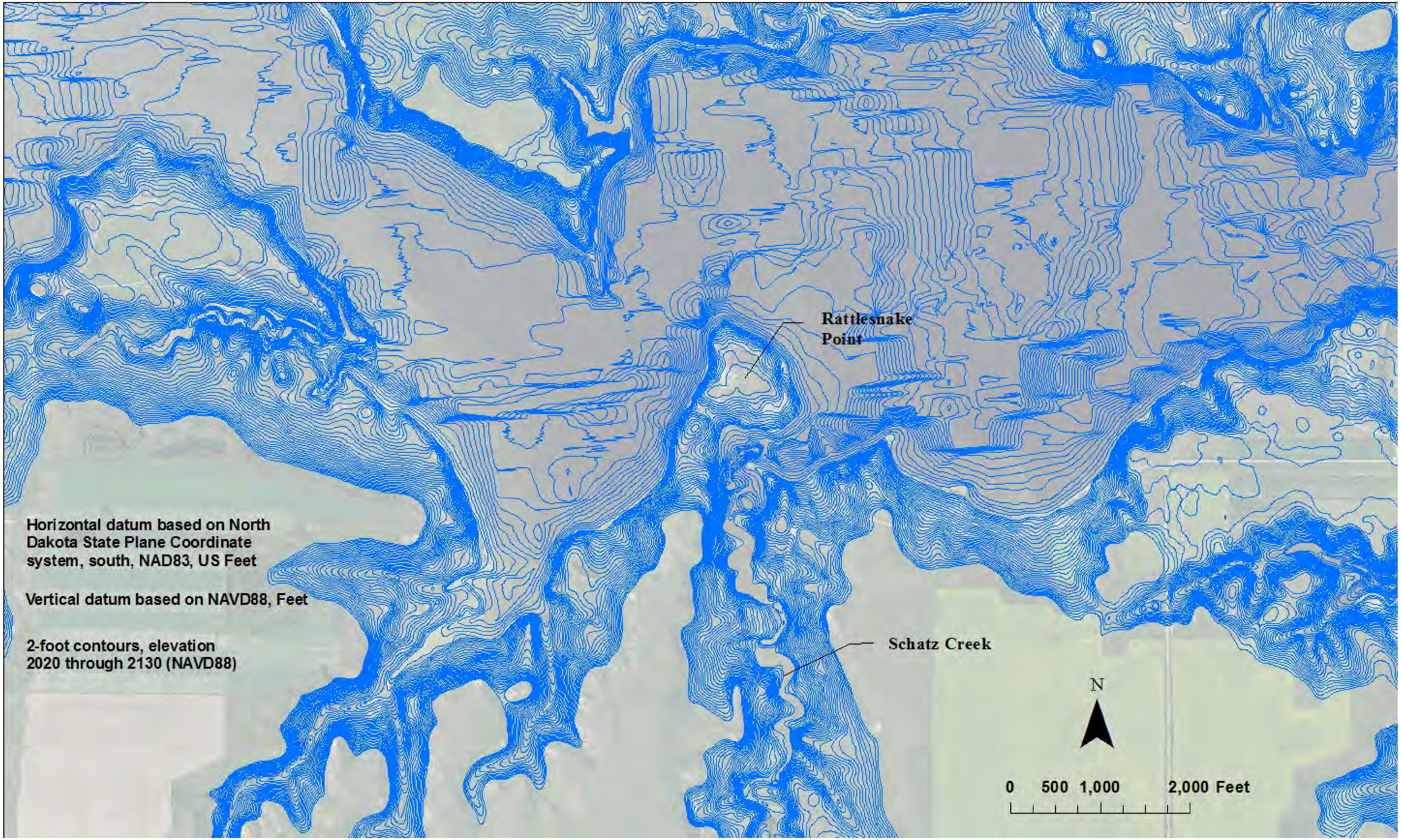

Figure 15 - Lake Tschida developed 2-foot contours from 2013 bathymetric survey and imported data coverages, 4 of 16 (NAVD88/GEOID12A).

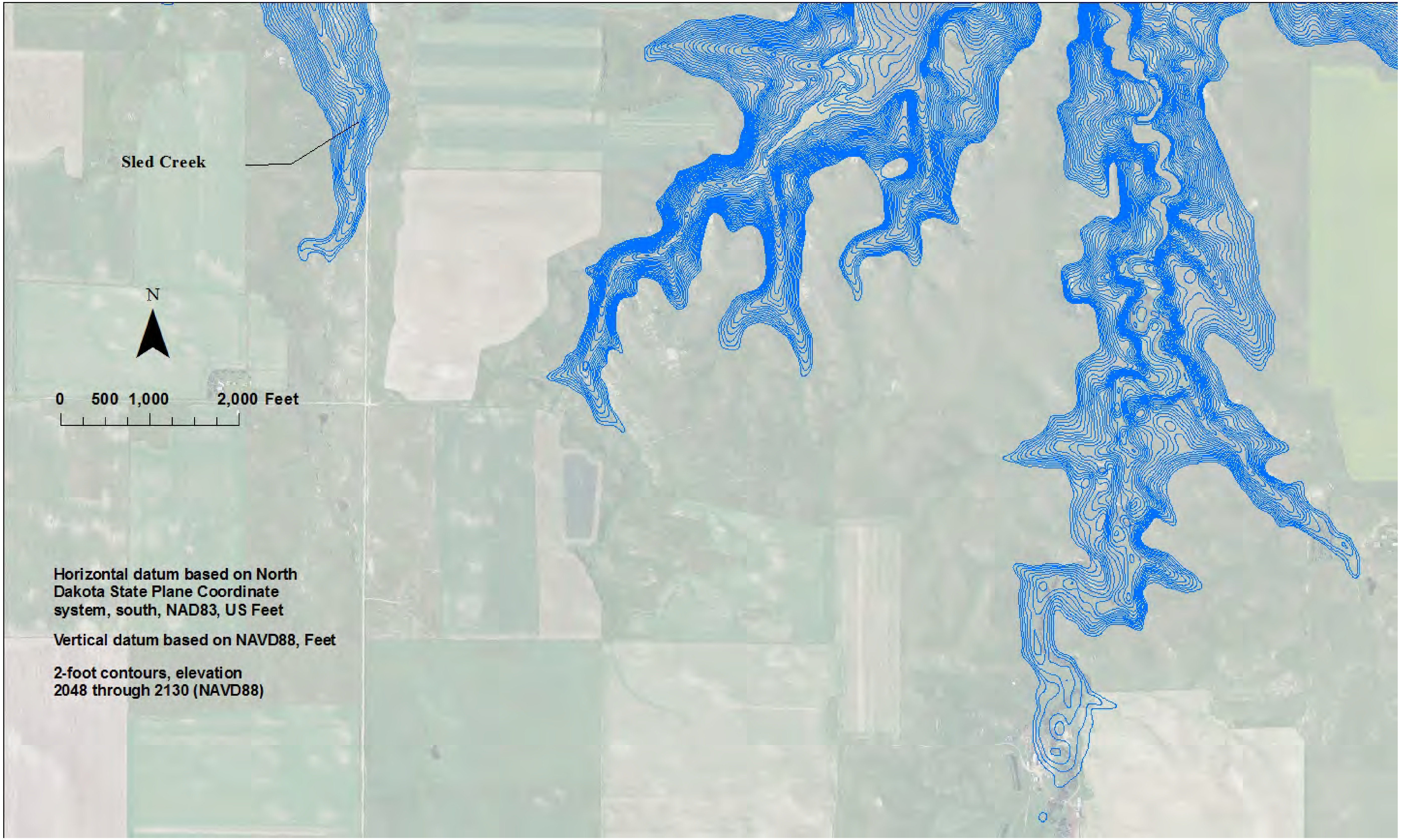

Figure 16 - Lake Tschida developed 2-foot contours from 2013 bathymetric survey and imported data coverages, 5 of 16 (NAVD88/GEOID12A).

