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Bathymetric and geophysical surveys of Englebright Lake, Yuba-Nevada Counties, California

by

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INTRODUCTION

Harry L. Englebright Lake (Englebright Lake, Figure 1) is a 9-mile-long (14-kilometer) reservoir located in the Sierra Nevada foothills of northern California on the Yuba River gorge known as The Narrows. The reservoir is impounded by Englebright Dam (photo, page 3), a concrete arch structure spanning 348 meters (1,142 feet) across and 79 meters (260 feet) high. The dam was constructed in 1941 for the primary purpose of trapping sediment derived from anticipated hydraulic mining operations in the Yuba River watershed. Hydraulic mining in the Sierra Nevada was halted in 1884 but resumed on a limited basis until the 1930's under the regulation of the California Debris Commission. Although no hydraulic mining in the upper Yuba River watershed resumed after the construction of the dam, the historical mine sites continued to contribute sediment to the river. Today, Englebright Lake is used primarily for recreation and hydropower. In 2001 and 2002, the U.S. Geological Survey (USGS) conducted bathymetric, geophysical, geophysical, and geological studies of the reservoir under the auspices of the Upper Yuba River Studies Program (UYRSP), a multi-disciplinary investigation into the feasibility of introducing anadromous fish species to the Yuba River system upstream of Englebright Dam. A primary purpose of these studies was to assess the quantity and nature of the sediment that has accumulated behind the dam over the past 60 years. This report presents the results of those surveys, including a new bathymetric map of the reservoir and estimates of the total accumulated sediment volume.

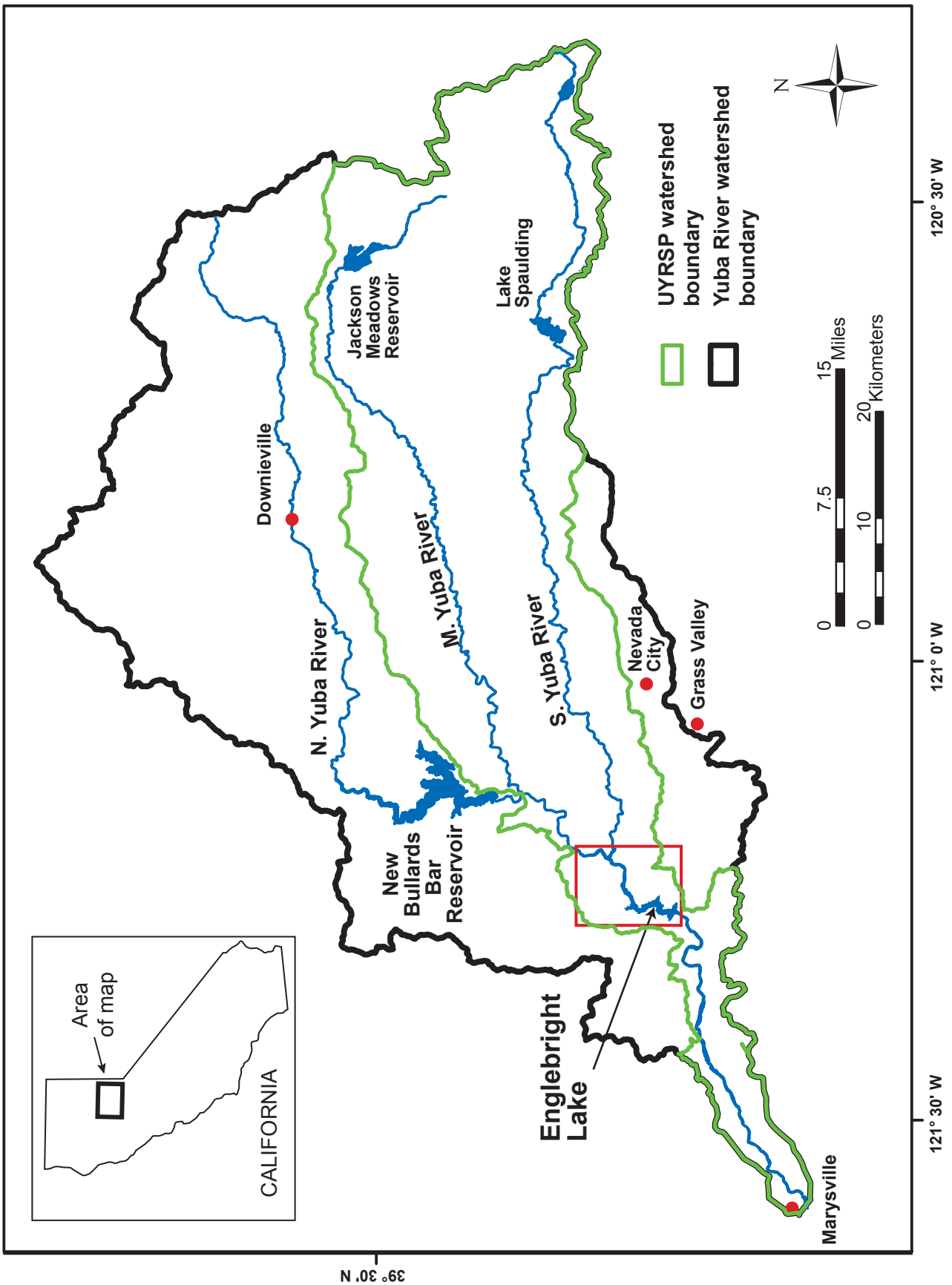

Figure 1: Upper Yuba River Watershed Studies Program (UYRSP) area. Small rectangle (in red) around Englebright Lake shows the geographic limits of the maps in this report.

The UYRSP is funded by the CALFED Bay-Delta Program, whose mission is to "develop and implement a long-term comprehensive plan that will restore ecological health and improve water management for beneficial uses of the San Francisco Bay-Delta System".

FIELD PROGRAMS

Bathymetric surveys

The principal bathymetric survey (USGS Field Activity ID F-1-01-NC) was conducted in May, 2001, using the R/V Fast Eddy, a 22-foot Boston Whaler (photo, page 4). The boat was equipped with a Lowrance LMS-130 digital fathometer, and CSI DGPS Max global positioning system (GPS) satellite receiver. All data were logged with the USGS PC-based data acquisition package YoNav.

The CSI DGPS Max receiver is capable of operating in Differential (DGPS) and Wide Area Augmentation System (WAAS) modes, both of which are available in the Englebright Lake vicinity. (WAAS reception was, however, sporadic in the uppermost reaches of the reservoir, probably due to steep terrain.) The DGPS Max receiver has a manufacturer-specified horizontal accuracy of less than 1 meter (95%) in DGPS mode; WAAS results are somewhat more accurate. Survey quality (centimeter accuracy, post-processed) positional data were simultaneously acquired during the survey using

Ashtech GPS receivers and surveyed base stations. In subsequent analysis, the higher precision positioning proved unnecessary, and all data in this report were located using the DGPS or WAAS results.

The Lowrance fathometer operates at a frequency of 192 kHz, and outputs digital depths with a precision of 10 centimeters (4 inches). However, because calculated water depth requires an assumption about the velocity of sound through water, the accuracy of the measurements was poorer than the instrument precision, and varied with water depth. The Lowrance fathometer uses a constant value of 1,463 meters/second (4,800 feet/second) for sound velocity.

