RECLAMATION

Managing Water in the West

Technical Report No. SRH-2009-36

Clear Lake
2007 Hydrographic Survey

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

September 2009

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Clear Lake
2007 Hydrographic 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

September 2009

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Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

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 Clear Lake in May 2007 to develop updated reservoir topography and compute the present storage-elevation relationships. The underwater survey was conducted near water surface elevation 4,528.5 feet (project datum) or 4,472.0 feet in North American Vertical Datum of 1988 (NAVD88). The underwater survey 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 total reservoir topography was determined by importing digital contour data from a regional aerial survey conducted on October 24, 2005 near water surface elevation 4,522 (project datum) or 4,465.5 feet (NAVD88). The developed topography elevations presented in this report are tied to NAVD88. The computed area and capacity information presented in this report is tied to the project vertical datum, measured during the 2007 survey as 56.5 feet greater than NAVD88.

As of May 2007, at reservoir water surface elevation 4,543.0 feet (spillway crest), the surface area was 25,344 acres with a total capacity of 507,252 acre-feet.

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Clear Lake
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Introduction

Clear Lake Dam and reservoir, located on the Lost River in Modoc County, California, is 39 miles southeast of Klamath Falls, Oregon, Figures 1 and 2. Clear Lake, part of the Klamath Project, provides irrigation storage, reduced flows into the reclaimed portion of Tule Lake, and flood control benefits to the towns of Tule Lake, Marline, Olene, and Merrill, Oregon. The reservoir, part of a National Wildlife Refuge, provides habitat for the endangered Lost River and Short Nose Suckers along with nesting areas for such birds as the California White Pelican, Figure 3. Clear Lake was a natural lake that was enlarged by the dam and occupies a flat alluvial basin in a barren volcanic terrain. The total drainage area above Clear Lake is 735 square miles.

Figure 1 - Bureau of Reclamation reservoirs in Northern California.

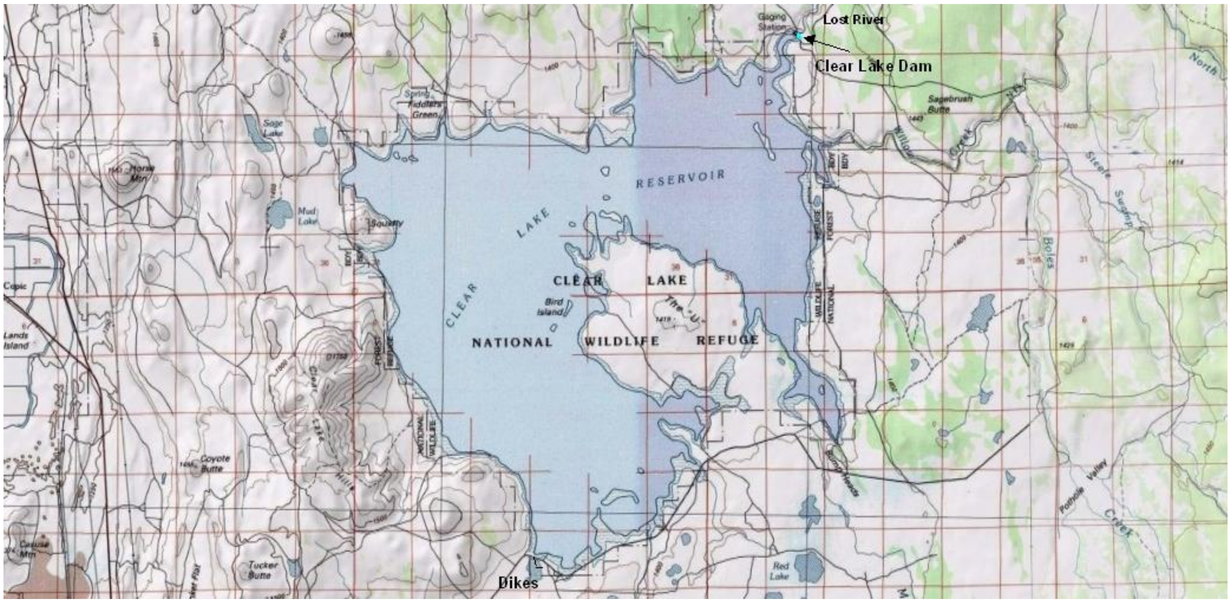

Figure 2 - Clear Lake Reservoir

Figure 3 - California White Pelicans on an island formed by Clear Lake, May 2007.

The original dam, completed in 1910, was an earthen structure. Due to deterioration, the original dam was replaced in 2002 by a concrete dam near the old alignment. The new dam has a crest elevation of 4,544.0 feet[1], a four foot parapet wall with top elevation 4,548.0, and a spillway with a crest elevation of 4,543.0. There is a small hydroelectric plant at the dam with a capacity of three megawatts. The dam is owned by Reclamation and operated by the Langell Valley Irrigation District.

The reservoir content is impounded by the dam on the north end and two earth-core, rip-rap protected dikes located in the shallow saddles at the south end of the reservoir. A 2005 aerial survey indicates the two interconnected dikes contain the reservoir body from water surface elevation 4536.5 up to the top of parapet wall elevation, 4,548.0 (Figure 4). The main dike was constructed in the late 1930's and runs east-west. The south dike runs in a northwest-southeast direction and was constructed in 1974.

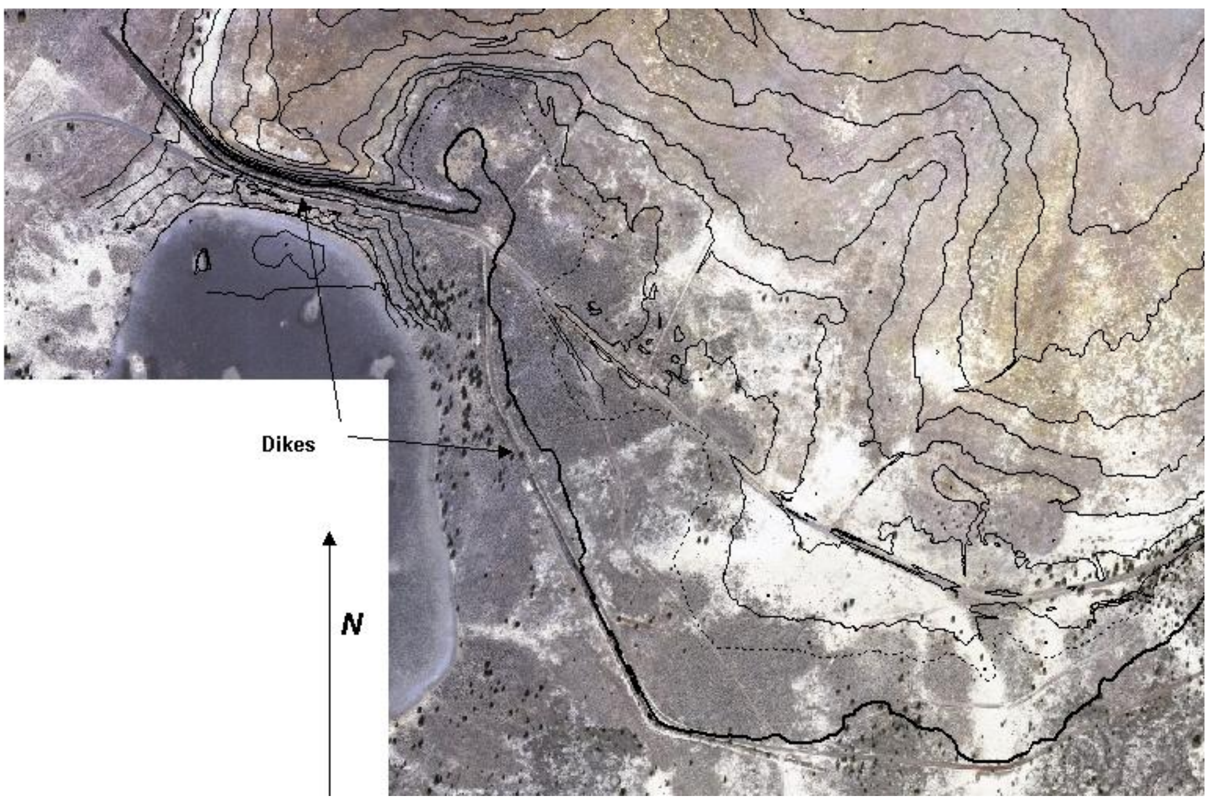

Figure 4 - Clear Lake Dikes.

[1]Elevations are shown in feet. Unless noted, all elevations in this report are based on the original project datum established by Reclamation that is around 60.1 feet higher than the National Geodetic Vertical Datum of 1929 (NGVD29) and 56.5 feet higher than the North American Vertical Datum of 1988 (NAVD88).

Summary and Conclusions

This Reclamation report presents the results of the 2007 survey of Clear Lake with the primary objectives to develop current reservoir topography and area-capacity relationships. The bathymetric survey was conducted using 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 system continuously recorded depth and horizontal coordinates of the survey boat as it navigated along previously established sediment range lines. The positioning system provided information that allowed the boat operator to maintain a course along these grid lines. Data were also collected as the boat traversed along the shoreline between profile lines. Water surface elevations recorded by a Reclamation gage during the time of collection were used to convert the sonic depth measurements to reservoir bottom elevations on the project datum. During collection, the water surface was also recorded using the RTK GPS collection system. The above water topography was developed by a regional aerial survey conducted on October 24, 2005 near water surface elevation 4,522.0.

Tables 1 and 2 contain the summary of the 2007 Clear Lake survey results. The 2007 survey determined that the reservoir had a total storage capacity of 507,252 acre-feet and a surface area of 25,344 acres at reservoir spillway crest elevation 4,543.0. The 2007 area and capacity tables were produced by a computer program that uses measured contour surface areas and a curve-fitting technique to compute the area and capacity at prescribed elevation increments (Bureau of Reclamation, 1985). The Clear Lake area and capacity tables, at elevation increments 0.1 feet, are presented in the appendix.

