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Technical Report No. SRH-2011-11

Jamestown Reservoir 2009 Bathymetric Survey

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

May 2011

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prepared by

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Bureau of Reclamation
Technical Service Center
Water and Environmental Resources Division
Sedimentation and River Hydraulics Group
Denver, Colorado

May 2011

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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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14. ABSTRACT

Reclamation surveyed Jamestown Reservoir in July 2009 to develop updated reservoir topography and compute the present storage-elevation relationship (area-capacity tables). The bathymetric survey, conducted between water surface elevation 1,435.2 and 1,436.4 (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 from a combination of digital bare earth Interferometric Synthetic Aperture Radar (IFSAR) data and digitized water's edge data from aerial photographs collected by the United States Department of Agriculture (USDA) at water surface elevations 1,430.1 and 1,435.3 feet.

As of July 2009, at active conservation pool elevation 1,428.0, the reservoir surface area was 1,875 acres with a total capacity of 24,226 acre-feet. Since the February 1954 dam closure, a total capacity change of 1,329 acre-feet below elevation 1,428.0 was measured for an average annual loss of 24.0 acre-feet. The capacity change is likely due to sediment deposition and differences in accuracy between the 2009 and previous studies. The reservoir topography from Jamestown Dam up to Jim Lake Dam (located in the Arrowwood National Wildlife Refuge) was redeveloped as part of the 2009 study.

15. SUBJECT TERMS

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Technical Report No. SRH-2011-11

Jamestown Reservoir 2009 Bathymetric Survey

Jamestown Dam
Jamestown, North Dakota

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3/6/12
Date

Table of Contents

Page

Index of Figures

Page

Index of Tables

Page

Jamestown Reservoir
2009 Bathymetric Survey

Introduction

Jamestown Dam and Reservoir are principal features of the Garrison Diversion Unit in Stutsman County located near east central North Dakota (Figure 1). The dam (located on the James River about 1.5 miles north of Jamestown, North Dakota) and reservoir provide flood protection and water for irrigation and municipal uses.

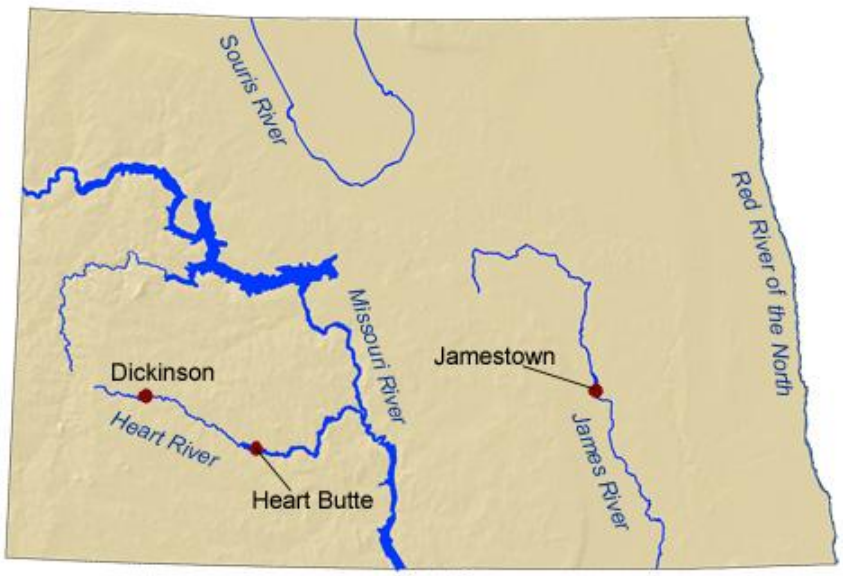

Figure 1 - Reclamation Reservoirs Located in North Dakota.

Jamestown Dam, a zone rolled earthfill structure, was constructed from 1952 through 1954 with first storage in February 1954. The dam's dimensions are:

Structural height[1]	110	Hydraulic height	69
Crest length	1,431	Crest elevation[2]	1,471.0

[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, confirmed by this study, tied to the National Geodetic Vertical Datum of 1929 (NGVD29). In the 2009 study area, NGVD29 is an average of 1.25 feet lower than the North American Vertical Datum of 1988 (NAVD88).

The spillway, located near the right abutment of the dam, is an uncontrolled morning glory with crest elevation 1,454.0. The spillway capacity is 2,930 cubic feet per second (ft^3/s) at reservoir elevation 1,464.4 (Figure 2). The river outlet works consist of a high pressure, gate-controlled, concrete conduit through the left abutment of the dam. The intake crest is at elevation 1,400.0 with an outlet capacity of 2,990.0 ft^3/s at reservoir elevation 1,464.4.

Figure 2 - Top of Jamestown Dam. Looking west towards morning glory spillway.

A well defined drainage area above the dam has yet to be developed. The published values for total drainage area range from 1,290 square miles (USBR, 1984) to 1,760 square miles (USGS, 2001), depending on the information source. The contributing drainage area from different published sources varies between 437 and 750 square miles. The drainage area has numerous smaller depressions or closed basins that rarely or never drain. Potential runoff from frequent rainfall events collects in these low areas and is lost to evaporation and infiltration. During low-intensity events, the sub-basins fill with and retain water, not contributing to the runoff. During high-intensity events the sub-basins may fill and spill over, contributing to the runoff. Thus, the contributing drainage area changes with the intensity of rainfall needed to produce the larger runoff events.

The original surface areas for Jamestown Reservoir were derived from 1940's USGS and USACE maps. The original storage capacity excluded the volume of the smaller lakes located within the Arrowwood National Wildlife Refuge

(ANWR). There are three low-head impoundments on the James River upstream of Jamestown Dam (Arrowwood and Jim Lakes in the ANWR and Lake Juanita in the northeast part of the basin) that trap a portion of the potential sediment inflow into Jamestown Reservoir. Near elevation 1,440, the backwater from Jamestown Dam begins to inundate Jim Lake Dam and its downstream diversion structures. The reservoir is around 13.8 miles long with an average width of 0.2 miles at elevation 1,428 and is over 30 miles long at maximum pool elevation 1,464.4 (Figure 3).

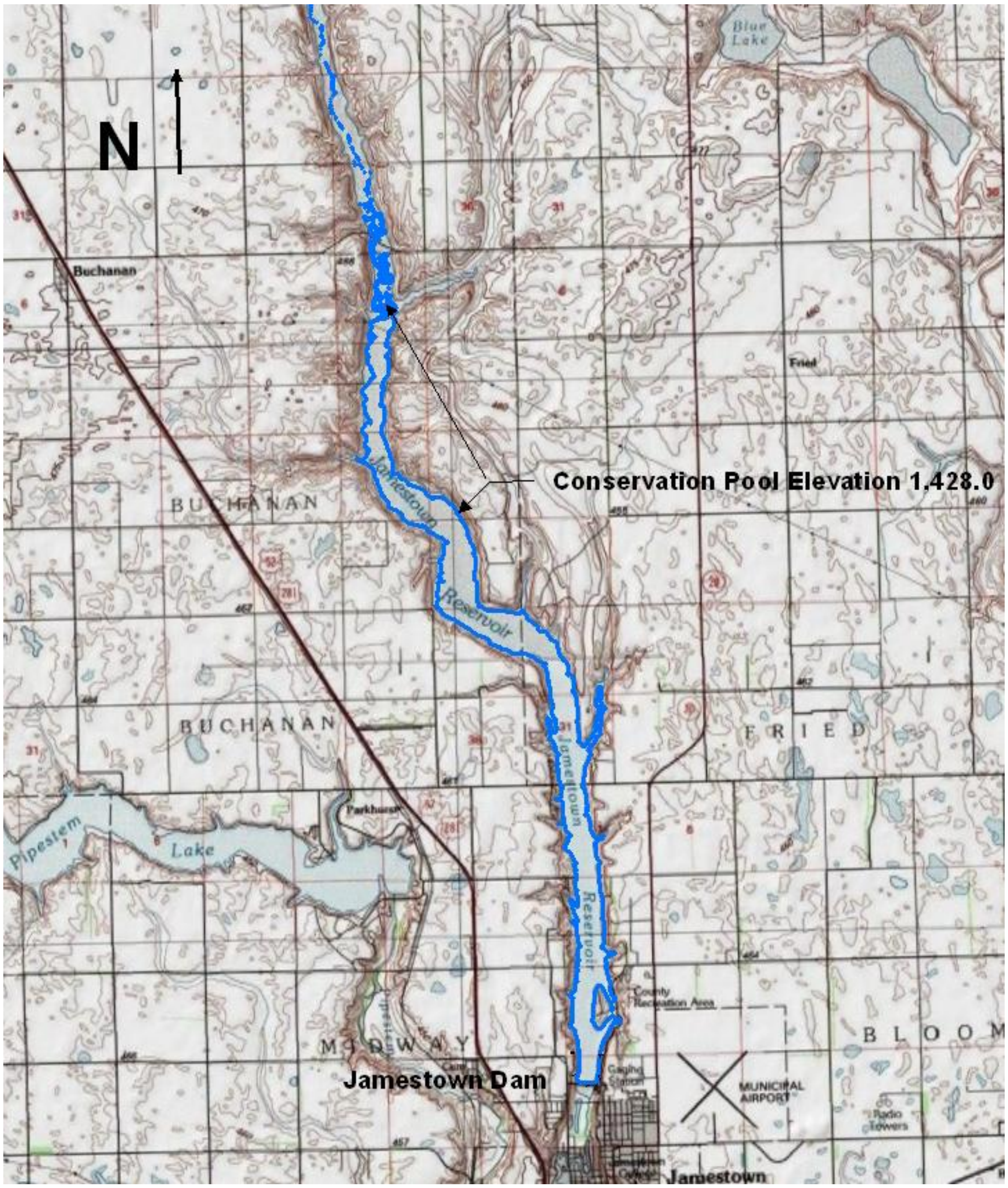

Figure 3 - Jamestown Reservoir location map, USGS quad map.

Control Survey Data Information

Prior to the 2009 bathymetric survey, a temporary control point was established on a mark on top of a rock in a flat open area upstream of the dam using the Online Positioning User Service (OPUS), Figures 4 and 5. OPUS, operated by the NGS, allows users to submit GPS data files that are processed with Continuously Operating Reference Station (CORS) network data to determine a point's horizontal and vertical positions relative to the National Spatial Reference System (NSRS) (www.ngs.noaa.gov/OPUS). This temporary point was used as the GPS base for the majority of the bathymetric survey, for establishing additional control points, measuring topographic data, and measuring water surface elevations during bathymetric data collection. The horizontal control was in North Dakota's south zone state plane coordinates in NAD83 and the vertical control was tied to NAVD88. Unless noted, all elevations in this report are referenced to Reclamation's project datum, tied to NGVD29, and 1.25 feet lower than NAVD88. Following is the OPUS solution for the temporary point:

NAD83/NAVD88		**NAD27/NGVD29**	
North	471,704.83	North	471,708.52
East	2,416,633.48	East	2,448,242.09
Elevation	1,492.92	Elevation	1,491.67

Figure 4 - GPS control point located on island upstream of the dam.

Figure 5 - GPS control point, marked on flat rock on island.

Reservoir Operations

Jamestown Reservoir, part of the Garrison Diversion Unit of the Pick-Sloan Missouri Basin Program, was designed to provide water storage for irrigation, municipal use, and flood control. The 2009 survey and analysis determined that the reservoir has a total storage capacity of 379,907 acre-feet with a surface area of 17,435 acres at maximum water surface elevation 1,464.4. The 2009 survey measured a minimum lake bottom elevation near 1,392.0. The following values are from the July 2009 capacity table:

158,917 acre-feet of surcharge pool storage between elevation 1,454.0 and 1,464.4
190,502 acre-feet of exclusive flood storage between elevation 1,431.0 and 1,454.0[3]
6,262 acre-feet of joint use storage between elevation 1,428.0 and 1,431.0
23,934 acre-feet of conservation pool storage between elevation 1,400.0 and 1,428.0
292 acre-feet of dead pool storage below elevation 1,400.0.

The computed annual inflow and reservoir stage records for Jamestown Reservoir are listed by water year in Table 1 starting in 1954. The values show the annual

[3] After September 1st the base flood control elevation is lowered to elevation 1,429.8 increasing storage to 193,182 acre-feet.

fluctuation with a computed average annual inflow of 47,070 acre-feet. Table 1 data shows the annual fluctuation of the reservoir water surface with maximum recorded elevation of 1,454.1 in 2009 followed by the second highest annual elevation of 1,445.9 in 1997. Since first filling in 1958, the reservoir was drawn down to a minimum elevation of 1,420.9 in 1993.

Hydrographic Survey Equipment and Method

Bathymetric Survey Equipment

The bathymetric survey equipment was mounted in the cabin of a 24-foot trihull aluminum vessel equipped with twin in-board motors (Figure 6). The hydrographic system included a GPS receiver with a built-in radio, single and multibeam depth sounders, helmsman display for navigation, computer, and hydrographic system software for collecting the underwater data. An on-board generator supplied power to all the boat equipment. A second smaller boat was equipped with survey equipment powered by 12-volt batteries and was used to map the shallow water areas of the reservoir upstream of the Buchan highway bridge. The shore equipment included a second GPS receiver with an external radio. The GPS receiver and antenna were mounted on a survey tripod over a known datum point with a 12-volt battery providing the power for the shore unit.

The Sedimentation and River Hydraulics Group uses RTK GPS to obtain precise heights measured in real time to monitor water surface elevation changes. The basic output 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 datum of GRS 1980, which the hydrographic collection software converted into North Dakota’s state plane coordinates, south zone in NAD83. The RTK GPS system employs two receivers that track the same satellites simultaneously.

Single Beam Survey

The Jamestown Reservoir bathymetric survey was conducted in July 2009 between water surface elevations 1,435.2 and 1,436.4 (project datum). The bathymetric survey was conducted using sonic depth recording equipment, interfaced with a RTK GPS, capable of determining sounding locations within the reservoir. The single beam survey system software continuously recorded reservoir depths and horizontal coordinates as the survey boat moved along closely-spaced grid lines covering the reservoir area. Most transects (grid lines) were run somewhat parallel to the upstream-downstream alignment of the reservoir at around 200-foot spacing. The survey vessel's guidance system gave directions to the boat operator to assist in maintaining the course along these predetermined lines. Data was also collected along the shore by the survey vessel. During each run, the depth and position data were recorded on the laptop computer hard drive for subsequent processing.

Figure 6 – Large survey vessel with mounted instrumentation on El Vado Reservoir, New Mexico.

