RECLAMATION

Managing Water in the West

Technical Report No. SRH-2014-08

Theodore Roosevelt Lake 2013 Sedimentation Survey

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

January 2014

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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

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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 86-68240), PO Box 25007, Denver, Colorado 80225-0007, www.usbr.gov/pmts/sediment/.

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14. ABSTRACT

Reclamation surveyed Theodore Roosevelt Lake in May of 2013 to develop updated reservoir topography and compute present storage-elevation relationships (area-capacity tables). The bathymetric survey was conducted near water surface elevation 2,109.7 feet tied to the National Geodetic Vertical Datum of 1929 (NGVD29) that is about 2.0 feet lower than the North American Vertical Datum of 1988 (NAVD88). The survey used sonic depth recording equipment interfaced with a real-time kinematic (RTK) global positioning system (GPS) that provided sounding positions throughout the underwater portion of the reservoir covered by the survey vessel. The above-water topography was developed from 5-foot aerial photography collected for the 1995 survey and January 2012 LiDAR that covered the upper reservoir areas in Tonto Creek and Salt River. The developed reservoir topography was tied to NAVD88. The resulting elevations versus area and capacity values were shifted down 2.0 feet to NGVD29 to match the reservoir's operation vertical datum.

As of May 2013, at active conservation use elevation 2,151.0, the reservoir surface area was 21,383 acres with a capacity of 1,636,254 acre-feet. Since April 1995, a total capacity change of 16,789 acre-feet below elevation 2,251.0 was measured resulting in 1.0 percent loss in reservoir capacity and an annual loss of 927.6 acre-feet since 1995. The capacity change is due to sediment deposition and methodology differences between the surveys. The 1995 and 2013 surveys were the first detailed surveys since the major dam modifications began in 1989 and were completed in 1996. A previous survey result, such as the 1981 survey before dam modification, may provide a better annual estimate of loss due to sediment. The 1981 survey measured an average annual capacity loss of 2,676 acre-feet since May 1909 dam closure.

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Theodore Roosevelt Lake 2013 Sedimentation Survey

Theodore Roosevelt Dam
Arizona

2/5/2014

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Introduction

The original Theodore Roosevelt (Roosevelt) Lake and Dam, the first major features developed by the Bureau of Reclamation (Reclamation), were constructed between 1903 and 1911. The dam and reservoir, operated as part of the Salt River Project (SRP), are located about 76 miles northeast of Phoenix and 30 miles northwest of Globe, Arizona (Figure 1). The original dam formed the reservoir downstream of the Salt River and Tonto Creek confluence. The dam was one of the last and highest thick-arch structures, measuring 280 feet high with a crest length of 723 feet. Between 1989 and 1996 the dam was raised 77 feet creating a concrete-gravity arch that increased the conservation storage capacity 20 percent, and for dam safety, added reservoir flood control space. In addition, two new spillways and outlet works were constructed, the powerplant was modified, and recreation facilities at Roosevelt Lake were improved. The dam and reservoir, part of the SRP multipurpose project, controls floods, generates power, and stores water. Additional project reservoirs located downstream include Apache Lake behind Horse Mesa Dam, Canyon Lake behind Mormon Flat Dam, and Saquaro Lake behind Stewart Mountain Dam (Figure 1).

Figure 1 - SRP reservoirs located downstream of Roosevelt Lake.

The dam and feature elevations are tied to NGVD29 that was confirmed by this survey to be around 2.0 feet lower than NAVD88. This shift was determined by comparing published elevations with measured reservoir water surface and top of the dam elevations. Unless noted, all elevations in this report are tied to NGVD29. The 2013 developed topography was tied to NAVD88 and elevations of the surface area computations were shifted down 2.0 feet to match NGVD29, the operation vertical datum. The concrete gravity arch dam, Figure 2, has the following dimensions in feet (NGVD29):

Structural height[1]	316	Crest length	1,210
Crest elevation[2]	2,218.0	Top width	21.6

Figure 2 - Downstream view of Roosevelt Dam and right abutment spillway.

The spillways, located on each abutment of the dam, have four top-seal radial gates with sill elevations 2,100.0 and a total maximum capacity of 150,000 cubic feet per second (cfs). Modification of the outlet works increased their capacity, at eighty percent open, to 10,840 cfs at water surface elevation 2,151.0.

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[1] Values for concrete dam section. 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 project's operation vertical datum (NGVD29) that is 2.0 feet lower than NAVD88. The 2013 reservoir topography was tied to NAVD88. The elevation versus surface area and capacity values were shifted down 2.0 feet to NGVD29 for operational purposes.

Previous Surveys

Original

The original topography of Theodore Roosevelt Lake was available as a hard copy map, Drawing 25-P-48, dated 1915. It is assumed the topography was developed using a plane table survey prior to dam closure. The developed 10-foot contours were the measured original surface areas used to compute the reservoir capacity (Bureau of Reclamation, 1996).

1981 Survey

Between 1914 and 1981 six surveys of varying degrees of accuracy were conducted using the range line method for collection and analysis. The 1981 survey included collection of bottom data along 39 range lines that were laid out to represent the entire reservoir prior to the raise of the original dam completed in 1909. The 1981 reservoir surface areas were computed by applying adjustment factors to the original contour areas. The input data included the original and 1981 range line data along with the surface areas for the affected contour elevations. Additional information on collection and analysis procedures are outlined in Chapter 9 of the *Erosion and Sedimentation Manual* (Ferrari and Collins, 2006). The 1981 survey and analysis estimated 193,765 acre-feet of total sediment had accumulated in the reservoir, over the first 72.4 years of operation, resulting in 12.7 percent of original loss of reservoir storage and an average annual loss of 2,676 acre-feet (Bureau of Reclamation, 1982).

1995 Survey

The April 1995 bathymetric survey, conducted near water surface elevation 2,126, was the first study that resulted in detailed contours of Roosevelt Lake since dam closure in 1909 and since the raising of the dam 77 feet that began in 1989 and was completed in 1996. Above water 5-foot contours were developed from aerial photography obtained on October 28, 1994 near reservoir elevation 2,087. Reclamation's Phoenix Area Office conducted the photography interpretation that provided 5-foot contour intervals from elevation 2,090.0 through 2,225.0. The bathymetric survey was conducted using a single beam depth sounder interfaced with GPS navigating along grid lines perpendicular to the original river alignment, spaced 400 feet apart, covering the underwater portion of the reservoir. Additional data was collected along the shore as the boat traversed between transects resulting in 70,500 underwater coordinate points. The resulting 1995 topography and surface areas consisted of 5-foot contours from elevation 1,965 through 2,225.0.

The measured surface area was 31,853 acres with a total capacity of 3,432,408 acre-feet at top-of-dam elevation 2,218.0. Since initial filling in 1909 about 182,185 acre-feet capacity had been lost by 1995 below elevation 2,136.0, the original active conservation capacity elevation prior to dam modification. The 1995 measured capacity loss was equivalent to an 11.9 percent lost and an annual loss of 2,121 acre-feet per year. The 1995 survey developed detailed topography with resulting reservoir area and capacity values, compared to the original less detailed developed topography affecting the sediment computation accuracy. The report summarizing the 1995 survey and the developed 5-foot developed contours are available on the Sedimentation Groups web site (Bureau of Reclamation, 1996).

Control Survey Data Information

The 2013 survey established a temporary control point in an open area overlooking the reservoir located within the fenced portion of the USDA Forest Service visitor center, Figures 3 through 5. The point is an aluminum cap stamped "ROSE 1" mounted on rebar driven into the ground, considered temporary since located in an area that can be disturbed, and used as the base during this survey. The National Geodetic Survey (NGS) survey marker "Roosevelt 1946" was located, but was near a building that could cause a GPS issue known as multipath, so was not used as the base.

The on-line positioning user service (OPUS) was used to establish horizontal and vertical control on point "Rose 1". 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 control network. The horizontal control was established in Arizona state plane east coordinates tied to the North American Datum of 1983 (NAD83) in International Feet. The elevation was tied to NAVD88 (GEOID12A) in US Survey Feet (feet). The 2013 OPUS generated coordinates were used to measure position and the vertical difference between NAVD88 (GEOID12A), the recorded water surface elevations during the 2013 survey, and RTK GPS topo measurements on the dam. The water surface measurements were collected during calm conditions between recorded gage readings 2,109.84 and 2,109.91 (NGVD29). RTK GPS measurements on "Roosevelt 1946" were compared to the NGS published coordinates, helping confirm the computed coordinates for "ROSE 1".

Figure 3 – "Rose 1" control point used as base for the 2013 hydrographic survey.

Figure 4 - Temporary monument labeled "Rose 1," looking east.

Figure 5 - Theodore Roosevelt Lake 2013 control points.

The 2013 survey confirmed the project features and water surface gage measurements are tied to NGVD29. The 2013 survey obtained measurements on top of dam and the water surface during calm conditions. The RTK GPS topo measurements, tied to NAVD88 (GEOID12A), were found to be from 1.95 to 2.03 feet higher than the recorded water surface measurements and from 1.87 to 2.07 feet higher than the design drawing elevation of the modified dam. On average, the RTK GPS elevation measurements (NAVD88) were around 2.0 feet higher. For this area the NGS published difference between NAVD88 and NGVD29 was around 2.0 feet. Following are the coordinates for the monuments used during the May 2013 survey. The horizontal control was established in Arizona state plane east coordinates, NAD83, International Feet, and elevations tied to NAVD88 (GEOID12A) in US Survey Feet.

	Rose 1 (OPUS Developed)	Roosevelt 1946 (RTK GPS Measured)	Roosevelt 1946 (NGS Published)
East	**406,094.07**	**406,035.92**	**406,035.84**
North	**972,557.01**	**972,489.02**	**972,488.92**
Elevation	**2,222.73**	**2,333.09**	**2,232.99**

Reservoir Operations

The reservoir is a multiuse facility for the SRP providing irrigation and municipal water, flood control storage space, and wildlife and recreation benefits. The 2013 reservoir topography was developed with elevations tied to NAVD88. The computed results were shifted downward 2.0 feet to match the operation vertical datum of NGVD29. The 2013 total capacity at maximum design operation elevation 2,218.0 was 3,410,897 acre-feet. The following values are from the May 2013 capacity table:

- 1,219,903 acre-feet of surcharge between elevation 2,175.0 and 2,218.0
- 554,740 acre-feet of flood control between elevation 2,151.0 and 2,175.0.
- 1,619,228 acre-feet of active conservation between elevation 1,989.0 and 2,151.0
- 17,026 acre-feet of dead storage below elevation 1,989.0.

Roosevelt Lake receives the majority of its inflow from the Salt River and Tonto Creek watersheds. The inflow and end-of-month stage records in Table 2 show the annual fluctuation for water years 1996 through May 2013. The annual values for the 1910 through 1995 operation period are available in the 1995 survey report (Bureau of Reclamation, 1996). The average reservoir water inflow for operation period 1996 through 2013 was 484,501 acre-feet. The average inflow for operation period 1910 through 1995 was 752,279 acre-feet. The average annual inflow since 1996 indicated a very dry period, but 2005, 2008, and 2010 showed very high above average inflows resulting in the highest levels of the reservoir. The table's water levels show wild fluctuations of the reservoir since 1996 from a maximum elevation of 2,152.1 in 2010 to a minimum elevation of 2,033.0 in 2002.

Hydrographic Survey, Equipment, and Method of Collection

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 built-in radio, multibeam depth sounder, helmsman display for navigation, computer, and hydrographic system software for collecting the underwater data. An on-board generator and batteries supplied power to all the boat equipment. 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 power for the shore unit.

Figure 6 - Large survey vessel with mounted instrumentation for mapping upstream of Grand Coulee Dam on Franklin D. Roosevelt Reservoir, Washington.

The Sedimentation Group uses RTK GPS with the major benefit being precise heights measured in real time to monitor water surface elevation changes and to determine the vertical datum of the projects. 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 Arizona's state plane east coordinates, NAD83 tied to International Feet, and elevations tied to NAVD88 (GEOID12A), in US Survey Feet.

The Theodore Roosevelt Lake bathymetric survey was conducted from May 5 through May 11, 2013 near water surface elevation 2,109.7. The bathymetric survey used multibeam 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. The survey vessel's guidance system provided directions to the boat operator to assist in maintaining a course along these predetermined lines. Compared to the 1995 single beam data along the bank slopes of the reservoir, the 2013 multibeam data allowed development of more accurate topography and resulting surface area computations, Figures 7 and 8. Figure 7 shows the detailed xyz data points collected with the multibeam sounder compared to the single beam data. Figure 8 shows the developed 5-foot contours from each data set where the 1995 contours were jagged interpolated contours between the range line data compared to more smooth contours developed from the 2013 multibeam data. The 2013 data provided better detail and more accurate information of the actual bottom below the water surface. Differences in the detail between the methods used in 1995 and 2013 are partially responsible for the computed differences between the surveys.

During the 2013 field collection the distances between the grid lines were increased in the areas of the reservoir the bottom was relatively flat and overlap of the profiles was not deemed necessary to develop accurate topography. In the upper shallow reservoir areas the vessel maneuvered within the vegetation openings where it was safe to obtain data. Large areas of thick vegetation and shallow water in the upper reaches prevented access by the survey vessel. In the surrounding areas that were accessible, there appeared to be no significant change in the reservoir bottom and interpolation to develop contours would not affect the accuracy. As each line was traversed, the multibeam depth and position data were recorded on the laptop computer hard drive for subsequent processing, resulting in point data at 5- and 10-foot grid spacing. The water surface elevations at the dam from the SRP gage records, shifted upward 2.0 feet to NAVD88, and the RTK GPS measurements, were used to convert the sonic depth measurements to lake bottom elevations tied to NAVD88. The developed reservoir topography was tied to NAVD88. The resulting elevation surface areas were shifted back down 2.0 feet to match the dam's operation vertical datum, NGVD29.

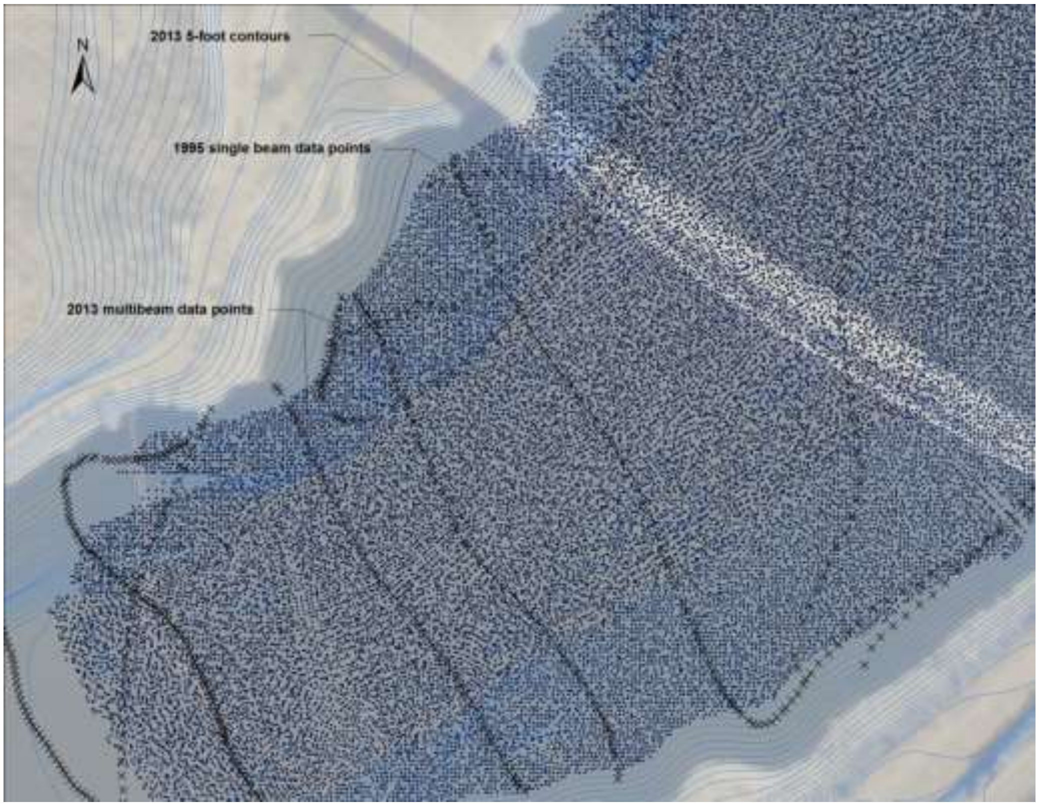


Figure 7 - 1995 and 2013 data points, Roosevelt Lake.

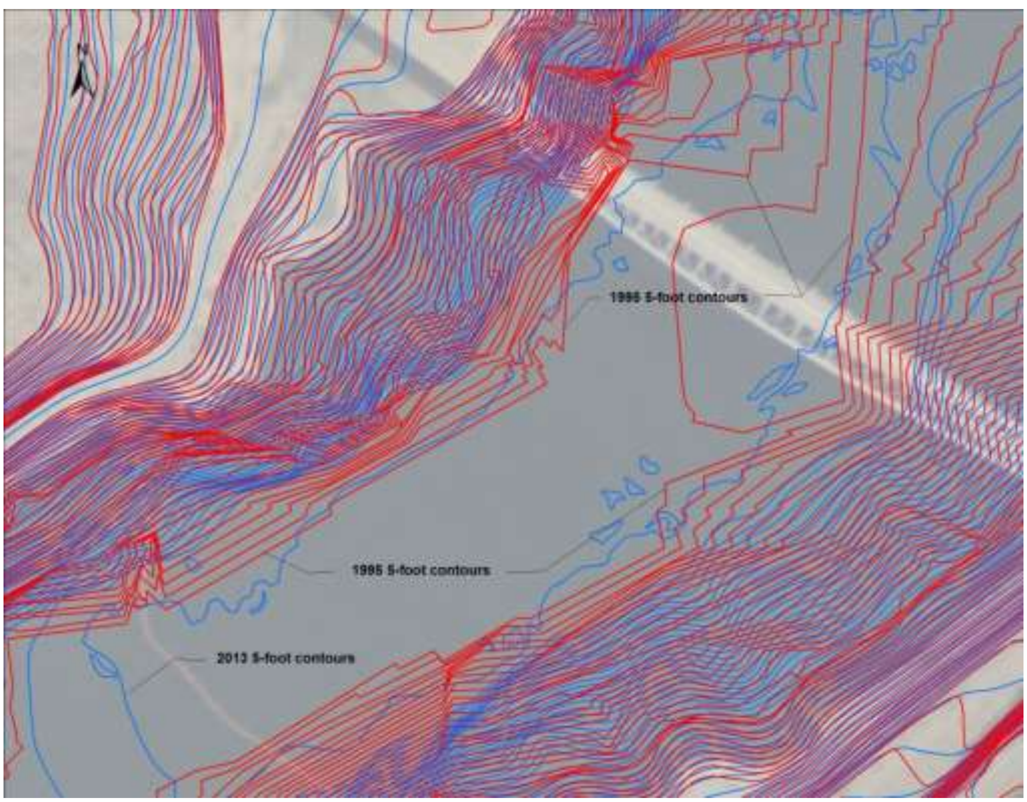


Figure 8 - 1995 and 2013 Roosevelt Lake 5-foot contours.

The integrated multibeam hydrographic survey 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 1½-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 that is about 3.5 times as wide as the water depth below the transducer. The 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. On Roosevelt Lake, the multibeam sounder was calibrated by lowering a velocity meter 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 xyz data set of the lake bottom.

The underwater collected data was processed using the same hydrographic system software used during the data collection where all corrections such as vessel location, 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 (all tied to NAVD88). To reduce the time required for topographic map processing, without compromising survey accuracy, the massive amount of the multibeam data was filtered into 5- and 10-foot cells or grids in the reservoir area surveyed by the multibeam system. The multibeam beam soundings resulted in a detailed data set of around 4,072,100 xyz points representing the reservoir below the water surface at the time of the data collection. 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). Figures 10 through 28 illustrate the 2013 bathymetric data profiles along with the 1995 aerial and 2012 LiDAR contours.

1995 Aerial Contours

For the 1995 reservoir survey, detailed above water contours were developed from aerial photography obtained on October 28, 1994 near reservoir elevation 2,087. Reclamation's Phoenix Area Office conducted the aerial photography interpretation resulting in 5-foot contour intervals from elevation 2,225.0 and below. For the 2013 analysis, the portion of the 1995 contours that were overlapped by the 2012 LiDAR and 2013 bathymetric data were deleted during the 2013 topographic development. The remaining 1995 contour lines were used as breaklines. The elevations of these contours were shifted upward 2.0 feet to NAVD88.

2012 LiDAR

The SRP provided LiDAR data of the upper Tonto Creek and Salt River arms of Roosevelt Lake. The data was collected in January 2012 near reservoir elevation 2,124 (NAVD88) providing a bare earth surface of the above water areas from the exposed deltas upstream for each upper arm of the reservoir, Figure 9. The bare earth surfaces did not remove the building structures, but these areas are not significant enough to affect the overall capacity computations for this study. Also, portions of these structures would remain within the reservoir if inundated. Figures 15 and 24 show the gaps between the 2012 LiDAR and 2013 bathymetric data sets. The 1995 contours were modified and used to fill in these data gaps. Using the 2012 and 2013 data elevations as a guide, the 1995 contours that represented the inflow channels were adjusted to reflect changes since 1995. For the Tonto Creek arm the LiDAR coverage was from elevation 2,124.0 (NAVD88) and extended upstream above the maximum water surface elevation 2,218.0 (NGVD29). For the Salt River arm the LiDAR coverage was from elevation 2,124 (NAVD88) and extended upstream to where the reservoir narrows, ending near elevation 2,182.0 (NAVD88). For the very upper portion of the Salt River arm the 1995 contours were used to develop the 2013 reservoir topography with no modifications.

The LiDAR was provided as raster files for each reach of the reservoir where 1-foot contours were generated and used as hard breaklines for the 2013 topographic development. Editing removed contours above elevation 2,250.0 (NAVD88) and line segments of the contours that were less than 100 feet in length. For the portion of the reservoir covered by the LiDAR, the 5-foot contours from the 1995 study were deleted and not used. Figures 10 through 28 provide images of the data sources used to develop the 2013 topography.

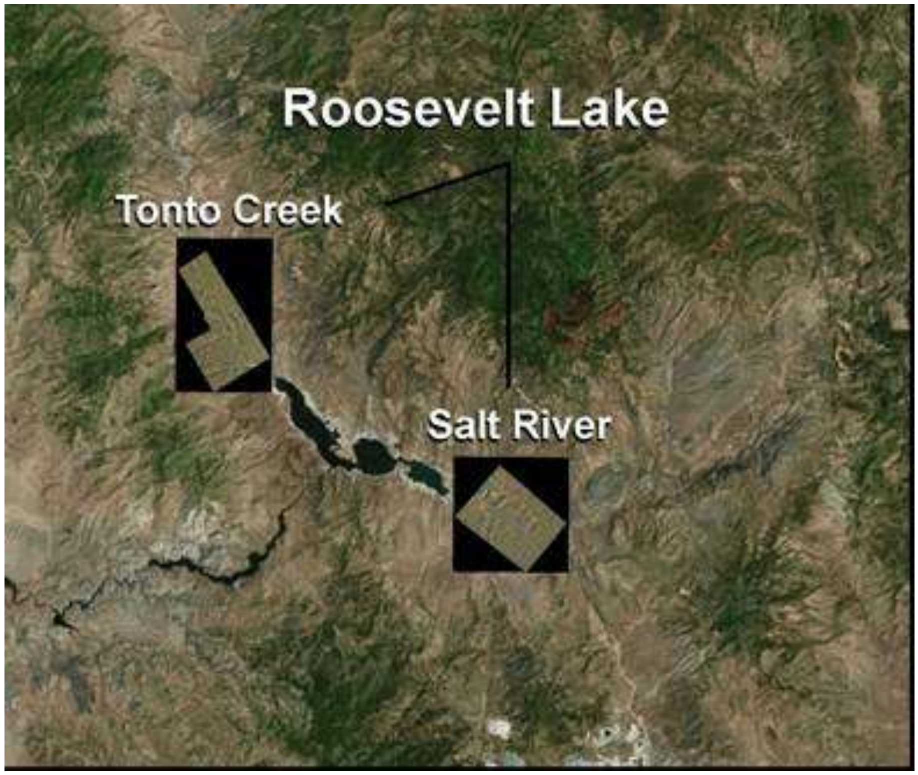


Figure 9 - Reservoir areas covered by the January 2012 LiDAR.

