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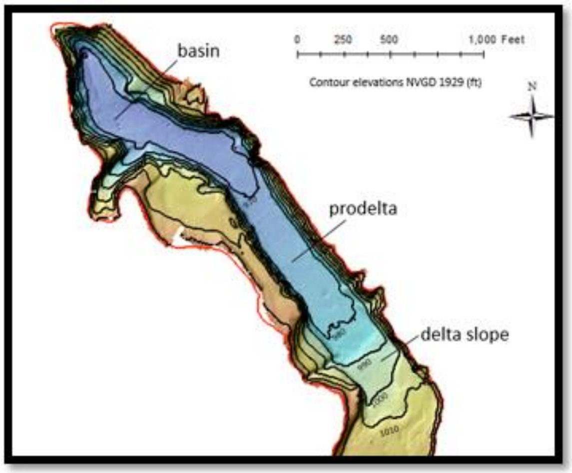

Summer/Fall 2017 Stage-Volume Relationship for Los Padres Reservoir, Carmel River, California

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Executive Summary

The Los Padres Reservoir was surveyed in 2017 to develop a new stage-volume relationship following the fall 2016 Soberanes Fire and heavy rainfall of winter 2017. A bathymetric survey during high water in the reservoir (June 2017) was augmented with a photogrammetric topography survey during low water (November 2017) to develop a stage-volume curve that extends up to the 1040 ft (NGVD29) elevation of the dam spillway. We report full reservoir capacity of 1679 acre-feet (af), and a full surface area of approximately 52 acres. The capacity is 7% less than the 1810 af measured in 2016.

This report may be cited as:

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- Dr. Amy East and Joshua Logan (USGS) provided photogrammetric elevation models that improved reservoir volume estimates in the upper terminus of the reservoir.
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- Greg James (MPWMD) provided hydrologic data.

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1 Introduction

Los Padres Reservoir retains water and sediment flowing from undeveloped land in the upper watershed of the Carmel River in Monterey County, California (Fig. 1). Pervasively fractured granitic and metamorphic rock underlying the watershed are easily eroded when disturbed by fire or human disturbance (Fig. 2), and reservoir studies have shown that the reservoir volume is gradually diminishing as water storage capacity is displaced by trapped sediment (e.g., Smith et al., 2009, Olden, 2016, Aecom, 2017). San Clemente Reservoir, located just several miles downstream of Los Padres, was removed in 2015 after it had trapped approximately 1350 acre-feet (af) of sediment (MEI 2005) generated from the same kind of rocks as occur upstream of Los Padres Dam (Fig. 2). While San Clemente Reservoir filled gradually over its 95 year life, there were also episodic fire and human-induced slope-failure events that caused unanticipated very rapid capacity loss (Smith et al. 2004). To better predict reservoir capacity loss due to fire impacts, Monterey Peninsula Water Management District (MPWMD) has resurveyed the Los Padres Reservoir following recent major wildfire events (e.g., Smith et al., 2009, Olden, 2016).

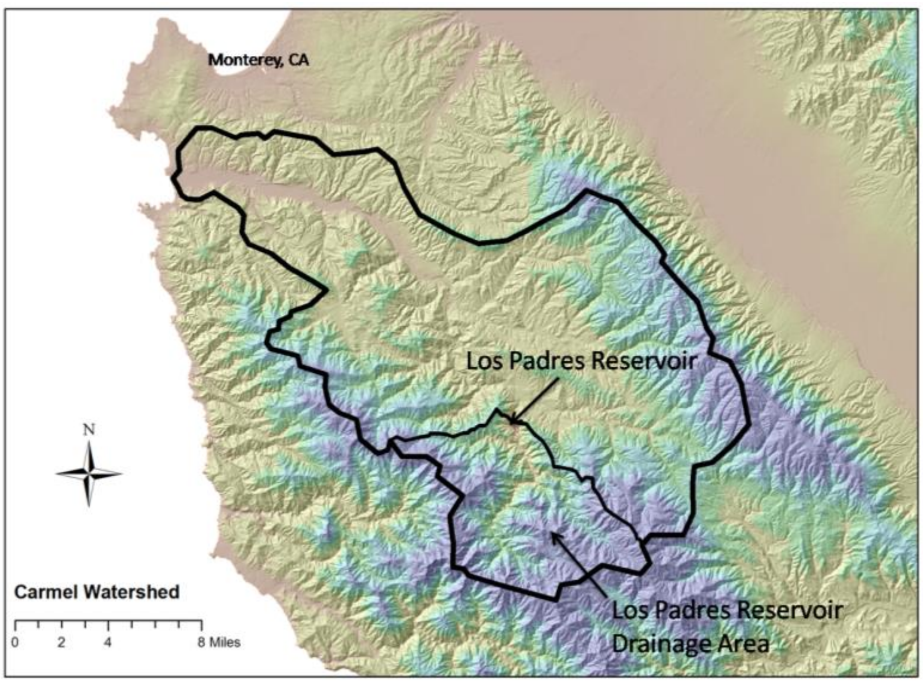

Figure 1: Study area location. The Los Padres Reservoir receives runoff from a drainage area of approximately 45 mi^2.

Post-fire weather patterns are the most important variable determining whether or not a wildfire will lead to excess sediment transport. Smith et al. (2009) found no capacity reduction in the Los Padres Reservoir in the first year following the 2008 Basin-Complex Fire, in large part because the post-fire year did not include intense rainfall events that are required to initiate mass wasting. That result was independently supported by unpublished time-series cross-section surveys that found no geomorphic signal of sediment storage in the Carmel River channel upstream of the reservoir. (Richmond, 2009; Kelly, 2012). Fire sediment response can be delayed for several years if rainfall intensity remains low. Olden (2016) found no significant reservoir capacity loss in a 2016 survey, indicating no sediment response in eight post-fire years. Given that slopes can revegetate and stabilize in that timeframe, we conclude that the Basin-Complex fire provided little to no additional sediment to the upper Carmel River. Those two studies (Smith et al. 2009; Olden 2016) stand in stark contrast to the situation following the 1977 Marble Cone Fire that produced catastrophic debris flows in coastal watersheds (USGS, 1979; Hecht, 1981; Watson et al., 2003; Smith et al, 2004). Sediment load following the Marble Cone Fire diminished the Los Padres capacity by 550 af (USGS, 1979; Hecht, 1981). If the original reservoir capacity was 2709 af (Aecom 2017), that single fire event reduced initial capacity by 20%.