The single beam depth sounder was calibrated by lowering a weighted cable below the boat with beads marking known depths. The collected data were digitally transmitted to the computer collection system through a RS-232 port. The single beam depth sounder also produced an analog digital image of the measured depths. The smaller survey vessel collected single beam data along the shoreline of the main body of the reservoir. These digital analog depth images were analyzed during post-processing, and when the analog depths indicated a difference from the computer-recorded bottom depths, the computer data files were modified. The water surface elevations at the dam, recorded by a Reclamation gage, were used to convert the sonic depth measurements to true lake-bottom elevations in NGVD29. During analysis all elevations were shifted to NAVD88 for final reservoir topographic development.

Multibeam Survey

In 2001, the Sedimentation and River Hydraulics Group began utilizing an integrated multibeam hydrographic survey system. The system consists of a single transducer mounted on the center bow or forward portion of the boat. From the single transducer, a fan array of narrow beams generates a detailed cross section of bottom geometry as the survey vessel passes over the areas mapped. The system transmits 80 separate 1-1/2 degree slant beams resulting in a 120-degree swath from the transducer. The 200 kHz high-resolution multibeam echo sounder system measures the relative water depth across a wide swath perpendicular to the vessel's track. Figure 7 illustrates the swath of the sea floor that is about 3.5 times as wide as the water depth below the transducer.

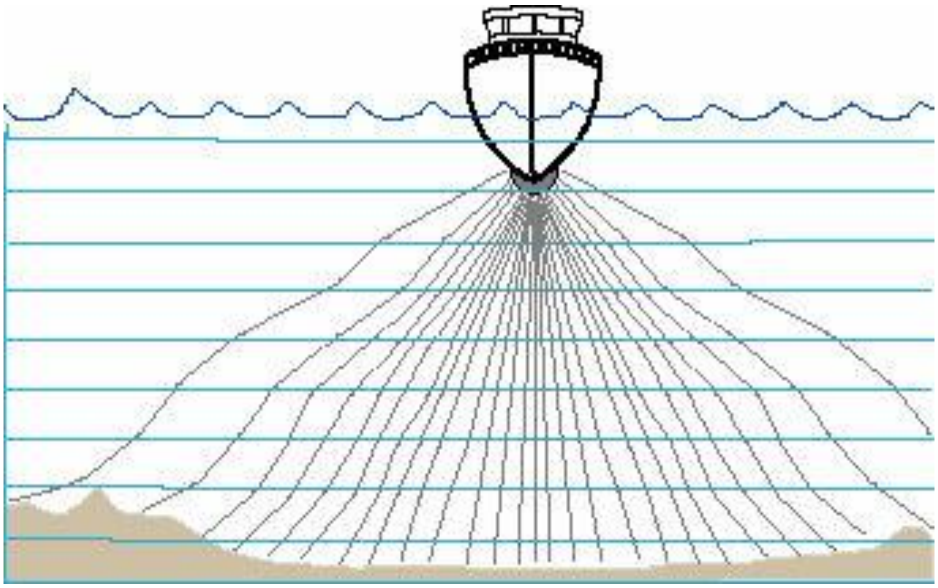

Figure 7 - Multibeam collection system.

The multibeam system is composed of several instruments all in constant communication with a central on-board laptop computer. The components include the RTK GPS for positioning; a motion reference unit to measure the heave, pitch, and roll of the survey vessel; a gyro to measure the yaw or vessel attitude; and a velocity meter to measure the speed of sound through the vertical profile of the reservoir water. The multibeam sounder was calibrated by lowering an instrument that measured the sound velocity through the reservoir water column. The individual depth soundings were adjusted by the measured speed of sound which can vary with density, salinity, temperature, turbidity, and other conditions. With proper calibration, the data processing software utilizes all the incoming information to provide an accurate, detailed x,y,z data set of the lake bottom.

The multibeam soundings, combined with the single beam soundings resulted in a detailed data set of around 1,717,000 x,y,z points representing the reservoir below the collection water surface elevation. The multibeam survey system software continuously recorded reservoir depths and horizontal coordinates as the survey vessel moved along closely-spaced grid lines covering the reservoir area. Most transects (grid lines) were run parallel to the reservoir alignment with the multibeam swaths overlapping in the deeper areas to provide full bottom coverage of the areas surveyed. The multibeam system could have provided more detailed bottom coverage throughout the reservoir by running more closely in the shallower areas of the reservoir, but time and budget did not allow for the rest of the reservoir bottom to be surveyed by this method. Regardless, the additional beams provided more reservoir bottom detail than would have been obtained if only mapped by the single system.

Bathymetric Data Set

Figures 8 and 9 show portions of the reservoir areas covered by the multibeam and single beam collection systems. The underwater collected data was processed using the same hydrographic system software used during the data collection. During processing, all corrections, such as vessel location and roll, pitch, and yaw effects, were applied. Other corrections included applying the sound velocity through the reservoir water column and converting all depth data points to elevations using the measured water surface elevation at the time of collection. To make it more manageable, the massive amount of multibeam data was filtered into 5-foot cells or grids of the reservoir area surveyed by the multibeam system. The multibeam data was combined with the single beam data to produce the x,y,z data set used for Jamestown Reservoir map development. Additional information on general bathymetric data collection and analysis procedures can be found in *Engineering and Design: Hydrographic Surveying* (Corps of Engineers, January 2002) and *Reservoir Survey and Data Analysis* (Ferrari and Collins, 2006).

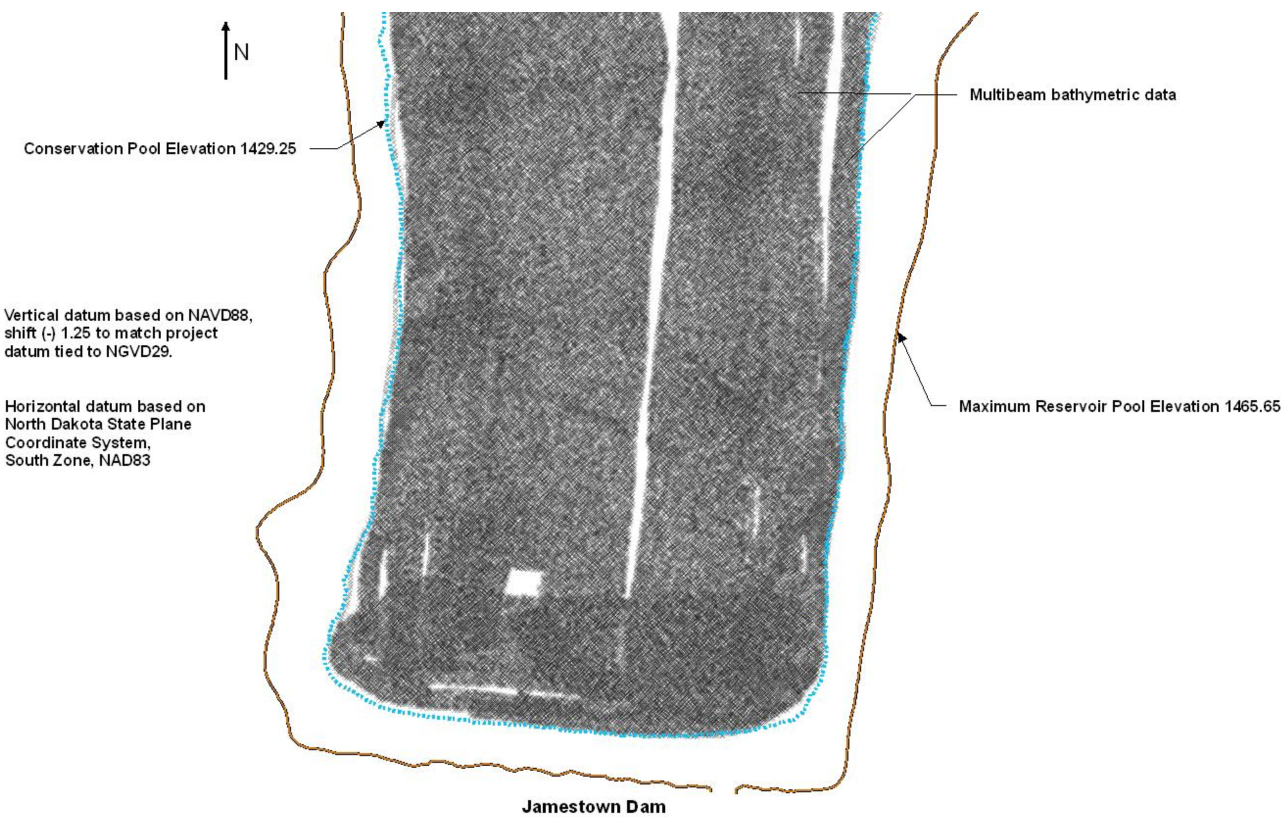

Figure 8 - Jamestown Reservoir bathymetric data points (NAVD88).

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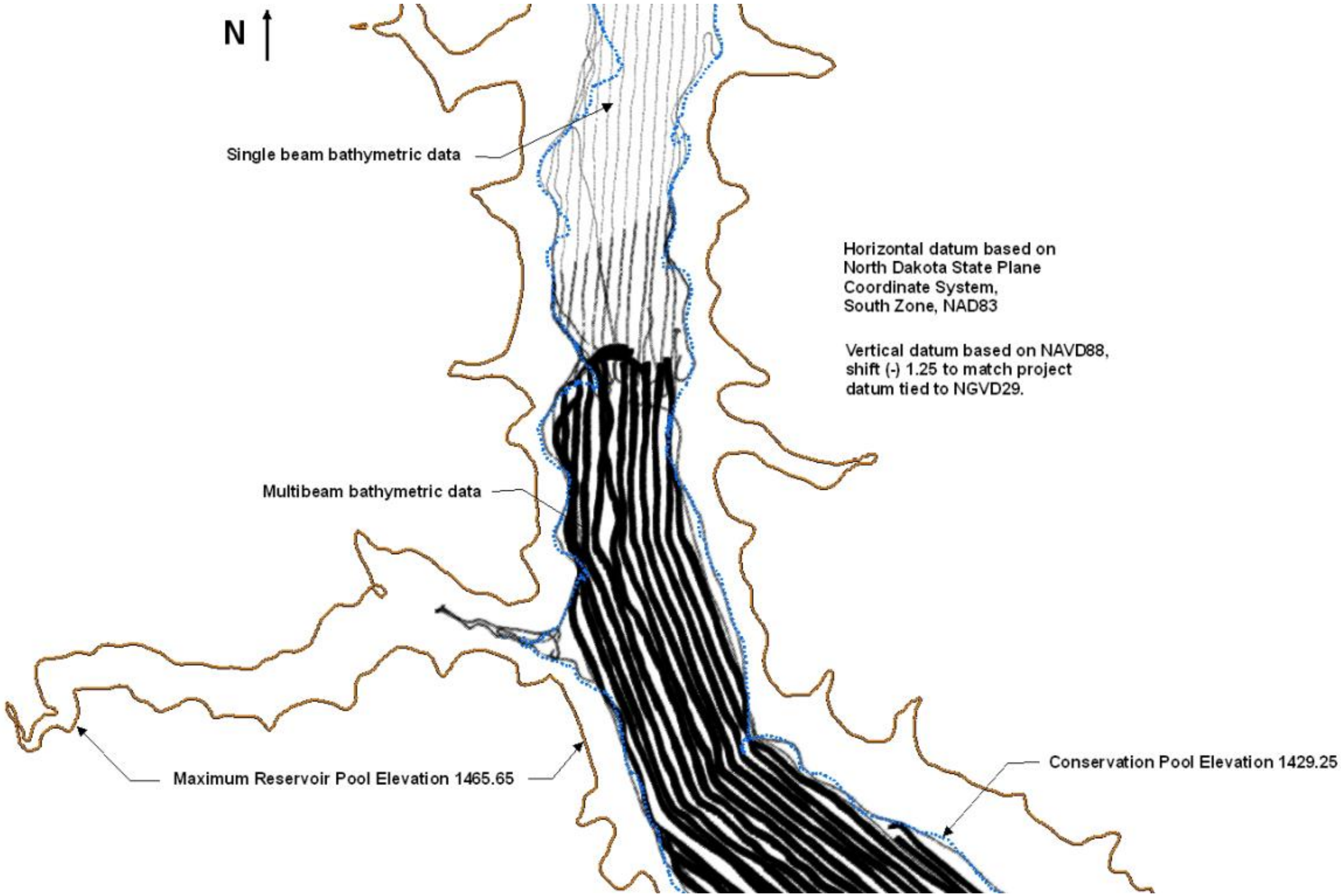

Figure 9 - Jamestown Reservoir bathymetric data points (NAVD88).

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Aerial Photographs

During the analysis, orthographic aerial images collected in 2009 near water surface elevations 1,430.1 and 1,431.1 (NGVD29) (1,431.35 and 1,432.35 (NAVD88)) and in 2010 near water surface elevation 1,435.3 (NGVD29) (1,436.5 (NAVD88)), were downloaded from the USDA data web site (USDA, 2010). The 2010 aerials were flown near the same reservoir water surface elevation as the 2009 bathymetric collection. A reservoir contour enclosing the bathymetric data was developed by digitizing the water's edge from the 2010 aerial images, Figures 10 and 11.

Figure 10 - Aerial image of Jametown Dam and Reservoir at water surface elevation 1,431.35 (NAVD88), flown in 2010 (USDA, 2010).

Figure 11 - Aerial image of upper Jamestown Reservoir downstream of Jim Lake at water surface elevation 1,431.35 (NAVD88), flown in 2009 (USDA, 2010).

IFSAR Data Set

To complete the topography for areas of the reservoir not covered by the 2009 bathymetric survey, additional data was needed. Interferometric Synthetic Aperture Radar (IFSAR) digital data was obtained as bare earth, 5-meter grid coordinates (east, north, elevation) tied to North Dakota's state plane south zone with vertical elevations tied to NAVD88. 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 aerial photogrammetry and LiDAR (Intermap, 2011). The IFSAR data was collected when Jamestown Reservoir was near water surface elevation 1,431 (NAVD88) and was the best option available, for areas not covered by the 2009 bathymetric survey, to develop the upper topography for Jamestown Reservoir. For this study the IFSAR data was obtained from Jamestown Dam to just upstream of Jim Lake Dam. The Jim Lake water surface elevation was also near 1,431 (NAVD88) during the time of the IFSAR collection, Figure 12. Due to budget constraints and purchase restrictions, the IFSAR data was limited to just upstream of Jim Lake, about one third of the total length of Jamestown at maximum elevation 1,464.4. The water levels in Jim Lake at the time of the collection limited the need to acquire the remaining IFSAR data in the upper reach. Future measurement of the bottom elevations in Jim and Arrowwood Lakes would be necessary to compute the total capacity of Jamestown Reservoir. Due to marsh type conditions in those lakes, a ground based survey would likely need to be conducted during the winter when leaves are off the vegetation and water levels are down. Also, the original capacity did not account for volumes within the refuge reservoirs, so including those volumes in the 2009 analysis would have invalidated the comparison to the original data.