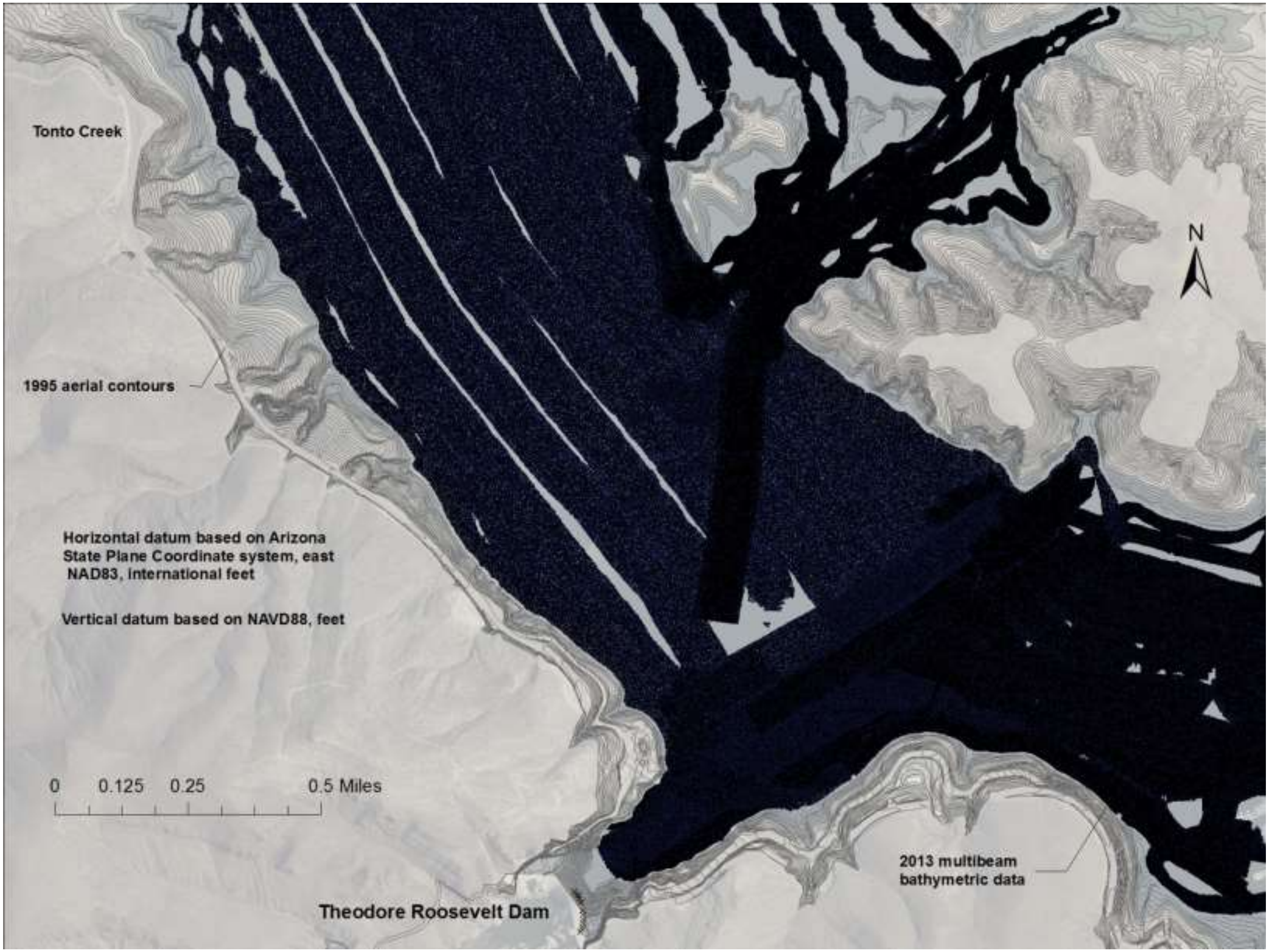


Figure 10 - Theodore Roosevelt Lake data sets, 1 of 19, NAVD88.

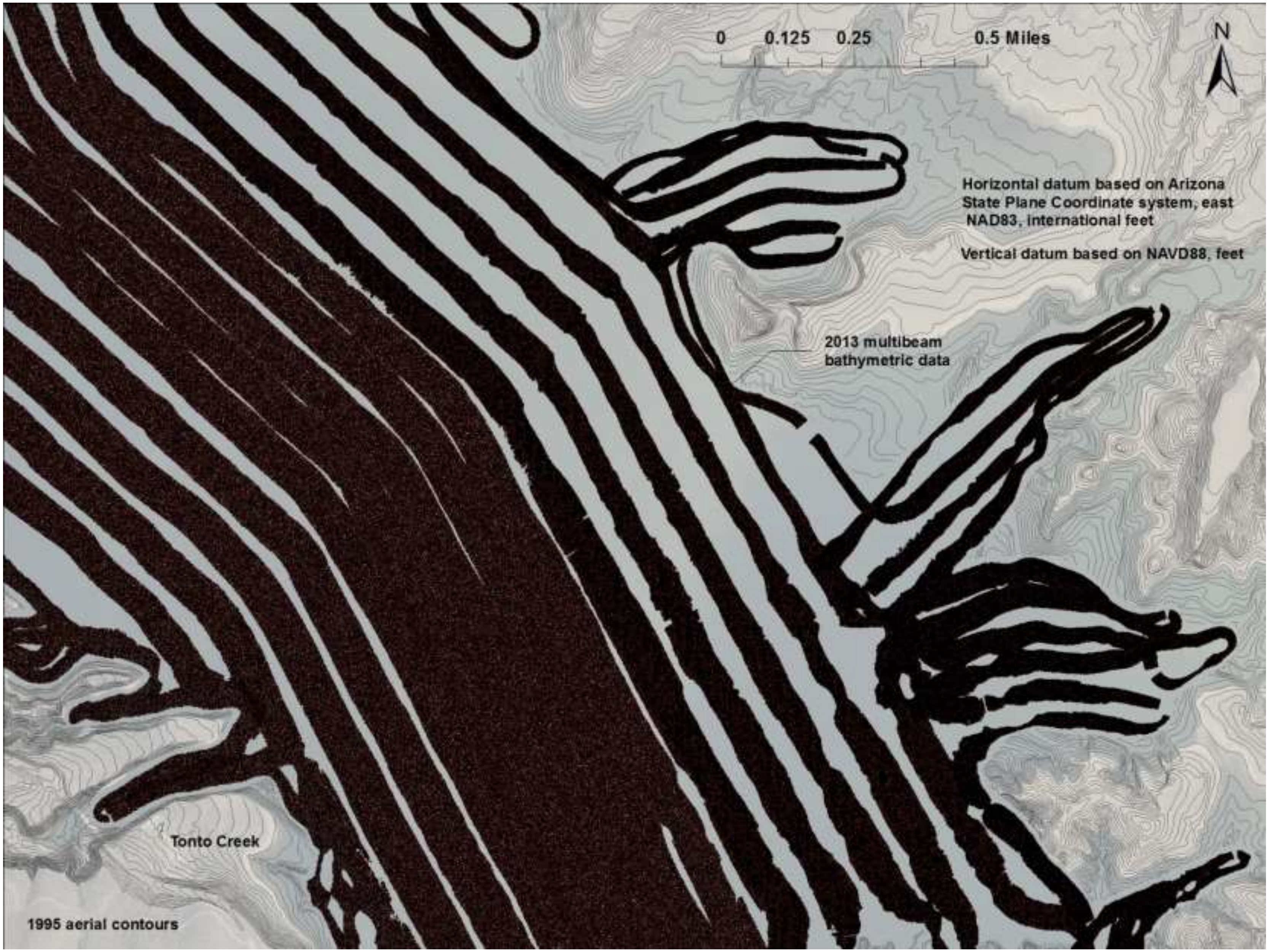


Figure 11 - Theodore Roosevelt Lake data sets, 2 of 19, NAVD88.

Figure 12 **- Theodore Roosevelt Lake data sets, 3 of 19, NAVD88.**

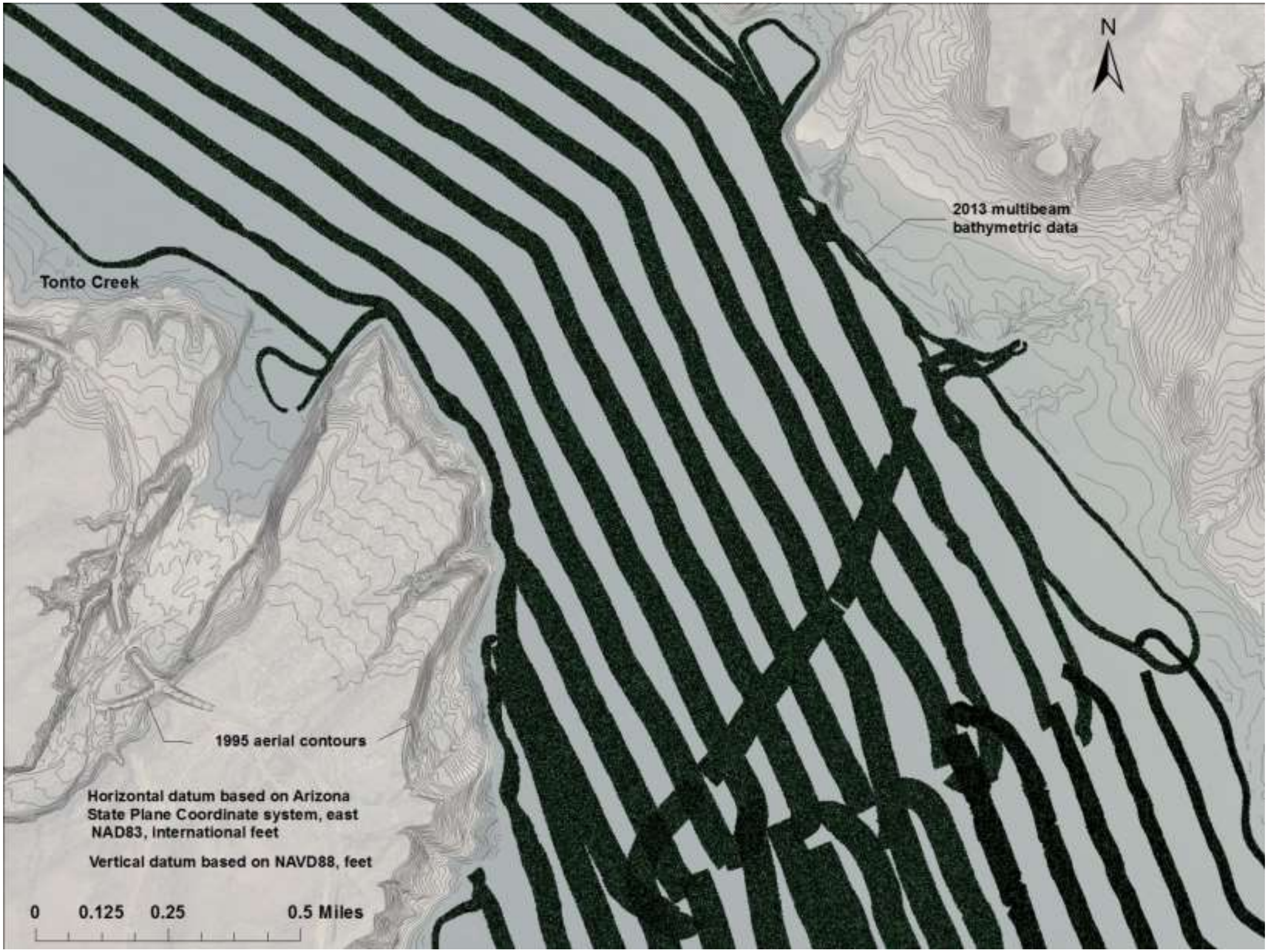


Figure 13 - Theodore Roosevelt Lake data sets, 4 of 19, NAVD88.

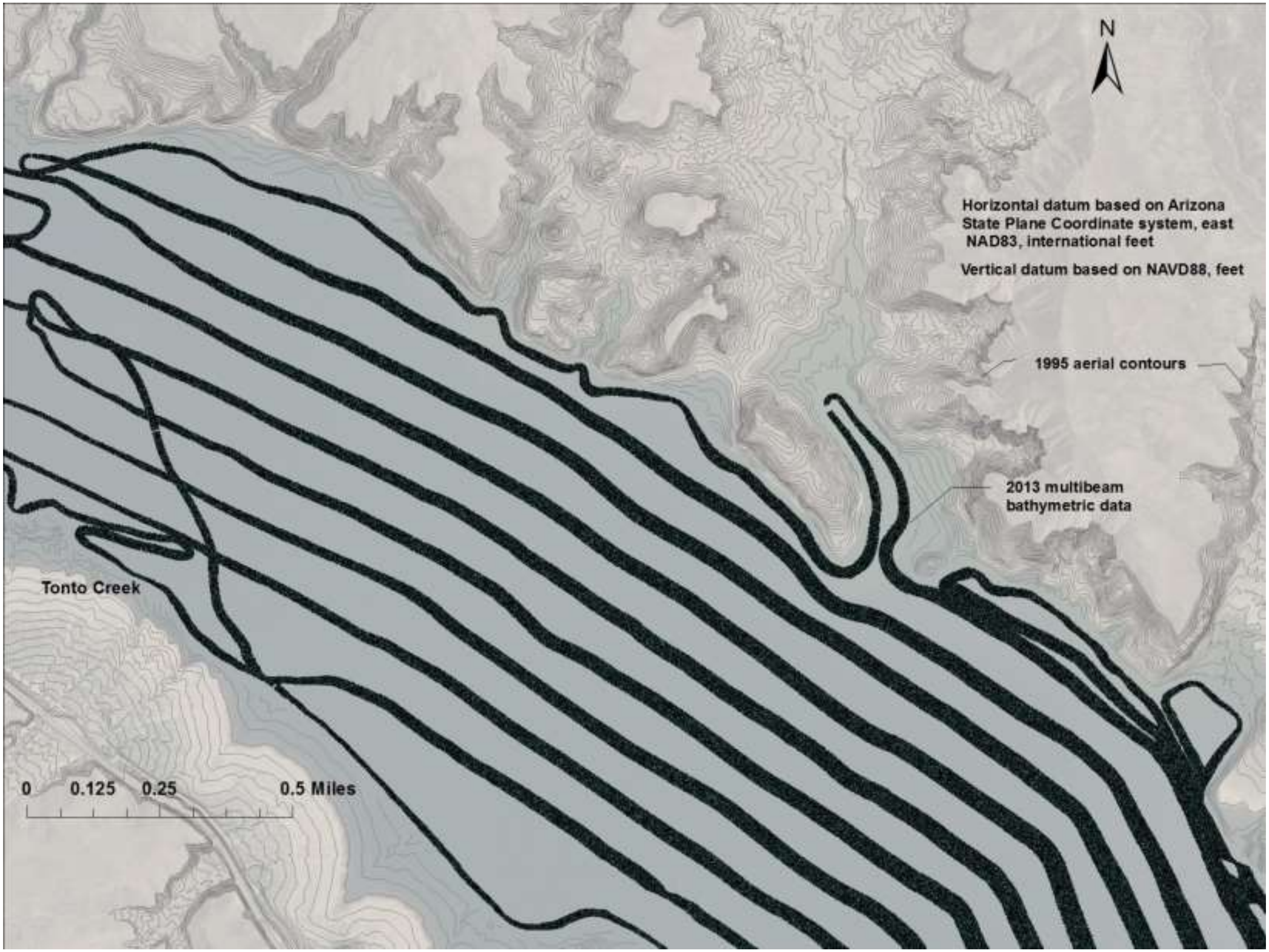


Figure 14 - Theodore Roosevelt Lake data sets, 5 of 19, NAVD88.

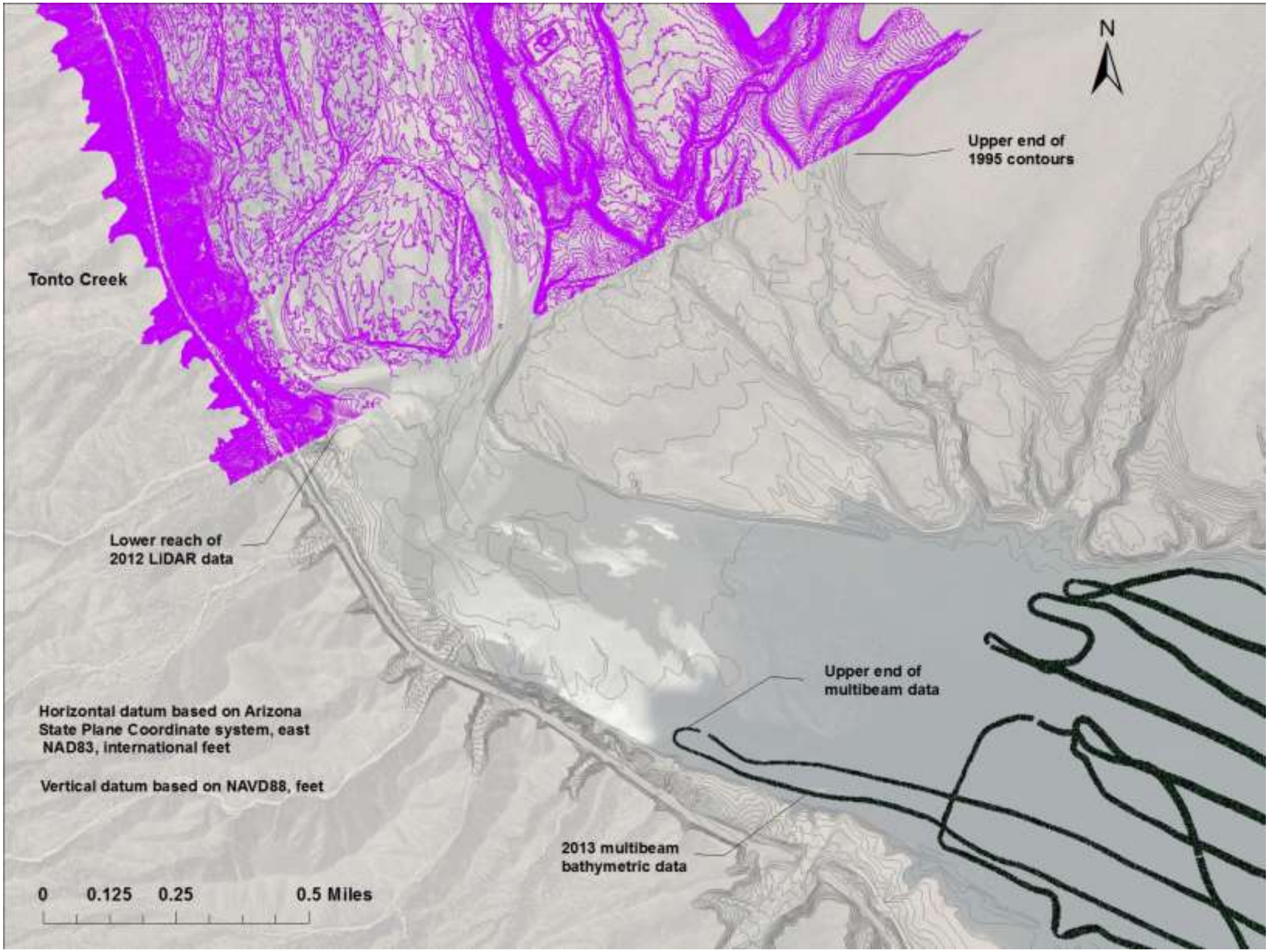
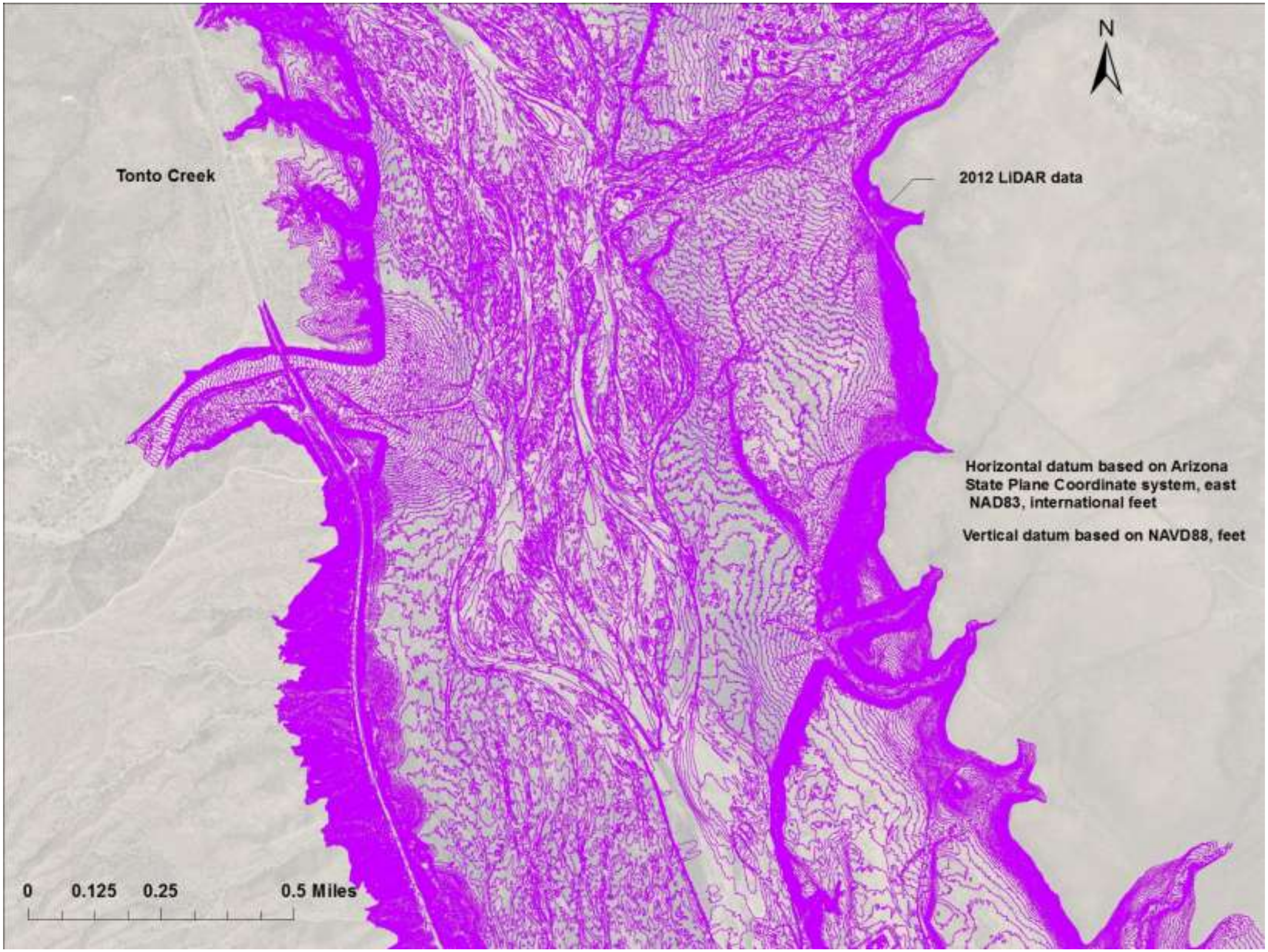


Figure 15 - Theodore Roosevelt Lake data sets, 6 of 19, NAVD88.



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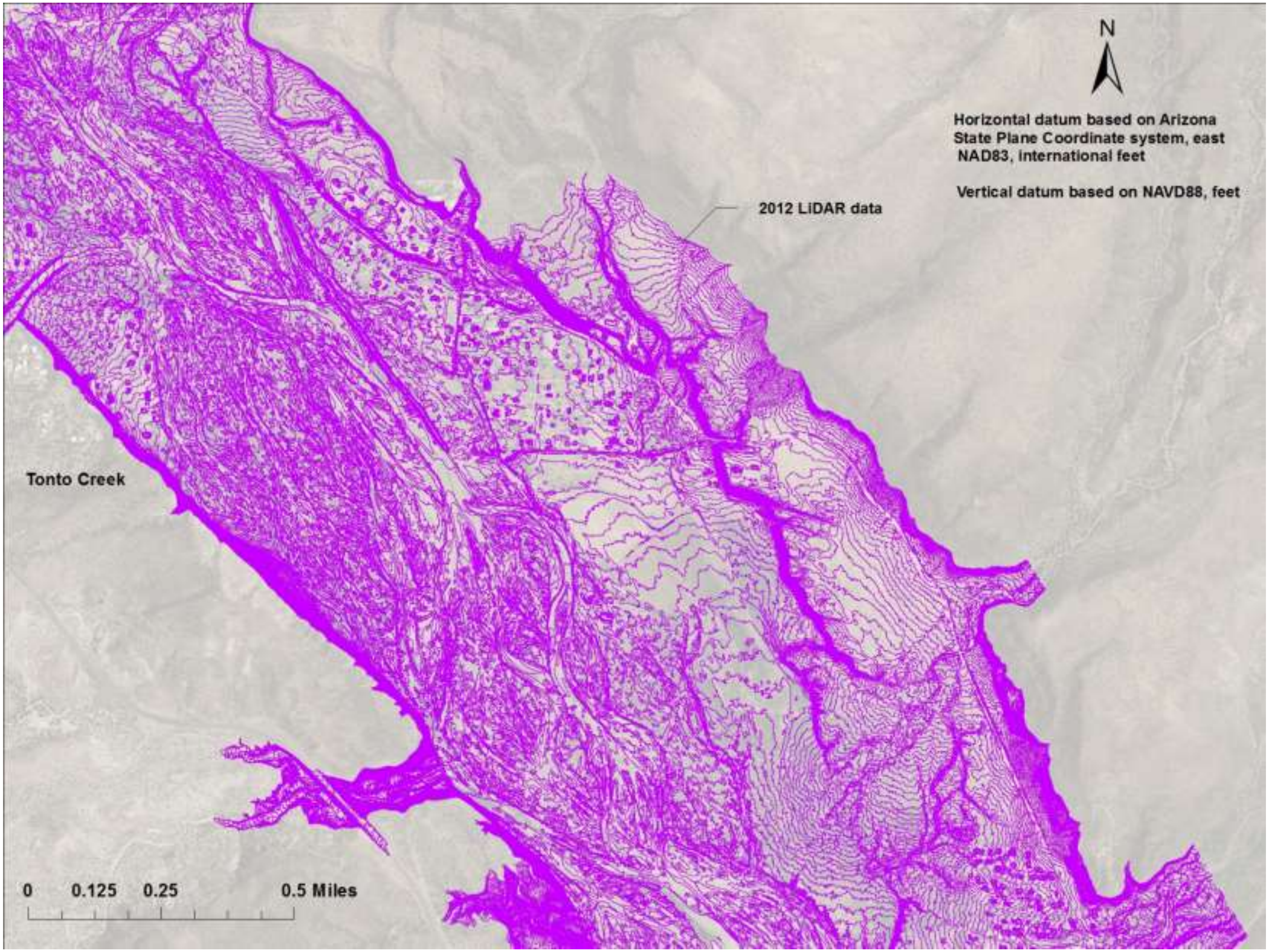


Figure 17 - Theodore Roosevelt Lake data sets, 8 of 19, NAVD88.

