RECLAMATION

Managing Water in the West

Technical Report No. SRH-2013-20

Flatiron Reservoir 2012 Bathymetric Survey

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

June 2013

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Flatiron Reservoir
2012 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

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Reclamation Report

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14. ABSTRACT

Reclamation surveyed Flatiron Reservoir on May 30 of 2012 to develop updated reservoir topography and compute the present storage-elevation relationship (area-capacity tables). The bathymetric survey, conducted near water surface elevation 5,471.6 (project datum in feet), used sonic depth recording equipment interfaced with a real-time kinematic (RTK) global positioning system (GPS) that provided continuous sounding positions throughout the underwater portion of the reservoir covered by the survey vessel. The above-water topography was developed by digitizing the reservoir water's edge from aerial photographs collected by the United States Department of Agriculture (USDA), digital bare earth Interferometric Synthetic Aperture Radar (IFSAR) data and topographic points measured by RTK GPS rovers. .

As of May 2012, at conservation pool elevation 5,472.8 (project datum in feet), the reservoir surface area was 45.0 acres with a capacity of 730 acre-feet. Since January 1954 dam closure, a total capacity change of 29 acre-feet below elevation 5,472.8 was measured. The capacity change is due to sediment deposition and methodology differences between this survey and past surveys.

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

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Flatiron Reservoir
2012 Bathymetric Survey

Flatiron Dam
Colorado

Prepared: Ronald L. Ferrari
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Date

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Date

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2012 Bathymetric Survey

Introduction

Flatiron Dam and Reservoir are part of the Colorado-Big Thompson (CBT) Project that provides storage capacity for irrigation and benefits for flood control, recreation, fish, wildlife, and power generation. The CBT Project consists of over 100 structures integrated into an intermountain water diversion system that stores, regulates, and diverts water from the Colorado River on the western slope of the Continental Divide to the eastern slope of the Rocky Mountains. Flatiron Reservoir, an afterbay storage for Flatiron Powerplant, provides storage for the Flatiron Pumping Plant and augments primary water supplies.

Flatiron Reservoir and Dam are located at the confluence of Dry and Chimney Hollow Creeks about 12 miles southwest of Loveland Colorado (Figure 1). The inflows consist of outflow from the Pinewood Reservoir through the Bald Mountain Pressure Tunnel, Carter Lake through the Carter Lake Pressure Tunnel and Conduit, and the small drainage area of 7.1 square miles. Normal releases from Flatiron Reservoir are through Charles B. Hansen Feeder Canal with a maximum design capacity of 930 cubic feet per second (cfs). The 930 cfs release can be used to fill Horsetooth Reservoir (up to 550 cfs) or diverted into the Big Thompson River to provide Project deliveries, replace “skim” water, or to evacuate flood water. Utilizing the pump turbine, a maximum of 370 cfs at a head of 240 feet can be pumped to Carter Lake through the Carter Lake Pressure Tunnel and Conduit. Excessive flood flows spill over the uncontrolled spillway crest.

Reclamation’s Eastern Colorado Area Office administers and operates the facility and Larimer County Park District operates the recreational facilities. At elevation 5,472.8 the reservoir length is 0.7 miles with an average width of 0.1 miles.

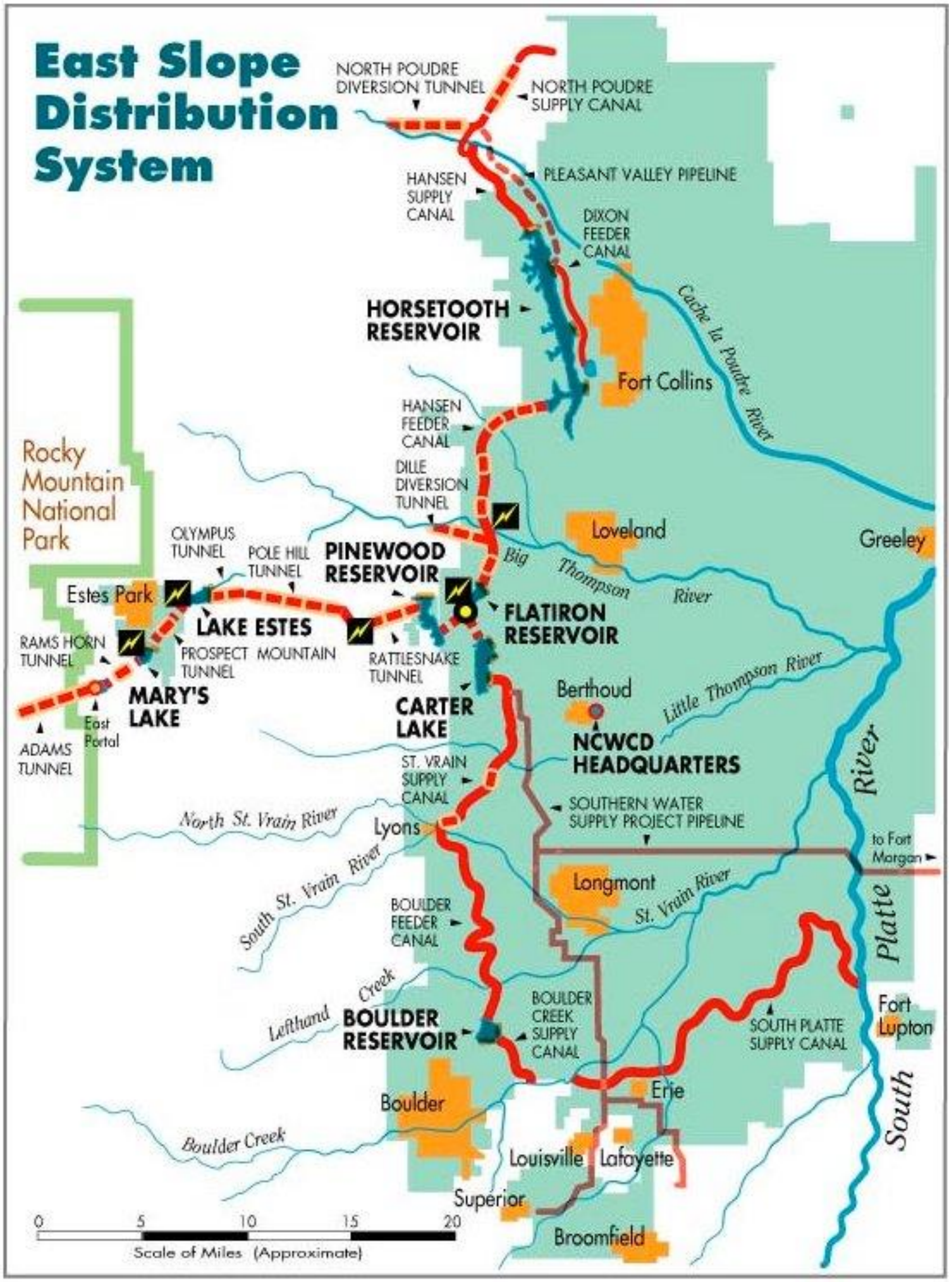

Figure 1 - Flatiron Reservoir – Colorado Big Thompson Project (CBT).

