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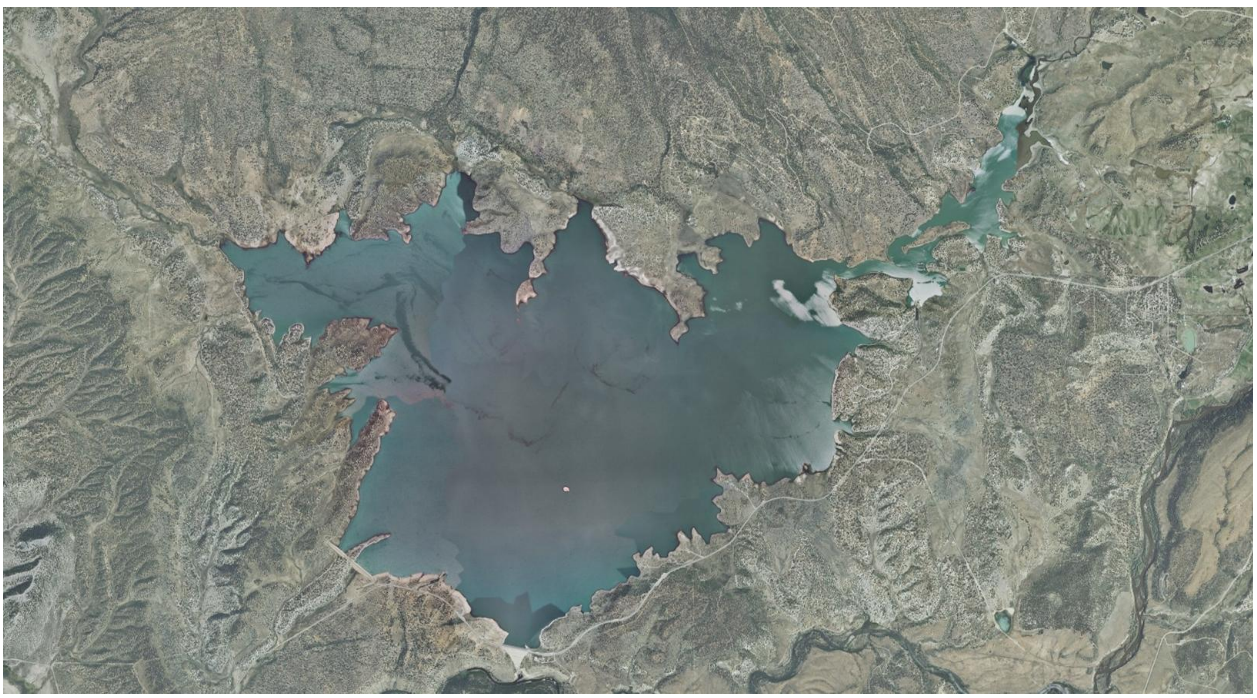
Technical Report No. SRH-2011-15

Heron Reservoir
2010 Bathymetric Survey



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

April 2011

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Heron Reservoir 2010 Bathymetric Survey

prepared by

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

April 2011

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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's July 2010 survey of Heron Reservoir developed updated reservoir topography and computed the present storage-elevation relationship (area-capacity tables). The underwater survey, conducted near water surface elevation 7,174.1 (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 obtained by digitizing the reservoir's water edge flown at elevation 7,174.0 from aerial photographs collected by the United States Department of Agriculture (USDA) and bare earth digital data, from around elevation 7,170 and above, Interferometric Synthetic Aperture Radar (IFSAR).

As of July 2010, at active conservation pool elevation 7,186.1, the surface area was 5,905 acres with a total capacity of 400,031 acre-feet. Since October 1970 dam closure, this study measured a total capacity change due to sediment deposition of 2,151 acre-feet below elevation 7,186.1 for an average annual loss of 51.5 acre-feet. A 1984 survey computed a total loss of 850 acre-feet that was computed from the survey of 26 sedimentation range lines that represented the reservoir and determined little to no change from the original topography from elevation 7,170.0 and above. The 2010 study redeveloped the total reservoir topography from detailed data and results concluded little changed from original topography from elevation 7, 170.0 and above. The original surface areas from elevation 7,170 and above were used to complete the 2010 Heron Reservoir area and capacity tables.

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Heron Reservoir 2010 Bathymetric Survey

Heron Dam
Chama, New Mexico

5-15-11

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Heron Reservoir
2010 Bathymetric Survey

Introduction

Heron Dam is located on Willow Creek at the confluence with the Rio Chama River in Rio Arriba County, New Mexico. The Dam and Heron Reservoir is about 9 miles west of the town of Tierra Amarilla, 25 miles southwest of Chama, 78 miles northwest of Santa Fe, and 28 miles south of the Colorado-New Mexico state line (Figure 1). The dam and reservoir are part of the San Juan-Chama Project that includes El Vado Dam and Reservoir that are located downstream on the Rio Chama. The reservoirs store water diverted from the Colorado River Basin, through the Continental Divide, to the Rio Grande Basin. The project's primary purpose is to provide water storage for supplemental irrigation to the Middle Rio Grande Valley and San Juan-Chama Project for irrigation, municipal, and industrial use. The project also provides flood control, hydroelectric power, recreation, and fish and wildlife benefits.

Figure 1 - Reclamation reservoirs located in New Mexico (Reclamation, 2008).

The dam and a dike, constructed between 1967 and 1971, are earthfill structures that form the reservoir. The embankments are compact gravelfill with a rockfill zone at the downstream toe and cobblefill zones downstream.

The dam's dimensions, in feet, are:

Top Width[1]	40	Structural height	275
Crest length	1,220	Crest elevation[2]	7,199.0

The spillway on the left abutment of the Heron Dike is located one mile northwest of Heron Dam and consists of an approach channel, concrete crest structure and an open chute. The crest elevation is 7,186.1 feet with a discharge capacity of 600 cubic-feet-per-second (cfs) at elevation 7,190.8. The outlet works, located in the left abutment of the dam, consists of an intake structure, 10-foot-diameter concrete-lined upstream tunnel, gate chamber, 11-foot modified horseshoe concrete-lined downstream tunnel, and a stilling basin. The discharge capacity is 4,160 cfs at reservoir elevation 7,190.8.

The total drainage above Heron Reservoir is 188 square miles bounded by the Continental Divide with 21 square miles considered non-contributing. Additional inflows are from Colorado River Basin diversions.

Control Survey Data Information

Prior to the 2010 bathymetric survey, a temporary point was set in a flat open area west of the dam using OPUS to establish the horizontal and vertical control datum. OPUS, operated by the NGS, allows users to submit GPS data files that are processed with known data to determine a point's position relative to the national control network (www.ngs.noaa.gov/OPUS). This temporary point was 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 New Mexico's central zone state plane coordinates in NAD83 and the vertical control tied to NAVD88. Unless noted, all elevations in this report are referenced to Reclamation's project datum, tied to NGVD29 that is 4.278 feet lower than

[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). Add 4.278 feet (rounded to 4.3 feet for this study) to match North American Vertical Datum of 1988 (NAVD88).

NAVD88. Following is the OPUS solution for the temporary point established west of the dam.

NAD83/NAVD88		NAD27/NGVD29	
North	2,062,305.715	North	2,062,239.261
East	1,506,143.812	East	365,897.932
Elevation	7,210.760	Elevation	7,206.482

Reservoir Operations

Heron Reservoir, part of the Middle Rio Grande Project, was designed to provide water storage for irrigation, municipal, and flood control. The reservoir's primary purpose is to provide storage for supplemental irrigation to the Middle Rio Grande Valley and San Juan-Chama Projects along with municipal and industrial uses. The 2010 survey determined that the reservoir has a total storage capacity of 428,355 acre-feet with a surface area of 6,148 acres at maximum water surface elevation 7,190.8. The 2010 survey measured a minimum lake bottom elevation near 6,963. The following values are from the July 2010 capacity table:

- 28,324 acre-feet of surcharge pool storage between elevation 7,186.1 and 7,190.8
- 398,938 acre-feet of joint use pool storage between elevation 7,003.0 and 7,186.1
- 1,093 acre-feet of dead pool storage below elevation 7,003.0.

The computed annual inflow and reservoir stage records for Heron Reservoir are listed by water year in Table 1 starting in 1971. The values show the annual fluctuation with a computed average annual inflow of 105,870 acre-feet. The data shows the reservoir operated annually near elevation 7,186 between 1982 and 1993 with maximum recorded elevation 7,186.1 in 1982, 1985, and 1992. Since first filling in 1982, the reservoir was drawn down to elevation 7,106 in 2004.

Hydrographic Survey Equipment and Method

Bathymetric Data Set

The bathymetric survey equipment was mounted in the cabin of a 24-foot trihull aluminum vessel equipped with twin in-board motors (Figure 2). 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 also equipped with survey equipment powered by 12-volt batteries and was used to map in the shallow water areas along the shoreline and in some of the smaller coves of the reservoir. 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 and a 12-volt battery provided 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 WGS-84 that the hydrographic collection software converted into New Mexico's state plane coordinates, central zone in NAD83. The RTK GPS system employs two receivers that track the same satellites simultaneously.

The Heron Reservoir bathymetric survey was conducted from July 6 through July 10 of 2010 at water surface elevation 7,174.1 (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 for the single beam collection. The 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 collected along the shore by the survey vessel for the majority of the reservoir. During each run, the depth and position data were recorded on the laptop computer hard drive for subsequent processing.

Figure 2 - Survey vessel with mounted instrumentation on El Vado Reservoir, New Mexico.

The single beam depth sounder for the 2010 underwater data 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. 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.

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 echosounder system measures the relative water depth across the wide swath perpendicular to the vessel's track. Figure 3 illustrates the swath of the sea floor that is about 3.5 times as wide as the water depth below the transducer.

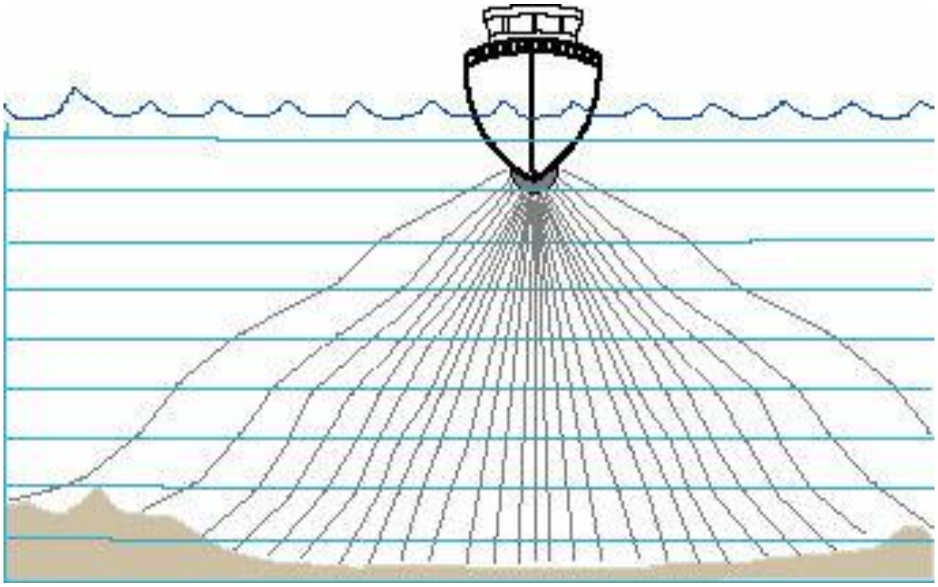

Figure 3 - Multibeam collection system.