Control Survey Data Information

During the 2007 bathymetric survey no known datum points, tied to 2005 aerial control network, were located near the reservoir. A control survey was conducted for the bathymetric survey using the on-line positioning user service (OPUS) and RTK GPS measurements to establish a horizontal and vertical control network near the reservoir. OPUS is operated by the National Geodetic Survey (NGS) and allows users to submit raw GPS data files that are processed with known point data to determine positions relative to the national control network. A GPS base was set over two bench marks established for the bathymetric survey with one located near the dam on the north bank and another located on the west bank of the reservoir, Figure 5. The coordinates for these points were computed using OPUS, and from these base locations additional features were measured including daily water surfaces, road alignment over the dam, and a Reclamation monument located near the dam with a published project elevation of 4,549.14. The OPUS processed coordinates measured at this location were:

California Zone 1, NAD83, NAVD88 (feet)

North	2,586,444.528
East	6,812,931.054
Elevation	4,492.661

The horizontal control was established in California state plane coordinates, zone 1, on the North American Datum of 1983 (NAD83). The vertical control for the established points was tied to NAVD88. RTK GPS water surface measurements were periodically collected and a comparison to the reservoir water surface recorded by the Reclamation gage found the NAVD88 vertical elevation measurements were around 56.5 feet lower than the recorded project elevations. The same vertical difference was found when comparing the RTK GPS measured elevation on the Reclamation bench mark. NGS published data in the study area shows the NAVD88 elevations are around 3.5 feet higher than NGVD29.

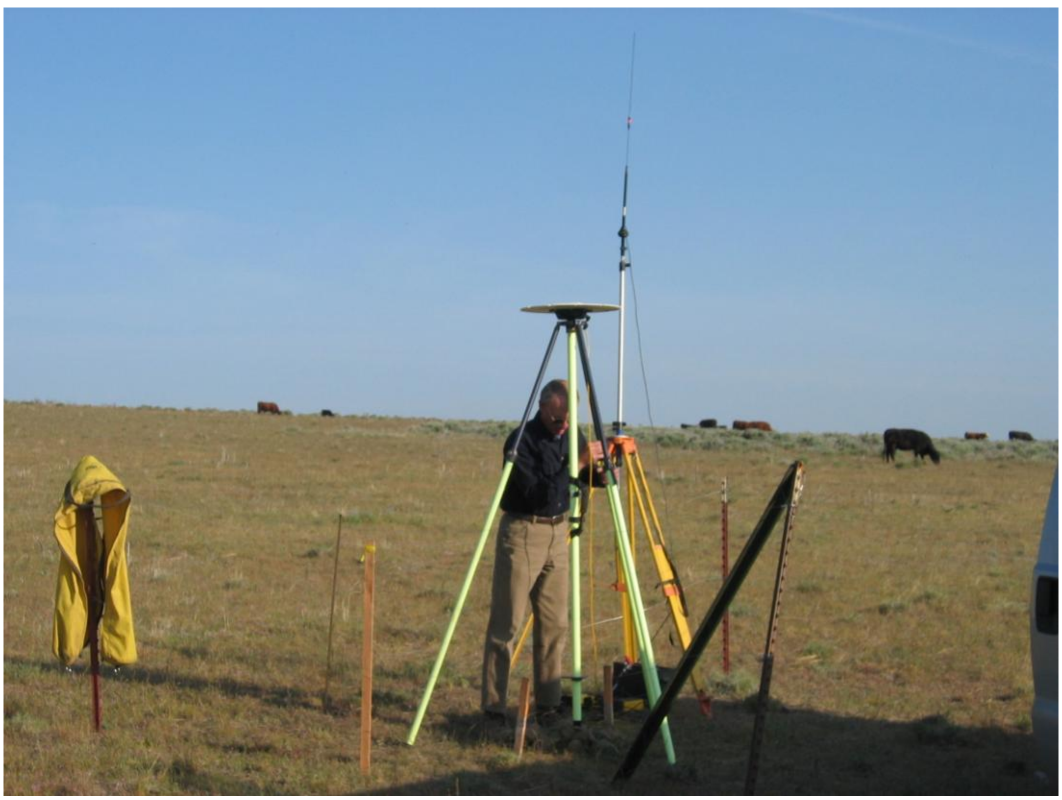

Figure 5 - BOR benchmark established for the 2007 bathymetric survey, east bank.

Hydrographic Survey Equipment and Method

The hydrographic survey equipment was mounted on a small, flat bottom, open, aluminum vessel equipped with an outboard motor, Figures 6 and 7. Originally it was proposed to use the Sedimentation Group's larger survey vessel in October 2006, but the low lake levels that persisted through May 2007 raised concerns about launching the vessel and getting it back on the trailer. The hydrographic system included a GPS receiver with a built-in radio, a depth sounder, a helmsman display for navigation, a laptop computer, hydrographic system software for collecting the underwater data, and 12-volt battery that powered the equipment. 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 the known datum points. A 12-volt battery provided the power for the shore unit.

The Sedimentation Group uses RTK GPS with the major benefit being 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 California's state plane

Figure 6 - Survey vessel with mounted instrumentation used for the Clear Lake survey.

Figure 7 - Bathymetric instrumentation used for the 2007 survey.

coordinates, zone 1, in NAD83. The RTK GPS system employs two receivers that track the same satellites simultaneously just like with differential GPS.

The Clear Lake bathymetric survey was conducted in 2007 from May 3 through May 17 between water surface elevations 4,528.3 and 4,528.5 (project datum). During post processing, the bathymetric depths were converted to bottom elevations in NAVD88 by shifting the Reclamation measured water surface gage elevations by 56.5 feet, then subtracting the depths from the shifted elevations. 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 navigated along the range lines and also while the boat traveled between range lines. A low water contour developed from the aerial survey, elevation 4,522.5, was used to determine the boundary for bathymetric data collection and once the boat crossed that contour, it was maneuvered to the next survey line while continuously collecting data. The survey vessel's guidance system provided directions to the boat operator to assist in maintaining the course along these predetermined lines. A layout of the survey vessels collection path is shown on Figure 8.

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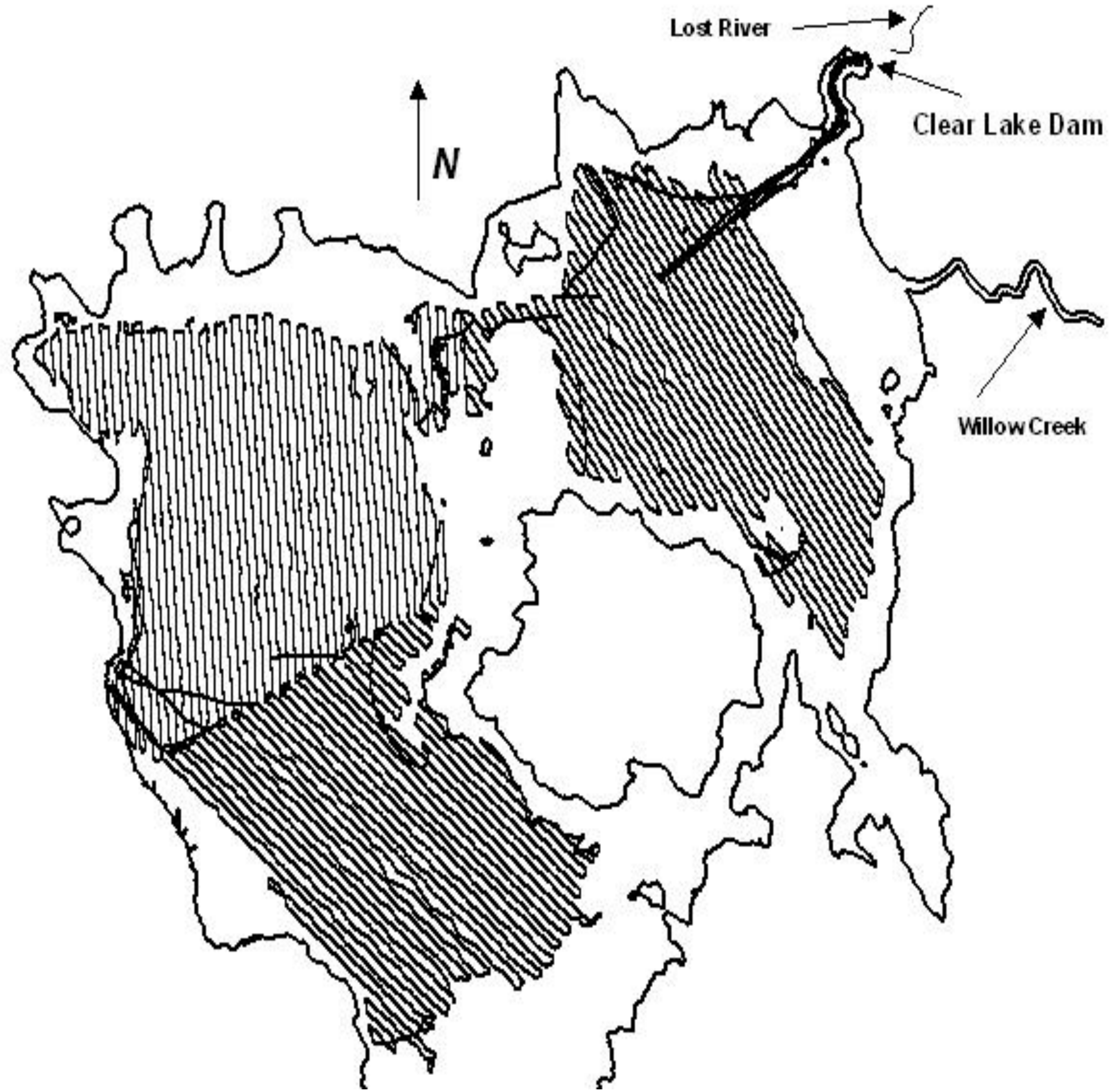

Figure 8 - Clear Lake Bathymetric Data Points, May 2007.

