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Bathymetry and Sediment Classification of the Klamath Hydropower Project Impoundments

Prepared for

PacifiCorp

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ABSTRACT

Bathymetric surveys were conducted on Lake Ewauna, Keno Reservoir, JC Boyle Reservoir, Copco Reservoir, and Irongate Reservoir. A supervised sediment classification was also conducted on each of these impoundments. A general assessment of the magnitude of accumulated sediment in the impoundments was conducted by comparing the current bathymetry of the impoundments with available information on pre-impoundment topography. The results indicate the sediment accumulation in the impoundments is relatively modest, generally ranging from 5 to 15 percent of the current volumes.

INTRODUCTION

Knowledge of lake morphometry provides critical information for understanding and managing lakes and impoundments. The information provides data on maximum depth and mean depth which are necessary for understanding lake stratification and functioning of biological and chemical dynamics in stratified and mixed systems. The information on lake area combined with depth provides knowledge of lake volume, which when combined with hydrological data, allows for calculation of hydraulic residence time.

Another important factor in managing lakes and impoundments is knowledge of the sediments. Sediments have the potential to strongly influence the chemistry of the water column through various diagenetic processes. Sediments can be especially important in impoundments because of the high trapping efficiency of lakes and their obvious location on riverine systems. High rates of sediment accumulation can lead to premature in-filling of impoundments with considerable loss in usable capacity for storage and hydropower production.

The primary purpose of this project was to provide information on the current bathymetry of the impoundments in the Klamath Hydropower Project Area (Figure 1). A second objective was to provide information on the nature and distribution of the sediments in the impoundments.

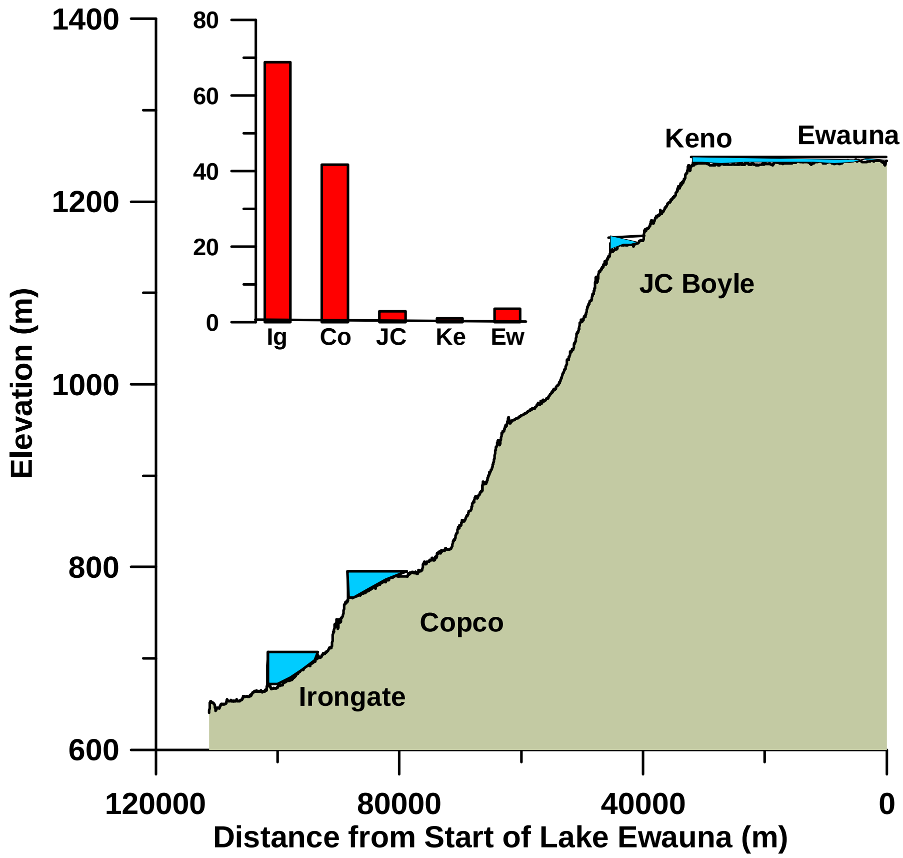

Figure 1. Diagram of Klamath Hydropower Project area illustrating the position of the impoundments and relative distances. The X axis is distance from the start of Lake Ewauna (m) and the Y axis is elevation (m). The inset bar chart shows the volume of the reservoirs (x 10^7 m^3).

METHODS

Bathymetry of the study impoundments was collected using a Simrad EK 120 KHz split-beam hydroacoustic echo sounder mounted on the bow of a 19 ft Workskiff vessel. A DGPS unit with a reported precision of < 1m was placed directly over the transducer. The operational error in the DGPS during the course of the survey was substantially less than the reported error, averaging closer to 20-30 cm. The acqusition rate for the hydroacoustics was set at six pings per second with a nominal boat speed of 10 kph. Data from the hydroacoustic unit was interlaced with the DGPS into a real-time Access database. Field acquisition work for the bathymetry was conducted October 21-27, 2001. Supplemental work on the laser edge-of water was conducted March 10-13, 2002. Substrate sampling was conducted March 10-15, 2002.

Transect distances were originally set at 75 m intervals. However, based on inspection of the study sites, a uniform transect density of 50 m was employed. The transect paths were superimposed on a digital outline of the study sites and the boat operator followed the prescribed paths, except where navigation impediments required adjustments.

The location of the shoreline was measured with a Laser Advantage laser rangefinder linked with the same DGPS used for the bathymetry. The laser measures distance and bearing, allowing the position of each recorded measurement to be determined, generally within about 1m. The laser edge-of-water data were edited to remove spurious measurements and the resulting digital shoreline was check against the USGS 10m digital elevation models (DEM) for fit.

In addition to recording depth to substrate, the hydroacoustic signal provides two echoes which can be interpreted to yield information regarding the bottom roughness and bottom hardness. These two echoes were used to generate unsupervised sediment classification maps of the impoundments. Based on the nature of the sediments indicated from the unsupervised sediment classification, sites in each impoundment were selected for sediment sampling. Sediments in each impoundment were sampled using a mini-Glew gravity corer. The upper sediments (defined as less than or equal to 10 cm) were collected and extruded into WhirlPac® bags, labeled, and stored in a cooler. The appearance of the sediment samples was documented with digital images (Appendix A). The sediment samples were sent to the Crop and Soil Science Laboratory at Oregon State University, Corvallis for analysis of percent water, carbon (C), nitrogen (N), phosphorus (P), and particle size analysis (Table 1).

Additional information on the nature of the sediments was derived from direct images of the sediment obtained with a Sea Viewer® infrared underwater camera. The camera was lowered to the sediments and in the case of soft sediments, was lowered into the sediments. An on-board monitor was used to follow deployment of the camera.

The data on particle size analysis and other observations were integrated with the unsupervised hydroacoustic analysis of the sediments by combining hydroacoustic images of similar type to yield a supervised mapped of sediment composition.

Table 1. Sediment analytical methods at the OSU Crop and Soil Science Laboratory.

Analyte	Method Description	Reference
Carbon	CNS Analyzer	Leco mode CNS-2000 elemental analyzer
Nitrogen	CNS Analyzer	Leco mode CNS-2000 elemental analyzer
Phosphorus	RFA methodology	Alpkem Corporation (1986) using the Kjeldahl

		digestion method (Bremner and Mulvaney, 1982)

RESULTS

1. <u>Bathymetry</u>

Bathymetric maps for the Project area are presented in Figures 2-6. Maps of reservoir slopes derived from the bathymetric maps are presented in Figures 7-11.

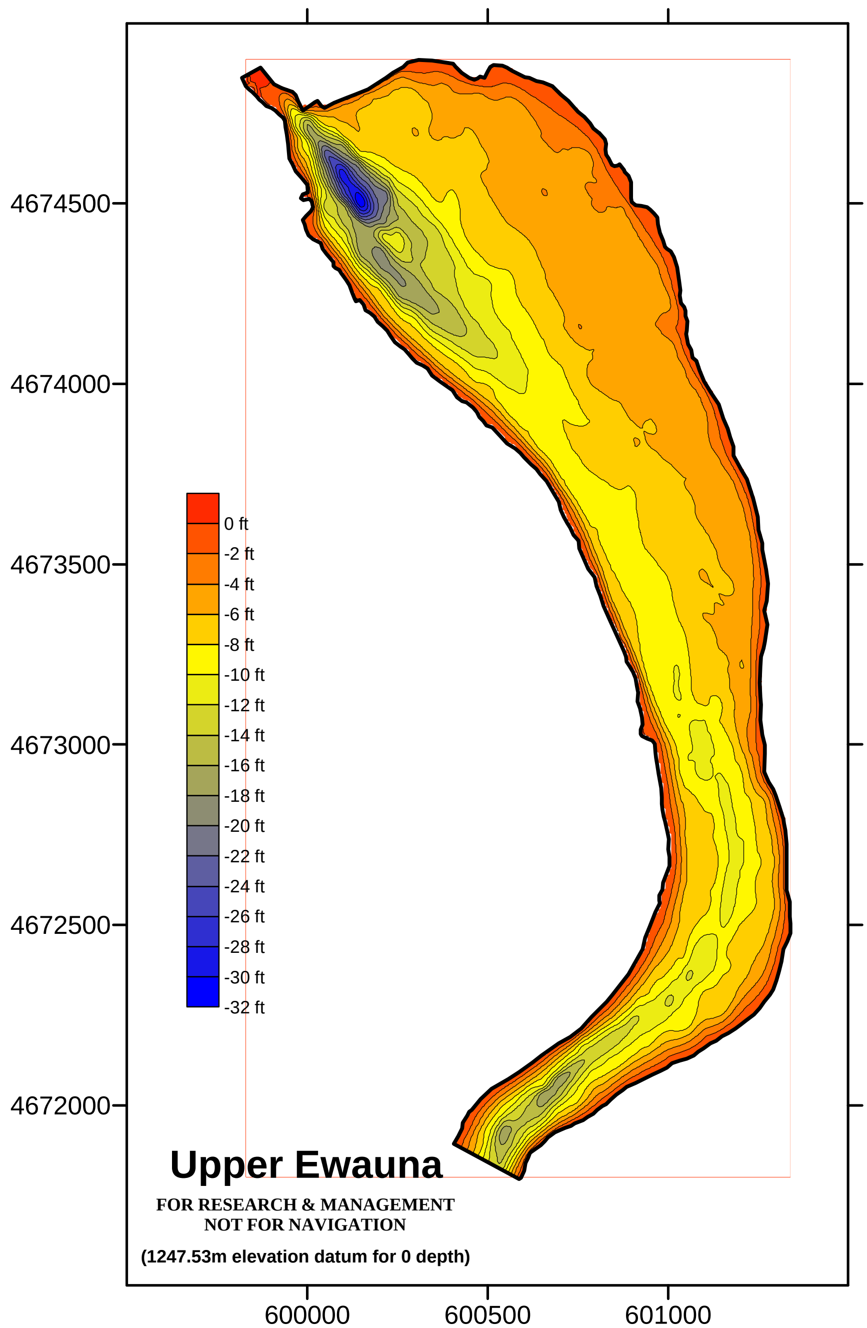

Figure 2. Bathymetric map of Lake Ewauna, Oregon.