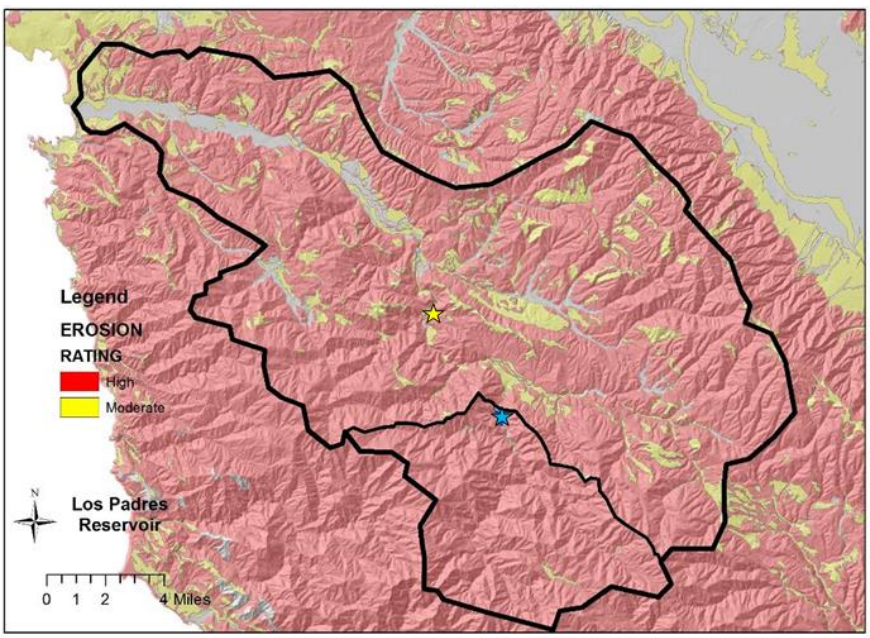

Figure 2: Erosion potential of geologic substrate in the region of the Carmel River watershed. Erosion data from Rosenberg (2001). Blue star is Los Padres Dam. Yellow star is location of former San Clemente Dam.

The Soberanes Fire burned the Santa Lucia Range from late July to early October 2016, and the following 2017 water year (WY 17) provided rainfall events that generated visible erosion in the still denuded watershed slopes (Fig. 3). Water Year 2017 produced 32.25 inches of rainfall at the former San Clemente Dam site and 51.92 inches of rainfall at the Santa Lucia Preserve golf course (Conlen et al., 2018). The 97-year simple average annual precipitation at the former dam is 21.27 inches, and the WY 17 value of 32.25 inches has an exceedance return period of approximately 10 years (Fig 4). The resulting runoff produced a peak flow with exceedance return period of approximately 25 years at a gage located downstream of the Los Padres Dam (Fig. 4). MPWMD commissioned the current Los Padres Reservoir capacity study to capture the potential impacts of the WY 17 post-Soberanes Fire runoff.

Figure 3: Rill erosion in Pine Creek drainage in WY 17 following Soberanes Fire. Photo Provided by Larry Hampson (MPWMD).

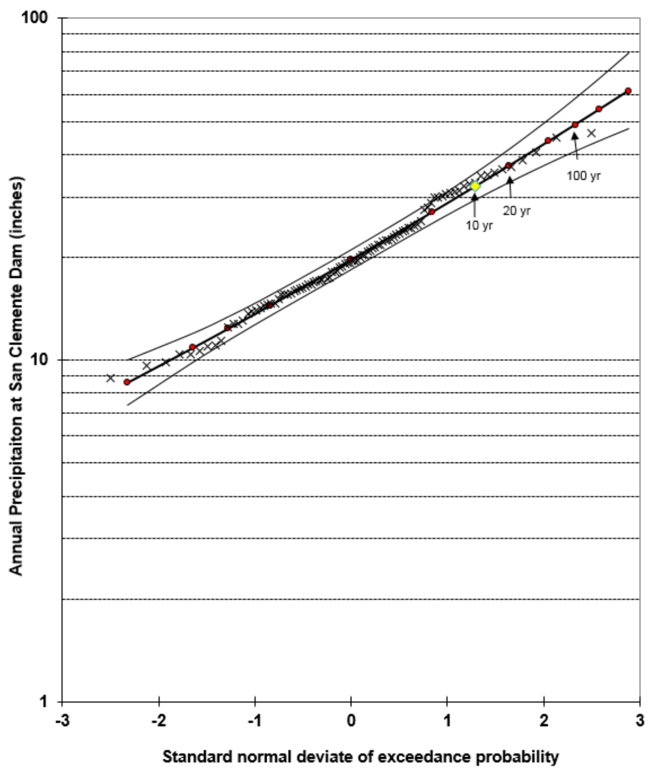

Figure 4: Log-Pearson Type-II frequency analysis of San Clemente Dam precipitation. WY 17 rainfall is the yellow symbol labelled 10 yr. California American Water data supplied by Greg James (MPWMD).

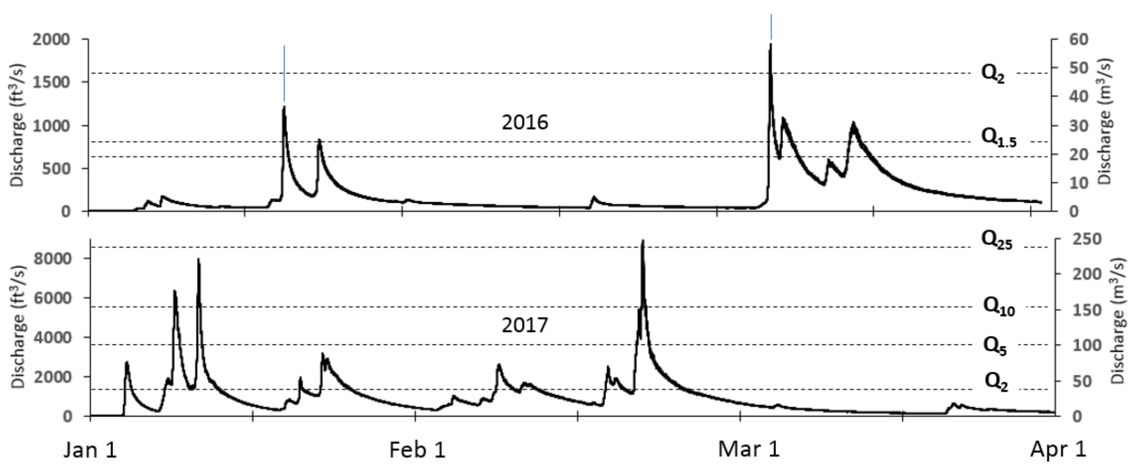

Figure 5: Annual hydrographs for WY 16 and WY 17 at the Sleepy Hollow stream gage. Data from Greg James (MPWMD). Frequencies based upon peak correlation and Log-Pearson Type-III analysis of long term record at USGS Robles del Rio gage (11143200) located several miles downstream of the Sleepy Hollow gage.

The objectives of the 2017 survey were to:

- produce an accurate Los Padres Reservoir stage-volume relationship at specific stages using high-precision bathymetry and terrestrial survey, and
- compare the present maximum volume with past estimates in order to assess the general changes through time.
- relate the recent changes to the Soberanes Fire.

2 Methods

We combined geospatial data from the following sources to produce a high-resolution bathymetric model of the reservoir:

1. vessel-mounted high-frequency interferometric sidescan sonar bathymetry for subaqueous soundings
2. photogrammetry of the upper watershed where the boat could not navigate during the survey.

