RECLAMATION

Managing Water in the West

Technical Report No. SRH-2014-20

2013 Edward Arthur Patterson Lake Sedimentation Survey

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

October 2014

ACKNOWLEDGMENTS

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 and Chris Murray of the Great Plains regional office conducted the bathymetry survey of the reservoir in July 2013. Ron Ferrari completed the processing that included generating the reservoir topography and area-capacity information presented in this report. Kent Collins of the Sedimentation Group performed the technical peer review of this document.

Mission Statements

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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 85-824000), PO Box 25007, Denver, Colorado 80225-0007, www.usbr.gov/pmts/sediment/.

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2013 Edward Arthur Patterson Lake Sedimentation Survey

prepared by

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Technical Service Center
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Denver, Colorado

October 2014

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*
October 2014

2. REPORT TYPE

3. DATES COVERED *(From – To)*

4. TITLE AND SUBTITLE
2013 Edward Arthur Patterson Lake Sedimentation Survey

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Ronald L. Ferrari

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Bureau of Reclamation, Technical Service Center, Denver, CO 80225

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Bureau of Reclamation, Denver Federal Center, PO Box 25007
Denver, CO 80225-0007

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Reclamation surveyed Edward Arthur Patterson Lake (Patterson Lake) 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 2,419.9 (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 vessels. 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. Due to extensive vegetation growth throughout the reservoir it was difficult to determine the shoreline for many areas from the aerial photographs, obtain boat access along the shoreline and in the upper reservoir, and acquire valid bare earth IFSAR reservoir contours.

As of July 2013, at conservation pool elevation 2,420.0, the reservoir surface area was 1,194 acres with a capacity of 8,479 acre-feet. At maximum reservoir elevation 2,435.5 the reservoir surface area was 2,693 acres with a capacity of 38,346 acre-feet. Since May 1950 dam closure, a total capacity change of 2,018 acre-feet below elevation 2,420.0 was measured, equal to an average annual reduction of 32 acre-feet. The capacity change is due to sediment deposition, methodology differences between the surveys, and limitations of 2013 data due to the heavy vegetation along the shore and upper reservoir area.

15. SUBJECT TERMS
reservoir area and capacity/ sedimentation/ reservoir surveys/ global positioning system/ sounders/ contour area/ RTK GPS/

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**a. THIS PAGE**			**19b. TELEPHONE NUMBER** *(Include area code)*

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

BUREAU OF RECLAMATION

Technical Service Center, Denver, Colorado
Sedimentation and River Hydraulics Group, 86-68240

Technical Report No. SRH-2014-20

2013 Edward Arthur Patterson Lake Sedimentation Survey

Dickinson Dam
North Dakota

2/4/2015

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Introduction

Dickinson Dam and Edward Arthur Patterson Lake (Patterson Lake) are part of the Dickinson 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 Stark County on the Heart River upstream of Lake Tschida, are 1.5 miles west of Dickinson, North Dakota as shown in Figure 1. Reclamation's Dakota Area Office administers and operates the facility. The recreational areas are operated by the Dickinson Park and Recreation District. At elevation 2,420.0 the length of the reservoir is around 12.1 miles along the main channel with an average width of 0.2 miles. The drainage area above Dickinson Dam is 406 square miles with all of that considered sediment contributing. The basin is mostly gently rolling farm land with the reservoir body heavily vegetated, affecting boat access near the shoreline and access to the upper, shallower water areas during this survey.

The homogeneous earthfill structure was constructed from 1949 through 1950 and became operational in May 1950. Dickinson Dam has the following dimensions:

Structural height[1]	64.6 feet	Hydraulic height	46 feet
Crest length	2,980 feet	Crest elevation[2]	2,436.6 feet
Top width	30 feet		

There is a gate controlled overflow concrete crest spillway located near the right abutment of the dam with crest elevation 2,416.5. The top of the closed gate crest is elevation 2,420.0 with design discharge capacity 38,770 cubic feet per second (cfs) at reservoir elevation 2,430.6, as shown in Figure 2. There is a grass-lined auxiliary spillway located near the right abutment that has a 1,100 foot concrete crest length at elevation 2,423.5 with a discharge capacity 66,020 cfs at elevation 2,430.6.

The outlet works structure is a high pressure controlled concrete conduit located through the left abutment of the dam. There are dual 2-foot wedge gate valves that regulate the 30-inch diameter steel pipe through the dam. The intake crest elevation is 2,404.0 with a discharge capacity of 58 cfs.

[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 Dickinson Dam. This study measured the Project datum 0.1 feet lower than National Geodetic Vertical Datum of 1929 (NGVD29) and 1.9 feet lower than the North American Vertical Dam of 1988 (NAVD88).

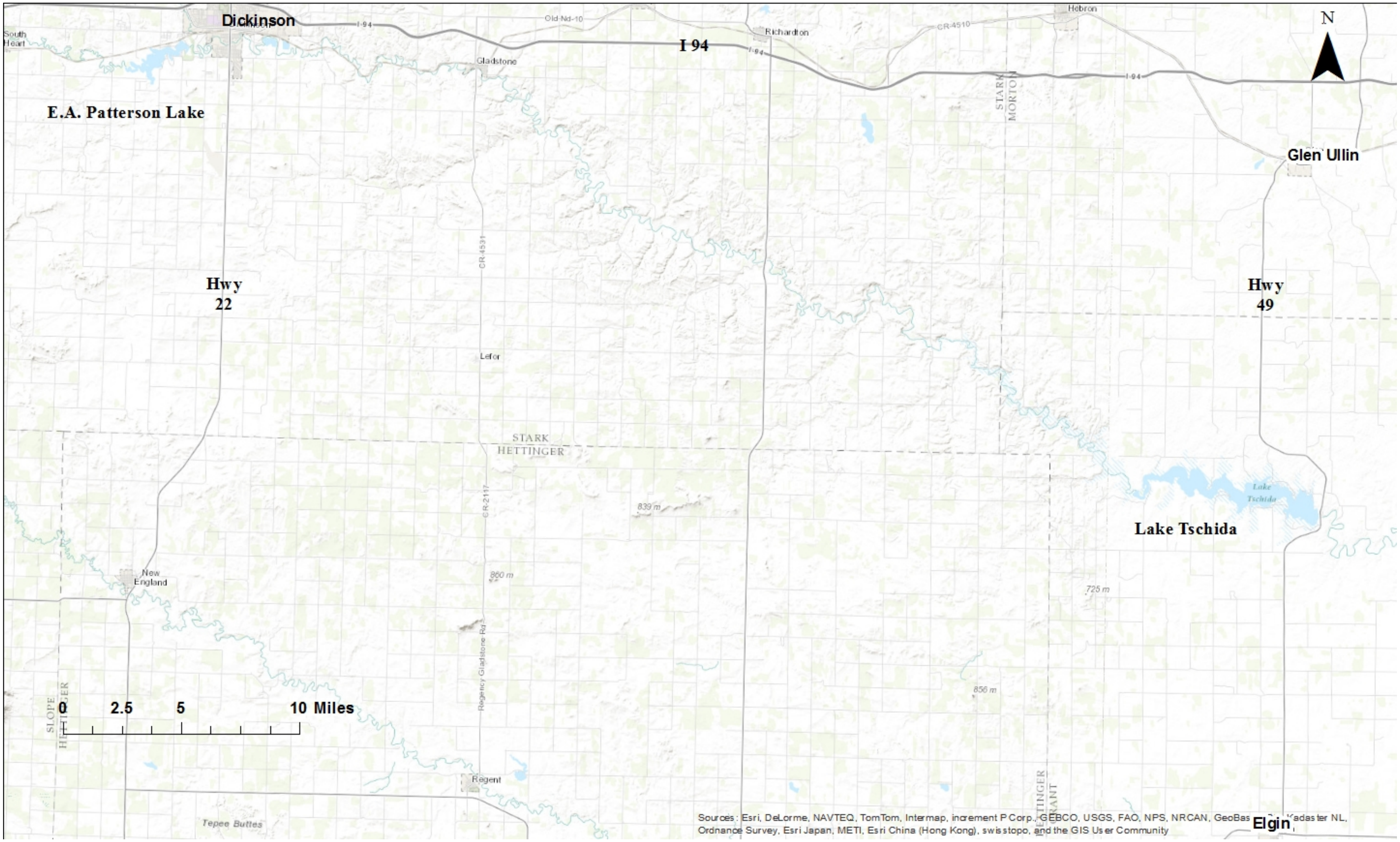

Figure 1 - Edward Arthur Patterson Lake and Dickinson Dam location map, North Dakota.

Figure 2 - Dickinson Dam spillway crest.

1991 Survey Summary

The Natural Resources Conservation Service surveyed Patterson Lake in 1991 using standard land surveying techniques. A survey of 41 range lines was conducted to represent the change of the entire reservoir. For the wetted zones the depths were taken from a boat using a survey rod. Reclamation conducted the analysis to monitor changes after the first 41 years of reservoir operations. 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 1991 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 1991 survey was 8,612 acre-feet with a surface area of 1,194 acres at elevation 2,420.0 feet. Since the reservoir's initial filling in May 1950, it was estimated that 1,885 acre-feet of sediment had been trapped in the reservoir by May 1991. The average annual rate of sediment accumulation for top of conservation storage elevation 2,420.0 was 46 acre-feet (Bureau of Reclamation, 1995). The 2013 study team was unable to locate any information on the segment areas measured during the 1991 study that could have been used during this analysis. The 1995 report was the only available information located.

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 Dickinson Dam, as shown in Figures 3 and 4. 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 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 was tied to the Reclamation's project vertical datum and NAVD88 computed using the geoid model of 2012A (GEOID12A). RTK GPS water surface measurements collected during the bathymetric survey tied to NAVD88 were around 1.9 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 was near NGVD29 and 1.9 feet lower than NAVD88 (GEOID12A). The 2013 developed reservoir topography elevations are tied to NAVD88 (GEOID12A). The computed surface area values from the 2013 reservoir topography were shifted down 1.9 feet to match the project vertical datum and were used for development of the 2013 surface areas and capacity values presented in this report.

Figure 3 - Reclamation monument stamped “2013”

Figure 4 - Bureau of Reclamation monument located along fence line.