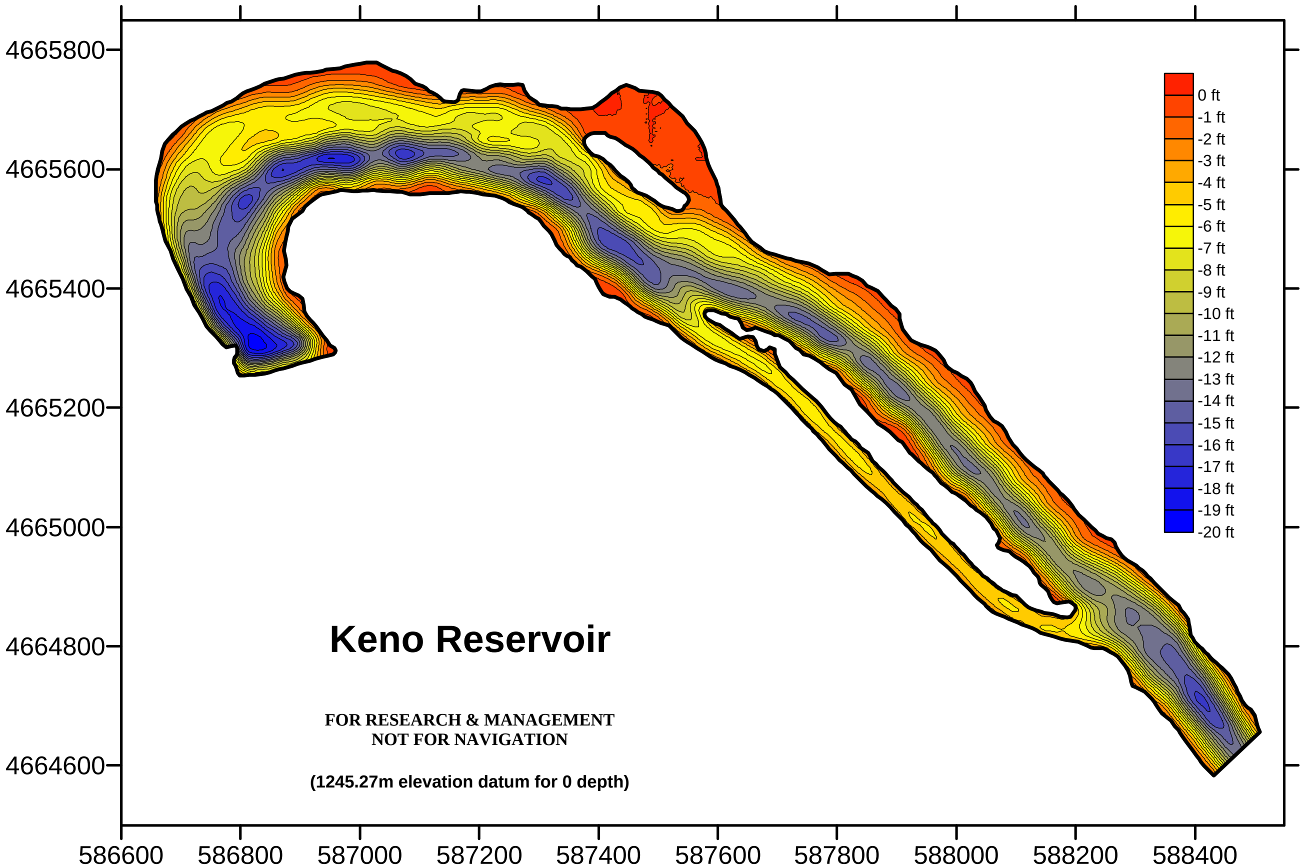

Figure 3. Bathymetric map of Keno Lake, Oregon up to the bridge at Highway 66.

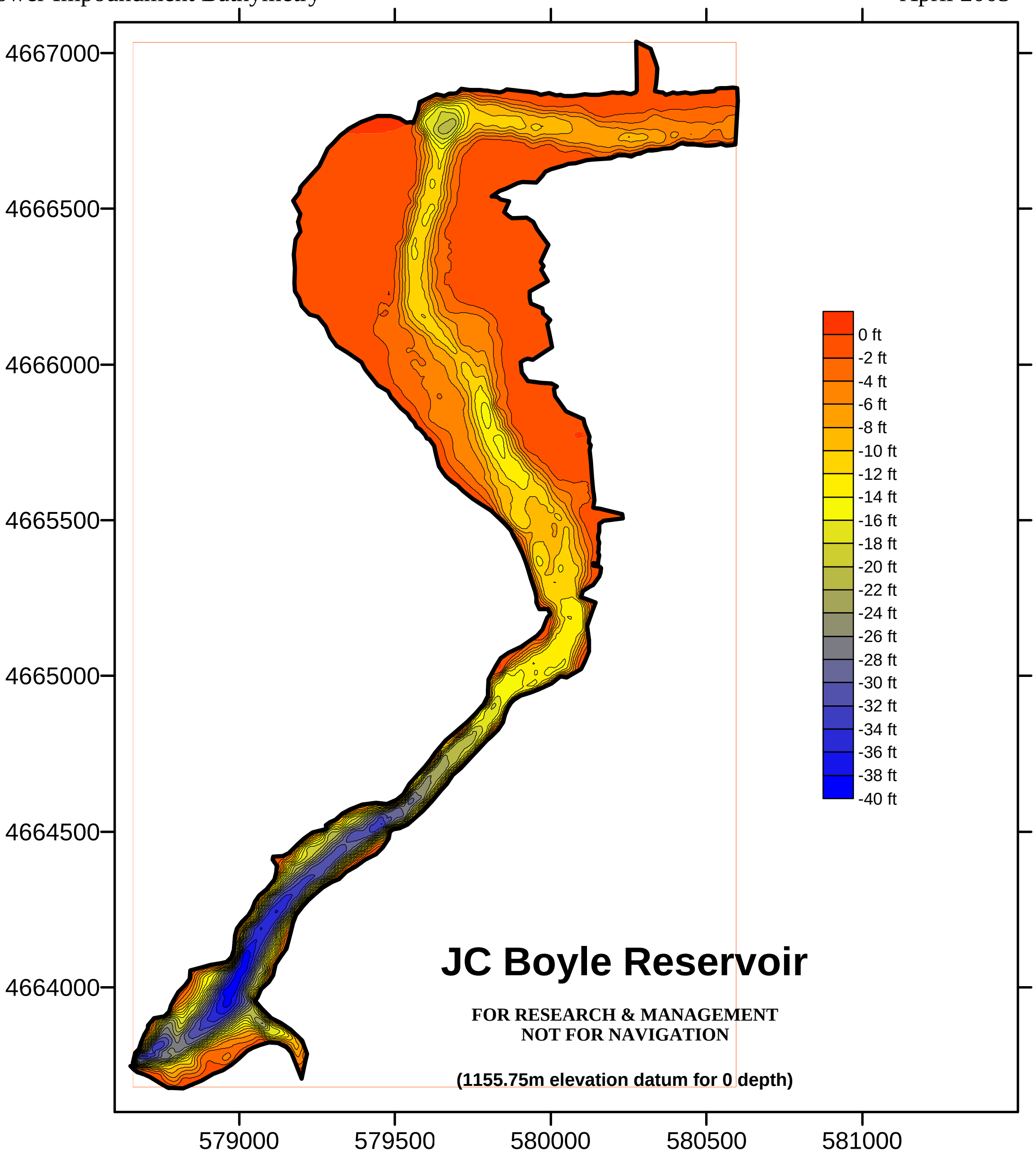

Figure 4. Bathymetric map of JC Boyle Reservoir. The shallow areas in the north half of the lake were not navigable during the survey and the depth in this region is estimated between 0 to 2 ft.