The earth and rockfill zoned compact structure dam, constructed from 1950 through 1953, has the following dimensions:

Structural height[1]	86 feet	Hydraulic height	55 feet
Crest length	1,725 feet	Crest elevation[2]	5,486 feet
Top width	30 feet		

Flatiron Dam's spillway, located in the left end of the embankment, is a concrete-lined, open-channel, uncontrolled-type spillway with crest elevation 5,472.8. The design discharge capacity is 23,600 cfs at maximum water surface elevation 5,480.0.

The outlet works, located in the left abutment, consists of twin-barrel concrete conduits controlled by two 6.75- by 9.0-foot radial gates that regulate the flow of water into Charles B. Hansen Feeder Canal. The maximum design flow is 930 cfs at water surface elevation 5,464.0 and 550 cfs at elevation 5,461.5.

Control Survey Data Information

Prior to the 2012 bathymetric survey, a control network was established using the on-line positioning user service (OPUS) and RTK GPS to set a temporary horizontal and vertical control point near Flatiron Reservoir for the hydrographic survey. OPUS, operated by the National Geodetic Survey (NGS), allows users to submit GPS data files that are processed with known point data to determine positions relative to the national control network. The OPUS generated coordinates were used to determine position and vertical difference between the North American Vertical Datum of 1988 (NAVD88), recorded water surface elevation at the dam, and monument points.

The horizontal control was established in Colorado state plane north coordinates on the North American Datum of 1983 (NAD83) in feet. The vertical control was tied to the Reclamation’s project vertical datum and NAVD88 computed using the geoid model of 2009 (GEOID09). RTK GPS water surface measurements collected during the bathymetric survey in NAVD88 were around 5.5 feet higher than the water surface gage readings. Unless noted, all elevation computations

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

[2] Elevations in feet. Unless noted, all elevations based on the original project datum established during construction of Flatiron Dam, around 2.0 feet less than National Geodetic Vertical Datum of 1929 (NGVD29) and 5.54 feet lower than NAVD88.

within this report are referenced to Reclamation's project datum that is around 2 feet lower than NGVD29 and around 5.54 feet lower than NAVD88 (GEOID09). The developed reservoir topography elevations herein are tied to NAVD88 (GEOID09) while computed surface area values were shifted down 5.54 feet to match the project vertical datum during development of the area and capacity tables for operational purposes.

When setting up the control network, an aluminum monument stamped "SRH-May2012" was set on a ½ inch rebar near the left abutment of Flatiron Dam. This monument was used during the Flatiron Reservoir 2012 survey and tied to monuments with known elevations near Pinewood Reservoir. The OPUS computed coordinates for SRH-May2012, using Geoid 2009, were:

East	**3,074,958.430**
North	**1,379,246.011**
Elev.	**5,486.452**

With the GPS base, set over SRH-May2012, measurements were taken on two Larimer (LAR) County monuments and a 1950 Reclamation brass cap stamped elevation 6,778.997. These measurements helped confirm the OPUS generated coordinates and the vertical datum shift between NAVD88 and the project vertical datum. Following are the coordinates for these monuments and how they compare with the May 24, 2012 measurements.

Monument Name:

Measurements (May 2012)		**Documented Coordinates**		**Vertical Difference**
LAR – MacFarlene 97				
East	3,063,896.212	East	3,063,896.291	
North	1,373,975.250	North	1,373,975.166	
Elev.	6,783.028	Elev.	6,783.038	+0.01
LAR – CP5 (used as base during the Pinewood Survey)				
East	3,060,556.353			
North	1,375,497.018			
Elev.	6,607.372			
BOR BM – RS 2, 1950, EL. 6,778.997				
East	3,063,892.007			
North	1,373,989.903			
Elev.	6,784.539	Elev.	6,778.997	+5.54

During the survey of Flatiron Reservoir and nearby Pinewood Reservoir, RTK GPS water surface measurements were collected in NAVD88 and compared to the water surface gages maintained by Reclamation. At Flatiron Reservoir the differences were between 5.3 and 5.4 feet while at Pinewood Reservoir the differences were between 5.4 and 5.5 feet. These water surface elevations were measured during fairly calm conditions, but water levels at Flatiron Reservoir vary more due to size and operations. Using Corp of Engineers software CORPSCON, vertical differences of 3.39 and 3.54 feet were computed between NAVD88 and NGVD29 at Flatiron and Pinewood Reservoirs respectively. Reclamation documents indicate that the reservoir designs were tied to mean sea level, but this survey found the project vertical datum around two feet lower than NGVD29 which would have been the implied sea level during construction. For computational purposes, a project or construction vertical datum 5.54 feet below NAVD88 was used for this study.

Reservoir Operations

Flatiron Reservoir is part of the CBT Project whose primary purpose is providing water storage capacity for diversion for irrigation needs and benefits for flood control, recreation, fish, wildlife, and power generation. The May 2012 total capacity of Flatiron Reservoir was 1,094 acre-feet below elevation 5,480.0. The minimum bottom elevation measured during the 2012 survey was 5,429.4. The following values are from the May 2012 capacity table:

364 acre-feet of surcharge pool storage between elevation 5,472.8 and 5,480.0.
418 acre-feet of active conservation storage between elevation 5,462.0 and 5,472.8.
182 acre-feet of inactive use storage between elevation 5,454.75 and 5,462.0.
130 acre-feet of dead pool storage below elevation 5,454.75.

Available end-of-month stage records for Flatiron Reservoir in Table 1 show the annual fluctuation for the limited period of operation from 2003 through 2012. There was no easy means to compute the average inflow during the life of the reservoir, but it is noted that the majority of the inflow consists of diverted flows from the western slope. Operating as an afterbay for the powerplant, Flatiron Reservoir levels can experience extreme fluctuations on a daily basis.

Hydrographic Survey, Equipment, and Method of Collection

Bathymetric Survey Equipment

The bathymetric survey equipment was mounted on a 9-foot cataraft powered by an electric trolling motor used to measure depths as it navigated on the reservoir (Figure 2). The bathymetric system included a GPS receiver with a built-in radio and depth sounder. All equipment was powered by on-board batteries. The shore equipment included a second GPS receiver with an external radio. The shore GPS receiver and antenna were mounted on a survey tripod over known datum point "SRH-May2012" with a 12-volt battery providing power.

Figure 2 - Vessel used to collect depth data near the spillway intake of Flatiron Dam.

The Sedimentation and River Hydraulics Group uses RTK GPS with the major benefit being precise heights measured in real time to monitor water surface elevation changes. The RTK GPS system employs two receivers that track the same satellites simultaneously. 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 Colorado's state plane north coordinates, NAD83, in feet.

The Flatiron Reservoir bathymetric survey was conducted on May 30, 2012 near water surface elevation 5,471.6 (project vertical datum). The bathymetric survey was conducted using sonic depth recording equipment interfaced with a RTK GPS capable of determining sounding locations within the reservoir. The survey system software continuously recorded reservoir depths and horizontal coordinates as the survey boat moved along visualized grid lines and the shoreline throughout the reservoir. The outlet area below the power plant in the upper reservoir could not be surveyed due to access and safety issues. The topography of this area was projected using original drawings of the topography of the reservoir area assuming no changes had occurred. As the survey vessels traversed the reservoir area, the depths and corresponding positions were recorded on a data logger for subsequent processing. The RTK GPS measurements on the vessel were used to convert the sonic depth measurements to lake-bottom elevations.