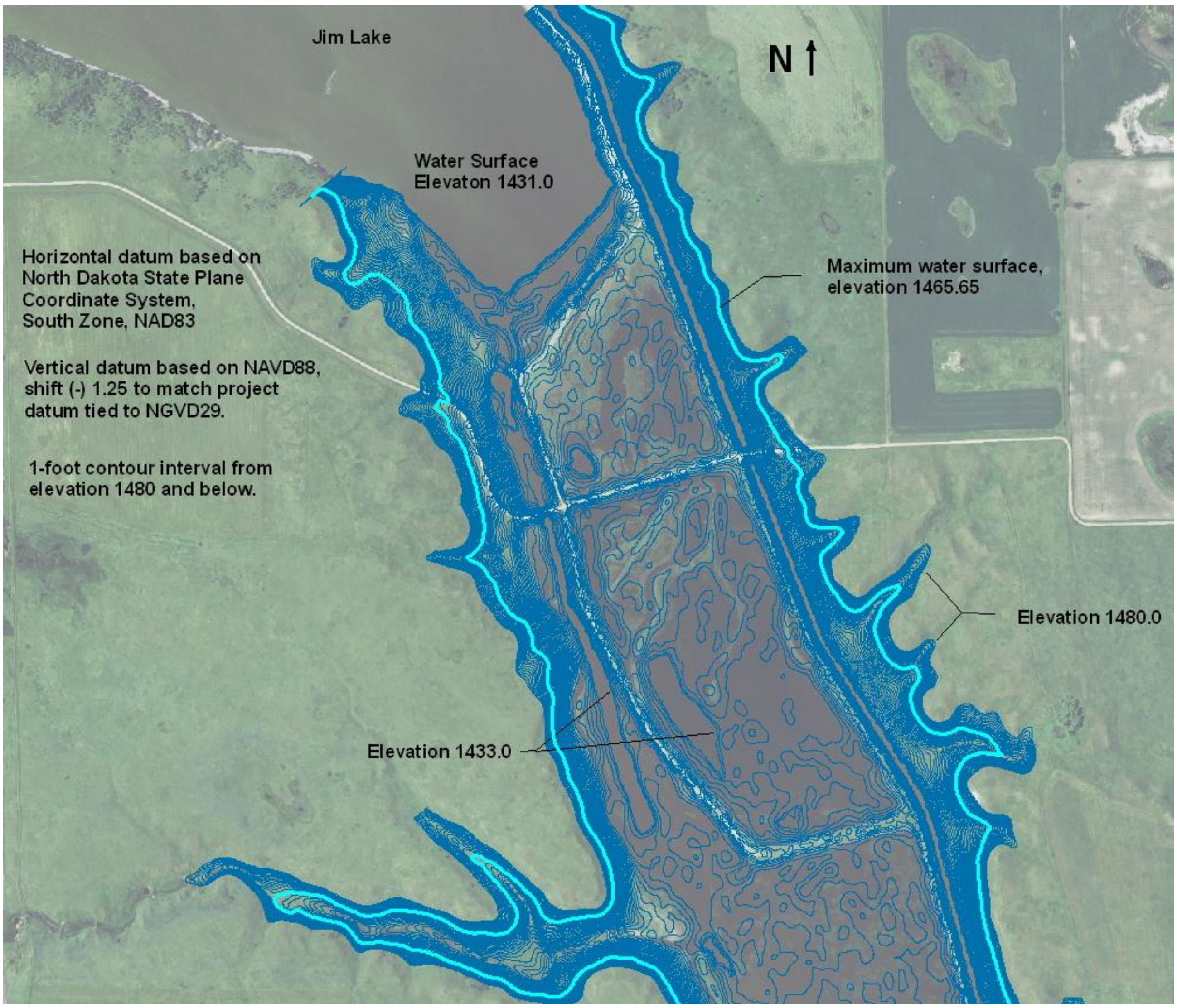

Figure 12 - Upper reach of the contours developed for the 2009 study. Ended just upstream of Jim Lake Dam.

IFSAR reported accuracies are 2 meters or better horizontally and 1 meter or better vertically for areas of unobstructed flat ground (Intermap, 2011). Analysis for this study showed that the IFSAR data was less accurate than the 2009 and 2010 USDA aerial photographic data. Although the IFSAR data did not show the details of the small inlets along the main shoreline of the reservoir, it was sufficient to help meet the study objective of measuring change over time by comparing the 2009 topography to the original data. Without the IFSAR data, no change from the original surface areas from elevation 1,428 and above would have been assumed for this study due to lack of data.

To check the reliability of the IFSAR data, a contour was developed for elevation 1,435.3 (NAVD88), the reservoir stage at the time the 2010 USDA aerial photography was collected. This IFSAR contour was then compared to the water line delineated from the 2010 USDA aerial photography to check for consistency (Figures 13 through 16). All elevations for the figures were tied to the vertical datum NAVD88. The figures show areas where the two contours, USDA and IFSAR, compared very well and areas where they varied. Where they differ, the IFSAR contour typically plots slightly inside of the digitized bankline from the USDA aerial images. The IFSAR data did not provide the same level of detail in the reservoir inlets as the USDA aerial photography.

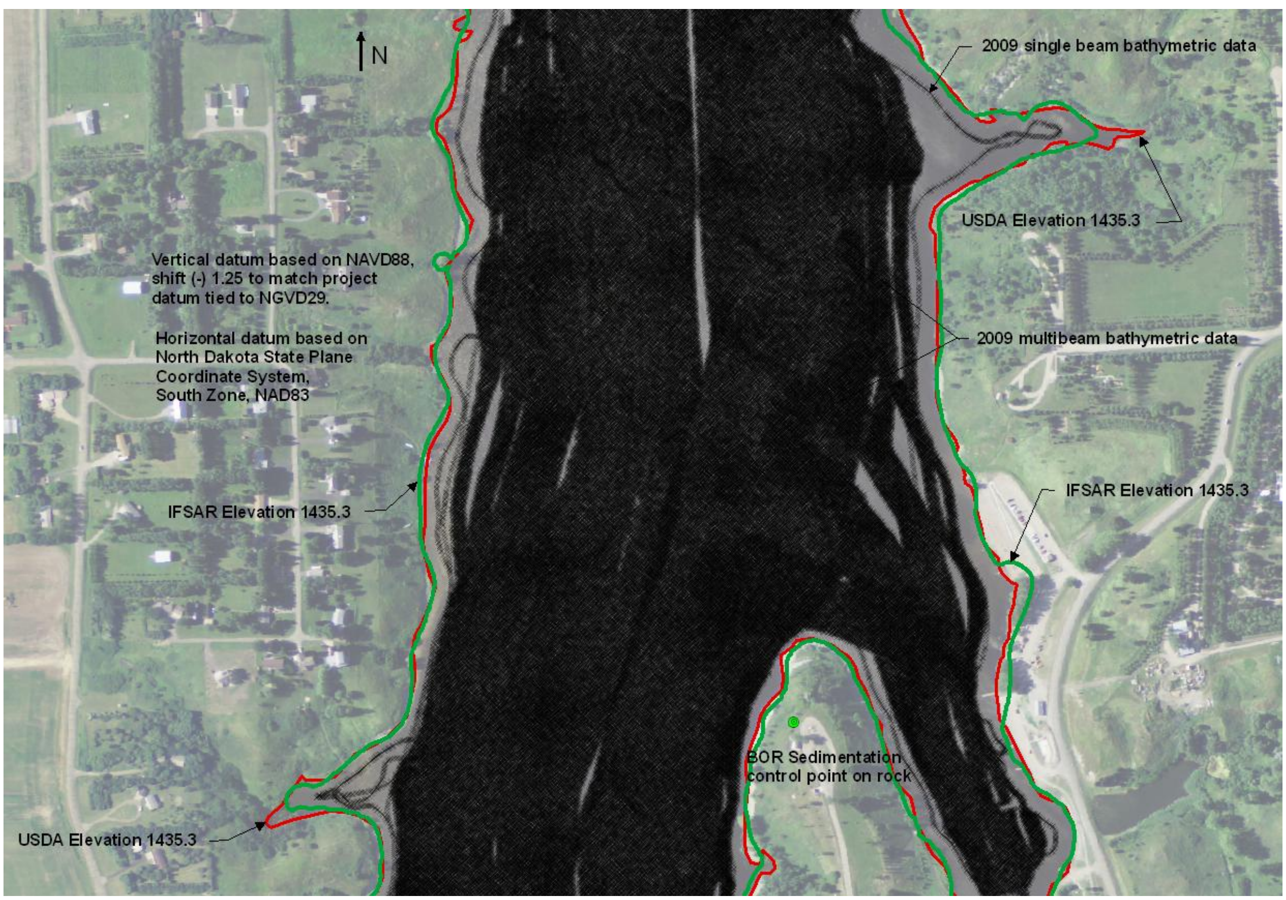

Figure 13 - Jamestown Reservoir USDA and IFSAR contour comparisons (NAVD88).

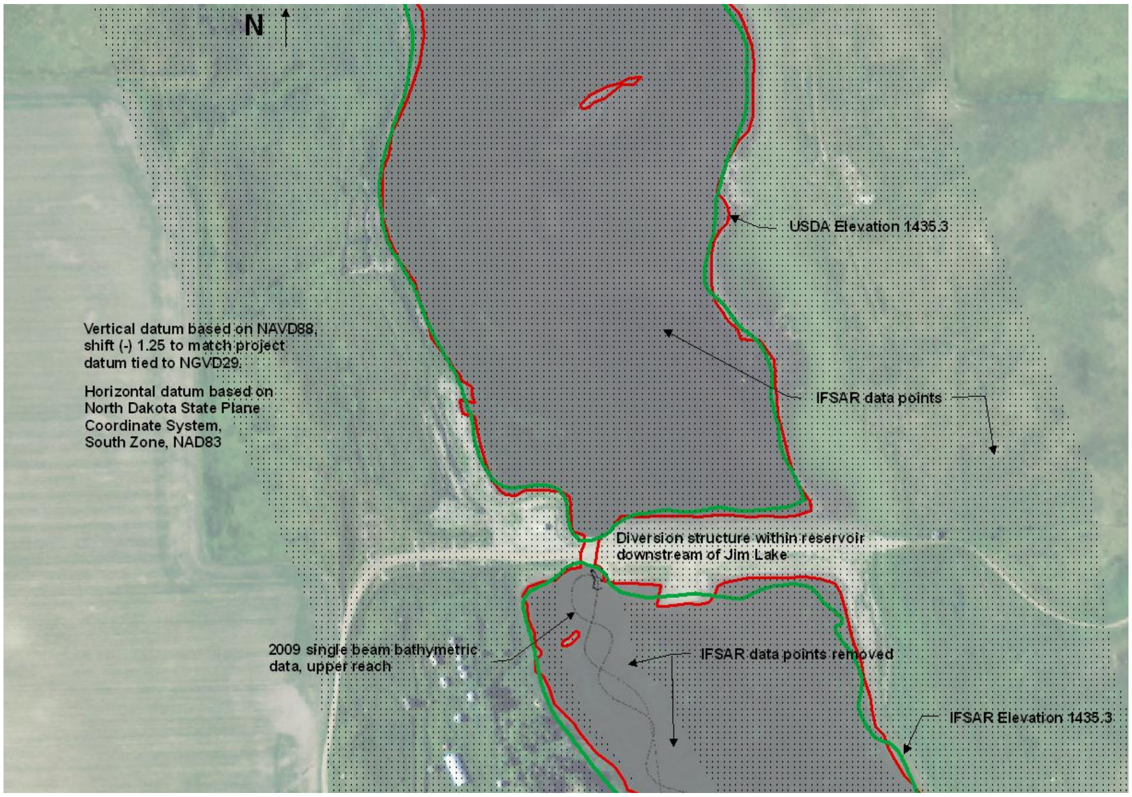

Figure 14 - Jamestown Reservoir USDA and IFSAR contour comparisons (NAVD88). Shows upper portion of the reservoir where the 2009 bathymetric single beam data ended.

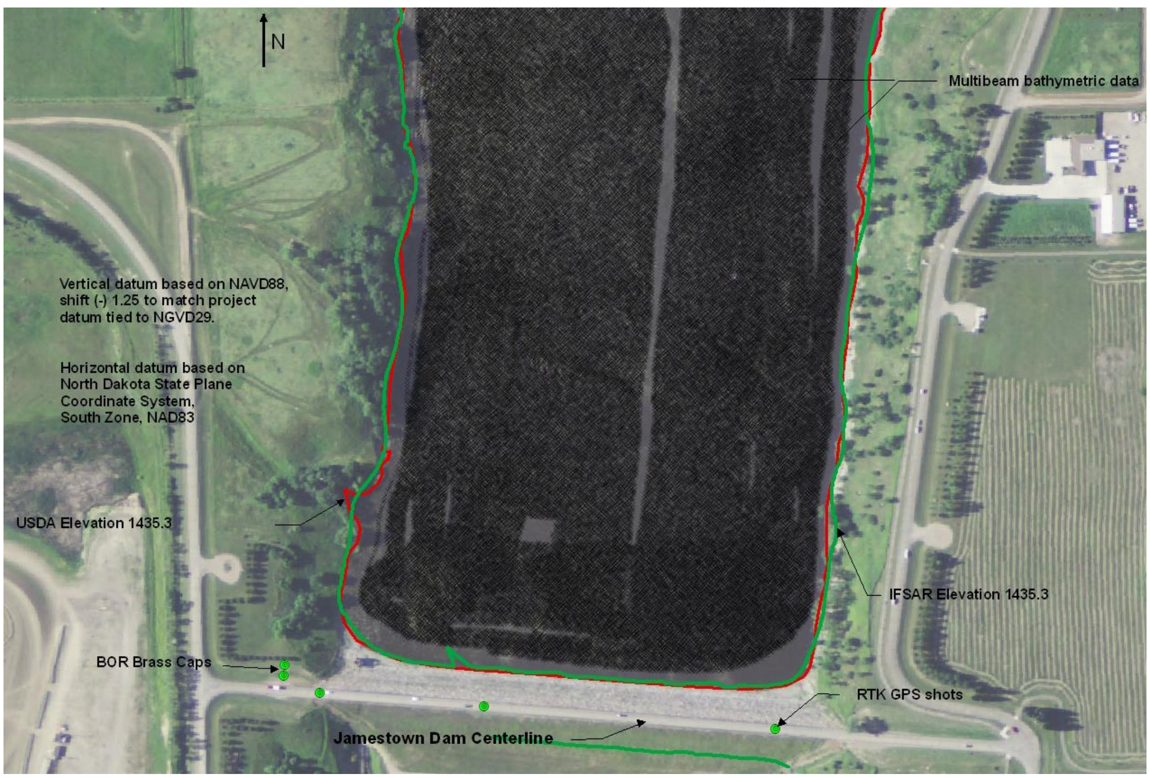

Figure 15 - Jamestown Dam, survey data layers (NAVD88).