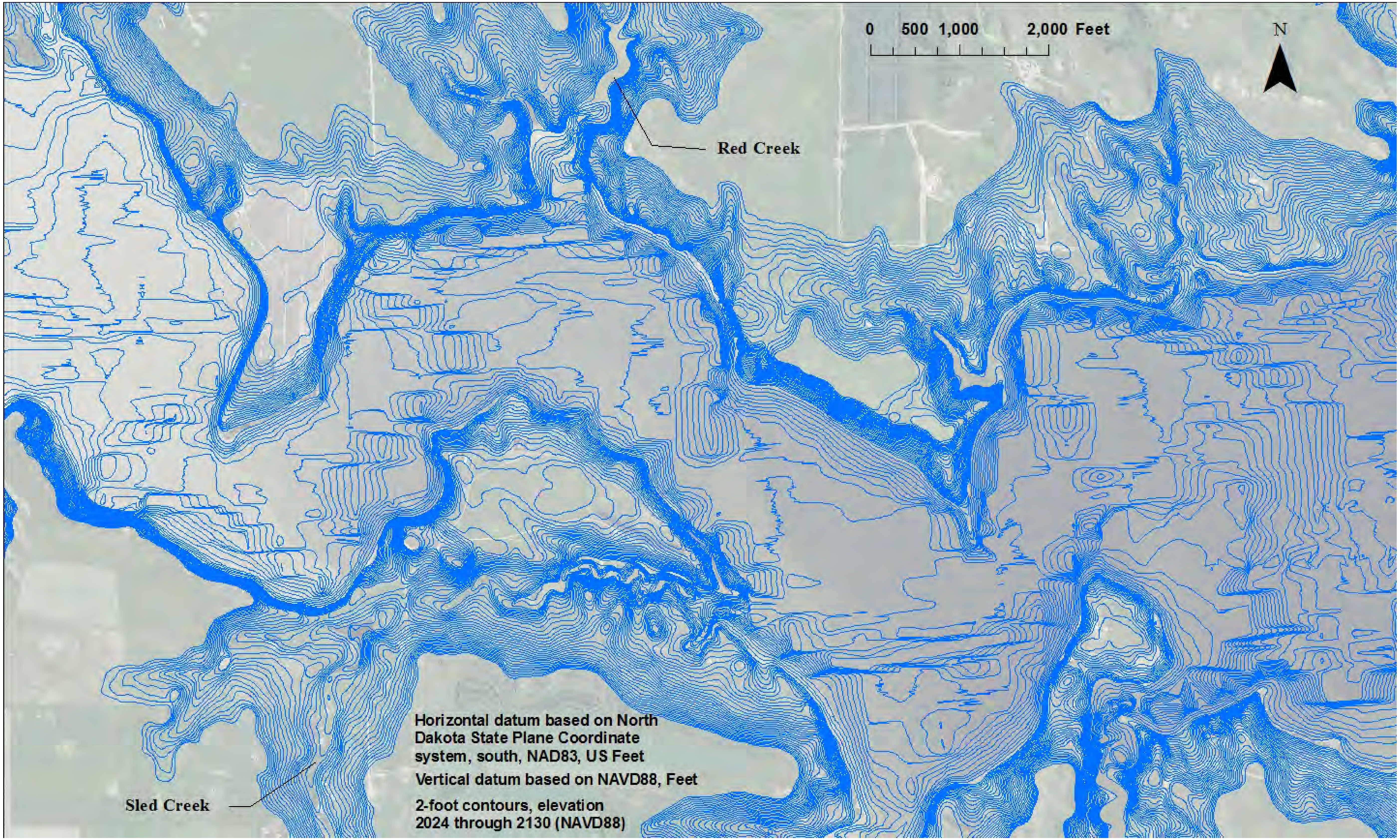

Figure 17 - Lake Tschida developed 2-foot contours from 2013 bathymetric survey and imported data coverages, 6 of 16 (NAVD88/GEOID12A).

Figure 18 - Lake Tschida developed 2-foot contours from 2013 bathymetric survey and imported data coverages, 7 of 16 (NAVD88/GEOID12A).

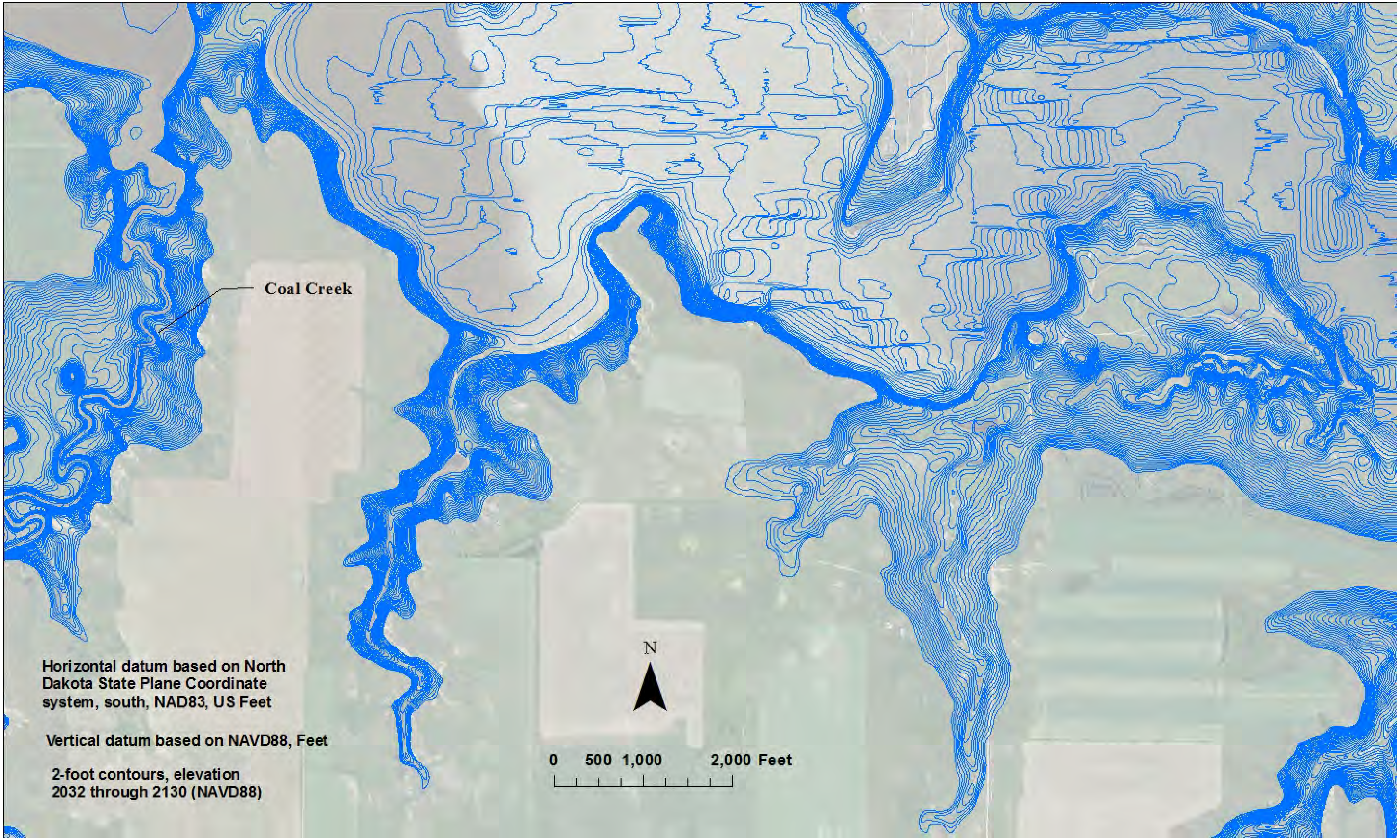

Figure 19 - Lake Tschida developed 2-foot contours from 2013 bathymetric survey and imported data coverages, 8 of 16 (NAVD88/GEOID12A).