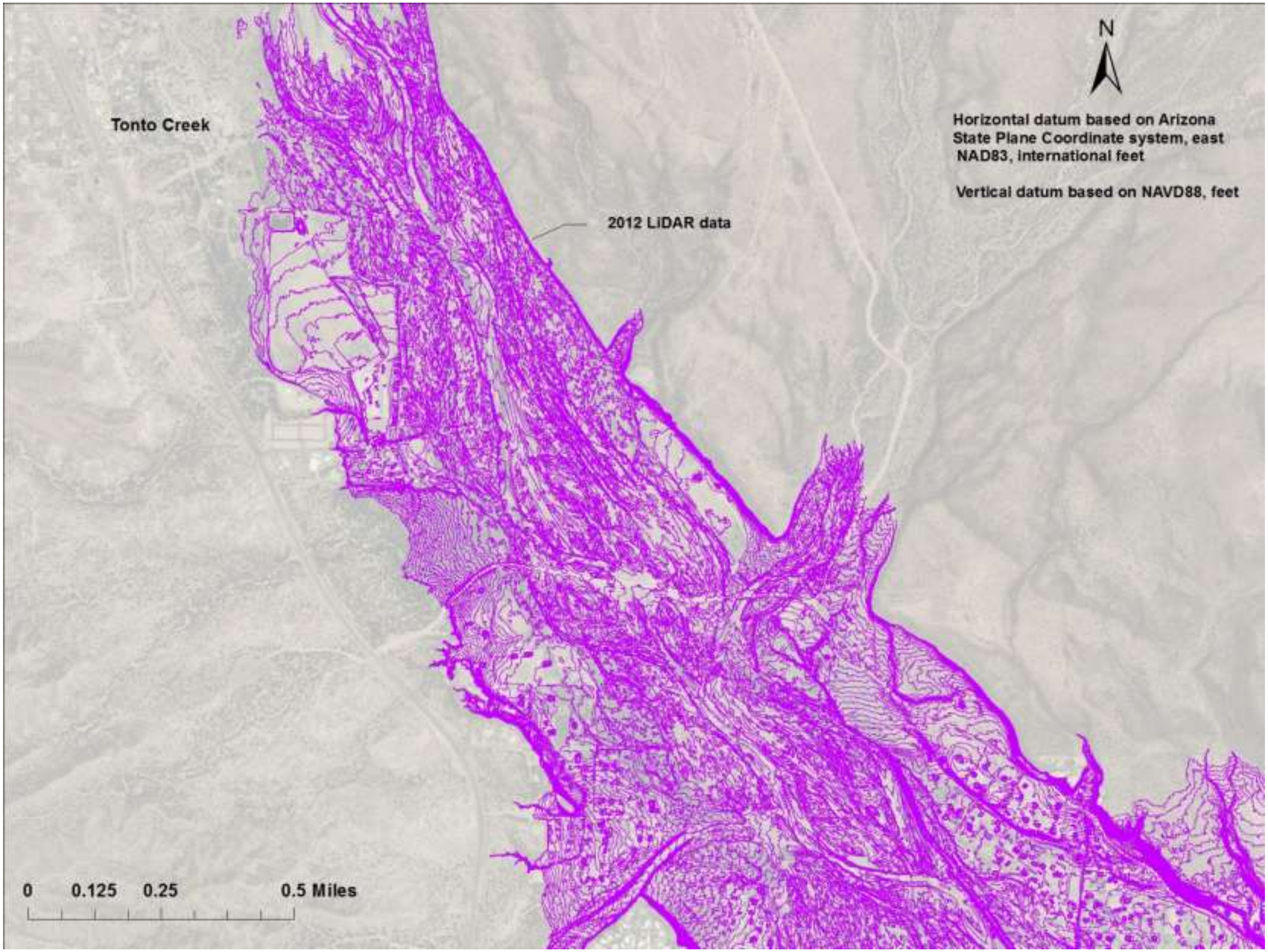


Figure 18 - Theodore Roosevelt Lake data sets, 9 of 19, NAVD88.

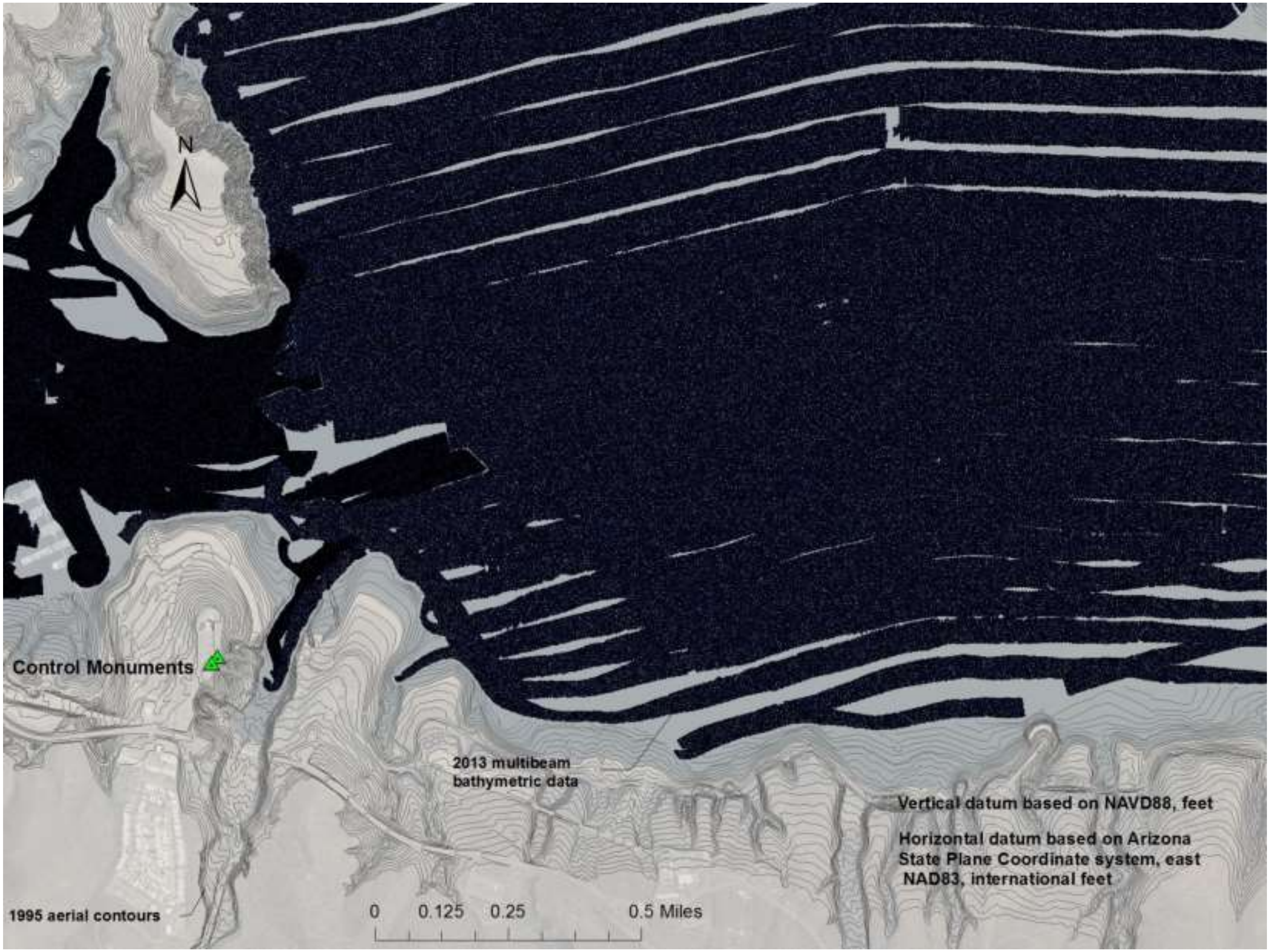


Figure 19 - Theodore Roosevelt Lake data sets, 10 of 19, NAVD88.

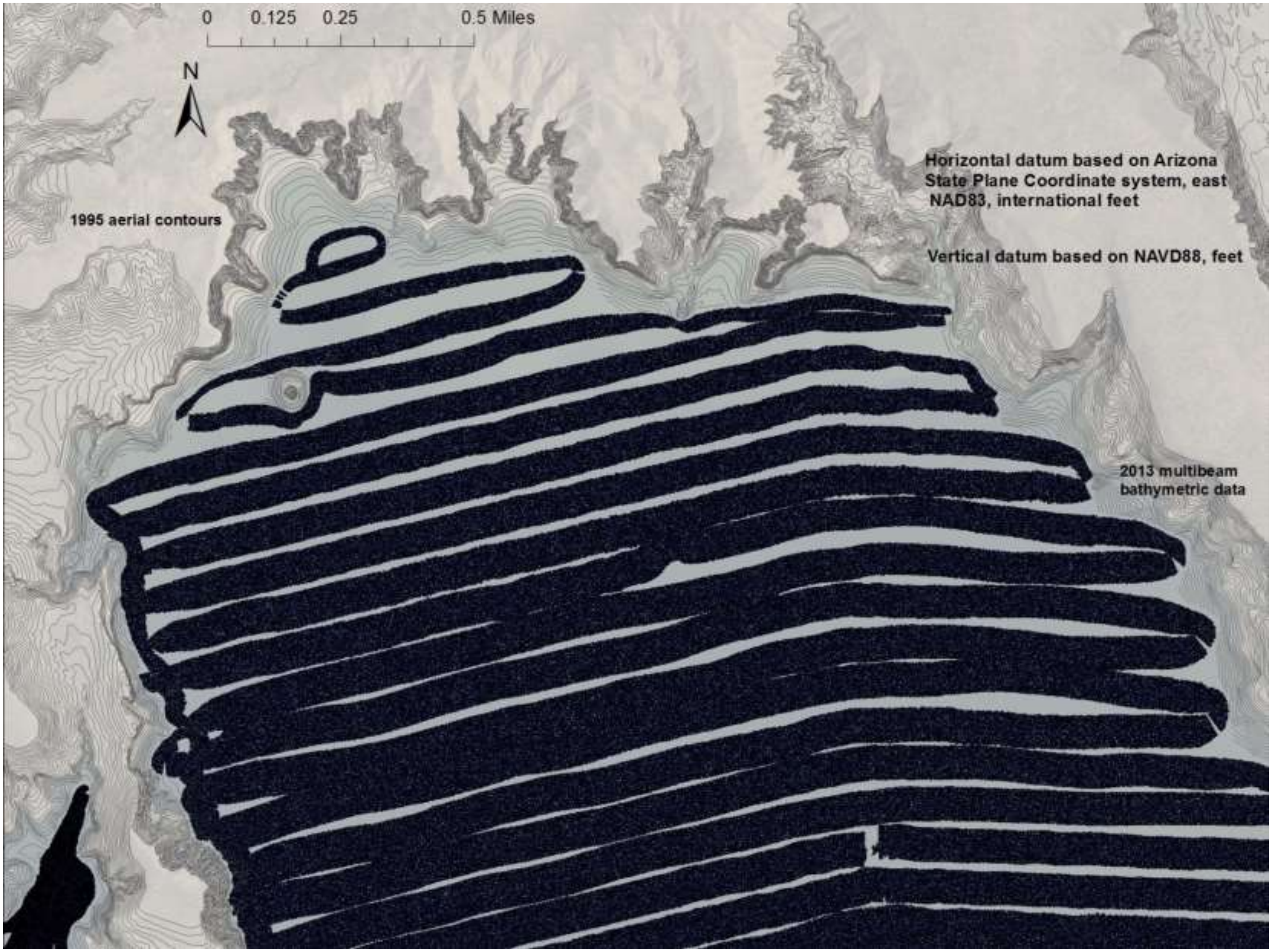
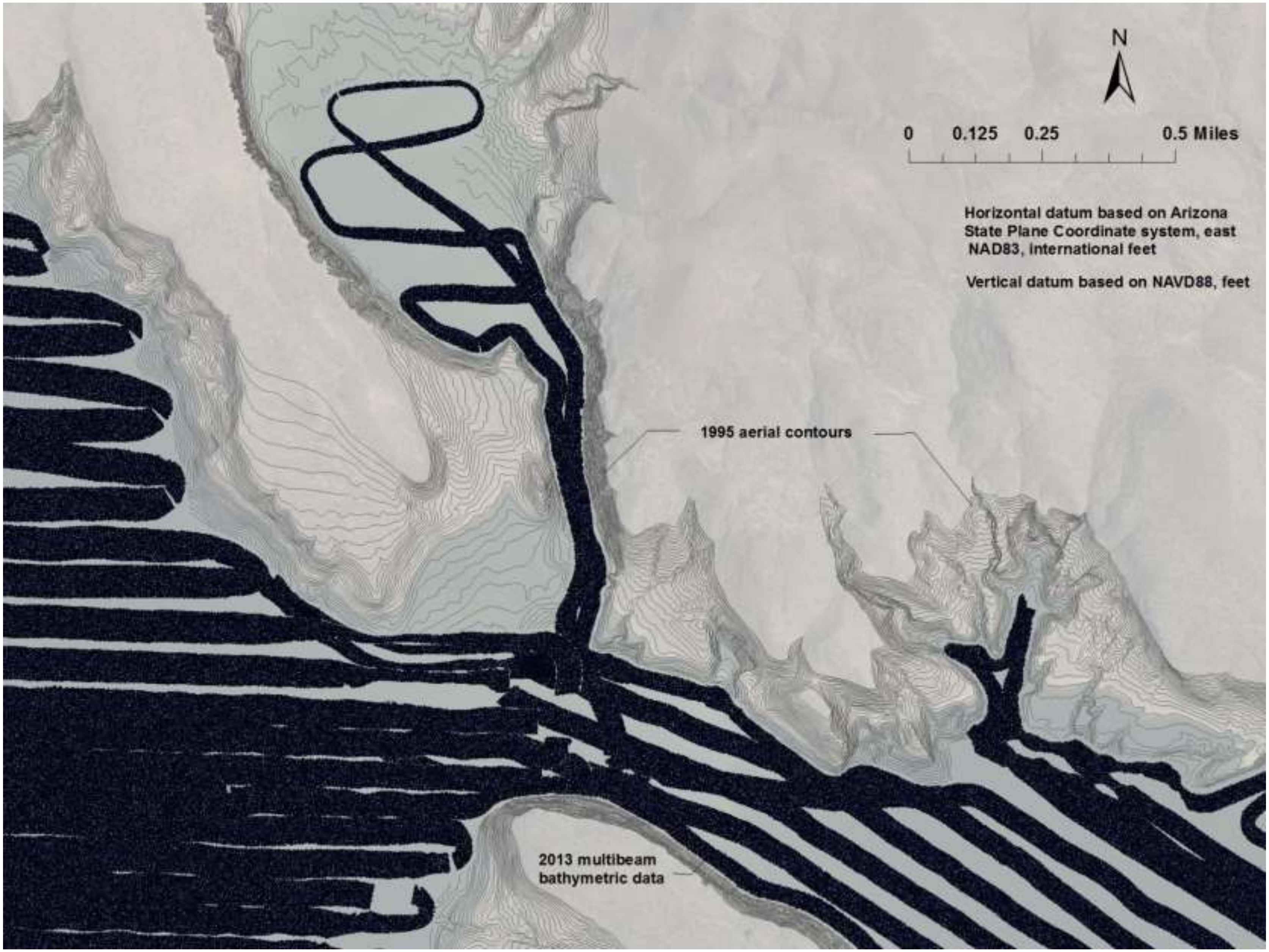


Figure 20 - Theodore Roosevelt Lake data sets, 11 of 19, NAVD88.



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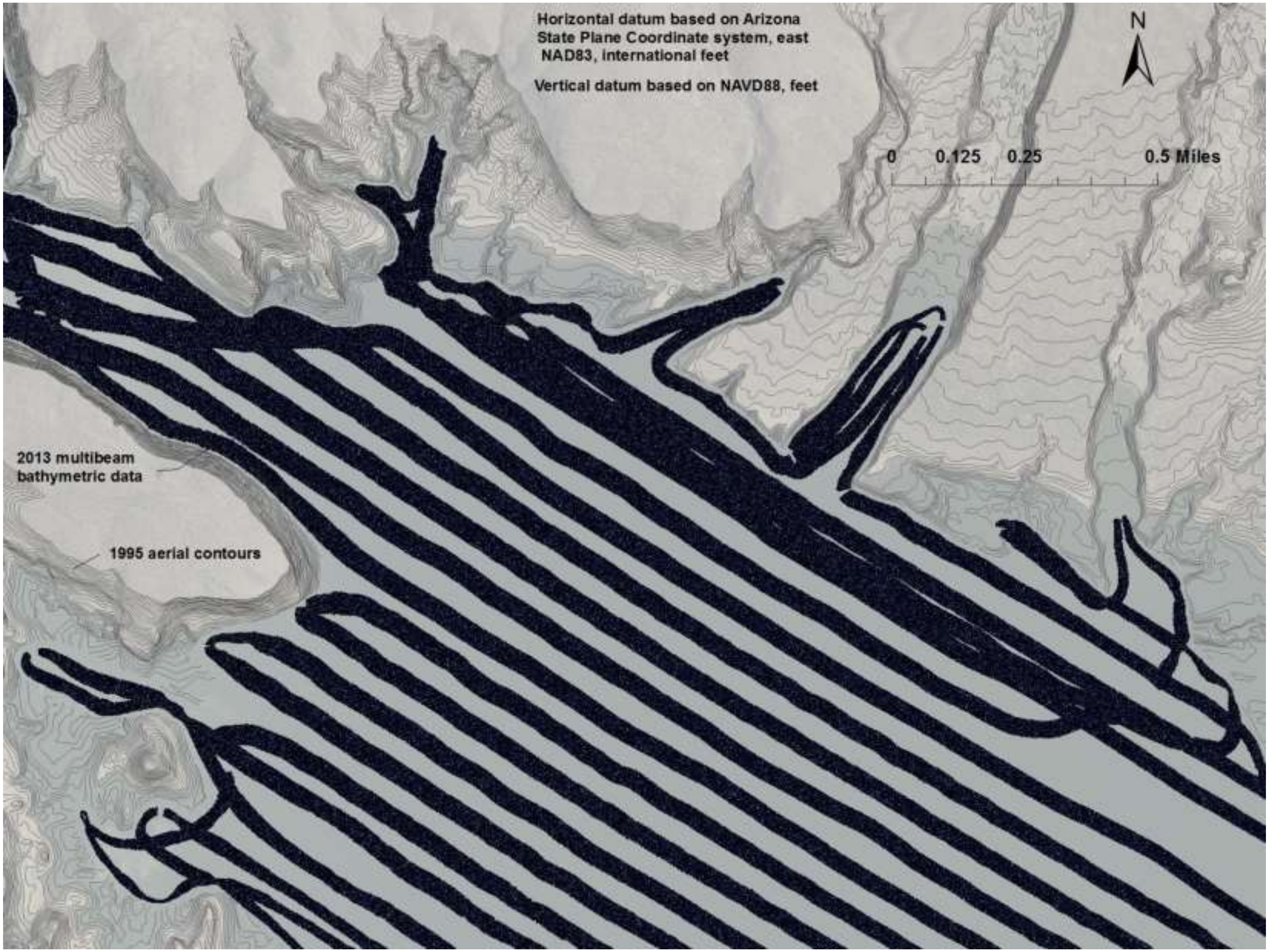

Figure 22 - Theodore Roosevelt Lake data sets, 13 of 19, NAVD88.

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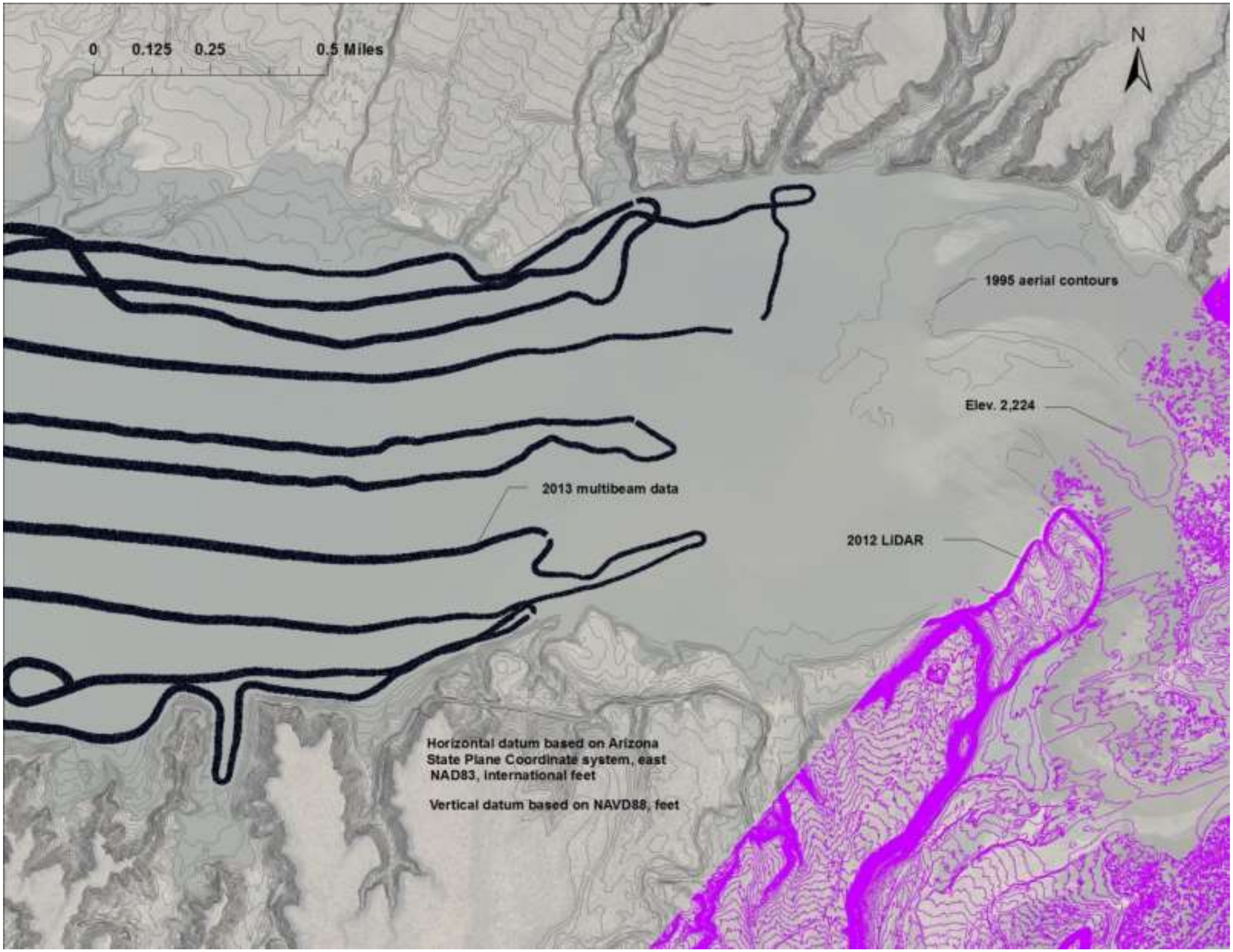

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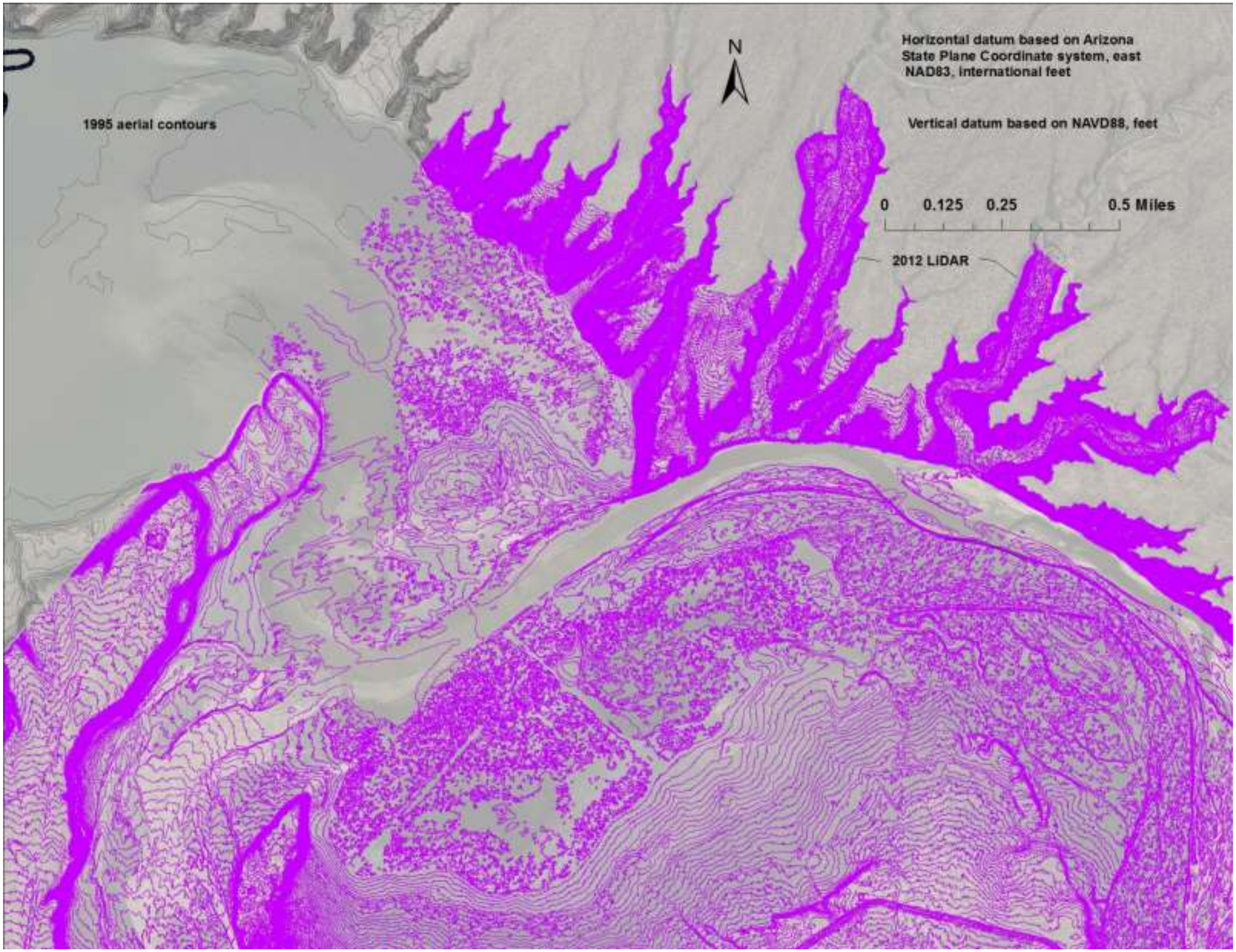

Figure 25 - Theodore Roosevelt Lake data sets, 16 of 19, NAVD88.