Above water geometry throughout much of the reservoir was measured by walking the shoreline, obtaining RTK GPS topographic measurements while the bathymetric data was being collected. When possible water edge measurements were collected while walking the shoreline, but in most cases steep topography and vegetation prevented this. Where the water edge was not accessible, positions and elevations were measured at higher elevations (on the bank above the water surface) and were included as part of the data set for 2012 topography development. RTK GPS measured elevations were tied to NAVD88 (GEOID09), the same vertical datum in which the reservoir topography within this report was developed. The computed surface areas were shifted down 5.54 feet to match the project or construction vertical datum. Final processing of the May 30, 2012 data sets resulted in 10,121 points, Figure 3.

Above Water Data

Aerial Photography

The 2012 study of Flatiron Reservoir focused on the collection of bathymetric or underwater data in areas accessible by the survey vessel. During bathymetric collection process a second person walked as much along the reservoir edge as possible. As seen in Figure 3, there were areas where it was not possible to walk the banks due to steep topography, vegetation along the reservoir shoreline, and time restraints. Acquisition of the best available pre-existing above water data was necessary to complete development of the topographic map. During analysis, orthographic aerial images collected in 2005, 2006, 2009, and 2011 between water surface elevations 5,463.7 and 5,471.4 were downloaded from the USDA data web site (USDA, 2010) and a Reclamation online service (Bureau of Reclamation, 2013). Reservoir contours were developed by digitizing the water's edge from these aerial images and assigning a water surface elevation to each. For data quality assurance the digitized lines were checked for cross over against the May 2012 RTK GPS bathymetry and topographic measurements. The contour developed from the Reclamation's online service aerial photos was assumed to be the best quality to determine the water's edge and was used as a breakline during the map development process where May 2012 data points were not available.

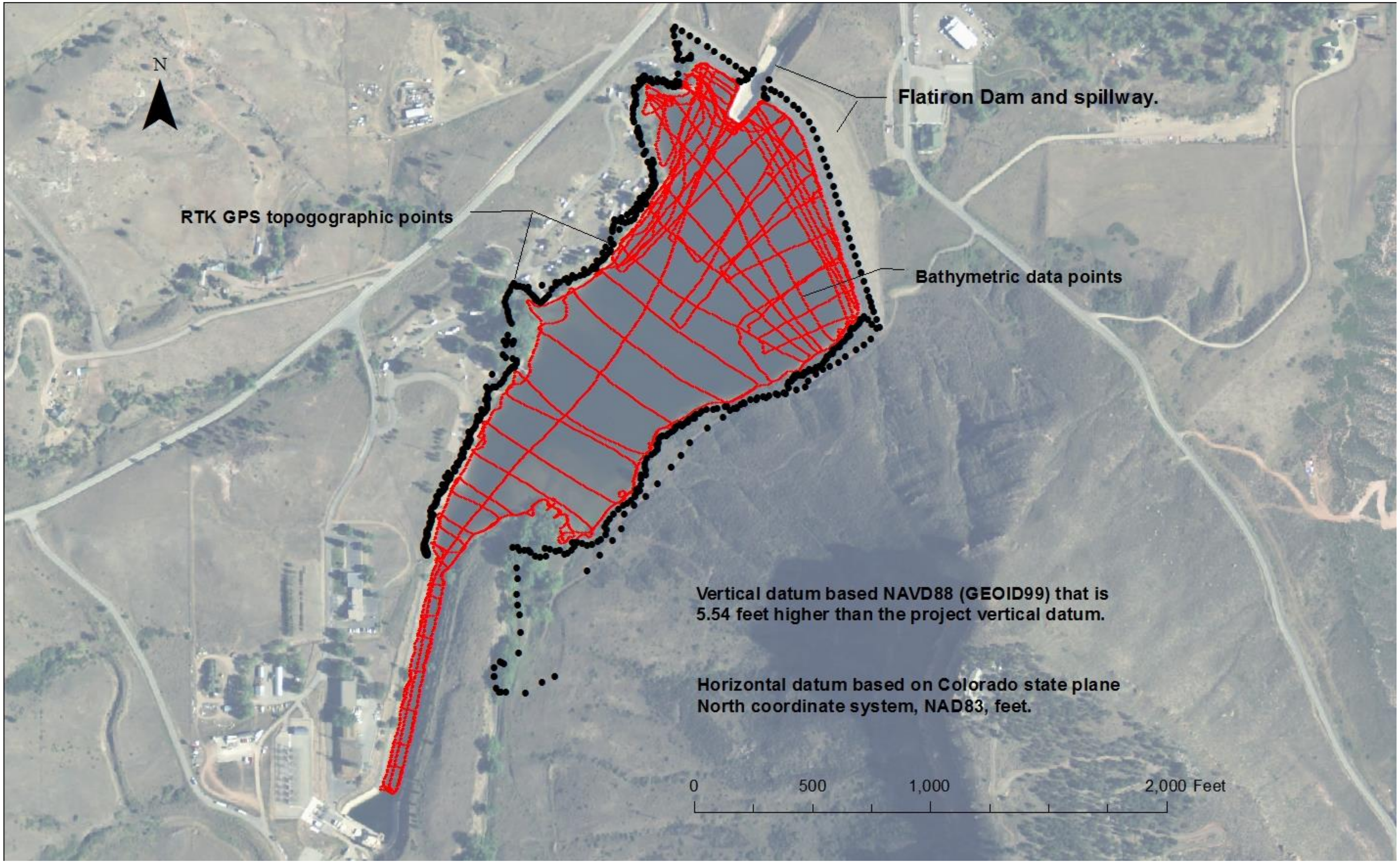

Figure 3 - Flatiron Reservoir, May 2012 data points, NAVD88 (GEOID09).

Aerial IFSAR

As part of this analysis, Interferometric Synthetic Aperture Radar (IFSAR) was obtained as digital bare earth data tied horizontally to NAD83 with elevations tied to NAVD88. IFSAR airborne technology enables mapping of large areas quickly and efficiently, resulting in detailed information at much lower costs than other technologies such as aerial photogrammetry and LiDAR. The data were collected when the reservoir was near elevation 5,478 (NAVD88), providing some overlap to compare with the RTK GPS topographic measurements. There were no areas of overlap between the IFSAR and the 2012 underwater data.

The IFSAR data provided detailed topographic images of the shoreline of the main reservoir body, coves, and area around the dam. The IFSAR reported accuracies are 2-meters horizontally and 1-meter vertically in areas of unobstructed flat ground (Intermap, 2011). In the open areas of the reservoir, with minimal vegetation along the shoreline, the developed contours from the IFSAR data matched well with the USDA digitized contours. In these areas, the elevation differences were at times less than 1 foot, much less than the IFSAR–reported 1-meter vertical accuracy. The reported dam crest was elevation 5,491.5 (NAVD88) and IFSAR point data on top of the dam were at times near this elevation. For areas of dense vegetation and steep slopes, the IFSAR developed contours were sometimes highly erratic and did not match well with the USDA contours. During processing, portions of the IFSAR data overlapped by the 2012 RTK GPS land survey data were removed with the remaining IFSAR data used in the final 2012 topographic development. Figures 4 and 5 show the breaklines used in developing the reservoir contours.