The level of the reservoir varies due to releases from the dam and variable inflow. All measured depths were adjusted for reservoir level variation, which is monitored by the US Army Corps of Engineers and reported on-line at: http://cdec.water.ca.gov/cgi-progs/staMeta?station_id=ENG The 527.0 foot (160.6 meter) spillway elevation of the reservoir represents the vertical datum.

In April, 2002, a second survey program (USGS Field Activity ID F-1-02-NC) was conducted, primarily for the purpose of collecting reservoir bottom sediment samples and grain-size information, and in May, 2002, the reservoir sediments were drilled and continuously cored at 7 locations. In September, 2002, additional geophysical profiles were acquired.

During the second field program, the depth in the deepest area of the reservoir just above the dam was measured with a bottom camera system (called the "flying eyeball"). This instrument consists of a video camera mounted within a steel ball that is lowered to the reservoir bottom with inelastic conducting cable. The cable was marked at the waterline when the camera was at the reservoir bottom according to the video camera, and the distance from the mark to the camera focal point was subsequently

measured, resulting in a depth (uncorrected for reservoir level or vertical datum) of 59.1 meters (193.9 feet) compared to a depth of 59.5 meters (195.2 feet) measured with the Lowrance fathometer, a difference of 0.7%. It is therefore estimated that water depths measured with the fathometer are accurate to better than 60 centimeters (2 feet) in the deepest portion of the reservoir, and to approximately 15 centimeters (6 inches) in the shallower portions.

Reflection profiling

Prior to the field program, it was expected that seismic reflection profiling would be able to image the post-dam sediment accumulation and stratigraphy, down to the pre-dam river bed and perhaps even reveal the pre-dam river sediment to the bedrock interface. Several profiling methods were used to attempt to image the reservoir sediments. In 2001, Geopulse and Bubble Pulser sources were employed, received with both a short single-channel hydrophone streamer and a Seistec line-in-cone array. In 2002, an Edgetech 512 Chirp profiler was tested in the reservoir. The results of all profiling was similar: the reservoir bottom appears to be acoustically impenetrable. The only reflection events that can be reliably interpreted are the reservoir bottom, and the subsequent multiple reverberations from the reservoir bottom. No reflection events within or at the base of a sediment package could be identified.

This surprising result remains unexplained. One possible explanation is a high concentration of biogenic gas in the sediment. The reservoir sediments are clearly gas charged, as evidenced by the frequent observance of gas bubbles in the reservoir. A uniformly high gas content would create a large acoustic impedance at the reservoir bottom, severely limiting the amount of transmitted energy. The geometry of the reservoir, consisting of a narrow and steep-sided canyon, also may degrade the amount of reflected energy returned.

PRIOR STUDIES

Pre-dam survey

Topographic maps of the reservoir area with pre-dam elevations are on file at the U.S. Army Corps of Engineers offices at the reservoir headquarters. These 1:4800 maps are contoured at a 20-foot interval between 300 and 500 feet, and at a 10 foot interval between 500 and 600 feet.

Swath bathymetry at dam

In March, 1998, the engineering firm Chris Ransome & Associates Northwest (CRA-NW) was subcontracted by Bookman-Edmonston Engineering to conduct a swath bathymetry and subbottom profile survey of the reservoir in the area immediately upstream (about 500 feet, or 152 meters) of the dam. That survey reported a reservoir bottom elevation of between 330 and 335 feet (101 and 102 meters), which is slightly higher than the 325 to 327 foot (99.1 to 99.7 meter) elevation reported here. The CRA-

NW used an average sound velocity of approximately 4,724 ft/s (1,440 m/s) (ranging between 4,718 and 4,767 ft/s or 1,438 and 1,453 m/s), compared with the constant velocity of 4,800 ft/s (1,463 m/s) used by the Lowrance fathometer. This 1.5% difference in the water velocity could account for a depth difference of 3 feet (90 centimeters) in 200 feet (61 meters) of water. The CRA-NW data were not incorporated into any of the results in this report.

CRA-NW also acquired subbottom profile data in a small area immediately behind the dam. Those results showed sediment thickness up to 50 feet (15 meters) in the channel 500 feet (152 meters) upstream of the dam. The CRA-NW report acknowledged the difficulty of profiling in the reservoir, although surprisingly it concluded that there was little or no biogenic gas present in the reservoir sediments.

RESULTS

Bathymetric map

Approximately 18,500 depth points along the ship tracklines shown in Figure 2 were used to construct the surface of the reservoir floor. In the upstream end of the reservoir (on both the Yuba River and South Yuba River arms), the water was too shallow to survey. In each of these two areas, an artificial set of depth points (shown as green symbols in Figure 2) was estimated by linear interpolation along the river thalweg from the end of the boat survey to the point upstream on the pre-dam topographic map where the river bed elevation equals the dam spillway datum (160.6 m, 527.0 feet). These irregular x,y,z data points were gridded at approximately 6-meter (20-foot) grid interval using the blockmedian and surface algorithms in Generic Mapping Tools. The blockmedian algorithm filters and grids the input (x,y,z) data using L1 norm, and surface creates a continuous curvature surface. A tension value 0.4 was used in the surface process. The resulting reservoir bathymetry is shown in Figure 3.

Predam elevation model

The pre-dam topographic sheets encompassing the reservoir were scanned and the elevation contours from 300 to 550 feet vectorized using the Golden Software product Didger 3. The vectorized contours were then transformed from US State Plane 1927, California II coordinates to geodetic latitude, longitude, WGS 1984 using the Blue Marble Geographics product Geographic Calculator. These vectorized contours were then gridded and smoothed using the TOPOGRID function within the ESRI Arc Geographic Information System (ArcGIS). To create a hydrologically correct elevation model, a pre-dam river thalweg estimated from the pre-dam contour maps was also input to the TOPOGRID algorithm. The resulting pre-dam elevation grid (with 16-ft, or 5-m, cells) is shown in Figure 4.