The multibeam system is composed of several instruments all in constant communication with a central on-board notebook 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 speed of sound of the measurements 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 created a detailed data set of around 4,617,000 x,y,z points representing the reservoir below water surface elevation 7,174.1. 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. The additional beams provided more reservoir bottom detail than would have been obtained if only mapped by the single system.

Figures 4 and 5 show portions of the reservoir areas covered by the multibeam and single beam collection systems. The underwater collected data was processed using the hydrographic system software that was also used during the data collection. The analysis applied all measurements such as vessel location and corrections for the roll, pitch, and yaw effects. The 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 Heron 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).

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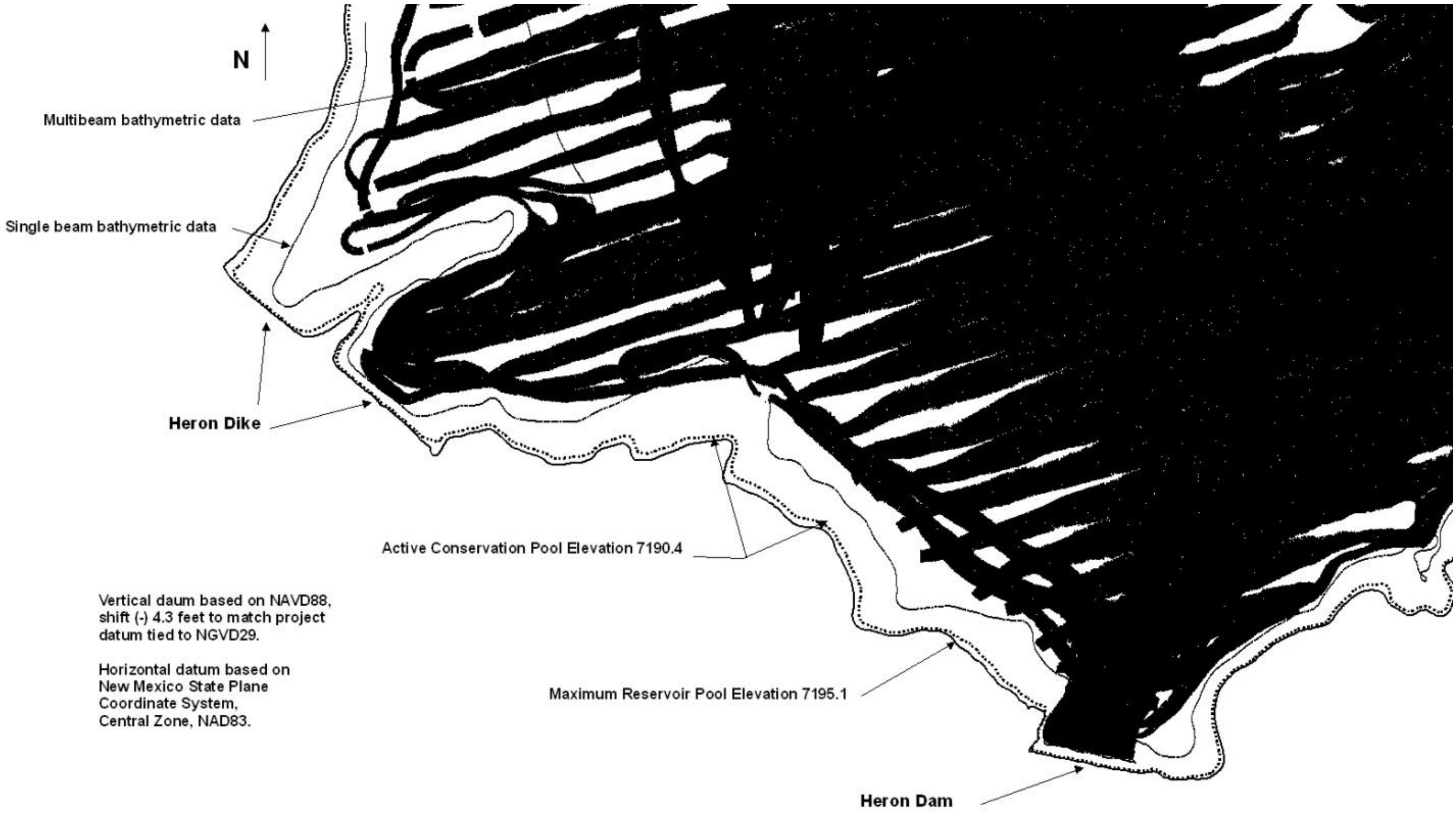

Figure 4 - Heron Reservoir bathymetric data points (NAVD88).

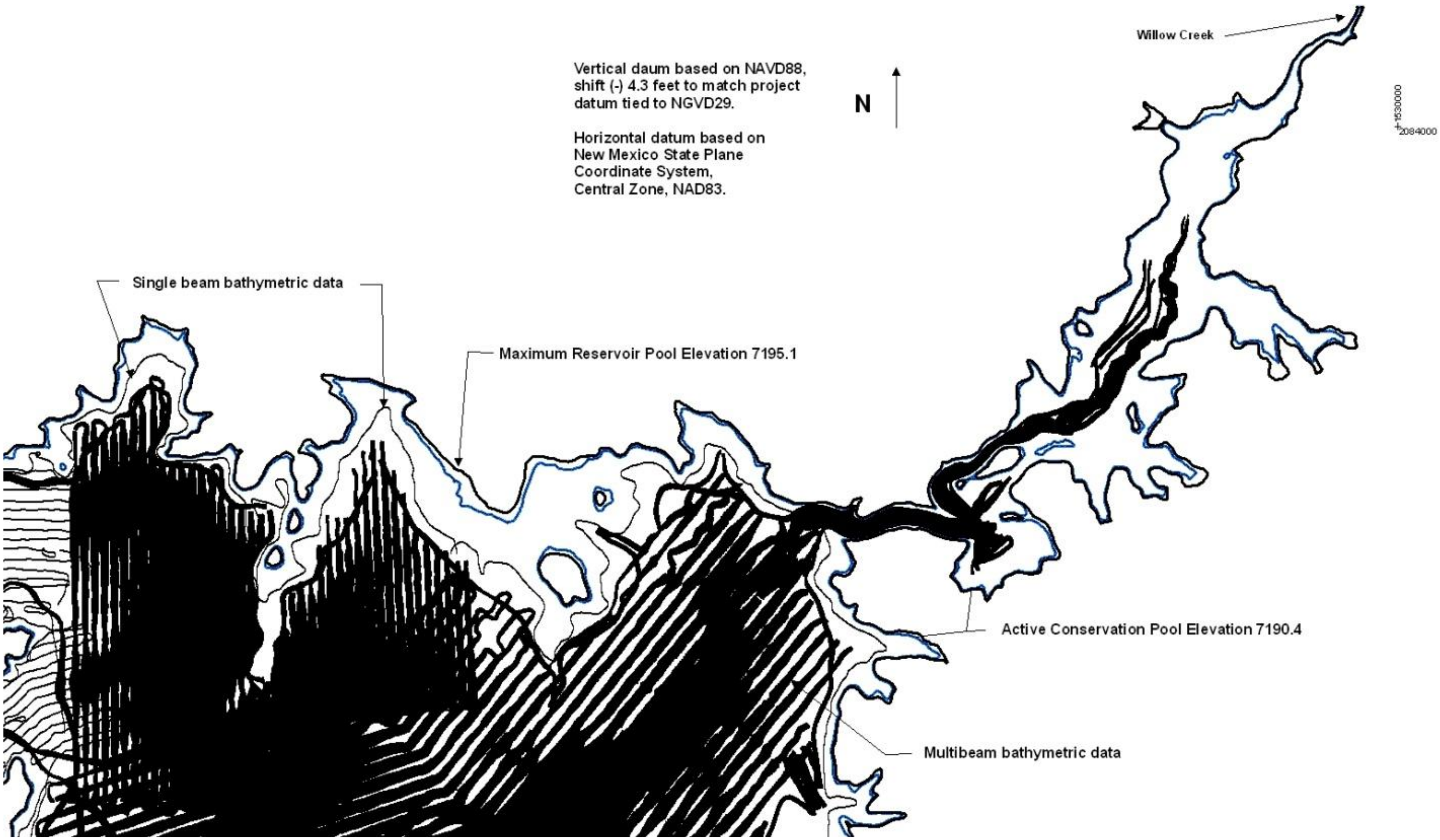

Figure 5 - Heron Reservoir bathymetric data points (NAVD88).

Aerial Photographs

During the analysis, orthographic aerial images collected in 2009 near water surface elevation 7,174 (NGVD29); or 7,178.3 (NAVD88); was downloaded from the USDA data web site (USDA, 2010). The majority of reservoir's water edge covered by the aerial that was flown at elevation 7,174.0 was near the same elevation as the 2010 bathymetric collection. This allowed a reservoir contour to be developed that enclosed the bathymetric data by digitizing the water's edge from the aerial image, Figure 6.

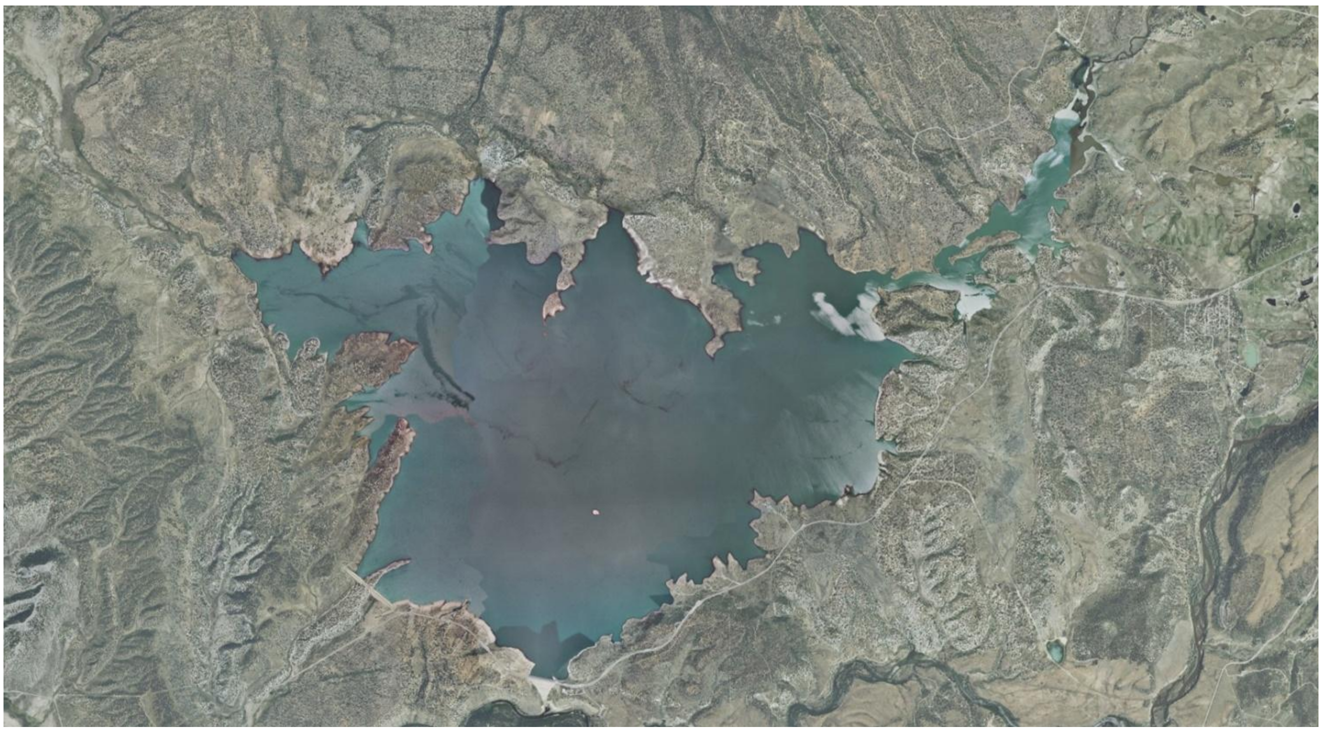

Figure 6 - Aerial image of Heron Reservoir flown in 2009 (USDA, 2010).