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The underwater data was collected by a depth sounder calibrated using a survey rod that measured the water depth below the transducer at different locations and times during the survey period. The sounder's digital depths were matched to the rod readings by adjusting the speed of sound through the water column, which can vary with density, salinity, temperature, turbidity, and other conditions. There were different locations on the reservoir, such as the deeper, western reservoir areas, where the survey rod could be pushed into the soft reservoir bottom from one-half to over one foot. These areas were located in the deepest portions of the reservoir where the "natural" lake existed prior to the dam. For calibration of the sounder, the depth used was where the survey rod settled on the reservoir bottom using little pressure to hold it in place. The collected data were digitally transmitted to the computer collection system through a RS-232 port. The depth sounder also produced an analog hard-copy chart of the measured depths. These graphed analog charts were analyzed during post processing, and when the analog charted depths indicated a difference from the computer recorded bottom depths, the computer data files were modified. Additional information on collection and analysis procedures are outlined in Chapter 9 of the *Erosion and Sedimentation Manual* (Ferrari and Collins, 2006).

The upper portion of the reservoir, not covered by the 2007 boat survey, was developed from an aerial survey conducted on October 24, 2005 near reservoir water surface elevation 4,466 (NAVD88), project elevation 4,522.5. As previously stated, this study developed the reservoir topography with the vertical elevations tied to NAVD88. The aerial data was tied to NAVD88 and having the same vertical datum for the aerial and bathymetric data allows it to be more easily distributed and used by others. During post processing, the developed area and capacity information presented in this report was tied to the Reclamation vertical datum by shifting the NAVD88 topographic data upward by 56.5 feet. The horizontal network is in California, zone 1, NAD83.

2007 Topography Development

The topography of Clear Lake was developed from the 2005 aerial data and the 2007 bathymetric survey data sets. All elevations presented on the following drawings are tied to NAVD88, which is 56.5 feet lower than the Clear Lake project datum. This means the top of the dam is 4,544.0 feet in project elevation and 4,487.5 feet in NAVD88 elevation.

The detailed aerial reservoir data layers were provided in digital format by Reclamation's Mid-Pacific Regional Office. The digital aerial data included the smooth contours, the developed breaklines, and point data that were used to develop the reservoir information for this study. The aerial data extended beyond the maximum height of the reservoir (elevation 4,548.0 - top of the parapet wall) and the size of these aerial data files was reduced by removing data points above elevation 4,520 (NAVD88) to make them more manageable. This point filtering, allowed development of a single Triangulated Irregular Network (TIN) over the entire reservoir to compute surface areas, volumes, and contours.

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. The TIN software 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, 2009).

The first TIN was developed using the aerial data sets as listed above along with the bathymetric data sets. From this TIN, one foot contours were developed starting at elevation 4,454.0 and extending beyond elevation 4,600.0 (NAVD88). These contours extended outside the reservoir area going downstream of the dam and dikes that enclose the water body. To force contour development only within the reservoir area, a hardclip contour was selected that ran around the entire reservoir and along the dam and dike alignment. Contour elevation 4,493.0 (NAVD88) was selected as the hard boundary for the 2007 developed contours, surface areas, and volumes. This boundary allowed mapping within the reservoir area as outlined by the hardclip polygon. Figures 9 and 10 are illustrations of the developed TIN of the reservoir.

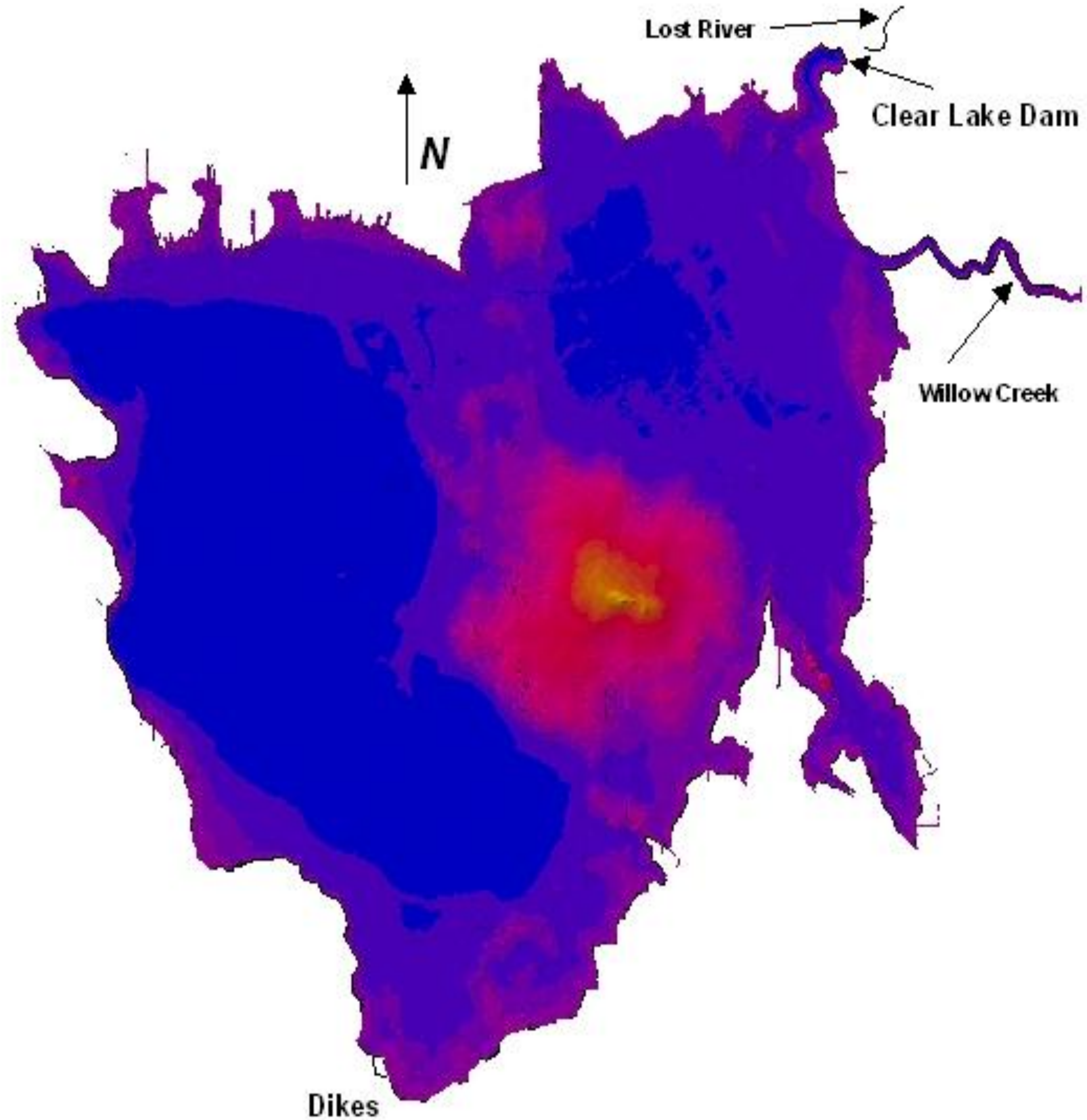

Figure 9 - Clear Lake fully developed TIN.

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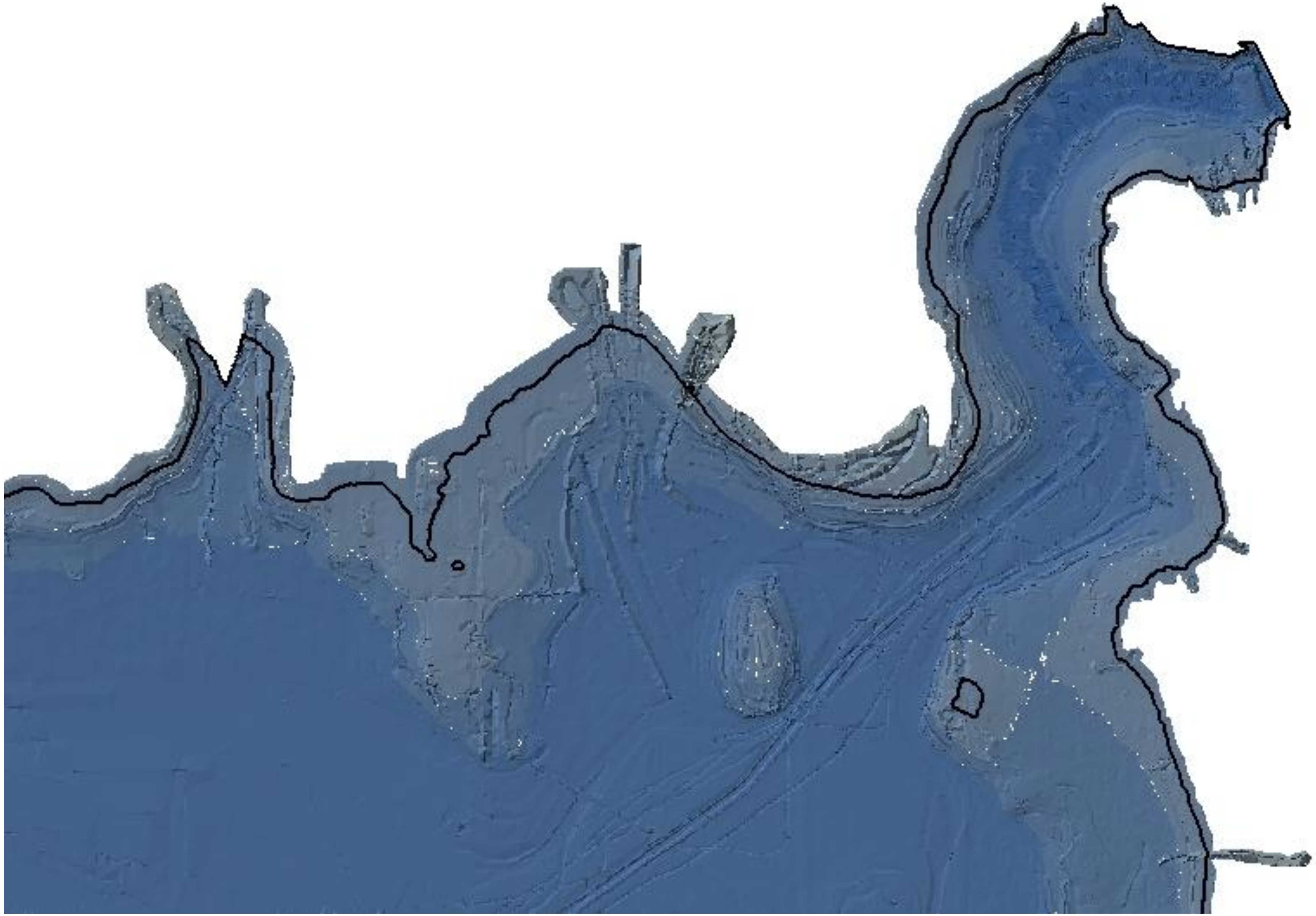

Figure 10 - Clear Lake TIN of the dam area. Dark outside line is top of parapet wall, elevation 4,491.5 (NAVD88).