Reservoir Area and Capacity

Topography Development

This section discusses the methods for generating topographic contours of Flatiron Reservoir. The data sources included the 2012 bathymetric data points, RTK GPS above water data points, digitized reservoir water surface edges from USDA and Reclamation aerial photographs, small portions of digitized breaklines projected from the original topography for upper reservoir not accessible during the boat survey, and IFSAR developed breaklines above all of these data sets. Break lines were projected from the 2012 bathymetric data points where they crossed the main channel alignment to form a continuous thalweg from the reservoir inlet towards the dam. These data were processed into a triangulated irregular network (TIN) that was then used to develop 1-foot contours tied vertically to NAVD88 (GEOID09).

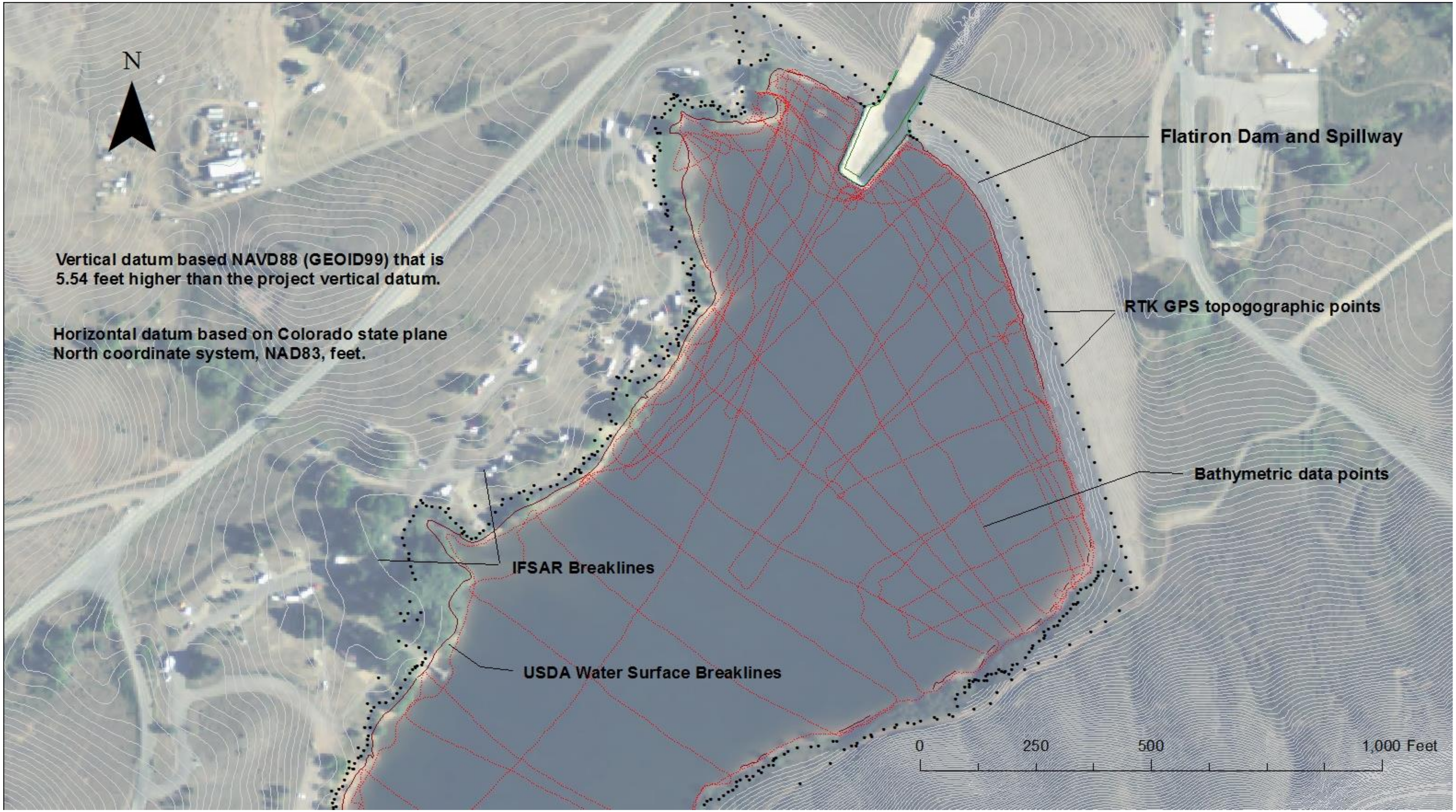

Figure 4 - Flatiron Reservoir, 2012 hydrographic, USDA aerial, and IFSAR data sets (1 of 2).