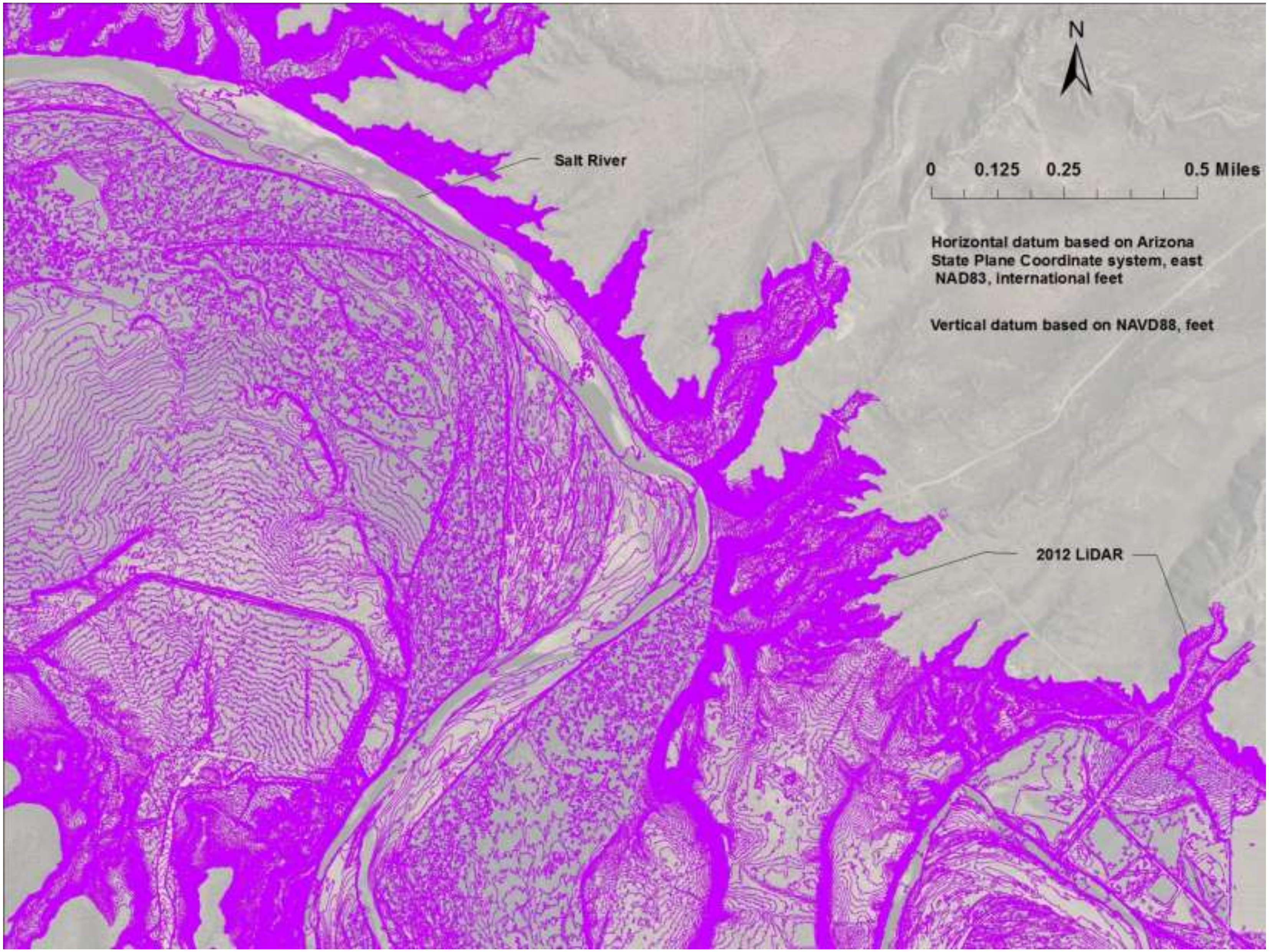

Figure 26 - Theodore Roosevelt Lake data sets, 17 of 19, NAVD88.

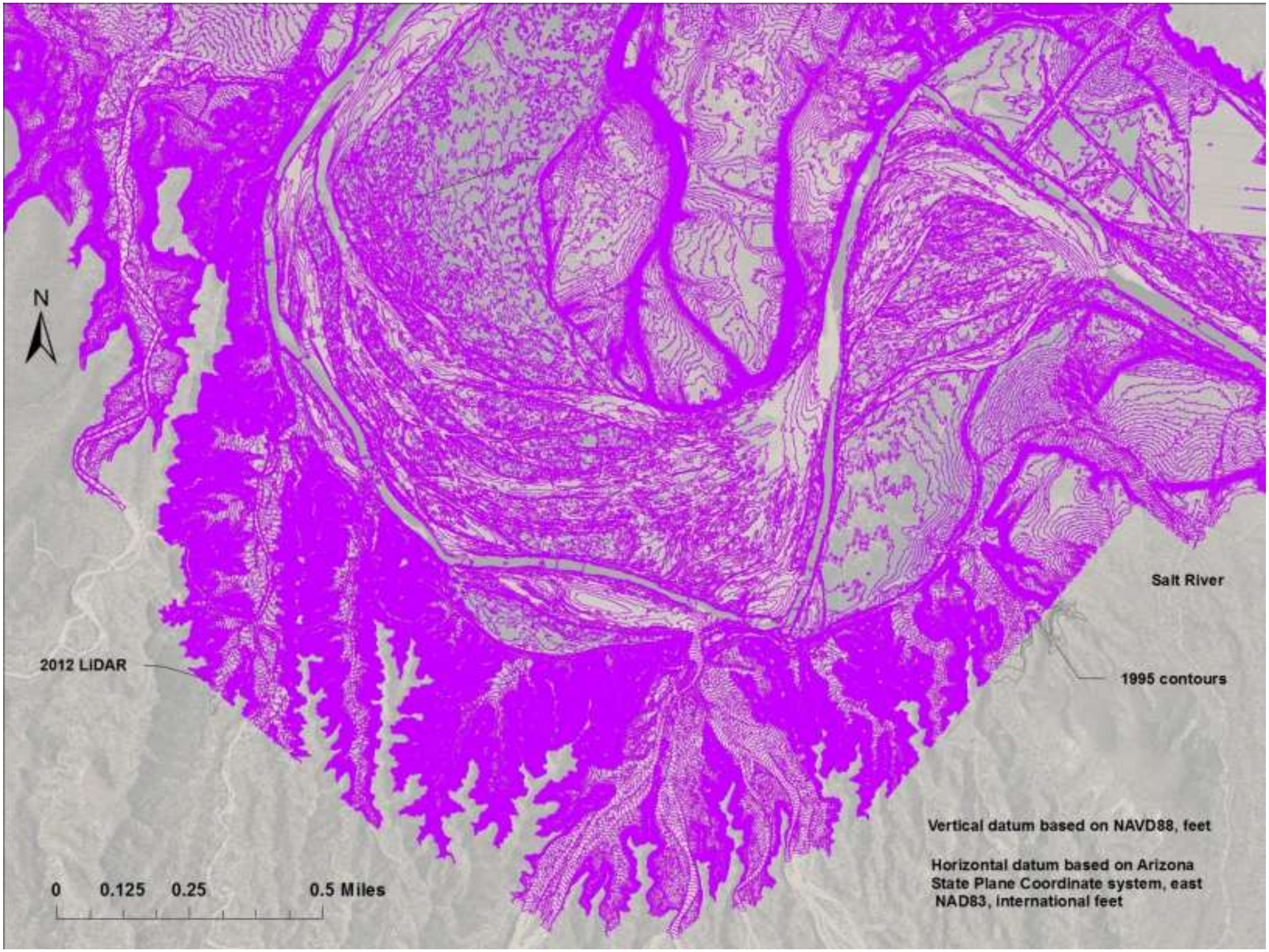

Figure 27 - Theodore Roosevelt Lake data sets, 18 of 19, NAVD88.

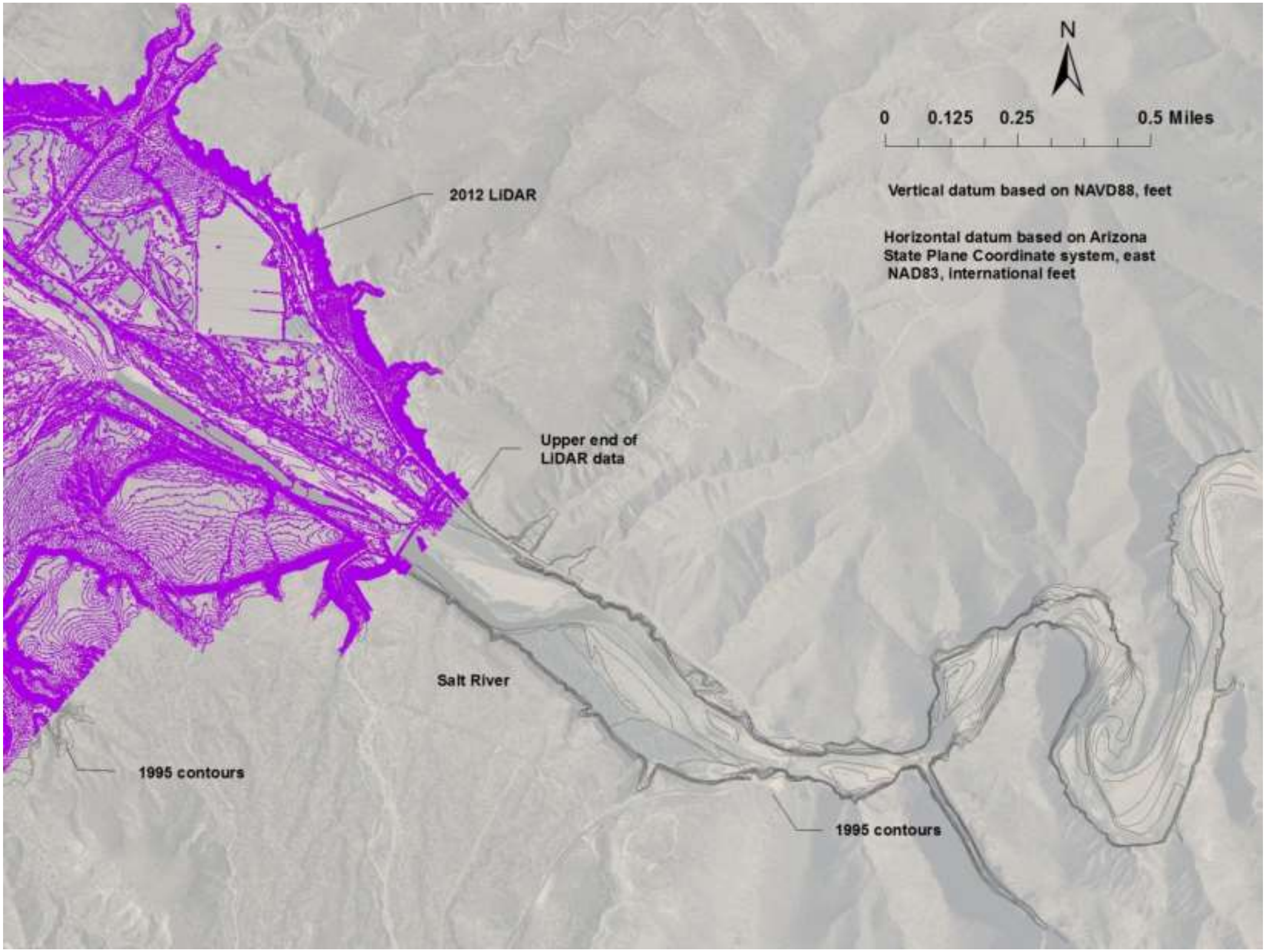

Figure 28 - Theodore Roosevelt Lake data sets, 19 of 19, NAVD88.

Reservoir Area and Capacity

Topography Development

The 2013 Theodore Roosevelt Lake topographic contours were generated from several data sources including the 2013 bathymetric survey, 2012 LiDAR, and 1995 developed 5-foot contours. The LiDAR was provided as raster files and covered the upper reaches of Tonto Creek and the Salt River. To obtain the necessary detail in a workable format, 1-foot contours were developed from the raster coverages and used as breaklines during the topographic development. The areas of the 1995 data overlapped by the 2013 bathymetric and 2012 LiDAR data were removed or erased using ArcGIS tools. The 2012 LiDAR and 2013 bathymetry did not overlap within the reservoir boundary. The remaining 1995 contour lines, with some modifications, were used as breaklines during the topographic development. The 2013 Roosevelt Lake topography elevations were tied to NAVD88 (GEOID12A).

The data coverages were processed into a triangulated irregular network (TIN), Figures 29 through 31, that was used to develop 2- and 5-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 allowing contour development of the reservoir study area along the dam alignment and 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, 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 the polygon clip. The method requires that a circle drawn through the three nodes of a triangle will contain no other point, meaning that all the data points are connected to their nearest neighbors to form triangles, preserving all the data points. The TIN method is described in more detail in the ArcGIS user's documentation (ESRI, 2012).

The linear interpolation option of the ArcGIS *TIN* and *CONTOUR* commands was used to interpolate contours from the Roosevelt Lake TIN. The surface areas of the enclosed contour polygons at 2- and 5-foot increments were computed for elevation 1,967.0 through 2,227.0 (NAVD88). The minimum or zero surface area of the reservoir was elevation 1,965.0 (NGVD29). The reservoir contour topography at 5-foot intervals are presented in Figures 32 through 50 from elevation 1,970.0 through elevation 2,225.0 (NAVD88).

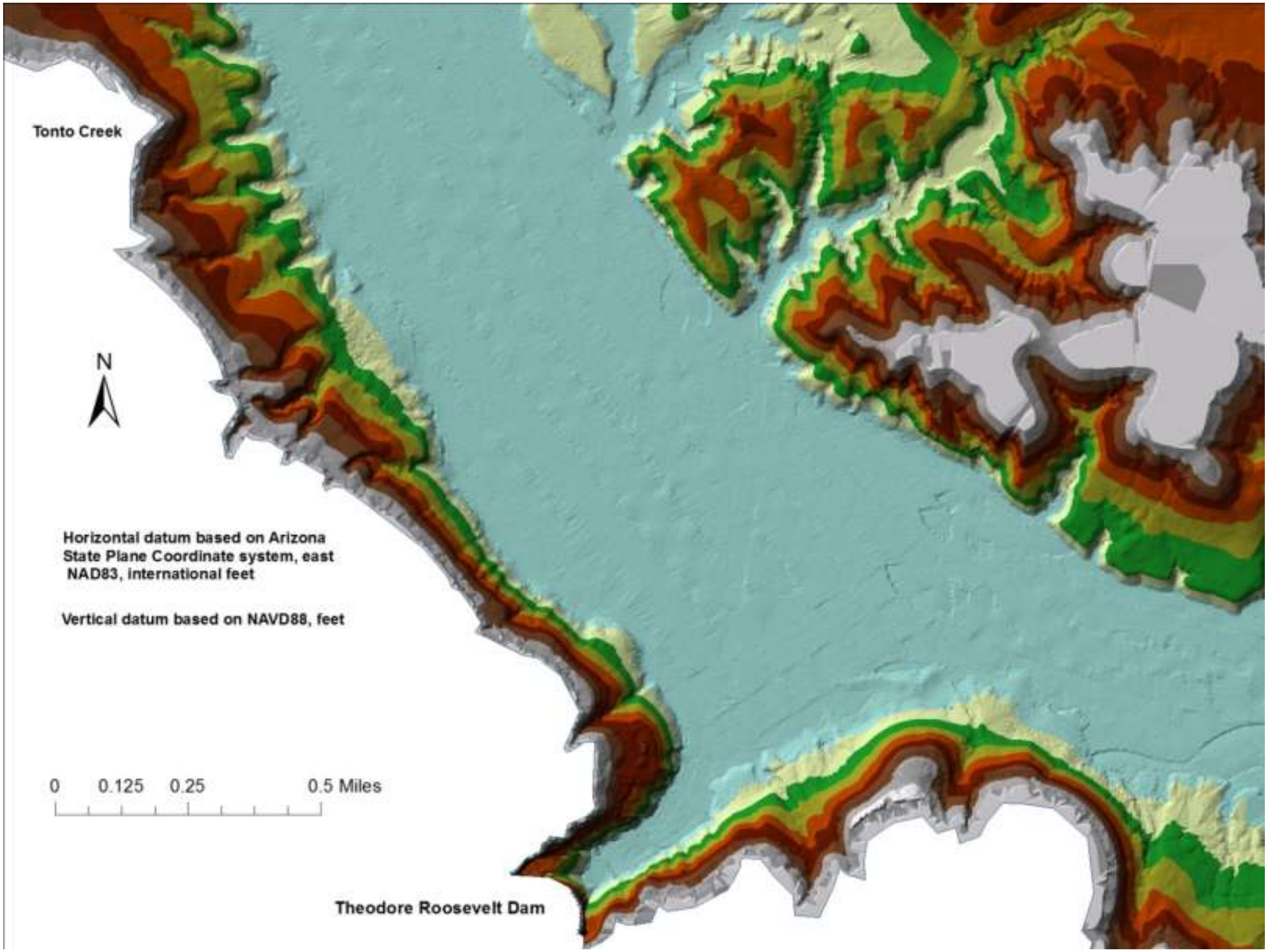

Figure 29 - Theodore Roosevelt Dam and reservoir developed TIN, 1 of 3, (NAVD88).

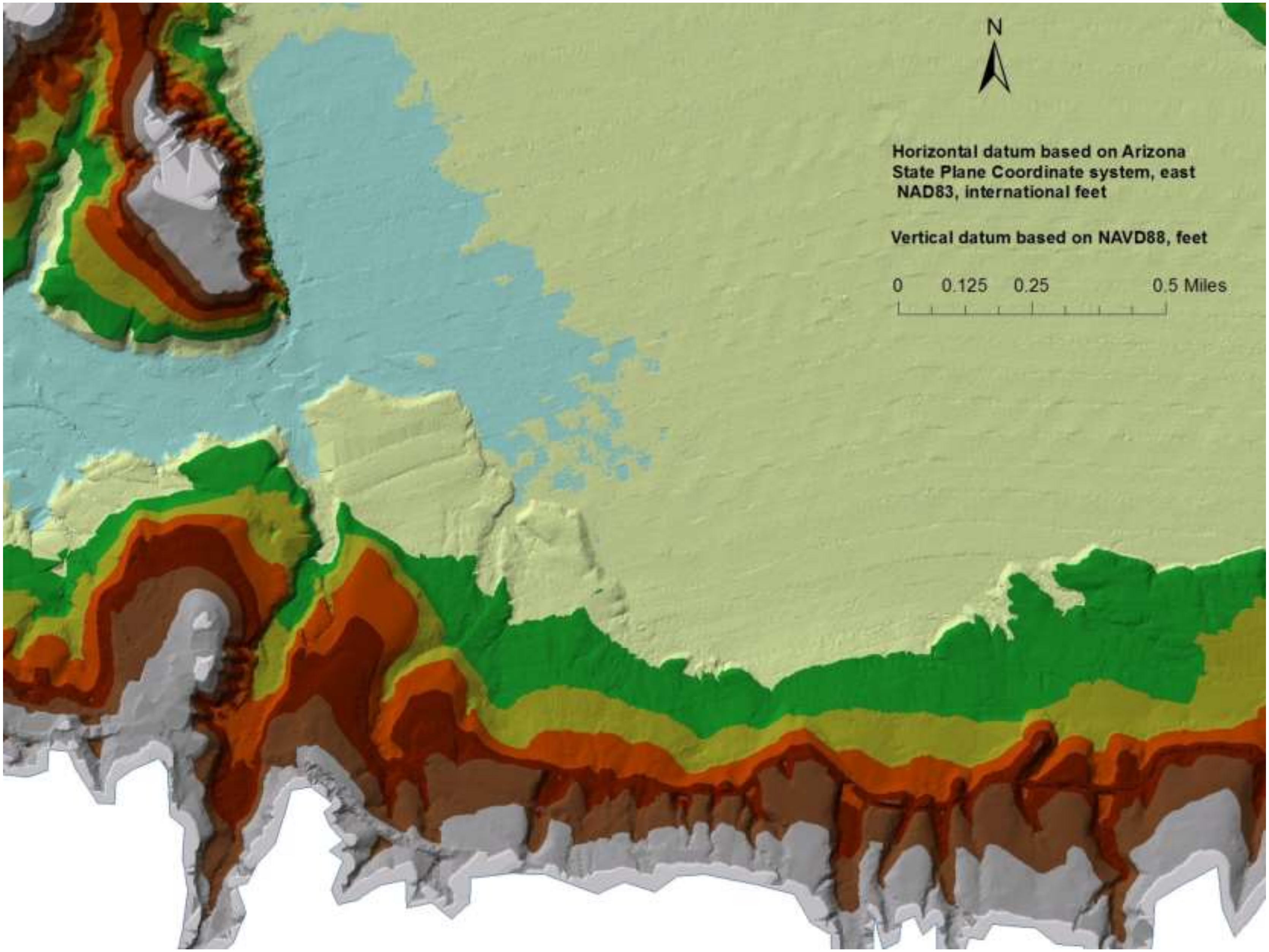

Figure 30 - Theodore Roosevelt Lake developed TIN, 2 of 3, (NAVD88).

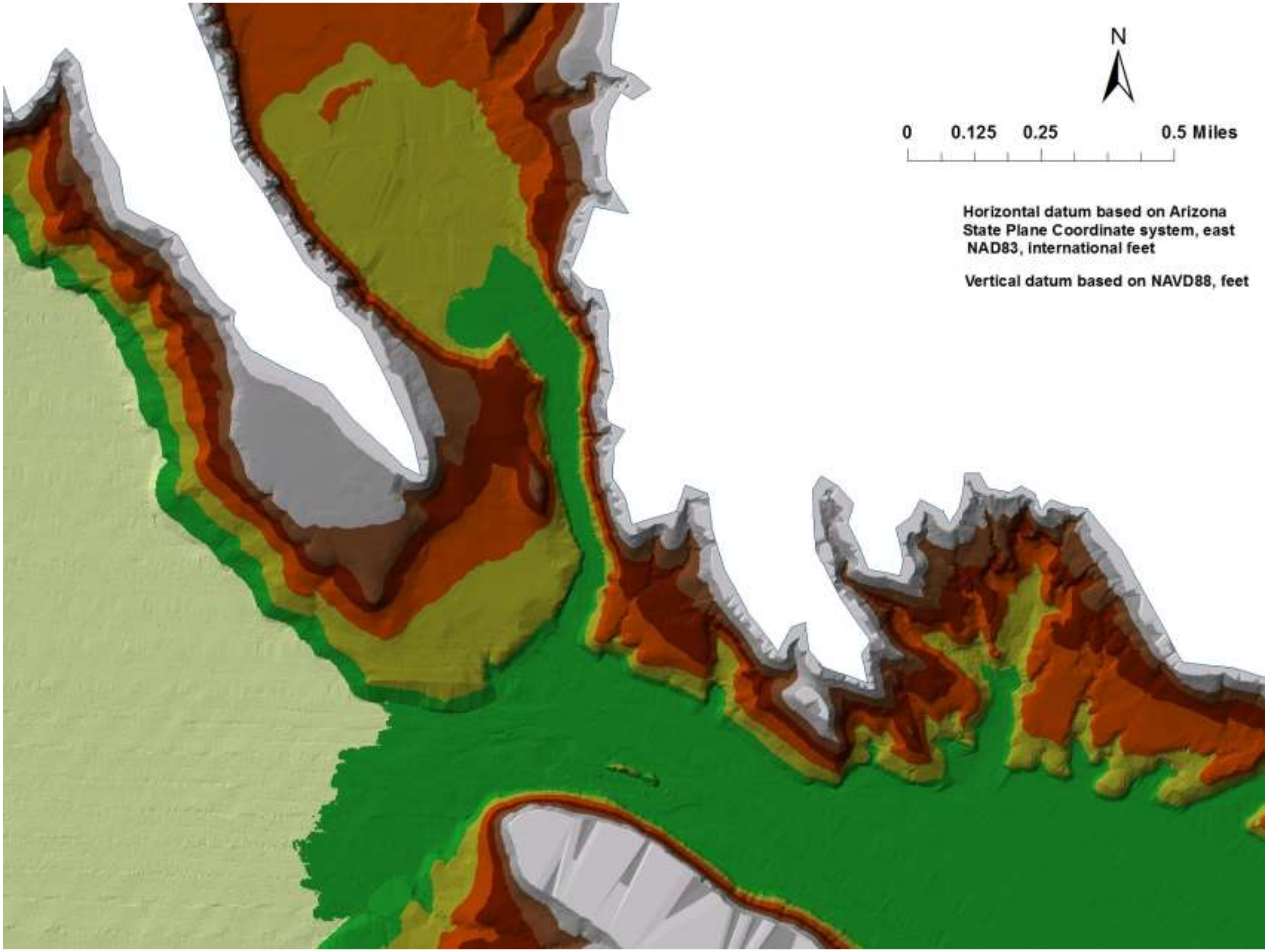

Figure 31 - Theodore Roosevelt Lake developed TIN, 3 of 3, (NAVD88).