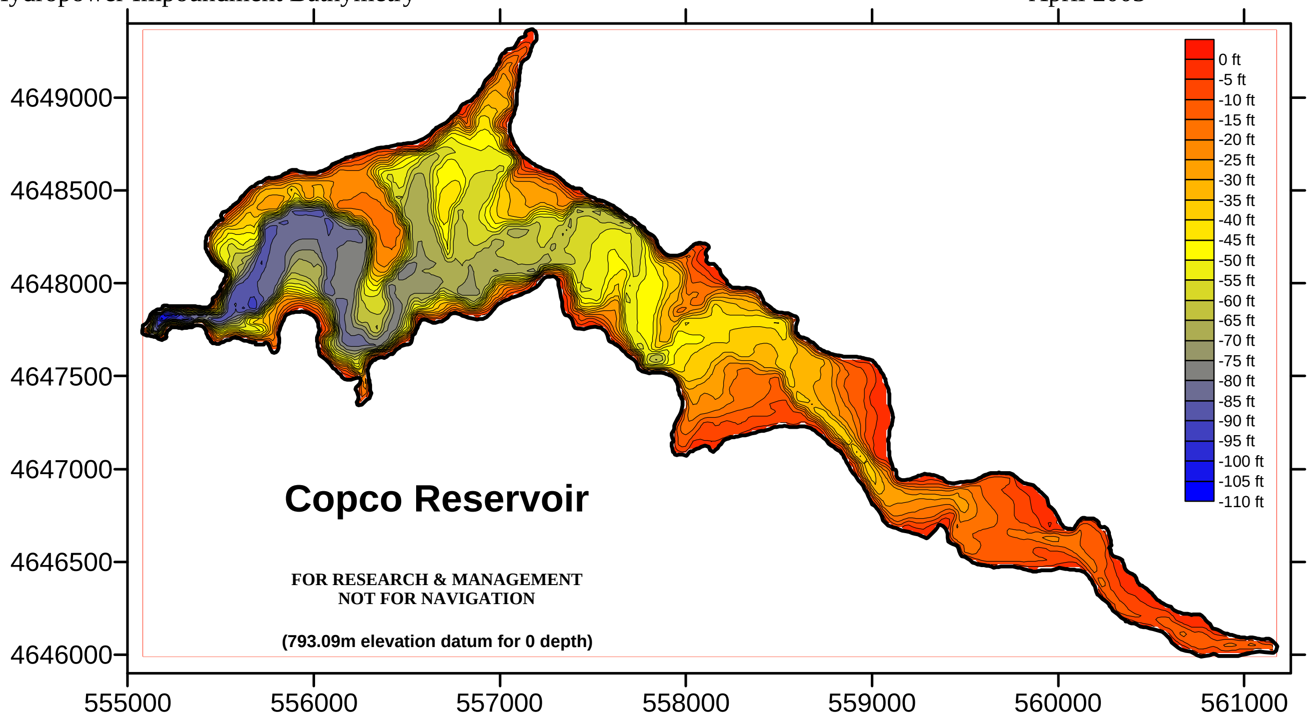

Figure 5. Bathymetric map of Copco Reservoir up to bridge crossing.

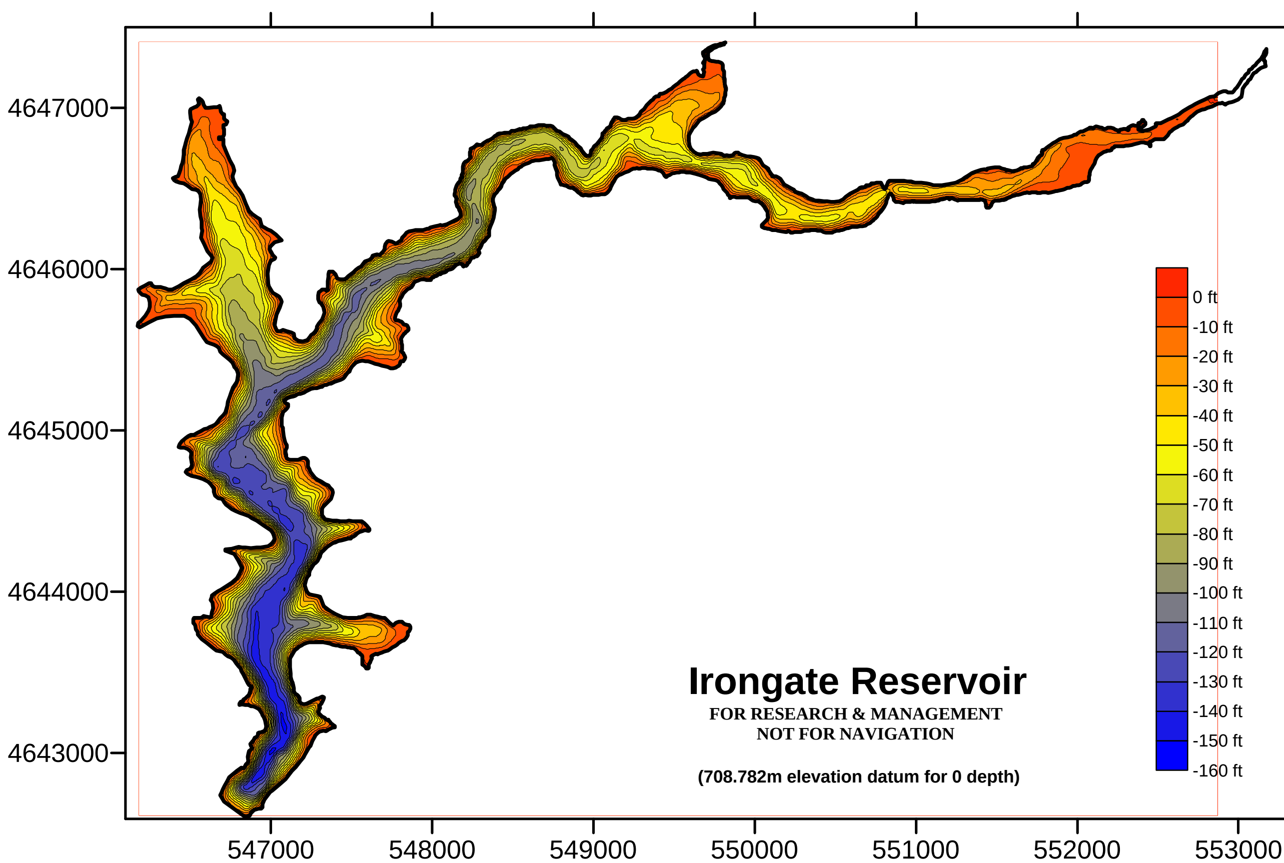

Figure 6. Bathymetric map of Irongate Reservoir.

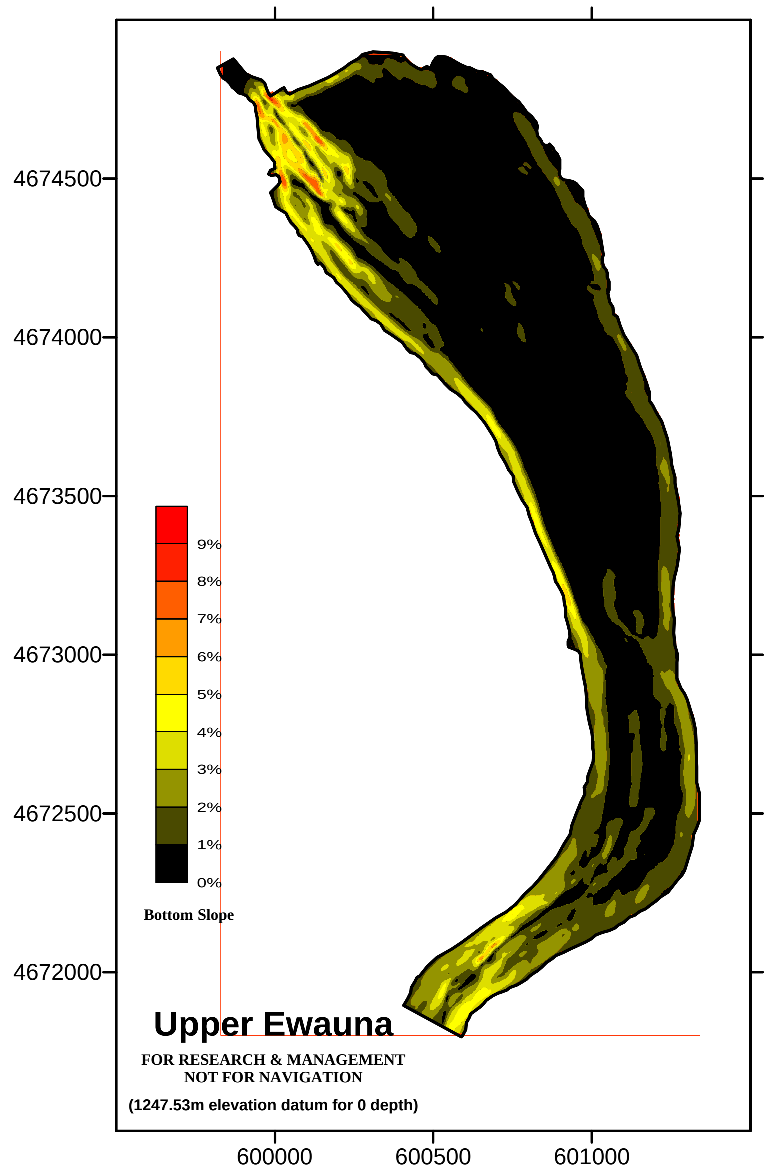

Figure 7. Slope map for Lake Ewauna based on bathymetric map presented in Figure 2.

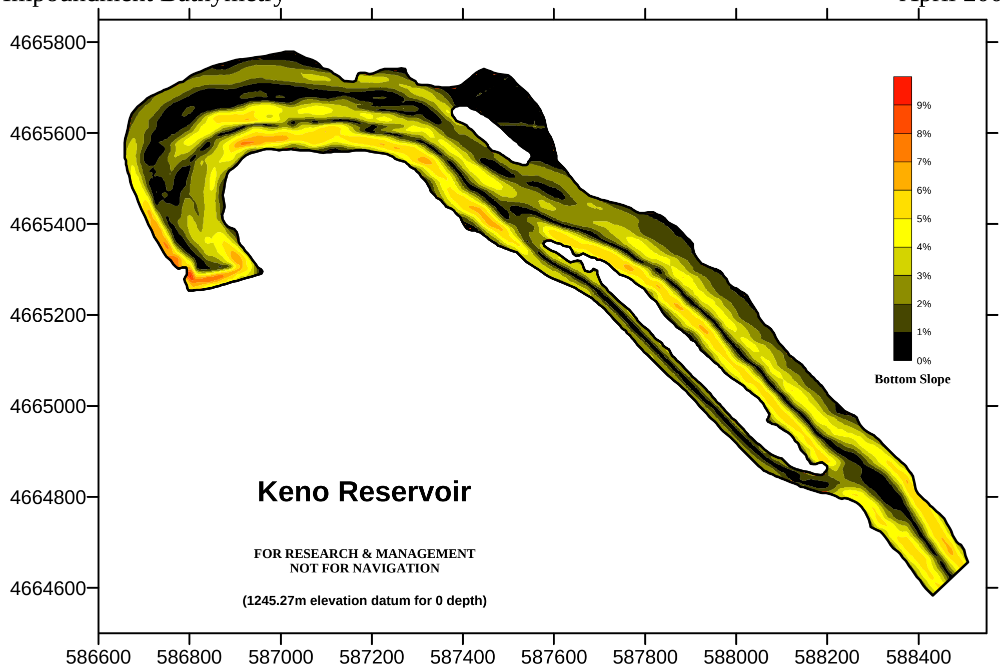

Figure 8. Slope map for Keno Reservoir.