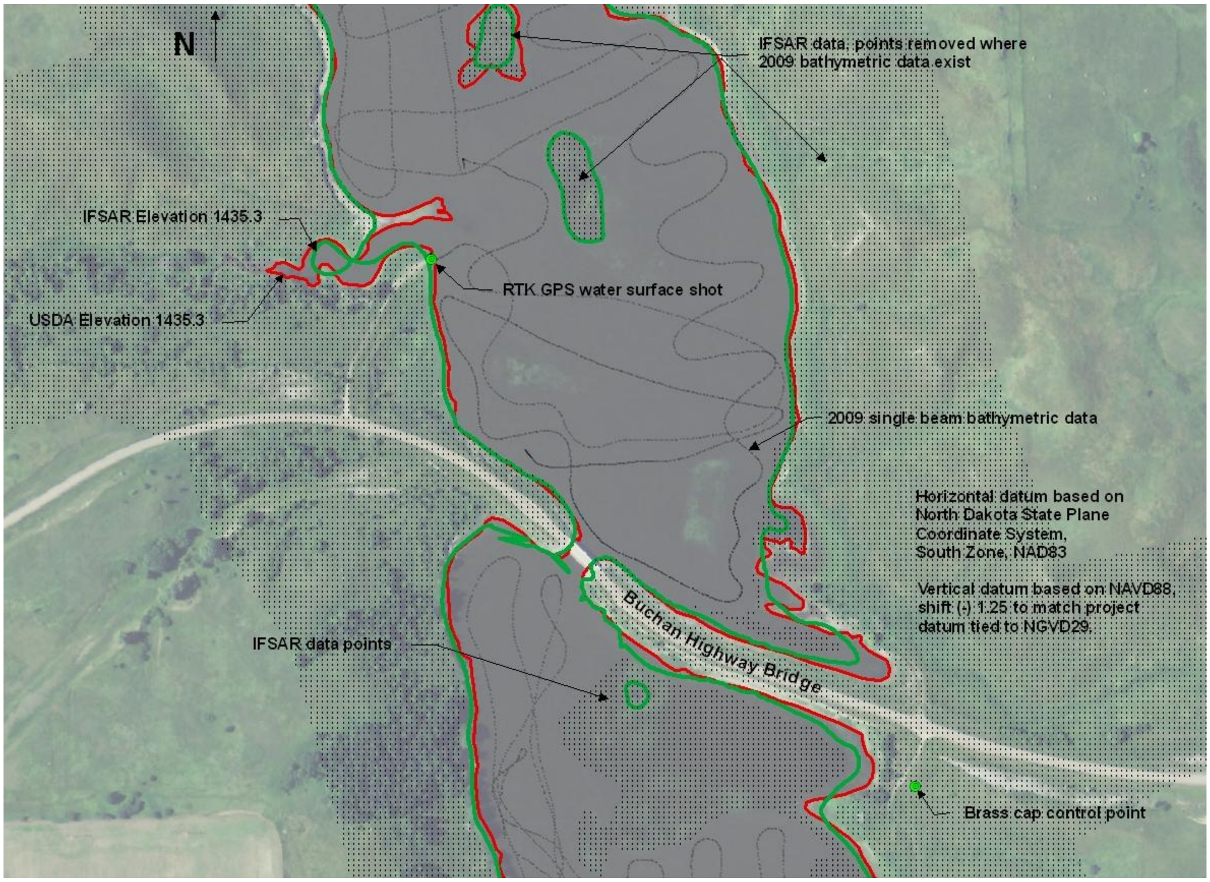

Figure 16 - Jamestown Reservoir area, USDA and IFSAR contour comparison (NAVD88).

RTK GPS topographic points were used to further check IFSAR data point elevations (Figures 17 and 18). RTK GPS measurements were also used to establish two bench marks for the 2009 survey to which all GPS measurements were referenced, such as RTK GPS shots on the dam and the water surface elevation measurements. At the control point located near Buchan Bridge (Figure 16), the IFSAR elevation was just over 1 foot higher than the RTK GPS measurement. However, at the bench mark on the island (Figures 13 and 17) from which the majority of the 2009 survey was conducted, the IFSAR elevations were around 12 feet lower than the established GPS base elevation. Both the Buchan Bridge and island rock base points were located higher than the surrounding reservoir area with the Buchan point having high grass vegetation around it and the island rock point surrounded by low-lying grass ground cover. The long grass surrounding the Buchan point could have fouled the IFSAR elevation measurement. Figure 4 shows the island point located in an open area near the vertical drop that may have caused the difference between the IFSAR and RTK elevations. From the island bench mark, RTK GPS measurements were taken on Jamestown Dam where the IFSAR elevations ranged from 1 to 3 feet lower. RTK GPS edge of water measurements were located in fairly open, flat areas of the reservoir where the IFSAR elevations were about 1 foot lower than the RTK GPS measurements. Despite localized problem areas, the IFSAR data was the best available information to merge with the 2009 bathymetric data to develop a continuous topographic surface of Jamestown Reservoir.

Reservoir Area and Capacity

Topography Development

This section discusses the methods used for generating 1-foot topographic contours for Jamestown Reservoir. The data sources included the 2009 bathymetric survey, the digitized reservoir water surface edges from the USDA aerial photographs, and the IFSAR bare earth data (Figures 17 through 26). These data were processed into a triangulated irregular network (TIN) that was then used to develop 1-foot contours. The 2010 USDA contour at elevation 1,436.5 (NAVD88) was part of the data set for the 2009 reservoir topography development. The IFSAR data points near this contour were removed in areas their elevations did not match the contour. Portions of the 2009 USDA contour, that were flown at much lower elevations (1,431.35 and 1,432.35 (NAVD88)) than the 2010 photos, were used in areas the 2009 bathymetric survey did not cover or did not provide enough detail. These areas included some of the inlets, but mainly included the upper reservoir areas above Buchan Bridge.

Jamestown Reservoir topography was tied vertically to NAVD88. The resulting surface areas and volume presented in this report are from that developed topography. The elevations were shifted -1.25 feet from NAVD88 to NGVD29 to match the project vertical datum used for reservoir operations. In preparation for developing the TIN, two polygons were created to enclose all of the data sets. These polygons were not assigned an elevation and were used as a hard boundary for the 2009 developed contours, allowing mapping only within the reservoir area outlined by these hardclip polygons. The hardclip was used during the triangular irregular network (TIN) development to prevent interpolation outside the enclosed polygon (Figure 27). One polygon allowed contour development both upstream and downstream of Jamestown Dam while the other was drawn along the alignment of Jamestown Dam so surface area and volume computations only included areas within the reservoir.

Contours for the reservoir from Jamestown Dam to just upstream of Jim Lake Dam 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 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 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. This method preserves all the collected data points. The TIN method is described in more detail in the ArcGIS user's documentation (ESRI, 2011).

The linear interpolation option of the ArcGIS TIN and CONTOUR commands was used to interpolate contours from the Jamestown Reservoir TIN. The surface areas of the enclosed contour polygons at 1-foot increments were computed for elevation 1,392.0 (NAVD88) and above. The reservoir contour topography at 1-foot intervals is presented on Figures 17 through 26. The ArcGIS software developed contours directly from the TIN using all the enclosed data points, resulting in a jagged representation of the contours. For presentation purposes the contour lines were smoothed using the smooth line option within ArcMap.

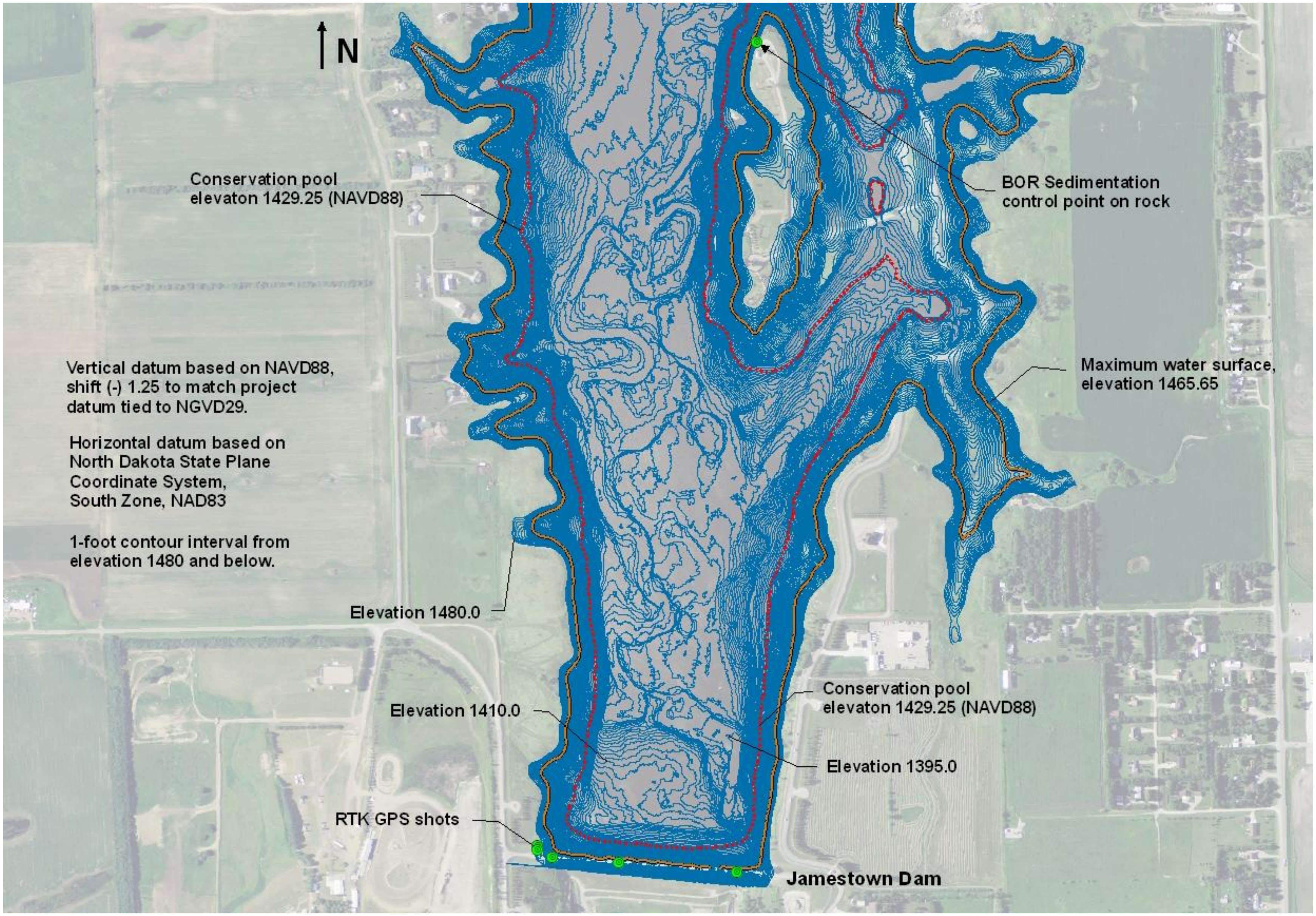

Figure 17 - Jamestown Reservoir topography (NAVD88).

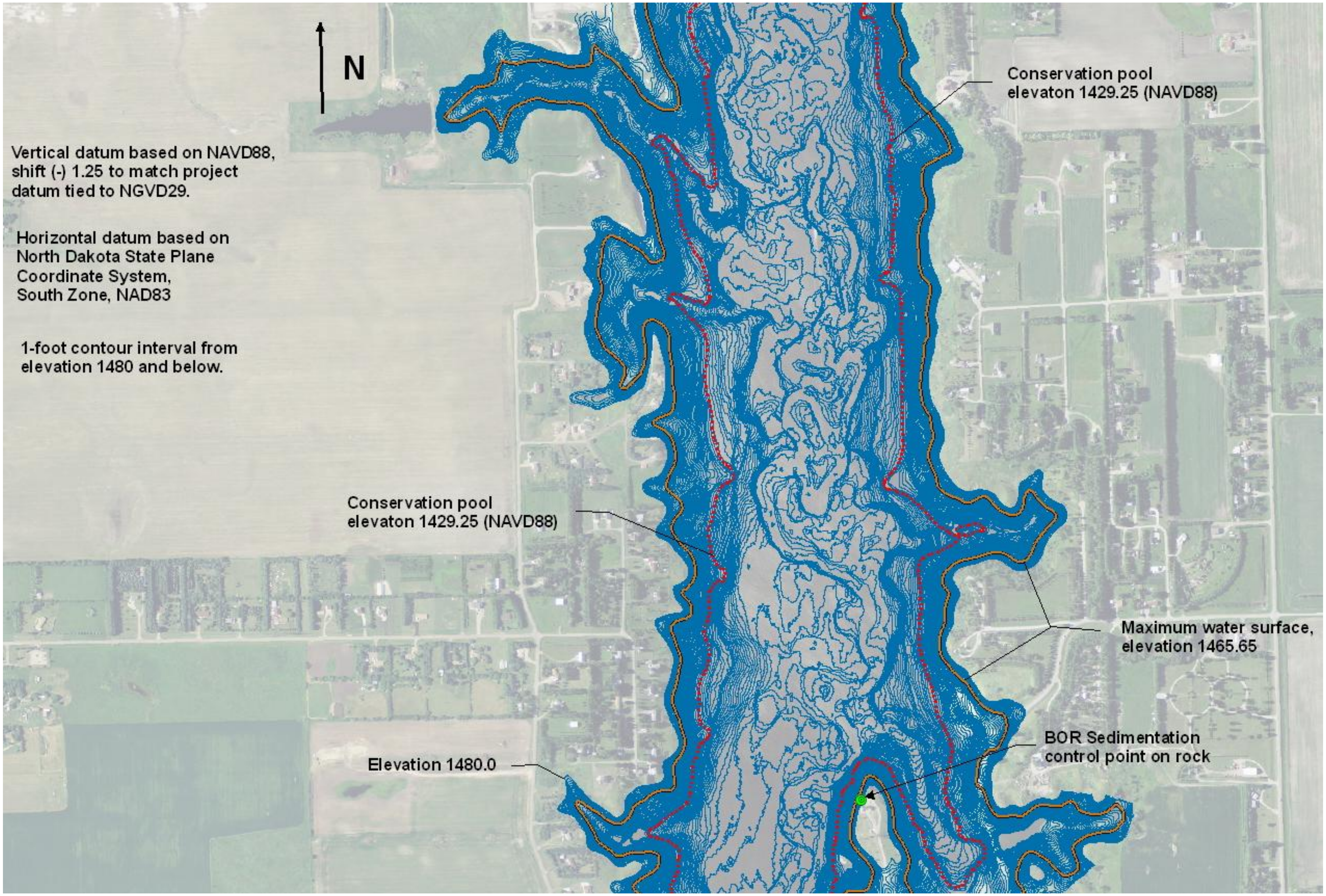

Figure 18 - Jamestown Reservoir topography (NAVD88).