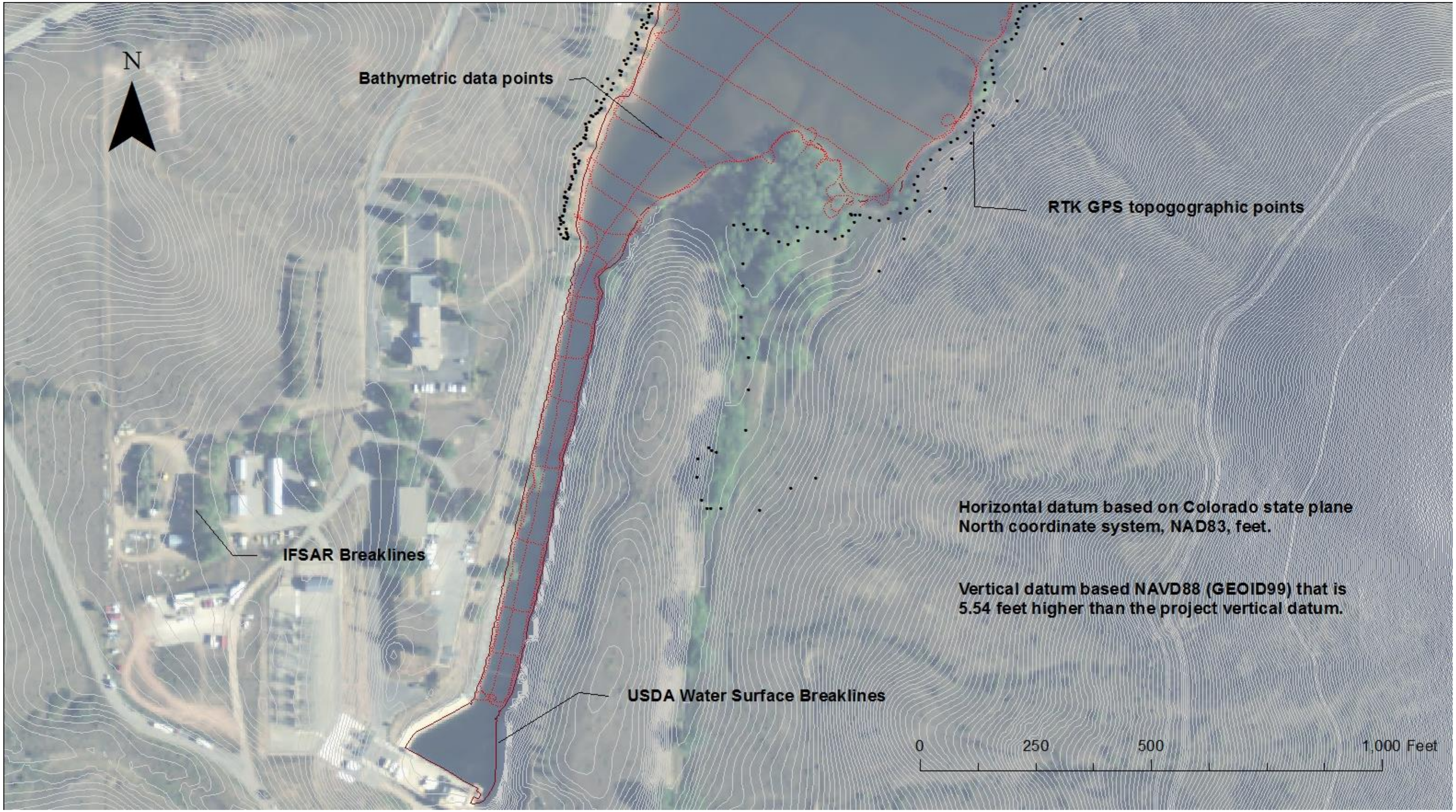

Figure 5 - Flatiron Reservoir 2012 hydrographic, USDA aerial, and IFSAR data sets (2 of 2).

The resulting surface areas and volumes presented in this report are from the developed TIN where the elevations were shifted down 5.54 feet from NAVD88 (GEOID09) to match the project vertical datum for reservoir operation use. In preparation for developing the TIN, a polygon was created to enclose all the data sets of the reservoir. The polygon, not assigned an elevation, was used as a boundary or hardclip during the TIN development to prevent interpolation outside the enclosed polygon. Data outside of the hardclip is labeled "no data" and not used during the TIN development. The polygon was used for the 2012 developed contours, allowing mapping within the reservoir area outlined by the hardclip polygon only. For developing the surface areas of only the reservoir, a hardclip was developed along the alignment of the dam (ESRI, 2011).

Contours for the reservoir from Flatiron Dam upstream 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 Flatiron Reservoir TIN. The surface areas of the enclosed contour polygons at 1-foot increments were computed for elevation 5,430.0 (Project Vertical Datum) and above. The reservoir contour topography at 2-foot intervals is presented on Figures 6 and 7. The ArcGIS software was used to develop contours directly from the TIN using all the enclosed data points presented in this report.

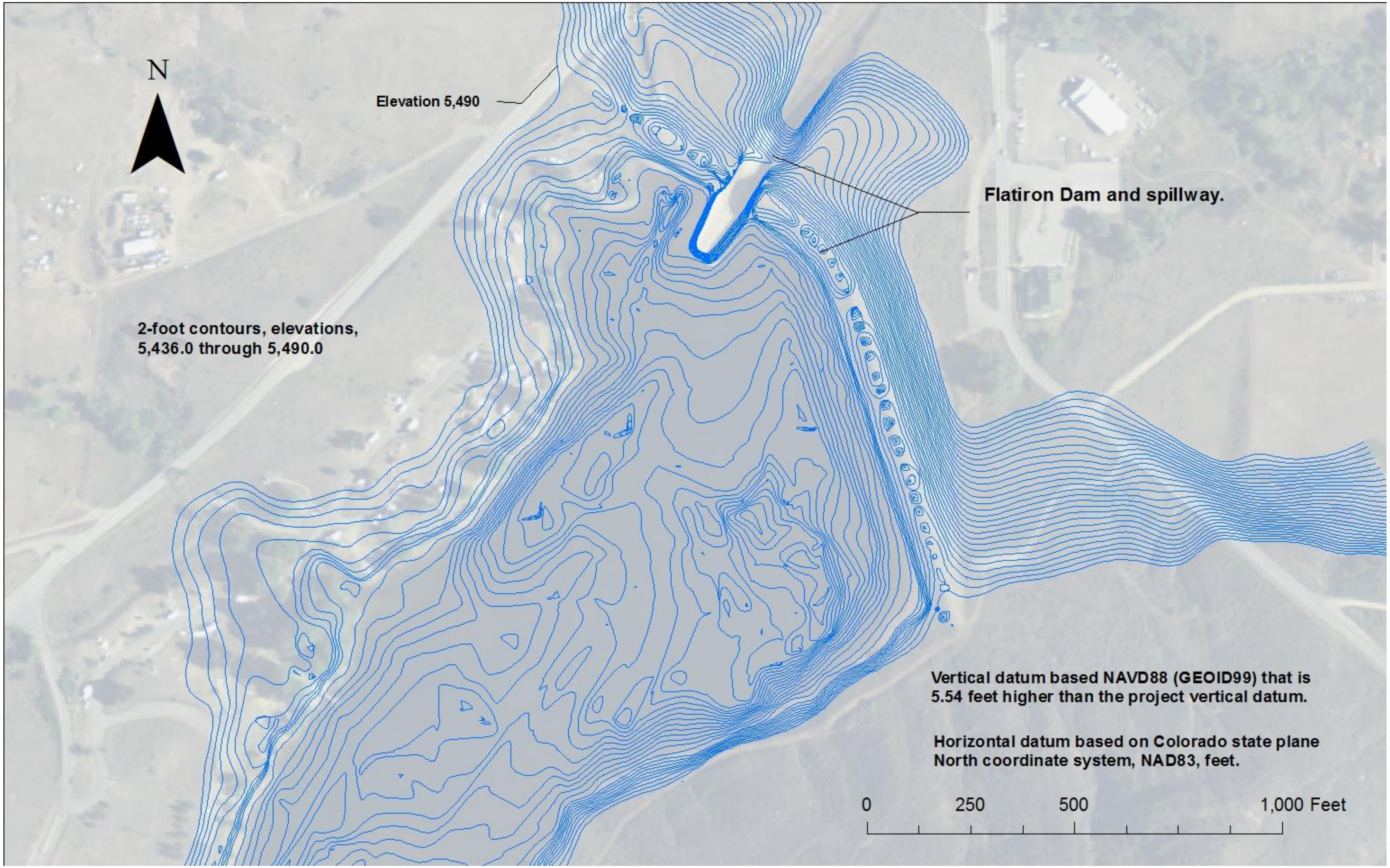

Figure 6 - Flatiron Reservoir topography, NAVD88 - GEOID09, (map 1 of 2).