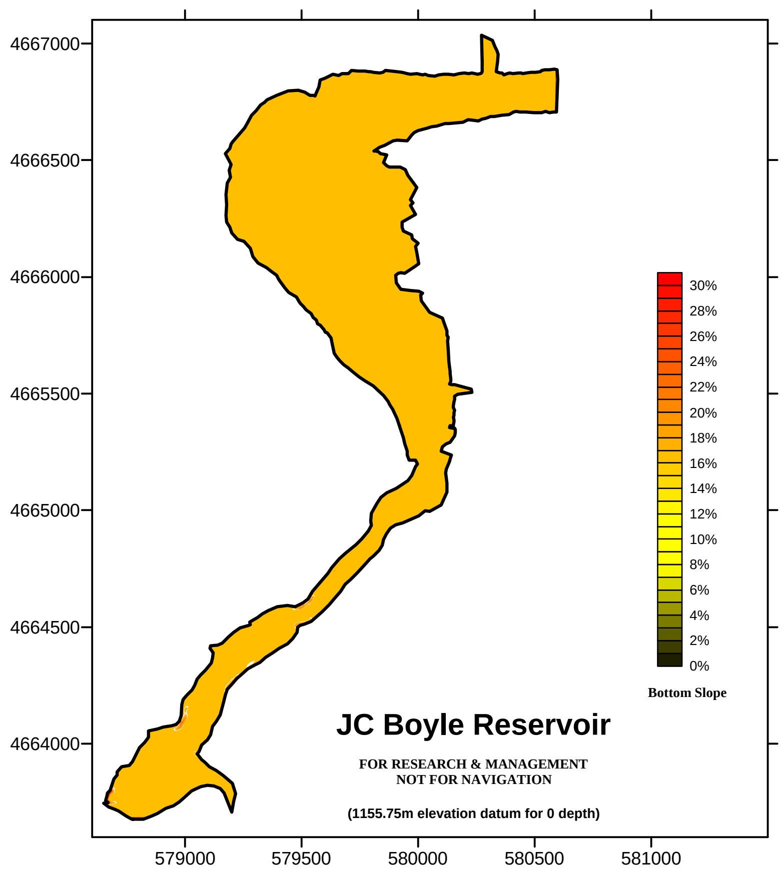

Figure 9. Slope map for JC Boyle Reservoir.

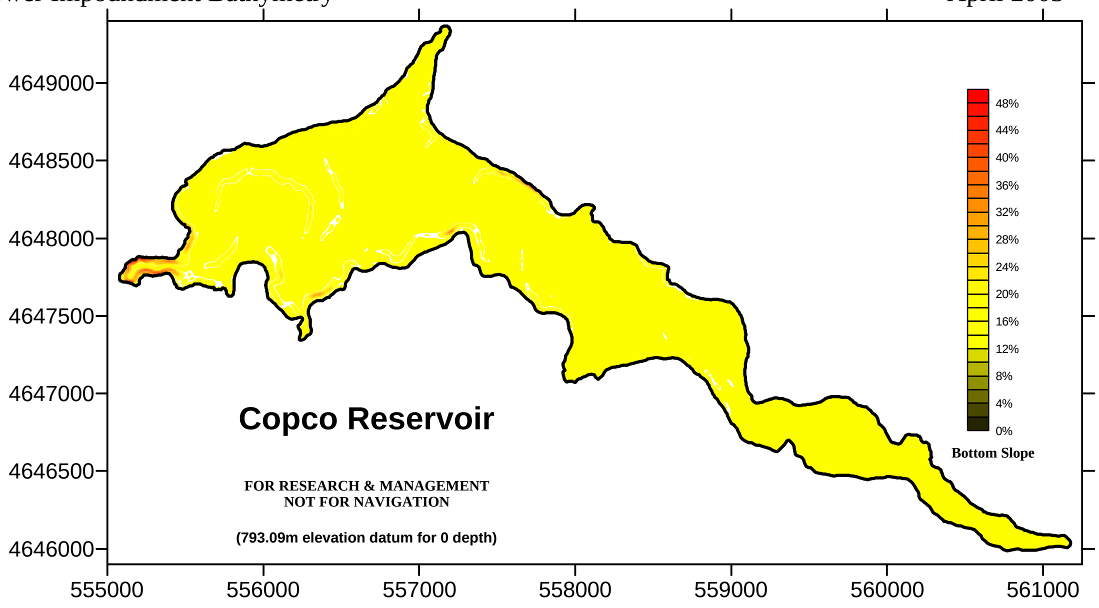

Figure 10. Slope map for Copco Reservoir.

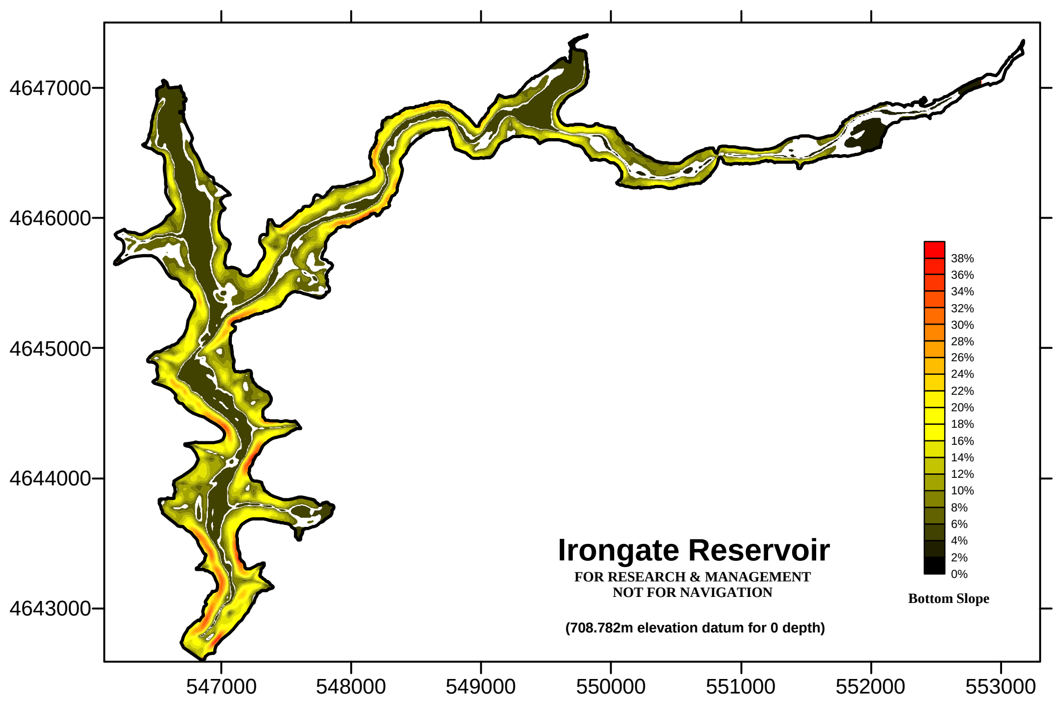

Figure 11. Slope map for Irongate Reservoir.

Although the channel between Lake Ewauna and Keno Reservoir was not surveyed in a manner comparable to that of the impoundments, we did conduct a bottom survey between the two systems to assess the general nature of the study area. The results show that the average depth of water is about 10 to 12 ft. The large fluctuations in depth down the length of the channel are associated with movement of the vessel across the thalweg and pools present near bends in the system (Figure 12).

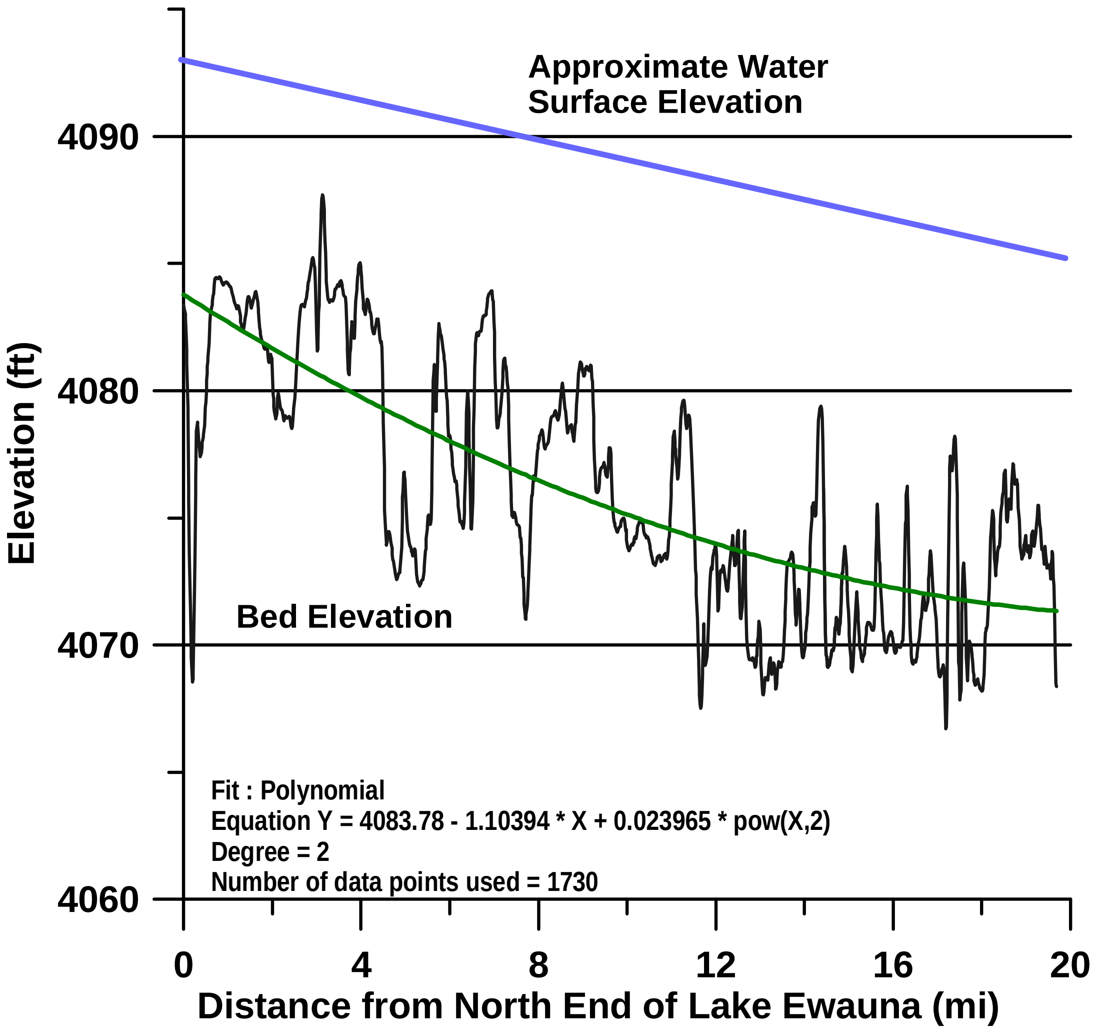

Figure 12. Bed elevation between Lake Ewauna and Keno Reservoir based on a single transect run. The average bed elevation is shown as a polynomial fit (curved line) of the observed data and the water surface elevation is depicted as a linear fit between maximum pool elevations for Lake Ewauna and Keno Reservoir.