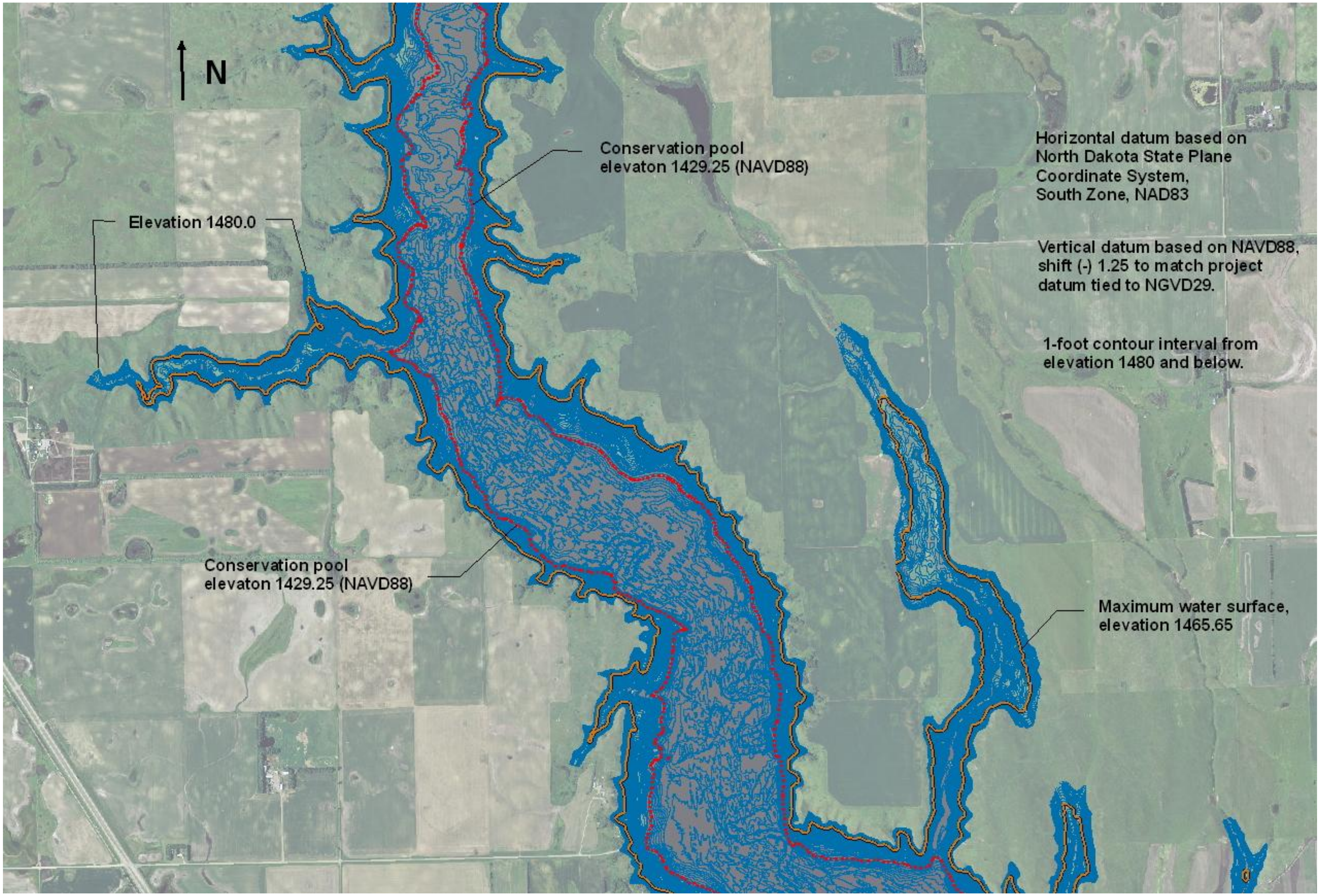

Figure 19 - Jamestown Reservoir topography (NAVD88).

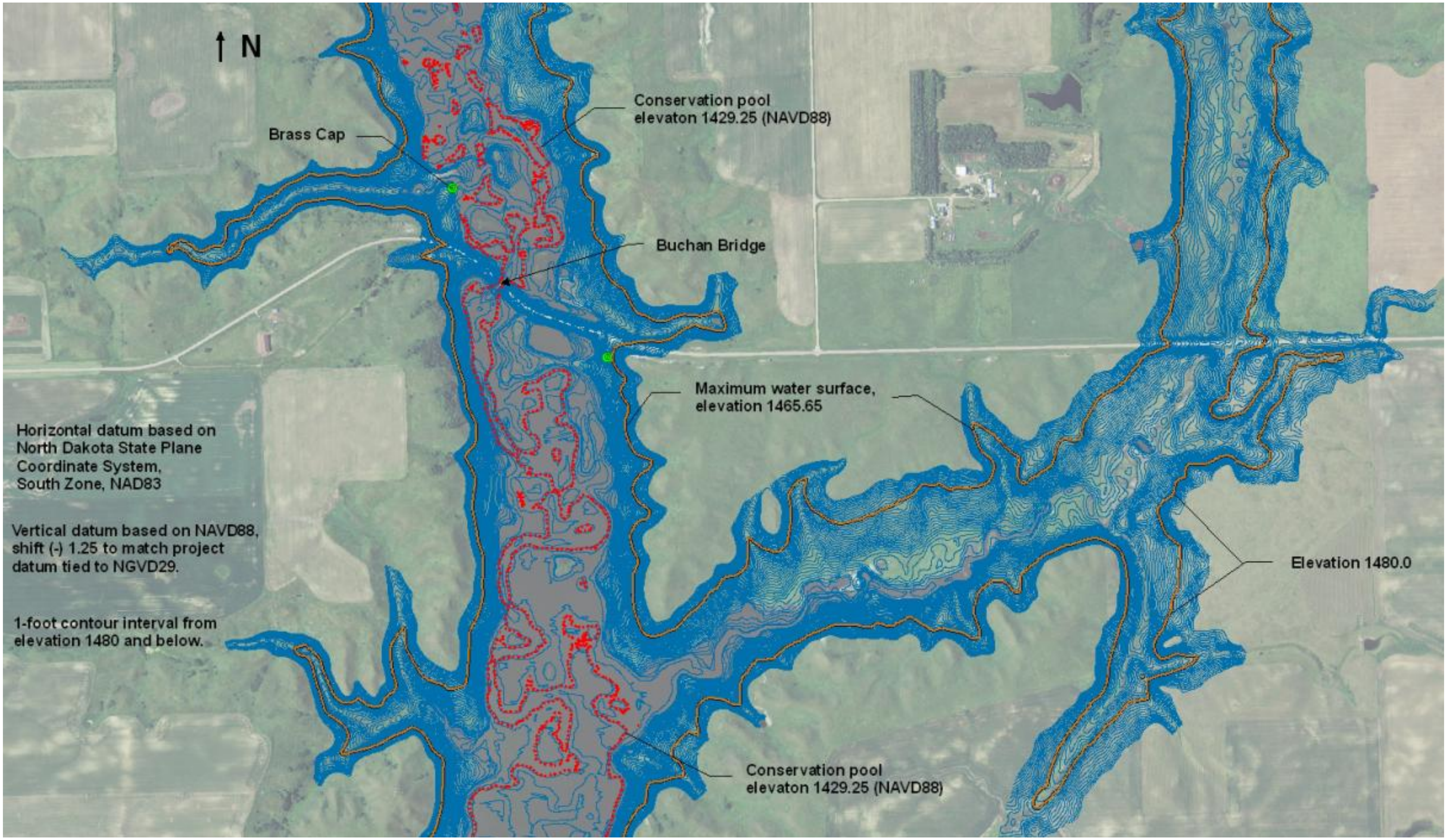

Figure 20 - Jamestown Reservoir topography (NAVD88).

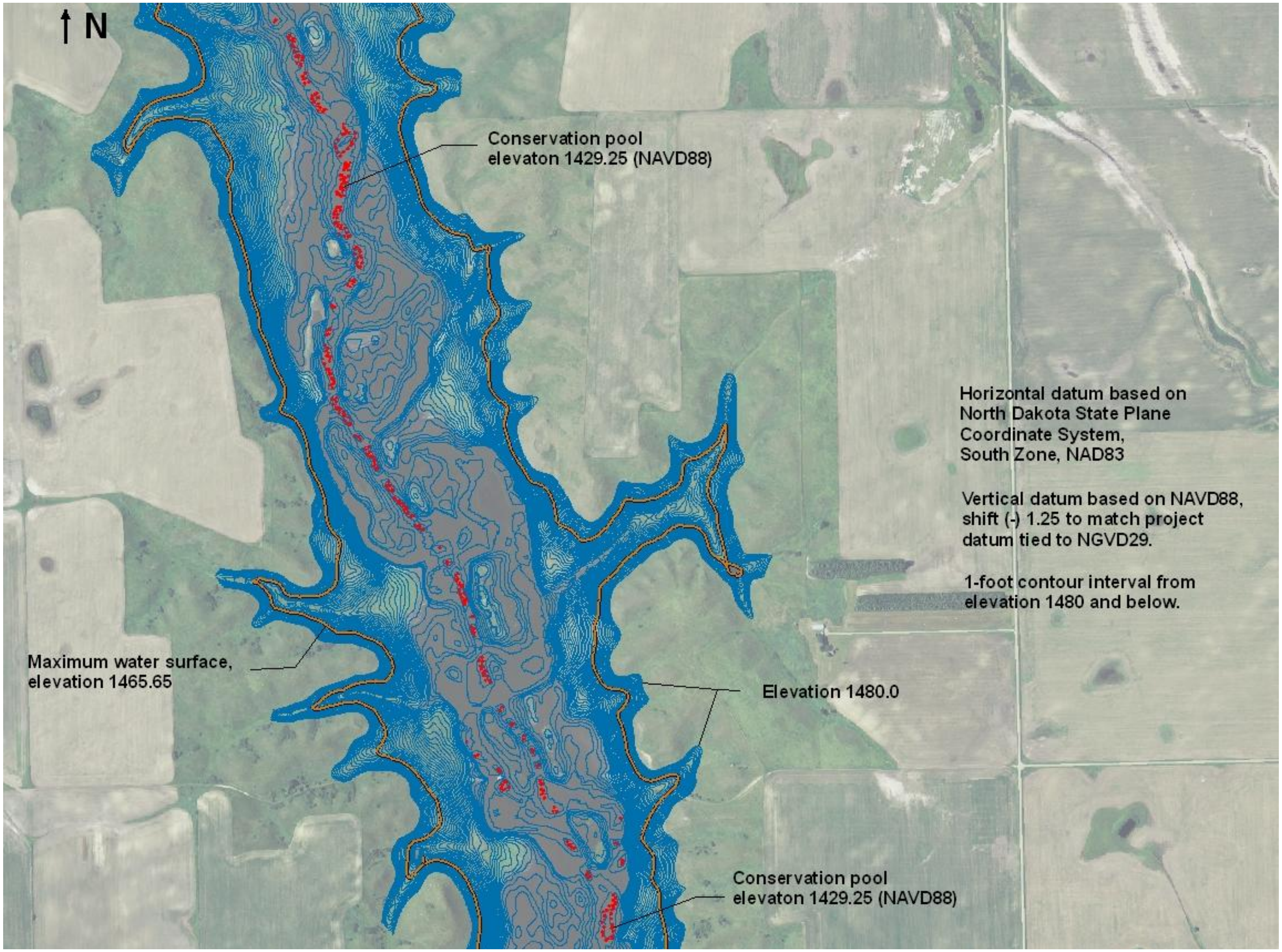

Figure 21 - Jamestown Reservoir topography (NAVD88).

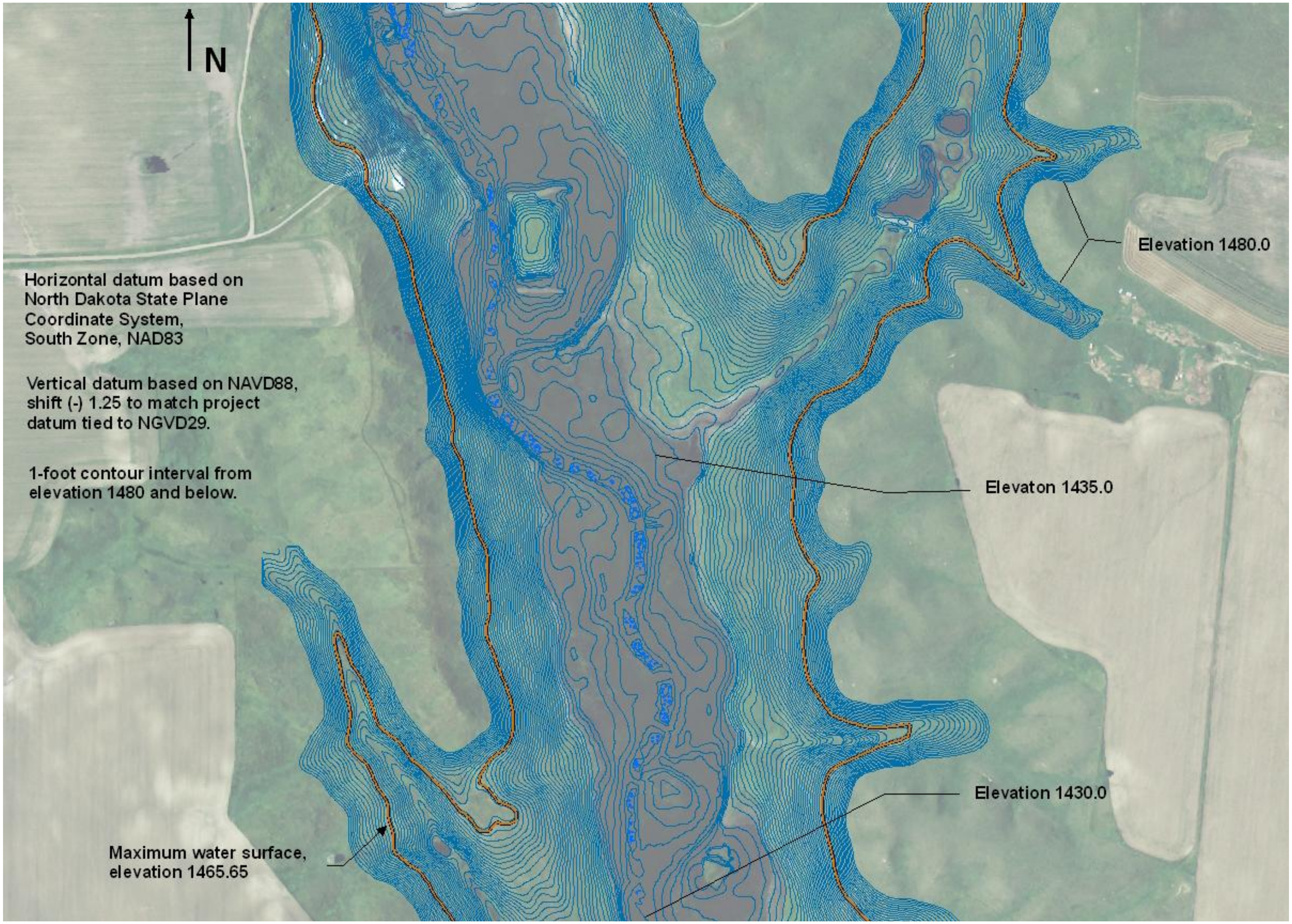

Figure 22 - Jamestown Reservoir topography (NAVD88).