IFSAR Data Set

To complete the reservoir topography for areas above elevation 7,174.0 ((7,178.3 (NAVD88)) and the shallow reservoir water areas not covered by the 2010 bathymetric survey, additional data was needed. IFSAR digital data was obtained as bare earth 5-meter grid coordinates (east, north, elevation) tied to New Mexico state plane central zone with vertical elevations tied to NAVD88. The IFSAR airborne technology enables mapping of large areas quickly and efficiently resulting in detailed information at a much reduced cost than other technology such as aerial photogramatry and LiDAR (Intermap, 2011). The IFSAR data collected near water surface elevation 7,149 and was the best option available, for areas not covered by the 2010 bathymetric survey, to develop the upper topography for Heron Reservoir.

IFSAR reported accuracies are 2 meters or better horizontally and 1 meter or better vertically for areas of unobstructed flat ground. This study determined the IFSAR data was less accurate then the aerial photographic data used to measure the original reservoir capacity. One objective of this study was to measure change over time by comparing the results developed by the different data sources. Without the IFSAR data this study would have had to assume no change from the original surface areas from elevation 7,174 and above just due to lack of data.

To check the reliability of the IFSAR data, a contour was developed for elevation 7178.3, the reservoir stage at the time of the USDA aerial photography. The IFSAR contour at 7178.3 was then compared to the water line delineated from the USDA aerial photography to check for consistency (Figures 7 through 9). All elevations for the figures were tied to the vertical datum NAVD88. Figures 8 and 9 shows the majority of the areas where the two contours, USDA and IFSAR, compared very well. Where they differ the IFSAR contour seems to usually plot slightly above the bank of the USDA aerial water's edge. The one major exception for the entire reservoir was west of Heron Dam ((Figure 7). This area is a high vertical bank that may have contributed to the IFSAR error.

Four GPS topographic points were also available to check the IFSAR data (Figure 7 and 8). RTK GPS #2 and #4 points were edge of water measurements located in fairly open flat areas of the reservoir where the IFSAR elevations matched within a few tenths of a foot. RTK GPS #1 and #3 are two bench marks established for the 2010 survey and from where all GPS measurements were tied, such as RTK GPS #2 and #4 water surface measurements, RTK GPS measurements on the dam, and bathymetric GPS locations for the bathymetric survey. For both RTK GPS #1 and #3 bench mark elevations, the IFSAR data was around 5.2 feet lower. Both of these bases were located slightly higher than the surround area, low vegetated ground cover and a good view of the reservoir. Figures 7 shows locations of RTK GPS measurements on Heron Dam where the IFSAR elevations were around 4 feet lower. Despite localized problem areas, the IFSAR data was the best available information to merge with the 2010 bathymetric data to develop a continuous topographic surface of Heron Reservoir.

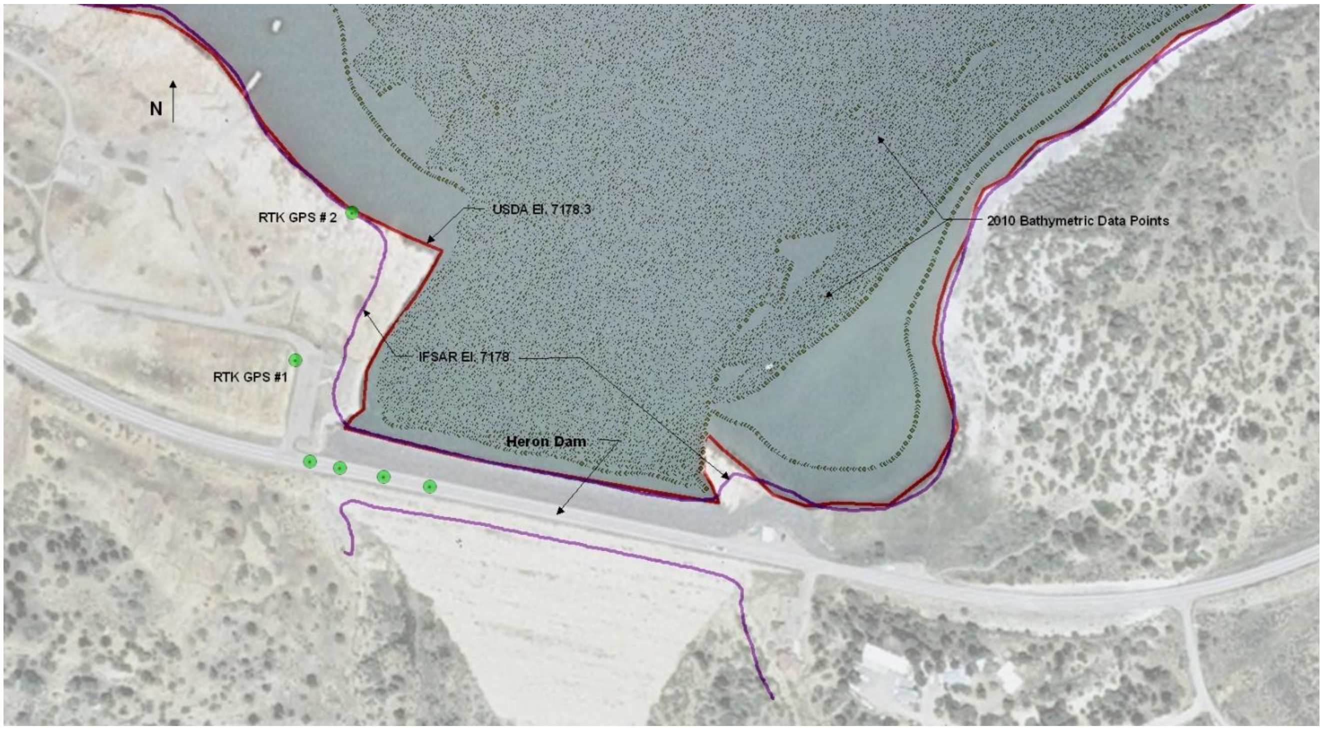

Figure 7 - Heron Dam, survey data layers (NAVD88).

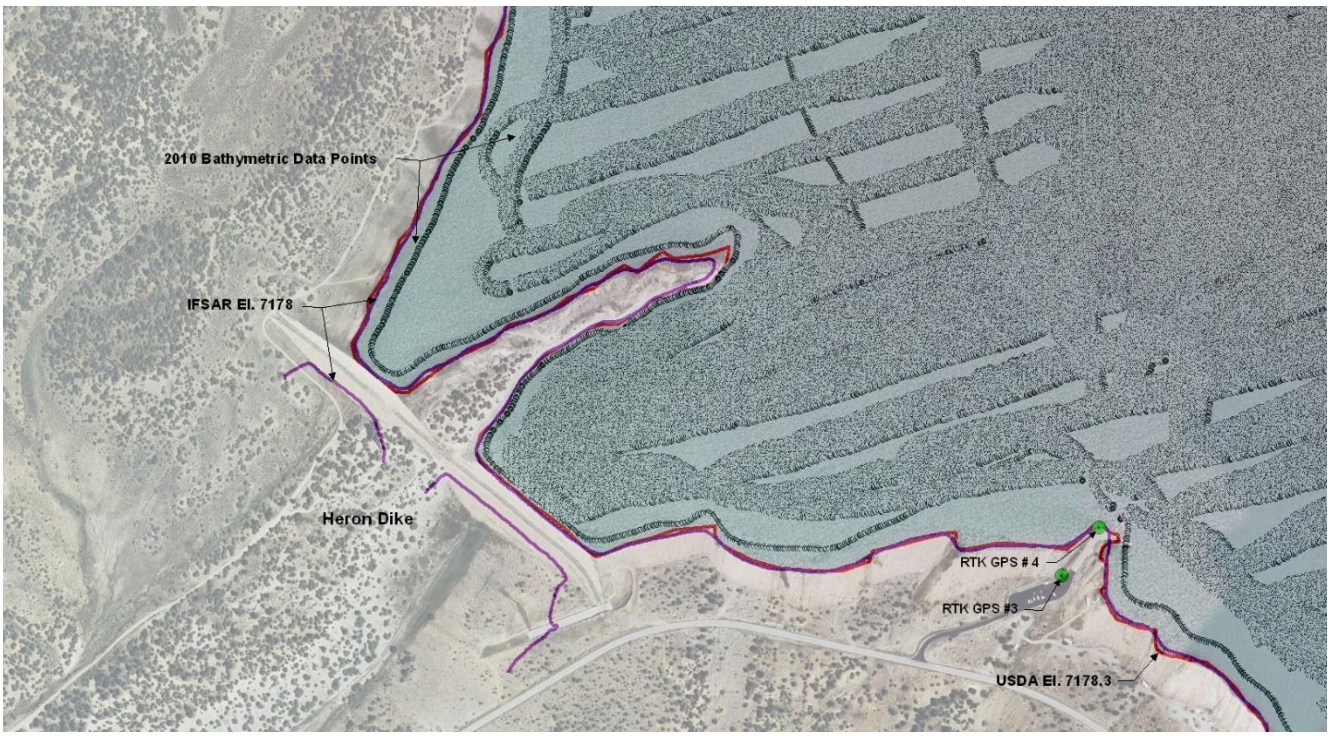

Figure 8 - Heron Dike area, USDA and IFSAR contour comparison (NAVD88).

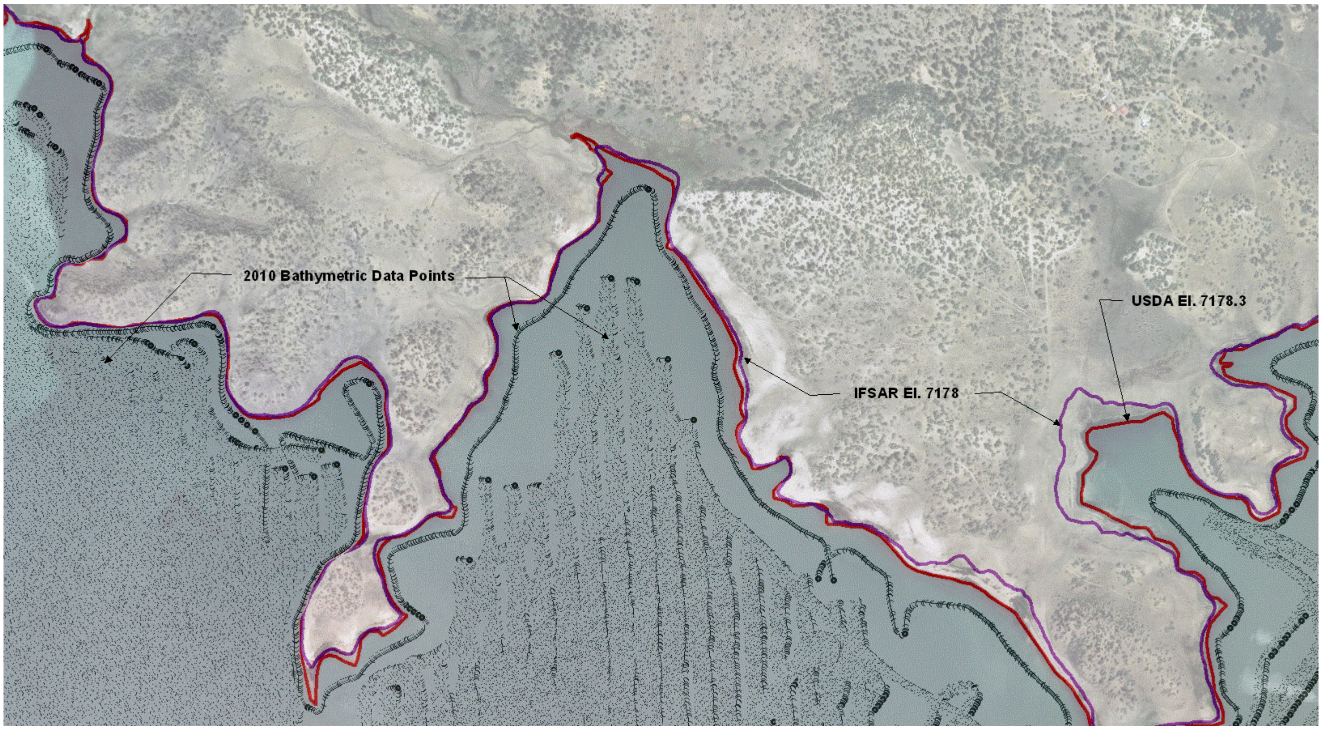

Figure 9 - Heron Reservoir USDA and IFSAR contour comparisons (NAVD88).