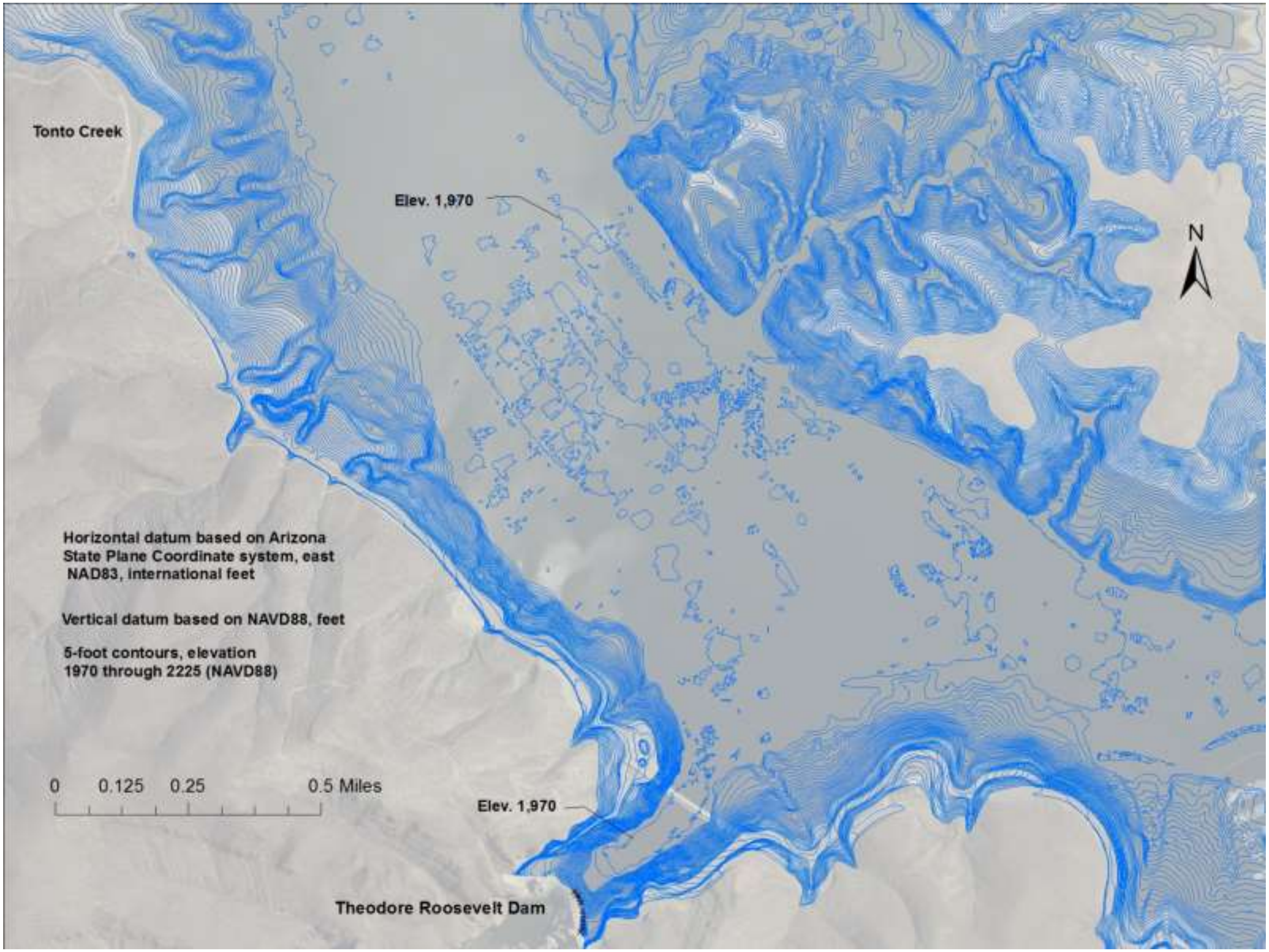

Figure 32 - 2013 Theodore Roosevelt Lake 5-foot contours, 1 of 19 (NAVD88).

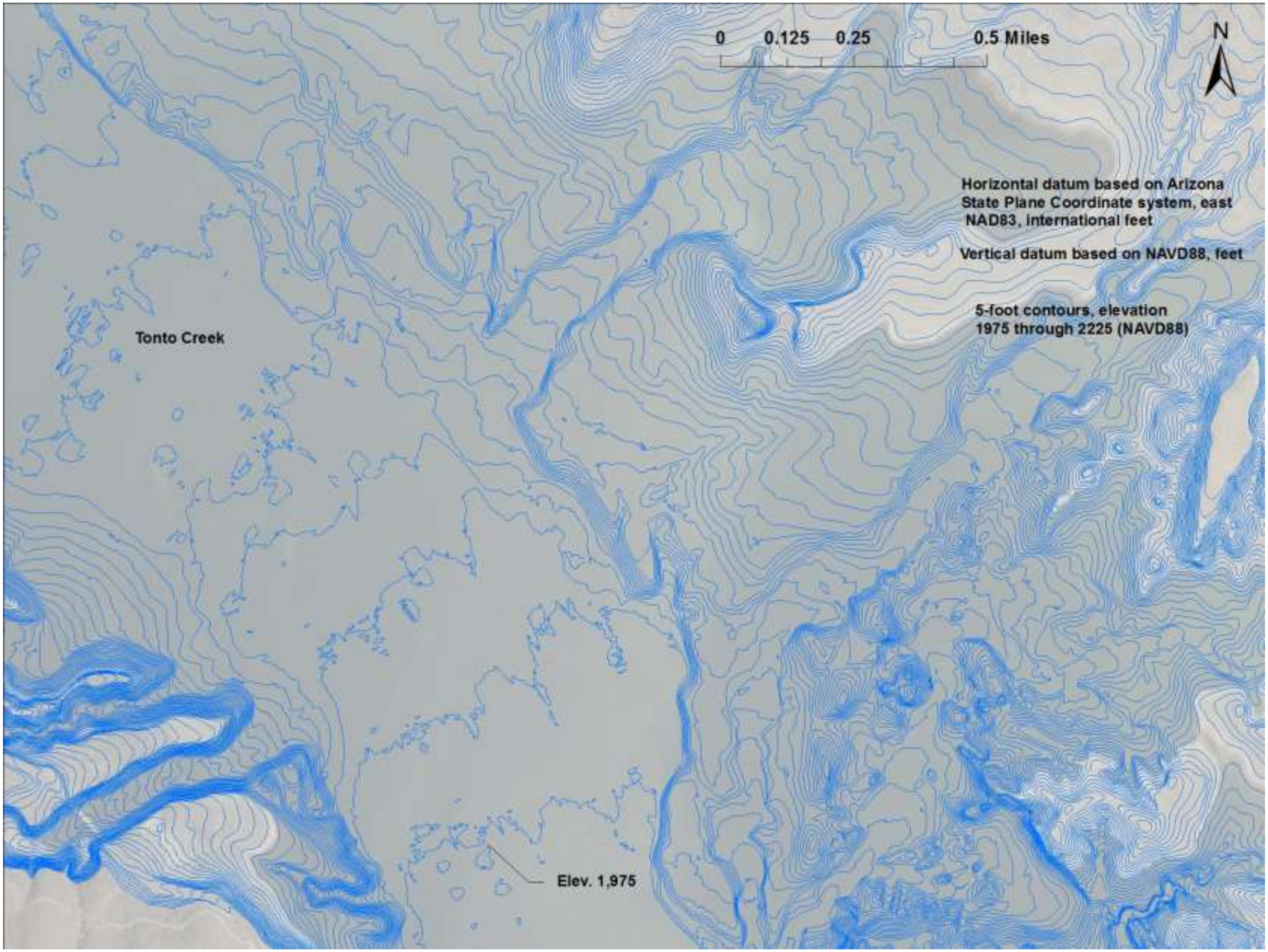

Figure 33 - 2013 Theodore Roosevelt Lake 5-foot contours, 2 of 19 (NAVD88).

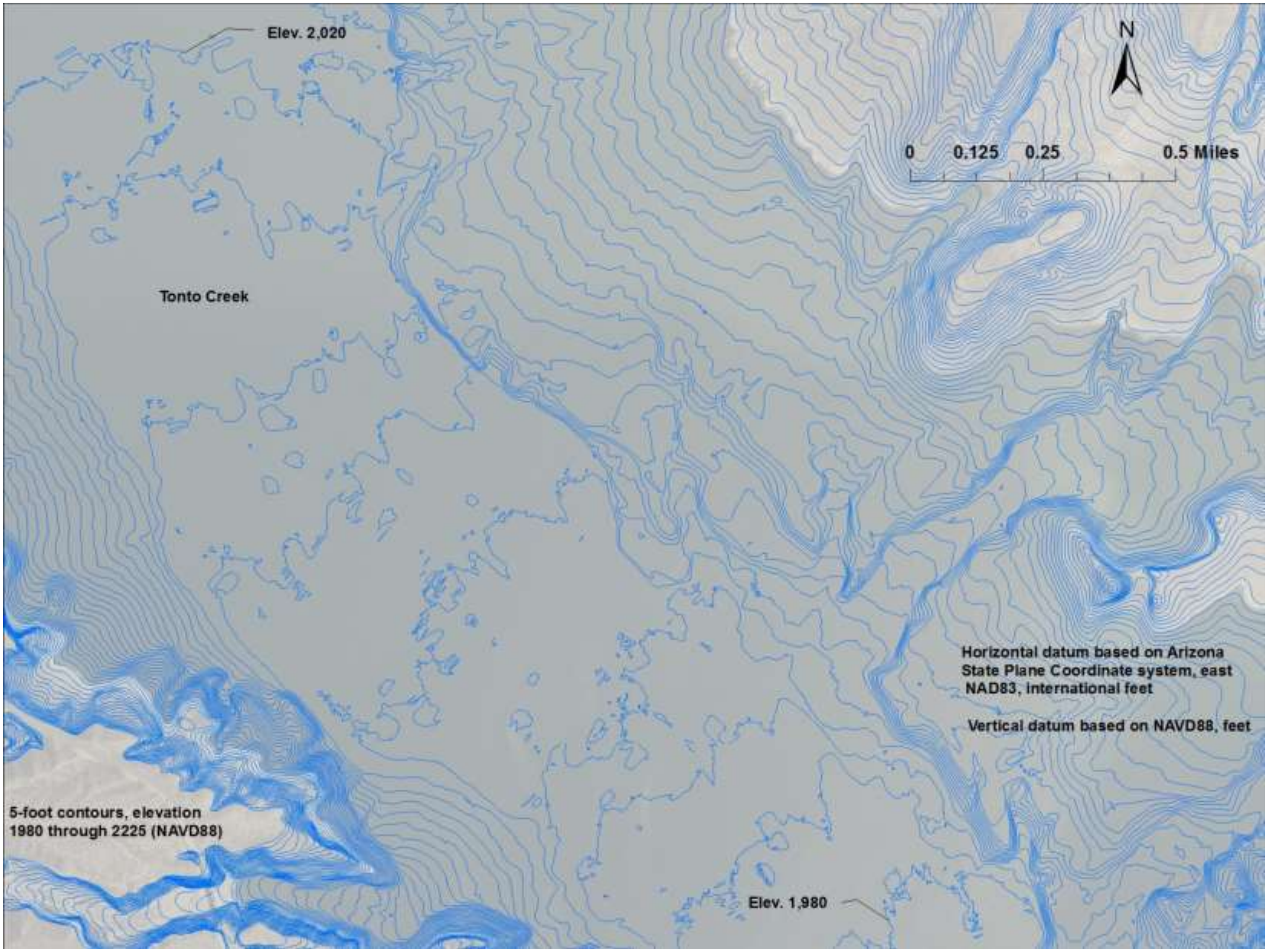

Figure 34 - 2013 Theodore Roosevelt Lake 5-foot contours, 3 of 19 (NAVD88).

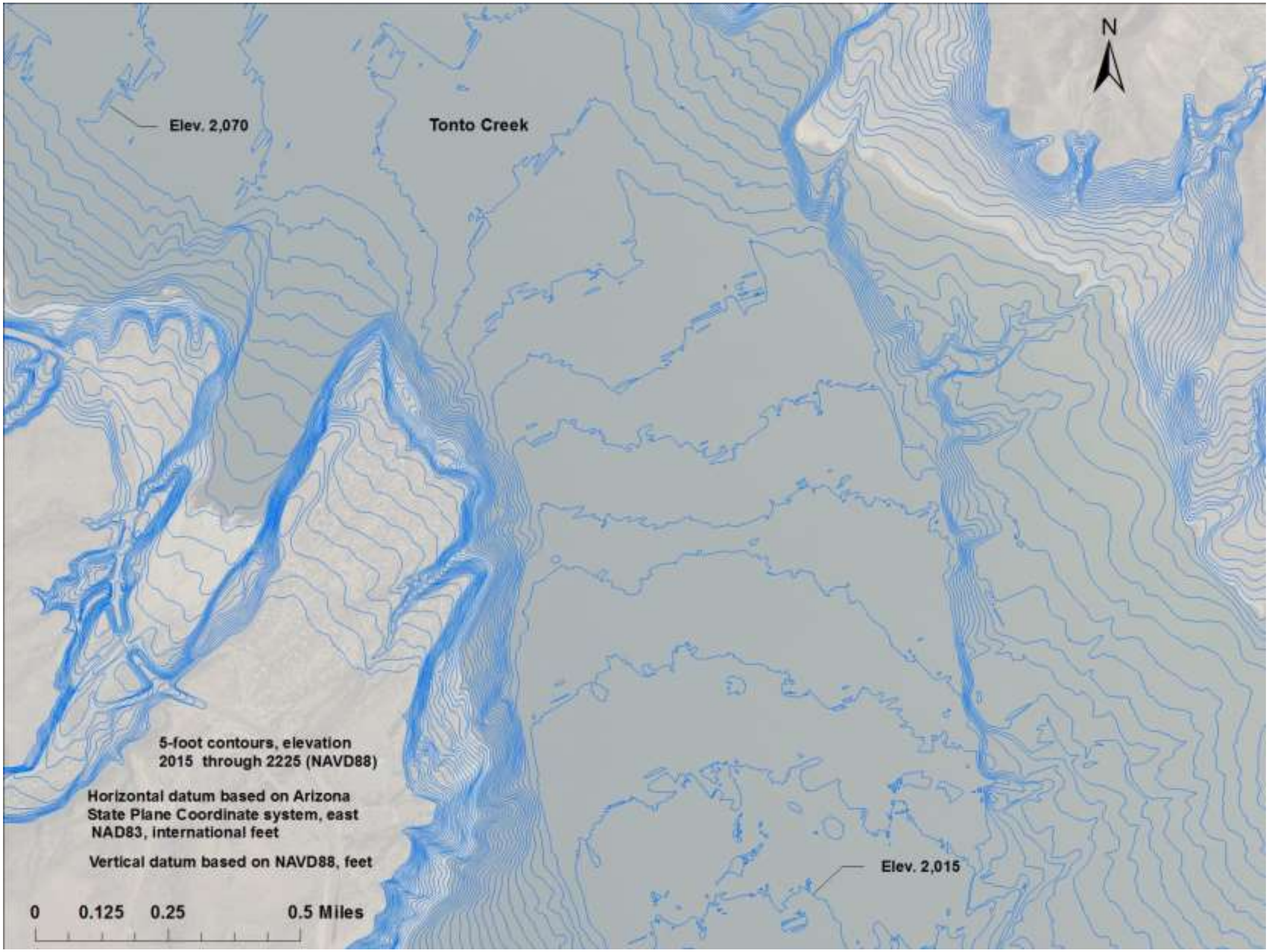

Figure 35 - 2013 Theodore Roosevelt Lake 5-foot contours, 4 of 19 (NAVD88).

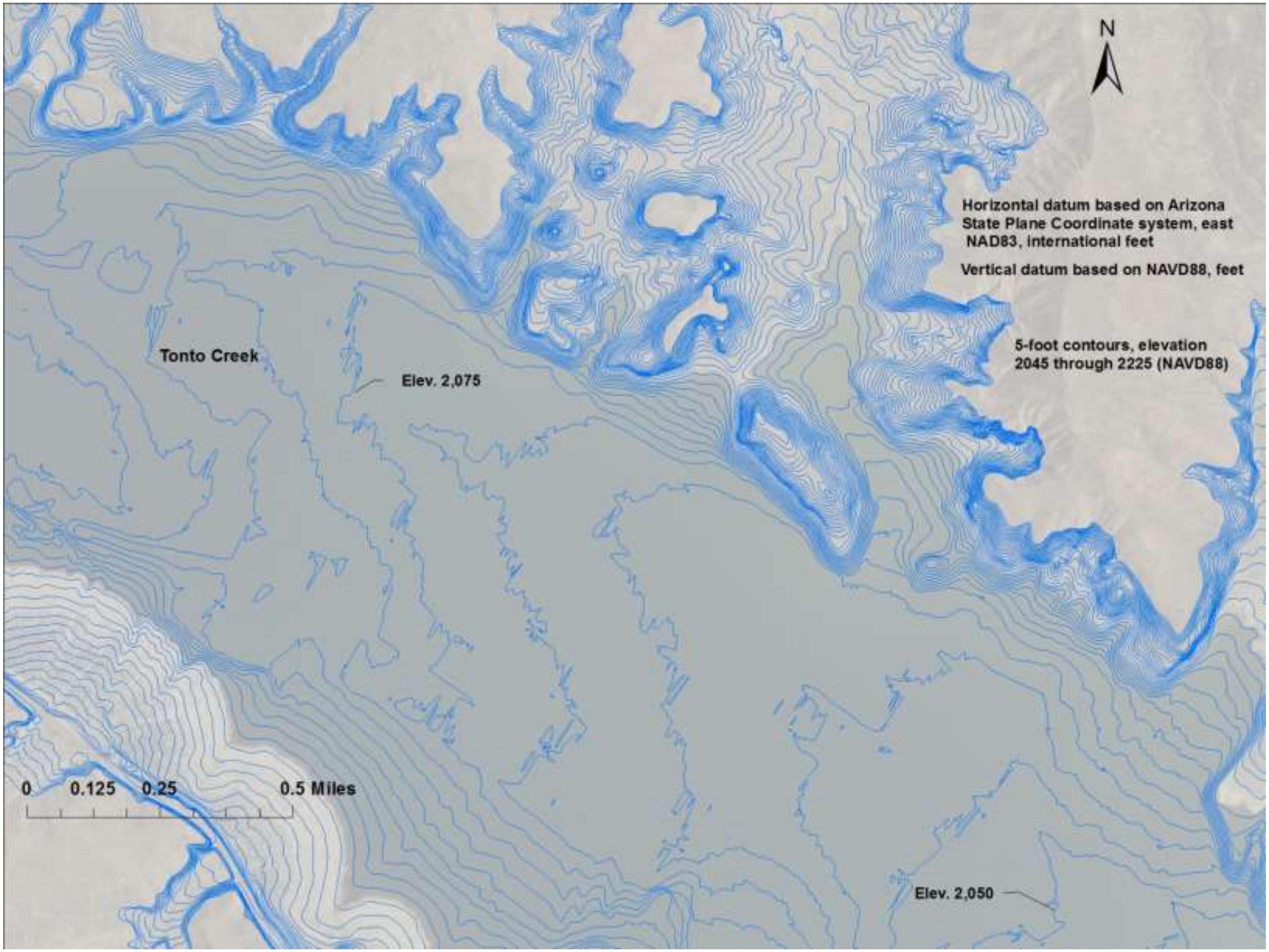

Figure 36 - 2013 Theodore Roosevelt Lake 5-foot contours, 5 of 19 (NAVD88).

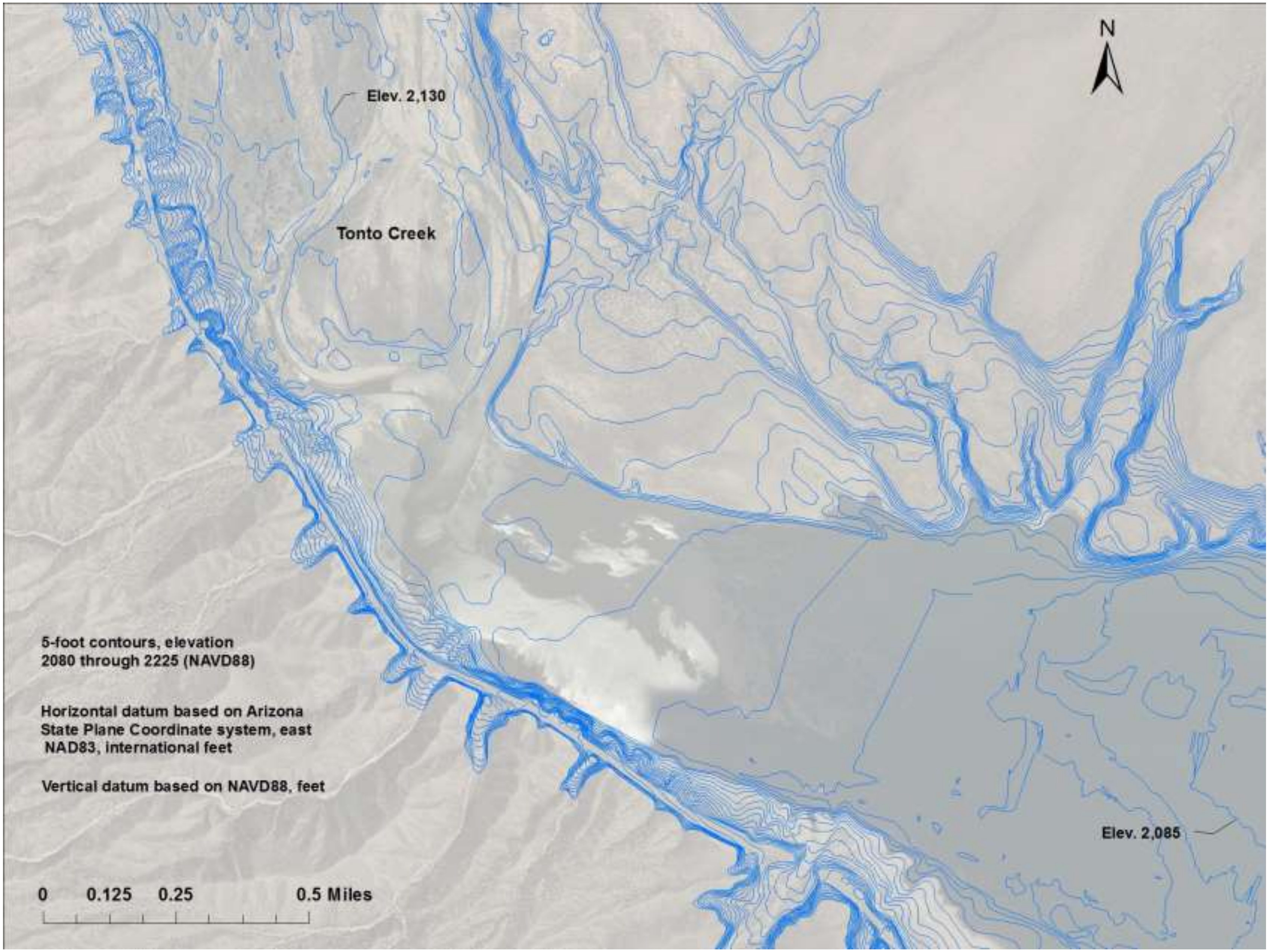

Figure 37 - 2013 Theodore Roosevelt Lake 5-foot contours, 6 of 19 (NAVD88).

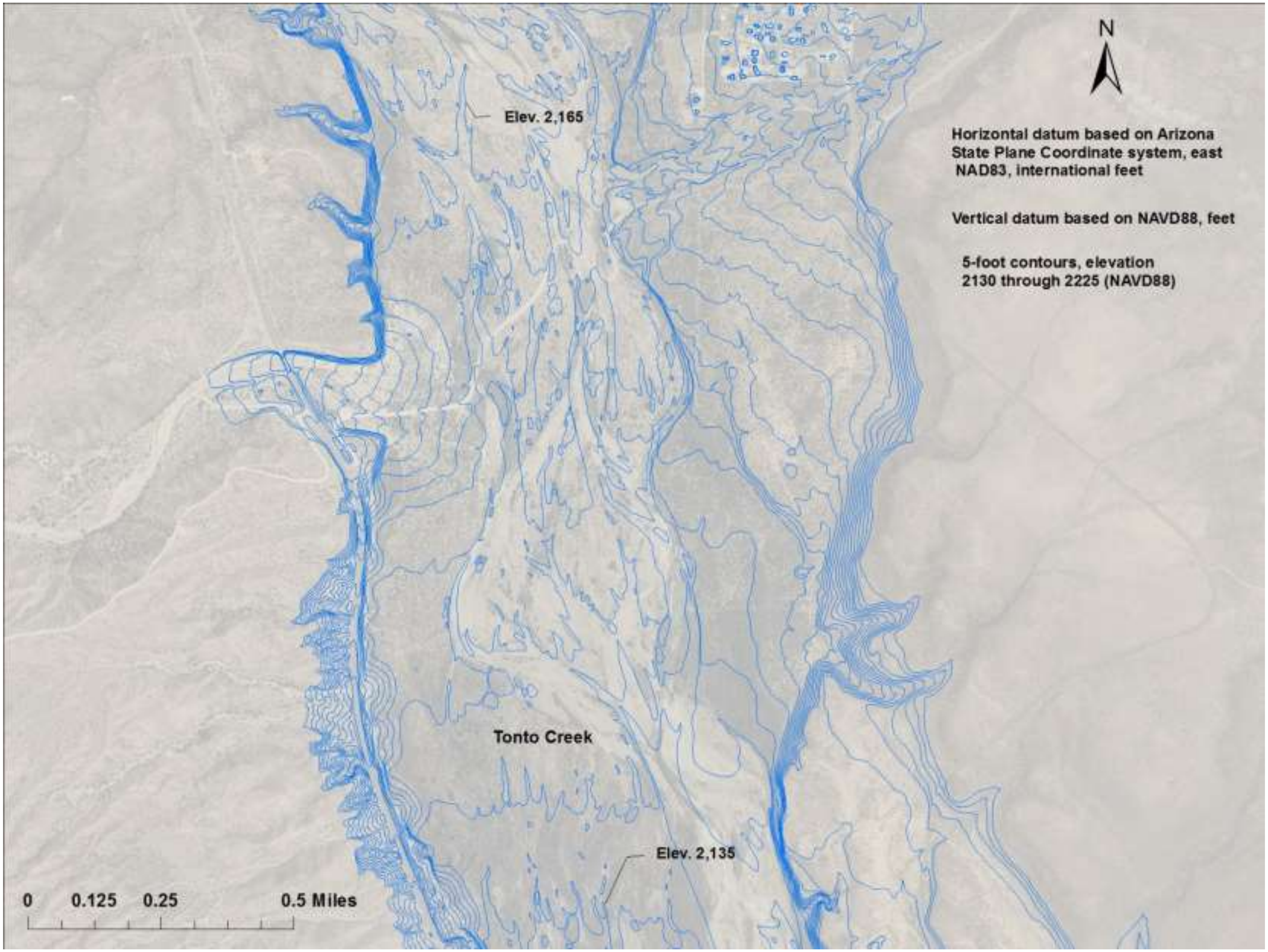

Figure 38 - 2013 Theodore Roosevelt Lake 5-foot contours, 7 of 19 (NAVD88).