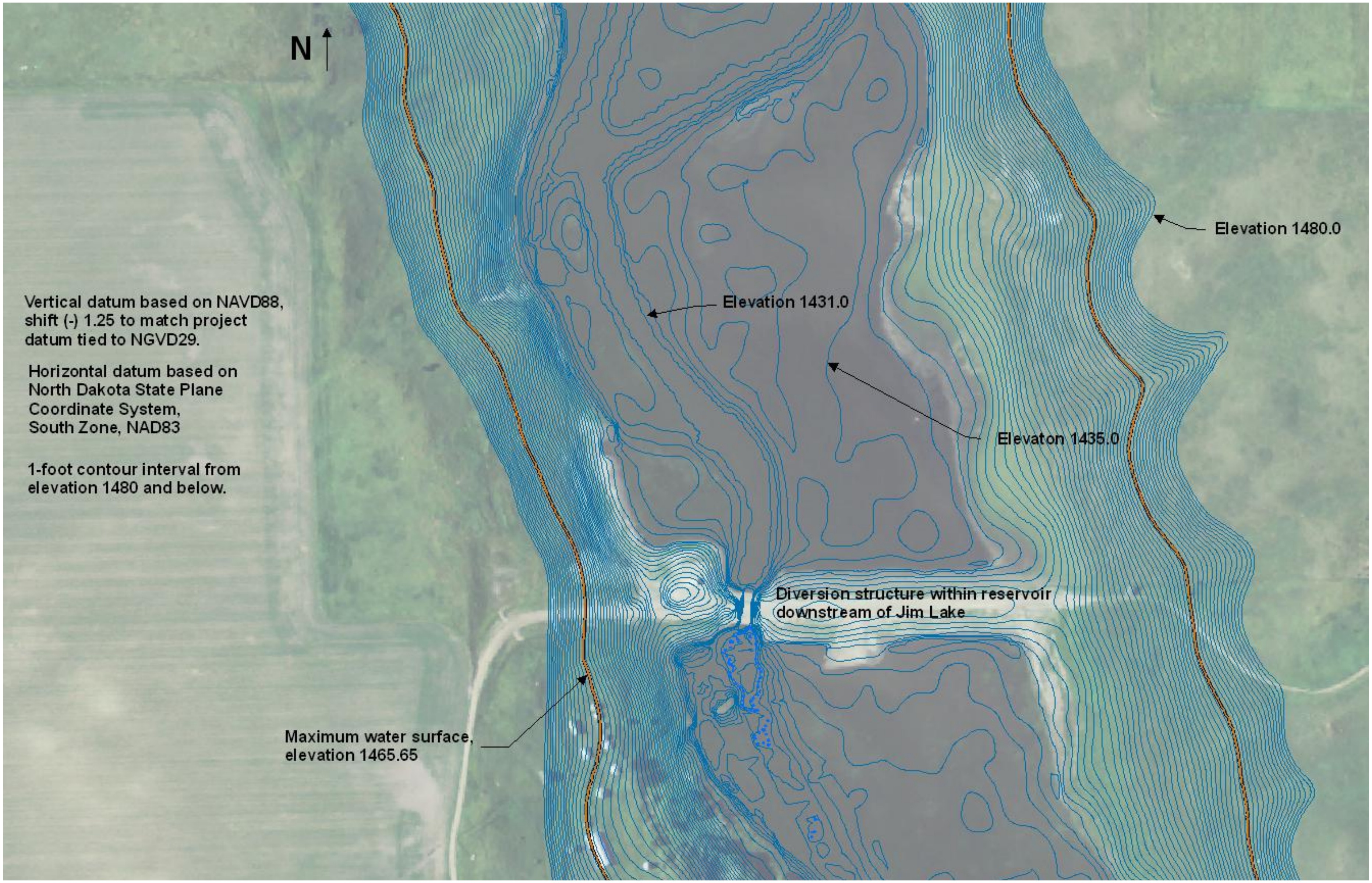

Figure 23 - Jamestown Reservoir topography (NAVD88).

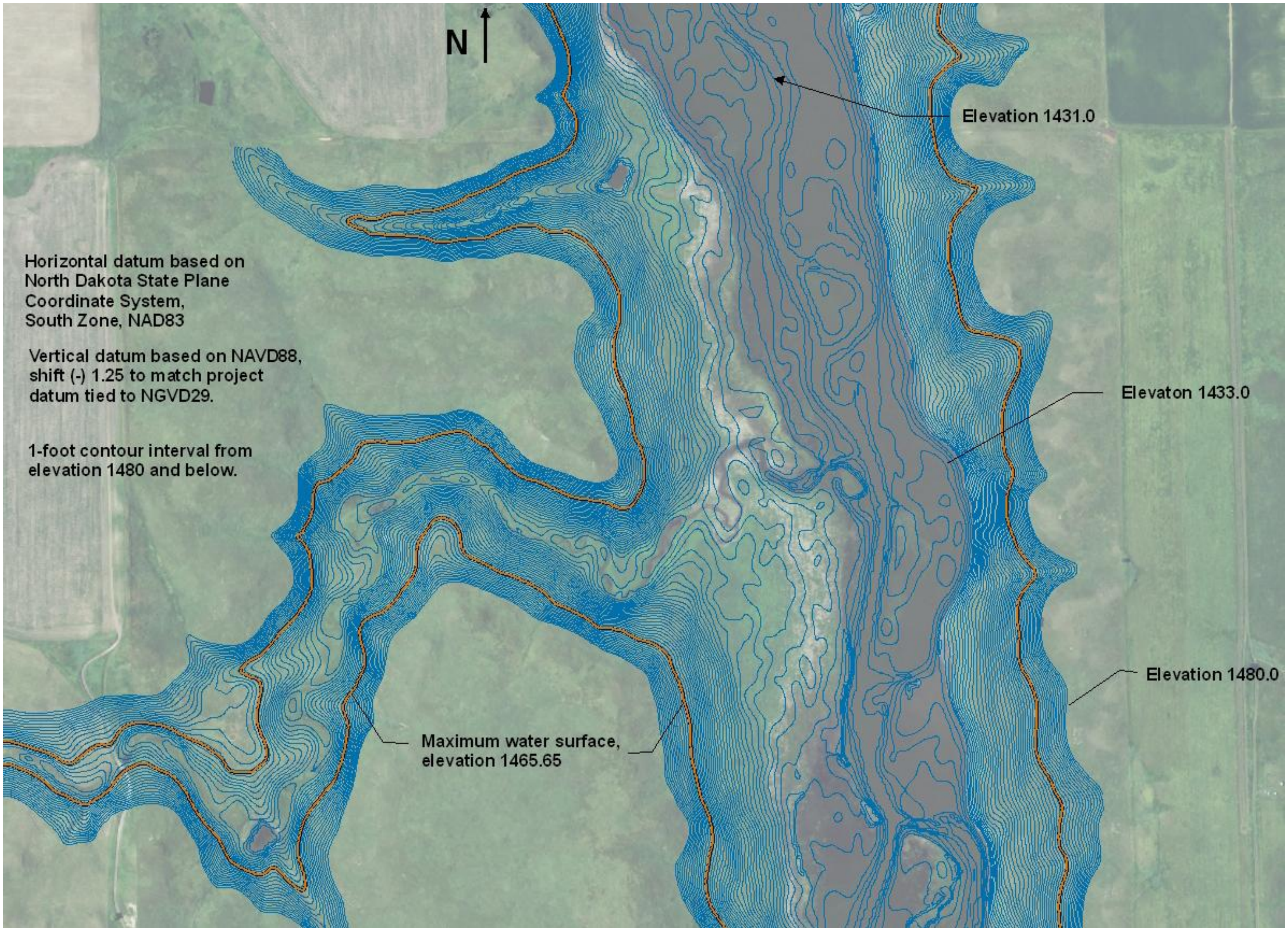

Figure 24 – Jamestown Reservoir topography (NAVD88).

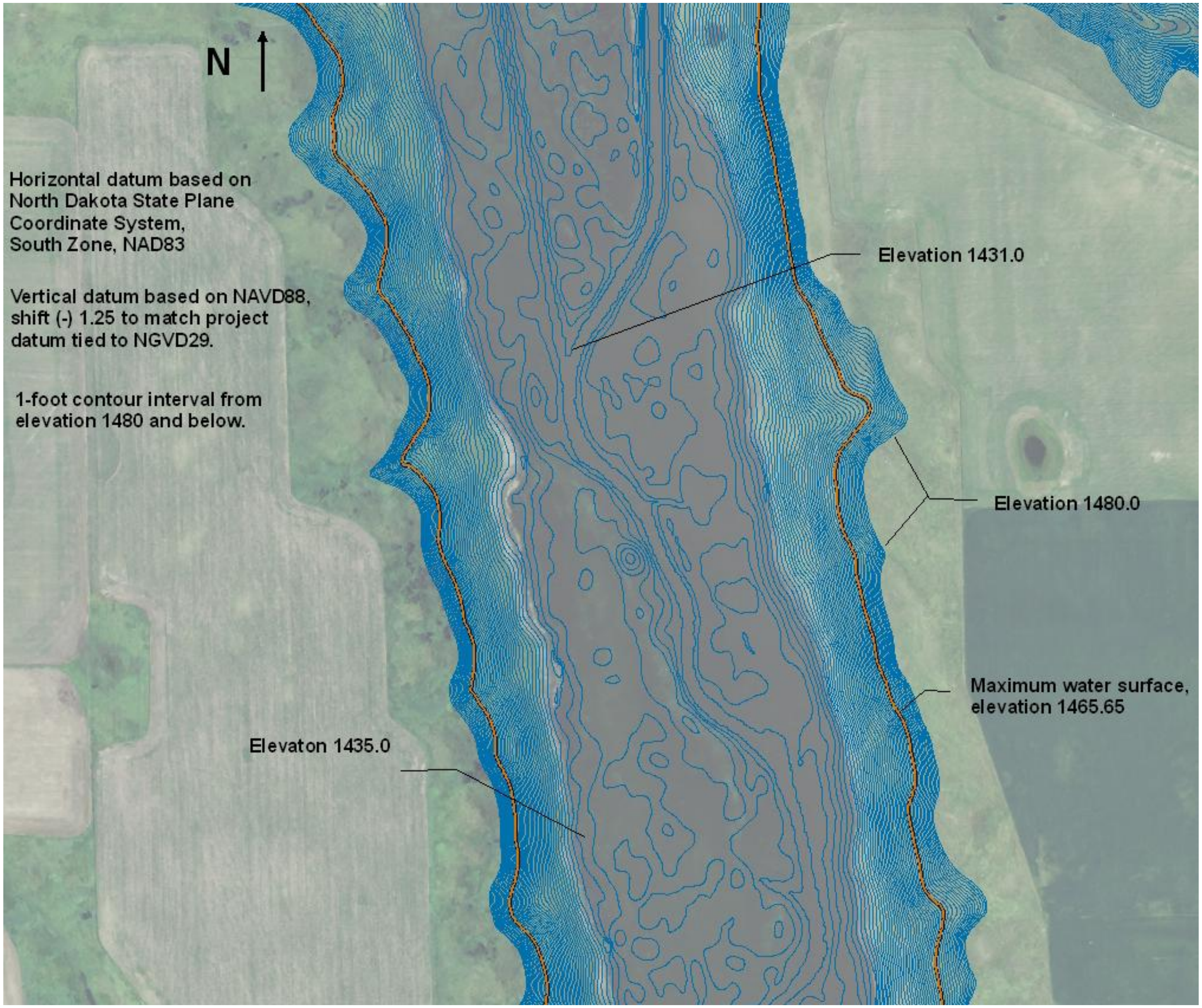

Figure 25 - Jamestown Reservoir topography (NAVD88).

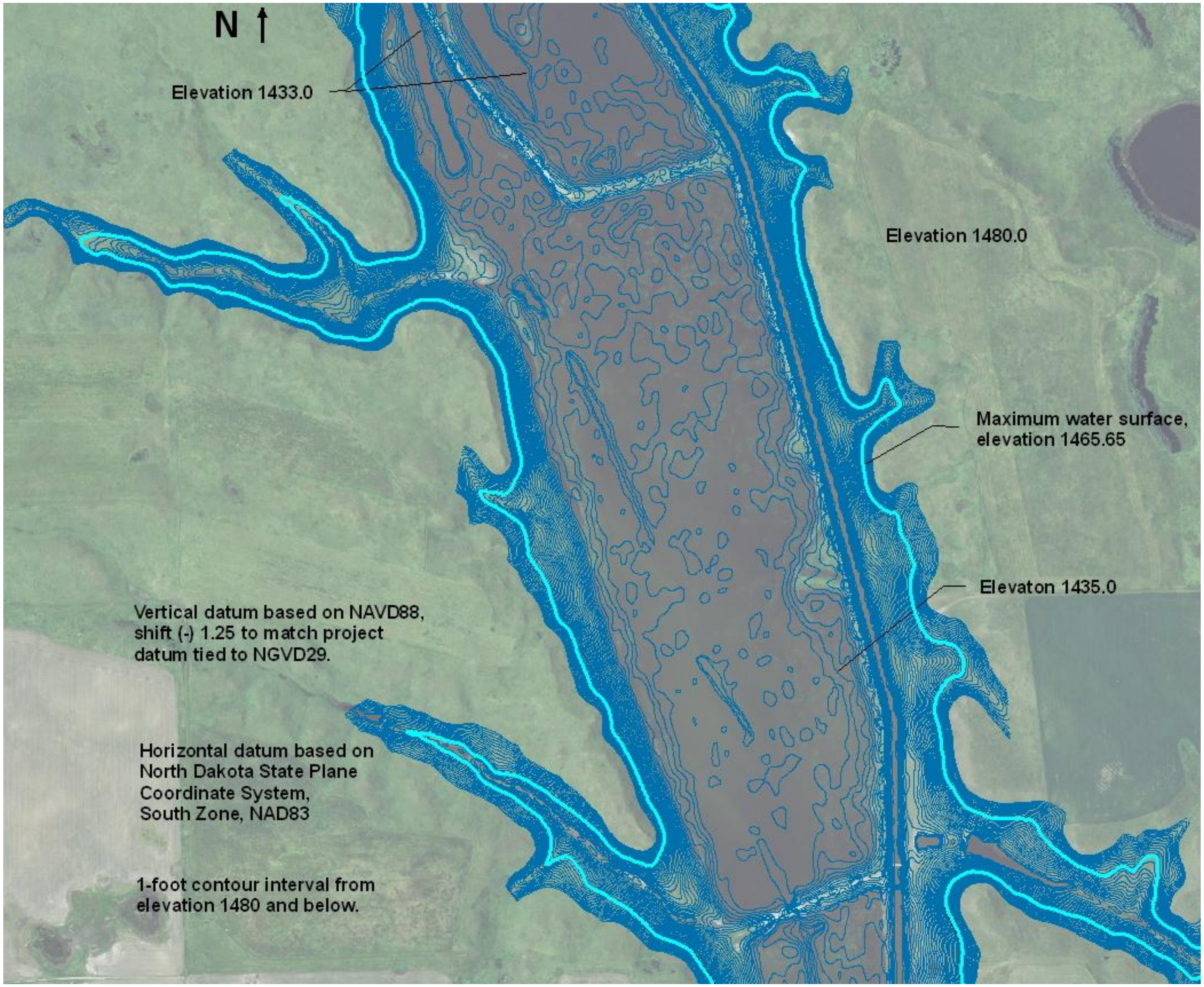

Figure 26 - Jamestown Reservoir topography (NAVD88).