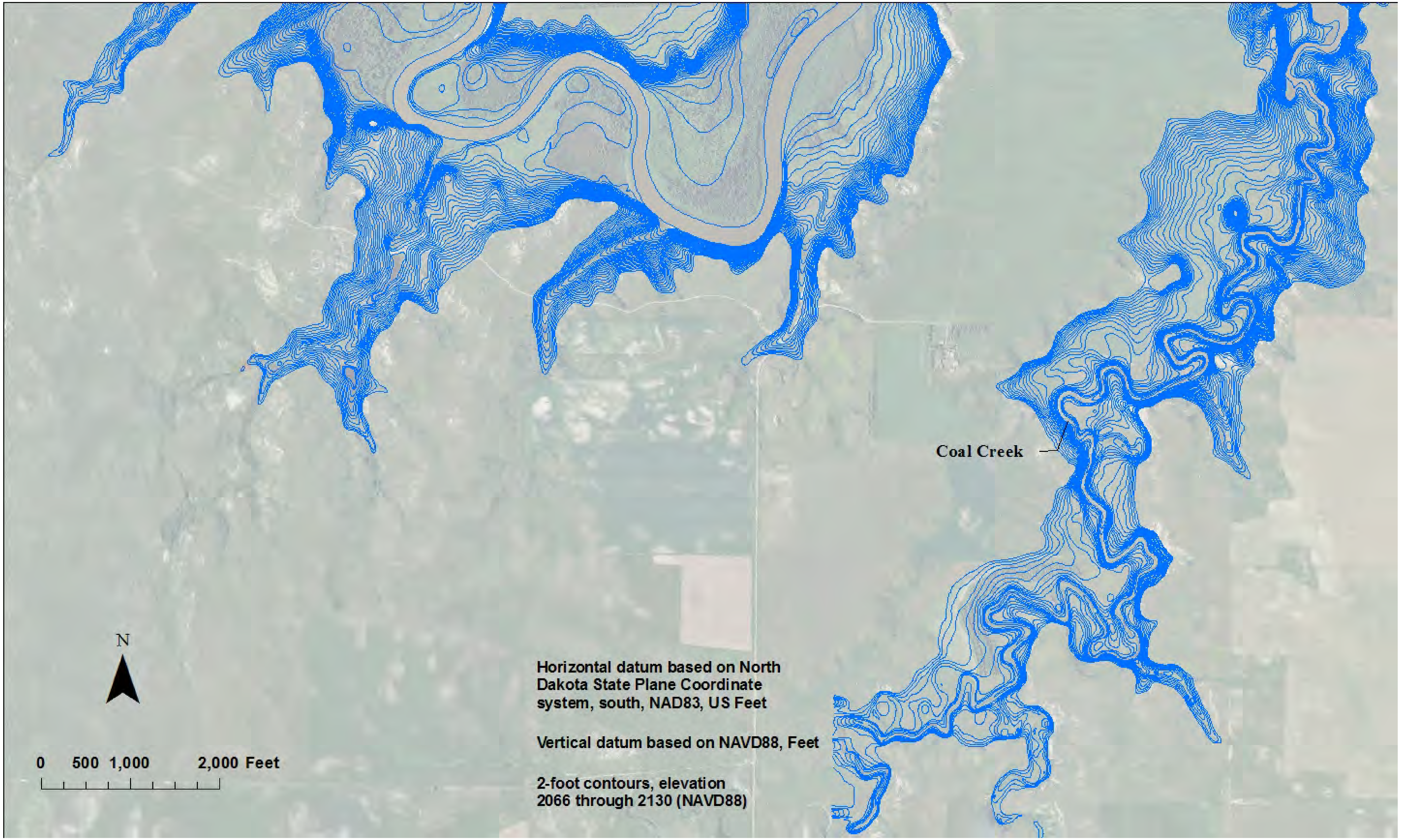

Figure 20 - Lake Tschida developed 2-foot contours from 2013 bathymetric survey and imported data coverages, 9 of 16 (NAVD88/GEOID12A).

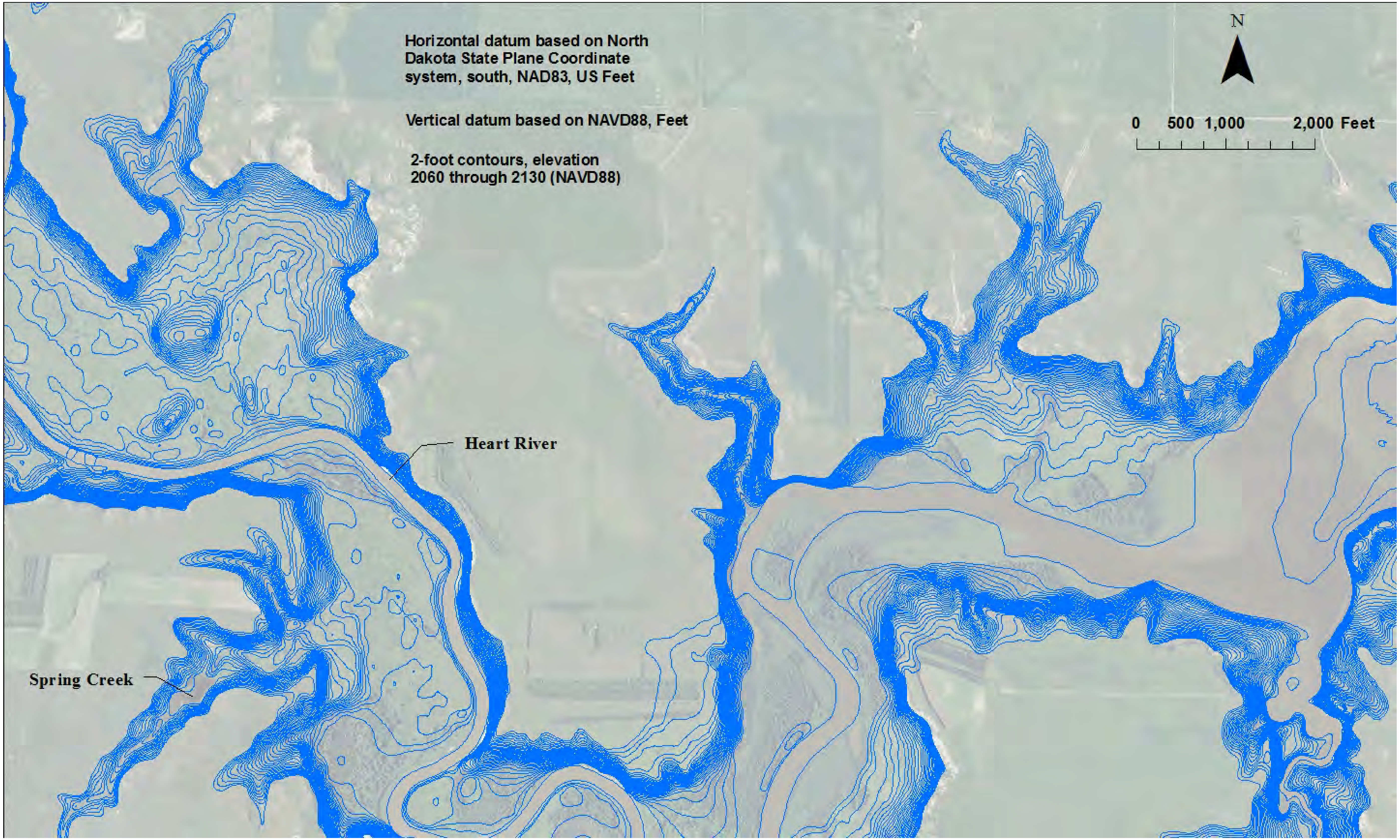

Figure 21 - Lake Tschida developed 2-foot contours from 2013 bathymetric survey and imported data coverages, 10 of 16 (NAVD88/GEOID12A).

Figure 22 - Lake Tschida developed 2-foot contours from 2013 bathymetric survey and imported data coverages, 11 of 16 (NAVD88/GEOID12A).

Figure 23 - Lake Tschida developed 2-foot contours from 2013 bathymetric survey and imported data coverages, 12 of 16 (NAVD88/GEOID12A).

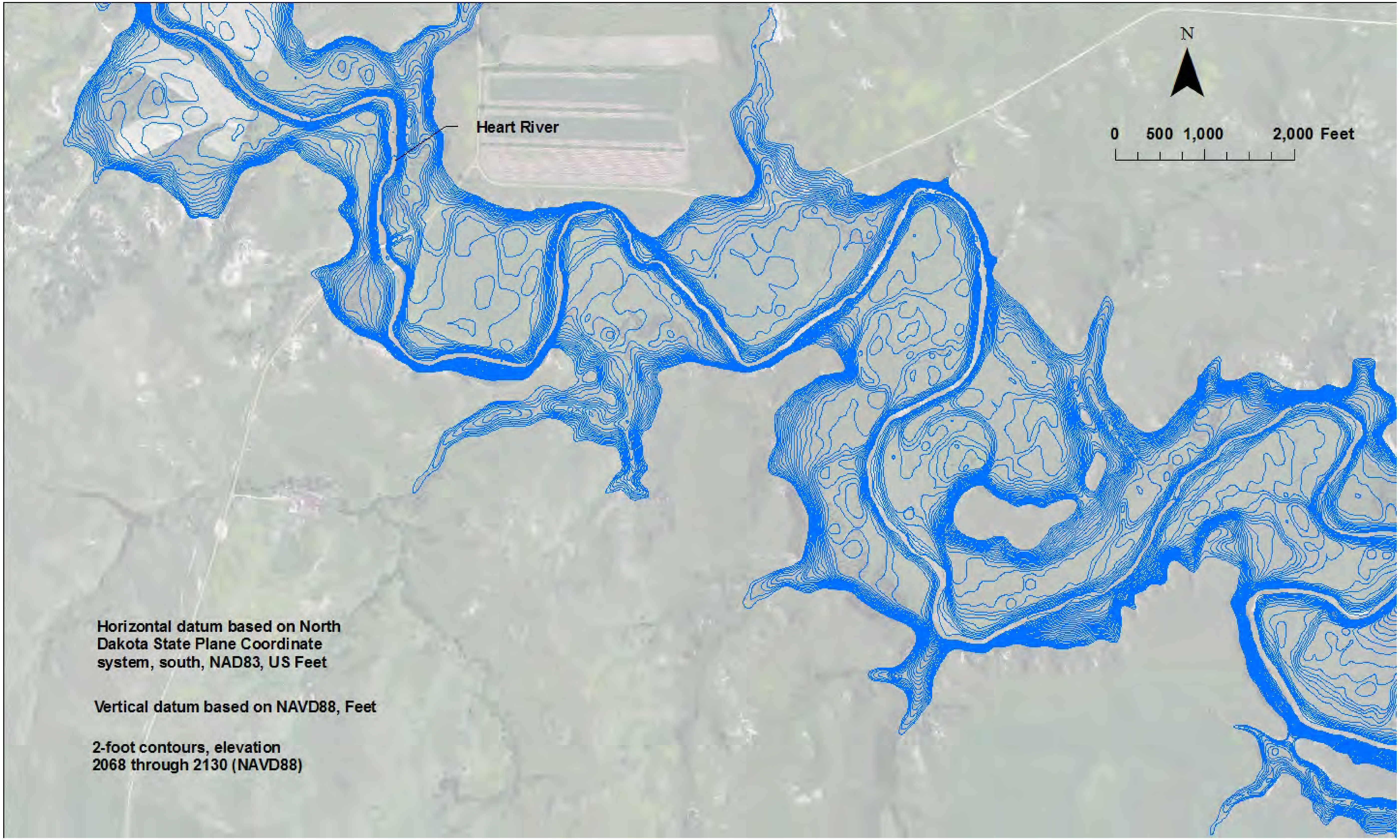

Figure 24 - Lake Tschida developed 2-foot contours from 2013 bathymetric survey and imported data coverages, 13 of16 (NAVD88/GEOID12A).