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The linear interpolation option of the ARCGIS TIN and CONTOUR commands was used to interpolate contours from the Clear Lake TIN. The contours were developed from the TIN at one- and two-foot increments from elevations 4,454.0 through 4,492.0 (NAVD88) and are presented in Figures 11 through 15. ARCGIS develops contours directly from the TIN using all the enclosed data points, resulting in a jagged representation of some contours for this study. The jagged contours appear mainly in the deeper flatter portions of the reservoir mapped during the bathymetric survey. During the 2007 survey, bathymetric data was collected primarily along cross sections, resulting in extremely jagged developed contours in the flatter areas of the reservoir as ARCMAP used all the data points which were of similar elevation. For presentation purposes, the contour lines were smoothed by removing the individual contour polygons containing minimal areas and using the smooth line option within ARCMAP. Additional hand editing was also completed for the lower bathymetric developed contours from elevation 4,455.0 through 4,465.0 (NAVD88). When using the extreme settings of the smooth line method, within ARCMAP, the contours tended to cross. Due to the crossing contours, extensive manually editing was used to develop the final contours presented on the maps in this report. The smoothing processes did not affect the reported surface areas of the topography since the surface areas were computed directly from the TIN using all the data points.

Figures 11 through 15 present the developed 1 and 2-foot contours with the elevations tied to NAVD88. The horizontal control is in California zone 1 state plane coordinates in NAD83. For presentation purposes the smooth aerial developed contours at 2-foot increments from elevation 4,466.0 through 4,486.0 (NAVD88) are illustrated. The dash line is elevation 4,487.5 (NAVD88) which represents the dam crest developed contour, project elevation 4,544.0. The upper solid line is elevation 4,491.5 (NAVD88) which represents the top of parapet wall, project elevation 4,548.0. To show the details through the narrows along with the two large water bodies in the east and west side of the reservoir, one-foot contours were developed and plotted from elevation 4,466.0 and below.

The developed contours show for the east large reservoir body, near the dam, the deepest pool elevation is around elevation 4,464.0 (NAVD88), project elevation 4,420.5. The deepest pool elevation of the west large reservoir body is around elevation 4,458.0 (NAVD88), project elevation 4,514.5. A “natural” lake existed in the west reservoir area prior to dam construction. Through the narrows that connects the two water bodies, there are some deep smaller pools developed from the 2007 bathymetric data. It appears at reservoir elevation 4,465.0 (NAVD88), project elevation 4,521.5, there is a continuous connection between the two large water bodies. Figure 16 is an aerial photo of the narrows reach that was taken in October 2005 near project elevation 4,522. The photo illustrates that there was a connection between the two water bodies at elevation 4,522, but the murky water in the middle indicates that it may not be very deep. Since the 2007 bathymetric survey did not obtain a continuous thalweg through the narrow reach, additional data would need to be collected to verify the minimum reservoir elevation that allows flow between the east and west water bodies.

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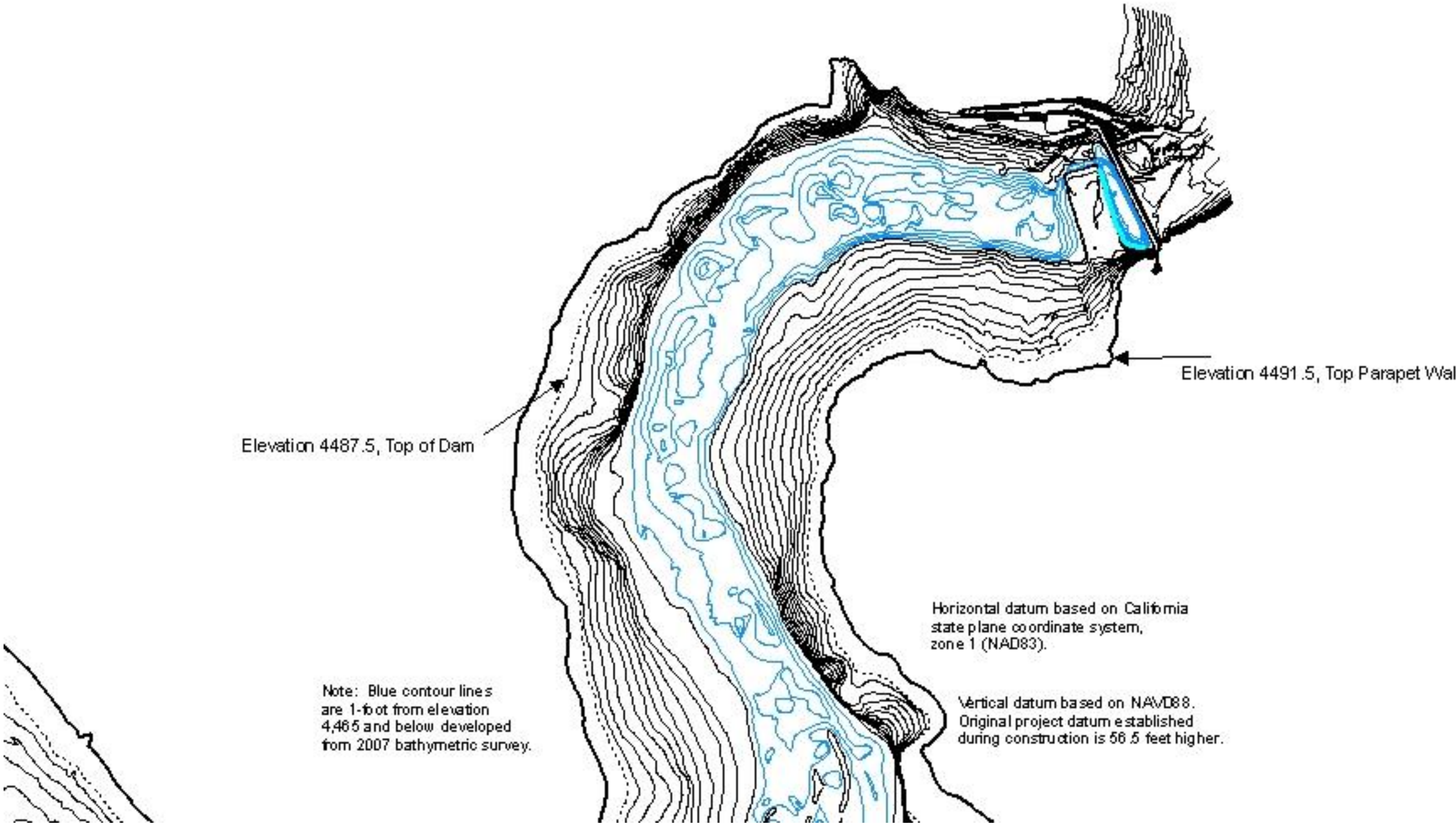

Figure 11 – Clear Lake contours at the dam, all elevations in NAVD88. Outside boundary elevation 4491.5, top of parapet wall. Dash line, top of dam elevation 4487.5. Contours presented at 1 and 2-foot increments.

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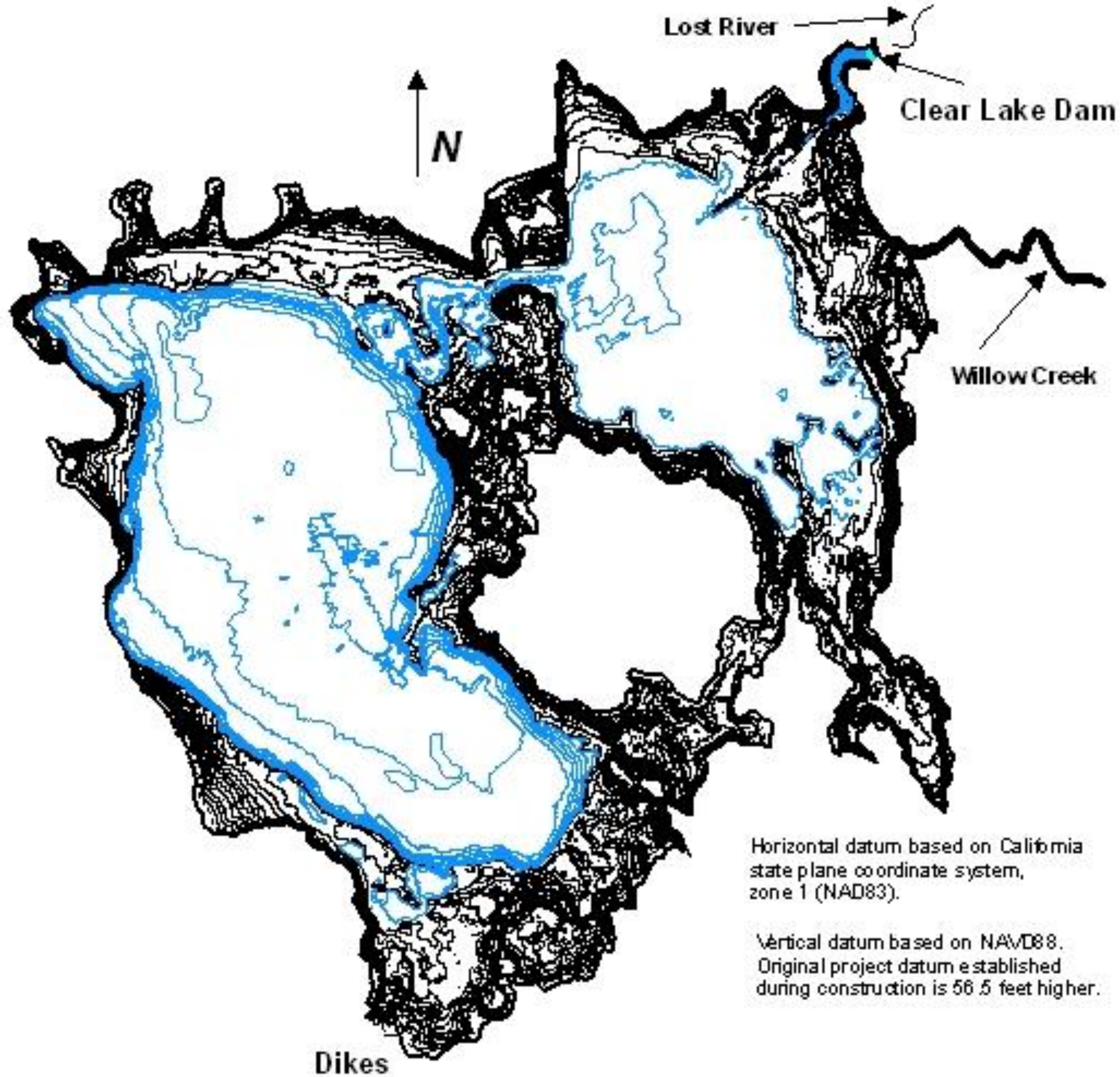

Figure 12 – Clear Lake contours.