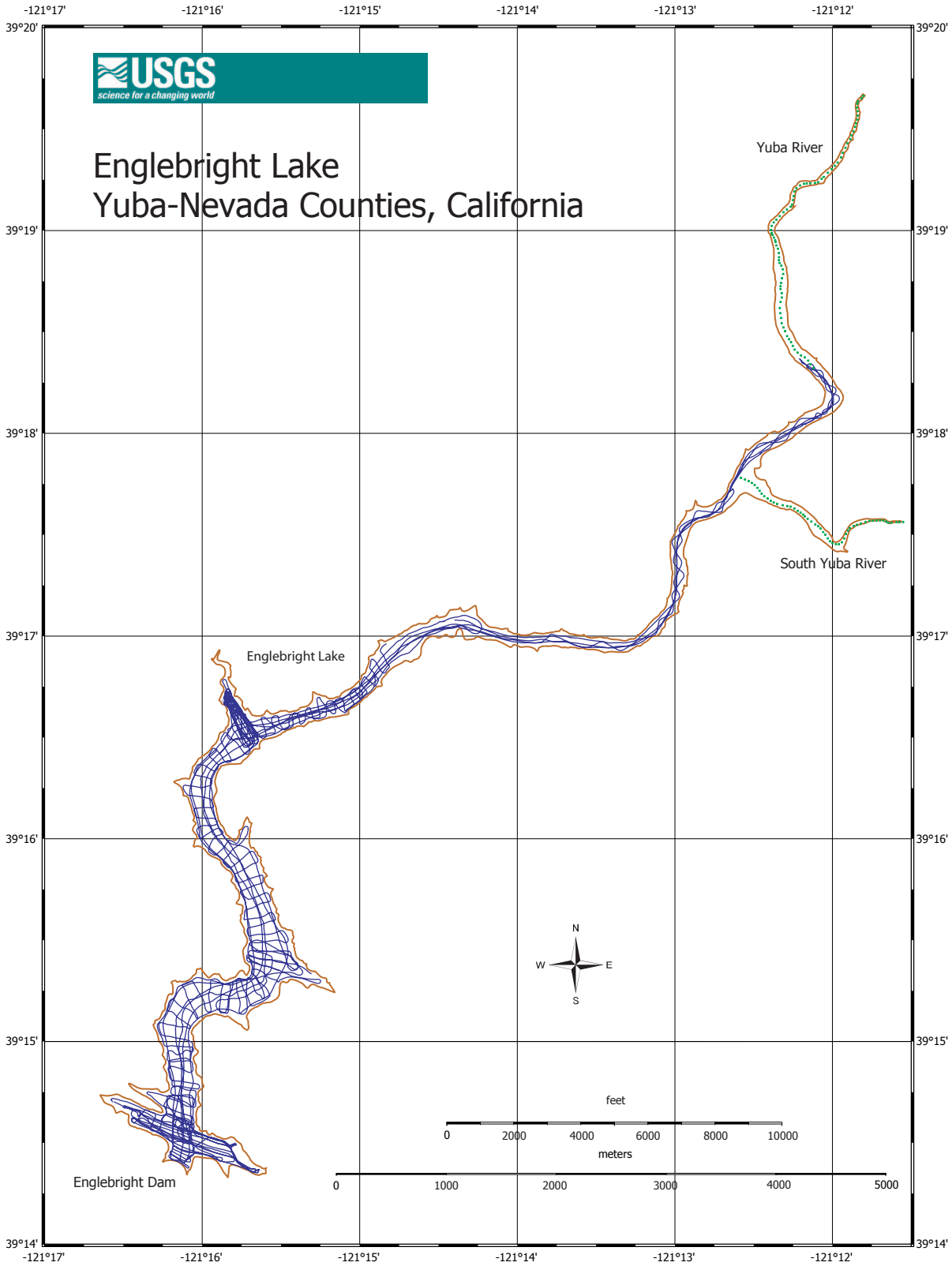

Figure 2. Boat tracklines (in blue) along which reservoir depth (bathymetry) measurements were made. Cross symbols in the South Yuba River and northern reach of the Yuba River (in green) indicate points where water depth was extrapolated along the pre-dam thalweg for gridding purposes.

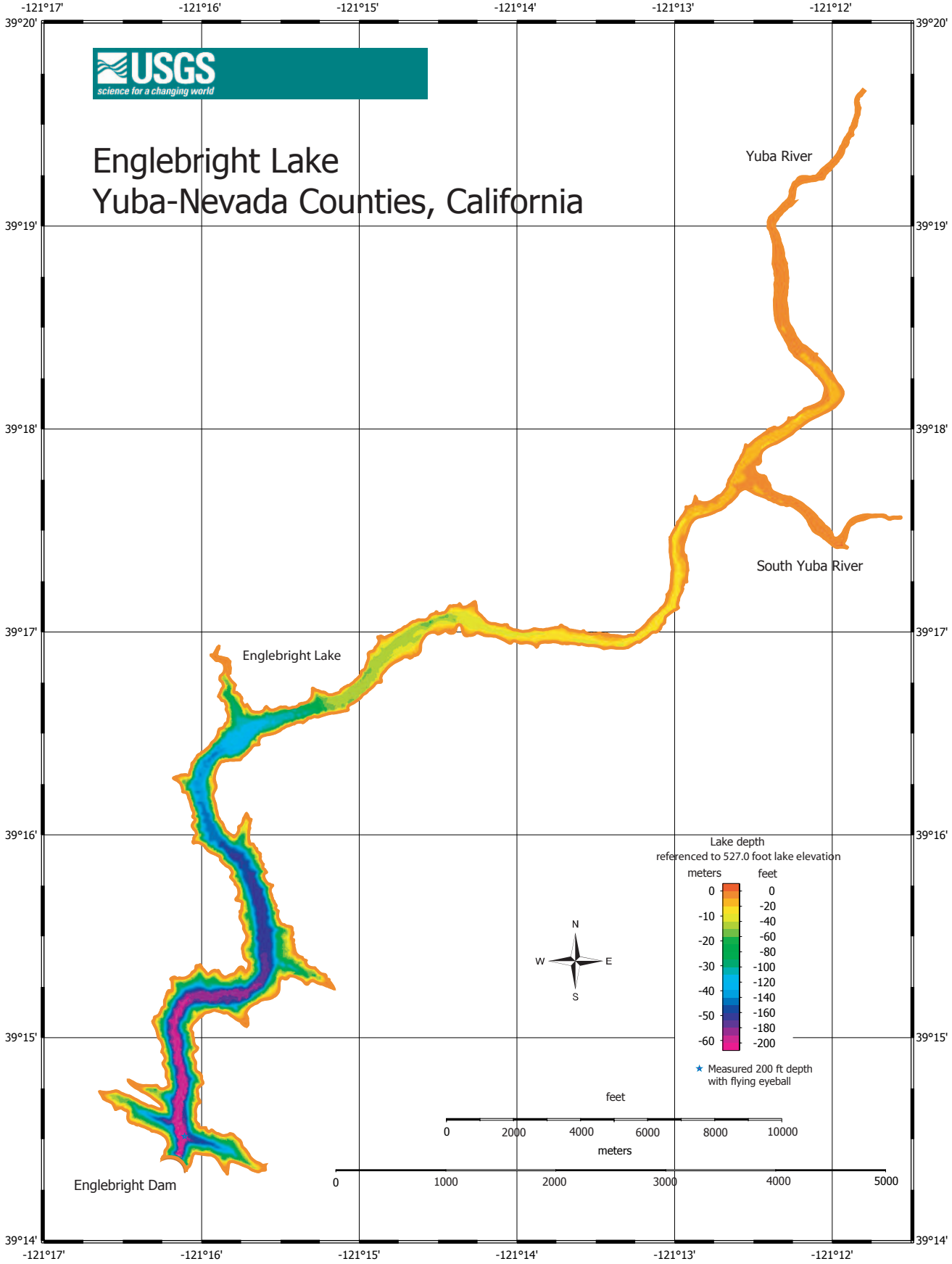

Figure 3. Bathymetry of Englebright Lake in May, 2001.