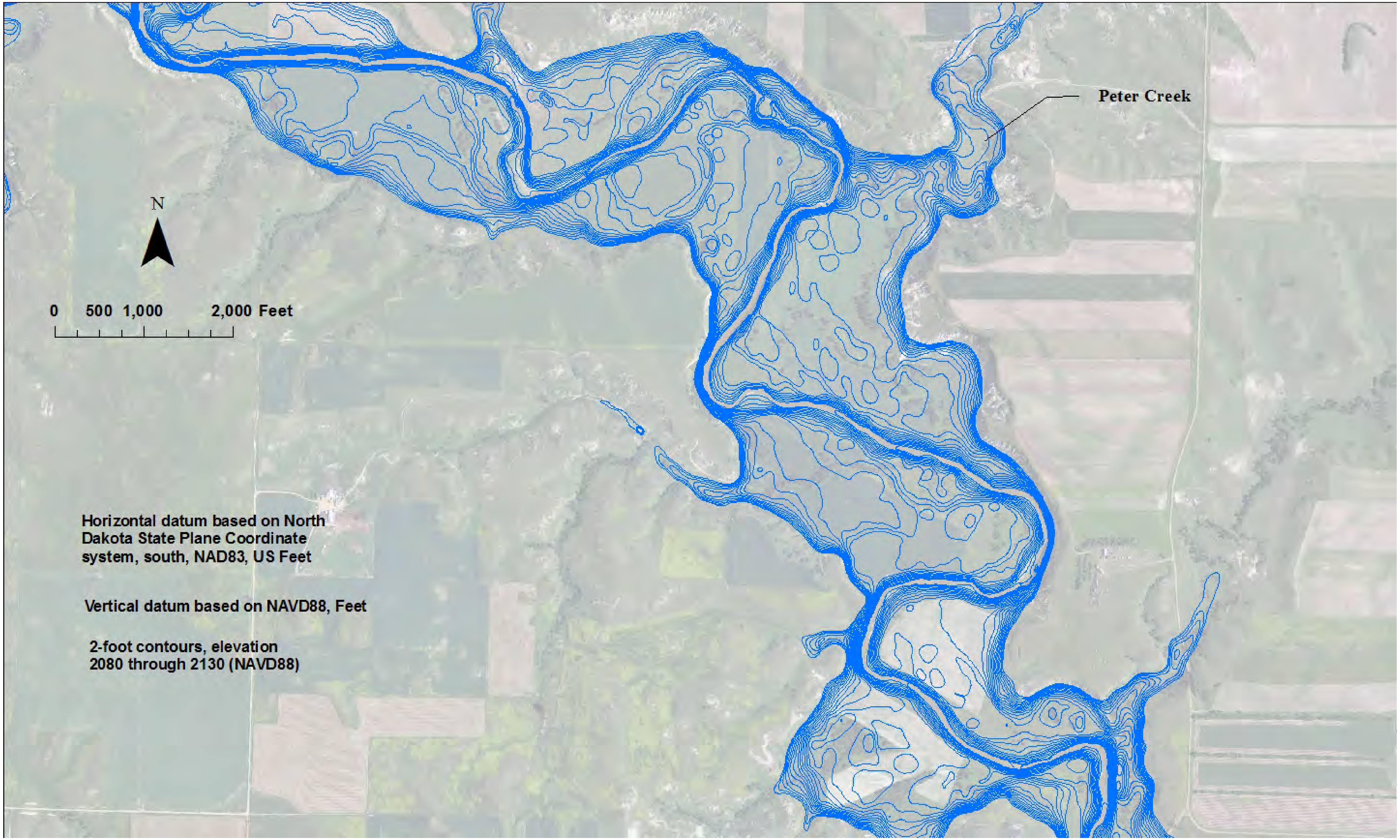

Figure 25 - Lake Tschida developed 2-foot contours from 2013 bathymetric survey and imported data coverages, 14 of 16 (NAVD88/GEOID12A).

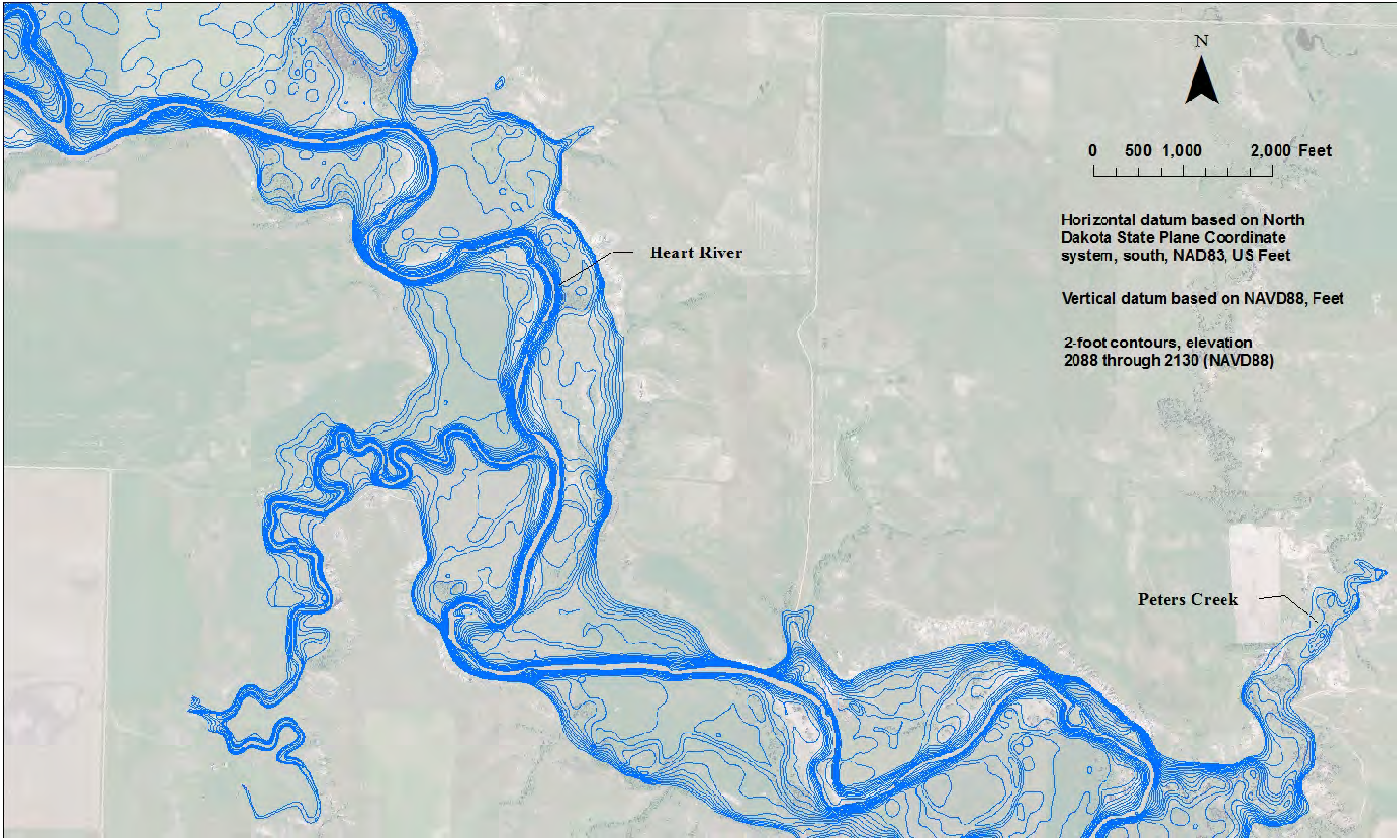

Figure 26 - Lake Tschida developed 2-foot contours from 2013 bathymetric survey and imported data coverages, 15 of 16 (NAVD88/GEOID12A).