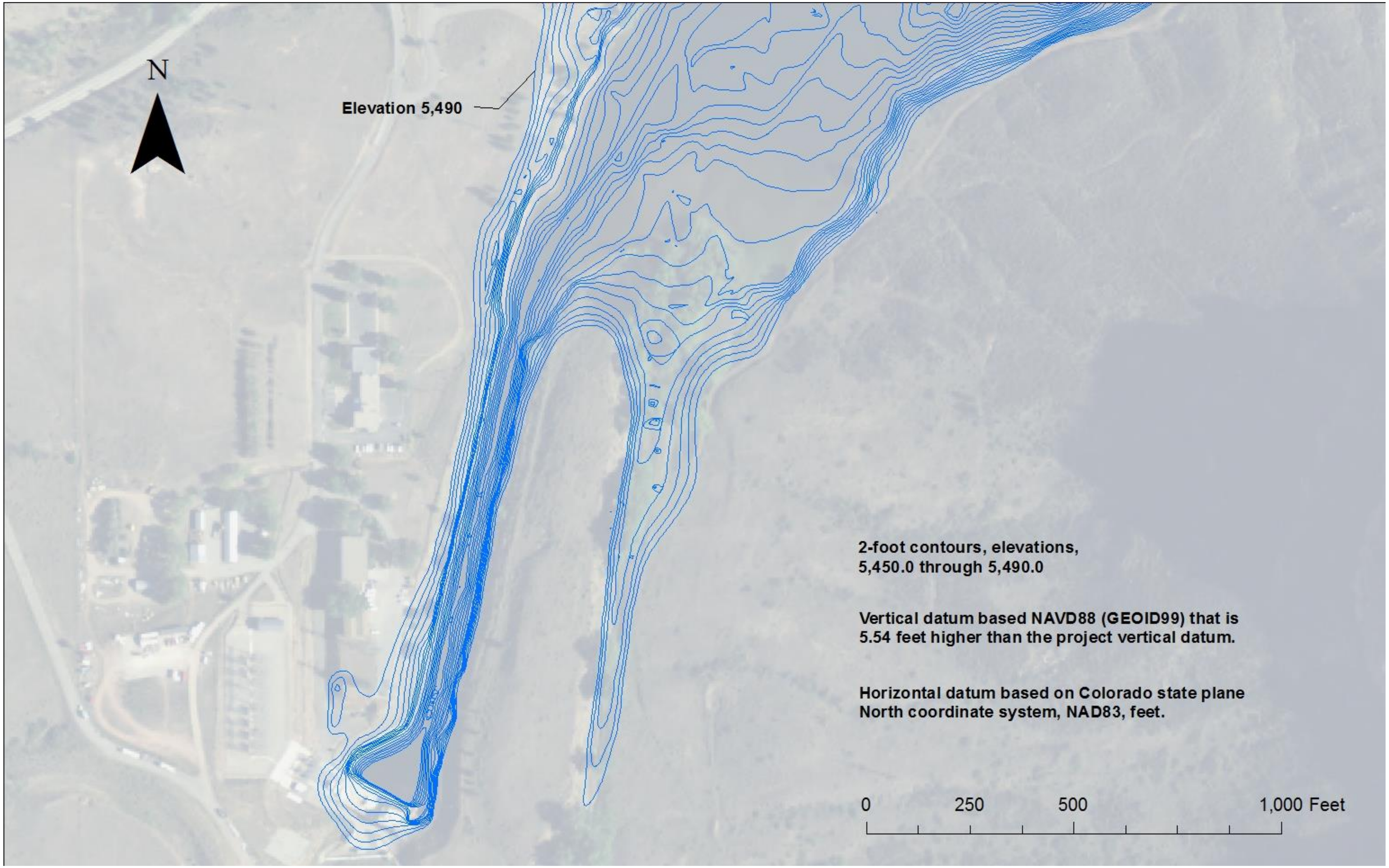

Figure 7 - Flatiron Reservoir topography, NAVD88 – GEOID09, (map 2 of 2).

2012 Flatiron 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. For this study the 2- and 5-foot computed surface areas from elevation 5,429.4 through 5,480.0 were used. The zero surface area was at elevation 5,429.4. The program begins by testing the initial capacity equation over successive intervals to ensure that the equation fits within an allowable error limit that was set at 0.000001 for Flatiron 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 Flatiron Reservoir area and capacity computations are listed in a separate set of 2012 area and capacity tables and have been published for 0.01, 0.1, and 1-foot elevation increments (Bureau of Reclamation, 2012). A description of the computations and coefficients output from the ACAP program is included with those tables. As of May 2012, at conservation use elevation 5,472.8, the surface area was 45.0 acres with a total capacity of 730 acre-feet. At maximum and top of surcharge elevation 5,480.0, the surface area was 57.3 acres with a total capacity of 1,094 acre-feet.

Flatiron Reservoir Surface Area and Capacity Results

This section provides 2012 surface area and capacity results along with volume changes over time for Flatiron Reservoir. Table 1 provides a summary of the changes in Flatiron Reservoir storage between the time of dam closure in January 1954 and the May 2012 topographic survey. The area and capacity curves for the original and 2012 surveys are plotted on Figure 8. Table 2 provides a summary of the original and 2012 surface areas and capacities. The 2012 bathymetric survey and the other data sources summarized in the *Topography Development* section provided adequate information for computing the surface areas from elevation 5,429.4 through 5,480.0. The ACAP program was used to interpolate and compute the area and capacity values between elevations from the surface area inputs.

RESERVOIR SEDIMENT
DATA SUMMARY

Flatiron Reservoir
NAME OF RESERVOIR

1
DATA SHEET NO.

D	1. OWNER: Bureau of Reclamation	2. STREAM: Chimney Hollow/Dry Creeks	3. STATE: Colorado
A	4. SEC 27 TWP. 5 N RANGE 70 W	5. NEAREST P.O. Loveland	6. COUNTY Larimer
M	7. LAT 40 ° 22 ' 25 " LONG 105 ° 13 ' 47 "	8. TOP OF DAM ELEVATION: 5,486.0 [1]	9. SPILLWAY CREST EL. 5,472.8 [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	5,480.0 [3]	57.3	376	1,136	
E	b. FLOOD CONTROL					
S	c. POWER					1/1954
E	d. JOINT USE					16. DATE NORMAL OPERATIONS BEGAN
R	e. CONSERVATION	5,472.8	47.3	436	760	
V	f. INACTIVE	5,462.0	33.3	199	324	
O	g. DEAD	5,454.75	20.3	125	125	1/1954
I R	17. LENGTH OF RESERVOIR 0.7 MILES		AVG. WIDTH OF RESERVOIR 0.1 MILES			

B	18. TOTAL DRAINAGE AREA 7.1 [4] SQUARE MILES	22. MEAN ANNUAL PRECIPITATION 13 [3] INCHES
A	19. NET SEDIMENT CONTRIBUTING AREA [4] SQUARE MILES	23. MEAN ANNUAL RUNOFF [5] INCHES
S	20. LENGTH MILES AVG. WIDTH MILES	24. MEAN ANNUAL RUNOFF [5] ACRE-FEET
I N	21.	25. ANNUAL TEMP, MEAN 50 °F RANGE -39 °F to 114 °F [3]

	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
SURVEY	1/1953			Contour (D)	5-ft	47.3	760 [6]	
	5/12	59	59	Contour (D)	2-ft	45.0 [8]	730 [7]	

	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
DATA	5/12	13.0 [3]	[5]				

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.
5/12	30 [9]	0.5		[9]		

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.
5/12				0.066 [9]	3.95 [9]		