2. <u>Unsupervised Sediment Classification</u>

The hydroacoustic signature produces two echoes which can be analyzed separately to yield information on sediment regularity (E1; bottom smoothness) and reflectivity (E2; bottom hardness). The images below for Lake Ewauna illustrate obvious differences in sediment composition in the original thalweg compared to the shallows extending up to the northeastern portion of the impoundment (Figure 13). The surprisingly high degree of reflectivity for much of the shallow area in Lake Ewauna may be associated with the high incident of wood fiber observed in these sediments.

In Keno Reservoir, much of the impoundment was characterized by reflective, irregular substrate which would be indicative of rock, possibly interspersed with some depositional material (Figure 14). Only in the forebay was there any indication of significant quantities of a high percentage of soft, flocculent material.

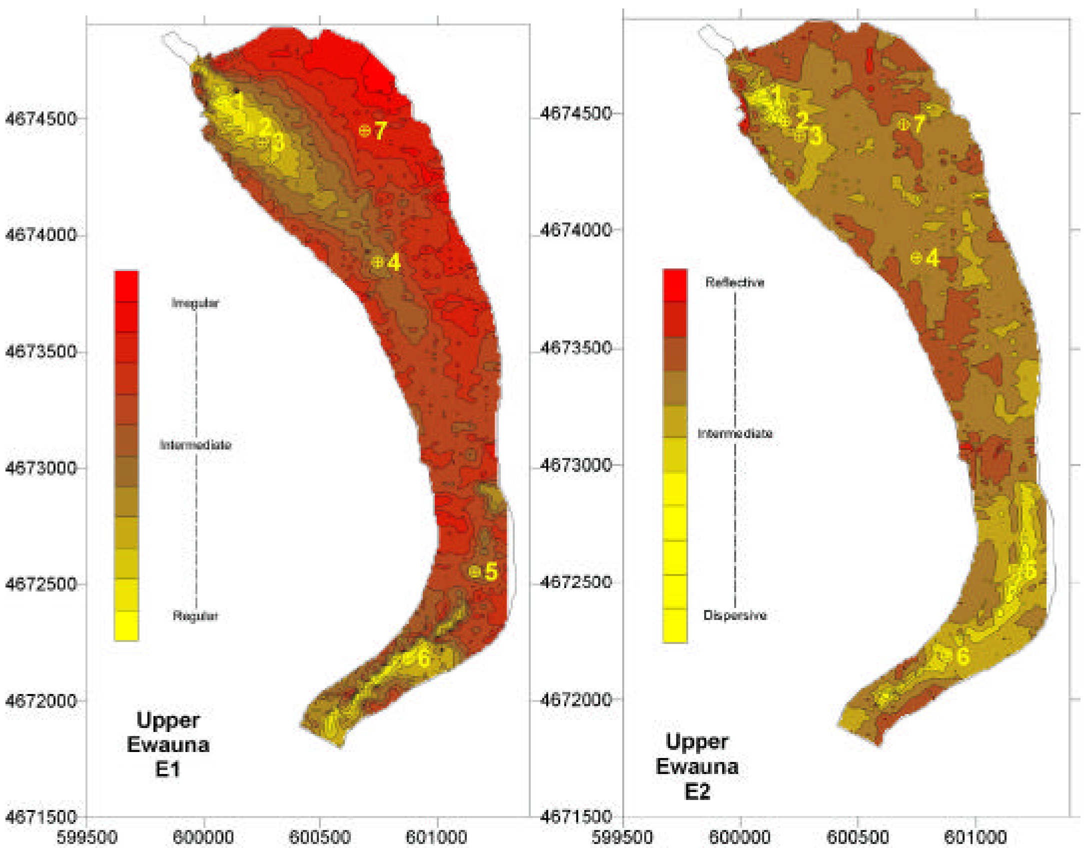

Figure 13. Unsupervised sediment classification for Lake Ewauna based on E1 and E2 hydroacoustic responses.

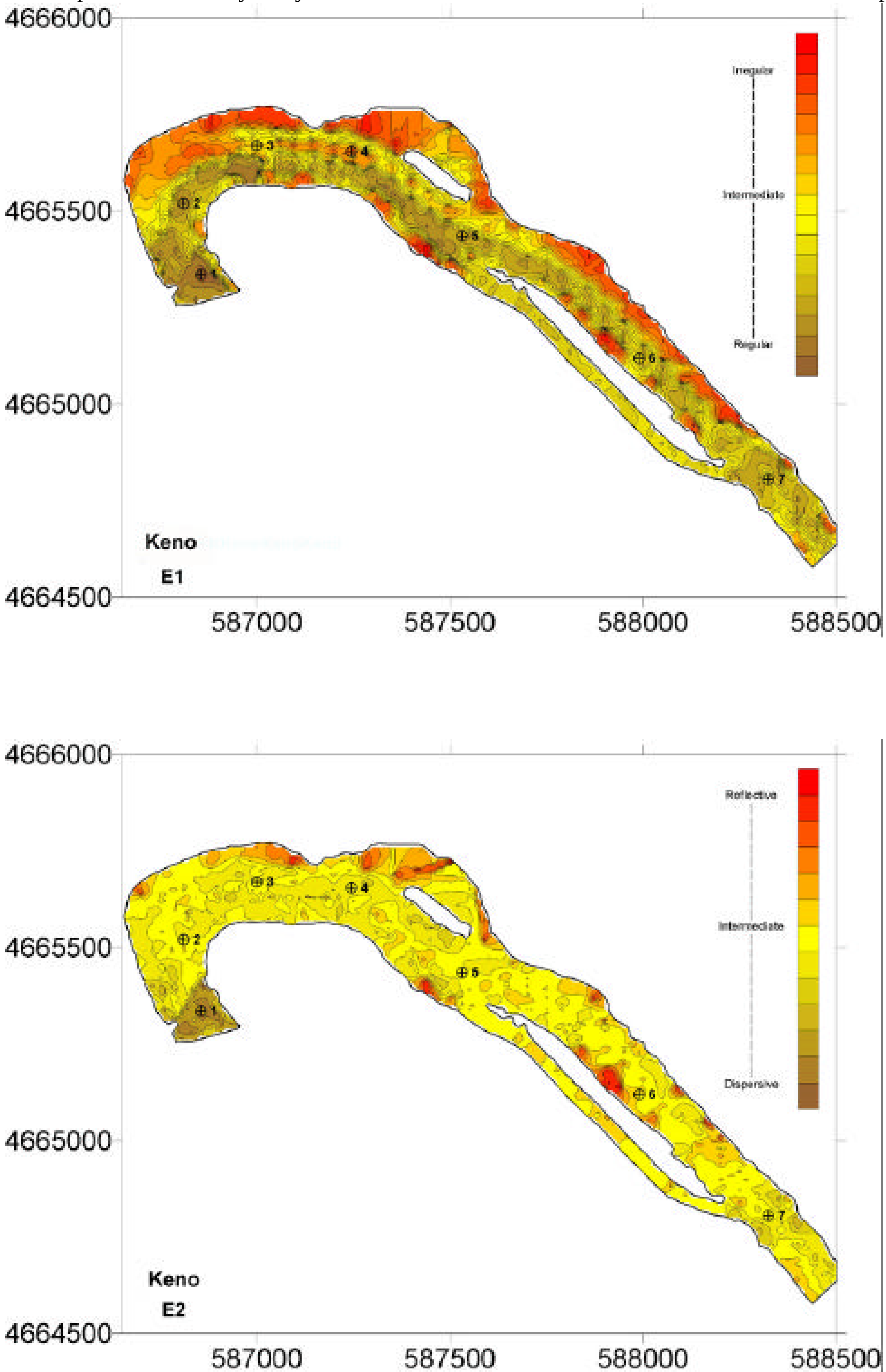

Figure 14. Unsupervised sediment classification based for Keno Reservoir based on E1 and E2 hydroacoustic responses.

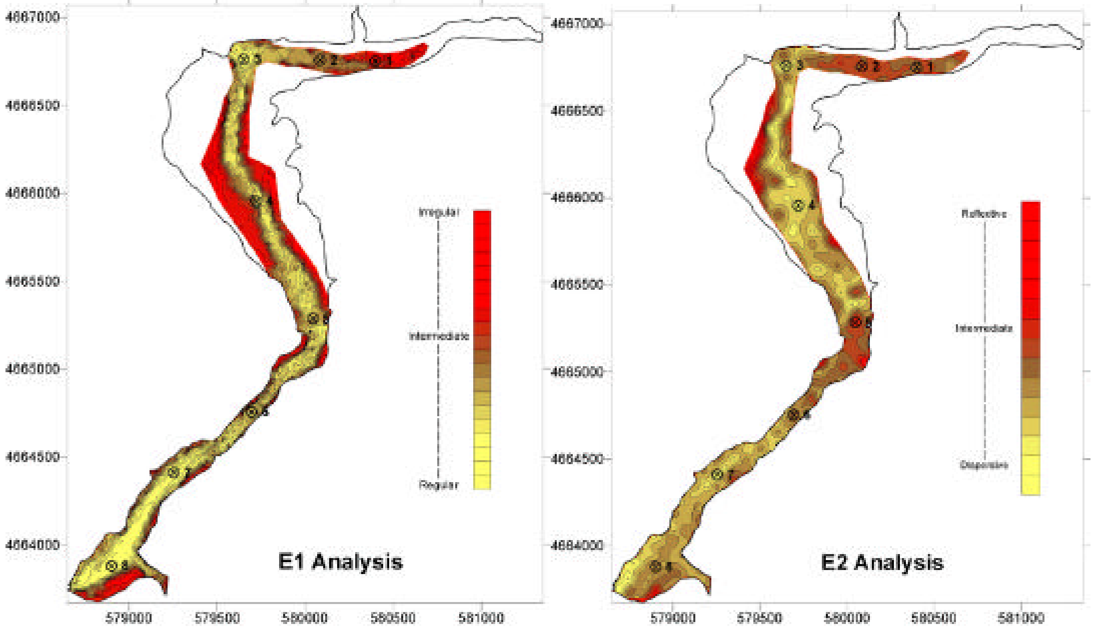

Figure 15. Unsupervised sediment classification for JC Boyle Reservoir based on E1 and E2 hydroacoustic responses.