When setting the control network two brass cap monuments were measured with one stamped "243" near a concrete pad on the dam and the other, unstamped, located near the end of the left abutment, Figure 6. The monument elevations were compared to design drawing elevations in an attempt to identify them and relate them to the design project vertical elevation datum. The comparison to published elevations is listed in Table 1. The OPUS computed coordinates for the base monument was:

East	**1,385,522.997**
North	**447,892.920**
Elevation	**2,435.395 (NAVD88/GEOID12A)**

During the survey, RTK GPS water surface measurements during calm conditions, tied to NAVD88, were compared to the water surface gage readings obtained by Reclamation and an average difference of 1.9 feet was calculated. Using Corp of Engineers software CORPSCON, an elevation difference of 1.77 was computed between NAVD88 and NGVD29 at the base station. At Lake Tschida downstream, CORPSCON computed an elevation difference of 1.54 feet. Reclamation documents indicate that the structure design was tied to mean sea level. The 2013 surveys at both locations determined the project vertical datum was near NGVD29, the implied sea level during time of construction. One reason for the measured difference from these surveys is the use and improvement of the geiod models in those areas with use of GPS technology. For computational purposes the project or construction vertical datum of 1.9 feet below NAVD88 was used for this study. Table 1 lists the July 2013 measurements on the brass-cap monuments and compares them to published coordinates and elevations from what appeared to be the same monuments on Reclamation design drawing files.

Monument Designation		**July 2013 Measurements (NAVD88) (GEOID12A)**	**Published Coordinates**	**Difference** (ft)
USBR Brass Cap, (left abutment)	Easting	1,385,814.283	n/a	n/a
	Northing	447,676.220	n/a	n/a
	Elevation	2,433.354	2,431.46 "D"	-1.894
USBR Brass Cap, ("243" near pad)	Easting	1,386,441.883	n/a	n/a
	Northing	446,520.372	n/a	n/a
	Elevation	2,435.827	2,433.97 "By Control Vault"	-1.857
Water Surface 7/16/2013	Easting	1,385,479.5	n/a	n/a
	Northing	447,538.4	n/a	n/a
	Elevation	2,421.8	2,419.9	-1.9

Table 1 - Control points used for July 2013 survey of Edward Arthur Patterson Lake

Reservoir Operations

Dickinson Dam is a multipurpose feature of the Missouri River Basin Project whose purpose is providing water storage capacity for irrigation, flood control, recreation, fish, and wildlife. The July 2013 total capacity was 38,346 acre-feet below elevation 2,435.5. The minimum bottom elevation measured during the 2013 survey was 2,394.3. The following values are from the July 2013 capacity table:

12,099 acre-feet of maximum flood storage between elevation 2,430.5 and 2,435.5.
17,768 acre-feet of surcharge pool storage between elevation 2,420.0 and 2,430.5.
8,041 acre-feet of active conservation storage between elevation 2,405.0 and 2,420.0.
90 acre-feet of inactive storage between elevation 2,404.0 and 2,405.0.
348 acre-feet of dead pool storage below elevation 2,404.0.

End-of-month stage records for Edward Arthur Patterson Lake in Table 2 show the annual fluctuation for operation water years 1950 through 2013. The average inflow during this period was 19,090 acre-feet with the highest measured being 66,625 acre-feet in 1978. The table's water levels show fluctuations of the reservoir. Since normal operation began in May 1950, the water levels have ranged from maximum elevation 2,422.2 in 1997 to minimum elevation 2,408.0 in 1992 and 1993.

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, as shown in Figure 5. 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 5 - 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 zone coordinates, NAD83, in US Survey Feet (feet).

The Patterson Lake bathymetric survey was conducted on July 15 and 16 of 2013 near water surface elevation 2,419.9. 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. Vegetation limited bathymetric data collection along the shoreline in the upper half of the reservoir, preventing boat access to those areas and to the Heart River

portion of the reservoir. The railroad that runs along north side of the reservoir also prevented access to several of the larger coves during the 2013 survey. The survey vessel was powered by an outboard with a jet outdrive and even small amounts of vegetation affected the performance. The vessel had a second small outboard propeller motor, but could not maneuver through the thicker areas of vegetation. A larger propeller outboard may have been able to penetrate the vegetation better, but the vegetation was too thick in spots to allow access by any boat. Figures 6 and 7 show some of shallow water areas where islands of vegetation have formed along with the railroad crossing..

Figure 6 - Pattern Lake vegetation and railroad crossing within reservoir area.

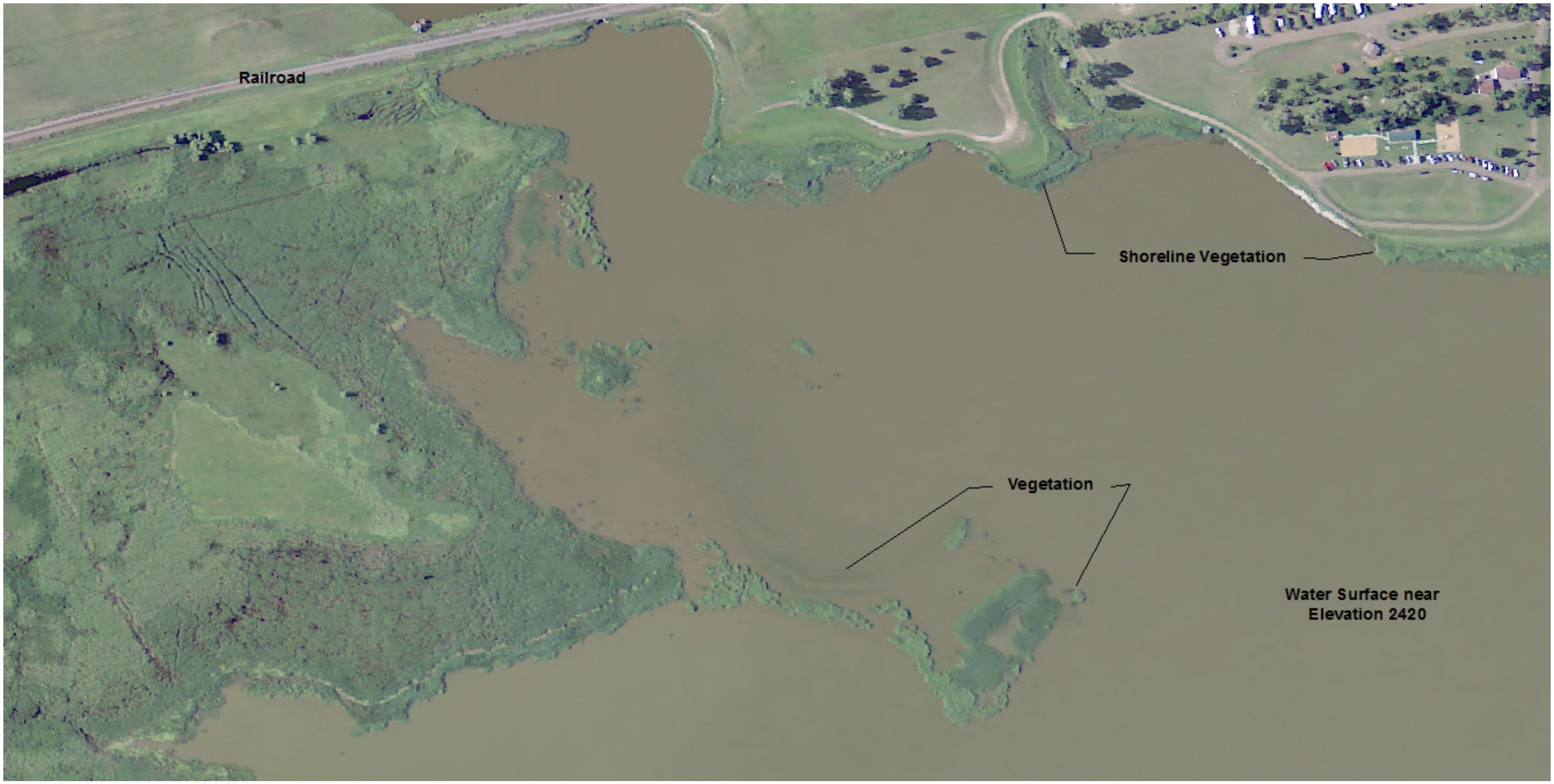

Figure 7 - Pattern Lake vegetation within reservoir area.

As each survey 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 elevation and to NAVD88, which is 1.9 feet higher. Figures 8 through 12 depict the final processing of the July 2013 bathymetric data, which resulted in around 25,900 points.

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 Patterson Lake focused on the collection of the bathymetric or underwater data in areas 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 2,420 were downloaded from the USDA data web site and used to develop a breakline to represent full reservoir conditions (USDA, 2010). The full reservoir contour was developed by digitizing the water's edge from a USDA aerial image and assigning it an elevation to be used during the 2013 reservoir contour development. The elevation of the digitized contour was rounded to elevation 2,420 (NAVD88) to represent the water surface at the top of the closed spillway crest gates.

Aerial IFSAR

Interferometric Synthetic Aperture Radar (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 Light Detection and Ranging (LiDAR). The IFSAR data at Patterson Lake were collected in May 2007 near reservoir water surface elevation

2,418 (NAVD88). The IFSAR data provided 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 as raster files from which 1-foot contours were developed and used as breaklines during topographic development.

The IFSAR data were not as accurate along the water surface shoreline and in other portions of the reservoir where thick vegetation had grown. Due to these IFSAR accuracy issues, the reservoir's water edge was represented by the digitized USDA water surface contour, assigned elevation 2,420.0 (NAVD88) for this study. Thick vegetation was the major obstacle in obtaining valid topographic information around the active portion of the reservoir from the IFSAR data set. Other methods of aerial collection may have been more successful at obtaining the bare earth reservoir topography information, but data needs would have to be determined and more research would be required.

The 2013 bathymetric data collection along the shoreline was limited due to the vegetation restricting access to many areas. The 2013 bathymetric data were only adequate to develop accurate topography from elevation 2,412.0 and below. The digitized USDA water surface contour represented the 2013 reservoir at top of closed spillway gate elevation 2,420.0. The IFSAR data above elevation 2,420.0 (NAVD88) were used to develop reservoir topography, but the resulting surface areas from the IFSAR were not used in developing 2013 reservoir volumes. This study assumed no change in reservoir surface areas since the 1991 study from elevation 2,414.0 and above. The 2013 bathymetric data only measured a slight change since 1991 at elevation 2,410.0, so the assumption of no change above elevation 2,414.0 appears valid and should have had no major effect on the reservoir volume 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 where needed. In other cases, however, the Sedimentation Group has found the IFSAR data were adequate, with some modifications, to be used for total reservoir volume computations. Studies such as Brantley Reservoir in New Mexico and Lake Tschida, located downstream of Patterson Lake, were far less restricted by vegetation (www.usbr.gov/pmts/sediment). For the 2013 Patterson Lake study, the surface areas from the IFSAR data were not part of the 2013 computations, but the data were used for reservoir topography development above spillway crest elevation 2,420.0 for illustration purposes only.