Reservoir Area and Capacity

Topography Development

This section discusses methods for generating 2-ft topographic contours for Heron Reservoir. The data sources included the 2010 bathymetric survey, the digitized reservoir water surface edge from the USDA aerial photograph, and the IFSAR bare earth data (Figures 10 through 12). These data were processed into a triangulated irregular network (TIN) that was then used to develop 2-ft contours.

As previously stated, the only major issue with the IFSAR data was west of Heron Dam (see Figures 7 and 10). IFSAR data west of the dam was removed and estimated contours were inserted as hard breaklines to represent the topography at this location. The USDA contour at elevation 7,178.3 (NAVD88) was part of the data set for the 2010 reservoir topography development and all IFSAR data above this elevation, except for portion removed west of the dam, was utilized. IFSAR data points were also added in shallow water reservoir areas not covered by the 2010 bathymetric survey (Figures 11 and 12). These areas were mainly in the coves throughout the reservoir and the upper portion of the reservoir on Willow Creek.

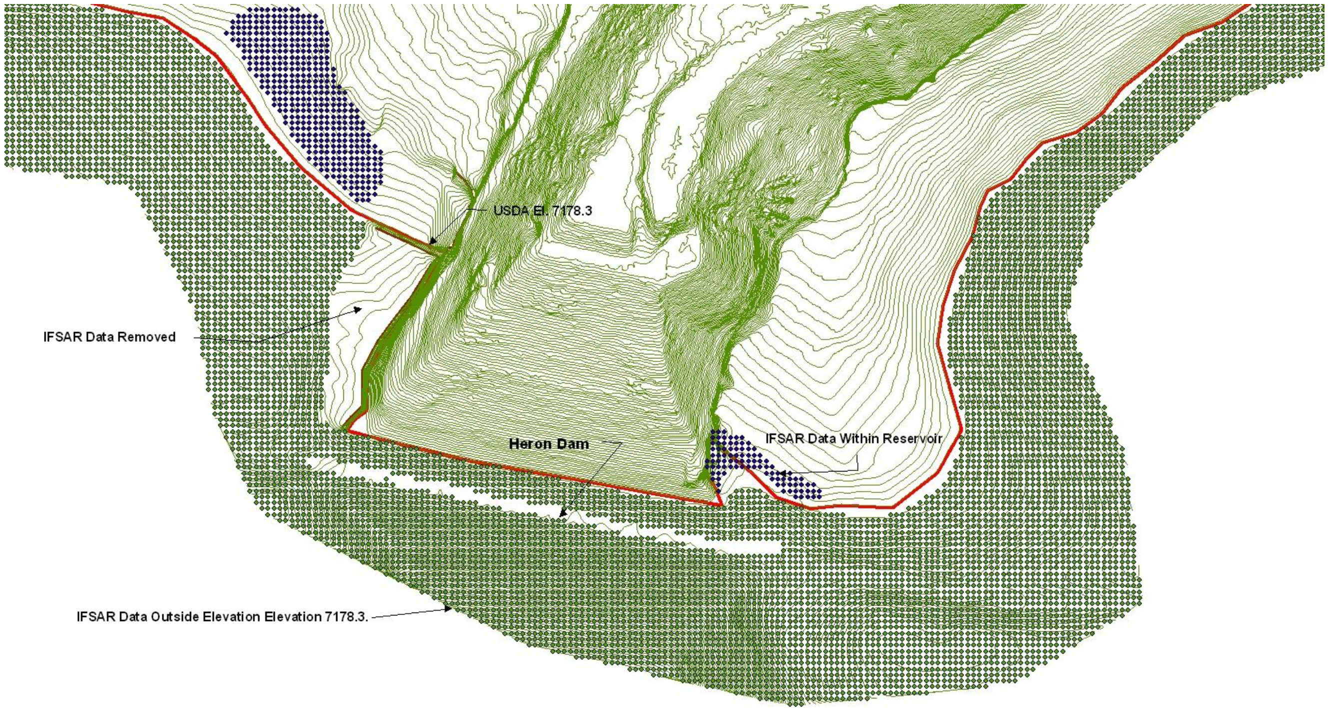

Figure 10 - Heron Dam data sets (NAVD88).

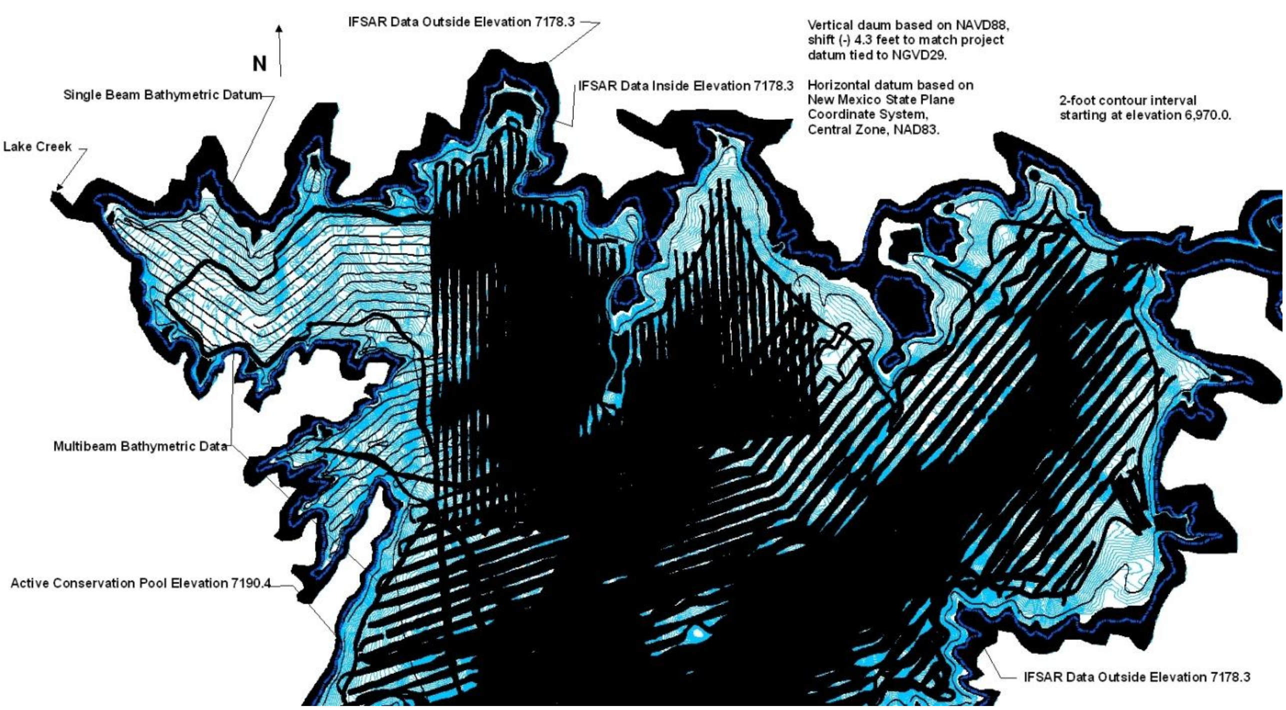

Figure 11 - Heron Reservoir data sources and coverage in north section of reservoir.

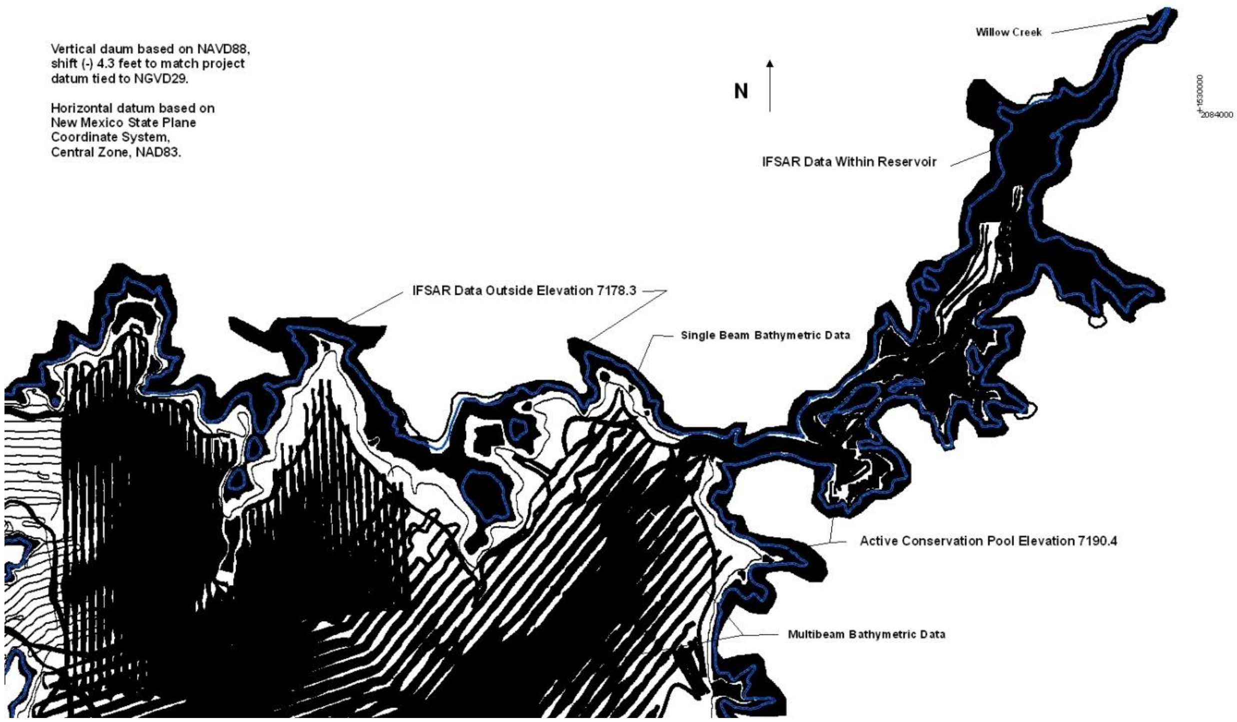

Figure 12 - Heron Reservoir data sources and coverage in northeast section of reservoir.