2.1 Interferometric Sidescan SONAR Bathymetry

Interferometric sidescan SONAR bathymetric data were collected on June 3, 2017. The R/V Kelpfly was rigged with Applanix WaveMaster POS MV, SEA SWATHplus Splash 468 kHz interferometric bathymetry sidescan sonar, YSI Castaway CTD/Soundvelocity profiler and IAPPK GNSS positioning system. Each sounding has a vertical precision of approximately 0.2 m. The survey was benchmarked on the same point (Fig. 6) used by Smith et al. (2009) and Aecom (2017), and referenced by Olden (2016).

Figure 6: General location of SFML benchmark near the dam crest. Inset shows close up of drill hole used as the horizontal and vertical reference. Photo is from 2008 survey.

The benchmark position was estimated from 7.3 hours of static GNSSS occupation in 2008. Precision of the position is presented in Smith et al. (2009). The position is:

UTM WGS-84 Zone 10
Easting [meters] 619388.986
Northing [meters] 4027605.397

NAVD 88 (Computed using GEOID03)
Elevation [meters] 322.418.

To convert from NAVD88 to NGVD29 used in the original dam elevation surveys, the NAVD88 elevation must be reduced by 0.893 m or 2.93 ft. The elevations reported here have been converted to NGVD29 ft to directly compare with the original stage-volume relationships. We provide estimates of volume (af) and area (ac) up to the spillway elevation of 1040 ft (NGVD29).

The bathymetric data were cleaned using industry standard hydrographic software (Caris Hips, Fledermaus, ArcGIS) to produce a "bare-earth" digital elevation model of the reservoir with 50 cm m cell size (Fig. 7). Given the ambient water stage, the vessel-based survey was able to generate a digital surface that extends from the bathymetric low point to a stage of approximately 1035 ft (NGVD1929). Locally, the highest elevations reached by the survey are close to, or exceed, the 1040 ft stage of the spillway. Where the survey does not reach 1040 ft, the volume analysis assumes vertical walls extending up from the limit of the data. This shortfall leads to a small underestimate of volume and area in the stage range from 1035 to 1040 ft (Fig. 7).

An independent estimate of several 2017 reservoir surface elevations provides an accuracy test for the bathymetry (Table 1).

Table 1: Comparison of Aecom (2017) boring elevations and DEM elevations (ft).

Aecom (2017) Boring	Elevation from boring	2017 dem elevation	Water depth	Elevation difference
B1	968.5	968.4	74.5	0.1
B2	978.3	977.9	65	0.4
B3	1018.7	1017.9	25	0.8
B4	1018.7	1018.4	24.5	0.3
B5	1026.6	1026.4	16.5	0.2
B7	1012.8	1012.9	30	-0.1

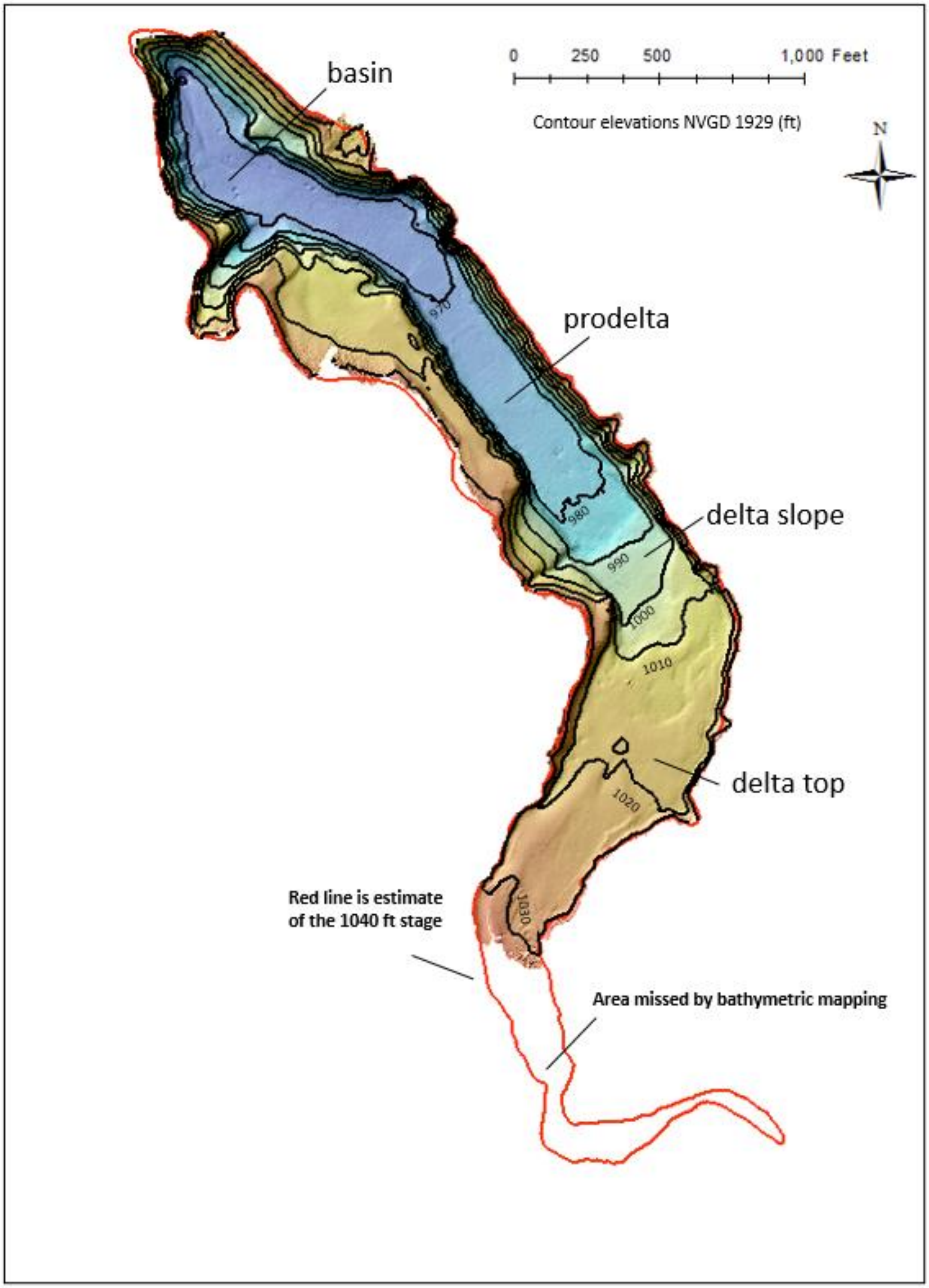

Figure 7: 2017 bathymetry of Los Padres Reservoir from vessel-based multibeam sonar.