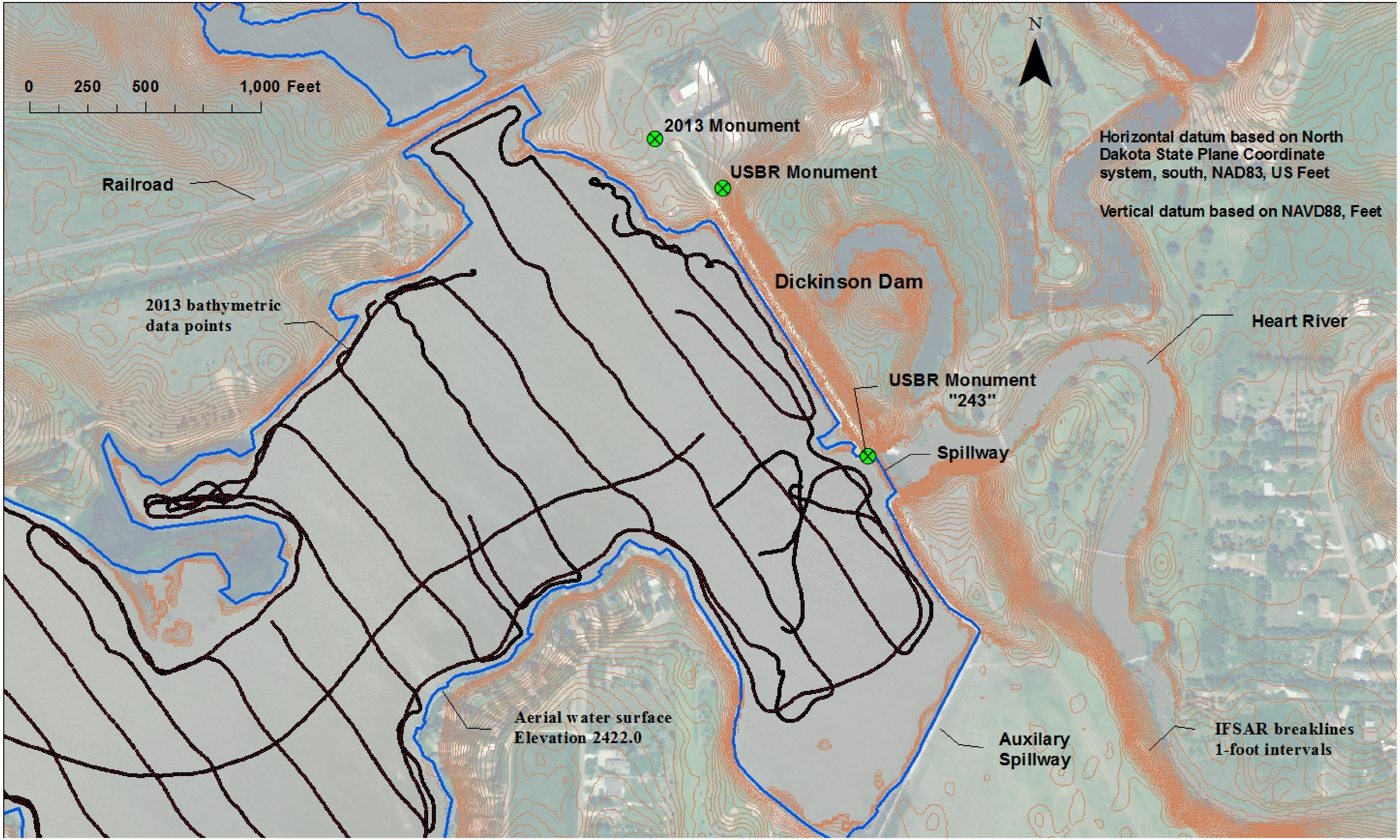

Figure 8 - Patterson Lake, 2013 bathymetric data and imported data coverages, 1 of 5 (NAVD88/GEOID12A).

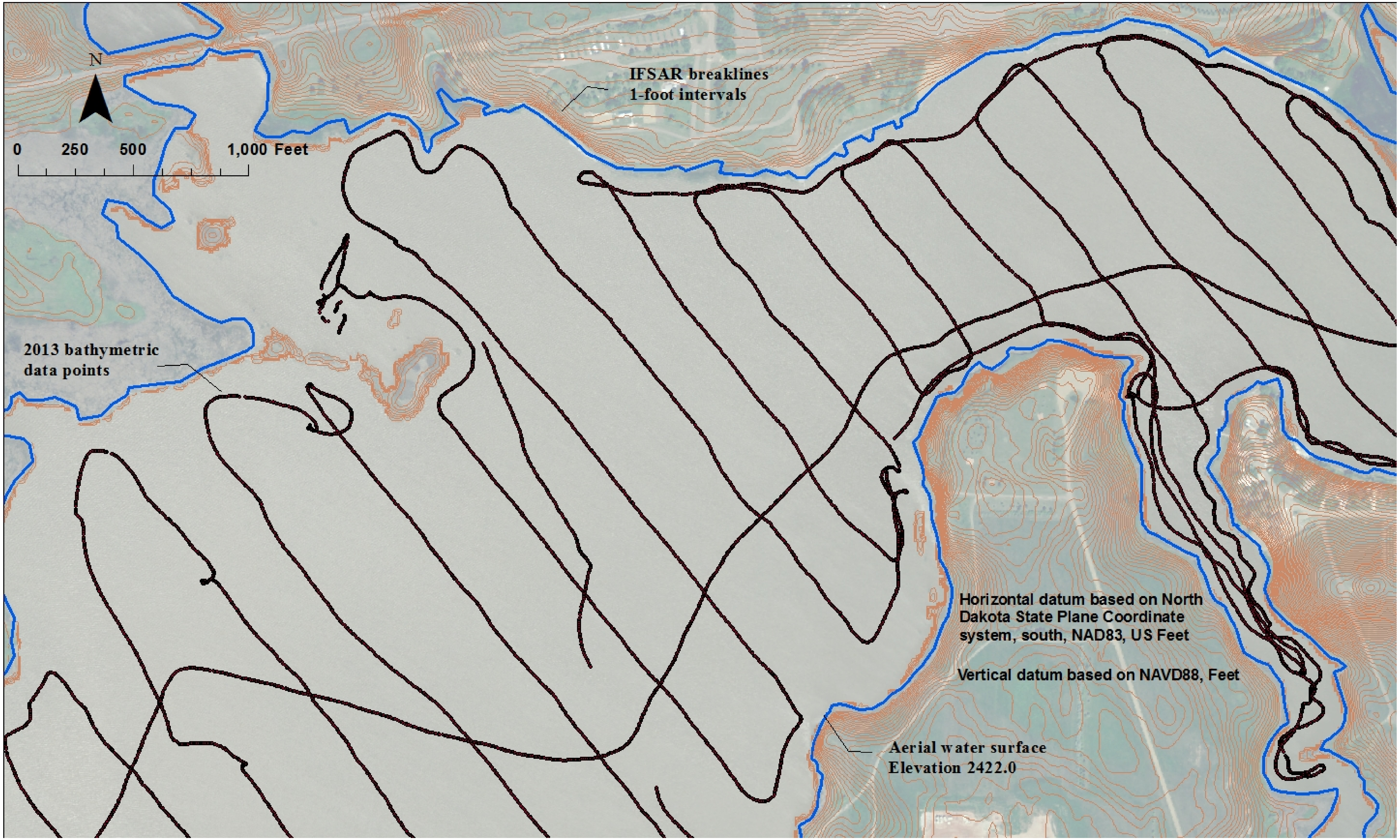

Figure 9 - Patterson Lake, 2013 bathymetric data and imported data coverages, 2 of 5 (NAVD88/GEOID12A).

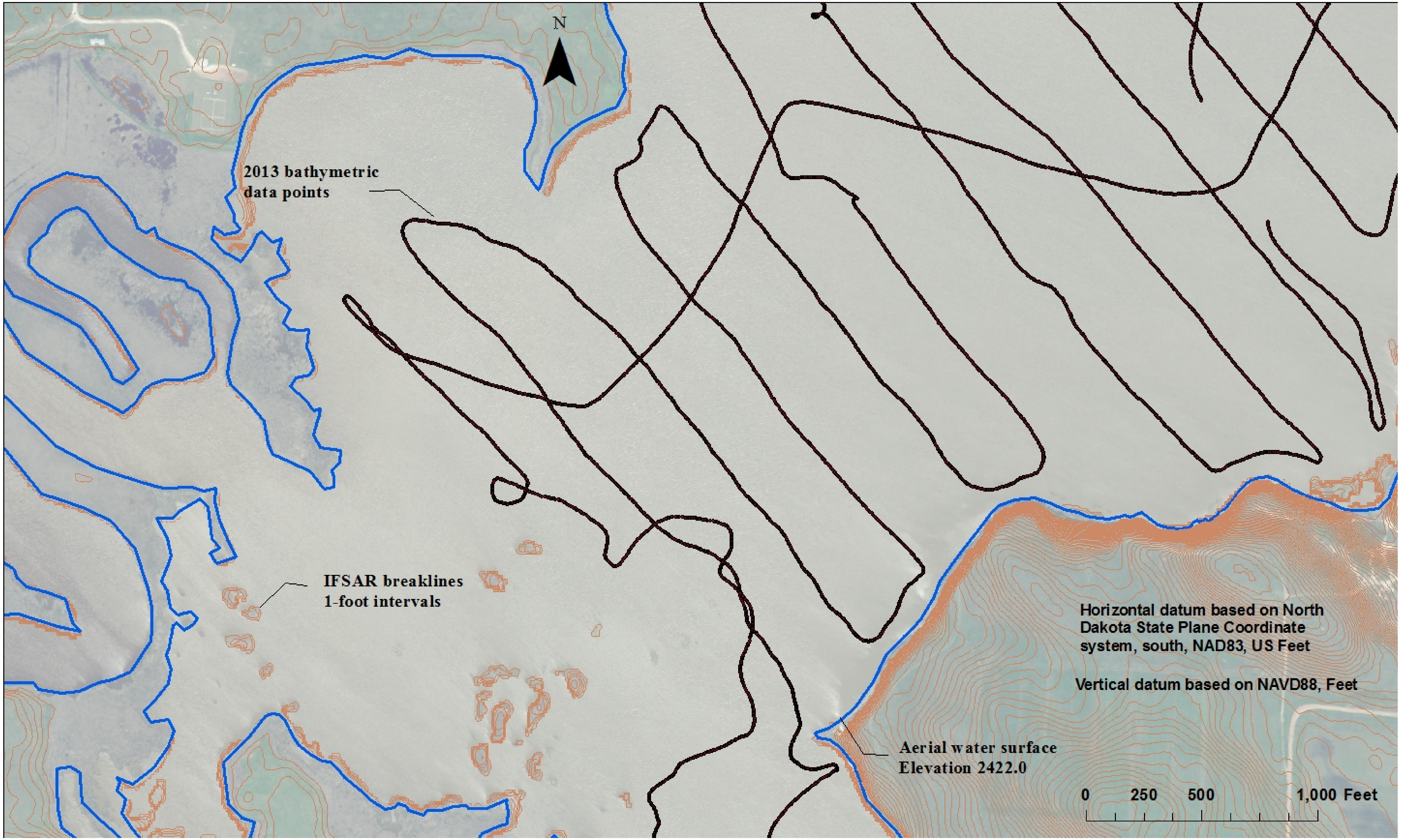

Figure 10 - Patterson Lake, 2013 bathymetric data and imported data coverages, 3 of 5 (NAVD88/GEOID12A).