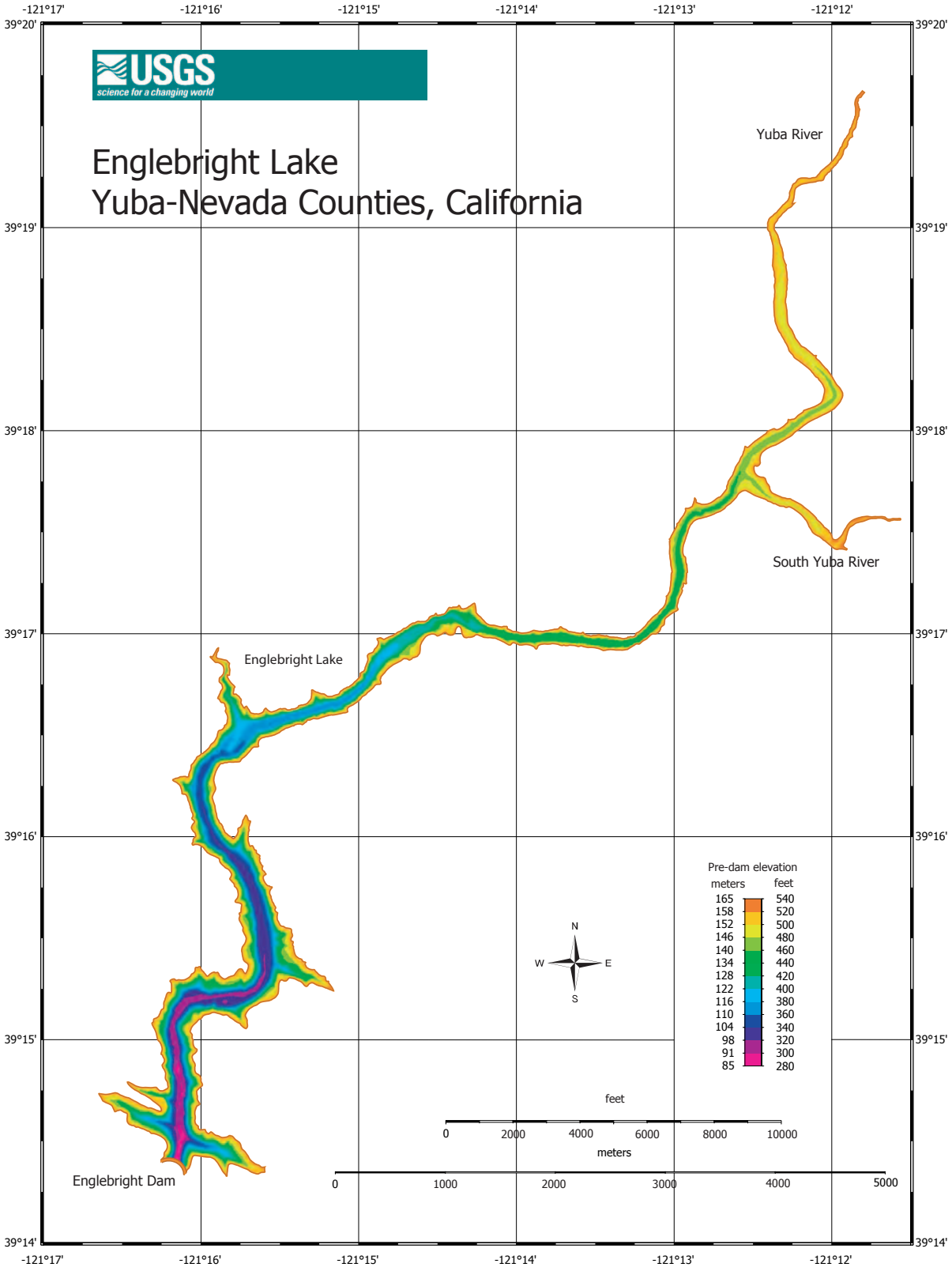

Figure 4. Pre-dam elevations from survey by U.S. Army Corps of Engineers (1939).

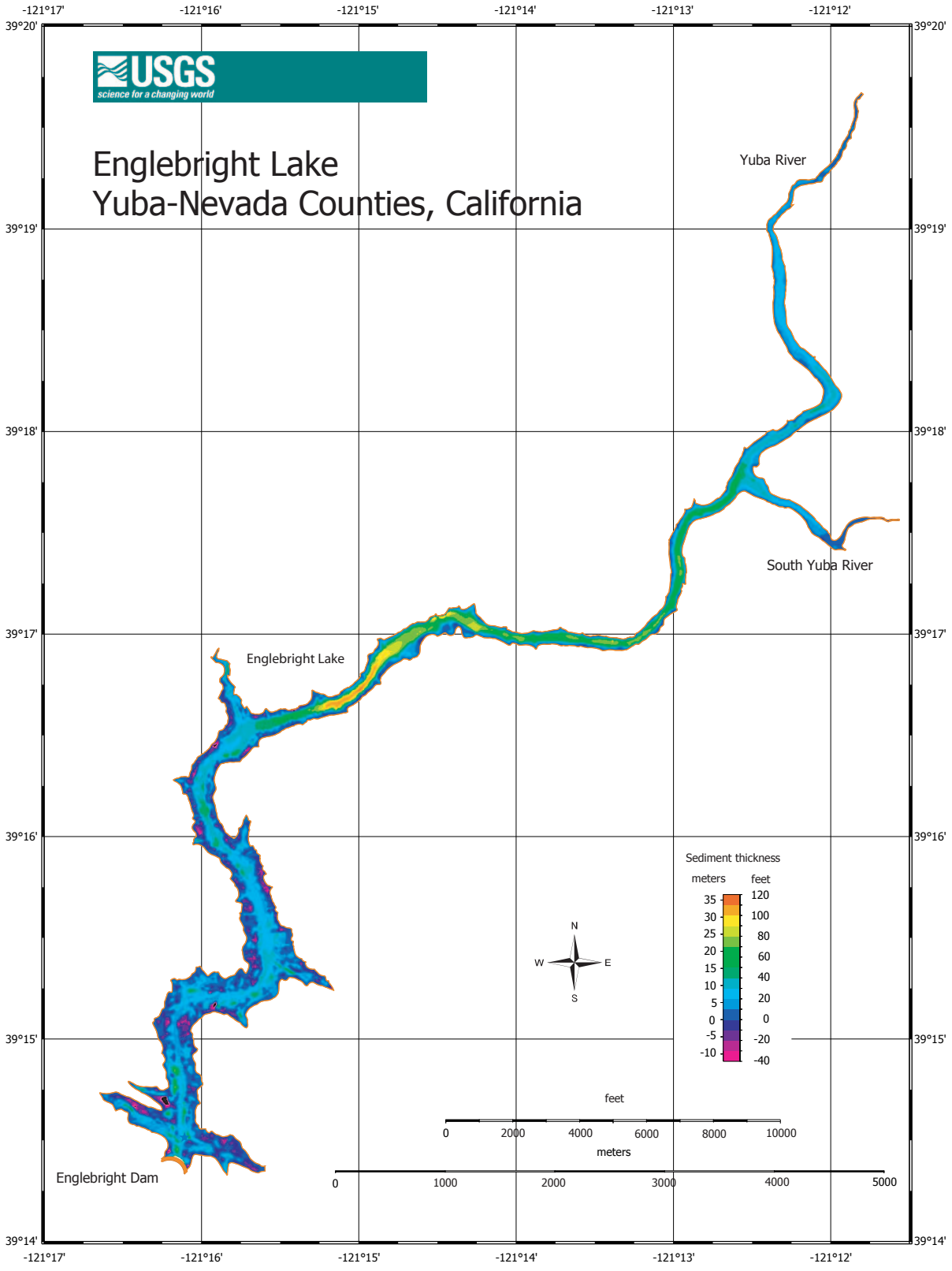

Figure 5. Sediment accumulation and erosion between 1941 and 2001.