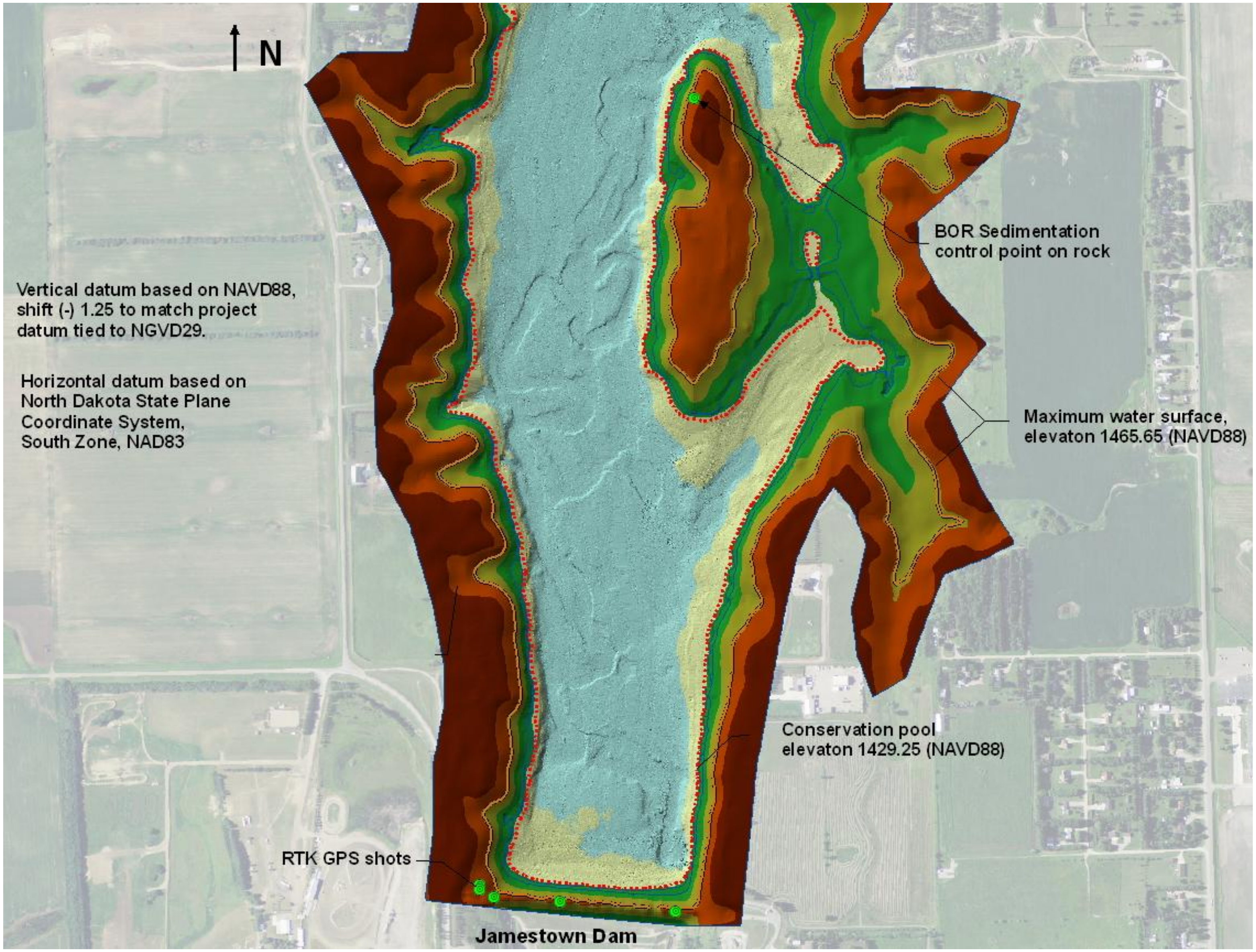

Figure 27 - Jamestown Reservoir 2009 TIN (NAVD88).

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2009 Jamestown Reservoir Surface Area Methods

The 2009 surface areas for Jamestown Reservoir were computed at 1-foot increments directly from the reservoir TIN from minimum elevation 1,392.0 to elevation 1,429.0 to provide information for the area-capacity tables. The upper most 2009 surface area entry was at elevation 1,429.8, also computed from the TIN. Surface area calculations were performed using ArcGIS commands that compute areas at user-specified elevations directly from the TIN. The data set for the 2009 study ended just upstream of Jim Lake Dam, a low-head impoundment that becomes inundated from the backwater of Jamestown Reservoir when water levels approach elevation 1,440. Water stored in Jim Lake during the IFSAR collection and was near surface elevation 1,431 (NAVD88), meaning the total reservoir capacity of Jamestown Reservoir cannot be computed until the bottom areas of Jim and Arrowwood Lakes area mapped. The 2009 study assumed no change in the reservoir surface areas from the original at elevation 1,435.0 and above. The surface areas and resulting capacity between elevations 1,429.8 and 1,435.0 were interpolated and computed by the ACAP program as described below.

2009 Jamestown Reservoir 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. The program begins by testing the initial capacity equation over successive intervals to ensure that the equation fits within an allowable error limit. The error limit was set at 0.000001 for Jamestown Reservoir. 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 Jamestown Reservoir area and capacity computations are listed in a separate set of 2009 area and capacity tables and have been published for the 0.01, 0.1 and 1-foot elevation increments (Bureau of Reclamation, 2009). A description of the computations and coefficients output from the ACAP program is included with these tables. As of July 2009, at conservation use elevation 1,428.0, the surface area was 1,875 acres with a total capacity of 24,226 acre-feet. At maximum elevation 1,464.4 feet the surface area was 17,435 acres with a total capacity of 379,907 acre-feet.

Jamestown Reservoir Surface Area and Capacity Results

This section provides 2009 surface area and capacity results for Jamestown Reservoir and evaluates changes over time. Table 1 provides a summary of the change in Jamestown Reservoir topography between the time of original construction and 2009. The area and capacity curves for the original and 2009 surveys area are plotted on Figure 28. Table 2 provides a summary of the original and 2009 surface area and capacity results.

For the purpose of this study the 2009 TIN computed surface areas from elevation 1,392.0 through 1,429.8 and were used in computing the 2009 area and capacity tables. For elevation 1,435.0 and above, the original surface areas were used with the assumption there was little change in these reservoir areas since the closure of Jamestown Dam. The ACAP program was used to interpolate and compute the area and capacity values between elevation 1,429.8 and 1,435.0. As noted previously, the original surface area tables excluded the storage capacity of the reservoirs within the Arrowwood Refuge area. The 2009 area and capacity computations excluded the same reservoirs due to the lack of bottom data for both Arrowwood and Jim Lakes.

RESERVOIR SEDIMENT
DATA SUMMARY

Jamestown Reservoir
NAME OF RESERVOIR

1
DATA SHEET NO.

DAM	1. OWNER: Bureau of Reclamation	2. STREAM: James River	3. STATE: North Dakota
	4. SEC 24 TWP. 140N RANGE 64W	5. NEAREST P.O. Jamestown	6. COUNTY Stutsman
	7. LAT 46 ° 55 ' 50 " LONG 98 ° 42 ' 23 "	8. TOP OF DAM ELEVATION: 1,471.0 [1]	9. SPILLWAY CREST EL. 1,454.0 [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	1,464.4 [3]	17,435	158,917	381,105	2/1954
	b. FLOOD CONTROL	1,454.0	13,213	190,425	222,188	
	c. POWER					
	d. JOINT USE	1,431.0	2,304	6,208	31,763	16. DATE NORMAL OPERATIONS BEGAN
	e. CONSERVATION	1,428.0 [4]	1,891	24,735	25,555	2/1954
	f. INACTIVE					
	g. DEAD	1,400.0	164	820	820	
	17. LENGTH OF RESERVOIR 13.8 [5] MILES		AVG. WIDTH OF RESERVOIR 0.2 MILES			

BASIN	18. TOTAL DRAINAGE AREA 1,290 [6] SQUARE MILES	22. MEAN ANNUAL PRECIPITATION 17.4 [7] INCHES
	19. NET SEDIMENT CONTRIBUTING AREA 550 [5] SQUARE MILES	23. MEAN ANNUAL RUNOFF 0.7 [8] INCHES
	20. LENGTH MILES AVG. WIDTH MILES	24. MEAN ANNUAL RUNOFF 47,070 [7] ACRE-FEET
	21. MAX. ELEVATION MIN. ELEVATION	25. ANNUAL TEMP, MEAN 40 °F RANGE -36 °F to 108 °F [7]

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
	2/1954 [9]			Contour (D)		1,891 [10]	25,555 [10]	0.54
	7/2009	55.4		Contour (D)	2-ft	1,875 [11]	24,226 [11]	0.51

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
2/1954						
7/2009	17.4	47,070 [8]	303,210	2,607,700	47,070	2,607,700

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.
2/1954						
7/2009	1,329 [12]	24.0		1,329	24.0	

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.
7/2009				0.09 [12]	5.20 [12]		

26. DATE OF SURVEY	43. DEPTH DESIGNATION RANGE BY RESERVOIR ELEVATION										
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION										

26. DATE OF SURVEY	44. REACH DESIGNATION PERCENT OF TOTAL ORIGINAL LENGTH OF RESERVOIR													
	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 [7, 13]							
YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF	YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF
1954	1,409.8		3,330	1955	1,416.8	1,407.6	5,131
1956	1,422.1	1,414.0	6,944	1957	1,421.3	1,420.1	-1,216
1958	1,428.3	1,420.5	9,616	1959	1,426.4	1,423.6	-4,659
1960	1,429.5	1,423.2	8,050	1961	1,428.1	1,426.2	-3,732
1962	1,428.6	1,425.2	3,938	1963	1,428.3	1,426.1	-3,959
1964	1,426.7	1,424.4	-2,872	1965	1,432.5	1,423.6	30,916
1966	1,439.9	1,429.3	83,381	1967	1,437.9	1,429.4	27,634
1968	1,430.4	1,429.2	-373	1969	1,443.8	1,429.1	95,244
1970	1,430.9	1,428.6	-1,248	1971	1,434.4	1,428.6	25,307
1972	1,434.2	1,429.4	19,406	1973	1,430.3	1,427.5	-2,208
1974	1,436.1	1,427.6	38,881	1975	1,439.6	1,429.3	69,436
1976	1,433.0	1,429.3	12,294	1977	1,429.8	1,428.6	-2,135
1978	1,433.3	1,428.5	10,689	1979	1,440.6	1,429.2	70,903
1980	1,432.1	1,429.5	5,354	1981	1,433.3	1,429.5	10,451
1982	1,438.1	1,429.6	44,139	1983	1,440.9	1,429.6	82,609
1984	1,436.1	1,429.6	40,224	1985	1,431.4	1,429.3	2,898
1986	1,434.5	1,429.6	22,503	1987	1,442.0	1,429.9	82,619
1988	1,432.8	1,428.1	421	1989	1,428.3	1,426.9	-2,090
1990	1,427.1	1,424.8	-3,837	1991	1,424.8	1,422.7	-3,069
1992	1,423.0	1,421.3	-1,749	1993	1,442.8	1,420.9	108,705
1994	1,440.6	1,429.8	106,097	1995	1,442.8	1,428.8	194,266
1996	1,444.6	1,429.5	156,679	1997	1,445.9	1,427.3	212,275
1998	1,439.4	1,426.4	68,157	1999	1,441.6	1,426.3	162,898
2000	1,438.7	1,425.9	101,038	2001	1,442.8	1,425.6	192,862
2002	1,431.9	1,428.0	18,622	2003	1,432.5	1,428.8	31,358
2004	1,437.5	1,428.4	92,133	2005	1,432.3	1,428.1	29,599
2006	1,431.1	1,428.5	10,059	2007	1,432.6	1,429.2	32,009
2008	1431,5	1,429.2	8,605	2009	1,454.1	1,429.7	303,210

46. ELEVATION - AREA - CAPACITY - DATA FOR **2009** [10]								
ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
2009	**SURVEY**	[10]	1,392.0	0	0	1,395.0	11	10
1,398.0	63	108	1,400.0	122	292	1,402.0	207	616
1,405.0	328	1,414	1,408.0	462	2,590	1,410.0	552	3,606
1,412.0	657	4,815	1,415.0	809	7,012	1,418.0	1,028	9,749
1,420.0	1,200	11,971	1,422.0	1,376	14,548	1,425.0	1,607	19,028
1,428.0	1,875	24,226	1,429.8	2,125	27,808	1,430.0	2,161	28,237
1,432.0	2,524	32,921	1,435.0	3,068	41,309	1,438.0	7,348	56,729
1,440.0	8,090	72,167	1,442.0	8,813	89,070	1,445.0	9,898	117,137
1,450.0	11,707	171,150	1,454.0	13,213	220,990	1,455.0	13,590	234,392
1,460.0	15,571	307,295	1,464.4	17,435	379,907			

47. REMARKS AND REFERENCES

[1] Elevations in feet based on project vertical datum tied to NGVD29. Add 1.25 feet to tie to NAVD88.

[2] Uncontrolled morning-glory inlet structure through right abutment of dam.

[3] Elevations from Reservoir Capacity Allocation in SOP, dated June 2004. Original area and capacity values recomputed using ACAP.

[4] Prior to 2002 the original Top of Conservation Storage was at elevation 1,429.8.