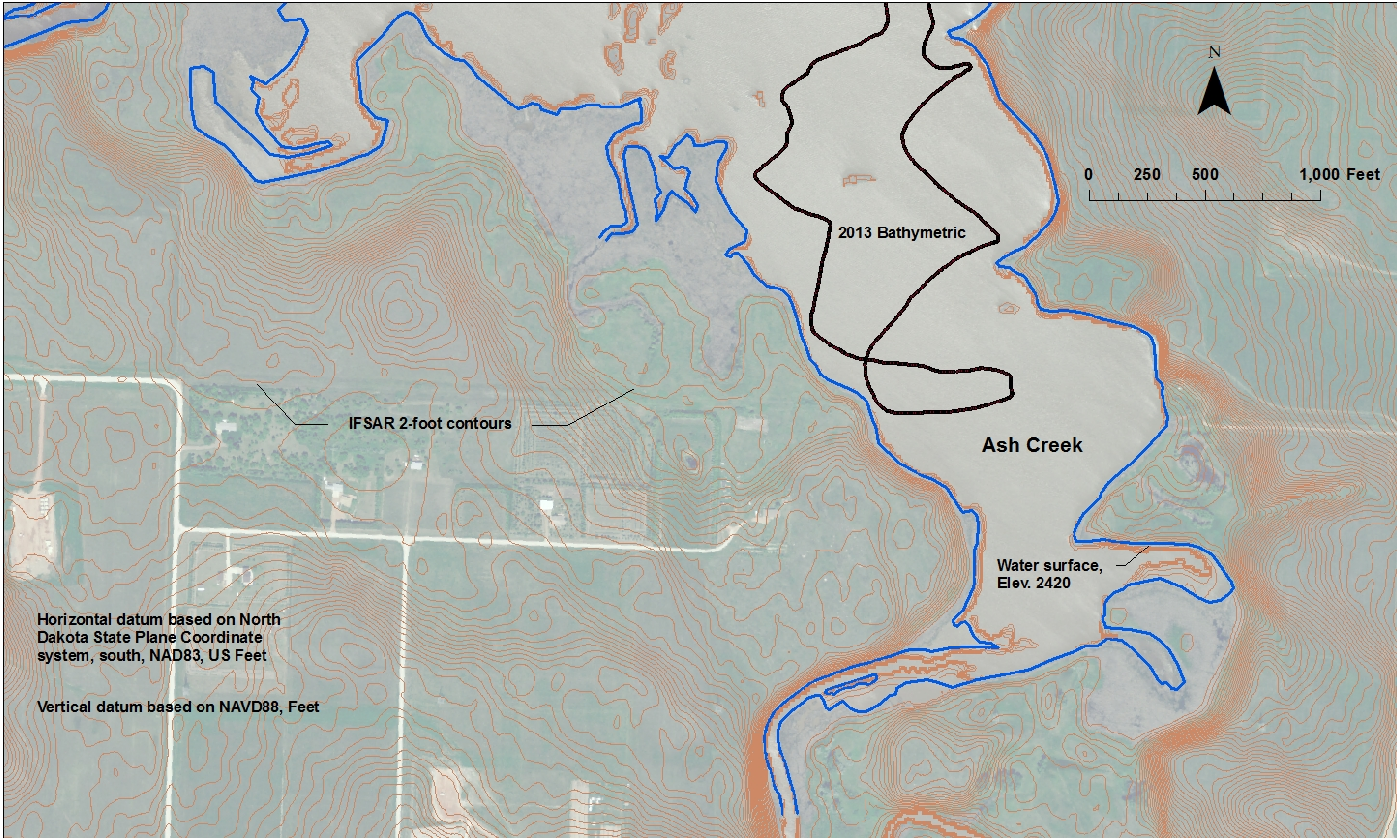

Figure 11 - Patterson Lake, 2013 bathymetric data and imported data coverages, 4 of 5 (NAVD88/GEOID12A).

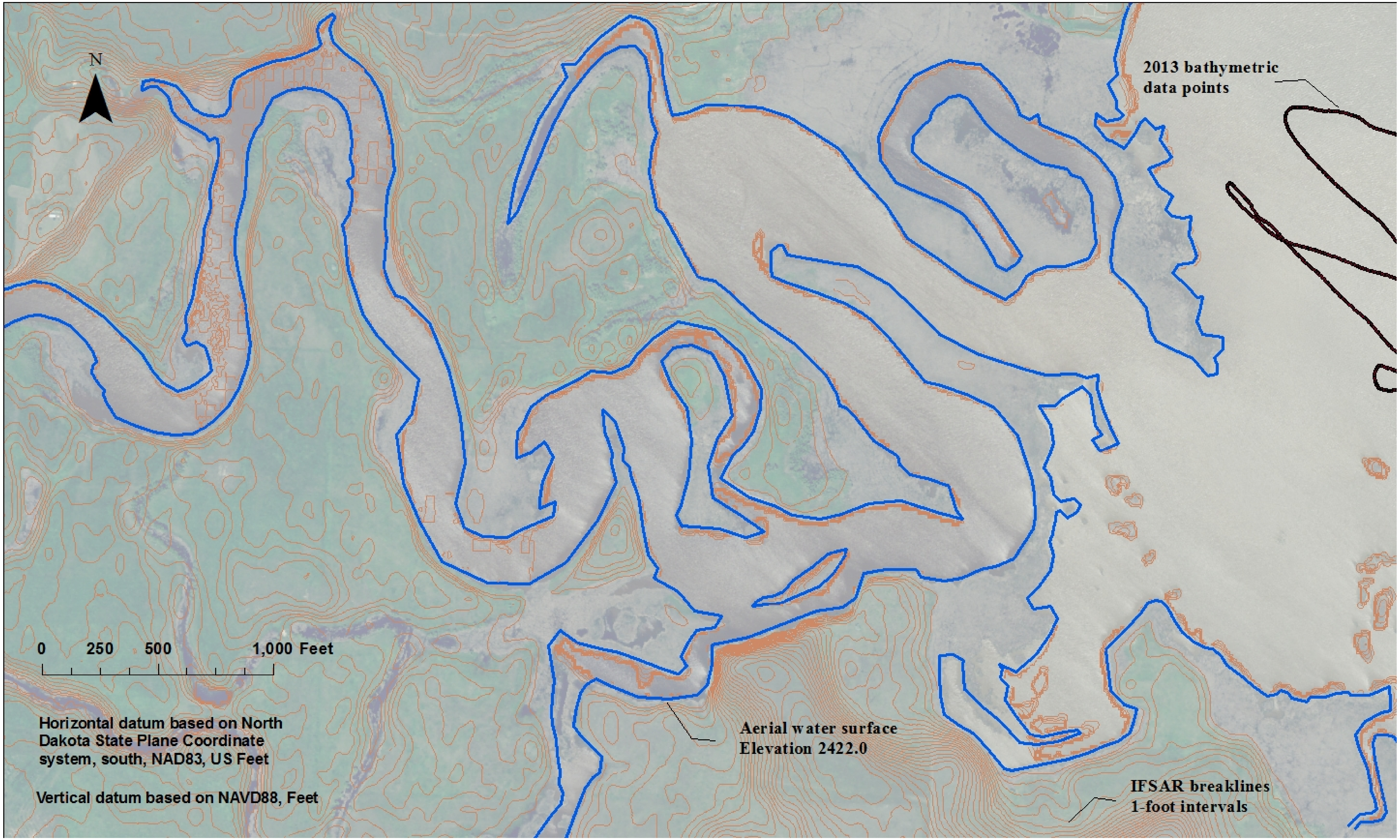

Figure 12 - Patterson Lake, 2013 bathymetric data and imported data coverages, 5 of 5 (NAVD88/GEOID12A).

Reservoir Area and Capacity

Topography Development

The 2013 Patterson Lake 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. One additional source was digitized breaklines projected from the above-water data in areas of the reservoir not accessible by boat during the 2013 survey.

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 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. The polygon, not assigned an elevation, was used as a hard boundary to represent the reservoir area by preventing development of the 2013 TIN and contours outside of the hardclip.

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 designed to deal with 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 a 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 1-foot increments were computed for elevations 2,396.0 through 2,436.0. The minimum or zero surface area of the reservoir was elevation 2,394.0. The reservoir contour topography at 2-foot intervals are presented in Figures 13 through 17 from elevation 2,398.0 through elevation 2,440.0 (NAVD88). Portions of the contours developed from the IFSAR data set were removed in areas where valid contours could not be developed. These areas were mainly along the shoreline and upper reservoir where thick vegetation was present.