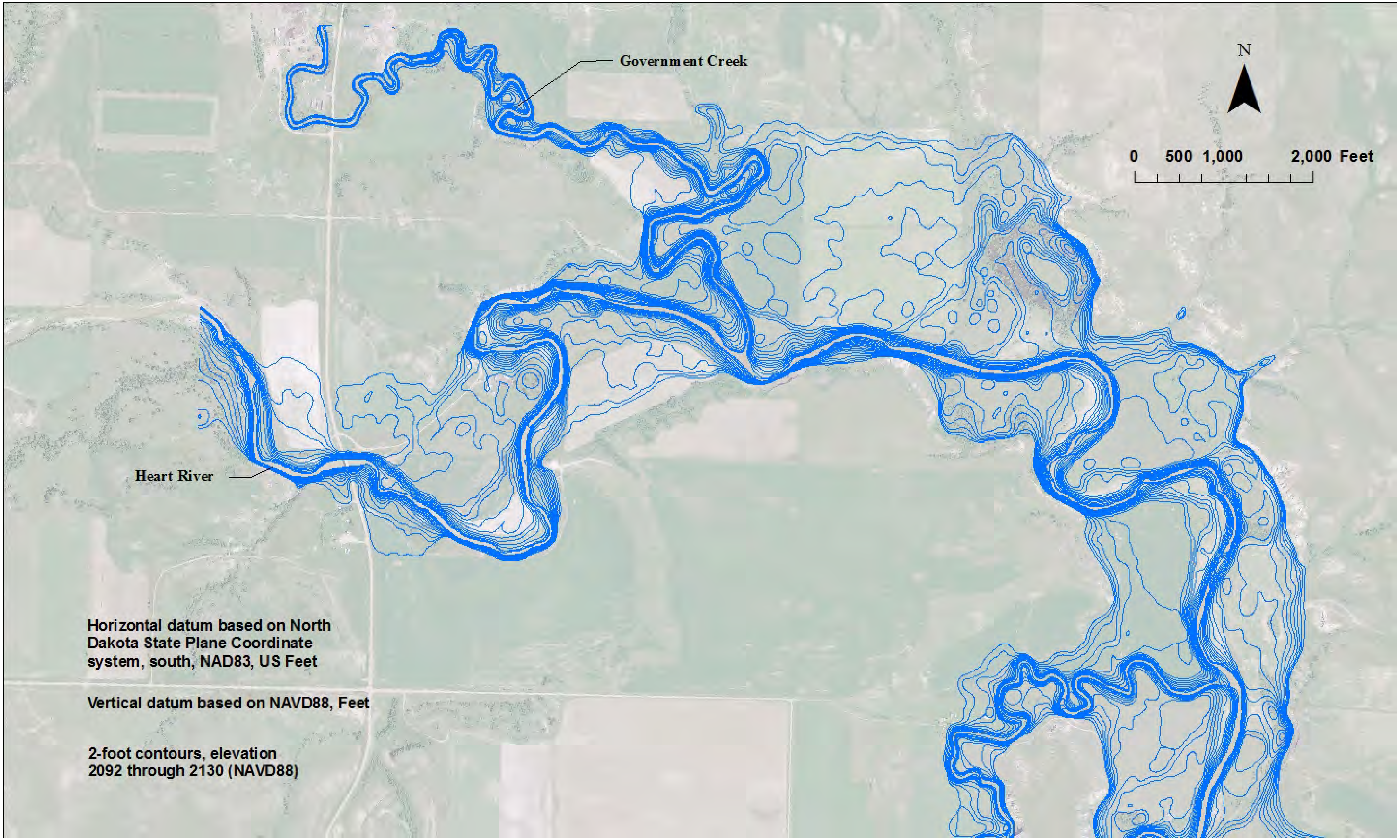

Figure 27 - **Lake Tschida developed 2-foot contours from 2013 bathymetric survey and imported data coverages, 16 of 16 (NAVD88/GEOID12A).**

2013 Lake Tschida Surface Area Methods

Using ArcGIS commands to calculate areas at user-specified elevations, the 2013 surface areas for Lake Tschida were computed at 2-foot increments directly from the reservoir TIN from minimum elevation 2,010.0 through 2,120.0 (NAVD88) to provide input information for the area-capacity table development. The elevations of these computed surface areas were reduced 1.7 feet to match the project vertical datum during construction of the project features and where the water surface gage and operation of Heart Butte Dam are referenced to.

2013 Lake Tschida Storage Capacity Methods

The storage-elevation relationships based on the measured surface areas were developed using the area-capacity computer program ACAP (Bureau of Reclamation, 1985). The ACAP program can compute the area and capacity at elevation increments from 0.01 to 1.0 foot by linear interpolation between the given contour surface areas. For this study the 2-foot computed surface areas from elevation 2,008.0 through 2,120.0 were used. The zero surface area was at elevation 2,008.0. The program begins by testing the initial capacity equation over successive intervals to ensure that the equation fits within an allowable error limit that was set at 0.000001 for Lake Tschida. The capacity equation is then used over the full range of intervals fitting within the allowable error limit. For the first interval at which the initial allowable error limit is exceeded, a new capacity equation (integrated from basic area curve over that interval) is used until it exceeds the error limit. Thus, the capacity curve is defined by a series of curves, each fitting a certain region of data. Through differentiation of the capacity equations, which are second order polynomials, final area equations are derived:

$$y = a_1 + a_2x + a_3x^2$$

where: y = capacity
x = elevation above a reference base
a_1 = intercept
a_2 and a_3 = coefficients

Results of the Lake Tschida area and capacity computations are listed in a separate set of 2013 area and capacity tables and have been published for 0.01, 0.1, and 1-foot elevation increments (Bureau of Reclamation, 2014). A description of the computations and coefficients output from the ACAP program is included with those tables. As of July 2013, at top of reservoir conservation use elevation 2,064.5, the surface area was 3,142 acres with a total capacity of 65,091 acre-feet. At maximum and top of surcharge elevation 2,119.5, the surface area was 11,214 acres with a total capacity of 435,123 acre-feet.

Lake Tschida Surface Area and Capacity Results

Table 1 provides a comparison of Lake Tschida surveys between the time of the dam closure in October 1949, resurvey of 1992, and the July 2013 hydrographic survey. The 2013 survey collected more detailed underwater data than the 1992 range line survey where the measured changes in 2013 result from a combination of sediment deposition and data density differences between the surveys. The area and capacity curves for the original (1949), 1992, and 2013 surveys, plotted in Figure 28 show relatively minimal changes between the 1992 and 2013 surveys except between elevation 2,055 and 2,065. Table 2 provides a comparison of the reservoir survey's computed surface area and capacity values that changed as a result of sediment accumulation and differences in survey methods. As stated previously, the area and capacity values are tied to the project vertical datum that is 1.7 feet lower than NAVD88 (GEOID12A). The 2013 bathymetric survey and the data sources summarized in the *previous* sections provided sufficient information for computing the surface areas from elevation 2,008.0 through 2,120.0. Reclamation's ACAP program was used to compute the area and capacity values from the 2-foot elevation surface areas.

RESERVOIR SEDIMENT
DATA SUMMARY

Lake Tschida (Heart Butte)
NAME OF RESERVOIR

1
DATA SHEET NO.

DAM	1. OWNER: Bureau of Reclamation	2. STREAM: Heart River	3. STATE: North Dakota
	4. SEC 13 TWP. 36 S RANGE 89 W	5. NEAREST P.O. Ellgin	6. COUNTY: Grant
	7. LAT 46 ° 35 ' 48 " LONG 101 ° 48 ' 34 "	8. TOP OF DAM ELEVATION: 2,124.0 [1]	9. SPILLWAY CREST EL. 2,064.5 [2]

RESERVOIR	10. STORAGE ALLOCATION	11. ELEVATION TOP OF POOL	12. Original SURFACE AREA, ACRES	13. Original CAPACITY, AC-FT	14. GROSS STORAGE ACRE-FEET	15 DATE STORAGE BEGAN
	a. SURCHARGE	2,118.20 [3]	10,985	356,346	433,000	10/4/49
	b. FLOOD CONTROL					
	c. POWER					
	d. JOINT USE					16 DATE NORMAL OPERATIONS BEGAN
	e. CONSERVATION	2,064.50	3,423	69,905	76,654	10/4/49
	f. INACTIVE	2,030.00	814	6,749	6,749	
	g. DEAD					
	17. LENGTH OF RESERVOIR 12.9 [4] MILES		AVG. WIDTH OF RESERVOIR 0.4 MILES			

BASIN	18. TOTAL DRAINAGE AREA 1,710 [5] SQUARE MILES		22. MEAN ANNUAL PRECIPITATION 16.2 [6] INCHES
	19. NET SEDIMENT CONTRIBUTING AREA 1,310 [5] SQUARE MILES		23. MEAN ANNUAL RUNOFF 0.94 [7] INCHES
	20. LENGTH 86 MILES	AVG. WIDTH 20 MILES	24. MEAN ANNUAL RUNOFF 86,050 [8] ACRE-FEET
	21. MAX. ELEVATION 3000	MIN. ELEVATION 2,000	25. ANNUAL TEMP, MEAN 43 °F RANGE -37 °F to 107 °F [6]

SURVEY DATA	26. DATE OF SURVEY	27. PER. YRS	28. PER. YRS	29. TYPE OF SURVEY	30. NO. OF RANGES OR INTERVALS	31. SURFACE AREA, AC.	32. CAPACITY ACRE - FEET	33. C/I RATIO AF/AF
	10/1949			Contour (D)	10-ft	3,423	76,044 [3]	0.88
	8/25/1992	42.9	42.9	Range (D)	20	3,290 [9]	67,146 [9]	0.78
	7/2013	21.9	64.8	Contour (D)	2-ft	3,142 [9]	65,091 [9]	0.76

26. DATE OF SURVEY	34. PERIOD ANNUAL PRECIPITATION	35. PERIOD WATER INFLOW, ACRE-FEET a. MEAN ANN.	b. MAX. ANN.	c. TOTAL	36 WATER INFLOW TO DATE, AF a. MEAN ANN.	b. TOTAL
8/1992	16.1	89,294 [10]	306,872	3,830,728	89,294	3,830,728
7/2013		79,694	279,254	1,745,291	86,050	5,576,019