26. DATE OF SURVEY	43. DEPTH DESIGNATION RANGE IN FEET, BY 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 [9]								
YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF		YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF
1986					1987			
1988					1989			
1990					1991			
1992					1993			
1994					1995			
1996					1997			
1998					1999			
2000					2001			
2002					2003	5,471.8	5,462.3	
2004	5,471.8	5,460.1			2005	5,471.9	5,461.3	
2006	5,471.8	5,460.1			2007	5,471.8	5,464.2	
2008	5,471.6	5,462.5			2009	5,471.7	5,462.8	
2010	5,471.8	5,462.7			2011			
2012	5,471.8	5,463.5						

46. ELEVATION - AREA - CAPACITY - DATA FOR **2012**										
ELEVATION	AREA	CAPACITY		ELEVATION	AREA	CAPACITY		ELEVATION	AREA	CAPACITY
2012	**SURVEY**			5,429.4	0.0	0		5,430.0	0.0	0
5,432.0	0.2	0		5,434.0	0.4	1		5,435.0	0.5	1
5,436.0	0.7	2		5,438.0	1.1	4		5,440.0	1.6	6
5,442.0	2.5	10		5,444.0	4.0	17		5,445.0	5.1	21
5,446.0	6.2	27		5,448.0	8.5	41		5,450.0	11.1	61
5,452.0	13.8	86		5,454.0	17.3	116		5,454.75	19.1	130
5,455.0	19.7	135		5,456.0	21.6	156		5,458.0	24.7	202
5,460.0	27.6	254		5,462.0	30.1	312		5,464.0	33.2	375
5,465.0	35.0	409		5,466.0	37.1	445		5,468.0	41.1	524
5,470.0	42.7	608		5,472.0	44.3	695		5,472.8	45.0	730
5,474.0	46.3	785		5,475.0	47.7	832		5,476.0	49.4	881
5,478.0	53.5	983		5,480.0	57.3	1,094				

47. REMARKS AND REFERENCES

[1] Design elevations tied to project vertical datum. 5.54 feet lower than NAVD88.

[2] Uncontrolled concrete crest and concrete lined channel.

[3] Bureau of Reclamation Project Data Book, www.usbr.gov, and SOP for Flatiron Dam and Reservoir, August 2003. Elevations, project datum.

[4] Total drainage area from Reclamation flood studies. Most water supplies from diverted water as part of Colorado - Big Thompson Project.

[5] Majority of inflow from diverted water from Pinewood Reservoir through powerplant operation.

[6] Surface area and capacity values at elevation 5,472.8 computed by ACAP.

[7] 2012 capacities computed by Reclamation's ACAP program. Surface areas from bathymetric survey, RTK GPS topo, and high flight LiDAR.

[8] Capacity loss or difference due to sedimentation and detail of collections.

[9] Maximum and minimum elevations by water year from available BOR web site.

48. AGENCY MAKING SURVEY Bureau of Reclamation

49. AGENCY SUPPLYING DATA Bureau of Reclamation DATE April 2013

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

1	2	3	4	5	6	7	8
					2012		
	Original	Original	2012	2012	Sediment	Percent	Percent
Elevation	Area	Capacity	Area	Capacity	Volume	Computed	Reservoir
Feet	Acres	Ac-Ft	Acres	Ac-Ft	Ac-Ft	Difference	Depth
5,480.00	57.3	1,136	57.3	1,094	41.4	100.0	100.0
5,475.00	50.2	867	47.7	832	34.6	83.6	90.1
5,472.80	47.3	760	45.0	730	29.2	70.6	85.8
5,470.00	43.8	632	42.7	608	24.3	58.8	80.2
5,465.00	37.1	429	35.0	409	20.0	48.2	70.3
5,462.00	33.3	324	30.1	312	11.8	28.5	64.4
5,460.00	30.5	260	27.6	254	5.6	13.6	60.4
5,455.00	21.0	130	19.7	135	-4.9	-11.9	50.5
5,454.75	20.5	125	19.1	130	-5.3	-12.8	50.0
5,450.00	11.9	51	11.1	61	-10.4	-25.0	40.7
5,445.00	4.8	9	5.1	21	-11.9	-28.7	30.8
5,440.00	0.0	0	1.6	6	-6.2	-14.9	20.9
5,435.00	0.0	0	0.5	1	-1.1	-2.7	11.0
5,430.00	0.0	0	0.0	0	0.0	0.0	1.1
5,429.45	0.0	0	0.0	0	0.0	0.0	0.0
1	Reservoir water surface elevations tied to project datum that is 5.54 feet lower than NAVD88.						
2	Original reservoir surface area.						
3	Original reservoir capacity recomputed using ACAP.						
4	2012 measured reservoir surface area.						
5	2012 reservoir capacity computed using ACAP.						
6	2012 measured change in volume, column (3) - column (5).						
7	Percent of total sediment, 41.4 acre-feet at elevation 5,480.0.						
8	Reservoir depth expressed in percentage total depth, 50.55 feet.						

Table 2 - Flatiron Reservoir 2012 survey summary.