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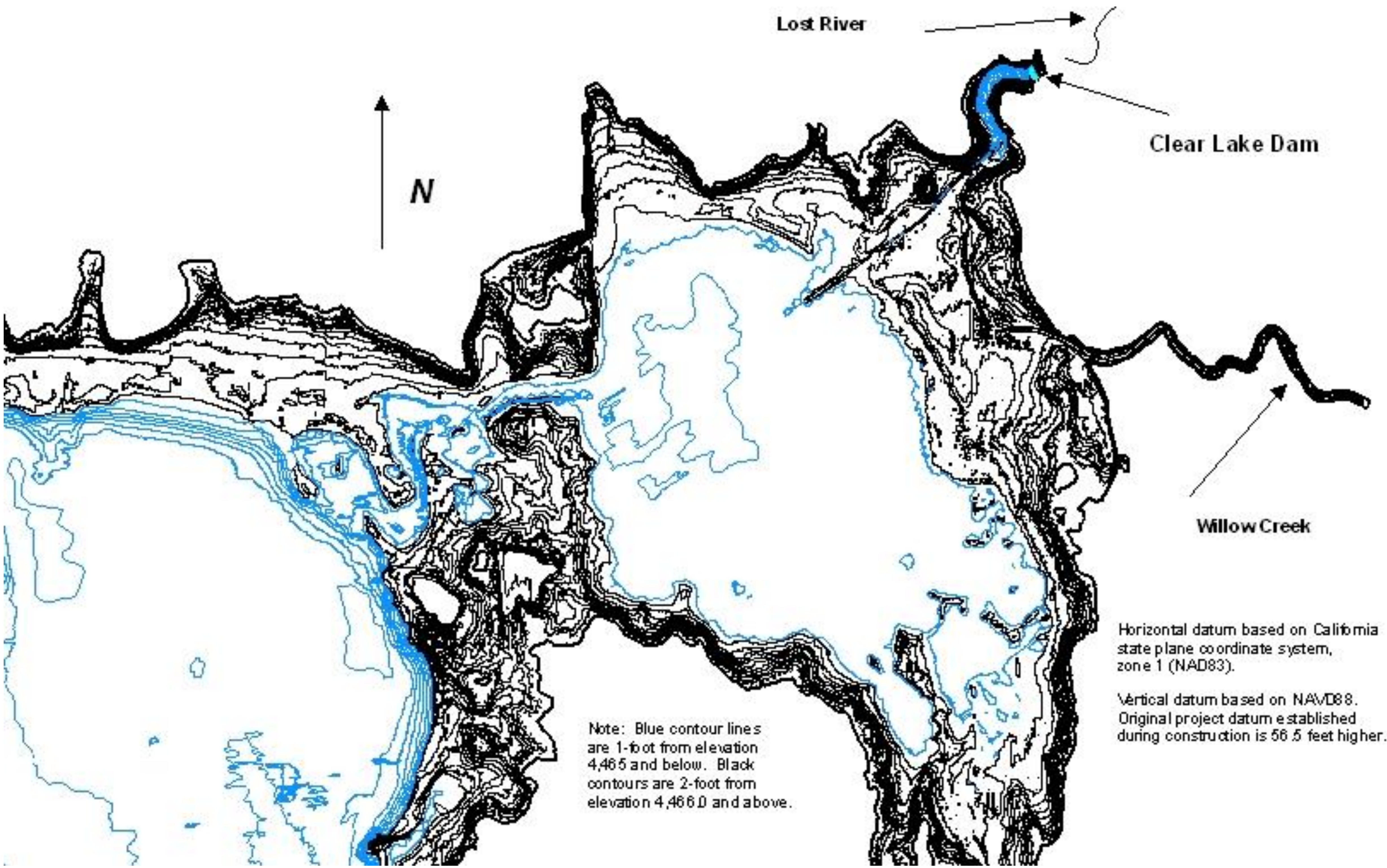

Figure 13 – Clear Lake contours, east area of the reservoir.

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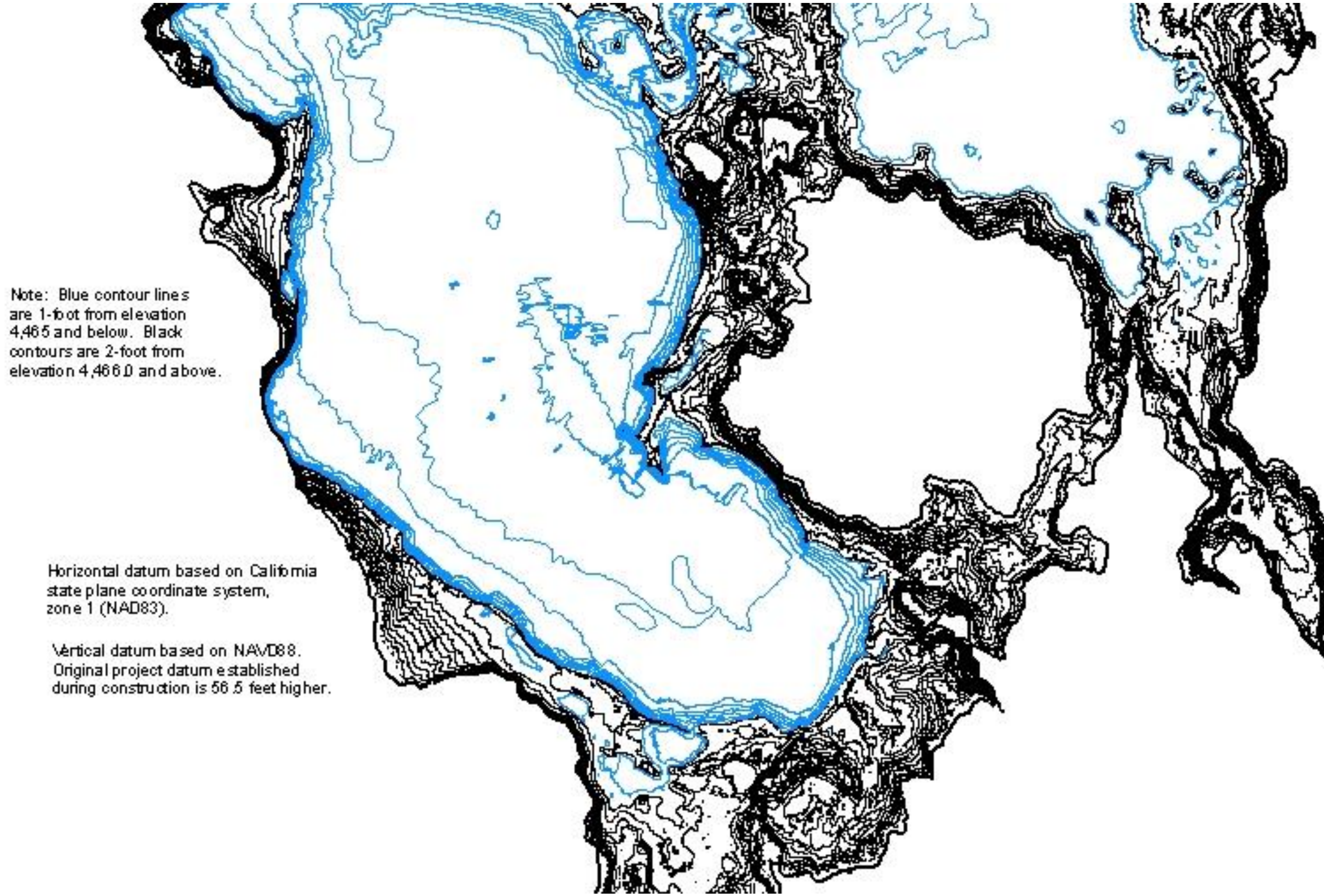

Figure 14 – Clear Lake contours, west area of the reservoir, (NAV88).