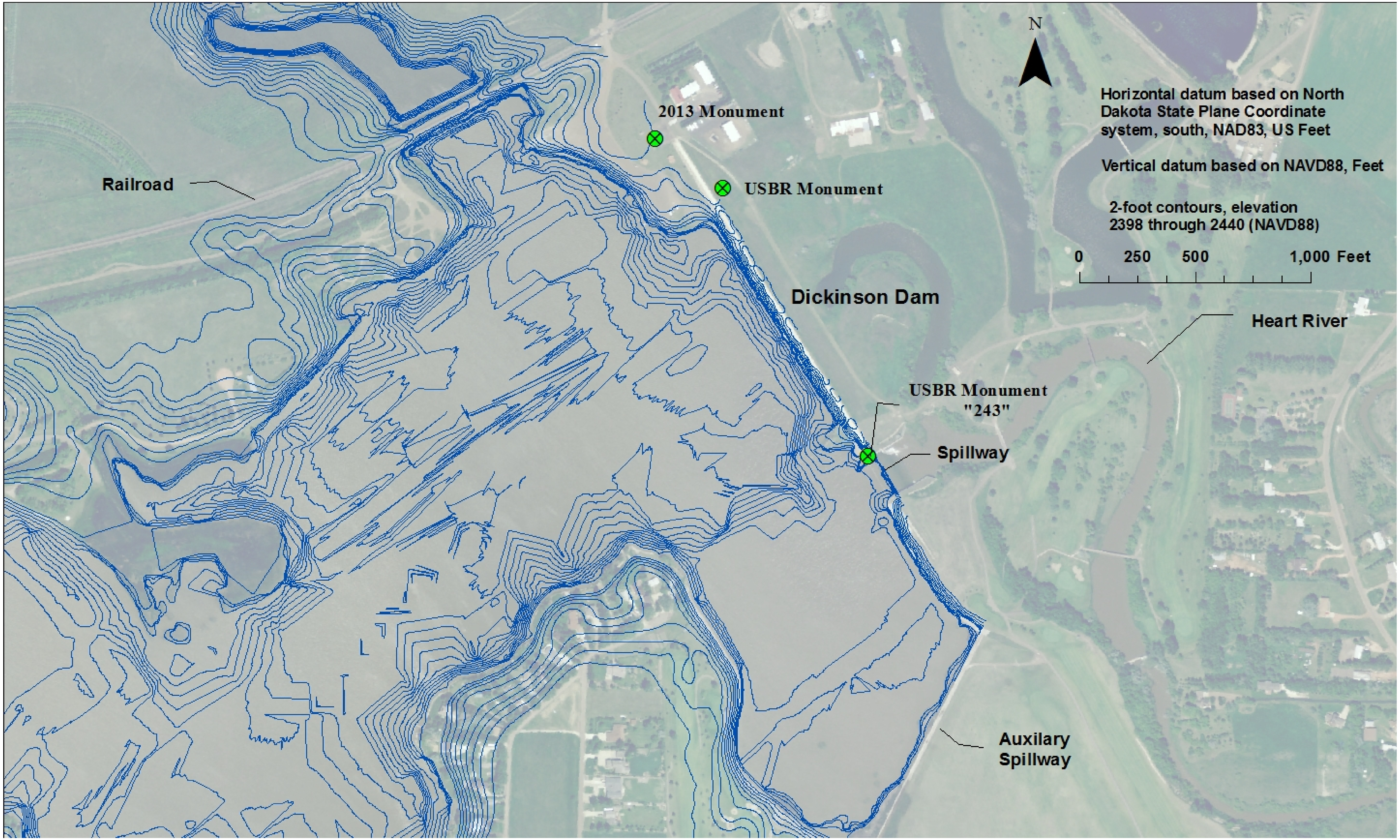

Figure 13 - Patterson Lake developed 2-foot contours from 2013 bathymetric survey and imported data coverages, 1 of 5 (NAVD88/GEOID12A).

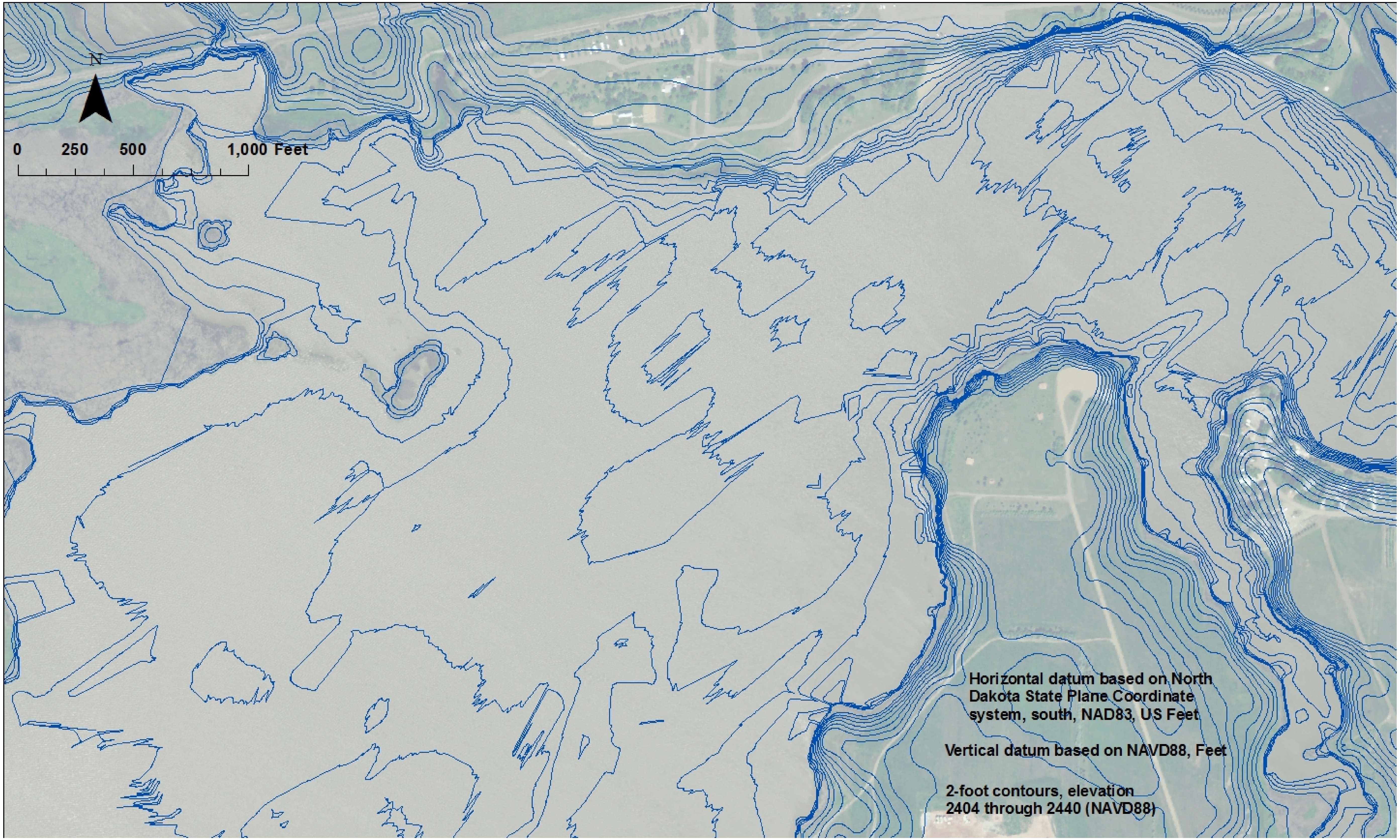

Figure 14 - Patterson Lake developed 2-foot contours from 2013 bathymetric survey and imported data coverages, 2 of 5 (NAVD88/GEOID12A).

Figure 15 - Patterson Lake developed 2-foot contours from 2013 bathymetric survey and imported data coverages, 3 of 5 (NAVD88/GEOID12A).

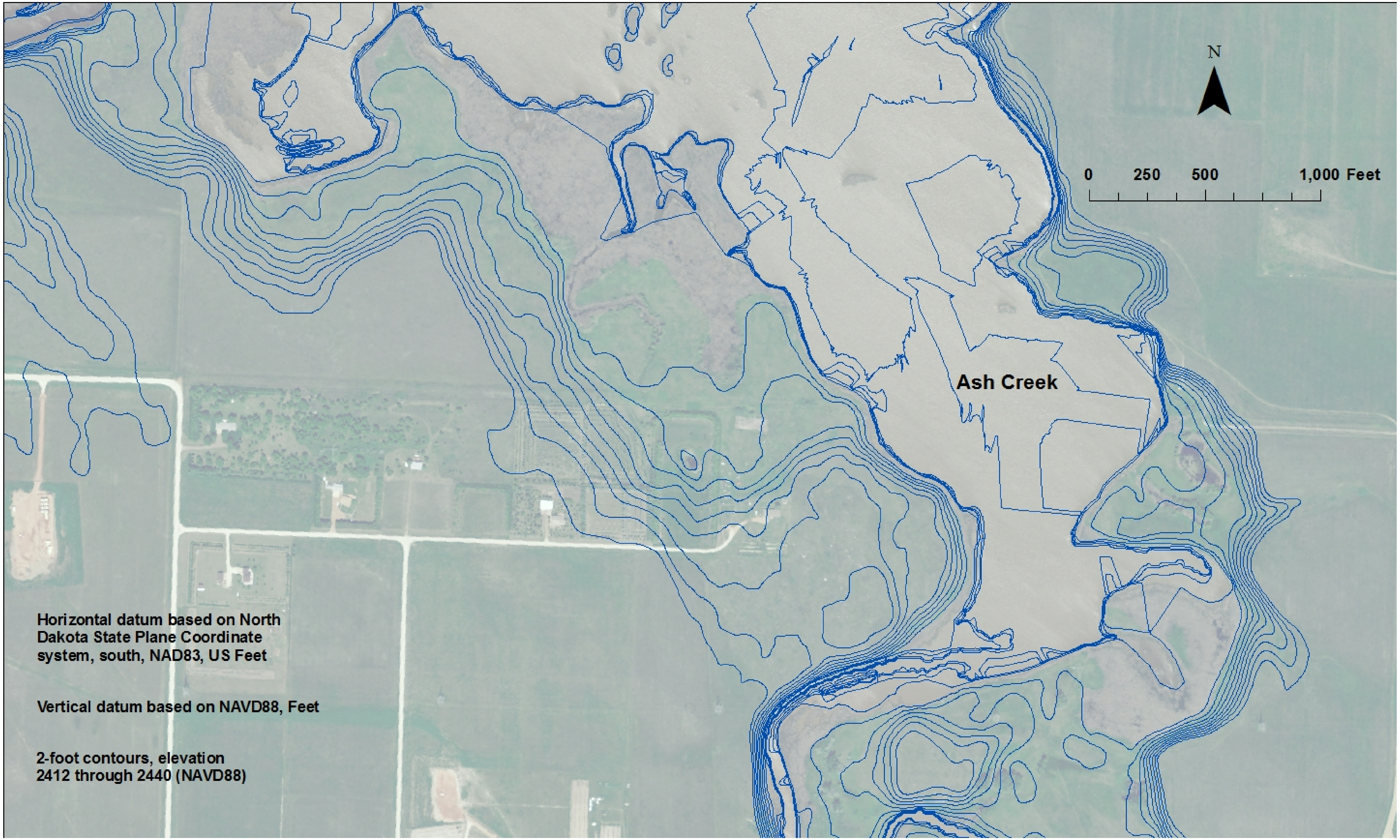

Figure 16 - Patterson Lake developed 2-foot contours from 2013 bathymetric survey and imported data coverages, 4 of 5 (NAVD88/GEOID12A).