2.2 UAS Photogrammetry

The vessel-based survey could not reach into the shallow upper reservoir where the 1040 ft shoreline terminates in the modern Carmel River channel. This missing 400 m long segment was captured on November 1, 2017 by unmanned aerial system (UAS), structure-from-motion (SfM) photogrammetry. The UAS mission was flown approximately 100 m above ground elevation with 70% photo overlap in a reference frame compatible with the bathymetric data. Registration of the point cloud was achieved using 19 ground control points (GCPs) spatially distributed throughout the mapping area. GCP positions were measured using 1-minute static RTK GNSS occupations with the base set on the SFML benchmark. Most vegetation and noise were removed from the SfM data using Agisoft Photoscan ground classification (30 deg, 0.5 meters, 20 m window). SfM points from the reservoir water surface were removed. SfM points from river water surface were left to produce more continuous coverage. The DEM in subaqueous river areas overestimates the true elevation by an amount roughly equal to the water depth (generally very shallow). The DEM was created by calculating the average of ground point elevations in a 10 cm window using LAStools, resulting in a DEM with 10 cm cell size (Fig. 8). The UAS SfM data were collected and processed by Amy East and Joshua Logan (USGS, Pacific Coastal and Marine Science Center, Santa Cruz, CA).

2.3 Combining Data Sets

Several months elapsed between the bathymetric and topographic surveys. The lapse was intentional so that vessel-based data could be maximized at high water in June, and topographic data could have maximum extent at low water in the fall. Leaf-off conditions in fall also optimizes photogrammetric results. During the intervening months from June to November, lobes grew on the delta top, and the delta top locally incised as the stage dropped base level for the Carmel River entering the reservoir (Fig. 8). The change in topography between the surveys means that combining the data does not result in a single “time-slice” survey. Sediment that had been creating the digital surface in June was subsequently eroded and transported to deeper regions as stage fell, and new sediment was introduced from above. DEM raster subtraction was used to assess the geomorphic changes.

The two digital surfaces have approximately 9.3 ac of overlap. Raster subtraction in the overlap region indicated that the absolute elevation differences between the surfaces were generally less than 0.3 m with the incised channel generating 0.5 m to 1.0 m elevation changes (Fig. 9). While it is clear that morphology changed during the time gap between the surveys, the average change in the overlap area was 0.05 m. The error resulting from that average elevation change is approximately 1.6 af, less than 1% of the reservoir capacity. Given the low “net” change between the surveys, there is confidence in assessing the reservoir capacity in the upper reservoir and adding it to the vessel-based capacities. We selected the 1030 ft bathymetry contour as the boundary between volumes calculated independently from vessel-based data and UAS-based data (Figs. 10 and 11). The 2017 photogrammetric data adds precise detail to the topography of the upper reservoir (Figs 8 and 10).

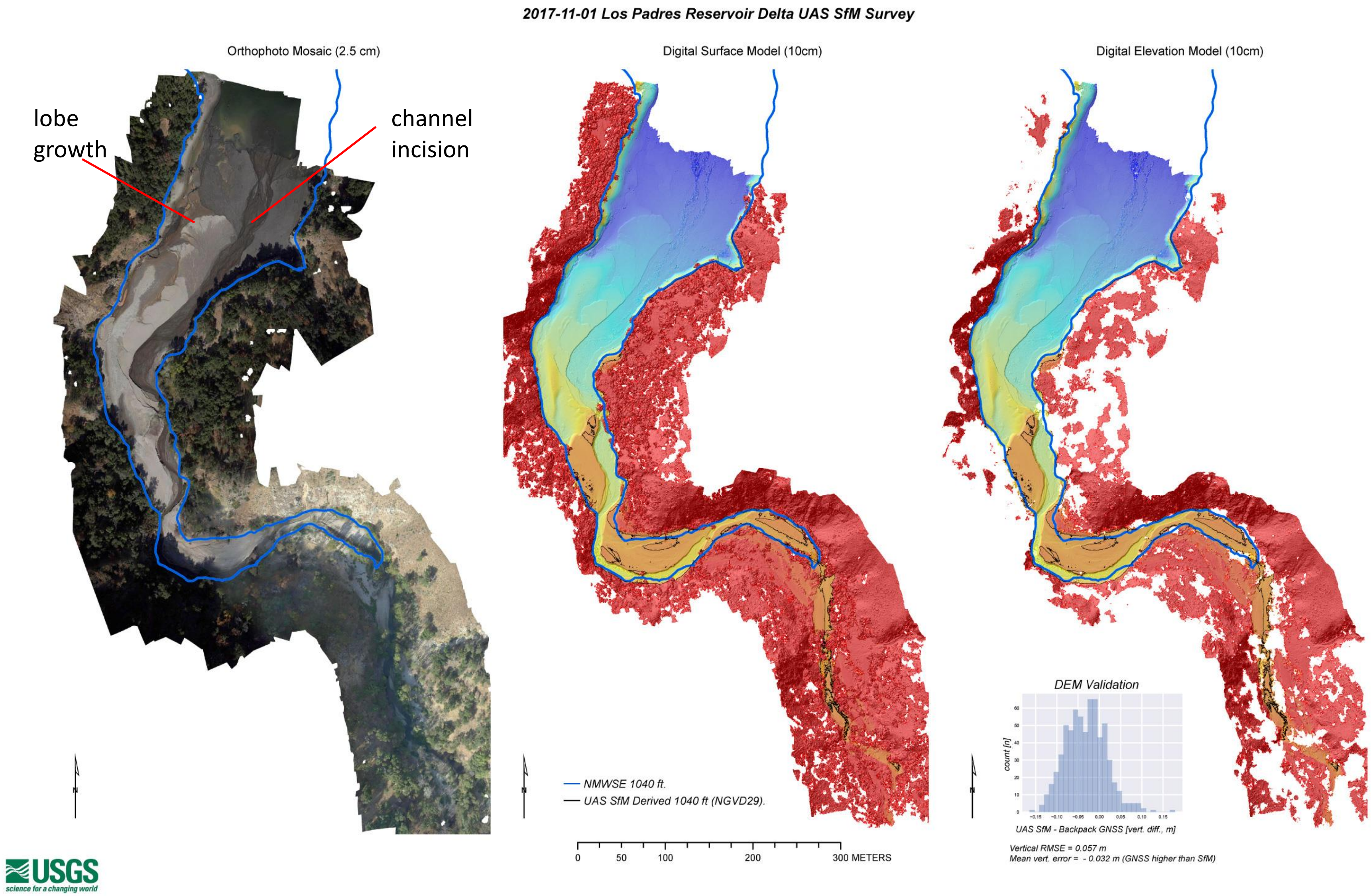

Figure 8: Orthophoto, digital surface model, and digital elevation model from photogrammetry.