Heron Reservoir topography was tied vertically to NAVD88. The resulting surface areas and volumes, presented in this report are from the developed topography. The elevations were shifted to NGVD29 to match the project vertical datum that is 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 2010 developed contours that allowed mapping 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 13). One polygon allowed contour developed both upstream and downstream of Heron Dam and Dike while the other was drawn along the alignment of both the dam and dike so surface area and volume computations were only for the reservoir itself.

Contours for the reservoir 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 Heron Reservoir TIN. The surface areas of the enclosed contour polygons at two-foot increments were computed for elevation 7,192.0 and below. The reservoir contour topography at 2-foot intervals is presented on Figures 14 and 17. 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.

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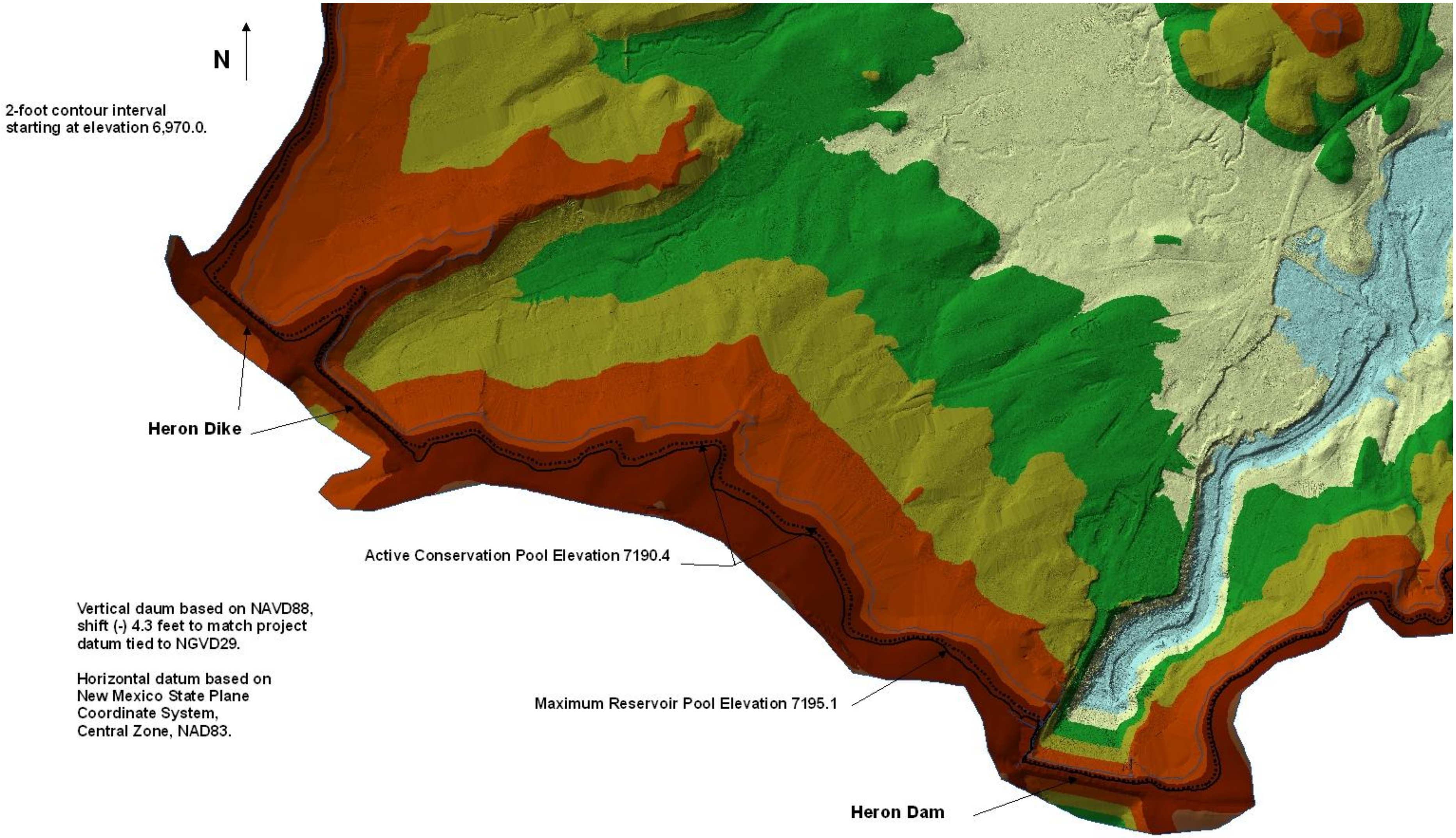

Figure 13 - Heron Reservoir 2010 TIN.

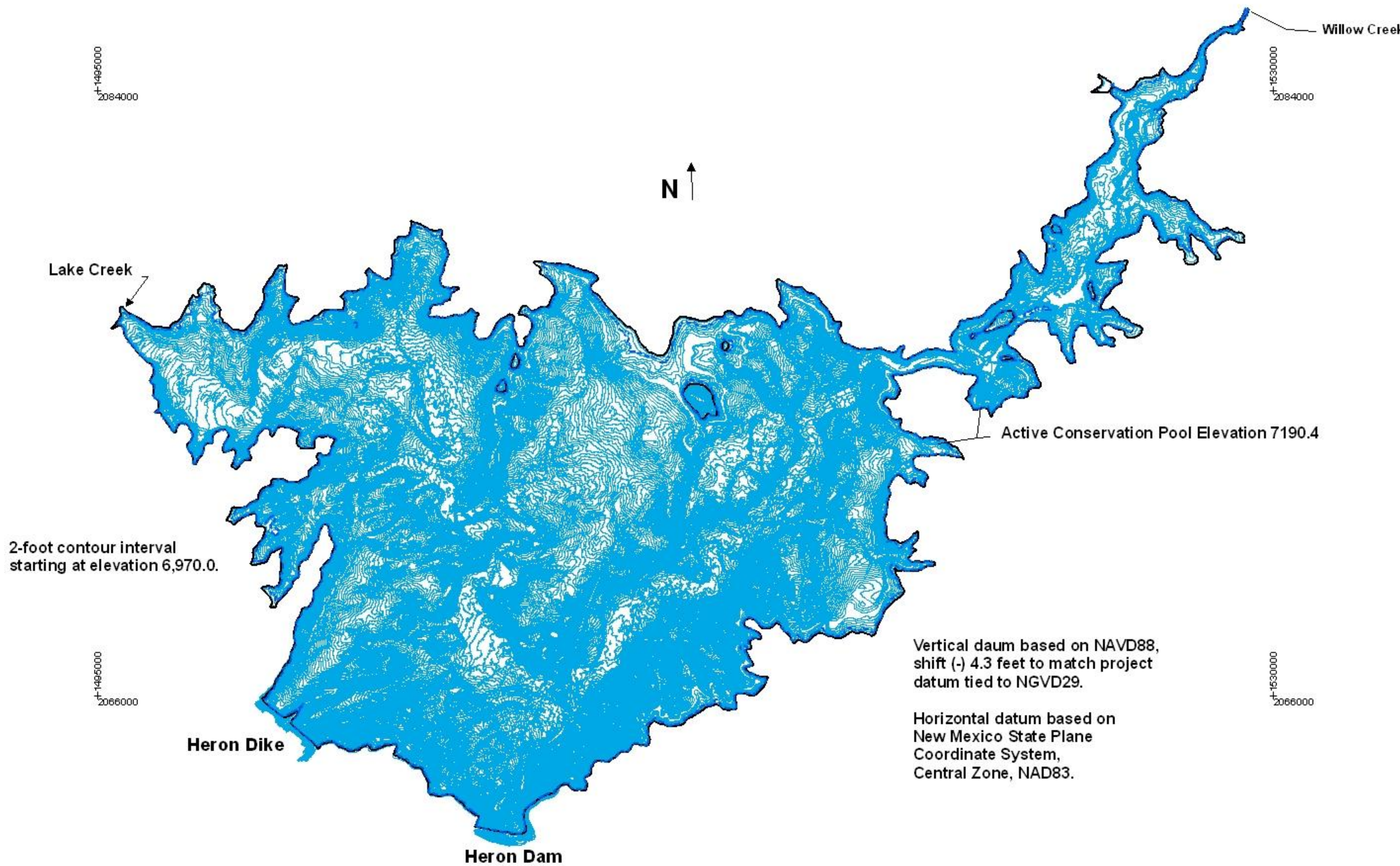

Figure 14 - Heron Reservoir topography (NAVD88).

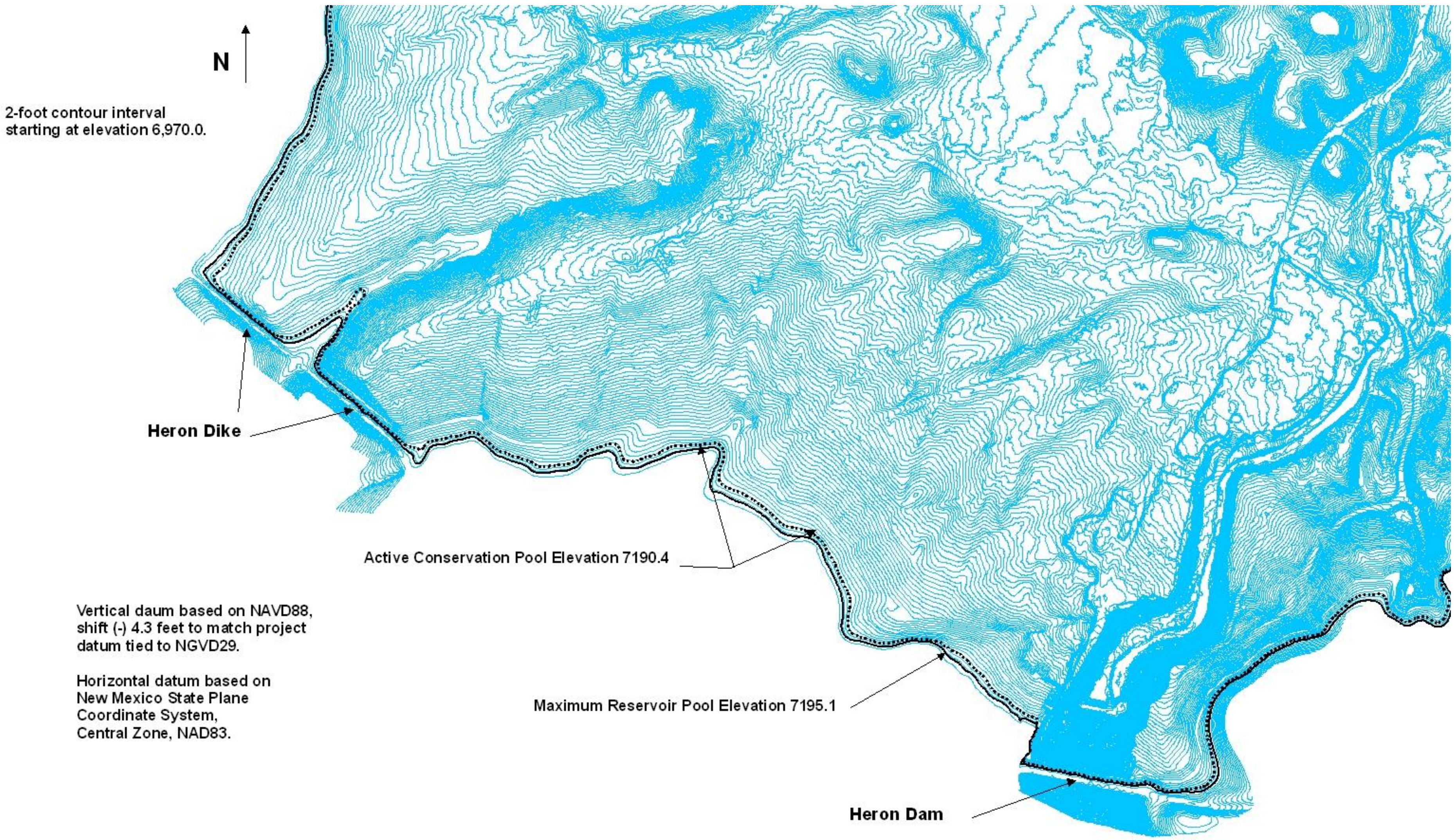

Figure 15 - Heron Reservoir topography (NAVD88).