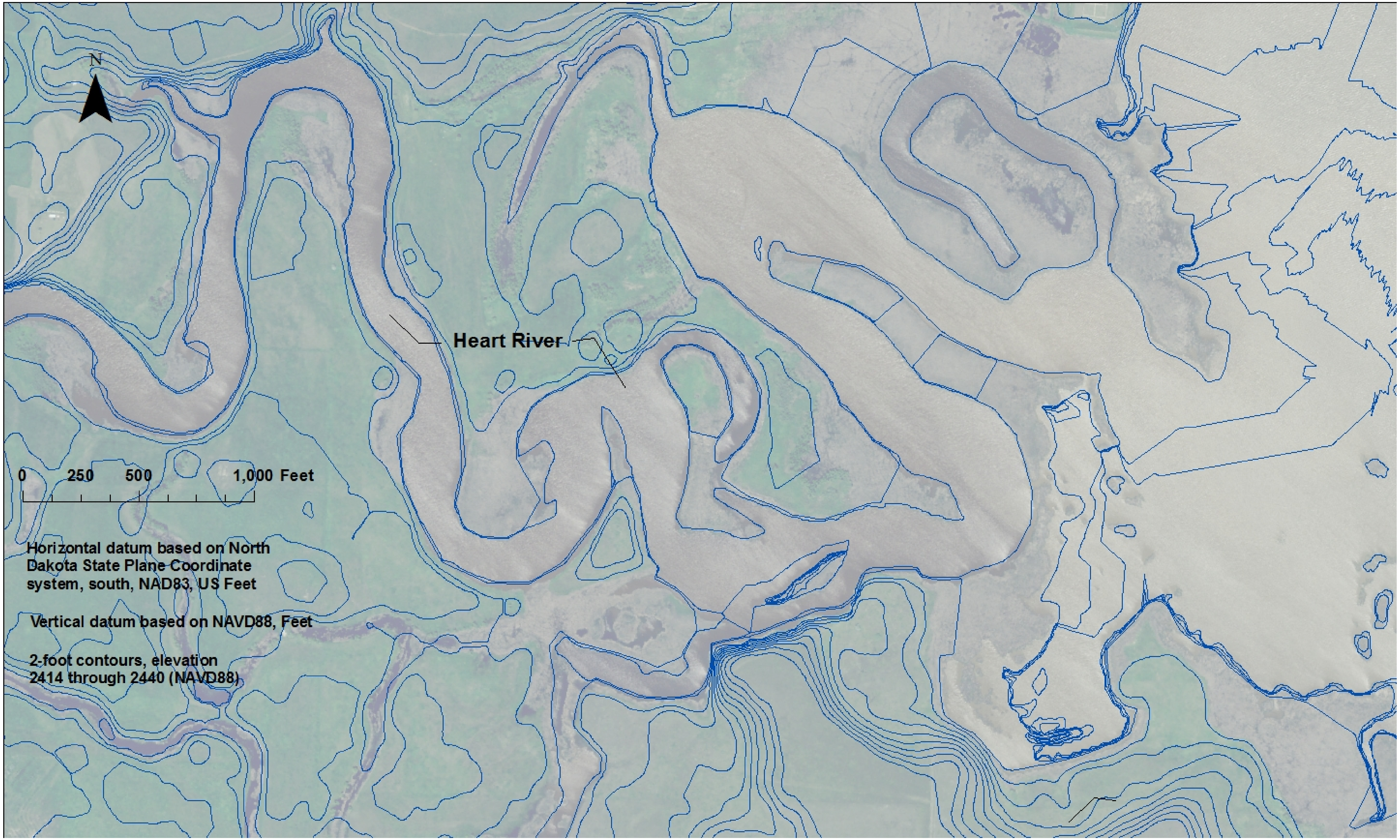

Figure 17 - Patterson Lake developed 2-foot contours from 2013 bathymetric survey and imported data coverages, 5 of 5 (NAVD88/GEOID12A).

2013 Patterson Lake Surface Area Methods

Using ArcGIS commands to compute areas at user-specified elevations, the 2013 surface areas for Patterson Lake were computed at 1-foot increments directly from the reservoir TIN from minimum elevation 2,395.9 through 2,437.9 (NAVD88) to provide information for the area-capacity table development. The elevations of these computed surface areas were reduced 1.9 feet to match the project vertical datum of the water surface gage for operation of Dickinson Dam. Due to coverage limitations of 2013 bathymetric data, no change in surface areas since the 1991 survey was assumed from elevation 2,414.0 and above. Although there has likely been some change over the 22-year period between surveys, the 1991 study only measured a slight change since the original from elevation 2,414.0 and above.

2013 Patterson Lake 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 2013 surface areas from elevation 2,395.0 through 2,412.0, computed at 1-foot intervals, were used. This study assumed no change of the surface areas since the 1991 study from elevation 2,414.0 and above and the 1991 areas were used to complete the 2013 tables. The zero surface area was at elevation 2,394.0. The ACAP 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 Patterson Lake. 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 utilized 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 of second order polynomial form, 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 Patterson Lake 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 conservation use elevation 2,420.0, the surface area was 1,194 acres with a total capacity of 8,479 acre-feet. At maximum and top of surcharge elevation 2,435.5, the surface area was 2,693 acres with a total capacity of 38,346 acre-feet.

Patterson Lake Surface Area and Capacity Results

Table 2 provides a summary of Patterson Lake between the time of the dam closure in May 1950, resurvey in 1991, and the July 2013 hydrographic survey. The 2013 survey collected more detailed underwater data than the 1991 range line survey from elevation 2,412.0 and below. The resulting measured changes in 2013 are due to sediment deposition and data density differences between the surveys. The area and capacity curves for the, original, 1991, and 2013 surveys are plotted on Figure 18 showing relatively minimal changes between the 1991 and 2013 surveys. Table 2 provides a summary of the survey's computed surface area and capacity values along with the changes due to sediment accumulation and methodological differences. As stated previously, the area and capacity values are tied to the project vertical datum that is 1.9 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 2,394.0 through 2,412.0, input to ACAP at 1-foot increments. The 2013 study assumed no surface area change since 1991 from elevation 2,414 and above. The 1991 surface areas at 2-foot increments were input to ACAP from elevation 2,414.0 through 2,430.0 to complete computations for that that portion of the reservoir. For the 1991 and 2013 studies a surface area at elevation 2,440.0 was measured from a USGS quad contour and was the input surface area to compute the area and capacity values from elevation 2,430.0 through 2,440.0. Reclamation's ACAP program was used to compute the area and capacity values from the input surface areas.

RESERVOIR SEDIMENT
DATA SUMMARY

Edward Arthur Patterson Lake
NAME OF RESERVOIR

1
DATA SHEET NO.

DAM

1. OWNER: Bureau of Reclamation	2. STREAM: Heart River	3. STATE: North Dakota
4. SEC 18 TWP. 139 N RANGE 96 W	5. NEAREST P.O. Dickinson, ND	6. COUNTY: Stark
7. LAT 46 ° 52 ' 11 " LONG 102 ° 49 ' 37 "	8. TOP OF DAM ELEVATION: 2,436.6 [1]	9. SPILLWAY CREST EL. 2,416.5 [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	2,430.6 [3]	2,092	16,708	27,205	5/1950
b. FLOOD CONTROL					
c. POWER					
d. JOINT USE					**16 DATE NORMAL OPERATIONS BEGAN**
e. CONSERVATION	2,420.0	1,195	9,246	10,497	5/1950
f. INACTIVE	2,405.0	216	1,251	1,251	
g. DEAD					

17. LENGTH OF RESERVOIR 20.6 [4] MILES — AVG. WIDTH OF RESERVOIR 0.2 MILES

BASIN

18. TOTAL DRAINAGE AREA 406 [5] SQUARE MILES	22. MEAN ANNUAL PRECIPITATION 16.3 [5] INCHES
19. NET SEDIMENT CONTRIBUTING AREA 406 [5] SQUARE MILES	23. MEAN ANNUAL RUNOFF 0.88 [6] INCHES
20. LENGTH 36 MILES — AVG. WIDTH 11.3 MILES	24. MEAN ANNUAL RUNOFF 19,090 [7] ACRE-FEET
21. MAX. ELEVATION 3000 — MIN. ELEVATION 2,420	25. ANNUAL TEMP, MEAN 42 °F RANGE -37 °F to 108 °F [5]

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
1950			Contour (D)	4-ft	1,195	10,497 [3]	0.55
1991	41	41	Range (D)	41	1,194 [8]	8,612 [8]	0.45
7/2013	22	63	Contour (D)	1-ft	1,194 [8]	8,479 [8]	0.44

26. DATE OF SURVEY	34. PERIOD ANNUAL PRECIPITATION	35. PERIOD WATER INFLOW, ACRE-FEET a. MEAN ANN.	35. b. MAX. ANN.	35. c. TOTAL	36 WATER INFLOW TO DATE, AF a. MEAN ANN.	36. b. TOTAL
1991	16.3	19,170 [9]	66,625	843,502	19,170	843,502
7/2013		16,326	65,844	359,169	19,090	1,202,671

26. DATE OF SURVEY	37. PERIOD CAPACITY LOSS, ACRE-FEET a. TOTAL	37. b. AVG. ANN.	37. c. /MI.^{2}-YR.	38. TOTAL SEDIMENT DEPOSITS TO DATE, AF a. TOTAL	38. b. AVG. ANN.	38. c. /MI.^{2}-YR.
1991	1,885 [10]	46.0	0.113	1,885	46.0	0.113
7/2013	133 [10]	6.0	0.015	2,018	32.0	0.079

26. DATE OF SURVEY	39. AVG. DRY WT. (#/FT^3)	40. SED. DEP. TONS/MI.^{2}-YR a. PERIOD	40. b. TOTAL TO DATE	41. STORAGE LOSS, PCT. a. AVG. ANNUAL	41. b. TOTAL TO DATE	42 SEDIMENT INFLOW, PPM a. PER.	42. b. TOT.
1991				0.440	18.0		
7/2013				0.305	19.2		