Sediment thickness

The bathymetric and pre-dam elevation surfaces were calculated on coincident grids, so calculation of sediment thickness (isopach) was accomplished by simple grid subtraction. The resulting isopach map is shown in Figure 5. The figure clearly shows that the sediment is thickest (35 m; 115 ft) in the middle of the reservoir, and thins to between 20 and 33 ft (6 to 10 m) in the lower reach of the reservoir, including the area near the dam.

The vertical structure of the deposit is more clearly visualized on the longitudinal profile shown in Figure 6, where the pre-dam and reservoir floor surfaces have been extracted along the pre-dam Yuba River thalweg. The pre-dam river profile shown in Figure 6 includes the locations of the points where the thalweg crossed the original contour lines (every 10 or 20 feet in elevation). The excellent correspondence of the profile with these locations indicates that the TOPOGRID algorithm was faithful to the contour data. The small-scale noise in the profile data (approximately 3 feet, or 1 meter) is the result of sampling the thalweg line with 5-m (16-ft) grid cells. Through the present-day reservoir, the Yuba River had a mean gradient of 0.48%, with a maximum of 1.95% around 7 km (4 miles) from the dam.

The current reservoir-floor surface shown in Figure 6 has considerable small-scale variability - up to 30 ft (9 m) in elevation over distances of 650 to 1000 ft (200 to 300 m). These features may result from a combination of factors: (1) the profile is selected along the pre-dam river thalweg, because no corresponding center line exists for the reservoir floor; (2) the reservoir-floor surface has probably scoured depressions at some locations; and (3) fluvial incision of the upstream part of the deposit during reservoir drawdowns may produce irregular, high-relief surface. In spite of this high-frequency variability, the reservoir-floor profile clearly shows that the deposit has a deltaic form, with a relatively gradual upstream section (mean gradient 0.13%), a steep front (maximum gradient 6.55% over the interval from 5,500 to 5,700 m from the dam), and a lower section that reflects the pre-dam river gradient (0.45%). This form is consistent with sediment accumulation by the growth of a prograding river delta, with the upper part modified by fluvial processes during reservoir drawdowns. This interpretation is supported by preliminary observations of the reservoir sediments from coring data (Snyder and others, 2002), with mostly sand and gravel in the high-energy, fluvial upper part, and silt and clay transported in suspension in the lower part of the reservoir.

Comparison of sediment thickness with sediment coring

In May—June 2002, seven locations in the reservoir were cored and sampled (Table 1; Figures 6-7; Snyder and others, 2002). At each location up to six parallel holes were made, penetrating the entire post-reservoir sediment section at six of the locations. Detailed results of the coring program and analysis of the sampled material will be presented elsewhere. Table 1 shows the locations and compares the reservoir-

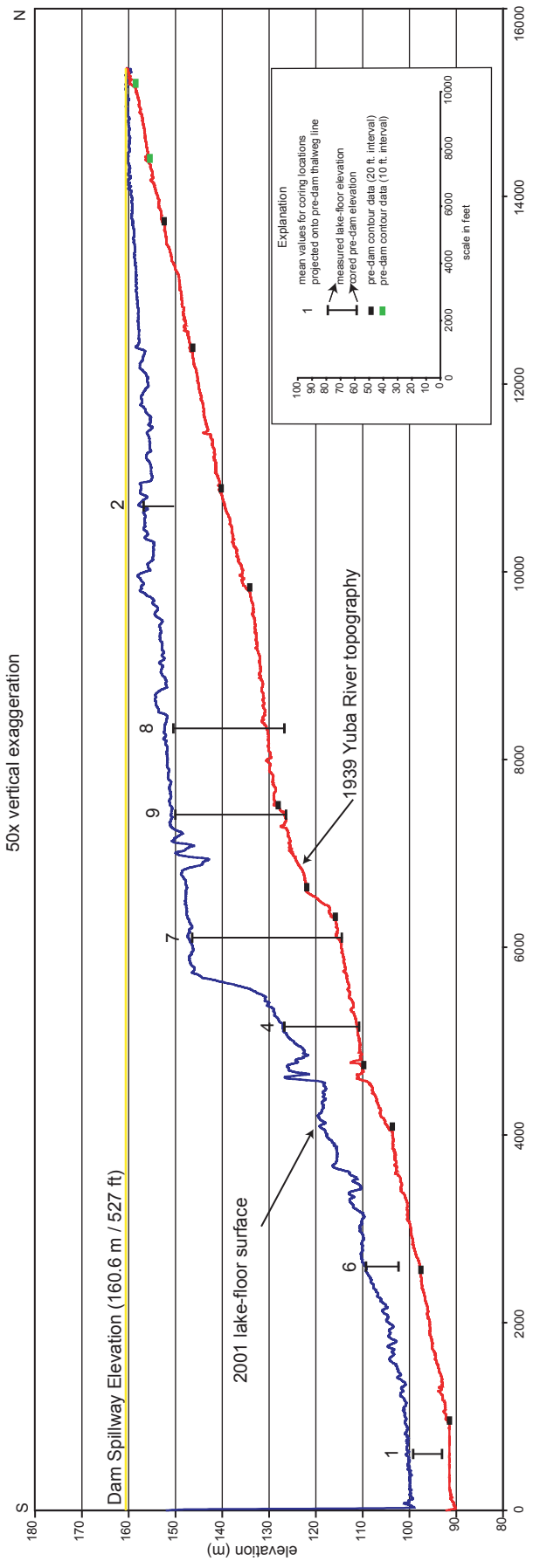

Figure 6: Englebright Lake longitudinal cross section

floor and pre-dam surface elevations for 23 boreholes with values from the bathymetric and pre-dam elevation grids at the same locations. The positions of the boreholes were measured with DGPS by surveying the four corners and center of the drill rig (about 6 m; 20 feet long). The range of estimates of the model values for the holes reflects the values at each of the five DGPS locations on the rig, providing an estimate of the uncertainty in the surface elevation at each hole. The mean cored intervals for each of the seven locations were projected onto the thalweg closest to their location, and plotted on the longitudinal cross section (Figure 6). The thalweg is by definition the deepest part of the pre-dam river, so in every case the value of the pre-dam profile at each coring location is lower than the model values on Table 1.

At each hole the depth from the reservoir surface to the reservoir floor was measured using a weighted rope. These depths were subsequently corrected for changes in the reservoir level (with the assumption that the reservoir surface is flat), and converted to elevations relative to sea level (Table 1). The field-measured reservoir floor elevations are 0.4 m (1.3 ft) higher to 2.3 m (7.6 ft) lower than the corresponding mean grid locations, with a mean difference of -0.9 m (-2.8 ft) and a standard deviation of 0.6 m (2.0 ft). In all but two holes, the measured reservoir floor elevation is lower than the model value from the bathymetric surveys. This systematic discrepancy may be the result of one or both of the following factors: (1) the presence of a transitional fine-grained sediment slurry layer at the sediment-water interface that acts as a reflector for soundings, but was not identified using the weighted rope; or (2) overestimation of the water depth in the field due to the rope line not oriented exactly vertical.