26. DATE OF SURVEY	37. PERIOD CAPACITY LOSS, ACRE-FEET a. TOTAL	b. AVG. ANN.	c. /MI.^{2}-YR.	38. TOTAL SEDIMENT DEPOSITS TO DATE, AF a. TOTAL	b. AVG. ANN.	c. /MI.^{2}-YR.
8/1992	8,898 [11]	207.4	0.160	8,898	207.4	0.160
7/2013	2,055	93.8	0.070	10,953	169.0	0.129

26. DATE OF SURVEY	39. AVG. DRY WT. (#/FT^3)	40. SED. DEP. TONS/MI.^{2}-YR a. PERIOD	b. TOTAL TO DATE	41. STORAGE LOSS, PCT. a. AVG. ANNUAL	b. TOTAL TO DATE	42 SEDIMENT INFLOW, PPM a. PER.	b. TOT.
8/1992				0.270	11.7		
7/2013				0.222	14.4		

43. DEPTH DESIGNATION RANGE IN FEET BELOW AND ABOVE CREST ELEVATION

26. DATE OF SURVEY	-60 to -50	-50 to -40	-40 to -30	-30 to -20	-20 to -10	-10 to 0	0 to 10	10 to 20			
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION										
8/1992	2	6	17	23	23	15	9	5			
7/2013	4.6	11.0	14.3	19.1	23.0	25.6	2.4	0.0			

44. REACH DESIGNATION PERCENT OF TOTAL ORIGINAL LENGTH OF RESERVOIR

26. DATE OF SURVEY	0-10	10-20	20-30	30-40	50-60	60-70	70-80	80-90	90-100	100-105	105-111	110-115	115-120	120-125
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN REACH DESIGNATION													

Table 1 - Reservoir sediment data summary (page 1 of 2).

45. RANGE IN RESERVOIR OPERATION [10]							
YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF	YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF
1950	2,081.7	2,015.1	184,294	1951	2,074.6	2,059.0	111,024
1952	2,086.2	2,059.2	198,882	1953	2,066.5	2,059.8	39,545
1954	2,072.0	2,058.0	84,348	1955	2,065.0	2,058.6	29,660
1956	2,065.1	2,056.7	33,788	1957	2,067.3	2,056.0	52,982
1958	2,066.2	2,058.5	37,330	1959	2,069.3	2,055.8	68,533
1960	2,066.3	2,056.0	51,766	1961	2,061.0	2,053.5	1,962
1962	2,062.6	2,052.5	26,697	1963	2,066.0	2,058.6	37,120
1964	2,069.2	2,058.5	51,138	1965	2,068.0	2,060.4	94,180
1966	2,069.2	2,059.1	111,596	1967	2,068.9	2,058.8	155,152
1968	2,062.2	2,058.2	19,256	1969	2,072.9	2,058.3	169,450
1970	2,082.7	2,058.5	198,831	1971	2,068.7	2,058.3	158,697
1972	2,079.8	2,059.6	251,810	1973	2,069.2	2,057.9	90,359
1974	2,064.3	2,056.9	25,496	1975	2,073.8	2,056.4	175,042
1976	2,065.8	2,058.1	39,466	1977	2,068.0	2,057.4	75,637
1978	2,083.8	2,061.4	245,489	1979	2,069.3	2,060.6	143,948
1980	2,064.1	2,060.1	18,879	1981	2,061.7	2,058.9	18,076
1982	2,073.7	2,061.4	306,872	1983	2,067.8	2,061.8	125,796
1984	2,068.3	2,059.0	78,950	1985	2,064.5	2,058.9	20,207
1986	2,073.2	2,058.9	146,623	1987	2,069.8	2,059.8	111,463
1988	2,062.1	2,055.1	7,120	1989	2,061.7	2,055.0	15,903
1990	2,056.6	2,051.7	6,838	1991	2,055.1	2,049.2	4,009
1992	2,052.0	2,049.0	6,514	1993	2,065.3	2,049.2	45,024
1994	2,066.6	2,062.2	42,634	1995	2,067.4	2,062.3	78,496
1996	2,067.3	2,061.2	76,238	1997	2,082.2	2,061.5	231,148
1998	2,067.3	2,061.8	58,323	1999	2,069.0	2,062.4	131,410
2000	2,064.0	2,060.9	13,753	2001	2,066.3	2,062.6	119,849
2002	2,063.9	2,059.6	19,838	2003	2,070.3	2,059.6	64,612
2004	2,068.8	2,060.6	68,530	2005	2,066.5	2,061.0	35,526
2006	2,065.2	2,058.2	12,869	2007	2,062.7	2,058.5	11,179
2008	2,060.5	2,055.8	857	2009	2,082.7	2,055.7	273,689
2010	2,068.9	2,061.5	82,753	2011	2,073.0	2,062.3	279,254
2012	2,064.9	2,061.3	19,334	2013	2,070.0	2,061.3	79,975

46. ELEVATION - AREA - CAPACITY - DATA								
ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
2013	**SURVEY** [12]							
2,008.0	0	0	2,010.0	1	1	2,015.0	43	84
2,020.0	157	579	2,025.0	354	1,740	2,030.0	659	4,328
2,035.0	912	8,267	2,040.0	1,175	13,492	2,045.0	1,505	20,178
2,050.0	1,893	28,638	2,055.0	2,321	39,185	2,060.0	2,759	51,918
2,064.5	3,142	65,091	2,065.0	3,284	66,697	2,070.0	3,915	85,186
2,075.0	4,348	105,788	2,080.0	4,895	128,845	2,085.0	5,480	154,795
2,090.0	6,113	183,756	2,094.5	6,740	212,696	2,095.0	6,812	216,084
2,100.0	7,599	252,029	2,105.0	8,480	292,202	2,109.0	9,262	327,669
2,110.0	9,460	337,030	2,115.0	10,359	386,594	2,119.5	11,214	435,123
2,120.0	11,307	440,754						

47. REMARKS AND REFERENCES

[1] All elevations are in feet tied to current water surface vertical datum that is 1.7 feet less than NAVD88.
Design crest elevation 2,124.0. Road over crest varies the elevation.

[2] Morning-glory spillway crest elevation 2,064.5. Auxiliary spillway crest elevation 2,109.0.

[3] Original values recomputed using ACAP. 1992 study max elev. 2,118.2, 2013 study surcharge maximum elevation listed at 2,119.5.

[4] Length of reservoir from 1993 study.

[5] From 1992 survey report. Net sediment drainage area removes drainage above E.A. Patterson Reservoir near Dickinson, North Dakota.

[6] Bureau of Reclamation Project Data Book, 1981.

[7] Computed from mean annual value of 86,050 acre-feet.

[8] Values computed by Reclamation GP Region.

[9] Surface area and capacity at conservation elevation 2,064.5. .

[10] Maximum & minimum elevations. From available USBR regional records by water year. Elevations tied to operation gage vertical datum.

[11] Total sediment inflow by comparing survey values with recomputed capacity from previous surveys.

[12] Capacity computed by Reclamation's ACAP computer program tied to the gage vertical datum that is 1.7 feet less than NAVD88 (GEOID12A).
2013 reservoir topography at 2-foot interval used to develop these 2013 tables. Values from 0.1 foot increment tables.

48. AGENCY MAKING SURVEY Bureau of Reclamation
49. AGENCY SUPPLYING DATA Bureau of Reclamation DATE March 2014

Table 1 - Reservoir sediment data summary (page 2 of 2).