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

45. RANGE IN RESERVOIR OPERATION [9]							
YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF	YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF
1952	2,419.2	2,412.8	-667	1953	2,417.2	2,412.7	10,808
1954	2,419.6	2,411.8	27,896	1955	2,418.2	2,411.8	12,858
1956	2,415.5	2,411.8	2,436	1957	2,419.3	2,413.0	23,335
1958	2,416.9	2,413.7	5,650	1959	2,418.5	2,413.7	16,867
1960	2,418.0	2,413.4	11,284	1961	2,414.4	2,410.7	244
1962	2,416.6	2,410.4	3,752	1963	2,417.1	2,413.2	12,244
1964	2,417.1	2,412.9	6,610	1965	2,418.2	2,413.6	32,642
1966	2,418.2	2,415.1	18,166	1967	2,418.2	2,412.8	37,613
1968	2,414.2	2,412.7	1,654	1969	2,418.3	2,412.7	50,236
1970	2,420.1	2,414.2	42,520	1971	2,418.0	2,414.4	39,947
1972	2,420.1	2,415.9	61,780	1973	2,418.1	2,413.6	18,601
1974	2,417.0	2,413.1	4,094	1975	2,418.5	2,412.8	41,272
1976	2,416.8	2,412.8	8,124	1977	2,417.4	2,412.5	11,967
1978	2,419.4	2,414.8	66,625	1979	2,417.9	2,413.9	39,012
1980	2,415.7	2,411.4	985	1981	2,416.8	2,410.9	5,934
1982	2,421.0	2,414.9	55,353	1983	2,420.9	2,416.0	27,831
1984	2,420.7	2,416.0	17,862	1985	2,418.6	2,415.6	1,197
1986	2,420.6	2,415.6	44,959	1987	2,420.8	2,418.7	21,744
1988	2,419.7	2,413.8	-378	1989	2,420.4	2,413.3	2,827
1990	2,416.5	2,413.5	758	1991	2,413.6	2,409.3	-81
1992	2,410.6	2,408.0	-347	1993	2,417.3	2,408.0	4,870
1994	2,420.5	2,416.0	16,908	1995	2,420.7	2,418.4	38,955
1996	2,420.7	2,417.4	33,022	1997	2,422.2	2,417.4	42,910
1998	2,420.5	2,418.3	11,975	1999	2,420.6	2,417.6	28,535
2000	2,418.6	2,416.1	2,431	2001	2,420.7	2,415.7	27,570
2002	2,420.6	2,418.0	2,394	2003	2,420.7	2,417.6	14,847
2004	2,420.8	2,417.4	18,660	2005	2,420.6	2,412.0	14,475
2006	2,415.0	2,411.0	6,378	2007	2,419.0	2,416.2	1,327
2008	2,417.2	2,413.6	-995	2009	2,420.8	2,410.9	50,099
2010	2,420.6	2,408.2	21,253	2011	2,420.8	2,418.8	65,844
2012	2,420.1	2,417.3	-651	2013	2,420.7	2,417.2	15,650

46. ELEVATION - AREA - CAPACITY - DATA								
ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
2013	**SURVEY** [11]							
2,394.0	0	0	2,395.0	0	0	2,396.0	2	1
2,398.0	18	15	2,400.0	49	89	2,402.0	64	201
2,404.0	84	349	2,405.0	95	438	2,406.0	111	541
2,408.0	181	826	2,410.0	303	1,306	2,412.0	466	2,075
2,414.0	603	3,144	2,415.0	697	3,794	2,416.0	791	4,538
2,418.0	978	6,307	2,420.0	1,194	8,479	2,422.0	1,410	11,083
2,424.0	1,593	14,085	2,425.0	1,684	15,724	2,426.0	1,775	17,453
2,428.0	1,934	21,161	2,430.0	2,092	25,187	2,430.5	2,147	26,247
2,432.0	2,311	29,590	2,434.0	2,529	34,429	2,435.0	2,639	37,013
2,435.5	2,693	38,346	2,436.0	2,748	39,706	2,438.0	2,966	45,421
2,440.0	3,185	51,572						

47. REMARKS AND REFERENCES

[1] All elevations are in feet tied to construction and current water surface vertical datum that is 1.9 feet less than NAVD88.
In 1981 there were modifications to crest of the dam and spillway.

[2] With gate closed top of gate elevation 2,420.0. Auxiliary spillway crest elevation 2,423.5.

[3] Surface area at elevation 2430.5 interpolated from original surface areas, 1950. Original values recomputed using ACAP.

[4] Length of reservoir from 1950 study at elevation 2430. Main 12.1 miles plus tributaries.

[5] From 1991 survey report and Bureau of Reclamation Project Data Book.

[6] Computed from mean annual value of 19,090 acre-feet.

[7] Values provided by Reclamation GP Region.

[8] Surface area and capacity at conservation elevation 2,420.0.

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

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

[11] Capacity computed by Reclamation's ACAP computer program tied to the gage vertical datum that is 1.9 feet less than NAVD88 (GEOID12A).
2013 reservoir topography at 2-foot interval used to develop these 2013 tables.

48. AGENCY MAKING SURVEY Bureau of Reclamation

49. AGENCY SUPPLYING DATA Bureau of Reclamation | DATE March 2014

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

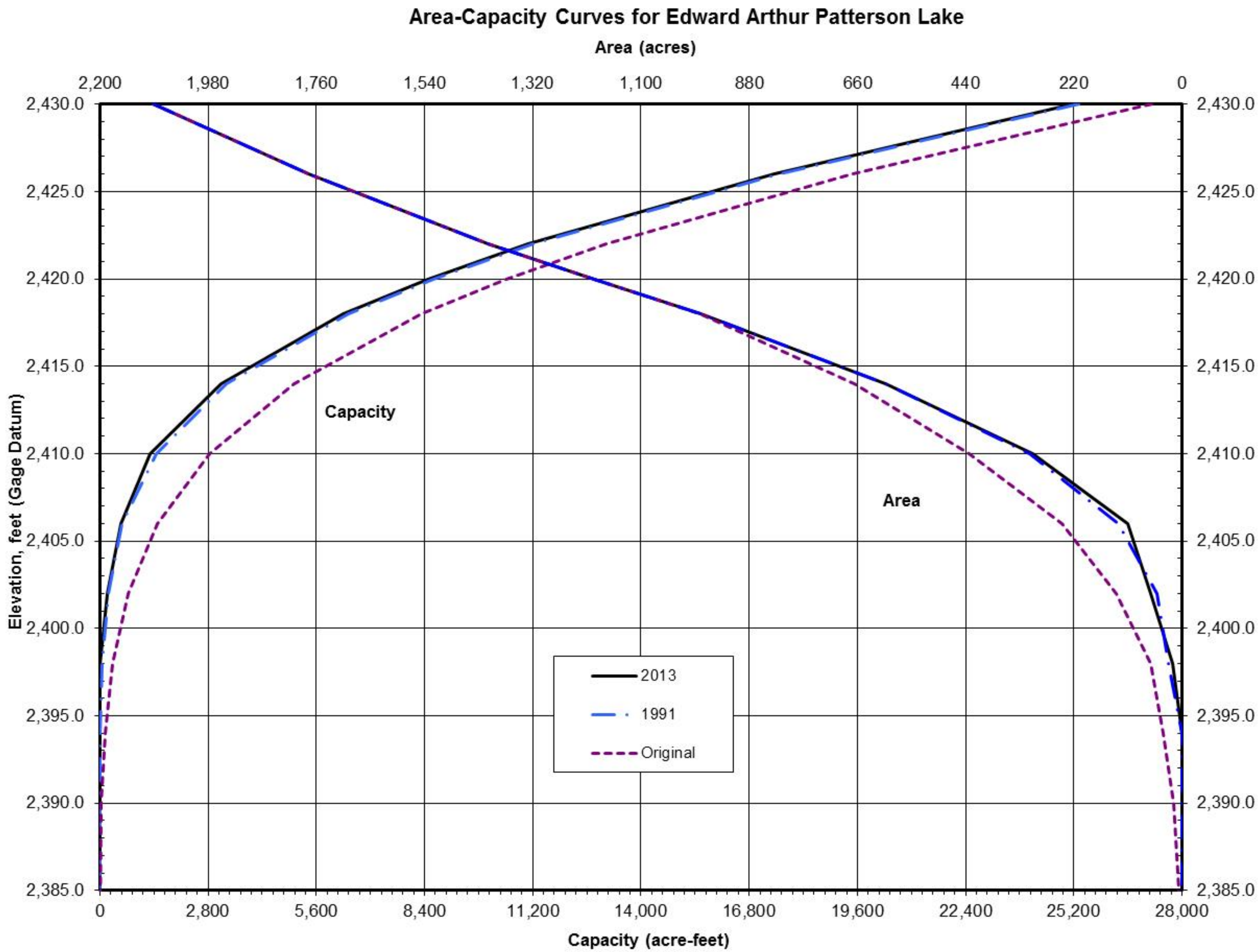

Figure 18 - Area and Capacity Curves, Patterson Lake.

1	2	3	4	5	6	7	8	9	10	11
Elevation Feet	Original Area Acres	Original Capacity Ac-Ft	1991 Area Acres	1991 Capacity Ac-Ft	1991 Sediment Volume Ac-Ft	2013 Area Acres	2013 Capacity Ac-Ft	2013 Sediment Volume Ac-Ft	Percent Reservoir Sediment	Percent Reservoir Depth
2,430.0	2,092	27,205	2,092	25,320	1,885	2,092	25,187	2,018		100.0
2,426.0	1,775	19,471	1,775	17,586	1,885	1,775	17,453	2,018		91.7
2,422.0	1,410	13,101	1,410	11,216	1,885	1,410	11,083	2,018		83.3
2,420.0	1,194	10,497	1,194	8,612	1,885	1,194	8,479	2,018	100.0	79.2
2,418.0	979	8,323	978	6,440	1,883	978	6,307	2,016	99.9	75.0
2,414.0	667	5,031	603	3,278	1,753	603	3,144	1,887	93.5	66.7
2,410.0	432	2,833	309	1,454	1,379	303	1,306	1,527	75.7	58.3
2,406.0	244	1,481	130	576	905	111	541	940	46.6	50.0
2,402.0	133	727	51	214	513	64	201	526	26.1	41.7
2,398.0	63	335	28	56	279	18	15	320	15.9	33.3
2,394.0	39	131	0	0	131	0	0	131	6.5	25.0
2,390.0	17	19	0	0	19	0	0	19	0.9	16.7
2,382.0	0	0	0	0	0	0	0	0	0.0	0.0

1 Reservoir water surface elevation tied to water surface gage vertical datum, 1.9 feet less than NAVD88.
2 Original reservoir surface area.
3 Original reservoir capacity recomputed using ACAP from original measured surface areas.
4 1991 reservoir surface areas computed from a 1991 range line survey.
5 1991 reservoir capacity computed using ACAP.
6 1991 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 (8).
10 2013 percent of total sediment, 2018 acre-feet, by indicated elevation zone.
11 Depth of reservoir expressed in percentage of total depth of 48 feet.