At 20 of the 23 holes, the pre-dam surface was identified by coring to an impenetrable layer, interpreted as the cobbles, boulders and bedrock of the pre-dam river surface (Table 1). In a few cases, sections of rock were recovered in the coring equipment. During coring, efforts were made to locate the boreholes in the thickest sediment sections, along the pre-dam river thalweg. Holes with a particularly large range of pre-dam model surface elevations (>2 m, e.g. 1D, 6D, 7A, 7B, 7C, 8A) penetrated areas on the steep sides of the canyon, not in the flat river valley. The cored pre-dam elevation ranged from 4.3 m (13.9 ft) above to 7.2 m (23.8 ft) below the mean model surface, with a mean difference of -0.4 m (-1.2 ft) and a standard deviation of 3.2 m (10.5 ft). The differences are generally similar at each coring location, with close correspondence between the cored and grid elevations at sites 4 and 9, lower cored elevations at sites 7 and 8, and higher cored elevations at sites 1 and 6. These discrepancies could result from a variety of factors including: (1) uncertainty in the depth of the impenetrable layer identified on the coring rig because of problems with incomplete core extension and/or sediment recovery; (2) imprecision in the original pre-dam contour maps; or (3) small-scale relief on the pre-dam river surface not included on the maps (for example scour holes in the river bed, bars, floodplains, or terraces).

Table 1. Comparison of reservoir coring data with elevation models. Coring sites ordered from downstream to upstream.

site / hole	latitude (WGS84) (degree)	longitude (WGS84) (degree)	measured reservoir floor elevation (m)	cored pre-dam elevation (m)	model reservoir floor elevation, mean (m)	model reservoir floor elevation range (low - high, m)	model pre-dam elevation, mean (m)	model pre-dam elevation range (low - high, m)	measured minus model reservoir floor (m)	cored minus model pre-dam (m)	notes
1A	39.24540	-121.26865	99.3	93.0	100.8	100.7 - 100.9	91.5	91.5 - 91.5	-1.6	1.5	location based on 2 DGPS points
1B	39.24543	-121.26875	99.1	93.3	100.4	100.3 - 100.7	91.5	91.5 - 91.5	-1.3	1.8	
1C	39.24545	-121.26879	99.3	93.4	100.4	100.3 - 100.6	91.5	91.5 - 91.6	-1.1	2.0	
1D	39.24536	-121.26852	99.1	92.3	101.5	100.9 - 102.1	93.4	91.6 - 95.1	-2.3	-1.1	
1 mean	39.24541	-121.26868	99.2	93.0	100.8	100.6 - 101.1	92.0	91.5 - 92.4	-1.6	1.1	site 1 water depths measured w/ fathometer
6A	39.25782	-121.25972	108.4	101.0	109.8	109.6 - 110.0	99.6	98.9 - 100.4	-1.4	1.4	
6B	39.25779	-121.25963	109.2	102.7	110.1	110.0 - 110.2	100.5	99.7 - 101.0	-0.9	2.2	
6D	39.25767	-121.25962	109.3	104.9	110.4	110.0 - 111.1	100.7	99.6 - 102.0	-1.1	4.3	
6E	39.25795	-121.25999	109.6	101.7	109.6	109.6 - 109.7	98.0	97.8 - 98.3	0.0	3.7	
6F	39.25787	-121.25994	109.7	101.3	109.6	109.4 - 109.7	98.3	97.8 - 98.9	0.2	3.0	
6 mean	39.25780	-121.25978	109.3	102.3	109.9	109.7 - 110.1	99.4	98.8 - 100.1	-0.6	2.9	
4A	39.27585	-121.25922	125.4	111.2	127.0	126.9 - 127.1	111.8	111.7 - 112.0	-1.6	-0.7	
4B	39.27599	-121.25928	127.5	110.3	127.1	127.0 - 127.1	111.2	111.1 - 111.4	0.4	-0.8	
4C	39.27597	-121.25933	127.1	110.7	127.1	na	111.1	na	0.0	-0.4	location based on 1 GPS point
4D	39.27600	-121.25933	126.9	110.7	127.1	127.1 - 127.2	111.3	111.1 - 111.5	-0.2	-0.5	
4 mean	39.27595	-121.25928	126.7	110.7	127.1	127.0 - 127.1	111.3	111.3 - 111.6	-0.4	-0.6	
7A	39.27904	-121.24922	146.5	*134.6*	147.1	147.0 - 147.3	123.7	121.1 - 127.2	-0.7	na	did not core to pre-dam surface, hole paired w/ 7B
7B	39.27906	-121.24920	146.5	115.5	147.2	146.9 - 147.3	122.7	121.1 - 124.3	-0.7	-7.2	continuation of 7A
7C	39.27904	-121.24933	146.3	113.4	147.0	146.9 - 147.3	117.7	116.2 - 121.1	-0.8	-4.3	
7 mean	39.27906	-121.24921	146.4	114.4	147.1	147.0 - 147.3	121.4	119.5 - 124.2	-0.7	-5.8	
9A	39.28390	-121.23751	150.0	125.9	150.9	150.9 - 151.0	126.8	126.7 - 127.0	-0.9	-0.9	
9B	39.28389	-121.23766	150.1	126.5	151.0	150.9 - 151.0	126.7	126.7 - 126.7	-0.9	-0.2	
9C	39.28381	-121.23755	149.9	126.6	151.0	150.9 - 151.0	126.5	126.2 - 126.7	-1.0	0.1	
9 mean	39.28387	-121.23757	150.0	126.4	151.0	150.9 - 151.0	126.7	126.5 - 126.8	-0.9	-0.3	
8A	39.28268	-121.22710	150.4	126.4	151.1	151.1 - 151.2	133.3	132.0 - 134.6	-0.7	-6.9	
8B	39.28277	-121.22717	150.6	*140.5*	151.5	151.4 - 151.5	131.2	131.0 - 131.4	-0.9	na	did not core to pre-dam surface, hole paired w/ 8C, location assumed to be approximately the same as 8C
8C	39.28277	-121.22717	150.3	127.0	151.5	151.4 - 151.5	131.2	131.0 - 131.4	-1.2	-4.2	continuation of 8B
8 mean	39.28266	-121.22710	150.4	126.7	151.4	151.3 - 151.4	131.9	131.4 - 132.5	-0.9	-5.5	
2B	39.29522	-121.21050	156.8	*150.5*	157.5	157.2 - 157.9	139.4	139.7 - 139.3	-0.7	na	did not core to pre-dam surface
							overall mean		-0.8	-0.4	
							overall standard deviation		0.6	3.2	

Explanation: *Italics indicate that the pre-dam surface was not reached, these values are not included in means.* na, not applicable.