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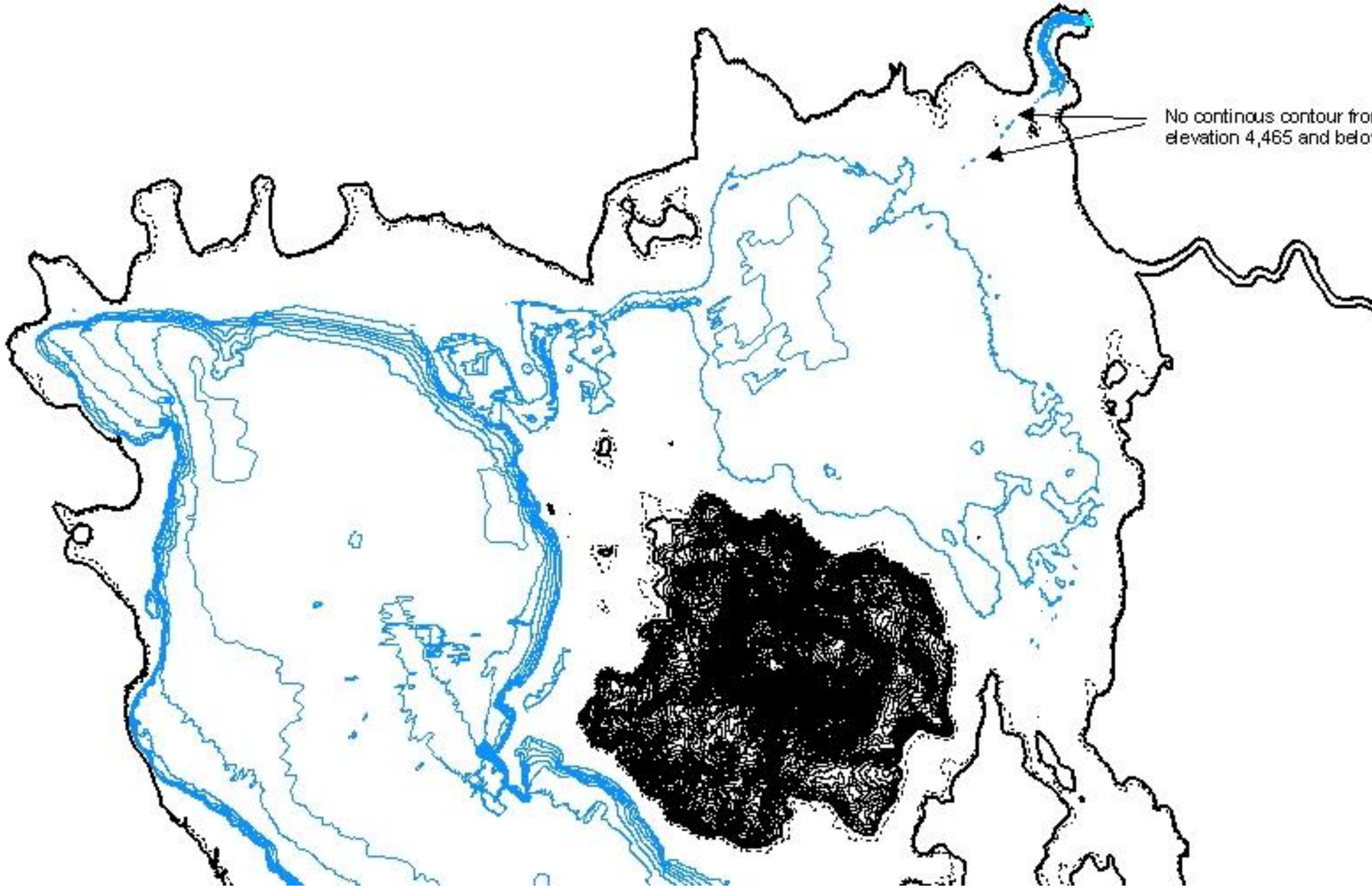

Figure 15 - Clear Lake 1-foot contours from elevation 4,465 (NAVD88) and below.

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Figure 16 - Clear Lake aerial photo, October 2005 near reservoir elevation 4,465.5 (NAVD88), project elevation 4,522. Area of the narrows between east and west water bodies.

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The 2007 surface areas for Clear Lake were computed at 1-foot increments directly from the reservoir developed TIN from elevation 4,454.0 (NAVD88) through 4,492.0 (NAVD88), project elevation 4,510.5 through 4,548.5. The TIN was developed from the collected data sets within the hard clip polygon where the dam and dikes enclosed the water body. Surface area calculations were performed using ARCGIS commands that compute areas at user-specified elevations directly from the TIN using all the data points. For the purpose of this study, the ARCMAP computed survey areas at 1-foot increments were shifted to the project vertical datum by increasing the elevations by 56.5 feet. The resulting surface areas versus elevation were input into the ACAP program (Reclamation, 1985) for computing the resulting Clear Lake 2007 area and capacity tables listed in the appendix.

2007 Storage Capacity

The storage-elevation relationships for Clear Lake, based on the measured surface areas, were generated in the area-capacity program ACAP using the least squares method of curve fitting. The ACAP program computes the surface area at 1.0-, 0.1-, and 0.01-foot increments by linear interpolation between basic data contours. The respective capacities and capacity equations are then obtained by integration of the area equations. The initial capacity equation is tested over successive intervals to check whether it fits within an allowable error term (set at 0.000001 for Clear Lake). The capacity equation is then used over the full range of intervals fitting within the allowable error limit. For the first interval at which the initial allowable error limit is exceeded, a new capacity equation (integrated from basic area curve over that interval) is utilized until it exceeds the error limit. Thus, the capacity curve is defined by a series of curves, each fitting a certain region of data. Differentiating the capacity equations, which are of second order polynomial form, the final capacity 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 2007 Clear Lake area and capacity computations were developed for 0.1-foot increments and are presented in the appendix of this report. A description of the computations and coefficients output from the ACAP program is included with these tables. The area-capacity relationships from the original survey and 2007 are listed on Table 2 and the area-capacity curves are plotted on Figure 17. As of May 2007, at reservoir water surface elevation 4,543.0 (spillway crest) the surface area was 25,344 acres with a total capacity of 507,252 acre-feet.

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RESERVOIR SEDIMENT
DATA SUMMARY

Clear Lake
NAME OF RESERVOIR

1
DATA SHEET NO.

DAM	1. OWNER Bureau of Reclamation	2. STREAM Lost River	3. STATE California
	4. SEC 8 TWP. 17N RANGE 8E	5. NEAREST P.O. Malin	6. COUNTY Modoc
	7. LAT 41 ° 55 ' 3 2 " LONG 121 ° 4 ' 32 "	8. TOP OF DAM ELEVATION 4544.0 [1]	9. SPILLWAY CREST EL 4543.00

RESERVOIR	10. STORAGE ALLOCATION	11. ELEVATION TOP OF POOL [2]	12. 2007 SURFACE AREA, AC-FT	13. 2007 CAPACITY, AC-FT	14. GROSS STORAGE ACRE-FEET	
	a. SURCHARGE					15 DATE STORAGE BEGAN
	b. FLOOD CONTROL	4,543.0	25,344	136,768	507,252	1910
	c. MULTIPLE USE					
	d. JOINT USE	4,537.4	23,547	23,376	370,484	16 DATE NORMAL OPERATIONS BEGAN
	e. CONSERVATION	4,536.4	23,198	298,748	347,108	
	f. INACTIVE	4,521.0	12,237	48,360	48,360	
	g. DEAD					1910
	17. LENGTH OF RESERVOIR	MILES	AVG. WIDTH OF RESERVOIR		MILES	

BASIN	18. TOTAL DRAINAGE AREA	SQUARE MILES	MEAN ANNUAL PRECIPITATION INCHES
	19. NET SEDIMENT CONTRIBUTING AREA 735	SQUARE MILES	23. MEAN ANNUAL RUNOFF INCHES
	20. LENGTH 27.5 MILES	AVG. WIDTH 45 MILES	24. MEAN ANNUAL INFLOW ACRE-FEET
	21. MAX. ELEVATION	MIN. ELEVATION	25. ANNUAL TEMP, MEAN °F RANGE °F to °F

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/ RATIO AF/AF
	May 2007				Contour 1-ft	25,344	507,252	

	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

	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.

	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.

26. DATE OF SURVEY	43. DEPTH DESIGNATION ELEVATION RANGE IN FEET										
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION										

26. DATE	44. REACH DESIGNATION PERCENT OF TOTAL ORIGINAL LENGTH OF RESERVOIR													
	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	105-	110-	115-	120-
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN REACH DESIGNATION													

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

46. ELEVATION - AREA - CAPACITY - DATA FOR

ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
4,510.0	0	0	4,512.0	4	4	4,514.0	7	14
4,516.0	6,510	5,731	4,518.0	8,349	21,114	4,520.0	8,929	38,431
4,522.0	14,286	61,651	4,524.0	16,381	92,312	4,526.0	18,296	127,108
4,528.0	19,690	165,172	4,530.0	20,792	205,749	4,532.0	21,688	248,262
4,534.0	22,408	292,386	4,536.0	23,058	337,857	4,538.0	23,739	384,669
4,540.0	24,337	432,756	4,542.0	24,992	482,084	4,544.0	25,669	532,760
4,546.0	26,290	584,735	4,548.0	26,863	637,905			

47. REMARKS AND REFERENCES

[1] Original dam, completed in 1910, was replaced in 2002 with a new dam with a lower crest elevation of 4,544.0 (project elevation). There is a 4-foot parapet wall with top elevation 4,548.0. All elevations are project vertical datum that is 56.5 feet higher than NAVD88.0

[2] All storage allocation values are computed using the 2007 area and capacity tables.