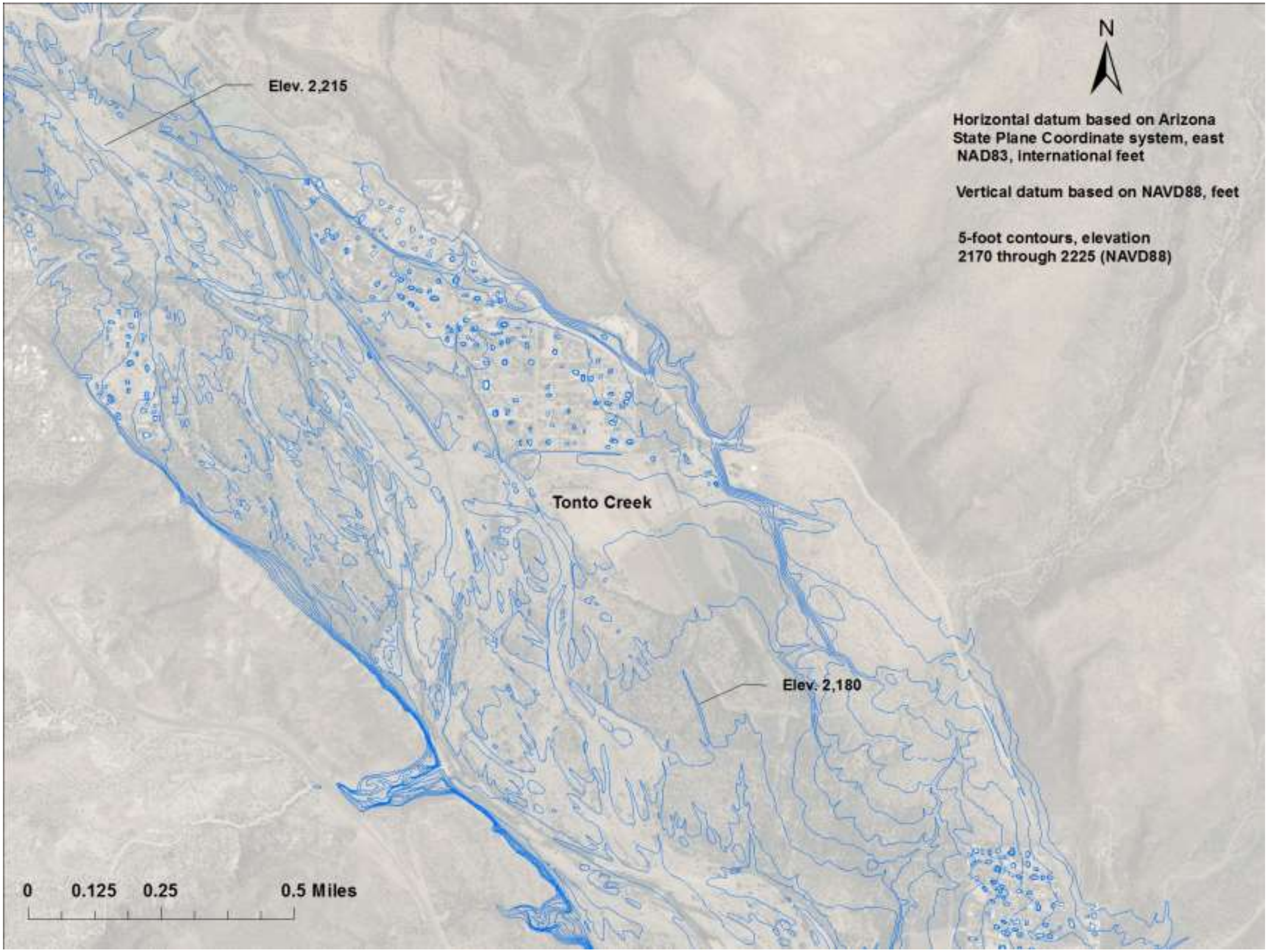

Figure 39 - 2013 Theodore Roosevelt Lake 5-foot contours, 8 of 19 (NAVD88).

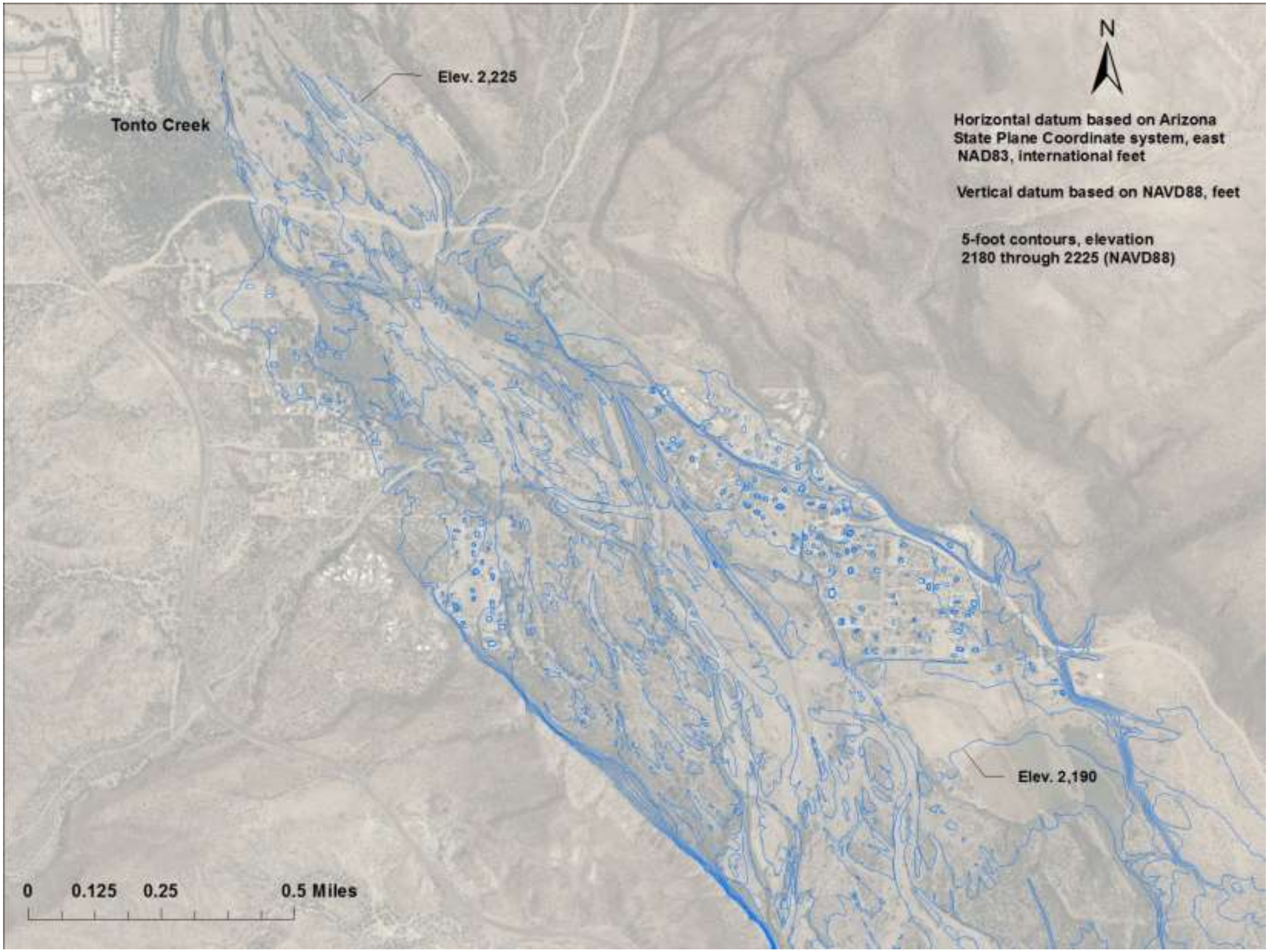

Figure 40 - 2013 Theodore Roosevelt Lake 5-foot contours, 9 of 19 (NAVD88).

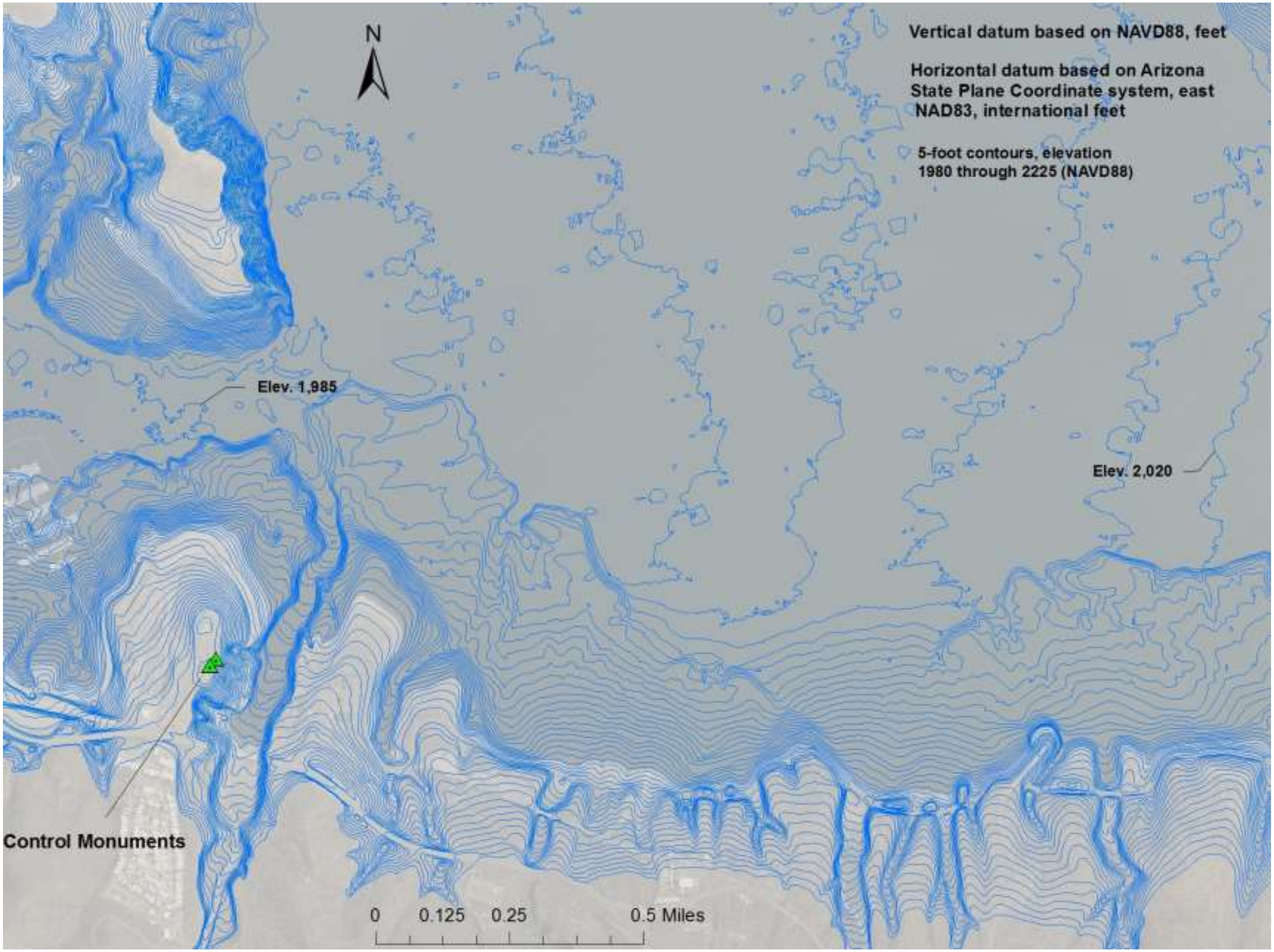

Figure 41 - 2013 Theodore Roosevelt Lake 5-foot contours, 10 of 19 (NAVD88).

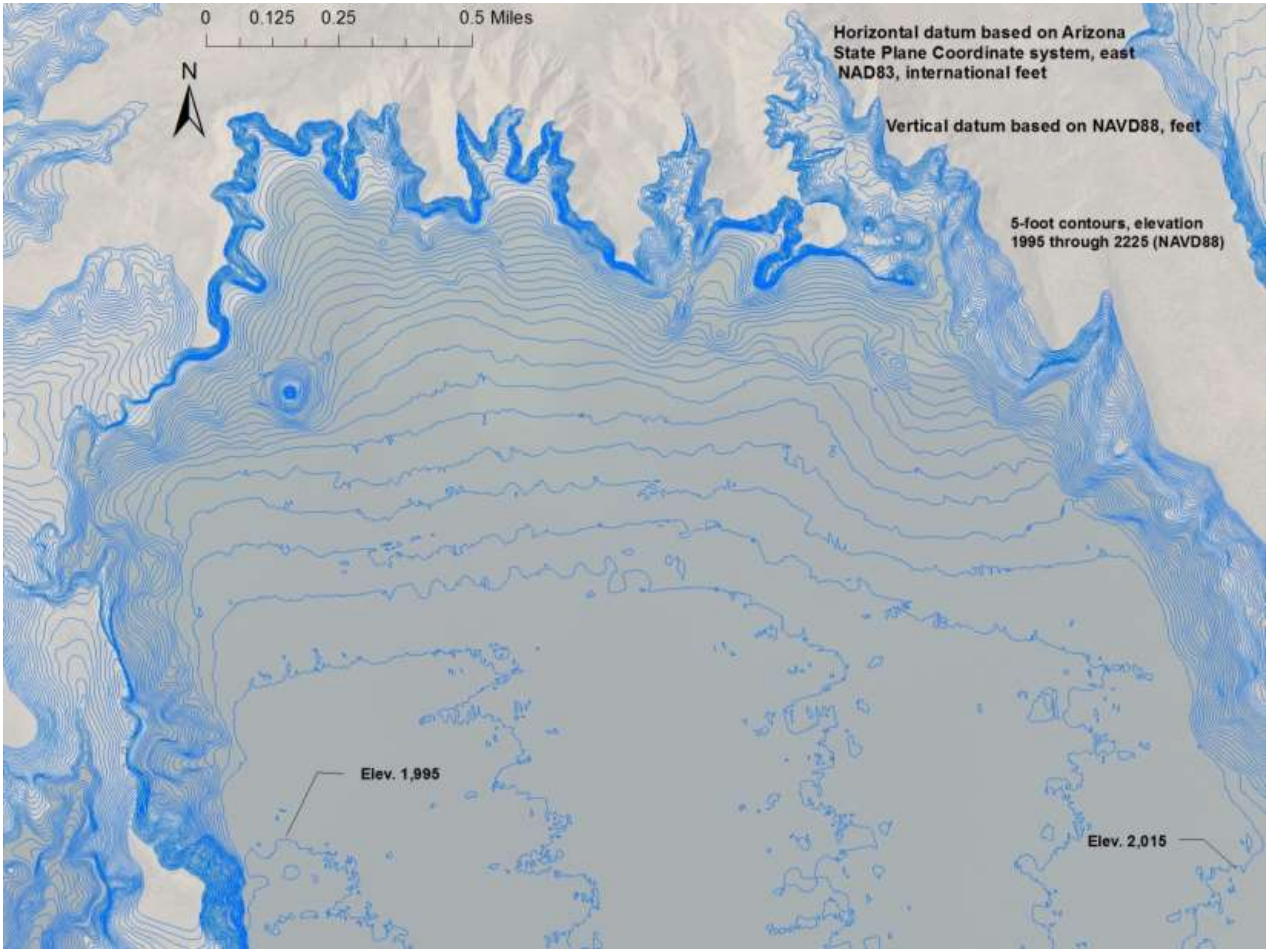

Figure 42 - 2013 Theodore Roosevelt Lake 5-foot contours, 11 of 19 (NAVD88).

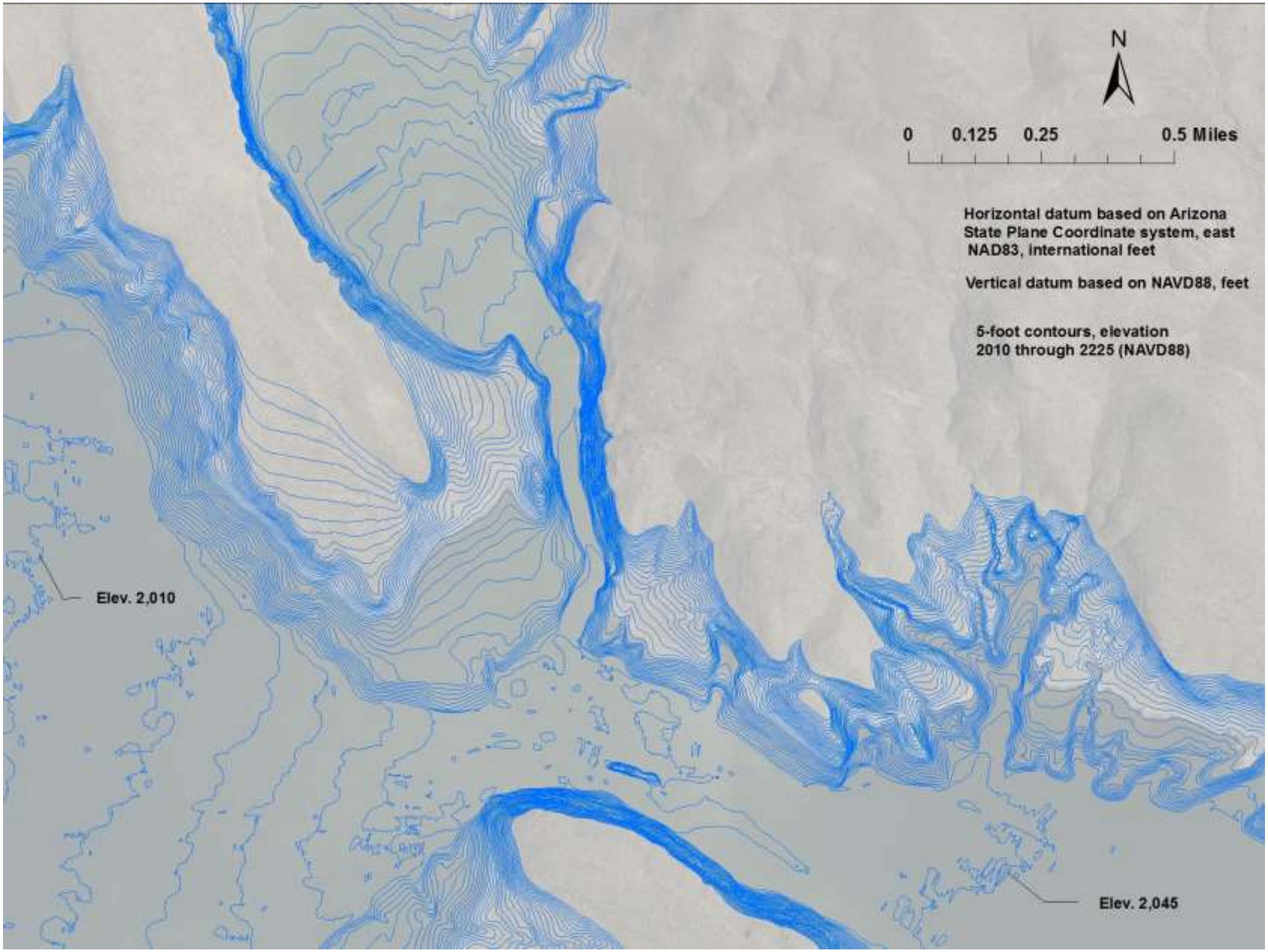

Figure 43 - 2013 Theodore Roosevelt Lake 5-foot contours, 12 of 19 (NAVD88).

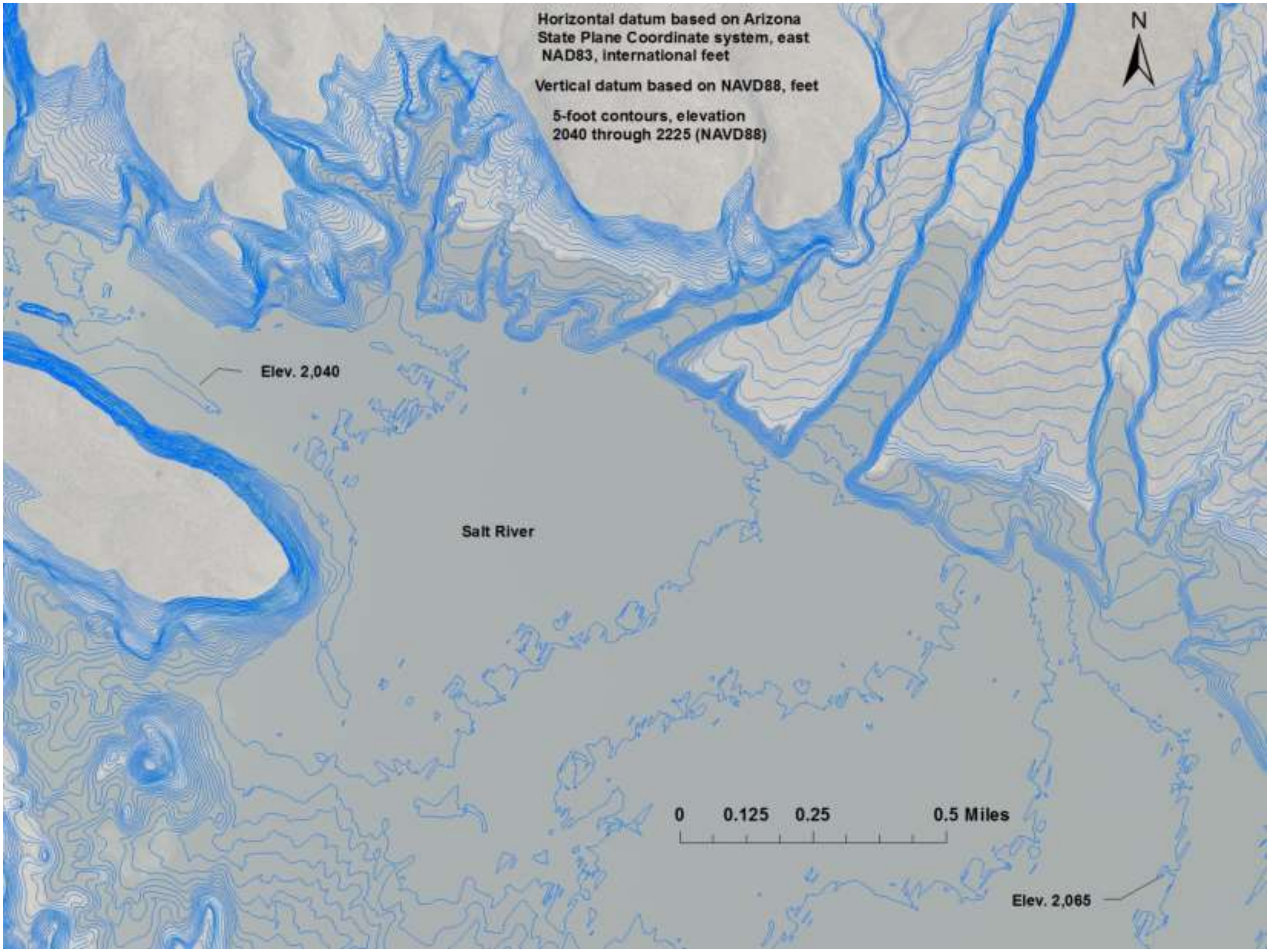

Figure 44 - 2013 Theodore Roosevelt Lake 5-foot contours, 13 of 19 (NAVD88).

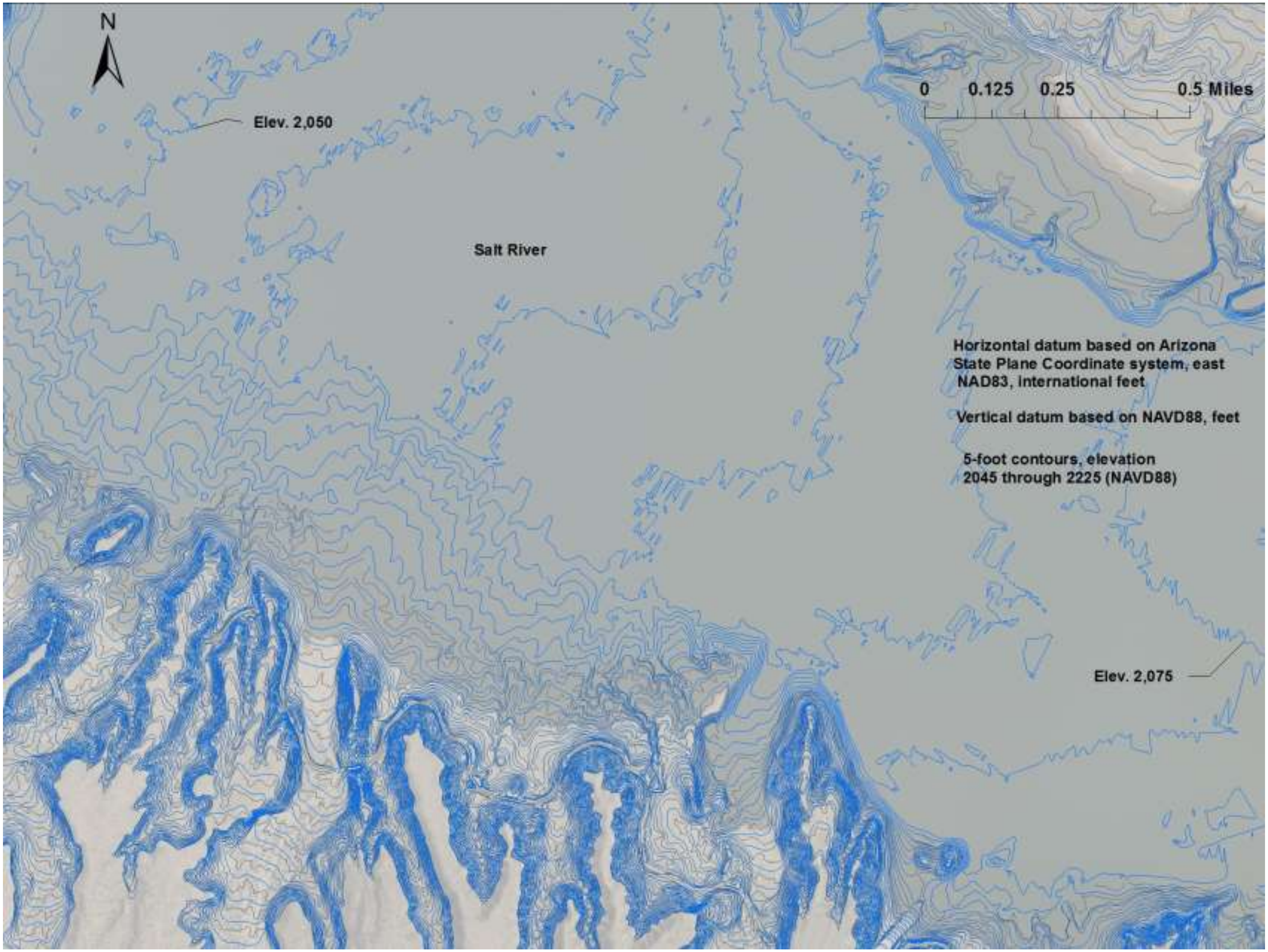

Figure 45 - 2013 Theodore Roosevelt Lake 5-foot contours, 14 of 19 (NAVD88).