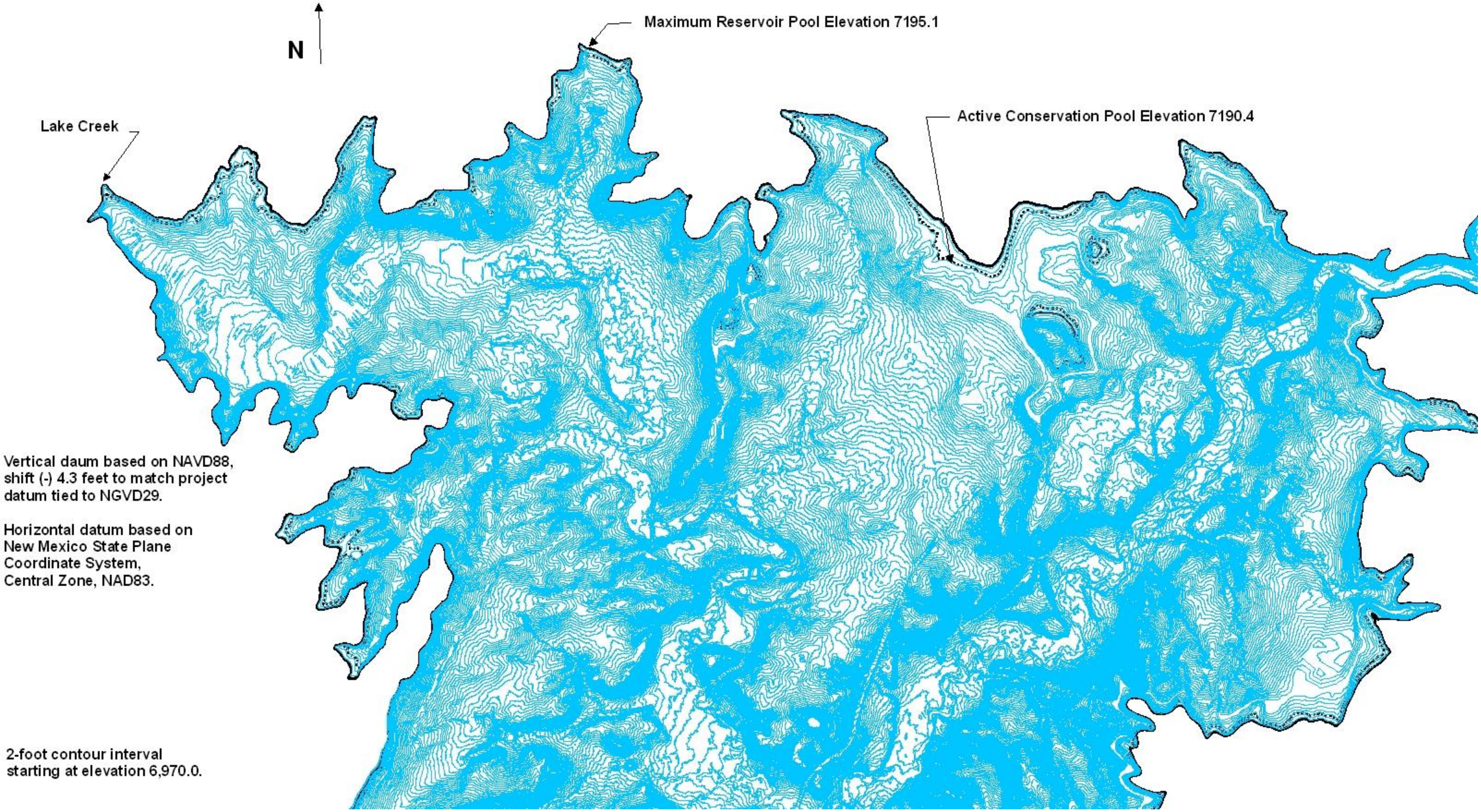

Figure 16 - Heron Reservoir topography (NAVD88).

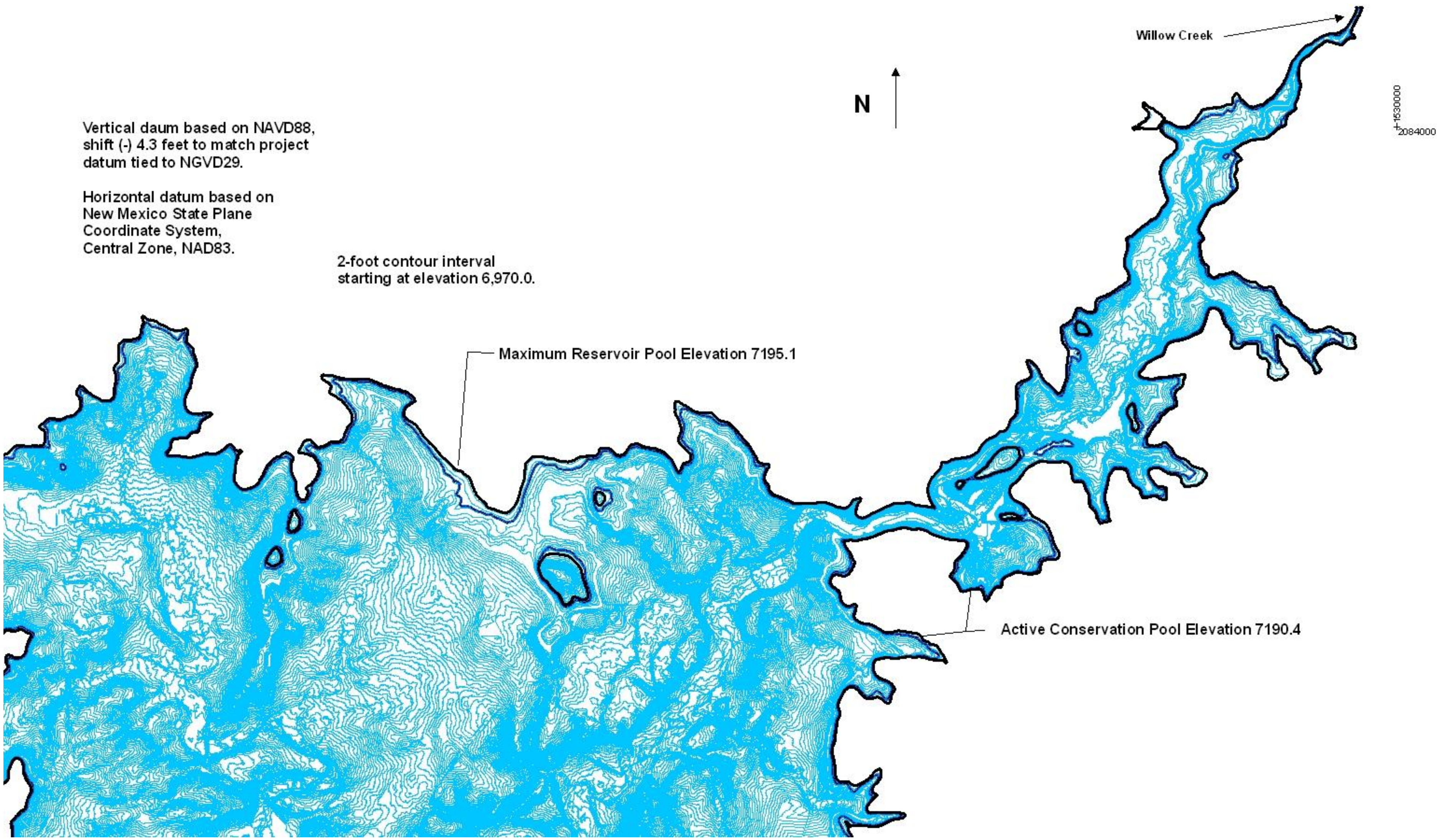

Figure 17 - Heron Reservoir topography (NAVD88).

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2010 Heron Reservoir Surface Area Methods

Surface areas at varying elevations were computed to provide information for the area-capacity tables. The 2010 surface areas for Heron Reservoir were computed at 2-foot increments directly from the reservoir TIN from elevation 6,964.0 through 7,192.0. The minimum elevation from the 2010 survey was elevation 6,963. Surface area calculations were performed using ARCGIS commands that compute areas at user-specified elevations directly from the TIN. The imported IFSAR data affected the surface areas from around elevation 7,170 and above and were within a few percent of the original surface area results. This study concluded accuracy differences between the original and IFSAR data contributed to these results, not due to topography changes such as shoreline erosion. The original surface areas from elevation 7,170.0 and above were used to develop the 2010 area tables.

2010 Heron 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 Heron 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 Heron Reservoir area and capacity computations are listed in a separate set of 2010 area and capacity tables and have been published for the 0.01, 0.1 and 1-foot elevation increments (Bureau of Reclamation, 2010). A description of the computations and coefficients output from the ACAP program is included with these tables. As of July 2010, at conservation use elevation

7,186.1, the surface area was 5,905 acres with a total capacity of 400,031 acre-feet.

Heron Reservoir Surface Area and Capacity Results

This section provides 2010 surface area and capacity results for Heron Reservoir and evaluates changes over time. Table 1 provides a summary of the change in Heron Reservoir topography between the time of original construction and 2010. The area and capacity curves for the original and 2010 survey areas are plotted on Figure 18. Table 2 provides a summary of the original, 1984, and 2010 surface area and capacity results at 10-ft increments.

Column 7 of Table 2 provides the computed surface areas for the generated TIN based on the IFSAR data merged with the 2010 bathymetric data set. The 1960s surface areas are shown in column 2. Column 8 shows the percent of difference between the original measured surface area and the new 2010 surface. The computations show the surface area losses occurred from elevation 7,120 and below. The 2010 generated TIN surface areas did show a slight gain in surface areas for some of the very lower portions of the reservoir between elevations 7,000.0 and 7,030.0, but overall the measured losses of surface areas due to sediment accumulation are from elevation 7,120.0 and below.

Using the IFSAR data, the 2010 computed surface areas, starting at elevation 7,170.0, began to show a gain of 0.7 percent from the original computed surface area. At elevation 7,180 and above the gains varied from 1.6 to 1.7 percent. Overall these percent of measured gains are small, but would indicate a large change along the reservoir banks due to shoreline erosion that was not observed during the 2010 collection. If there were significant shoreline eroded material it would settle in the lower elevations of the reservoir. This survey did not measure a large surface area change in the lower elevations to account for significant erosion of the shoreline. As seen on column 8 of table 2, the 2010 survey data showed little to no change from elevation 7,130.0 to 7,160.0 where the eroded bank material would have been expected to settle. It is the conclusion of this study the change in the upper reservoir areas from elevation 7,170 and above is due to the accuracy differences between the IFSAR data and the original 1960s topography, not due to actual changes of the reservoir shoreline. The results determined the original topography accuracies were better than the IFSAR data. The original surface areas from elevation 7,170.0 and above were used to develop the 2010 area and capacity tables.