48. AGENCY MAKING SURVEY Bureau of Reclamation

49. AGENCY SUPPLYING DATA Bureau of Reclamation DATE September 2009

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

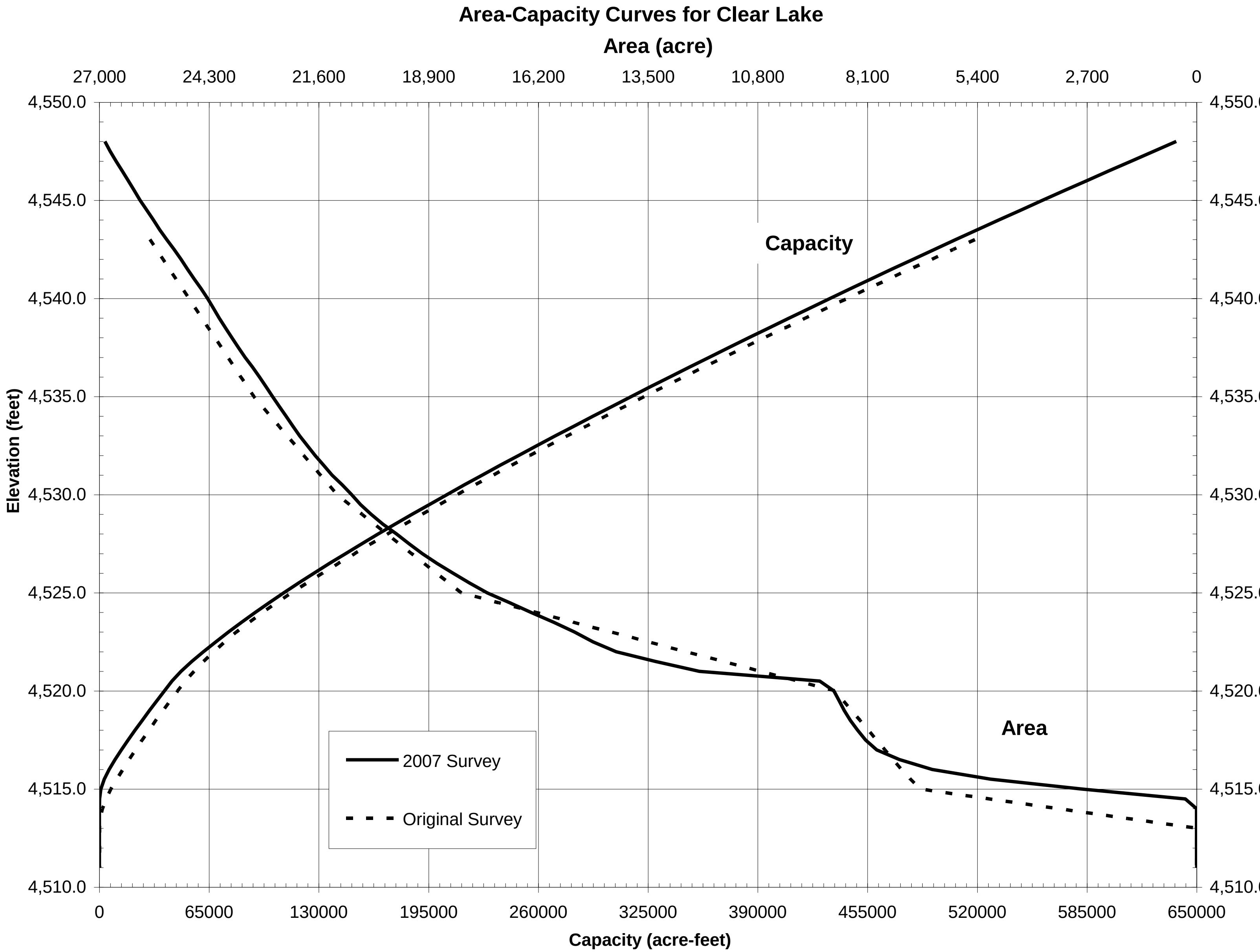

Figure 17 – Clear Lake area and capacity plots.

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						2007	2007
	Elevations	**Original**	**Original**	**2007**	**2007**	**Volume**	**Percent of**
		Survey	**Capacity**	**Survey**	**Survey**	**Difference**	**Difference**
	(feet)	**(acres)**	**(acre-feet)**	**(acres)**	**(acre-feet)**		
1	4,548.0			26,863	637,905		
	4,547.0			26,591	611,176		
	4,546.0			26,290	584,735		
	4,545.0			25,996	558,592		
2	4,544.0			25,669	532,760		
3	4,543.0	25,760	518,510	25,344	507,252	11,258	100
	4,542.0	25,440	492,910	24,992	482,084	10,826	96
	4,541.0	25,120	467,630	24,667	457,255	10,375	92
	4,540.0	24,800	442,670	24,337	432,756	9,914	88
	4,539.0	24,480	418,030	24,050	408,563	9,467	84
	4,538.5	24,320	405,830	23,894	396,577	9,253	82
	4,538.0	24,160	393,710	23,738	384,669	9,041	80
	4,537.0	23,840	369,710	23,412	361,091	8,619	77
	4,536.0	23,520	346,030	23,058	337,857	8,173	73
	4,535.0	23,200	322,670	22,740	314,957	7,713	69
	4,534.0	22,790	299,675	22,408	292,386	7,289	65
	4,533.0	22,380	277,090	22,075	270,145	6,945	62
	4,532.0	21,970	254,915	21,688	248,262	6,653	59
	4,531.0	21,560	233,150	21,276	226,780	6,370	57
	4,530.0	21,150	211,795	20,792	205,749	6,046	54
	4,529.0	20,540	190,950	20,317	185,186	5,764	51
	4,528.0	19,930	170,715	19,690	165,172	5,543	49
	4,527.0	19,320	151,090	19,055	145,795	5,295	47
	4,526.0	18,710	132,075	18,296	127,108	4,967	44
	4,525.0	18,100	113,670	17,458	109,223	4,447	40
	4,524.0	16,260	96,490	16,381	92,312	4,178	37
	4,523.0	14,420	81,150	15,313	76,477	4,673	42
	4,522.0	12,580	67,650	14,286	61,651	5,999	53
	4,521.0	10,740	55,990	12,237	48,360	7,630	68
	4,520.0	8,900	46,170	8,929	38,431	7,739	69
	4,519.0	8,491	37,475	8,673	29,631	7,844	70
	4,518.0	8,082	29,188	8,348	21,114	8,074	72
	4,517.0	7,673	21,311	7,873	12,984	8,327	74
	4,516.0	7,264	13,843	6,510	5,731	8,112	72
	4,515.0	6,800	6,800	2,823	863	5,937	53
	4,514.0	3,400	1,700	7	14	1,686	15
	4,513.5	1,700	425	6	11	414	4
	4,513.0	0	0	5	8	-8	0
	4,510.0	0.0	0.0	0.0	0.0	0.0	0
1	Top of Parapet Wall						
2	Dam crest						
3	Spillway crest						

Table 2 - Summary of 2007 survey results.

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2007 Analyses of Results

The Clear Lake original and 2007 area and capacity values are illustrated on Figure 17 and listed on Tables 1 and 2. These presentations illustrate the capacity differences from the two different surveys and show very little change, 11,258 acre-feet below the survey crest (project elevation 4,543.0). This change maybe primarily due to the accuracy differences between the two methods of collection since it is assumed the 2005 aerial survey provided much better detail of the actual reservoir topography than any previous collection. The area and capacity comparison plots provide a good illustration of how minor the changes are for the different elevation zones. The results from the 2007 survey present the current area and capacity of the reservoir along with the digitally developed topography of the reservoir bottom.

References

American Society of Civil Engineers, 1962. ***Nomenclature for Hydraulics***, ASCE Headquarters, New York.

Bureau of Reclamation, 1981. ***Project Data,*** Denver Office, Denver CO.

Bureau of Reclamation, 1985. Surface Water Branch, ***ACAP85 User's Manual***, Technical Service Center, Denver CO.

Bureau of Reclamation, 1987(a). ***Guide for Preparation of Standing Operating Procedures for Bureau of Reclamation Dams and Reservoirs***, U.S. Government Printing Office, Denver, CO.

Bureau of Reclamation, 1987(b). ***Design of Small Dams***, U.S. Government Printing Office, Denver CO.

Bureau of Reclamation, January 2006. ***Standing Operating Procedures (SOP), Clear Lake Dam and Reservoir, Klamath Falls Project,*** Mid-Pacific Region, Sacramento, California.

ESRI, 2009. **Environmental Systems Research Institute, Inc.** (www.esri.com)

Ferrari, R.L. and Collins, K. (2006). ***Reservoir Survey and Data Analysis,*** Chapter 9, Erosion and Sedimentation Manual, Bureau of Reclamation, Sedimentation and River Hydraulics Group. Denver, Colorado. www.usbr.gov/pmts/sediment

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Appendix

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UNTIED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MID PACIFIC REGION

KLAMATH FALLS PROJECT

CLEAR LAKE

CALIFORNIA

AREA AND CAPACITY TABLES

MAY 2007

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Clear Lake tables were generated by means of the area-capacity program ACAP, using the least squares method of curve fitting developed by Reclamation's Technical Service Center. This program computes area at 1.0-, 0.1-, and 0.01-foot increments by linear interpolation between provide data. The capacity equations are obtained by integration of the area equations. The initial capacity equation is tested over successive intervals to check if it fits within an allowable error term. At the next interval beyond, a new capacity equation (integrated from the basic area equation over that interval) begins testing the fit until it exceeds the error term. The capacity curve becomes a series of curves, each fitting a certain region of data. The final area equations are obtained by differentiation of the capacity equations. Capacity equations are of the form $y = a_1 + a_2x + a_3x^2$ where y is capacity and x is the elevation above an elevation base. The capacity equation coefficients for the reservoir are shown below ($\varepsilon = 0.000001$).

CLEAR LAKE 2007 SURVEY

AREA-CAPACITY TABLES (BOR VERTICAL DATUM)

EQUATION NUMBER	ELEVATION BASE	CAPACITY BASE	COEFFICIENT A1(INTERCEPT)	COEFFICIENT A2(1ST TERM)	COEFFICIENT A3(2ND TERM)
1	4510.00	0	0.0000	0.0000	0.9000
2	4514.00	14	14.4000	7.2000	275.4000
3	4514.50	86	86.8500	282.6001	2540.7996
4	4515.00	863	863.3500	2823.3996	2245.2008
5	4515.50	2836	2836.3501	5068.6003	1441.0984
6	4516.00	5730	5730.9247	6509.6994	804.0039
7	4516.50	9186	9186.7753	7313.7009	559.3994
8	4517.00	12983	12983.4757	7873.1007	276.0986
9	4517.50	16989	16989.0505	8149.2008	199.3024
10	4518.00	21113	21113.4765	8348.4990	175.6034
11	4518.50	25331	25331.6270	8524.0984	149.0060
12	4519.00	29630	29630.9263	8673.1134	125.3767
13	4519.50	33998	33998.8281	8798.5155	130.4687
14	4520.00	38430	38430.7023	8929.0130	346.7773
15	4520.50	42981	42981.9021	9275.8048	2961.5931
16	4521.00	48360	48360.2035	12237.4098	1081.6755
17	4521.50	54749	54749.3285	13319.0895	967.2223
18	4522.00	61650	61650.6797	14286.3179	566.4620
19	4522.50	68935	68935.4540	14852.7886	460.2260
20	4523.00	76476	76476.9057	15313.0059	509.1797
21	4523.50	84260	84260.7045	15822.1942	558.9146
22	4524.00	92311	92311.5315	16381.0971	521.8052
23	4524.50	100632	100632.5321	16902.8957	555.2037
24	4525.00	109222	109222.7810	17458.0977	435.6166
25	4525.50	118060	118060.6552	17894.7287	401.6645
26	4526.50	136356	136356.9693	18696.9802	358.3426
27	4527.00	145795	145795.0485	19055.2916	326.0324
28	4527.50	155404	155404.2037	19381.2971	309.0123
29	4528.00	165172	165172.1105	19690.3156	333.9844
30	4528.50	175100	175100.7679	20024.2832	292.2991
31	4529.00	185185	185185.9866	20316.5689	255.4687
32	4529.50	195408	195408.1429	20571.9908	220.3125
33	4530.00	205749	205749.2210	20792.2720	235.9375
34	4530.50	216204	216204.3454	21028.1554	247.7958
35	4531.00	226780	226780.3300	21276.4759	205.6090
36	4532.00	248262	248262.1788	21689.6564	192.7921
37	4533.00	270144	270144.2021	22075.7401	166.2624
38	4534.00	292385	292386.1560	22402.9083	168.3129
39	4535.00	314957	314957.5815	22741.6295	157.9582
40	4536.00	337857	337857.4757	23054.2296	179.0428
41	4537.00	361091	361090.8584	23418.3575	160.2018
42	4538.00	384669	384669.1305	23738.0844	155.8129
43	4539.00	408562	408562.8826	24048.3634	144.3692
44	4540.00	432755	432756.0007	24331.4054	167.7718
45	4541.50	469630	469630.5839	24823.1694	169.0632
46	4542.50	494623	494622.8217	25172.4744	171.0082
47	4543.50	519965	519966.1597	25505.7792	163.3868
48	4545.00	558592	558592.7358	25994.4792	147.5632
49	4546.50	597916	597916.5979	26446.6708	144.0049
50	4547.50	624506	624506.9865	26729.3659	134.0770