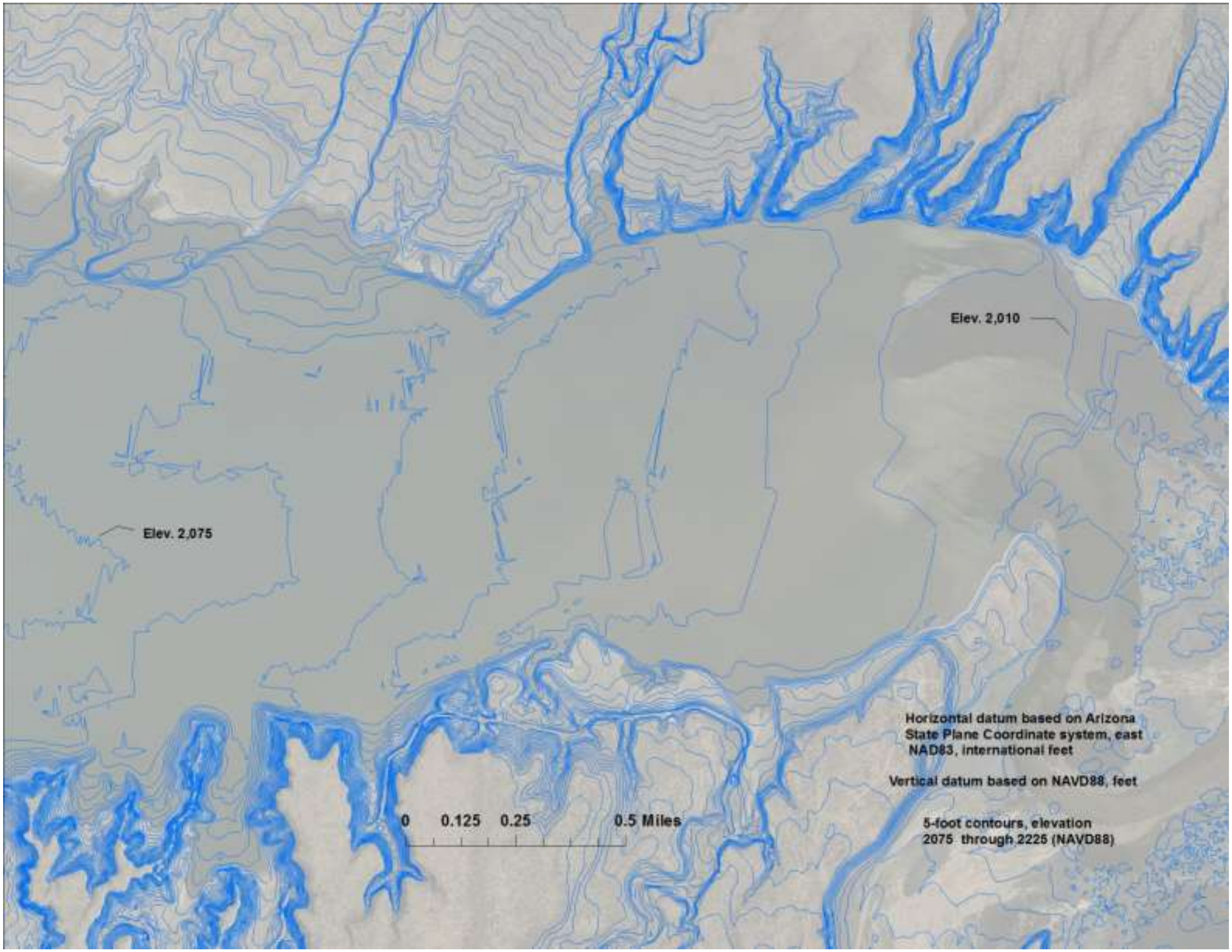

Figure 46 - 2013 Theodore Roosevelt Lake 5-foot contours, 15 of 19 (NAVD88).

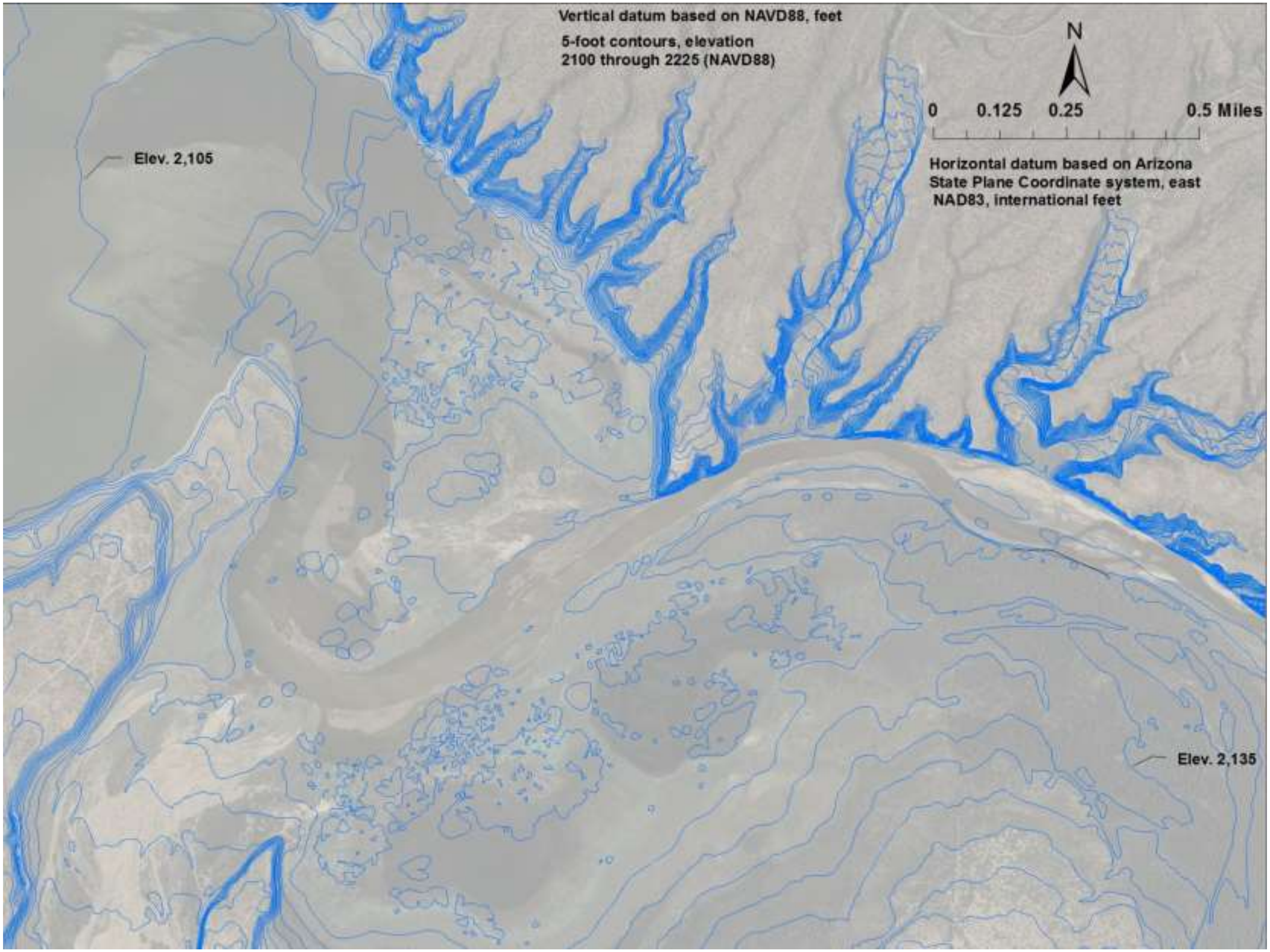

Figure 47 - 2013 Theodore Roosevelt Lake 5-foot contours, 16 of 19 (NAVD88).

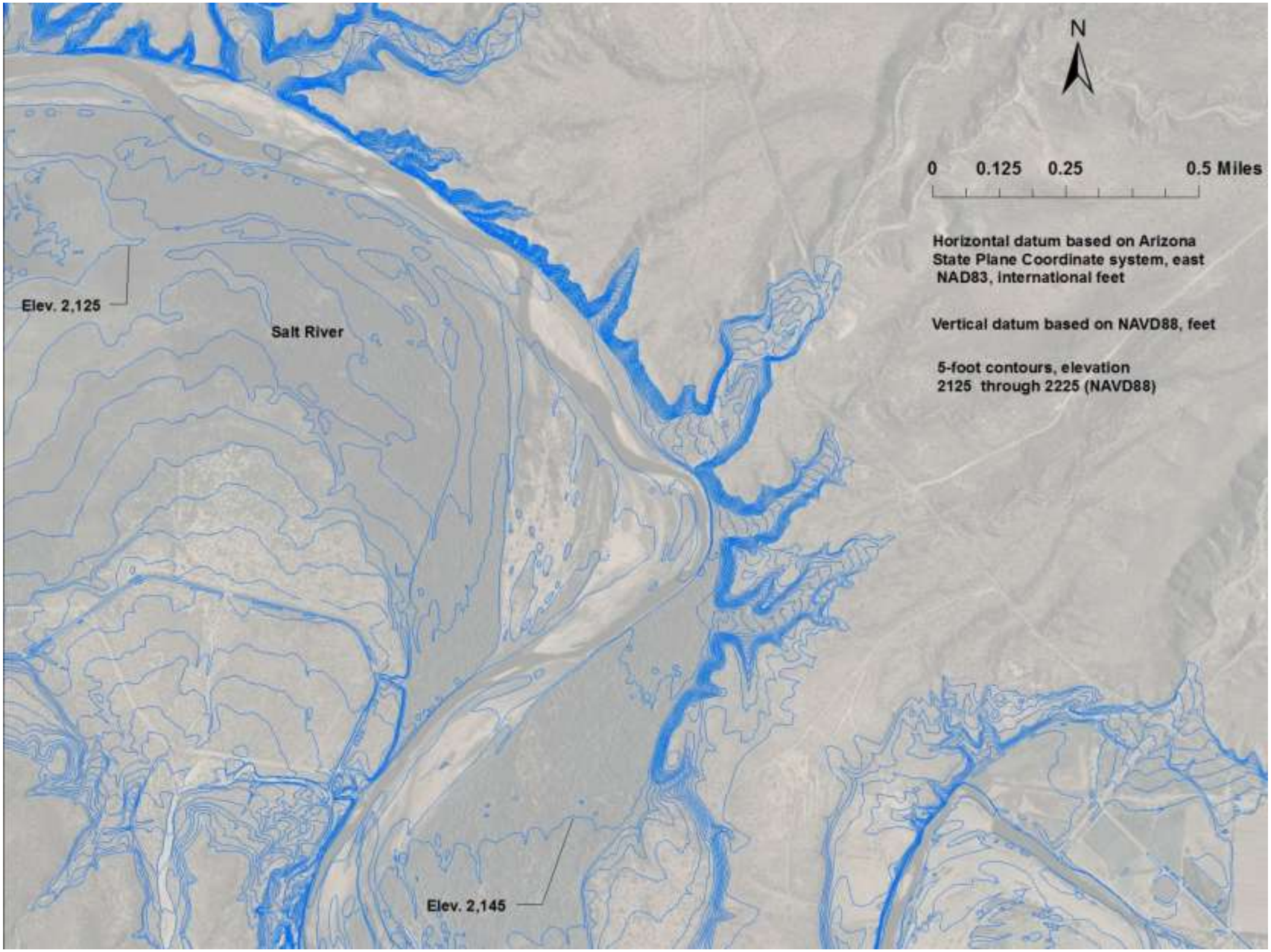

Figure 48 - 2013 Theodore Roosevelt Lake 5-foot contours, 17 of 19 (NAVD88).

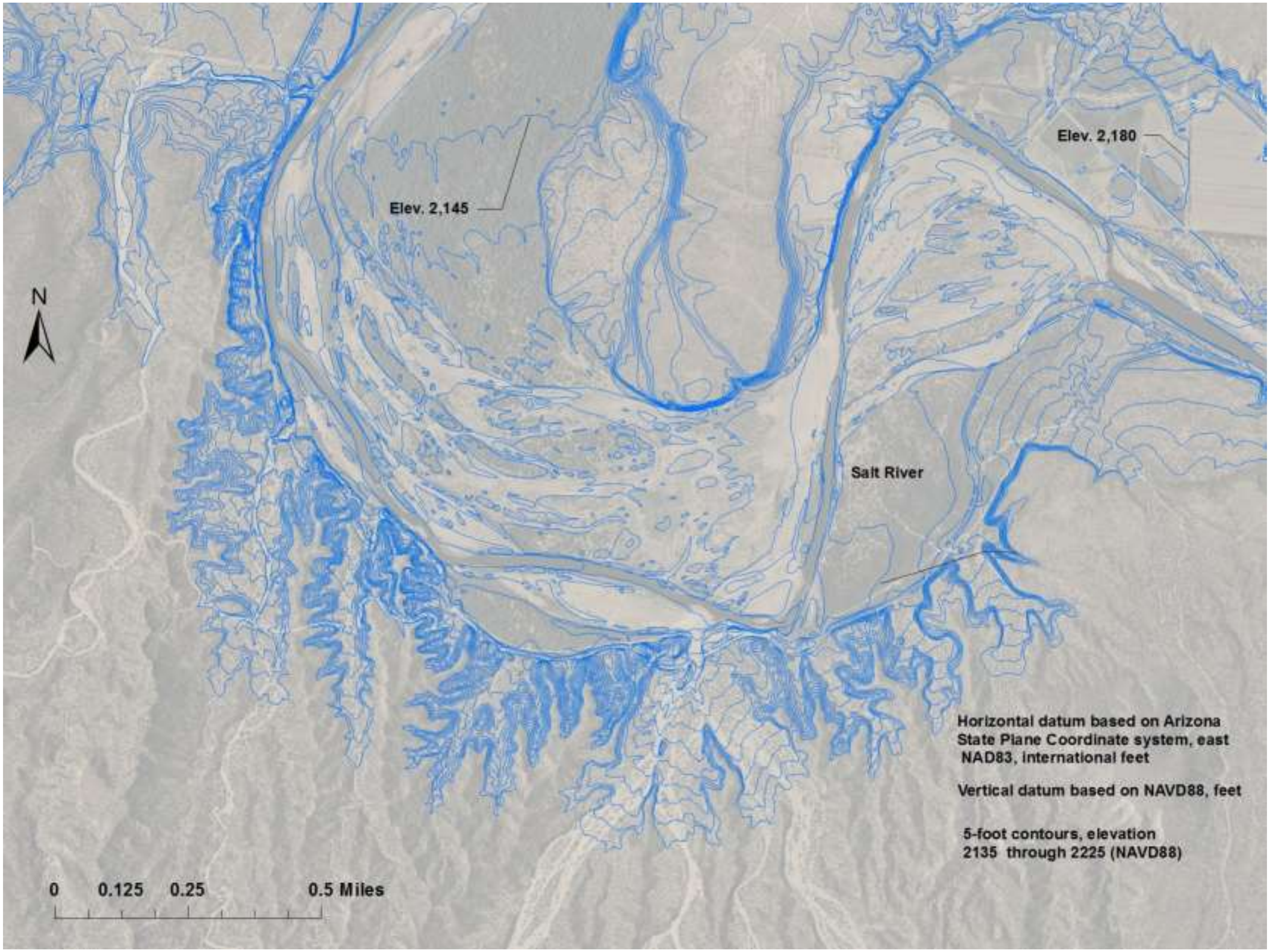

Figure 49 - 2013 Theodore Roosevelt Lake 5-foot contours, 18 of 19 (NAVD88).

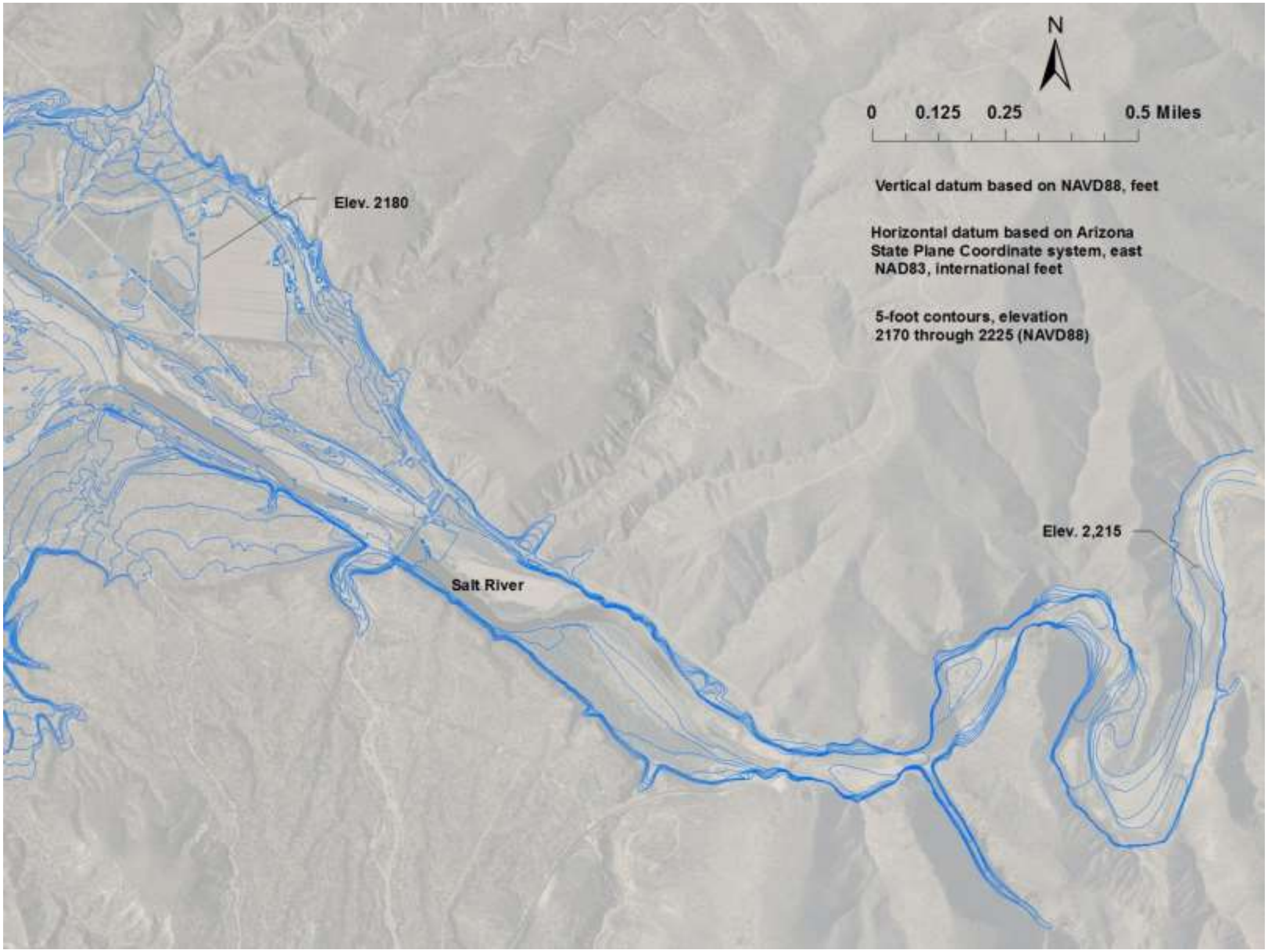

Figure 50 - 2013 Theodore Roosevelt Lake 5-foot contours, 19 of 19 (NAVD88).

2013 Roosevelt Lake Surface Area Methods

Using ArcGIS commands to compute areas at user-specified elevations, the 2013 surface areas for Roosevelt Lake were computed at 2- and 5-foot increments directly from the reservoir TIN from minimum elevation 1,967.0 through 2,227.0 (NAVD88) to provide information for the area-capacity table development. The elevations of these computed surface areas were reduced 2.0 feet to match NGVD29 which is the vertical datum of the water surface gage and operation of Theodore Roosevelt Dam.

2013 Roosevelt 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 data input included the 2- and 5-foot computed surface areas from the 2013 topography from elevation 1,965.0 through 2,225.0 (NGVD29). 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 (set at 0.000001 for this study). 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 Roosevelt 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, May 2013). A description of the computations and coefficients output from the ACAP program is included with these tables. As of May 2013, at conservation use elevation 2,151.0 the surface area was 21,383 acres with a total capacity of 1,636,254 acre-feet. At maximum and top of surcharge elevation 2,218.0, the surface area was 31,800 acres with a total capacity of 3,410,897 acre-feet.

Roosevelt Lake Surface Area and Capacity Results

This section provides 2013 surface area and capacity results for Roosevelt Lake and changes over time. Table 1 provides a summary of the Roosevelt Lake between the time of the original dam closure in May 1909, the resurveys of 1981 and 1995, and the May 2013 hydrographic survey. The 1981 survey was the last survey prior to the modification of the dam that was completed in 1996. The 1995 survey was the first survey since the dam modification began and the first ever detailed survey of the reservoir topography with the collection of above water aerial data. The 1995 results were used by this study as the base for measuring change over time. The 2013 survey collected more detailed underwater data than the 1995 survey and as a result, the measured changes in 2013 are due to sediment deposition and data density differences between the surveys. The area and capacity curves for the 1995 and 2013 surveys are plotted on Figure 51 showing relatively minimal changes except between elevation 2,110 and 2,130 (NAVD88). 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 vertical datum NGVD29 that is 2.0 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 1,965.0 through 2,225.0. Reclamation's ACAP program was used to compute the area and capacity values from the 2- and 5-foot elevation input surface areas.

Longitudinal Distribution

To illustrate the bottom topography along the length of the reservoir Tonto Creek and Salt River thalwegs were plotted from the dam upstream to the upper reach of the reservoir, Figures 52 and 53. The plots started at the dam using the 1995 developed contours to determine the alignment of the thalweg for both reaches. The elevations of the 1995 contours were shifted up 2.0 feet to match NAVD88 and the 2013 developed contours. The longitudinal profiles were developed by cutting alignments through the 1995 and 2013 contours resulting in distance versus elevation profiles. The profiles show the sediment accumulation that has occurred since the 1995 survey, the inlet sill level of the outlet works at elevation 1,991.0 (NAVD88), and measured top of sediment deposition starting at the dam, elevation 1,965. The Tonto Creek plot showed sediment accumulation near the dam and small delta formations near elevation 2,095 (NAVD88) and 2,135 (NAVD88). The Salt River profile showed sediment deposition near the dam along with delta formations near elevations 2,050; 2,090; and 2,110. Overall the plots showed only a small accumulation of sediment starting at the lower elevations from the dam through the main reservoir body. In the upper reaches, the Tonto Creek profile showed only a small amount of deposition while Salt

River showed a much larger accumulation of sediment. The general conclusion is that since 1995 the Salt River drainage area has contributed the largest percentage of the reservoir sediment.

RESERVOIR SEDIMENT
DATA SUMMARY

Theodore Roosevelt Reservoir
NAME OF RESERVOIR

1
DATA SHEET NO.

DAM	1. OWNER: Salt River Project	2. STREAM: Salt River and Tonto Creek	3. STATE: Arizona
	4. SEC 20 TWP. 4 N RANGE 12 E	5. NEAREST P.O. Globe	6. COUNTY: Gila
	7. LAT 33 ° 33 ' 13 " LONG 104 ° 26 ' 33 "	8. TOP OF DAM ELEVATION: 2,218.0 [1]	9. SPILLWAY CREST EL. 2,100.0 [2]

RESERVOIR	10. STORAGE ALLOCATION	11. ELEVATION TOP OF POOL	12. 1995 SURFACE AREA, ACRES	13. 1995 CAPACITY, AC-FT	14. GROSS STORAGE ACRE-FEET	15 DATE STORAGE BEGAN
	a. SURCHARGE	2,218.0 [3]	31,852	1,223,169	3,432,408	5/1909
	b. FLOOD CONTROL	2,175.0	24,978	556,196	2,209,239	
	c. POWER					
	d. JOINT USE					16 DATE NORMAL OPERATIONS BEGAN
	e. CONSERVATION	2,151.0	21,493	1,634,391	1,653,043	
	f. INACTIVE					
	g. DEAD	1,989.0	1,184	18,652	18,652	
	17. LENGTH OF RESERVOIR 32.5 [4] MILES		AVG. WIDTH OF RESERVOIR 1.5 MILES			

BASIN	18. TOTAL DRAINAGE AREA 5,736 [5] SQUARE MILES		22. MEAN ANNUAL PRECIPITATION 21.0 [5] INCHES
	19. NET SEDIMENT CONTRIBUTING AREA 5,709 [5] SQUARE MILES		23. MEAN ANNUAL RUNOFF 2.39 [6] INCHES
	20. LENGTH MILES	AVG. WIDTH MILES	24. MEAN ANNUAL RUNOFF 726,678 [6] ACRE-FEET
	21. MAX. ELEVATION 11,000	MIN. ELEVATION 1,929	25. ANNUAL TEMP, MEAN RANGE 38 °F to 77 °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
	5/1909			Contour	10-ft	17,785	1,530,499 [7]	2.11
	9/1981	72.4	72.4	Range (D)	39	17,337	1,336,734 [7]	1.84
	4/1995	13.5	85.9	Contour (D)	5-ft	21,493 [8]	1,653,043 [8]	2.27
	5/2013	18.1	104.0	Contour (D)	2-ft	21,383 [9]	1,636,254 [9]	2.25

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
9/1981	21	717,131	2,582,996	50,199,184	717,131	50,199,184
4/1995	22.5	1,035,485 [6]	2,744,900	14,496,790	752,279	64,695,974
5/2013		484,501 [6]	1,278,287	8,769,477	706,399	73,465,451

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.
9/1981	193,765 [10]	2,676	0.469	193,765	2,676	0.469
4/1995	[11]			182,185 [11]	2,121 [11]	0.372
5/2013	16,789 [12]	928	0.162	16,789 [13]	928	0.162

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.
9/1981	49.3	504	504	0.175 [5]	12.67	3.054	3.050
4/1995				0.139 [5]	11.90		
5/2013				0.056 [13]	1.01		

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

45. RANGE IN RESERVOIR OPERATION							
YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF	YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF
1996	2,106.4	2,065.0	182,501	1997	2,090.3	2,051.3	442,468
1998	2,108.1	2,050.4	783,430	1999	2,093.9	2,077.2	281,476
2000	2,078.2	2,051.8	147,134	2001	2,091.2	2,051.1	511,506
2002	2,067.3	2,033.0	152,264	2003	2,078.4	2,037.2	501,736
2004	2,089.0	2,073.2	283,233	2005	2,148.0	2,074.2	1,278,287
2006	2,136.5	2,113.0	322,358	2007	2,120.2	2,100.1	307,995
2008	2,150.1	2,098.7	1,178,644	2009	2,151.2	2,133.0	512,071
2010	2,152.1	2,130.6	1,066,199	2011	2,146.4	2,124.9	190,621
2012	2,124.7	2,100.0	212,284	2013	2,109.9	2,093.7	415,270

46. ELEVATION - AREA - CAPACITY - DATA								
ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
2013	**SURVEY**		1,965.0	0	0	1,970.0	423	607
1,975.0	685	3,457	1,980.0	904	7,421	1,985.0	1,094	12,428
1,989.0	1,204	17,026	1,990.0	1,231	18,244	1,995.0	1,544	25,058
2,000.0	2,134	34,217	2,005.0	2,756	46,441	2,010.0	3,385	61,746
2,015.0	3,909	80,048	2,020.0	4,305	100,581	2,025.0	4,687	123,076
2,030.0	4,992	147,301	2,035.0	5,302	173,010	2,040.0	5,670	200,399
2,045.0	6,122	229,827	2,050.0	6,703	261,993	2,055.0	7,291	296,951
2,060.0	7,923	334,961	2,065.0	8,603	376,271	2,070.0	9,284	420,975
2,075.0	10,005	469,176	2,080.0	10,707	520,964	2,085.0	11,387	576,251
2,090.0	12,704	634,946	2,095.0	12,723	696,948	2,100.0	13,371	762,217
2,105.0	14,013	830,829	2,110.0	14,638	902,725	2,115.0	15,160	977,351
2,120.0	15,664	1,054,528	2,125.0	17,010	1,135,827	2,130.0	17,810	1,222,971
2,135.0	18,758	1,314,500	2,140.0	19,603	1,410,516	2,145.0	20,430	1,510,727
2,150.0	21,209	1,614,958	2,151.0	21,383	1,636,254	2,155.0	21,957	1,722,998
2,160.0	22,659	1,834,662	2,165.0	23,352	1,949,754	2,175.0	24,884	2,190,994
2,180.0	25,682	2,317,500	2,185.0	26,497	2,447,947	2,190.0	27,335	2,582,528
2,195.0	28,144	2,721,225	2,200.0	28,978	2,864,030	2,205.0	29,756	3,010,866
2,210.0	30,544	3,161,616	2,215.0	31,305	3,316,239	2,218.0	31,800	3,410,897
2,220.0	32,130	3,474,827	2,225.0	32,956	3,637,610			

47. REMARKS AND REFERENCES

[1] All elevations in feet tied to design vertical datum NGVD29, that is 2.0 feet less than NAVD88.
Modification of Roosevelt Dam, completed in 1996, raised the original dam 77 feet to elevation 2,218.0.