[5] Reservoir length and drainage area information

[6] Total drainage area above reservoir. USBR 1984 flood study computed 1,290 mi^2 with 46 mi^2 as non contributing, USGS list 1,760 mi^2 of which 1,010 mi^2 is probably non contributing. There are 3 low-head impoundments upstream of Jamestown Reservoir. Arrowwood and Jim Lakes in Arrowwood National Wildlife Refuge and Lake Juanita upstream in the northeast part of the basin.

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

[8] Mean annual runoff from Reclamation's computed inflows. Some years have negative inflows since reservoir evaporation is computed.

[9] Original surface areas derived from 1948 USGS maps and 1940 USCE maps.

[10] Surface area and capacity at elevation 1,428.0. Total storage excludes volumes within the refuge reservoirs.

[11] 2009 capacities computed by Reclamation's ACAP program.

[12] Capacity losses by comparing original and 2009 capacity. Sediment deposition within refuge reservoirs not calculated. Assume 2009 data is more accurate than original.

[13] Maximum and minimum elevations for the fiscal year.

48. AGENCY MAKING SURVEY Bureau of Reclamation

49. AGENCY SUPPLYING DATA Bureau of Reclamation DATE May 2011

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

1	2	3	4	5	6	7
					2009	
Elevations	Original	Original	2009	2009	Volume	Percent of
	Survey	Capacity	Survey	Survey	Difference	Reservoir
(feet)	(acres)	(acre-feet)	(acres)	(acre-feet)	(acre-feet)	Depth
1,464.4	17,435	381,105	17,435	379,907		100.0
1,460.0	15,571	308,493	15,571	307,295		94.1
1,454.0	13,213	222,188	13,213	220,990		86.0
1,450.0	11,707	172,348	11,707	171,150		80.6
1,445.0	9,898	118,335	9,898	117,137		73.9
1,440.0	8,090	73,365	8,090	72,167		67.2
1,438.0	7,348	57,927	7,348	56,729		64.5
1,437.0	6,917	50,795	6,917	49,597		63.2
1,436.0	3,295	45,689	3,295	44,491	1,198	61.8
1,435.0	3,068	42,507	3,068	41,309	1,198	60.5
1,431.0	2,304	31,763	2,342	30,488	1,275	55.1
1,430.0	2,113	29,555	2,161	28,237	1,318	53.8
1,429.8	2,086	29,135	2,125	27,808	1,327	53.5
1,428.0	1,891	25,555	1,875	24,226	1,329	51.1
1,425.0	1,567	20,368	1,607	19,028	1,340	47.0
1,422.0	1,364	15,971	1,376	14,548	1,423	43.0
1,420.0	1,229	13,378	1,200	11,971	1,407	40.3
1,418.0	1,089	11,059	1,028	9,749	1,310	37.6
1,415.0	880	8,105	809	7,012	1,093	33.6
1,412.0	705	5,728	657	4,815	913	29.6
1,410.0	588	4,435	552	3,606	829	26.9
1,408.0	492	3,355	462	2,590	765	24.2
1,405.0	347	2,098	328	1,414	684	20.2
1,402.0	237	1,221	207	616	605	16.1
1,400.0	164	820	122	292	528	13.4
1,395.0	82	205	11	10	195	6.7
1,392.0	33	33	0	0	33	2.7
1,390.0	0	0	0	0	0	0.0

1	Elevation of reservoir water surface. (Project vertical datum, 1.25 feet less than NAVD88).
2	Original reservoir surface area. Areas derived from USGS Maps of 1948 and USCE maps of 1940.
3	Original reservoir capacity. Storage excludes volume within existing Arrowwood Refuge reservoirs.
	Original capacity recomputed using ACAP. Original tables did not include the dead storage of 822 acre-feet.
4	Reservoir surface area from 2009 survey.
5	Reservoir capacity from 2009 survey computed using ACAP.
6	Volume difference between original and 2009 survey = column (3) - column (5). 2009 study assume no change from orig
	above elevation 1429.8.
7	Depth of reservoir expressed in percentage of total depth, 74.4 feet.

Table 2 - Jamestown Reservoir 2009 survey summary.

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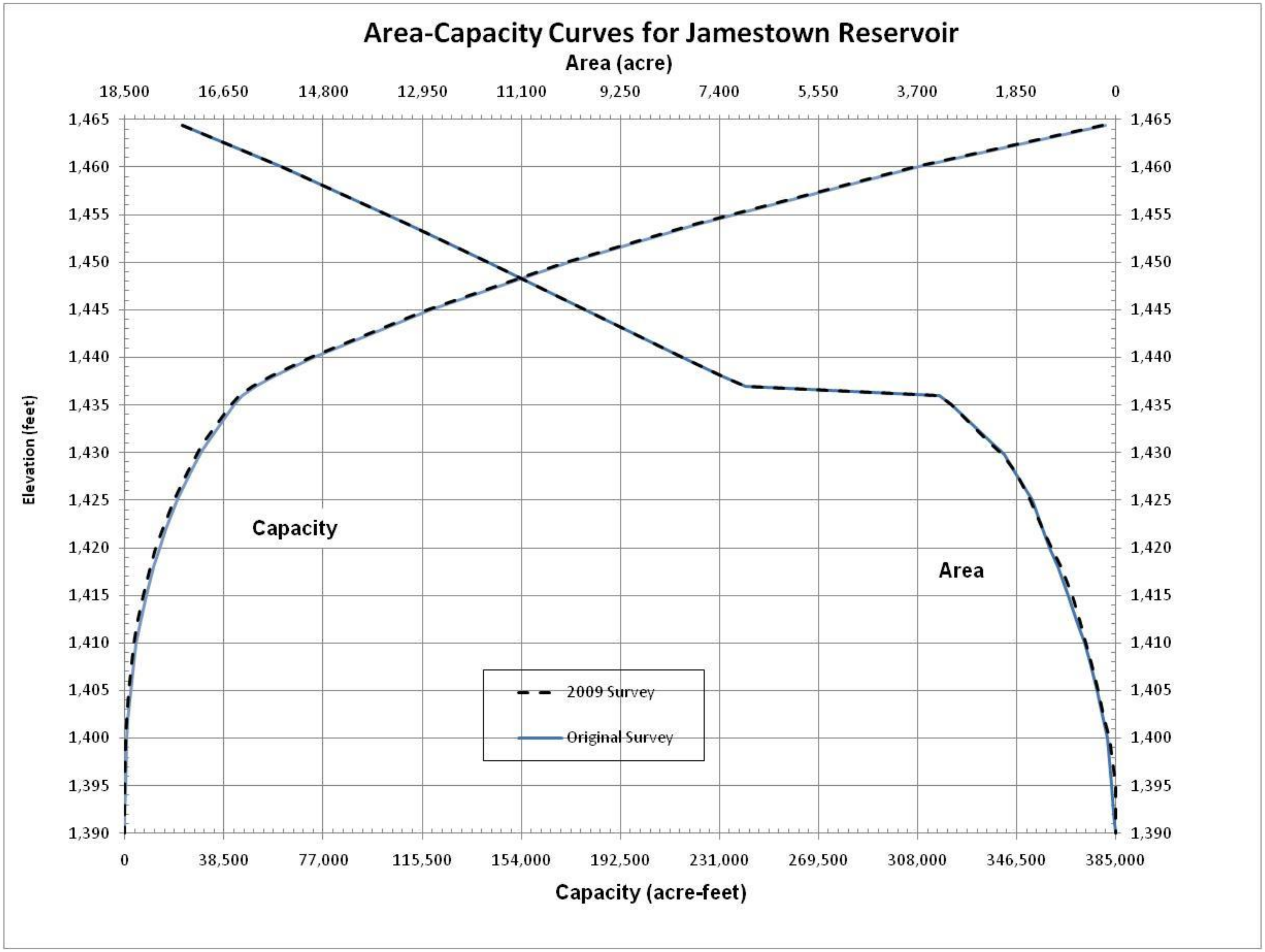

Figure 28 - Jamestown Reservoir area and capacity plots.

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2009 Jamestown Reservoir Analyses

Results of the 2009 Jamestown Reservoir area and capacity computations are listed in Table 1 and columns 4 and 5 of Table 2. Columns 2 and 3 in Table 2 list the original area and capacity values as recomputed for this study using the ACAP program. Figure 28 is a plot of the Jamestown Reservoir surface area and capacity values for the original and 2009 surveys and illustrates the changes in storage that have occurred since Jamestown Dam closure in February 1954.

Table 2 shows the conservation use capacity at elevation 1,428.0 for the two surveys along with the computed differences due to sediment deposition. The reservoir capacity in 2009 was 1,329 acre-feet less than the original (1954) volume at reservoir elevation 1,428.0. The 2009 area and capacity tables were generated assuming no surface area change since the original survey from elevation 1,435.0 and above. The last 2009 surface area entry was at elevation 1,429.8. Surface area values between 1,429.8 and 1,435.0 were interpolated using ACAP. Assuming no change above elevation 1,435.0 is probably not entirely accurate, but any loss due to sediment deposition above this elevation is assumed insignificant. Even though the refuge reservoirs of Jim and Arrowwood Lakes would have captured a portion of the inflowing sediments over the years, the original capacity table did not account for volumes within these reservoirs. The 2009 developed topography measured the majority of change from the original surface areas from elevation 1,422.0 and below with a slight increase in surface areas beginning at elevation 1,425.0 (Table 2). This measured increase in surface area could be due in part to shoreline erosion throughout the reservoir. Precision differences between the original and 2009 surveys also likely contributed to the measured increase. The original reservoir surface areas were derived from 1940's maps while the 2009 bathymetric data was denser, providing much greater detail than the original. While less dense than the bathymetric data, the IFSAR data also provided good detail, and for some areas the precision may be greater than the 1940's maps.

During the planning phase for Jamestown Reservoir, the originally estimated 250-year sediment accumulation was 10,000 acre-feet for an average annual storage loss of 40 acre-feet. The 2009 study measured 1,329 acre-feet of total sediment accumulation or an average annual rate of 24.2 acre-feet, only 60 percent of the original estimate. No information was located on how the original sediment accumulation was calculated. The results of the 2009 Jamestown Reservoir study provide up-to-date surface area and capacity information for the reservoir upstream to Jim Lake Dam. A resurvey should be scheduled in the future if a significant change in the sediment basin runoff is noted.

Summary and Conclusions

This Reclamation report presents the results of the July 2009 survey of Jamestown Reservoir. The primary objectives of the survey were to gather data needed to:

- develop reservoir topography;
- compute area-capacity relationships; and
- estimate storage depletion by sediment deposition since dam closure.

A control survey was conducted using the Online Positioning User Service (OPUS) and a real-time kinematic (RTK) global positioning system (GPS) to establish a horizontal and vertical control network near the reservoir for the hydrographic survey. OPUS is operated by the National Geodetic Survey (NGS) and allows users to submit GPS data files that are processed with known point data to determine positions relative to the National Spatial Reference System (NSRS). The GPS base was set over a temporary mark located on high ground of an island upstream of the dam and was used as the GPS base for the majority of the hydrographic survey. The coordinates for this point were processed using OPUS and from this base additional control points were established and the water surface measured for comparing with the reservoir gage readings. The coordinates for the additional control points were also confirmed through OPUS processing.

The study's horizontal control was in feet, North Dakota South state plane coordinates, in the North American Datum of 1983 (NAD83). The vertical control, in feet, was tied to NAVD88 and the project's vertical datum of NGVD29. Unless noted, all elevations in this report are referenced to the project vertical datum in NGVD29 that is 1.25 feet lower than NAVD88. The developed reservoir topography presented in this report was tied to NAVD88. The computed surface areas and reservoir volumes from the developed reservoir topography were shifted to NGVD29, project vertical datum, for reservoir and water operation purposes.

The July 2009 underwater survey was conducted between reservoir elevations 1,435.2 and 1,436.4 as measured by the Reclamation gage at the dam and tied vertically to NGVD29. 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 boats navigated along grid lines covering Jamestown Reservoir. The positioning system provided information to allow the boat operator to maintain a course along these grid lines.

The initial above-water topography for the 2009 field survey was determined by digitizing contour lines from the USGS quads of the reservoir area. These outlines were used to assure coverage of the reservoir during the July survey. During analysis, orthographic aerial images collected in 2009 and 2010 near water surface elevations 1,432 (NAVD88) and 1,436.5 (NAVD88) respectively were downloaded. The 2010 edge of water surface enclosed the 2009 bathymetric data in the reservoir and was digitized for this study's topographic development (USDA, 2010).

The areas above elevation 1,436.5 (NAVD88) and shallow reservoir water areas not covered by the 2009 bathymetric survey vessels required additional data to complete the reservoir topographic development. Airborne collected digital data was obtained as Interferometric Synthetic Aperture Radar (IFSAR) bare-earth information in east, north, elevation coordinates (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 Light Detection and Ranging (LiDAR). The reported accuracies for the IFSAR data are 2 meters or better horizontally and 1 meter or better vertically for unobstructed flat ground areas. Other technologies may produce more accurate data than IFSAR, but this study did not have the funding to acquire these other data sets. The IFSAR data was the only available digital data within the reservoir pool to develop the reservoir topography outside of the bathymetry data for this study. The original reservoir topography was developed from maps developed in the 1940's whose accuracies are unknown, but was useful for defining the original topography in the small inlets throughout the the reservoir.

The 2009 Jamestown Reservoir topographic map is a combination of the IFSAR digital data, the digitized water surface edge from the USDA photographs, and the 2009 underwater survey data, all tied to the vertical datum NAVD88. The 2009 reservoir topography development covered the area from Jamestown Dam upstream to Jim Lake Dam and used the 2009 bathymetric data up to elevation 1,429.8 (the original top of conservation storage elevation). A computer program was used to generate the 2009 topography and resulting reservoir surface areas at predetermined contour intervals from the combined reservoir data. The IFSAR data for Jamestown Reservoir was used for the general representation of the reservoir topography above elevation 1,430.0. The original surface areas from elevation 1,435.0 and above were used to develop the 2009 area and capacity tables for the upper elevations. For reservoir operation purposes the resulting reservoir surface areas were shifted to project vertical datum in NGVD29. The 2009 area and capacity tables were produced using a computer program (ACAP) that calculated area and capacity values at prescribed elevation increments using the measured contour surface areas and a curve-fitting technique.

Tables 1 and 2 contain summaries of the Jamestown Reservoir and watershed characteristics for the 2009 survey. The 2009 survey determined the reservoir has a total storage capacity of 379,907 acre-feet with a surface area of 17,435 acres at maximum water surface elevation 1,464.4 and a storage capacity of 24,226 acre-feet with a surface area of 1,875 acres at conservation water surface elevation 1,428.0. Since closure of Jamestown Dam on February 1954, this survey measured a 1,329 lost in reservoir capacity below elevation 1,428.0. The losses were computed by comparing the original and the 2009 capacities for the reservoir. It is assumed the majority of the measured loss was due to sediment deposition, but data precision differences also contributed to this value as the bulk of the loss was measured below elevation 1,422.0.

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