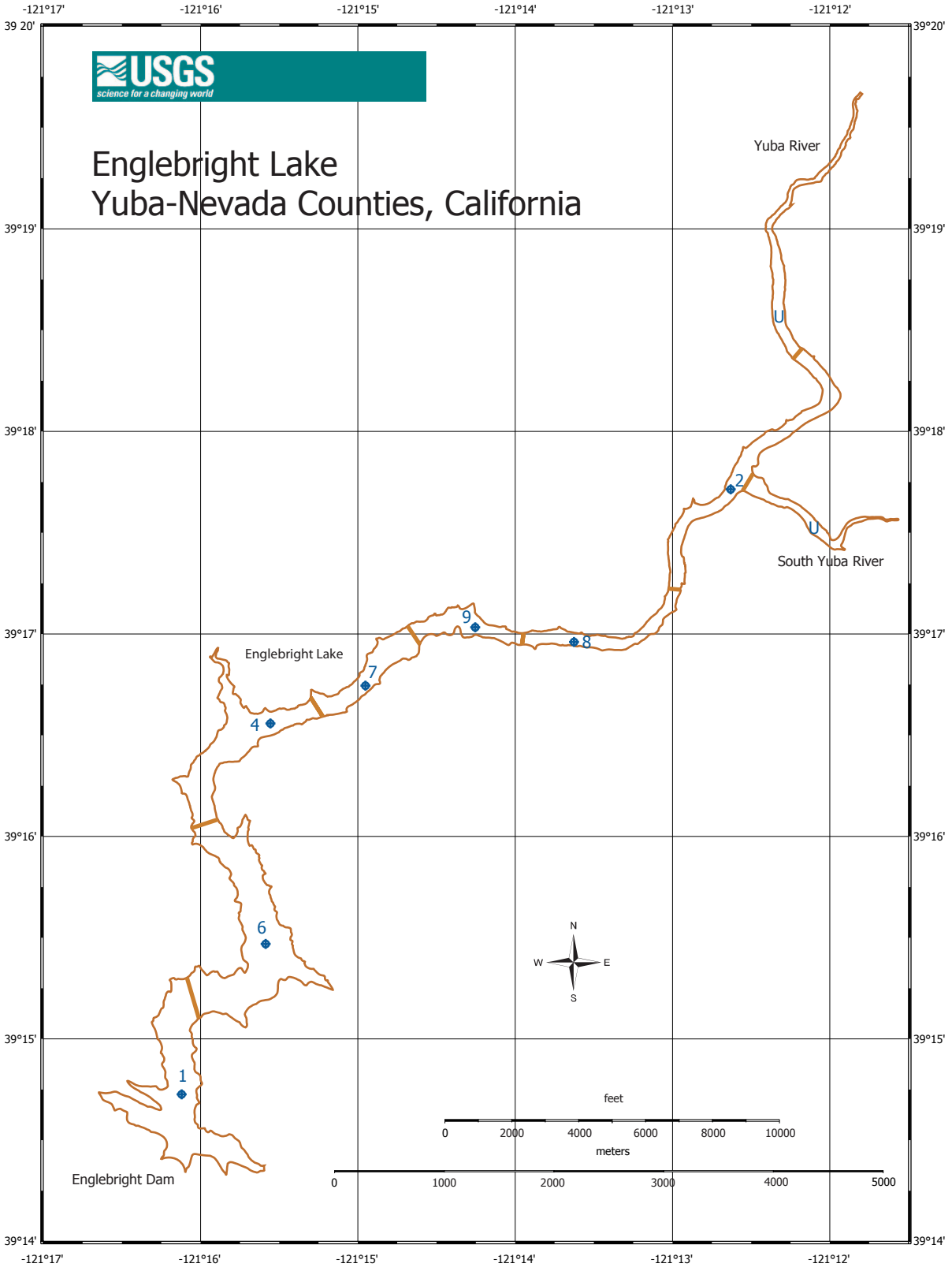

Figure 7. Coring locations and regions for volume estimates.

Sediment volume calculations

Using the midpoints between the seven coring locations, seven regions of the reservoir were defined for the sediment volume calculation (Figure 7). An eighth region (U) was defined to include the shallowest, unsurveyed areas; for these unsurveyed reaches of the Yuba and South Yuba Rivers, the water depth was extrapolated to 0 at the 527 foot (160.6 meter) elevation. Table 2 shows the volume, area, and reach of the regions of the reservoir. To calculate the sediment volumes and region areas, the reservoir was divided into nine polygons using ArcGIS. The reach lengths for each region were calculated along the pre-dam river thalweg. The original volume of the reservoir (calculated using the pre-dam elevation model) is 85,970,000 cubic meters (69,700 acre-feet), which compares well with the storage capacity of the reservoir of 86,000,000 cubic meters (70,000 acre-feet) published at http://cdec.water.ca.gov/misc/resinfo.html.
Because the reservoir now contains 21,890,000 cubic meters (17,750 acre-feet) of sediment (Table 2), the storage capacity has been reduced by 25.5%.

Table 2. Sediment volume calculations. Regions ordered from downstream to upstream.

Region	reach (m)	area (m^2)	volume (m^3)	volume (acre-feet)	average thickness (m)
1	1,595	739,000	2,420,000	1,960	3.3
6	2,252	857,000	3,410,000	2,770	4.0
4	1,761	474,000	2,910,000	2,360	6.1
7	1,145	232,000	3,470,000	2,820	15.0
9	1,110	175,000	2,260,000	1,830	12.9
8	1,646	187,000	2,380,000	1,930	12.7
2	3,029	378,000	3,470,000	2,810	9.2
U	4,553*	306,000	1,570,000	1,270	5.1
Total		3,348,000	21,890,000	17,750	
reservoir capacity			85,970,000	69,700	

* Includes both the Yuba River and South Yuba River.

Figure 8 shows transverse cross sections of the reservoir-floor and pre-dam elevation models at each of the seven coring locations (Figure 7). On several of these cross sections the pre-dam surface is above the reservoir-floor surface, indicating apparent net erosion of the valley walls during the post-impoundment period. Similar