The hydroacoustic signals in JC Boyle Reservoir indicated the presence of a high percentage of rock substrate (Figure 15). However, this does not include the very shallow material in the upper half of the reservoir which was not navigable during the survey work. Thus, much of the deeper portions of the impoundment is comprised of the original river channel which has retained much of its recognizable shape.

Copco Reservoir shows considerable contrasts in substrate types ranging from highly reflective materials on the upper portion, indicative of exposed rock, to dispersive material in the deep areas indicative of soft sediment (Figure 16). This is a typical pattern observed in many reservoirs where higher velocities in the upper areas associated with inflows and exposed shorelines during lake-stage fluctuations provide little opportunity for deposition of fine particles. However, the deep, lower ends of elongate impoundments provide considerable opportunity for deposition of all but the smallest particles. A somewhat similar pattern is achieved in Irongate Reservoir, although the bend in the upper northeast arm of the impoundment appears to offer an intermediate depositional zone prior to the main deep basin approaching the forebay (Figure 17).

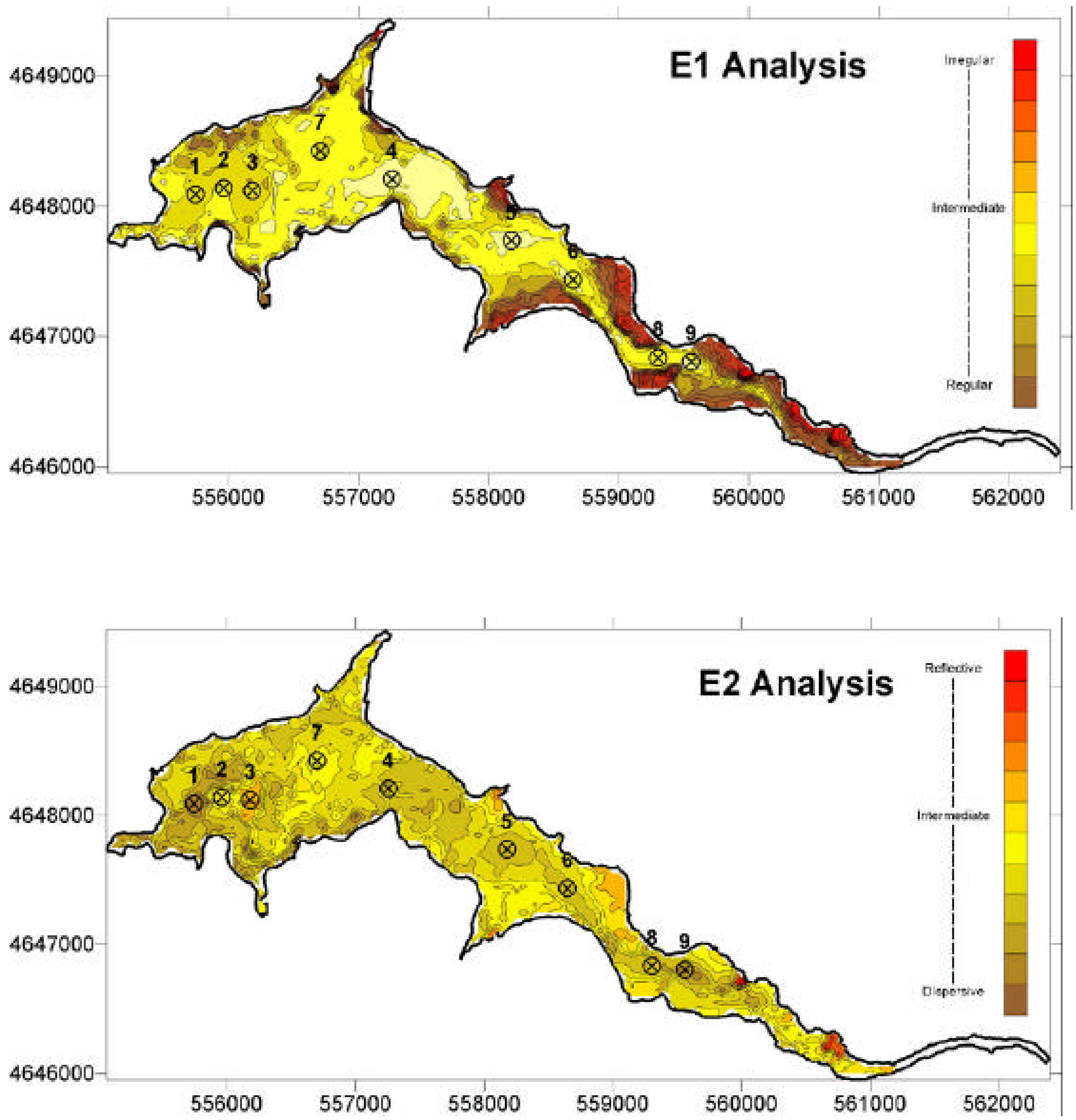

Figure 16. Unsupervised sediment classification of Copco Reservoir based on E1 and E2 hydroacoustic responses.

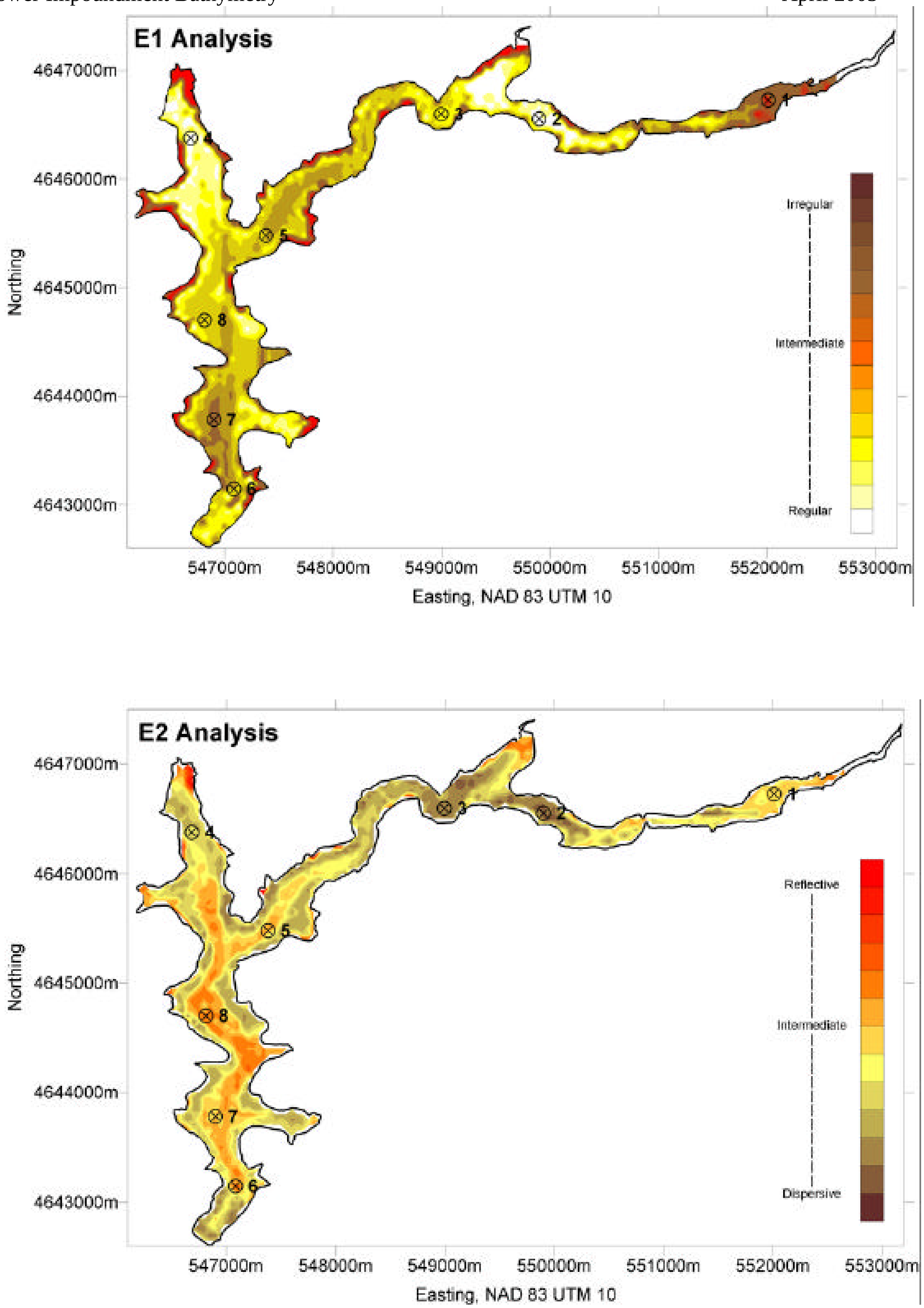

Figure 17. Unsupervised sediment classification of Irongate Reservoir based on E1 and E2 hydroacoustic responses.