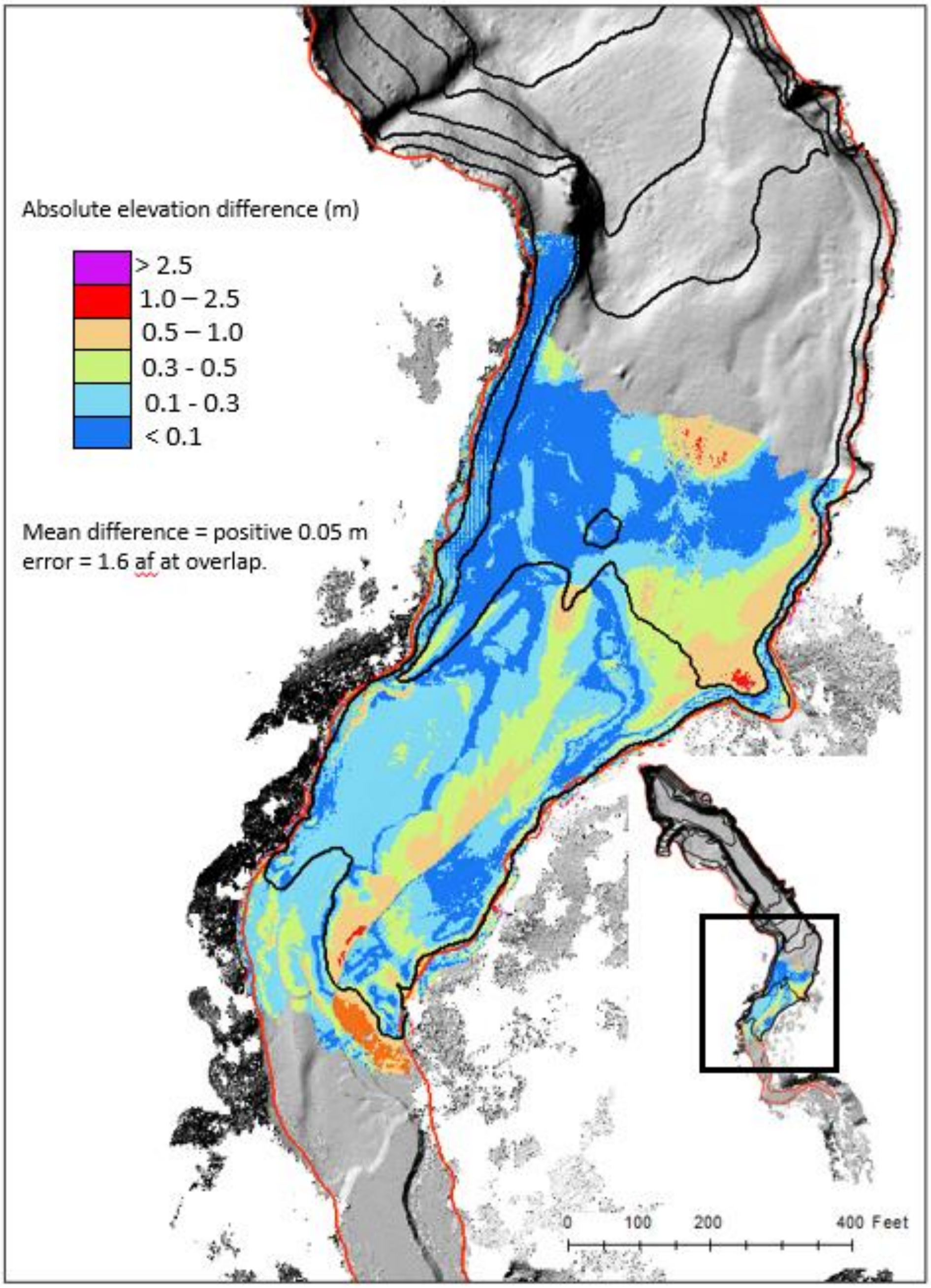

Figure 9: Absolute differences in elevation in the region overlapped by bathymetric and topographic surveys.

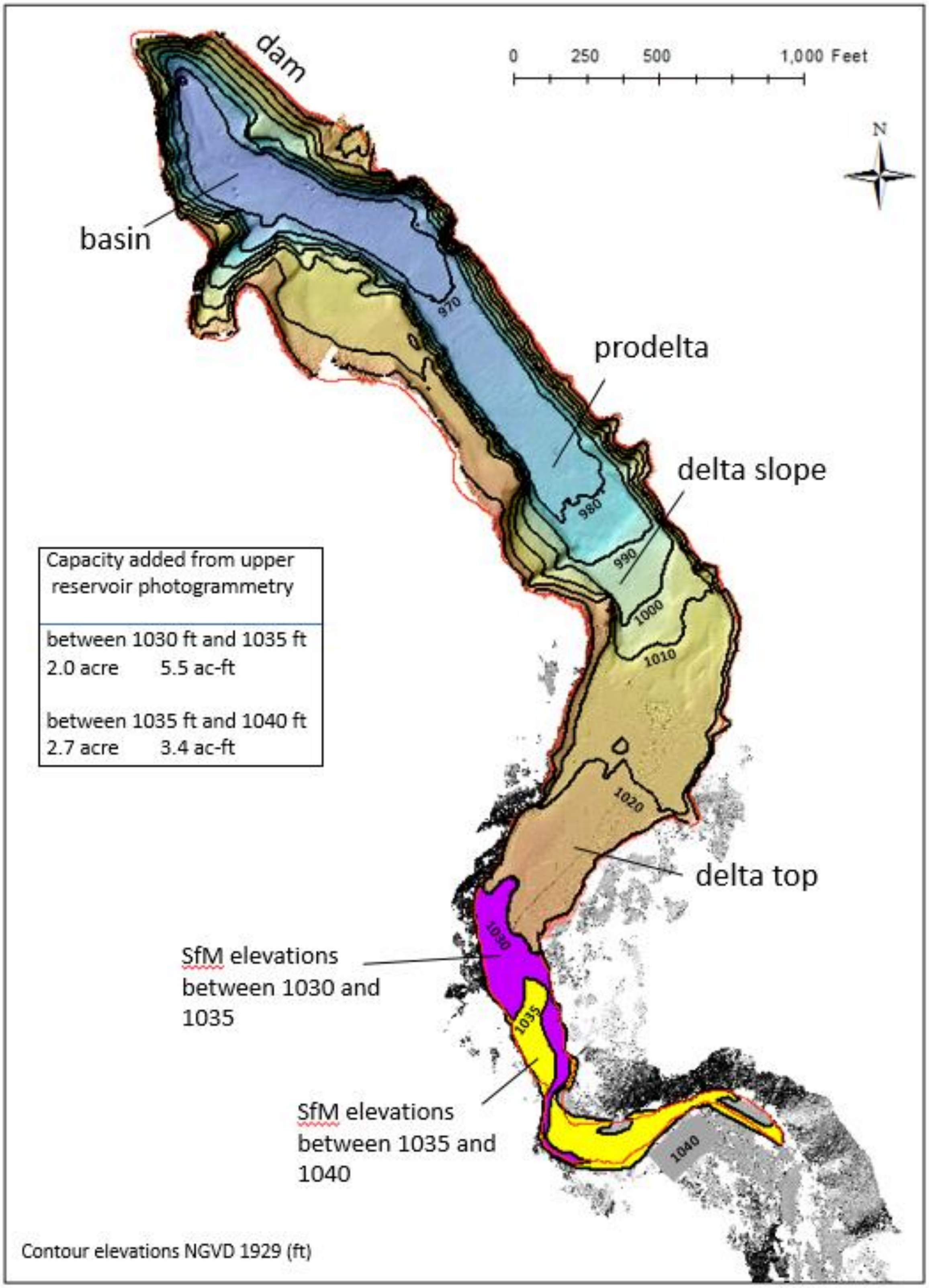

Figure 10: Topography of the upper reservoir from SfM photogrammetry. The 1030 ft bathymetric contour separates the bathymetric and topographic data sets.