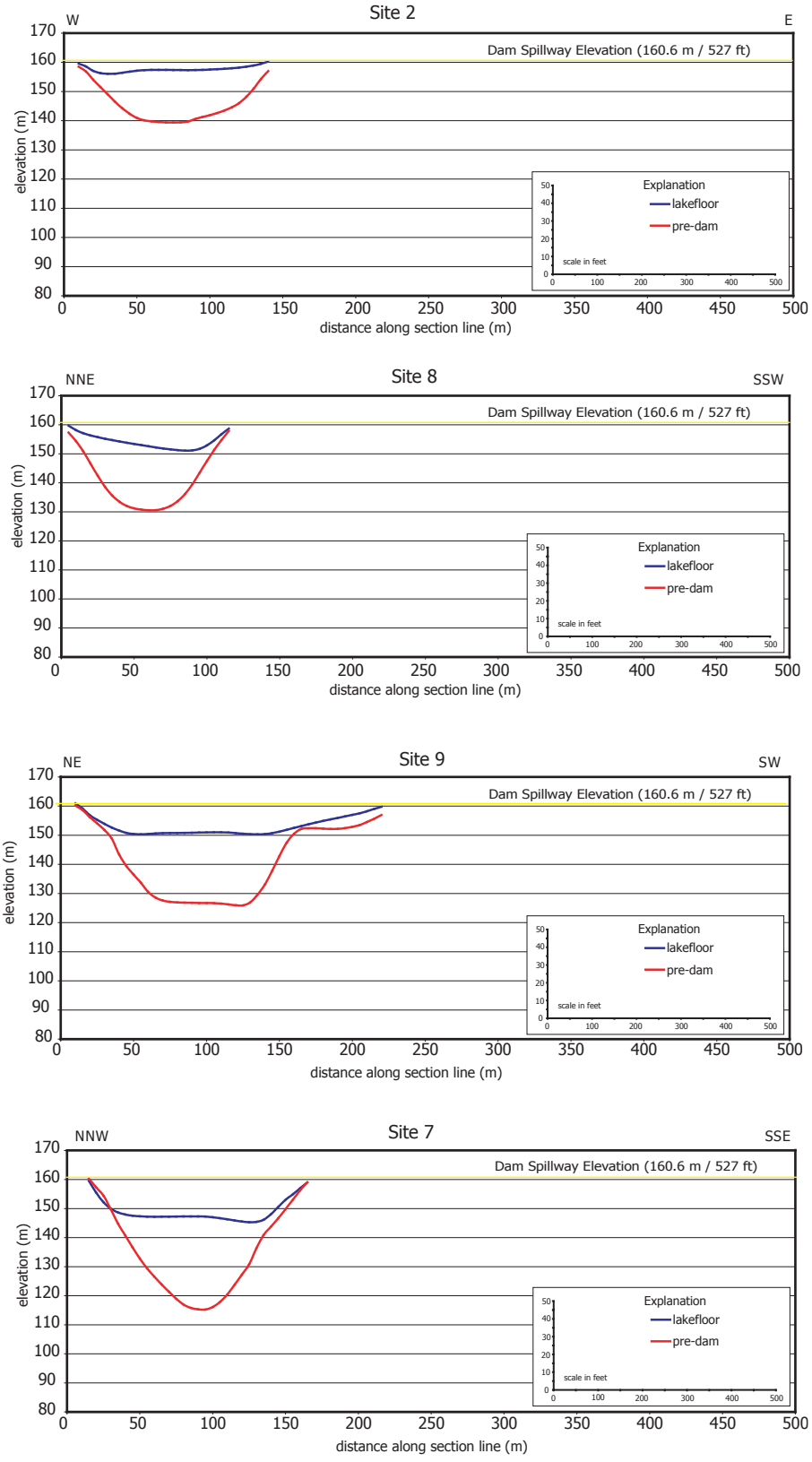

Figure 8a. Transverse cross sections of lake floor and pre-dam elevation models at coring locations, from upstream (Site 2) to downstream (Site 1). 2X vertical exaggeration.

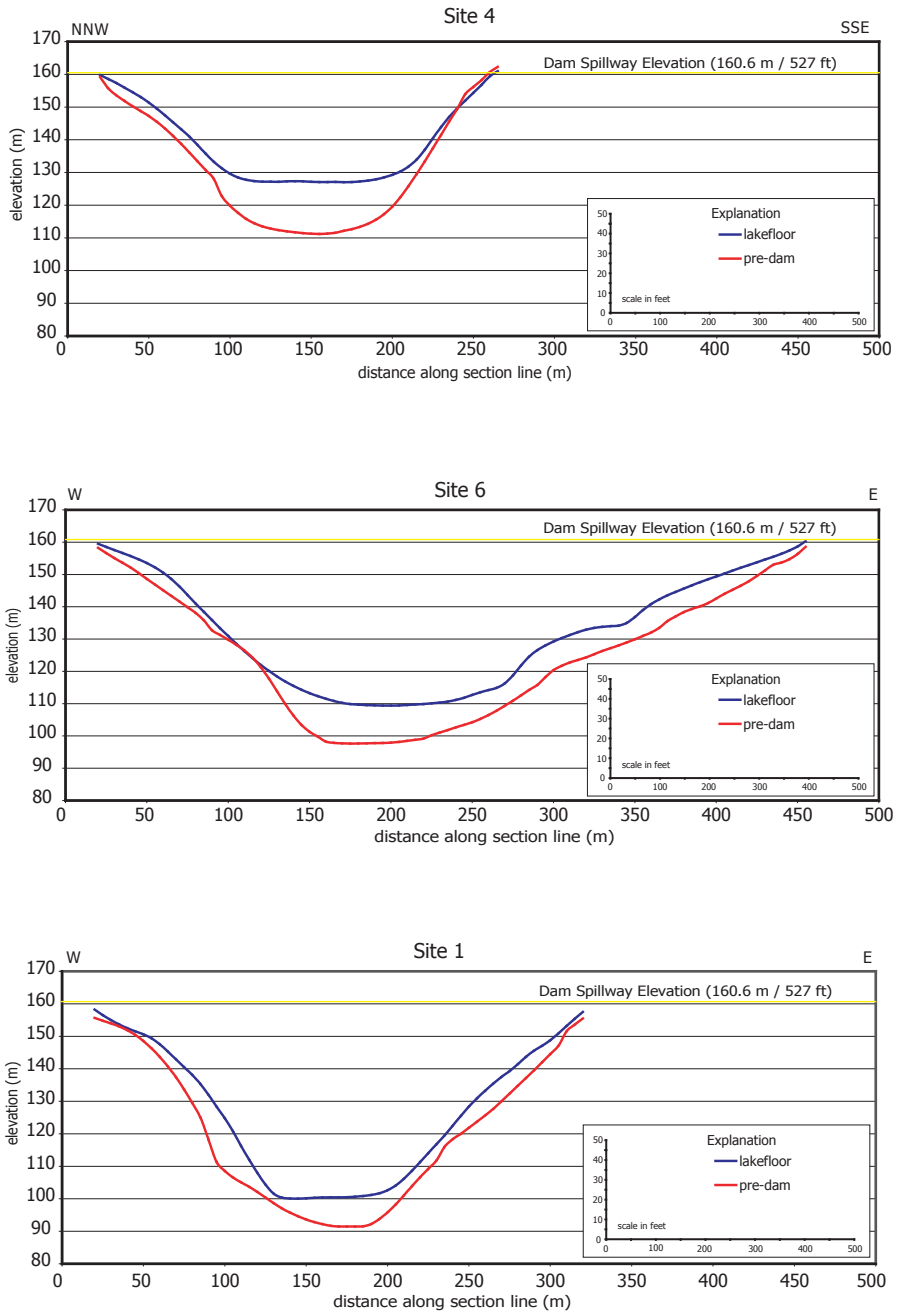

Figure 8b. Transverse cross sections of lake floor and pre-dam elevation models at coring locations, from upstream (Site 2) to downstream (Site 1). 2X vertical exaggeration.

areas of apparent net erosion are seen along the sides of the reservoir on Figure 5. While the erosion interpretation is possible, these areas may reflect minor inaccuracies in the original datasets (both horizontally and vertically) or problems with the gridding algorithms used. The total volume of apparently eroded material on the isopach map is 990,000 cubic meters (800 acre-feet), and this gives a sense of an upper bound on the size of potential error in the sediment volume calculations (4.5%).

FUTURE WORK

The USGS is planning to remap the reservoir bathymetry using a phase-discrimination wide-swath sonar system. This mapping produces both continuous swath bathymetry with a lateral resolution of better than 20 cm (8 in), as well as sidescan backscatter images. Another attempt to image the subbottom by seismic reflection profiling using different acoustic sources is also under consideration.

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