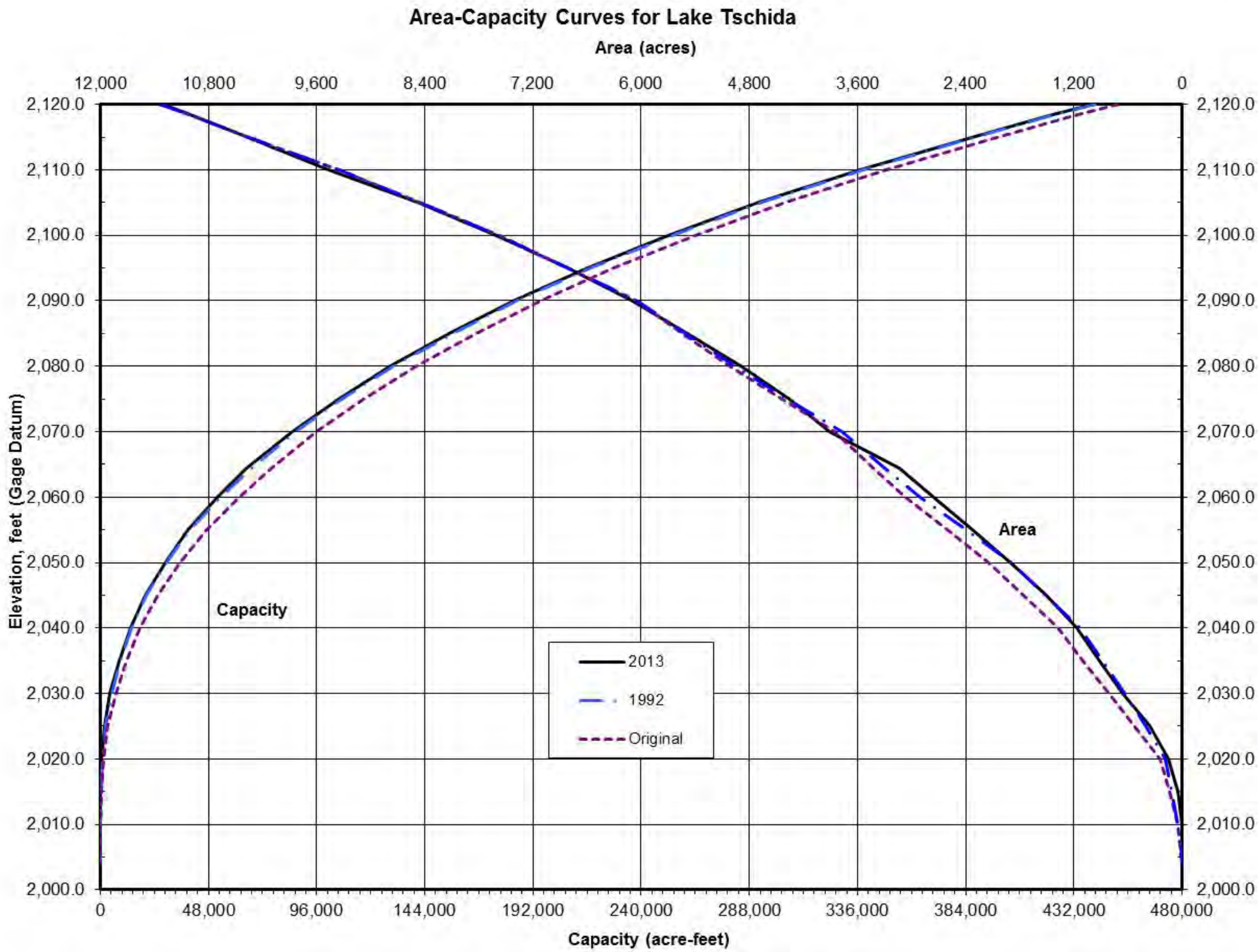

Figure 28 - Area and Capacity Curves, Lake Tschida.

1	2	3	4	5	6	7	8	9	10	11
Elevation Feet	Original Area Acres	Original Capacity Ac-Ft	1992 Area Acres	1992 Capacity Ac-Ft	1992 Sediment Volume Ac-Ft	2013 Area Acres	2013 Capacity Ac-Ft	2013 Sediment Volume Ac-Ft	Percent Reservoir Sediment	Percent Reservoir Depth
2,120.0	11,344	451,972	11,344	441,619	10,353	11,307	440,754	11,218	100.0	100.0
2,118.2	10,985	431,874	10,985	421,521	10,353	10,969	420,705	11,169	99.6	98.4
2,115.0	10,346	397,747	10,346	387,394	10,353	10,359	386,594	11,153	99.4	95.7
2,110.0	9,348	348,512	9,348	338,159	10,353	9,460	337,030	11,482	102.4	91.4
2,105.0	8,458	303,999	8,462	293,633	10,366	8,480	292,202	11,797	105.2	87.1
2,100.0	7,566	263,942	7,577	253,535	10,407	7,599	252,029	11,913	106.2	82.8
2,095.0	6,812	227,996	6,814	217,558	10,438	6,812	216,084	11,912	106.2	78.4
2,090.0	6,059	195,817	6,051	185,395	10,422	6,113	183,756	12,061	107.5	74.1
2,085.0	5,538	166,823	5,509	156,493	10,330	5,480	154,795	12,028	107.2	69.8
2,080.0	5,018	140,432	4,968	130,300	10,132	4,895	128,845	11,587	103.3	65.5
2,075.0	4,437	116,794	4,371	106,955	9,839	4,348	105,788	11,006	98.1	61.2
2,070.0	3,856	96,062	3,774	86,594	9,468	3,915	85,186	10,876	97.0	56.9
2,064.5	3,423	76,044	3,299	67,146	8,898	3,142	65,091	10,953	97.6	52.2
2,060.0	3,069	61,437	2,910	53,175	8,262	2,759	51,918	9,520	84.9	48.3
2,055.0	2,602	47,258	2,400	39,899	7,359	2,321	39,185	8,073	72.0	44.0
2,050.0	2,136	35,412	1,890	29,173	6,239	1,893	28,638	6,774	60.4	39.7
2,045.0	1,759	25,674	1,511	20,670	5,004	1,505	20,178	5,496	49.0	35.3
2,040.0	1,382	17,822	1,133	14,059	3,763	1,175	13,492	4,330	38.6	31.0
2,035.0	1,098	11,622	883	9,019	2,603	912	8,267	3,355	29.9	26.7
2,030.0	814	6,842	634	5,225	1,617	659	4,328	2,514	22.4	22.4
2,025.0	528	3,487	408	2,622	865	354	1,740	1,747	15.6	18.1
2,020.0	242	1,562	181	1,149	413	157	579	983	8.8	13.8
2,015.0	143	599	113	414	185	43	84	515	4.6	9.5
2,010.0	44	132	44	22	110	1	1	131	1.2	5.2
2,005.0	7	4	0	0	4	0	0	4	0.0	0.9
2,004.0	0	0	0	0	0	0	0	0	0.0	0.0

1 Reservoir water surface elevation tied to water surface gage vertical datum, 1.7 feet less than NAVD88.
2 Original reservoir surface area.
3 Original reservoir capacity recomputed using ACAP from original measured surface areas.
4 1992 reservoir surface areas computed from a 1992 range line survey.
5 1992 reservoir capacity computed using ACAP.
6 1992 computed sediment volume, column (3) - column (5).
7 2013 reservoir surface area computed from a 2013 topographic mapping survey.
8 2013 reservoir capacity computed using ACAP.
9 2013 computed sediment volume, column (3) - column (9).
10 2013 percent of total sediment, 11,218 acre-feet, by indicated elevation zone.
11 Depth of reservoir expressed in percentage of total depth of 116.0 feet.

Table 2 - Summary of 2013 survey results.

Longitudinal Distribution

To illustrate the bottom topography along the length of the reservoir, the Heart River thalweg was plotted from just upstream of the dam to elevation 2,070.0 in the upper reach of the reservoir, Figure 29. The distances upstream of the dam and thalweg elevations for the 1949 and 1992 longitudinal profiles were scaled from the thalweg profile plot in the 1992 survey report that showed the thalweg elevations at the sediment range locations for both surveys. The minimum elevations for the 2013 plot, shifted downward 1.7 feet to match the project vertical datum, were determined by projecting the sediment range lines onto the 2013 developed contours. The location of the sediment range lines were projected from maps within the 1992 report that were of poor quality and may not be exact. Regardless of data limitations, the profiles show the sediment accumulation that has occurred along the river thalweg since the original and 1992 surveys. The inlet sill of the outlet works at elevation 2,030.0 and measured top of sediment deposition at the dam, elevation 2,016, are also plotted. The plots showed only a small accumulation of sediment since 1992, starting at the lower elevations near the dam upstream through the main reservoir body. The current downstream toe of the sediment delta is shown in the upper reservoir around elevation 2,045, about 5.2 miles upstream of the dam. The pivot point or top of the current delta is near elevation 2,062 and about 6.6 miles upstream of the dam. The upper limits of the 2013 bathymetric data were near elevation 2,062. From elevation 2,062 upstream to elevation 2,070, the 2013 thalweg plot was extrapolated.