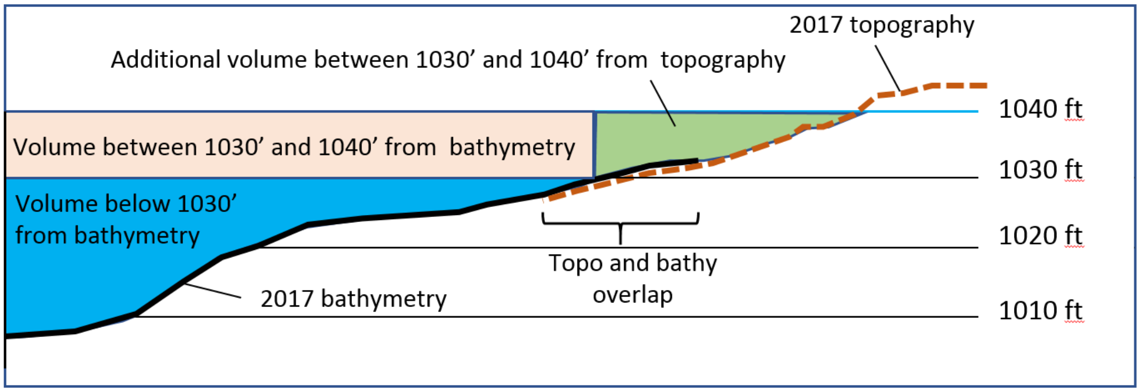

Figure 11: Schematic cross section showing how bathymetric and topographic data were combined.

3 Reservoir Capacity Results

The stage-dependent volumes and surface areas of the Los Padres Reservoir are presented in Table 2 and Figures 12 and 13. Smith et al. (2009) suggested an empirical approach to adjusting from NAVD88 elevations to the putitive NGVD29 elevations used in the historic stage elevations. Local historic survey data indicated to them that the stages might not be precisely NGVD29. They derived a shift of 2.54 ft based upon local survey data. Ogden (2016) could not reproduce the derivation in Smith et al. (2009), choosing instead to use the standard vertical shift between the vertical datums of 2.93 ft. It is clearly important to have the ***same*** vertical reference when comparing change through time. To facilitate direct comparison, we used the full datum shift (2.93 ft) in the 2017 analysis, and have adjusted the values in the 2008 data set as well (Table 2 and Figs 12 and 13). We note that the 2008 survey did not extend far into the upper reservoir. Using the 2017 upper reservoir capacity as a reference, there could be up to approximately nine more acre-feet (Fig. 10) in the 1040 ft stage category in 2018 (Table 2). Such an adjustment would bring the 2008 and 2016 surveys into even closer agreement. However, the addition of 4 more acres of area to the 2018 area would make it exceed the other surveys.

3.1 Reservoir Capacity Change Through Time

Figure 12 shows that there was negligible bathymetric change between the 2008 and 2016 surveys during the relatively dry years following the Basin-Complex and Soberanes Fires. Water year 2017 (Fig. 5), the second year following the Soberanes Fire produced measurable change from the 2016 survey (Fig. 12). Most of the deposition occurred on the delta top, shallower than 1020 ft stage (Figs. 14 and 15). Virtually no deposition occurred in the prodelta and basin areas (Fig. 16).

Table 2: Volume and area of Los Padres Reservoir at selected stage elevations (NGVD29). Blue cells indicate values influenced by the upper reservoir photogrammetry.

	Volume (af)				Area (ac)		
stage (ft)	2008	2016	2017	stage (ft)	2008	2016	2017
960	0	0	0	960	0.0	0.0	0.0
965	0	5	0	965	0.7	3.2	0.0
970	20	31	11	970	6.0	6.9	4.7
975	58	72	42	975	9.0	9.8	7.7
980	110	128	89	980	11.8	12.2	10.9
985	173	193	149	985	13.3	13.6	13.0
990	244	264	218	990	14.7	15.0	14.3
995	322	344	293	995	16.7	16.9	15.9
1000	411	433	378	1000	18.8	18.6	18.0
1005	509	530	472	1005	20.8	20.5	19.7
1010	618	639	576	1010	23.2	23.2	22.0
1015	747	766	695	1015	30.7	28.5	25.7
1020	918	927	838	1020	37.5	35.4	32.8
1025	1117	1117	1015	1025	41.5	41.1	38.0
1030	1334	1332	1217	1030	44.7	44.9	42.6
1035	1563	1565	1448	1035	47.1	47.7	47
1040	1803	1810	1679	1040	50.0	51.1	51.6