The Clear Lake survey in May 2007 used the contour method to obtain the basic data for these tables. Close interval profiles of the underwater portion of the reservoir were collected by standard surveying techniques using a global positioning system and echo sounder. The above-water portion was developed from aerial photography obtained in October of 2005. The computed surface areas from these surveys provided measured surface areas 0.5-foot increments from elevation 4,510 to 4,548.5. All data for these tables are tied to the project vertical datum that is 56.5 feet greater than the North American Vertical Datum of 1988.

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CLEAR LAKE 2007 SURVEY
AREA -CAPACITY TABLES (BOR VERTICAL DATUM, FEET)

AREA TABLE IN ACRES

Elevation	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
4510	0	0	0	1	1	1	1	1	1	2
4511	2	2	2	2	3	3	3	3	3	3
4512	4	4	4	4	4	5	5	5	5	5
4513	5	6	6	6	6	6	7	7	7	7
4514	7	62	117	172	228	283	791	1,299	1,807	2,315
4515	2,823	3,272	3,722	4,171	4,620	5,069	5,357	5,645	5,933	6,222
4516	6,510	6,671	6,831	6,992	7,153	7,314	7,426	7,538	7,649	7,761
4517	7,873	7,928	7,984	8,039	8,094	8,149	8,189	8,229	8,269	8,309
4518	8,349	8,384	8,419	8,454	8,489	8,524	8,554	8,584	8,614	8,643
4519	8,673	8,698	8,723	8,748	8,773	8,799	8,825	8,851	8,877	8,903
4520	8,929	8,998	9,068	9,137	9,206	9,276	9,868	10,460	11,053	11,645
4521	12,237	12,454	12,670	12,886	13,103	13,319	13,513	13,706	13,899	14,093
4522	14,286	14,400	14,513	14,626	14,740	14,853	14,945	15,037	15,129	15,221
4523	15,313	15,415	15,517	15,619	15,720	15,822	15,934	16,046	16,158	16,269
4524	16,381	16,486	16,590	16,694	16,799	16,903	17,014	17,125	17,236	17,347
4525	17,458	17,545	17,632	17,720	17,807	17,894	17,975	18,055	18,136	18,216
4526	18,296	18,377	18,457	18,537	18,618	18,698	18,769	18,840	18,912	18,984
4527	19,055	19,121	19,186	19,251	19,316	19,381	19,443	19,505	19,567	19,629
4528	19,690	19,757	19,824	19,891	19,958	20,024	20,083	20,141	20,200	20,258
4529	20,317	20,368	20,419	20,470	20,521	20,572	20,616	20,660	20,704	20,748
4530	20,792	20,840	20,887	20,934	20,981	21,028	21,078	21,127	21,177	21,226
4531	21,276	21,318	21,359	21,400	21,441	21,482	21,523	21,564	21,605	21,647
4532	21,688	21,728	21,767	21,805	21,844	21,882	21,921	21,960	21,998	22,037
4533	22,075	22,109	22,142	22,176	22,209	22,242	22,275	22,309	22,342	22,375
4534	22,408	22,437	22,470	22,504	22,538	22,571	22,605	22,639	22,672	22,706

CLEAR LAKE 2007 SURVEY
AREA -CAPACITY TABLES (BOR VERTICAL DATUM, FEET)

AREA TABLE IN ACRES

Elevation	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
4535	22,740	22,773	22,805	22,836	22,868	22,900	22,931	22,963	22,994	23,026
4536	23,058	23,090	23,126	23,162	23,198	23,233	23,269	23,305	23,341	23,377
4537	23,412	23,450	23,482	23,515	23,547	23,579	23,611	23,643	23,675	23,707
4538	23,739	23,769	23,800	23,832	23,863	23,894	23,925	23,956	23,987	24,019
4539	24,050	24,077	24,106	24,135	24,164	24,193	24,222	24,251	24,279	24,308
4540	24,337	24,365	24,399	24,432	24,466	24,499	24,533	24,566	24,600	24,633
4541	24,667	24,701	24,734	24,768	24,801	24,835	24,857	24,891	24,925	24,958
4542	24,992	25,026	25,060	25,094	25,128	25,161	25,207	25,241	25,275	25,309
4543	25,344	25,378	25,412	25,446	25,480	25,515	25,539	25,571	25,604	25,637
4544	25,669	25,702	25,735	25,767	25,800	25,833	25,865	25,898	25,931	25,963
4545	25,996	26,024	26,054	26,083	26,113	26,142	26,172	26,201	26,231	26,260
4546	26,290	26,319	26,349	26,378	26,408	26,437	26,476	26,504	26,533	26,562
4547	26,591	26,620	26,648	26,677	26,706	26,735	26,756	26,783	26,810	26,837

CLEAR LAKE 2007 SURVEY
AREA -CAPACITY TABLES (BOR VERTICAL DATUM, FEET)

CAPACITY TABLE IN ACRE-FEET

Elevation	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
4510	0	0	0	0	0	0	0	0	1	1
4511	1	1	1	2	2	2	2	3	3	3
4512	4	4	4	5	5	6	6	7	7	8
4513	8	9	9	10	10	11	12	12	13	14
4514	14	18	27	41	61	87	141	245	400	606
4515	863	1,168	1,518	1,912	2,352	2,836	3,358	3,908	4,487	5,094
4516	5,731	6,390	7,065	7,756	8,463	9,187	9,924	10,672	11,431	12,202
4517	12,984	13,774	14,569	15,370	16,177	16,989	17,806	18,627	19,452	20,281
4518	21,114	21,950	22,790	23,634	24,481	25,332	26,186	27,042	27,902	28,765
4519	29,631	30,500	31,371	32,244	33,120	33,999	34,880	35,764	36,650	37,539
4520	38,431	39,327	40,230	41,141	42,058	42,982	43,939	44,956	46,031	47,166
4521	48,360	49,595	50,851	52,129	53,428	54,749	56,091	57,452	58,832	60,232
4522	61,651	63,085	64,531	65,988	67,456	68,936	70,425	71,924	73,433	74,950
4523	76,477	78,013	79,560	81,117	82,684	84,261	85,849	87,448	89,058	90,679
4524	92,312	93,955	95,609	97,273	98,948	100,633	102,328	104,035	105,753	107,483
4525	109,223	110,973	112,732	114,499	116,276	118,061	119,854	121,656	123,465	125,283
4526	127,108	128,942	130,784	132,634	134,491	136,357	138,230	140,111	141,998	143,893
4527	145,795	147,704	149,619	151,541	153,469	155,404	157,345	159,293	161,246	163,206
4528	165,172	167,145	169,124	171,109	173,102	175,101	177,106	179,117	181,134	183,157
4529	185,186	187,220	189,260	191,304	193,354	195,408	197,468	199,531	201,600	203,672
4530	205,749	207,831	209,917	212,008	214,104	216,204	218,310	220,420	222,535	224,655
4531	226,780	228,910	231,044	233,182	235,324	237,470	239,620	241,775	243,933	246,096
4532	248,262	250,433	252,608	254,786	256,969	259,155	261,345	263,539	265,737	267,939
4533	270,145	272,353	274,566	276,782	279,001	281,224	283,450	285,679	287,911	290,147
4534	292,386	294,628	296,874	299,122	301,374	303,630	305,889	308,151	310,416	312,685

CLEAR LAKE 2007 SURVEY
AREA -CAPACITY TABLES (BOR VERTICAL DATUM, FEET)

CAPACITY TABLE IN ACRE-FEET

Elevation	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
4535	314,957	317,233	319,512	321,794	324,080	326,368	328,659	330,954	333,252	335,553
4536	337,857	340,165	342,476	344,790	347,108	349,429	351,755	354,083	356,415	358,751
4537	361,091	363,434	365,781	368,131	370,484	372,840	375,200	377,562	379,928	382,297
4538	384,669	387,045	389,423	391,805	394,189	396,577	398,968	401,362	403,759	406,160
4539	408,563	410,969	413,378	415,790	418,205	420,623	423,044	425,468	427,894	430,323
4540	432,756	435,191	437,629	440,071	442,515	444,964	447,415	449,870	452,329	454,790
4541	457,255	459,724	462,195	464,670	467,149	469,631	472,115	474,602	477,093	479,587
4542	482,084	484,585	487,090	489,597	492,108	494,623	497,142	499,664	502,190	504,719
4543	507,252	509,788	512,327	514,870	517,417	519,966	522,518	525,074	527,633	530,195
4544	532,760	535,328	537,900	540,475	543,054	545,635	548,220	550,808	553,400	555,995
4545	558,592	561,194	563,798	566,404	569,014	571,627	574,243	576,861	579,483	582,107
4546	584,735	587,365	589,999	592,635	595,274	597,917	600,563	603,212	605,864	608,518
4547	611,176	613,836	616,500	619,166	621,835	624,507	627,181	629,858	632,538	635,220
4548	637,905									