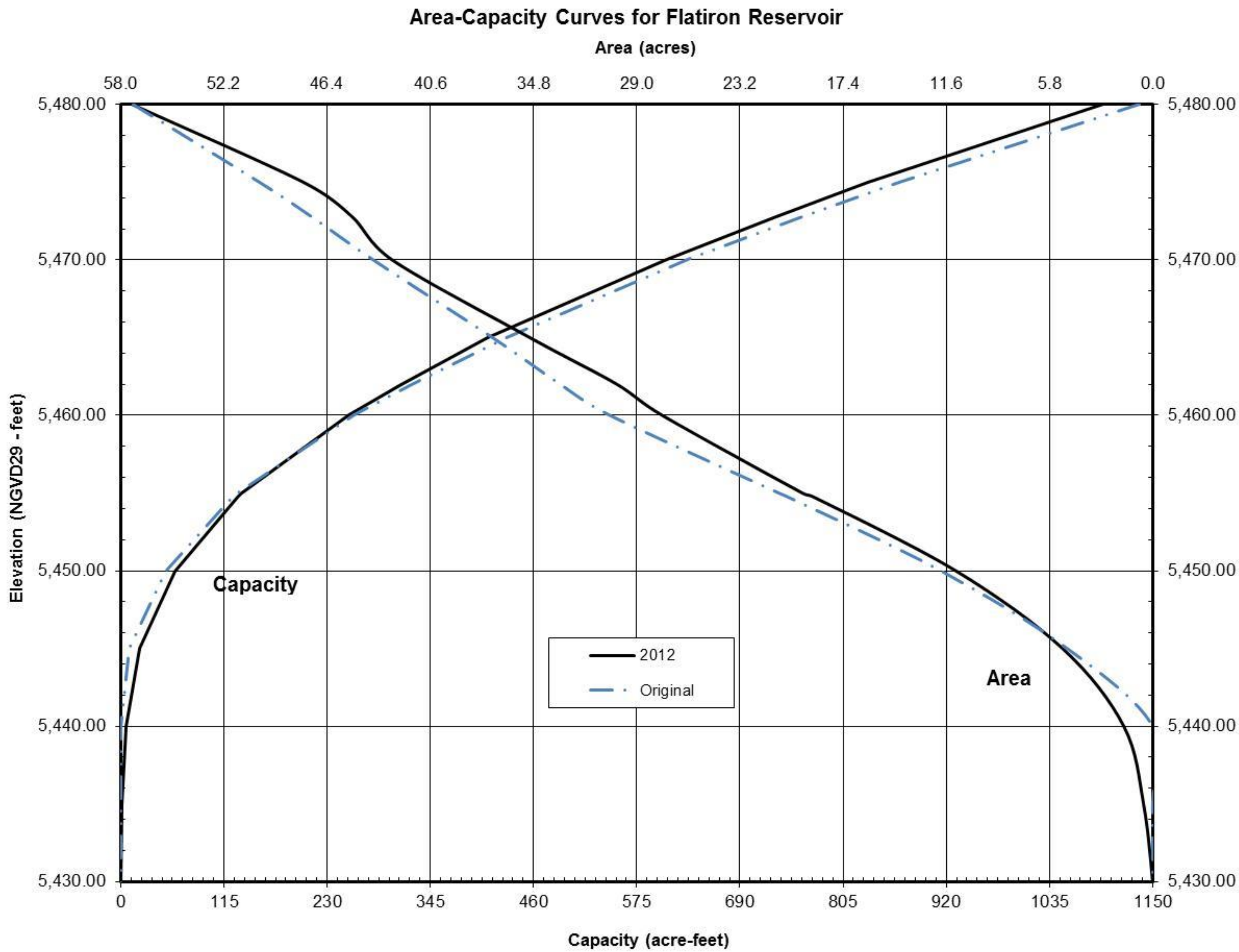

Figure 8 - Flatiron Reservoir area and capacity plots.

2012 Flatiron Reservoir Analyses

Results of the 2012 Flatiron Reservoir area and capacity computations are listed in Table 1 and columns 4 and 5 of Table 2. Columns 2 and 3 in Table 2 list the original area and capacity values recomputed using the ACAP program. Figure 8 is a plot of the Flatiron Reservoir surface area and capacity values for the surveys and illustrates the differences in surface area and storage. Table 1 shows the conservation use capacity at elevation 5,472.8 for both surveys along with the computed differences due to sediment deposition and methods of collection. Table 2 compares results from the original and 2012 surveys along with computation differences from maximum water surface elevation 5,480.0 and below. The 2012 measured surface area at elevation 5,480.0 was 57.3 acres, matching the original area at the same elevation. The 2012 survey measured a gain in surface area and resulting volumes compared to the original survey at elevation 5,445.0 and below. It is assumed that the original survey did not map below elevation 5,445.0 possibly due to stream flow at time of survey or changes in these lower elevation zones during construction of the facilities.

At conservation water surface elevation 5,472.8 the computed total change in reservoir volume was 29.2 acre-feet between 1954 and 2012. It is assumed the measured change is due to sediment accumulation occurring during the years of reservoir operation and methods of collection.

Summary and Conclusions

This Reclamation report presents the results of the May 2012 survey of Flatiron Reservoir. The primary objectives of the survey were to gather data needed to:

- develop reservoir topography; and
- compute area-capacity relationships.

A control survey was conducted using the online positioning user service (OPUS) and RTK GPS to confirm the horizontal and vertical control network near the reservoir for the hydrographic survey. OPUS is operated by the NGS and allows users to submit GPS data files that are processed with known point data to determine positions relative to the national control network. The GPS base was set over an aluminum cap on a ½ inch rebar, stamped “SRH-May 2012”, and located where it provided continuous radio link throughout the hydrographic survey.

The study's horizontal control was in feet, Colorado state plane coordinates, north zone, in NAD83. The vertical control, in US survey feet, was tied to the project's vertical datum that is about 5.54 feet lower than NAVD88 (GEOID09). Unless noted, all elevations in this report are referenced to the project vertical datum. The developed reservoir topography presented in this report is tied to NAVD88 (GEOID09).

The May 2012 underwater survey was conducted near reservoir elevation 5,471.6 as measured by the Reclamation gage at the dam and confirmed by RTK GPS measurements. The bathymetric survey used sonic depth recording equipment interfaced with a RTK GPS for determining sounding locations within the reservoir. The system continuously recorded depth and horizontal coordinates as the survey boat navigated along visual grid lines and the shoreline covering Flatiron Reservoir.

The above-water 2012 topography was from several sources such as RTK GPS measured topographic points, digitized water surface edges of orthographic aerial images of the reservoir (USDA, 2010 and Reclamation, 2013), and airborne digital data obtained as IFSAR bare-earth information for the reservoir area (Intermap, 2011). IFSAR technology enables mapping of large areas quickly and efficiently, resulting in detailed information at a much reduced cost compared to other technologies such as aerial photogrammetry and LiDAR. The reported accuracies for the IFSAR data are 2-meters or better horizontally and 1-meter or better vertically in unobstructed flat-ground areas. Other technologies would produce more accurate data than IFSAR, but this study did not have funding to acquire these other data sets. In the open, above-water areas of the reservoir, the IFSAR data points matched well with known elevation information and were retained for this analysis. In areas with dense vegetation around the reservoir, the IFSAR data did not match well and was removed from those areas for this analysis. The remaining IFSAR data points along with the other data sources were used to develop the 2012 Flatiron Reservoir topography. For the reservoir areas where the IFSAR data was removed, the topographic mapping software interpolated contours from the surrounding data sources.

The final 2012 Flatiron Reservoir topographic map is a combination of the digitized water surface edge from the USDA and Reclamation aerial photographs, IFSAR data, and the 2012 hydrographic survey data, all tied vertically to NAVD88 (GEOID09). A computer program was used to generate the 2012 topography and resulting reservoir surface areas at predetermined contour intervals from the combined reservoir data from elevation 5,480.0 and below. The 2012 surface area at elevation 5,480.0 was 57.3 acres that match the original surface area at the same elevation. The input from the 2012 surface areas was from elevation 5,480.0 and below. The 2012 area and capacity tables were produced using the computer program (ACAP) that calculated area and capacity values at prescribed elevation increments using the measured contour surface areas and a curve-fitting technique that interpolated values between the input elevation surface areas.

Tables 1 and 2 contain summaries of the Flatiron Reservoir and watershed characteristics for the 2012 survey. The 2012 survey determined the reservoir has a total storage capacity of 1,094 acre-feet with a surface area of 57.3 acres at maximum reservoir water surface elevation 5,480.0. At conservation water surface elevation 5,472.8 the total capacity was 730 acre-feet with a surface area of 45.0 acres. Since closure of Flatiron Dam in January 1954, this survey measured a 29.2 acre-foot loss in reservoir capacity below elevation 5,472.8. The 2012 losses were computed by comparing the original and 2012 capacities for the reservoir. It is assumed the measured loss was primarily due to sediment deposition, with some variation due to data accuracy differences between methods of collection and analysis. The 2012 survey measured a gain in surface area and resulting volumes from the original survey at elevation 5,445.0 and below. It is assumed that the original survey didn’t capture these areas due to possible flows at time of survey and possible changes in these zones during construction of the facilities.

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