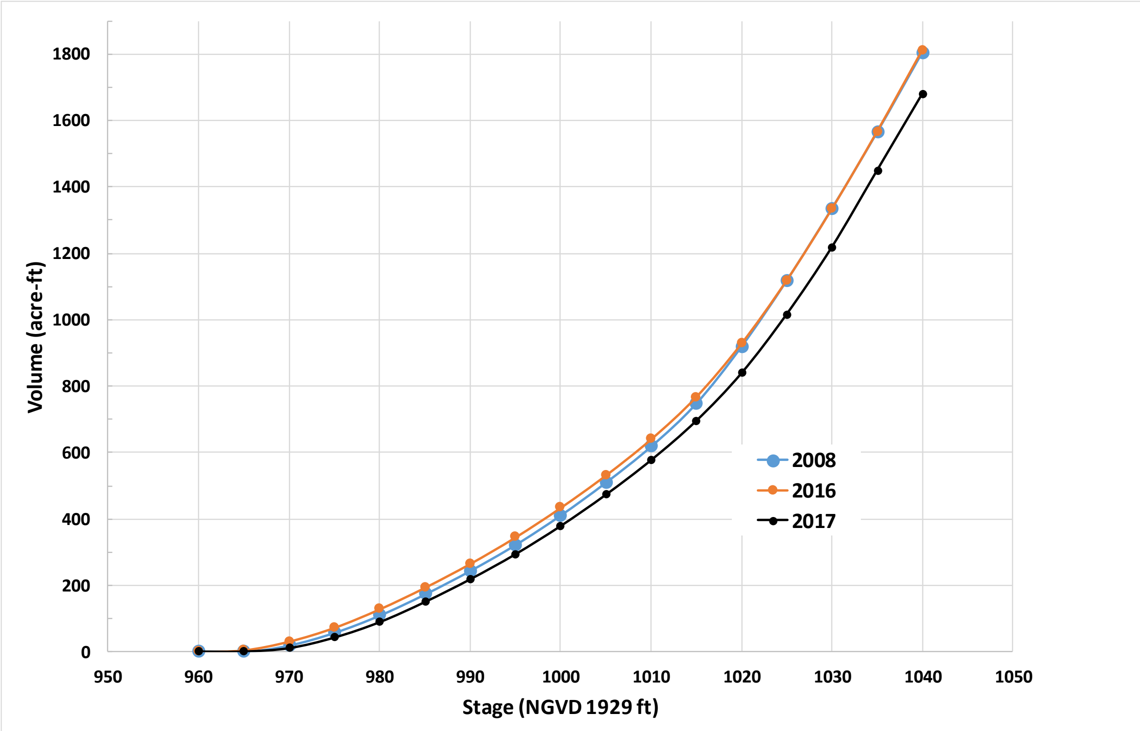

Figure 12: 2017 stage and volume in Los Padres Reservoir

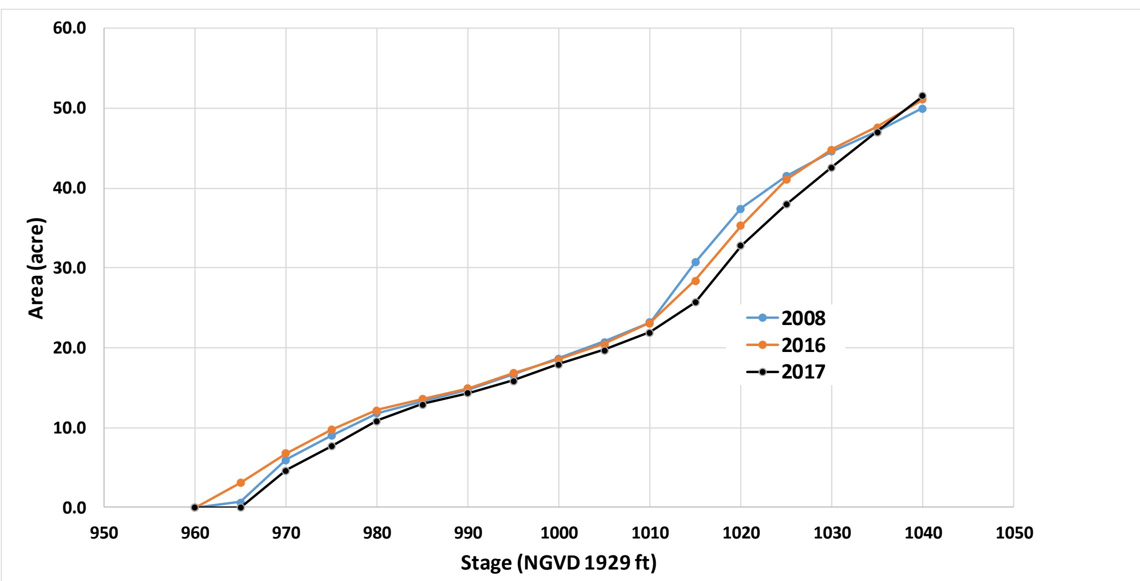

Figure 13: 2017 stage and area in Los Padres Reservoir

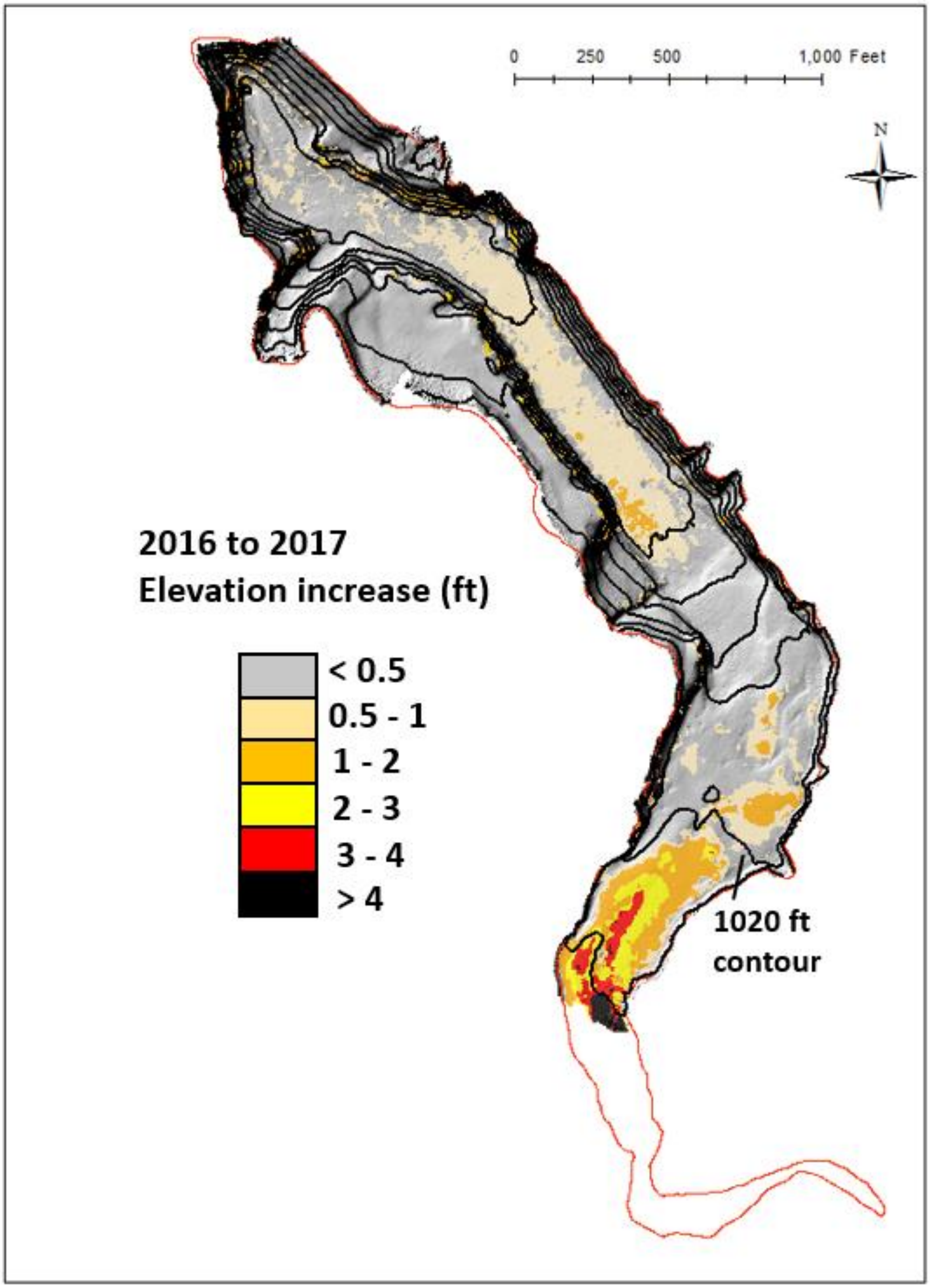

Figure 14: Elevation change between 2016 and 2017 plotted on 2017 hillshade.