2. Sediment Composition

Sediment sample sites are described in Table 2 and analytical results for all 39 sediment samples collected are presented in Table 3. Histograms of all results are presented in Figures 18-20. The water content of the sediment samples ranged from 68 to 90 percent, with a median value of 82 percent. The water content of the sediments in these impoundments is considerably lower than those in Upper Klamath Lake (Eilers et al., unpublished data). Low water content is indicative of a higher proportion of inorganic material in the sediments. The carbon content for the sediments ranged from 4.3 to 16.9 percent with a median of 6.3 percent. The highest values were associated with samples collected in Lake Ewauna obtained with an anchor. These samples had large wood chips imbedded in the sediment, which greatly affected the carbon and nitrogen results (Appendix). Excluding these wood-fiber samples, the sediments had relatively low carbon content, which is consistent with a higher proportion of inorganic inputs or high rates of decomposition and loss of carbon through sediment diagenesis. The samples with low concentrations of nutrients were associated with sediment samples with a high percentage of sand. Nitrogen and phosphorus concentrations in the sediment are also comparatively low even when compared to carbon concentrations. The ratio of C:N on a percentage basis averaged 10.2 (sd 2.2), which is almost twice as great as the Redfield ratio (5.56) expected for phytoplankton (Chapra 1997). The N:P ratio averaged 10.1 (sd 3.2), which is also considerably greater than the Redfield ratio of 7.2.

Table 2. Sediment site location and sediment descriptions.

Lake/ Site ID	Latitude Longitude	Depth (m)	Sample Type	Description
Ewauna				
ewa-01	42 13 00.8 121 47 14.7	8.5		No sample; rock and gravel
ewa-02	42 12 57.0 121 47 09.0	5.9		No sample; gravel
ewa-03	42 12 55.2 121 47 07.4	3.6		No sample; rock and gravel
ewa-04	42 12 37.6 121 46 46.8	2.6	Core; 12 cm	bark chips up to 10 cm long on anchor; mollusk shells, sulfur smell, light to med brown
ewa-05	42 11 54.9 121 46	3	Core; anchor	2 distinct layers in core; large wood chips on anchor

	28.8			
ewa-06	42 11 43.2 121 46 40.5	3.3		No sample; too hard
ewa-07	42 12 56.6 121 46 48.0	1.6	Core; 12 cm; anchor	2 distinct bands in core, upper organic ooze; wood chips abundant on anchor
ewa-08	42 12 10.9 122 46 31.1	3.3		No sample; 2 cm sediment over rock
ewa-09	42 12 25.2 121 46 28.0	2.1	Core; anchor	2 bands in core; wood chips on anchor and sawdust in sediment
Keno				
keno-01				No sample; Dredging in progress at site
keno-02	42 08 13.1 121 56 58.3	5.2		No sample; too hard
keno-03	42 08 17.7 121 56 50.2	1.7		No sample; gravel under silt
keno-04	42 08 17.3 121 56 40.0	1.7	Core	Upper has high water content; medium to dark brown
keno-05	42 08 10.6 121 56 27.2	4.8		No sample; too hard
keno-06	42 08 26.4 121 56 31.9	4.7		No sample; too hard
keno-07	42 07 50.3 121 55 53.6	4.5		No sample; too hard
JC Boyle				
jcb-01	42.149081 122.026550	2		No sediment sample; bent core tube;collected *Potomogeton* sample; 2 cm flocculent material over imbedded gravel
jcb-02	42.149114 122.031080	3.1		No sample; 1-2 cm of floc over hard substrate
jcb-03	42.149586 122.036004	6.7	Core; 15 cm	Upper med brown grading to dark brown; soft, sulfur odor; chironomid tube
jcb-04	42.142376 122.035658	4	Core; 18 cm	Similar appearance to JCB-03; chironomid tube; no sulfur odor

jcb-05	42.135477 122.031855	4.6		No sample; 2-3 cm of floc over cobble
jcb-06	42 07 50.9 122 02 08.5	7.5		No sample; rocky
jcb-07	42 07 40.1 122 02 28.5	10.7	Core; 15 cm	Med brown grading to dark brown; mild organic odor; very flocculent
jcb-08	42 07 22.7 122 02 44.3	11.5	Core; 20 cm	Similar to JCB-07; chironomid tubes
Copco				
copco-01	41 58 57.6 122 19 37.7	27	Core; 19 cm	6 layers, distinct bands (grey/black); top/bot samples
copco-02	41 58 59.6 122 19 27.8	23.9	Core	Similar to Copco-01
copco-03	41 58 59.2 122 19 18.2	25.8		Minimal sample from core sidewall
copco-04	41 59 01.5 122 18 31.2	21	Core	Very flocculent sed; poor settling properties; top/bottom samples
copco-05	41 58 46.4 122 17 52.0	14.1	Core	More cohesive sediments than Copco-04
copco-06	41 58 36.4 122 17 30.8	13.1	Cores	Duplicate cores collected; top/bottom samples
copco-07	41 59 08.9 122 18 55.9	14.2	Core	Top/bottom samples
copco-08	41 58 16.6 122 17 02.9	8.5	Core	Top/bottom samples
copco-09	41 58 15.9 122 16 52.0	7.5	Core	Top/bottom samples
Irongate				
Iron-01	41 58 13.1 122 22 22.8	3.4	Cores	Duplicate cores; macrophytes on anchor
Iron-02	41 58 09.9 122 23 52.9	16.5	Core; 28 cm	Chironomids at bottom of core

Iron-03	41 58 12.7 122 24 30.1	24.7	Core	
Iron-04	41 58 06.4 122 26 12.8	17		Corer broke; fine black organic sediment
Iron-05	41 57 37.5 122 25 41.0	37		No sample; corer malfunctioned
Iron-06	41 56 17.5 122 25 55.9	47.6	Core; 16 cm	Grey/black bands
Iron-07	41 56 41.1 122 26 02.6	44.7		No sample; two attempts
Iron-08	41 57 10.5 122 26 08.9	41	Core	High water content; black ooze present on top
Iron-09	41 56 40.2 122 25 43.5	24		No sample; substrate too hard

Table 3. Analytical results for sediment samples collected from the Klamath Hydropower impoundments.

Lake	Sample Number	Lab Number	TP ppm	C %	N %	Water %	C_N	N_P
Ewauna	EWA-04	2377.24	734	10.6	0.95	88.3	11.13	12.96
Ewauna	EWA-05	2377.25	754	8.2	0.90	90.2	9.15	11.90
Ewauna	EWA-05 bottom	2377.26	269	4.8	0.52	86.7	9.38	19.17
Ewauna	EWA-07	2377.27	846	10.5	0.74	87.7	14.11	8.78
Ewauna	EWA-09	2377.28	815	11.2	0.95	89.1	11.73	11.71
Ewauna	EWA-09 bottom	2377.29	379	7.4	0.64	87.2	11.71	16.76

Ewauna	EWA-05 anchor	2377.3	349	6.6	0.56	82.0	11.92	15.94
Ewauna	EWA-07 anchor	2377.31	542	13.6	0.76	84.2	17.97	14.02
Ewauna	EWA-09 anchor	2377.32	534	13.5	0.75	80.4	17.92	14.05
Keno	Keno-04	2377.23	639	5.6	0.56	80.5	10.14	8.70
Boyle	JCB-03	2377.19	1042	9.6	1.16	87.4	8.30	11.16
Boyle	JCB-04	2377.2	604	4.3	0.46	73.6	9.35	7.57
Boyle	JCB-07	2377.21	686	6.8	0.72	81.7	9.42	10.50
Boyle	JCB-08	2377.22	902	8.1	0.97	88.3	8.40	10.71
Copco	Copco-01	2377.01	615	5.3	0.62	82.7	8.57	10.00
Copco	Copco-01 bottom	2377.02	605	5.6	0.68	78.6	8.21	11.21
Copco	Copco-02 duplicate	2377.03	645	5.5	0.63	83.7	8.72	9.74
Copco	Copco-01 bottom	2377.04	663	5.4	0.60	79.0	9.00	9.08
Copco	Copco-04	2377.05	989	6.1	0.67	85.6	9.02	6.81
Copco	Copco-04 bottom	2377.06	778	6.0	0.66	80.4	9.08	8.43
Copco	Copco-05	2377.07	787	6.7	0.75	85.2	8.98	9.52
Copco	Copco-05 bottom	2377.08	705	6.4	0.71	80.2	9.08	10.02
Copco	Copco-06	2377.09	733	6.6	0.69	83.8	9.60	9.35
Copco	Copco-06 bottom	2377.1	774	6.2	0.65	77.5	9.51	8.36
Copco	Copco-06 duplicate	2377.11	738	6.8	0.72	85.0	9.43	9.77
Copco	Copco-06 duplicate bottom	2377.12	696	6.7	0.73	80.5	9.26	10.47
Copco	Copco-07	2377.13	665	5.6	0.60	84.2	9.31	8.98
Copco	Copco-07 bottom	2377.14	637	5.7	0.63	79.8	9.09	9.88
Copco	Copco-08	2377.15	899	6.9	0.76	84.1	9.17	8.40
Copco	Copco-08 bottom	2377.16	723	6.3	0.62	76.8	10.08	8.60
Copco	Copco-09	2377.17	825	5.9	0.59	78.9	9.92	7.15
Copco	Copco-09 bottom	2377.18	690	5.0	0.48	67.9	10.39	6.95
Irongate	Iron-01	2377.33	730	6.6	0.55	69.7	11.97	7.52
Irongate	Iron-02	2377.34	1039	6.1	0.64	83.6	9.47	6.18
Irongate	Iron-02 bottom	2377.35	712	4.5	0.44	73.7	10.21	6.20
Irongate	Iron-06	2377.36	875	5.2	0.64	80.3	8.20	7.29
Irongate	Iron-06 bottom	2377.37	822	5.8	0.71	78.5	8.19	8.64
Irongate	Iron-01 anchor	2377.38	915	16.9	1.46	74.3	11.60	15.94
Irongate	Iron-03	2377.39	970	4.6	0.39	75.8	11.84	3.98