For elevation 7,170.0 the percent of gain was 0.7 percent and 1.6 to 1.7 percent for elevation 7,180 and above. Since the bathymetric survey was collected near elevation 7,174.0 the 7,170.0 contour was developed from all the combined data sources including the IFSAR data while the areas above elevation 7,174 were developed from IFSAR data only. For the purpose of this study the 2010 TIN computed surface areas from elevation 6,964.0 through 7,160.0 were used in computing the new area and capacity tables. For elevation 7,170.0 and above the original surface areas were used with the conclusion there has been little change over the years of these reservoir areas since the October 1970 closure of Heron Dam. The ACAP program computed the area and capacity values between elevation 7,160.0 and 7,170.0.

The 1984 computed surface area values were evaluated to see if there was any evidence of historical shoreline erosion. The 1984 Heron Reservoir surface areas were computed using the range width ratio method that is explained in more detail in Chapter 9 of the Sedimentation Groups Erosion and Sedimentation Manual (Ferrari and Collins, 2006). There was limited information of the 1984 analysis except for tables summarizing the results. The 1984 survey measured change at 26 range lines that represented the reservoir and results showed little to no change in surface areas since the original measured surface areas from elevation 7,130 and above. The lack of extensive surface area change measured in 1984 at the upper reservoir elevations was further confirmation the 2010 increase in surface area was solely due to level of accuracy of the IFSAR and original data. For this study the IFSAR detailed data allowed development of the upper reservoir topography, but the IFSAR resulting surface areas were not used because it was determine there was little shoreline erosion and the original developed topography was determine to be more accurate. For this study the IFSAR results were within a few percent of the original results meaning the IFSAR data should be considered for future studies, but needs to be evaluated as all data should.

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RESERVOIR SEDIMENT
DATA SUMMARY

Heron Reservoir
NAME OF RESERVOIR

1
DATA SHEET NO.

D	1. OWNER: Bureau of Reclamation	2. STREAM: Willow Creek	3. STATE: New Mexico
A	4. SEC 1 TWP. 28N RANGE 2E	5. NEAREST P.O. Tierra Amarilla	6. COUNTY Rio Arriba
M	7. LAT 36 ° 39 ' 56 " LONG 106 ° 42 ' 13 "	8. TOP OF DAM ELEVATION: 7,199.0 [1]	9. SPILLWAY CREST EL. 7,186.1 [2]

	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
R	a. SURCHARGE	[3]				10/21/1970
E	b. FLOOD CONTROL					
S	c. POWER					
E	d. JOINT USE	7,186.1	5,905	399,980	401,317	16. DATE NORMAL OPERATIONS BEGAN
R	e. CONSERVATION					04/02/1971
V	f. INACTIVE	7,003.0	109	1,337	1,337	
O	g. DEAD					
I R	17. LENGTH OF RESERVOIR 9.5 [4] MILES		AVG. WIDTH OF RESERVOIR 1.0 MILES			

B	18. TOTAL DRAINAGE AREA 188 [5] SQUARE MILES		22. MEAN ANNUAL PRECIPITATION 8-30 [6] INCHES
A	19. NET SEDIMENT CONTRIBUTING AREA 167 [5] SQUARE MILES		23. MEAN ANNUAL RUNOFF [7] INCHES
S	20. LENGTH MILES	AVG. WIDTH MILES	24. MEAN ANNUAL RUNOFF 117,900 [7] ACRE-FEET
I N	21. MAX. ELEVATION 9900+	MIN. ELEVATION 6,900.0	25. ANNUAL TEMP, MEAN °F RANGE -30 °F to 105 °F [6]

SURVEY DATA	26. DATE OF SURVEY	27. PER. YRS	28. PER. YRS	29. TYPE OF SURVEY	30. NO. OF RANGES OR INTERVALS	31. SURFACE AREA, AC.	32. CAPACITY ACRE - FEET	33. C/I RATIO AF/AF
	10/1970			Range (D)		5,905 [8]	402,182 [8]	3.41
	6/1984	13.7	13.7	Range (D)	26	5,905	401,334	3.40
	7/2010	26.1	39.8	Contour (D)	2-ft	5,905 [9]	400,031 [9]	3.39

26. DATE OF SURVEY	34. PERIOD ANNUAL PRECIPITATION	35. PERIOD WATER INFLOW, ACRE-FEET			36. WATER INFLOW TO DATE, AF	
		a. MEAN ANN.	b. MAX. ANN.	c. TOTAL	a. MEAN ANN.	b. TOTAL
6/1984		117,900 [7]	192,870	1,650,980	117,900	1,650,980
7/2010		116,490	174,390	2,795,720	105,870	4,446,700

26. DATE OF SURVEY	37 PERIOD CAPACITY LOSS, ACRE-FEET			38. TOTAL SEDIMENT DEPOSITS TO DATE, AF		
	a. TOTAL	b. AVG. ANN.	c. /MI.^{2}-YR.	a. TOTAL	b. AVG. ANN.	c. /MI.^{2}-YR.
6/2009	850 [10]	62.0	0.37	850	62.0	0.37
7/2010	1,303	49.9	0.30	2,051	51.5	0.31

26. DATE OF SURVEY	39 AVG. DRY WT. (#/FT^3)	40. SED. DEP. TONS/MI.^{2}-YR		41. STORAGE LOSS, PCT.		42 SEDIMENT INFLOW, PPM	
		a. PERIOD	b. TOTAL TO DATE	a. AVG. ANNUAL	b. TOTAL TO DATE	a. PER.	b. TOT.
6/1984				0.015 [10]	0.21 [10]		
7/2010				0.013 [10]	0.53 [10]		

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, 11]							
YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF	YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF
				1971	7,079.3	6,991.8	63,900
1972	7,098.3	7,079.3	66,840	1973	7,144.8	7,088.2	179,800
1974	7,143.1	7,131.2	55,170	1975	7,157.4	7,123.4	169,070
1976	7,146.8	7,130.4	90,120	1977	7,135.5	7,119.0	22,730
1978	7,142.9	7,119.0	116,060	1979	7,167.8	7,130.6	192,870
1980	7,178.2	7,154.8	179,480	1981	7,177.0	7,166.3	59,650
1982	7,186.1	7,166.2	158,200	1983	7,186.0	7,171.6	157,380
1984	7,186.0	7,170.8	139,710	1985	7,186.1	7,171.0	134,520
1986	7,186.1	7,172.1	124,920	1987	7,186.0	7,174.0	114,050
1988	7,185.2	7,176.3	88,000	1989	7,185.6	7,179.8	59,350
1990	7,182.8	7,171.3	82,820	1991	7,185.8	7,171.6	132,350
1992	7,186.1	7,175.2	107,070	1993	7,186.0	7,169.9	139,250
1994	7,185.5	7,176.0	107,740	1995	7,185.9	7,172.4	123,950
1996	7,181.8	7,168.7	66,760	1997	7,180.1	7,159.9	164,260
1998	7,181.8	7,168.4	115,940	1999	7,185.6	7,164.6	123,150
2000	7,182.4	7,160.8	53,150	2001	7,175.7	7,159.1	131,020
2002	7,165.7	7,134.5	8,030	2003	7,144.9	7,122.5	71,340
2004	7,122.4	7,106.0	91,520	2005	7,153.4	7,116.4	174,390
2006	7,148.0	7,131.6	84,050	2007	7,155.2	7,135.0	117,830
2008	7,171.6	7,144.3	161,920	2009	7,175.9	7,155.5	113,090
2010	7,174.2	7,151.7	105,250				

46. ELEVATION - AREA - CAPACITY - DATA FOR **2010**								
ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
2010	**SURVEY**	[9]	6,963.0	0	0	6,970.0	3	8
6,980.0	11	67	6,990.0	31	246	7,000.0	87	802
7,003.0	107	1,093	7,010.0	156	2,011	7,020.0	244	3,990
7,030.0	372	7,040	7,040.0	501	11,403	7,050.0	626	17,026
7,060.0	772	24,015	7,070.0	929	32,496	7,080.0	1,138	42,811
7,090.0	1,400	55,448	7,100.0	1,733	71,064	7,110.0	2,179	90,497
7,120.0	2,690	114,815	7,130.0	3,190	144,242	7,140.0	3,707	178,729
7,150.0	4,184	218,200	7,160.0	4,671	262,450	7,170.0	5,110	311,358
7,170.0	5,110	311,358	7,180.0	5,604	364,928	7,186.1	5,905	400,031
7,190.0	6,107	423,453	7,190.8	6,148	428,355			

47. REMARKS AND REFERENCES

[1] Elevations in feet based on project vertical datum tied to NGVD29. Add 4.3 feet to tie to NAVD88.
[2] Spillway located on Heron Dike.
[3] Elevations from Reservoir Capacity Allocation in SOP, dated 10/2010.
[4] Reservoir length and drainage area information from 1984 developed table.
[5] Total drainage area above reservoir with 21 square miles consider naturally non-contributing. Does not account for trans basin flow area.
[6] Bureau of Reclamation Project Data Book, 1981.
[7] Mean annual runoff from Reclamation's Regional computed inflows. Portions diverted flow from Colorado River Basin.
[8] Surface area and capacity at elevation 7,186.1.
[9] 2010 capacities computed by Reclamation's ACAP program.
[10] Capacity losses by comparing original and 2010 capacity. Losses from natural drainage above Heron, trans basin suspended sediment, erosion of bed downstream of tunnel, and bank erosion on Willow Creek.
[11] End of month maximum and minimum elevations.

48. AGENCY MAKING SURVEY Bureau of Reclamation
49. AGENCY SUPPLYING DATA Bureau of Reclamation DATE April 2011

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

1	2	3	4	5	6	7	8	9	10	11	12
					1984	2110	Percent			2010	
Elevations	Original	Original	1984	1984	Volume	Survey	2010 Area	2010	2010	Volume	Percent of
	Survey	Capacity	Survey	Survey	Difference	w/ IFSAR	Difference	Survey	Survey	Difference	Reservoir
(feet)	(acres)	(acre-feet)	(acres)	(acre-feet)	(acre-feet)	(acres)	(acres)	(acres)	(acre-feet)	(acre-feet)	Depth
7,190.8	6,148	430,507	6,148	429,657	850	6,248	1.6	6,148	428,355	2,152	100.0
7,186.1	5,905	402,182	5,906	401,334	848	6,007	1.7	5,905	400,031	2,151	98.0
7,180.0	5,604	367,080	5,604	366,230	850	5,700	1.7	5,604	364,928	2,152	95.4
7,170.0	5,110	313,510	5,108	312,670	840	5,145	0.7	5,110	311,358	2,152	91.2
7,160.0	4,670	264,610	4,660	263,836	774	4,671	0.0	4,672	262,450	2,160	86.9
7,150.0	4,188	220,320	4,182	219,630	690	4,184	-0.1	4,184	218,200	2,120	82.7
7,140.0	3,704	180,860	3,703	180,205	655	3,707	0.1	3,707	178,729	2,131	78.4
7,130.0	3,186	146,410	3,185	145,765	645	3,190	0.1	3,190	144,242	2,168	74.2
7,120.0	2,716	116,900	2,705	116,315	585	2,690	-1.0	2,690	114,815	2,085	69.9
7,110.0	2,218	92,230	2,206	91,760	470	2,179	-1.8	2,179	90,497	1,733	65.7
7,100.0	1,744	72,420	1,737	72,045	375	1,733	-0.6	1,733	71,064	1,356	61.5
7,090.0	1,427	56,565	1,421	56,255	310	1,400	-1.9	1,400	55,448	1,117	57.2
7,080.0	1,156	43,650	1,156	43,370	280	1,138	-1.6	1,138	42,811	839	53.0
7,070.0	956	33,090	956	32,810	280	929	-2.8	929	32,496	594	48.7
7,060.0	781	24,405	781	24,125	280	772	-1.2	772	24,015	390	44.5
7,050.0	628	17,360	628	17,080	280	626	-0.3	626	17,026	334	40.2
7,040.0	508	11,680	505	11,415	265	501	-1.4	501	11,403	277	36.0
7,030.0	362	7,330	360	7,090	240	372	2.8	372	7,040	290	31.7
7,020.0	237	4,335	235	4,115	220	244	3.0	244	3,990	345	27.5
7,010.0	162	2,340	159	2,145	195	156	-3.7	156	2,011	329	23.3
7,000.0	86	1,100	83	935	165	87	1.2	87	802	298	19.0
6,990.0	39	475	37	335	140	31	-20.5	31	246	229	14.8
6,980.0	19	185	15	75	110	11	-42.1	11	67	118	10.5
6,970.0	6	60	0	0	60	3	-50.0	3	8	52	6.3
6,960.0	4	10	0	0	10	0	-100.0	0	0	10	2.0
6,955.2	0	0	0	0	0	0		0	0	0	0.0
1	Elevation of reservoir water surface. (Project vertical datum tied to NGVD29).										
2	Original reservoir surface area.										
3	Original reservoir capacity.										
4	Reservoir surface area from 1984 survey.										
5	Reservoir 1984 capacity.										
6	Volume difference between original and 1984 survey = column (3) - column (5).										
7	2110 survey areas computed using 2010 bathymetry data merged with IFSAR data for upper reservoir areas.										
8	Percent of area difference between original and 2010 survey = column (3) - column (7).										
9	Reservoir surface area from 2010 survey.										
10	Reservoir capacity from 2010 survey computed using ACAP.										
11	Volume difference between original and 2010 survey = column (3) - column (10).										
12	Depth of reservoir expressed in percentage of total depth, 235.6 feet.										