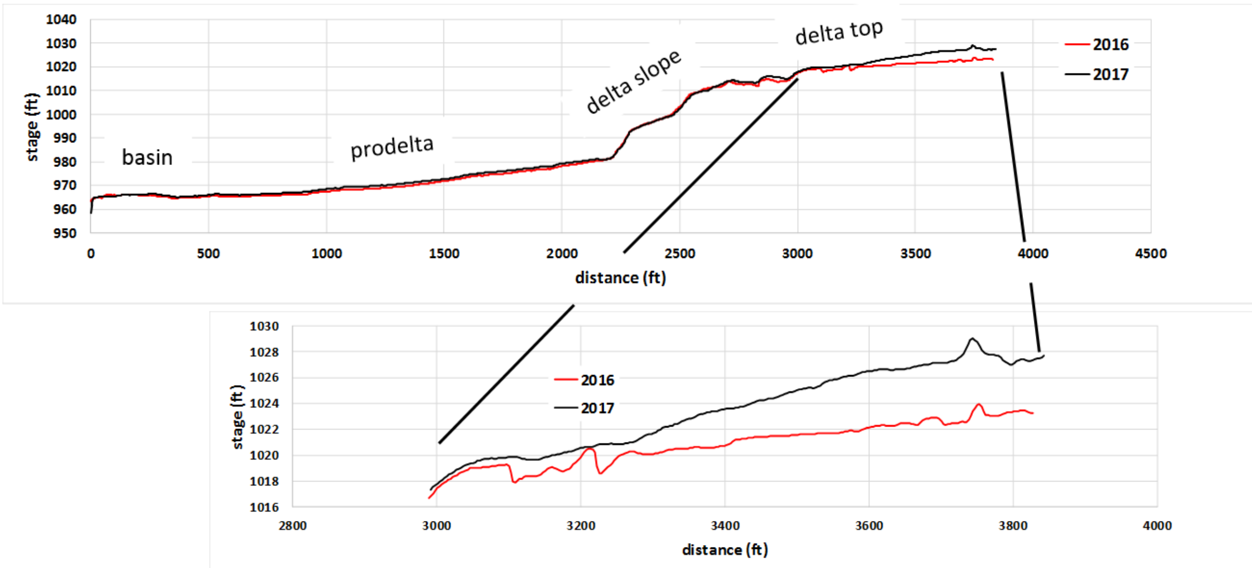

Figure 15: Longitudinal profile of thalweg from the basin to start of delta top. Delta top is enlarged in lower panel.

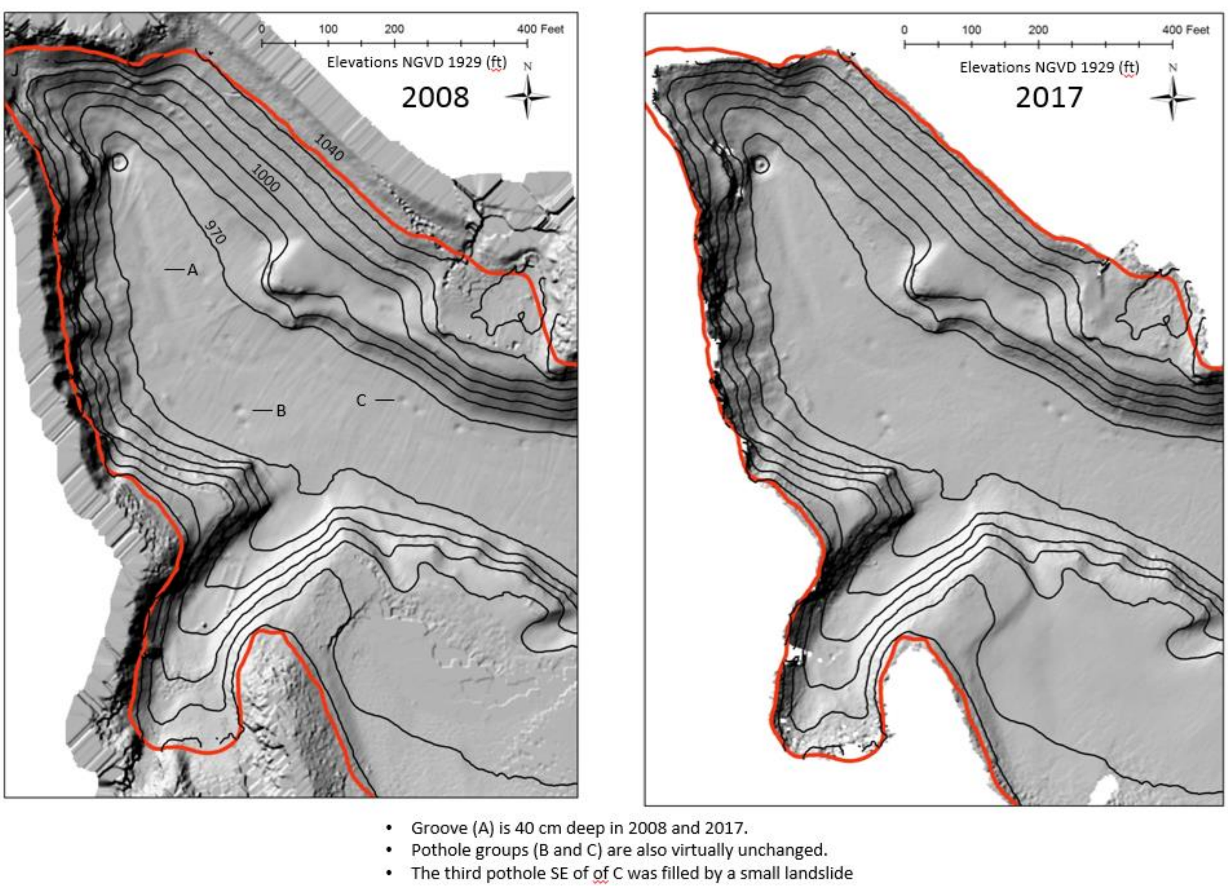

Figure 16: Hillshade of dam and deep basin floor. Shallow depressions in basin floor surveyed in 2008 are virtually unchanged in 2017. Hillshades are from 50 cm pixel DEMs.

4 Discussion

Through combined bathymetric and topographic surveys, we estimate the 2017 Los Padres Reservoir capacity to be 1679 af below the 1040 ft spillway elevation. This value represents a 7% decrease from 2016 (Table 2). While our survey reports capacity loss only below the 1040 ft. stage, there is likely only very little additional sediment storage located upstream of the 1040 ft contour. The valley is constricted to less than 40 m wide, which greatly limits accommodation space for sediment accumulation. Further, the 2017 up-valley extent of the 1040 ft contour line matches the extent published in 2016 (Olden, 2016), indicating that very little accumulation occurred in that part of the valley.

Since inception, the reservoir capacity has dropped from 2709 af to 1679 af, a loss of 1030 af. The combined losses ascribed to the Marble Cone Fire (550 af) and Soberanes Fire (131 af) sum to 681 af. Therefore, 66% of the total capacity loss

(100% x (681 af /1030 af)) = 66%

can be ascribed to just two fire events in the 68 year history of the reservoir. While fire is clearly a critical factor in reservoir lifespan, it is also clear that post-fire rainfall patterns are equally important. Apparently, the large and intense Basin Complex Fire resulted in no measurable capacity loss because it occurred before several drought years. Likewise, the Marble Cone and Soberanes Fires produced significant capacity loss because they preceded relatively wet years directly followed those events (Figs 4 and 5).

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