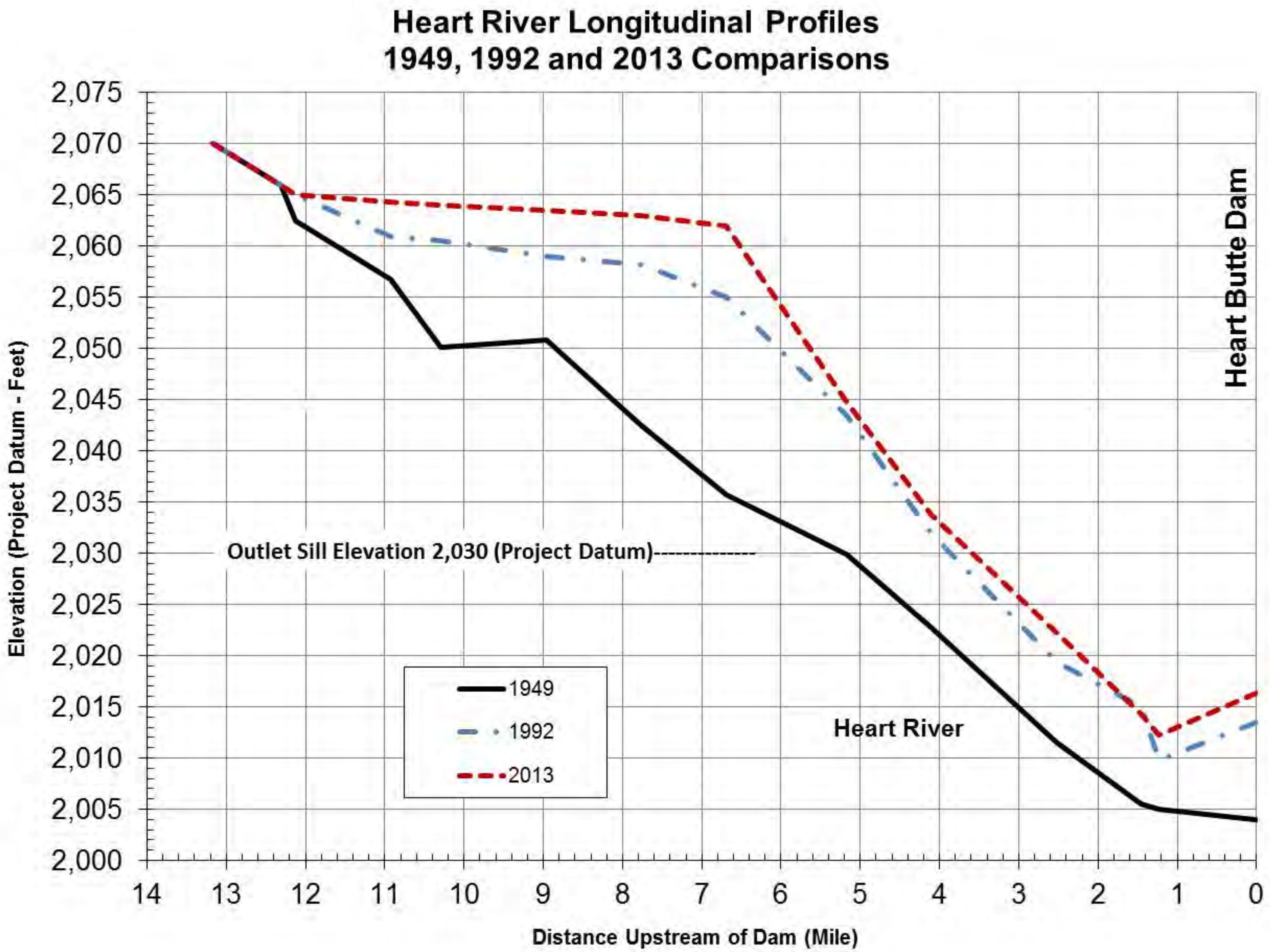

Figure 29 - Longitudinal profile of Heart River above Heart Butte Dam.

2013 Lake Tschida Analysis

Results of the 2013 Lake Tschida area and capacity computations are listed in Table 1 and Table 2. The original surface areas were measured from 10-foot contours of the reservoir area that were collected before dam closure in 1949. The 1992 study was a survey of 20 range lines that was used to compute changes in the surface areas and capacity since the original 1949 survey. The 2013 survey resulted in detailed topography of Lake Tschida from which elevation versus surface area and volume relationships were computed. The 2013 bathymetry was conducted near water surface elevation 2,064, near top of reservoir conservation elevation 2,064.5. The contour of the conservation elevation was represented by aerial photography obtained from the USDA. The reservoir topography above the conservation elevation was developed from IFSAR data collected in 2007.

The 2013 data sets allowed mapping of the reservoir topography from the dam, minimum elevation 2,010.3 (NAVD88), to above the top of surcharge elevation extended to 2,130.0 (NAVD88) using the IFSAR data set. The best means to measure reservoir topography above the collected bathymetric data would have been to obtain additional data using methods such as aerial LiDAR to overlap with the 2013 bathymetric survey. However, the data sets used for this analysis represented the best available estimate of reservoir conditions as of July 2013.

The 2013 Lake Tschida topography was developed with the elevations tied to NAVD88 (GEOID12A). The reservoir surface area, capacity, and sediment accumulation results are tied to the project vertical datum used for operation of the reservoir. This study determined the project vertical datum was 0.2 feet lower than NGVD29 and around 1.7 feet lower than NAVD88 (GEOID12A). The tables within this report list the area and capacity results for the 2013 survey, in project vertical datum, and compare the 2013 results to the original and 1992 surface area and capacity values. The tables list elevation 2,118.2 as the maximum reservoir level as used for the 1992 study. Current information list the maximum operation level as elevation 2,119.5 (Bureau of Reclamation, August 2003). The area and capacity tables were extended to elevation 2,120.0 to include the entire surcharge zone. Operation records list the reservoir's maximum water surface reached to date as elevation 2,086.2 in 1952, meaning the reservoir extended into the flood zone, but has never entered into the surcharge zone which starts at elevation 2,094.5.

The surface area and volume differences on Table 1 are referenced to conservation elevation 2,064.5 where the 2013 study measured a total decrease in capacity of 10,953 acre-feet since dam closure in 1949. The capacity change is due to sediment deposition and methodology differences between the surveys. The computed average annual loss since dam closure was 169.0 acre-feet. The study found that after the first 64.8 years of reservoir operations 14.4 percent of the conservation volume has been lost due to sediment deposition. The thalweg elevation at range line 1 just upstream of the dam is 2,016.5 or 13.5 feet below the outlet sill elevation of 2,030.0. The 2013 survey determined that currently there is not a sediment issue affecting the intake of the outlet works.

Summary and Conclusions

This Reclamation report presents the results of the July 2013 survey of Lake Tschida. The primary objective of the survey was to gather data needed to:

- develop reservoir topography;
- compute area-capacity relationships; and
- storage depletion due to sediment deposition.

A control survey was conducted using the online positioning user service (OPUS) and RTK GPS to confirm the horizontal and vertical control network near the reservoir for the hydrographic survey. OPUS is operated by the NGS and allows users to submit GPS data files that are processed with known point data to determine positions relative to the national control network. The GPS base was set over a Reclamation monument stamped “2121.542” located within the fenced in area of the dam tender’s property downstream of the dam. The base location provided continuous radio link throughout the hydrographic survey.

The study’s horizontal control was in feet, North Dakota state plane coordinates, south zone, in NAD83 (2011). The vertical control, in US survey feet, was tied to the project’s vertical datum that is about 1.7 feet lower than NAVD88 (GEOID12A). Unless noted, all elevations in this report are referenced to the project vertical datum. The developed reservoir topography presented in this report is tied to NAVD88 (GEOID12A).

The July 2013 underwater survey was conducted near reservoir elevation 2,064 as measured by the Reclamation gage at the dam and confirmed by RTK GPS measurements. The bathymetric survey used sonic depth recording equipment interfaced with an RTK GPS for determining sounding locations within the reservoir. The system continuously recorded depth and horizontal coordinates as the survey boat navigated along predetermined grid lines and the shoreline covering the reservoir.

The above-water 2013 topography was developed from several sources such as digitized water surface edges of orthographic aerial images of the reservoir (USDA, 2010) and airborne digital data obtained as IFSAR bare-earth information for the reservoir area (Intermap, 2011). IFSAR technology enables mapping of large areas quickly and efficiently, resulting in detailed information at a much reduced cost compared to other technologies such as aerial photogrammetry and LiDAR. The reported accuracies for the IFSAR data are 2-meters or better horizontally and 1-meter or better vertically in unobstructed flat-ground areas. Other technologies can produce more accurate data than IFSAR, but this study did not have funding to acquire these other data sets. In certain areas around the reservoir water edge, mainly in steeper shoreline areas, the IFSAR data did not match well and were removed from this analysis. The remaining IFSAR data points along with the other data sources were used to develop the 2013 Lake Tschida topography. In the reservoir areas where the IFSAR data were removed, the topographic mapping software interpolated contours from the surrounding data sources.

The final 2013 Lake Tschida topographic map is a combination of the digitized water surface edge from the USDA aerial photographs, IFSAR data, and the 2013 hydrographic survey data, all tied vertically to NAVD88 (GEOID12A). A computer program was used to generate the 2013 topography and resulting reservoir surface areas at predetermined contour intervals from the combined reservoir data from elevation 2,008.0 and above. The input from the 2013 surface areas from elevation 2,120.0 and below was used to develop the area and capacity tables. The 2013 area and capacity tables were produced using the computer program (ACAP) that calculated area and capacity values at prescribed elevation increments using the measured contour surface areas and a curve-fitting technique that interpolated values between the input elevation surface areas.

Tables 1 and 2 contain summaries of the Lake Tschida and watershed characteristics for the 2013 survey. The results of the 2013 survey show that the reservoir has a total storage capacity of 435,123 acre-feet below elevation 2,119.5. At top of conservation water surface elevation 2,064.5 the total capacity is 65,091 acre-feet with a surface area of 3,142 acres. Since closure of Heart Butte Dam in 1949, this survey measured a 10,953 acre-foot decreased in reservoir capacity below elevation 2,064.5. The volume decrease was computed by comparing the 1949 and 2013 surveyed capacities for the reservoir. The measured loss was primarily due to sediment deposition, with some variation due to data accuracy differences between methods of collection and analysis from the previous surveys.

A resurvey should be scheduled in the future if a significant change in the sediment basin runoff is noted. The resurvey should consider collection of detailed above water data upstream from the dam merged with overlapping underwater collection. If only an underwater survey is conducted, it should be scheduled after high inflow years and at high reservoir levels such as the level during the 2013 survey.

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