Table 3 - 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 2,418.0 in the upper reach of the reservoir, Figure 19. The distances upstream of the dam and thalweg elevations for the 1950 and 1991 longitudinal profiles were scaled from the thalweg profile plot in the 1991 survey report that showed the thalweg elevations at the sediment range locations for both surveys. The minimum elevations for the 2013 plot, shifted downward 1.9 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 the data limitations, the profiles show the sediment accumulation that has occurred along the river thalweg since the original and 1991 surveys. The inlet sill of the outlet works at elevation 2,404.0 and measured top of sediment deposition at the dam, elevation 2,396, are also plotted. The plots showed only a small accumulation of sediment since 1991, starting at the lower elevations near the dam upstream through the main reservoir body. In the upper reaches, the 2013 profile plot ends around elevation 2,413, the extent of the bathymetric survey data. If measured, the 2013 plot would likely have followed the 1991 alignment, eventually joining it upstream near elevation 2,418.

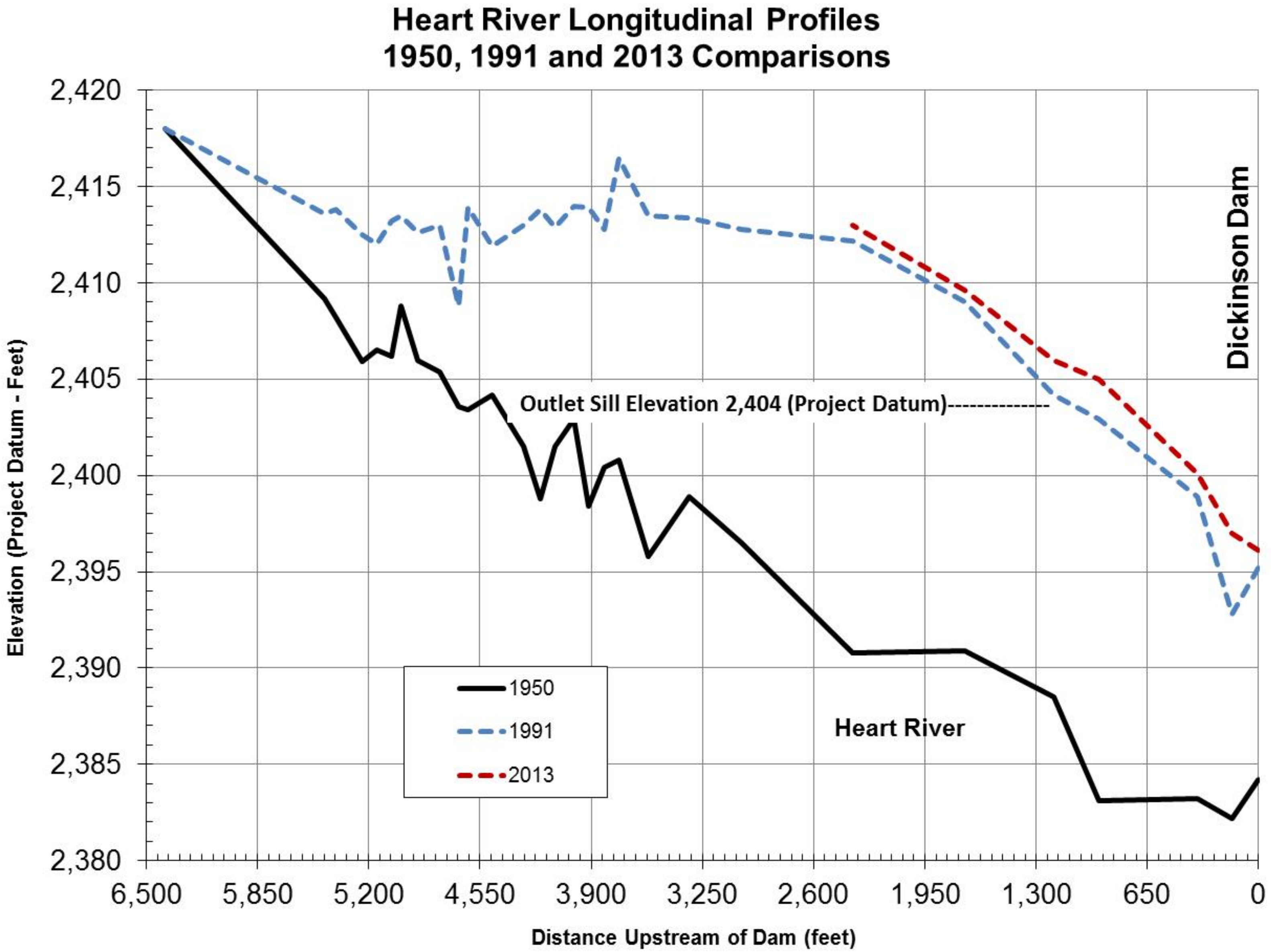

Figure 19 - Longitudinal profile of Heart River above Dickinson Dam.

2013 Patterson Lake Analysis

Results of the 2013 Patterson Lake area and capacity computations are listed in Table 2 and columns 7 and 8 of Table 3. Columns 2 and 3 in Table 3 list the original area and capacity values and columns 4 and 5 list the 1991 area and capacity values. The original surface areas were measured from 4-foot contours of the reservoir area that were assumed collected before dam closure in 1950. The 1991 study was a survey of 41 range lines that were used to compute change of the original measured surface areas and resulting capacities. The 2013 survey developed updated detailed topography of Patterson Lake from which elevation versus surface area and volume relationships were computed from elevation 2,412.0 and below. Due to thick vegetation throughout the upper reservoir and near the entire shoreline, the survey vessel could not access these areas, limiting the detailed collection needed to map above elevation 2,412 throughout the reservoir. The 2013 bathymetric survey was conducted near water surface elevation 2,420.0, the reservoir conservation elevation, and over 25,900 data points were collected from minimum elevation 2,394.3 up to elevation 2,417.0. Dense vegetation above elevation 2,412 prevented the development of accurate contours within that upper zone. The contour of the conservation elevation 2,420.0 was digitized from aerial photography obtained from the USDA, but interpolated contours developed between elevation 2,412 and 2,420 were not sufficient to calculate accurate surface areas to be used for this study. 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 2,496.0 (NAVD88), to above the top of the surcharge elevation extended to 2,440.0 (NAVD88) using the IFSAR data set. The best means to truly measure the 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.

The 2013 Patterson Lake 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 0.1 feet lower than NGVD29 and around 1.9 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 1991 surface area and capacity values. Figure 18 illustrates the differences in the Patterson Lake surface area and capacity values for the original, 1991, and 2013 surveys. Table 3 lists elevation 2,430.0 as the maximum reservoir level as used for the 1991 study, but current information lists the maximum level as elevation 2,435.5. The area and capacity tables were extended to elevation 2,440.0 to fully cover the surcharge zone. The 2013 assumed no change from elevation 2,420.0

and above since the 1991 study due to lack of 2013 data above elevation 2,413. Operation records list the reservoir's maximum water surface to date as elevation 2,422.2 in 1997, meaning the reservoir extended into the flood zone, but has never entered into the surcharge zone which starts at elevation 2,430.5.

The surface area and volume differences on Table 2 are referenced to conservation elevation 2,420.0 where the 2013 study measured a total decrease in capacity of 2,018 acre-feet since dam closure in 1950. The capacity change is due to sediment deposition and methodology differences between the surveys. The computed average annual reduction since dam closure was 32.0 acre feet. The study found that after the first 63 years of reservoir operations sediment deposition accounted for 19.2 percent of the conservation volume. The thalweg elevation at range line 1, just upstream of the dam, is 2,396 or 8 feet below the outlet sill elevation of 2,404.0. The survey determined that the sediment level in 2013 at the intake to the outlet works is currently not interfering with reservoir operations.

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 water surface elevation during the 2013 survey. If aerial data is collected it should be scheduled during a major drawdown of the reservoir when vegetation is dead or dormant, allowing collection of bare earth data in otherwise vegetated areas of the reservoir.

Summary and Conclusions

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

- develop reservoir topography;
- compute area-capacity relationships; and
- determine storage depletion since dam closure and the 1991 survey.

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 temporary monument near the dam. The base location provided continuous radio link throughout the hydrographic survey.

The study's horizontal control was in US Survey 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 1.9 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 2,420 as measured by the Reclamation gage at the dam and confirmed through RTK GPS measurements. The bathymetric survey used sonic depth recording equipment interfaced with a RTK GPS for determining sounding locations within the reservoir. The system continuously recorded depth and horizontal coordinates as the survey boat navigated along set 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 would produce more accurate data than IFSAR, but this study did not have funding to acquire these other data sets. In densely vegetated areas around the reservoir, the IFSAR data did not match well and were removed for this analysis. The remaining IFSAR data points, along with the other data sources, were used to develop the 2013 Patterson Lake topography. For the reservoir areas where the IFSAR data were removed, the topographic mapping software interpolated contours from the surrounding data sources, but the limited data due to vegetation prevented computation of accurate surface areas above elevation 2,412.0.

The final 2013 Patterson Lake 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 2,396.0 and above. The input from the 2013 surface areas was from elevation 2,412.0 and below was used to develop the area and capacity tables. The surface areas from elevation 2,414.0 and above were from the 1991 study assuming no change since then. 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 2 and 3 contain summaries of the Patterson Lake and watershed characteristics for the 2013 survey. The 2013 survey determined the reservoir has a total storage capacity of 38,346 acre-feet below elevation 2,435.5. At conservation water surface elevation 2,420.0 the total capacity was 8,479 acre-feet with a surface area of 1,194 acres. Since closure of Dickinson Dam in 1950, this survey measured a 2,018 acre-foot reduction in reservoir capacity below elevation 2,420.0. The capacity difference was computed by comparing the original and 2013 capacities for the reservoir. It is assumed the measured change was primarily due to sediment deposition, with some variation due to data accuracy differences between methods of collection and analysis from the previous surveys.

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