[2] Spillway crest elevation. Four top-seal radial gates control releases creating conservation storage at elevation 2,151.0.

[3] 1995 values computed, using Reclamation's program ACAP.

[4] Length of reservoir at elevation 2,218. Salt River Arm = 19.3 miles. Tonto Creek Arm = 13.2 miles.

[5] From previous survey publications in 1981 and 1995.

[6] Maximum & minimum elevations by water year. Elevations tied to NGVD29.
Inflows through 1995 from 1996 survey report. Inflows from 1995 through 2013 from SLP operation records by water year.

[7] Computed values at original conservation elevation 2,136.0. Conservation level raised to elevation 2,151.0 with dam modification.

[8] Computed values at conservation elevation 2,151.0. 1995 survey measured a surface area of 19,075 acres and total volume of 1,348,314 acre-feet at elevation 2,136.0.

[9] Computed values at conservation elevation 2,151.0. 2013 survey measured a surface area 18,950 acres and total volume of 1,333,354 acre-feet at elevation 2,136.0.

[10] Total sediment inflow since dam closure, May 1909, at original conservation elevation 2,136.0.

[11] 1995 study was first detailed survey, bathymetric and above water aerial from elevation 2,087 and above. Increased mapping detail resulted in lower sediment deposit estimate in 1995 compared to the 1981 survey result.

[12] Total sediment calculation at conservation elevation 2,151.0. 2013 survey was a detailed underwater multibeam collection resulting in larger volume in the lower elevations compared to the single beam 1995 survey. Accuracy difference of surveys affected the sediment calculations.

[13] 2013 was first resurvey since the 1995 detailed survey and the 1995 raising of the dam. Computations reference to 1995.

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

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

1	2	3	4	5	6	7	8
					2013		
	1995	1995	2013	2013	Sediment	Percent	Percent
Elevation	Area	Capacity	Area	Capacity	Volume	Computed	Reservoir
Feet	Acres	Ac-Ft	Acres	Ac-Ft	Ac-Ft	Sediment	Depth
2,218.0	31,853	3,432,408	31,800	3,410,897	21,511		100.0
2,210.0	30,614	3,182,584	30,544	3,161,616	20,968		96.9
2,200.0	29,053	2,884,154	28,978	2,864,030	20,124		92.9
2,190.0	27,402	2,601,879	27,335	2,582,528	19,351		89.0
2,180.0	25,753	2,336,067	25,682	2,317,500	18,567		85.1
2,175.0	24,978	2,209,239	24,884	2,190,994	18,245		83.1
2,170.0	24,163	2,086,387	24,102	2,068,468	17,919		81.2
2,160.0	22,732	1,852,129	22,659	1,834,662	17,467		77.3
2,151.0	21,493	1,653,043	21,383	1,636,254	16,789	100	73.7
2,150.0	21,351	1,631,622	21,209	1,614,958	16,664	99	73.3
2,140.0	19,746	1,425,957	19,603	1,410,516	15,441	92	69.4
2,136.0	19,075	1,348,314	18,950	1,333,354	14,960	89	67.8
2,130.0	18,000	1,237,049	17,810	1,222,971	14,078	84	65.5
2,120.0	16,356	1,065,544	15,664	1,054,528	11,016	66	61.6
2,110.0	14,831	909,867	14,638	902,725	7,142	43	57.6
2,105.0	14,191	837,312	14,013	830,829	6,483	39	55.7
2,100.0	13,579	767,887	13,371	762,217	5,670	34	53.7
2,090.0	12,194	638,669	12,074	634,946	3,723	22	49.8
2,080.0	10,769	524,050	10,707	520,964	3,086	18	45.9
2,070.0	9,396	423,232	9,284	420,975	2,257	13	42.0
2,060.0	7,979	336,245	7,923	334,961	1,284	8	38.0
2,050.0	6,714	262,987	6,703	261,993	994	6	34.1
2,040.0	5,581	202,025	5,670	200,399	1,626	10	30.2
2,030.0	4,954	149,442	4,992	147,301	2,141	13	26.3
2,020.0	4,273	103,035	4,305	100,581	2,454	15	22.4
2,010.0	3,440	64,357	3,385	61,746	2,611	16	18.4
2,000.0	2,198	36,147	2,134	34,217	1,930	11	14.5
1,990.0	1,211	19,850	1,231	18,244	1,606	10	10.6
1,989.0	1,184	18,652	1,204	17,026	1,626	10	10.2
1,980.0	927	9,120	904	7,421	1,699	10	6.7
1,970.0	551	1,850	423	607	1,243	7	2.7
1,965.0	157	80	0	0	80	0	0.8
1,963.0	0	0	0	0	0	0	0.0

1 Reservoir water surface elevations tied to NGVD29 that is 2.0 feet than NAVD88.

2 1995 reservoir surface area.

3 1995 developed reservoir capacity.

4 2013 measured reservoir surface area.

5 2013 reservoir capacity computed using ACAP.

6 2013 measured sediment volume, column (3) - column (5).

7 Percent of total sediment, 16,789 acre-feet at elevation 2,151.0.

8 Reservoir depth expressed in percentage total depth, 255 feet.

Table 2 - Theodore Roosevelt Lake 2013 survey summary.

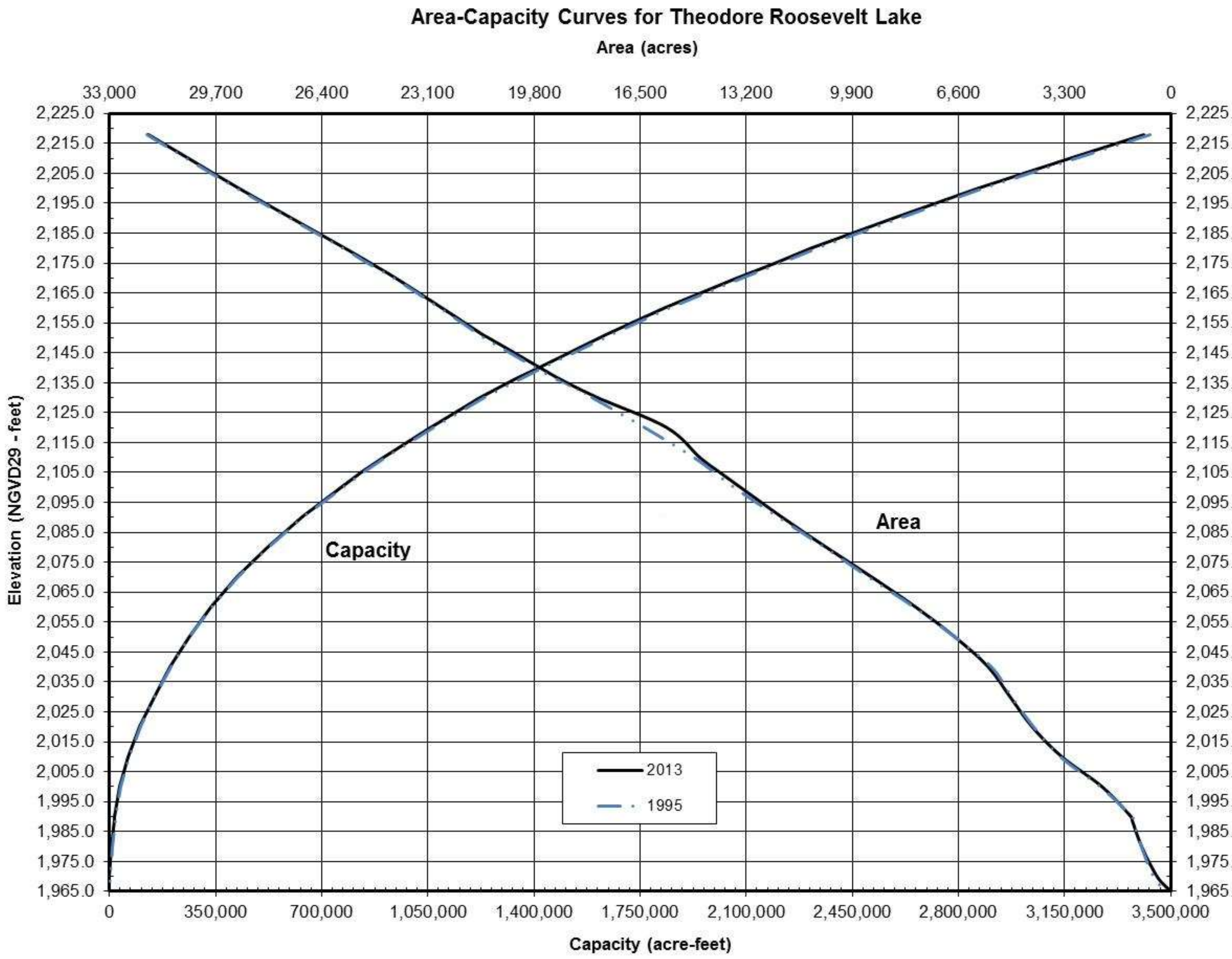

Figure 51 - Theodore Roosevelt Lake area and capacity plots.

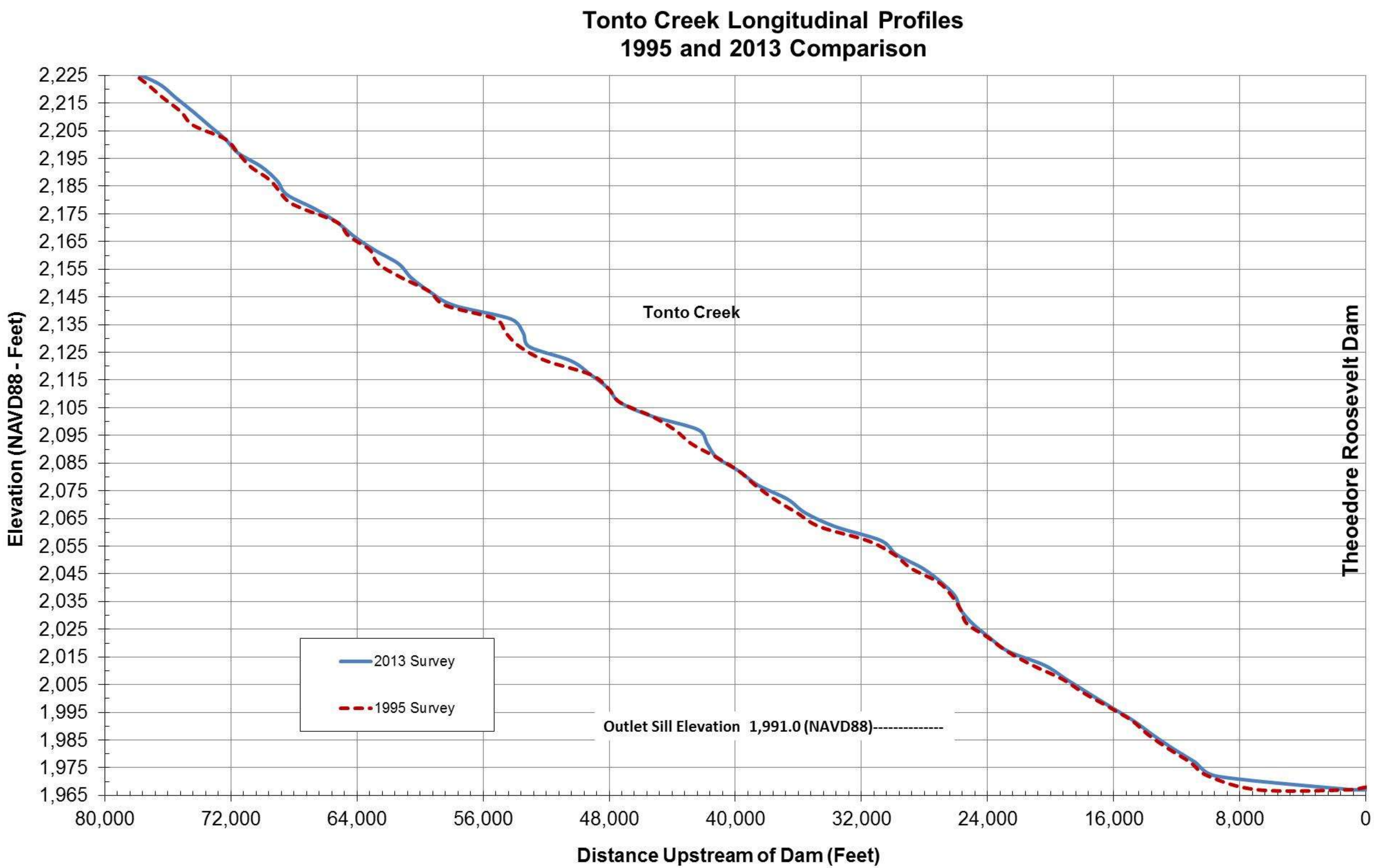

Figure 52 - Longitudinal profile of the Tonto Creek from the dam upstream.

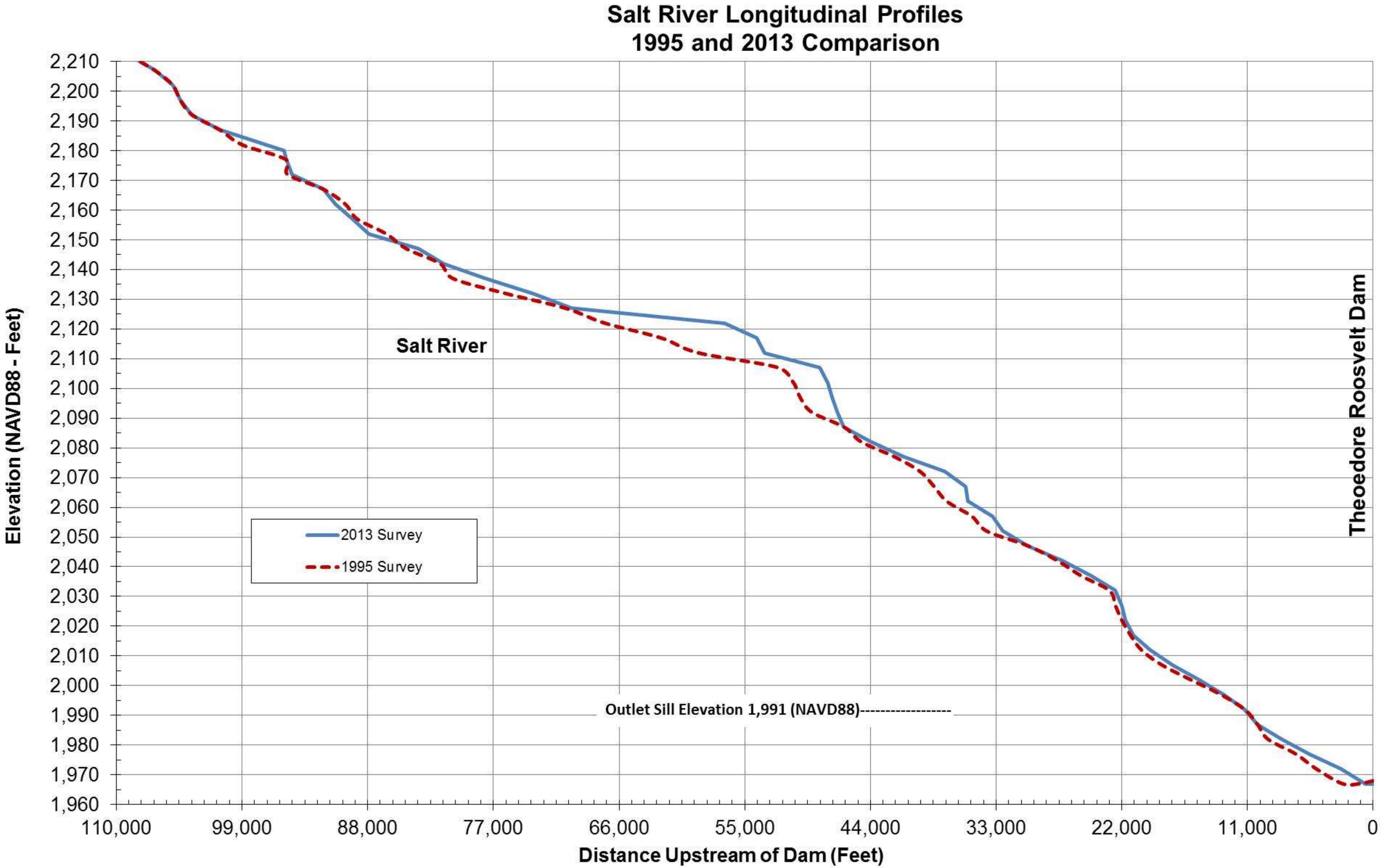

Figure 53 - Longitudinal profile of the Salt River from the dam upstream.

2013 Roosevelt Lake Analysis

Results of the 2013 Roosevelt Lake area and capacity computations are listed in Table 1 and columns 5 and 6 of Table 2. Columns 2 and 3 in Table 2 list the 1995 area and capacity values. The 1995 surface areas were measured from 5-foot contours of the reservoir area that were collected near the 1996 completion of the dam modification that raised it 77 feet. The 1995 survey was the first detailed collection of Roosevelt Lake topography and included 1994 aerial combined with a May 1995 single beam bathymetric survey. Major modification of the dam resulted in higher operation elevation levels, so the 2013 study used the 1995 results as the base for measuring change over time. The 2013 bathymetric survey collected much greater detail of the underwater portion of the reservoir than the 1995 survey, resulting in computation differences that are affected by both sediment inflows and accuracy differences between the collection methods.

The 2013 survey developed updated topography of Roosevelt Lake from which elevation versus surface area and volume relationships were computed. The 2013 study was conducted near water surface elevation 2,109.7, about 141 feet below reservoir conservation elevation 2,151.0. Following the 1995 survey, the reservoir was operated near or above elevation 2,151 from water years 2008 through 2010, so changes would be expected from sediment deposition since the 1994 aerial collection. The 2013 study used LiDAR data collected in January 2012 near elevation 2,124 that reflected the changes since 1994 in the upper elevations due to inflows and reservoir operations. The LiDAR data was of greater detail than the 5-foot contours from the 1994 aerial meaning a portion of the computed changes in the upper elevation range is also due to differences in data precision. Visual comparisons of the contours indicate minimal changes. The surface area and thalweg plots, Figures 51 through 53, also show minimal differences.

The 2013 data sets allowed mapping of the reservoir topography from the dam, minimum elevation 1967 (NAVD88), to above the top of the surcharge elevation 2,220.0 (NAVD88). The 2013 reservoir topography was extended to elevation 2,225.0 (NAVD88) to cover the operating range of the reservoir. As previously discussed, there was about a mile gap between the 2012 LiDAR and 2013 bathymetric data. In these areas the 1995 developed 5-foot contours were used to complete the topography assuming no changes except for lower elevations within the active reservoir channel. These lower elevations were adjusted using the 2012 and 2013 data as a guide. The only 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 survey. However, the data sets used for this analysis adequately reflect the overall conditions as of May 2013.

The 2013 Roosevelt Lake topography was developed with the elevations tied to NAVD88 (GEOID12A). The reservoir surface area, capacity, and sediment accumulation results are tied to NGVD29 matching the vertical datum used to measure the reservoir water surface and volumes. This study determined NGVD29 was around 2.0 feet lower than NAVD88 (GEOID12A). The tables within this report list the area and capacity results for the 2013 survey and compare the 2013 results to the 1995 surface area and capacity values. Figure 51 illustrates the differences in the Roosevelt Lake surface area and capacity values for the 1995 and 2013 surveys. Overall the differences were minimal.

The tables lists elevation 2,151.0 as the conservation level with elevation 2,218.0 as the maximum surcharge pool level. The area and capacity tables were extended to elevation 2,225.0, allowing computation of reservoir volumes above elevation 2,218.0 up to the parapet walls. From operation records, the reservoir's maximum water surface to date was elevation 2,152.1 in 2010, meaning the reservoir extended into the flood zone about 1.1 feet. In 2009 the maximum elevation was 2,151.2 and was only other year the reservoir operated in the flood zone.

The surface area and volume differences on Table 1 are referenced to conservation elevation 2,151.0 where the 2013 study measured a total decrease in capacity of 16,789 acre feet since the April 1995 survey. The measured decrease is due to sediment deposition and survey methodology differences between the two studies. The computed average annual loss since 1995 was 928 acre feet.

For computing annual sediment accumulation for Roosevelt Lake the 1981 results should be reviewed. The 1981 survey computed an average annual loss due to sediment inflow of 2,676 acre-feet. The resurveys of the reservoir since dam closure in 1909 through 1981 were by range line collection where the analysis process measured bottom changes at specific range line locations. The collection methodology differences between these surveys would have much less of an impact compared to the detailed differences between the 1981 and 1995 and the 1995 and 2013 surveys. Other factors, such as water inflow, also need to be considered. Table 1 shows that since 1995 the average inflow was 484,501 acre-feet compared to an average inflow of 1,035,485 acre-feet from 1981 through 1995, and 752,279 acre-feet from 1909 through 1995. A resurvey should be scheduled in the future if a significant change in the sediment basin runoff is noted. The resurvey should consider detailed above water collection from the dam upstream 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 those that occurred 2008 through 2010.

Summary and Conclusions

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

- develop reservoir topography;
- compute area-capacity relationships; and
- storage depletion since the 1995 survey.

A control survey was conducted using the online positioning user service (OPUS) and RTK GPS to establish a 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 rebar and cap located where it provided continuous radio link throughout the bathymetric survey. From this location measurements were obtained of the water surface and project features that were used to determine the vertical datum (NGVD29) used for developing the May 2012 area and capacity values.

The study's horizontal control was in international feet, Arizona state plane east coordinates, in NAD83 (2011). The vertical control, in US survey feet, was tied to NAVD88 (Geoid12A) that is around 2.0 feet higher than the project's vertical datum, NGVD29. Unless noted, all elevations presented in this report are tied to NGVD29. The developed reservoir topography presented in this report is referenced to NAVD88 (GEOID12A). The May 2013 underwater survey was conducted near reservoir elevation 2,109.7 as measured by the SRP gage at the dam and confirmed by 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 grid lines covering Roosevelt Lake. The positioning system provided information to allow the boat operator to maintain a course along these grid lines. The above-water topography for the 2013 study was developed from the 1995 developed 5-foot contours and 2012 LiDAR that covered the upper reaches of the Tonto Creek and Salt River arms of the reservoir. The LiDAR provided by SRP was collected in January 2012 at a higher reservoir level than the May 2013 bathymetry survey. The data gap between these data sets was filled in with the 1995 contours modified using the 2012 and 2013 data as a guide.

The 2013 Roosevelt Lake topographic map is a combination of the 1995 modified contours, 2012 LiDAR, and 2013 underwater survey data, all tied to NAVD88. A computer program was used to generate the 2013 topography and resulting reservoir surface areas at predetermined contour intervals from the combined reservoir data at elevation 2,225.0 and below. The 2013 area and capacity tables were produced using a computer program (ACAP) that calculated area and capacity values at prescribed elevation increments using a curve-fitting technique.

Tables 1 and 2 contain summaries of Roosevelt Lake and watershed characteristics for the 2013 survey. The 2013 survey determined the reservoir has a total storage capacity of 3,410,897 acre-feet with a surface area of 31,800 acres at maximum reservoir water surface elevation 2,218.0. At conservation water surface elevation 2,151.0 the total capacity was 1,636,254 acre-feet with a surface area of 21,383 acres. Since 1995, this study a measured a loss of 16,789 acre-feet below reservoir elevation 2,151.0. This measured 1 percent change was due to sediment accumulation and collection method differences. A resurvey should be scheduled in the future if a significant change in the sediment basin runoff is noted.

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