Table 2 - Heron Reservoir 2010 survey summary.

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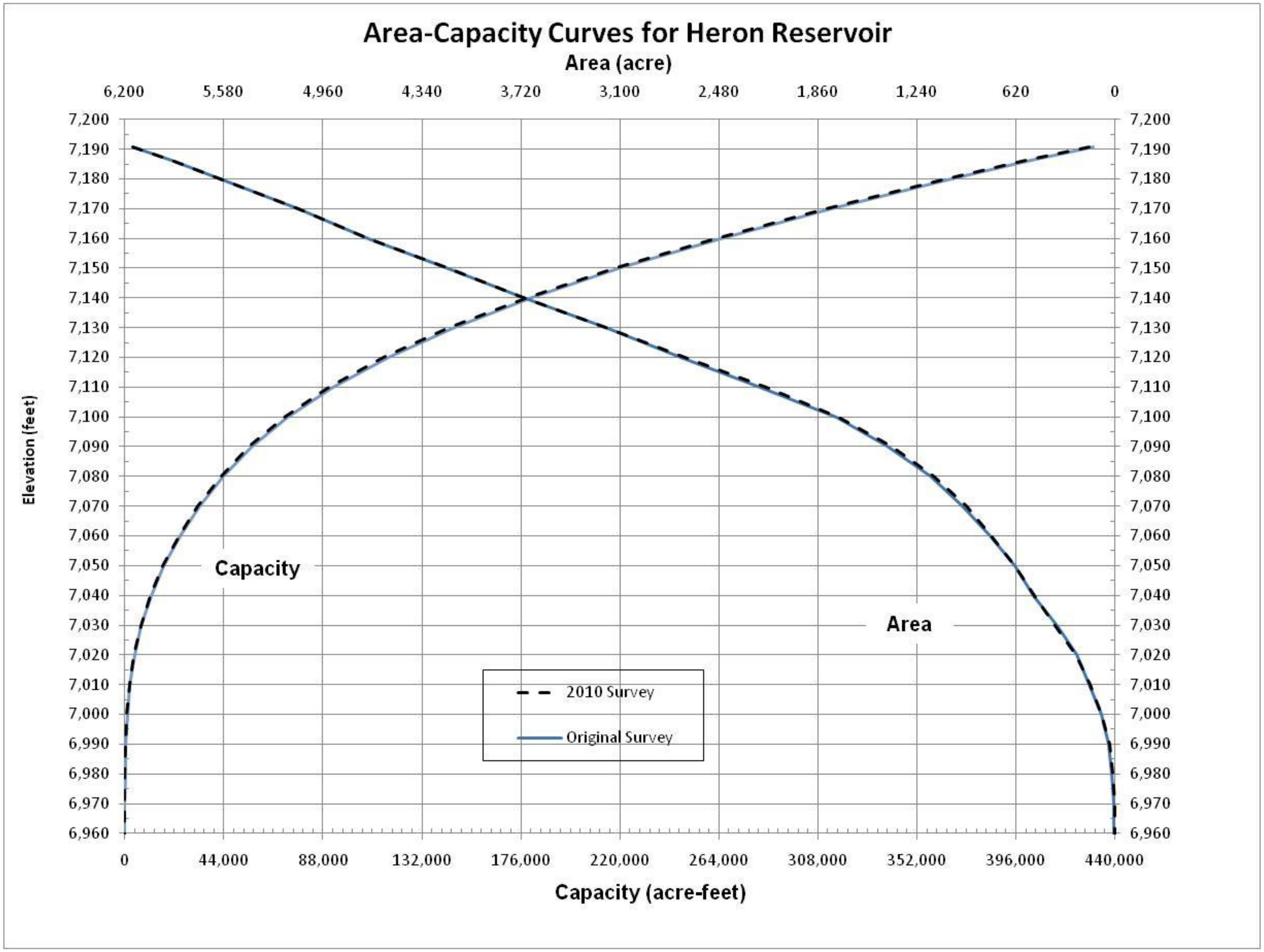

Figure 18 - Heron Reservoir area and capacity plots.

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2010 Heron Reservoir Analyses

Results of the 2010 Heron Reservoir area and capacity computations are listed in Table 1 and columns 9 and 10 of Table 2. Column 2 and 3 in Table 2 lists the original area and capacity values as recomputed for the 1984 survey study. Figure 18 is a plot of the Heron Reservoir surface area and capacity values for the original and 2010 surveys that illustrates the very small changes in storage that have occurred since Heron Dam closure in October 1970.

Table 1 shows the joint use capacity at elevation 7,186.1 for all known surveys along with the computed differences due to sediment deposition. The reservoir capacity in 2010 is 2,051 acre-feet less than the original (1970) volume at reservoir elevation 7,186.1. The 2010 area and capacity tables were generated assuming no surface area change since the original survey from elevation 7,170.0 and above because of small inaccuracies in the IFSAR data used to represent the topography. Assuming no change at elevation 7,170.0 is probably not entirely accurate, but any loss due to sediment deposition above this elevation is assumed not significant. The 2010 developed topography measured the majority of change from the original surface areas being below elevation 7,130.0 with very little change for elevation range 7,130.0 through 7,160.0 (Table 2). The 1984 range line survey also showed little to no change in surface areas from the original surface areas from elevation 7,130 and above.

IFSAR data was used to develop the topography above elevation 7,170 and in shallow reservoir areas that were not surveyed in 2010. The resulting surface areas using the IFSAR data showed a gain in storage from the original for the upper reservoir from elevation 7,170.0 and above, column 7 and 8 of table 2. The 2010 increase in surface areas in these upper contours was due to accuracy differences from the originally developed contours, not due to shoreline erosion of the reservoir. If there were extensive erosion along the reservoir shoreline this material would have settled in the lower elevation reaches of the reservoir that was not apparent from the 2010 bathymetric survey data.

During the planning phase for Heron Reservoir, the originally estimated 100-year sediment accumulation was 23,420 acre-feet from the toe of the dam to elevation 7,186.1, for an average annual storage loss of 234 acre-feet. The 2010 study measured 2,051 acre-feet of total sediment accumulation or an average annual rate of 51.5 acre-feet that is only 22 percent of the original estimate. There was no information found on how the original sediment accumulation was calculated. The results of the 2010 Heron Reservoir study provide up-to-date surface area and capacity information for the entire reservoir. Overall the 1984 and 2010 surveys indicated little sediment has deposited within the reservoir area since dam closure in June of 1970. A resurvey should be scheduled no sooner than the year 2030 unless a significant change in the sediment basin runoff is noted. An example of a significant change would be if a large basin fire occurred upstream of Heron Reservoir within its natural or diverted flow drainage areas.

Summary and Conclusions

This Reclamation report presents the results of the July 2010 survey of Heron Reservoir. The primary objectives of the survey were to gather data needed to:

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

A control survey was conducted using the on-line 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 control network. The GPS base was set over a temporary mark located on high ground west 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 control points were also confirmed from OPUS processing.

The study's horizontal control was in feet, New Mexico Central 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 4.278 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 2010 underwater survey was conducted near reservoir elevation 7,174.1 as measured by the Reclamation gage at the dam. 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 Heron 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 2010 field survey was determined by digitizing contour lines from the USGS quads of the reservoir area. This outline was used to assure coverage of the reservoir during the July survey. During analysis, an orthographic aerial image collected in 2009 near water surface elevation 7,174 was downloaded. The edge of water surface at elevation 7,174.0 or 7,178.3 (NAVD88), covered the majority of the reservoir and was digitized (USDA, 2010). This digitized reservoir contour enclosed the bathymetric data since the aerial was flown at the same elevation as the 2010 bathymetric collection.

The areas above elevation 7,174 and shallow reservoir water areas not covered by the 2010 bathymetric survey vessels required additional data to complete the reservoir topographic development. Airborne collected digital data was obtained from Interferometric Synthetic Aperture Radar (IFSAR) method as 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 is 2 meters or better horizontally and 1 meter or better vertically for unobstructed flat ground areas. Other technologies have better accuracies 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 above the reservoir pool (USDA digitized aerial contour at elevation 7,174). The original reservoir topography was developed from aerial photogrammetry flown in the 1960's (prior to filling of the reservoir) whose accuracies are assumed slightly better than the IFSAR accuracies. The 1960's topographic data was only available in hard copy form and there would have been errors to rectify to a digital format.

The 2010 Heron Reservoir topographic map is a combination of the IFSAR digital data, the digitized water surface edge from the USDA orthographic aerial photograph at elevation 7,174 (7,178.3-NAVD88) and the 2010 underwater survey data. All data was adjusted vertically to NAVD88 for the topographic map development. A computer program was used to generate the 2010 topography and resulting reservoir surface areas at predetermined contour intervals from the combined reservoir data. The IFSAR data for Heron Reservoir was used for the general representation of the reservoir topography above elevation 4,170, but due to accuracy differences and little to no shoreline erosion the resulting surface areas from the IFSAR data was not used for this study. The original surface areas from elevation 7,170.0 and above were used to develop the 2010 area and capacity tables since this study concluded little change within this reach. For reservoir operation purposes the resulting reservoir surface areas were shifted to project vertical datum in NGVD29. The 2010 area and capacity tables were produced by 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 Heron Reservoir and watershed characteristics for the 2010 survey. The 2010 survey determined the reservoir has a total storage capacity of 428,355 acre-feet with a surface area of 6,148 acres at maximum water surface elevation 7,190.8 and a storage capacity of 400,031 acre-feet with a surface area of 5,905 acres at normal water surface elevation 7,186.1. Since closure of Heron Dam on October 21, 1970, this survey measured a 2,151 acre-feet change in reservoir capacity below elevation 7,186.1 that is attributed to sediment accumulation. The losses were computed by comparing the original and the 2010 capacities for the reservoir. The majority of the sediment deposition was measured below elevation 7,130.0.

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