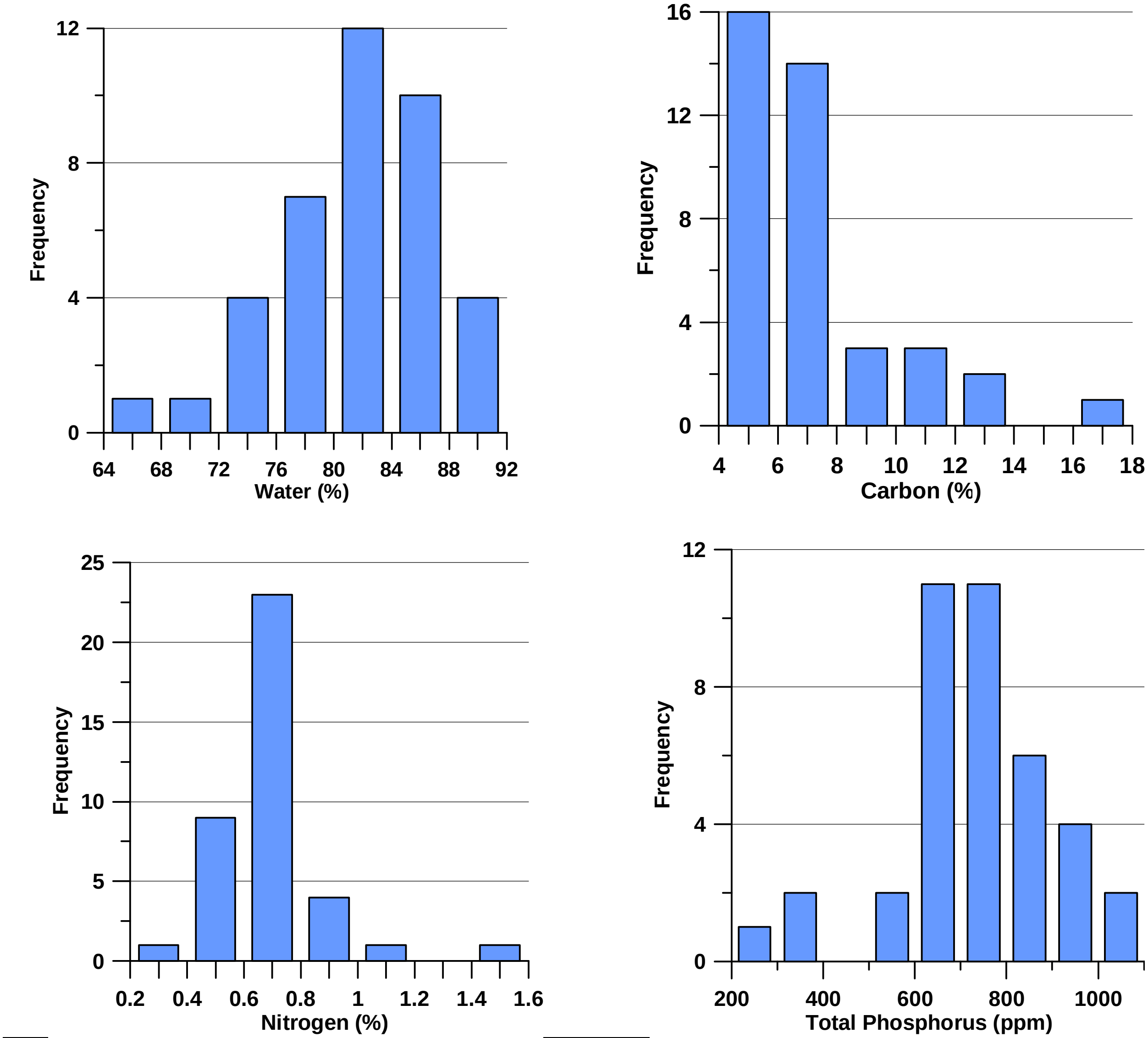

Figure 18. Histograms of water, carbon, nitrogen, and phosphorus content in sediment samples from the Klamath Hydropower Project area.

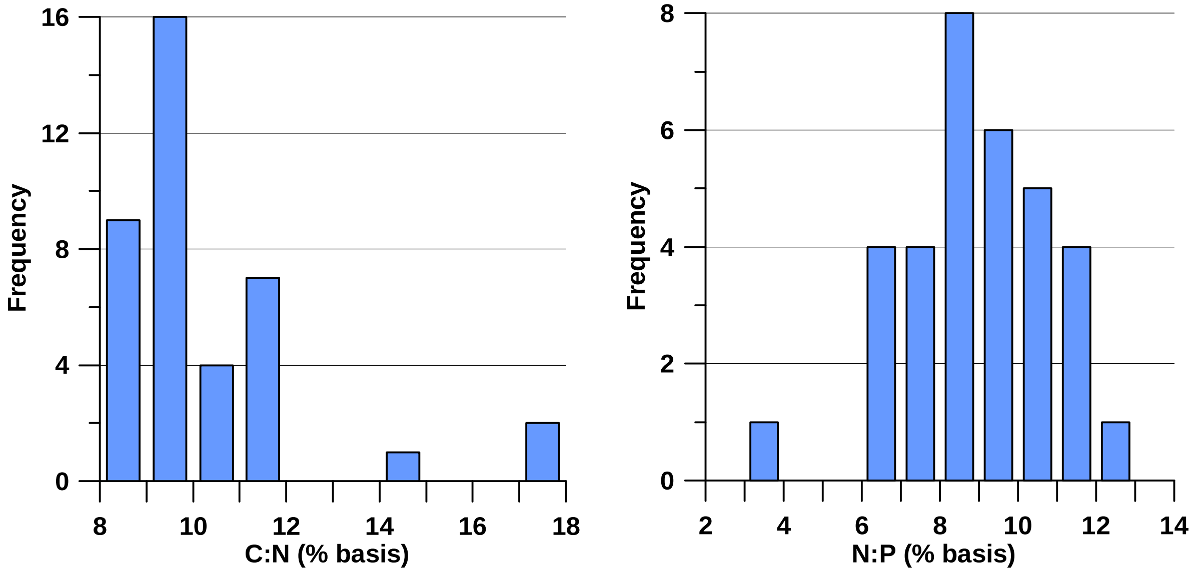

Figure 19. Histograms of C:N and N:P ratios (on a percent dry weight basis) for sediment samples from the Klamath Hydropower Project area.

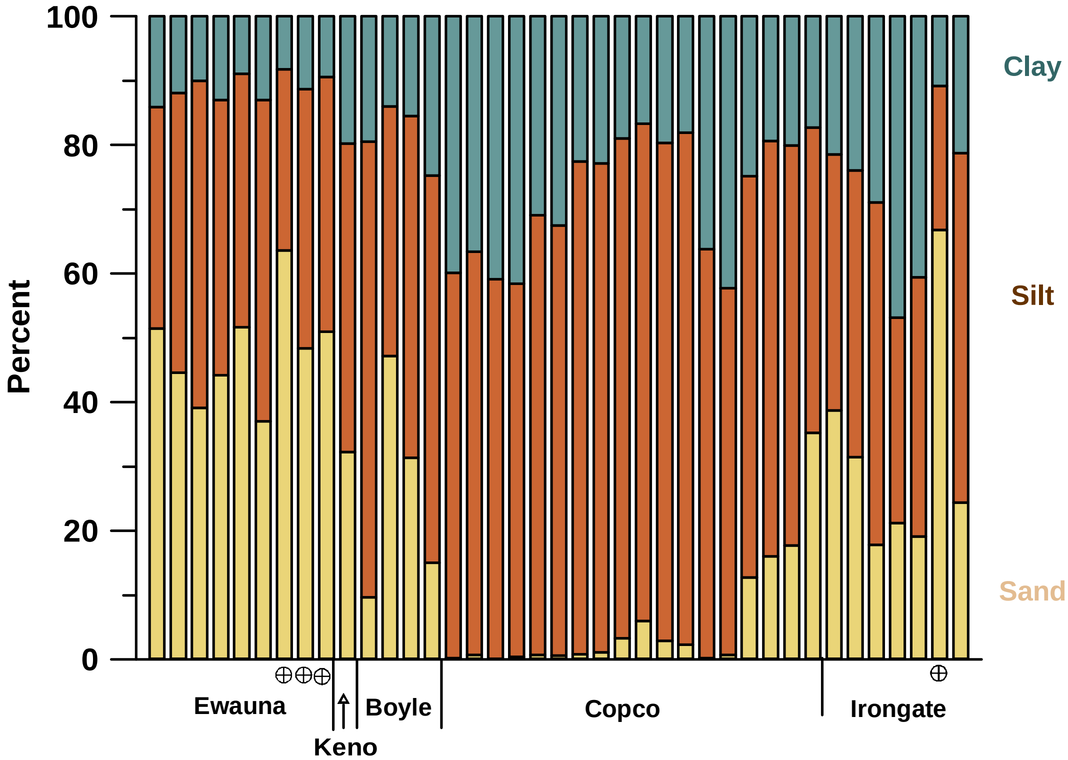

Figure 20. Textural classes of sediment samples from the Klamath Hydropower Project. The samples are arranged in the same order as shown in Table 3. Samples identified with a cross-filled circle were collected with an anchor.

The textural analysis of the samples illustrates that the sediments in the upper impoundments (Ewauna thru JC Boyle) typically have a greater percentage of sand based on the sites sampled. This spatial trend is reversed somewhat in Irongate Reservoir where percentages of sand again increase over those found in Copco Reservoir. Percentages of clay are greatest in the samples from Copco and Irongate Reservoirs. A comparison of sediment samples from the upper 10 cm with those below 10 cm shows that the upper sediments have higher values of nutrients and water content (Table 4).

Table 4. Comparison of analytical results (mean and standard deviation) for sediment samples collected from depths of 0-10 cm (Top) versus 10-20 cm (Bottom) for eleven paired samples from the Klamath impoundments. The P value is presented for a one-way ANOVA comparing top and bottom sample results.

Variable	Top	Bottom	P Value
Carbon (%)	6.70 (1.7)	5.79 (0.82)	0.128
Nitrogen (%)	0.71 (0.121)	0.61 (0.911)	0.045
Phosphorus (ppm)	818 (128)	645 (172)	0.015
Water (%)	84.3 (3.3)	78.8 (5.4)	0.009

Supervised sediment classifications were derived by integrating the hydroacoustic signals (E1 and E2) with the sediment sampling results. The resulting maps for the 50 meter grid nodes (Ewauna and Keno were prepared at 25 meter grid nodes) illustrate major differences in sediment composition of the upper impoundments (Ewauna, Keno, JC Boyle) with the lower impoundments (Copco and Irongate). The upper systems are characterized by higher proportions of rock, sand, and silt, whereas the lower impoundments have higher proportions of silt and clay (Figures 21-25).

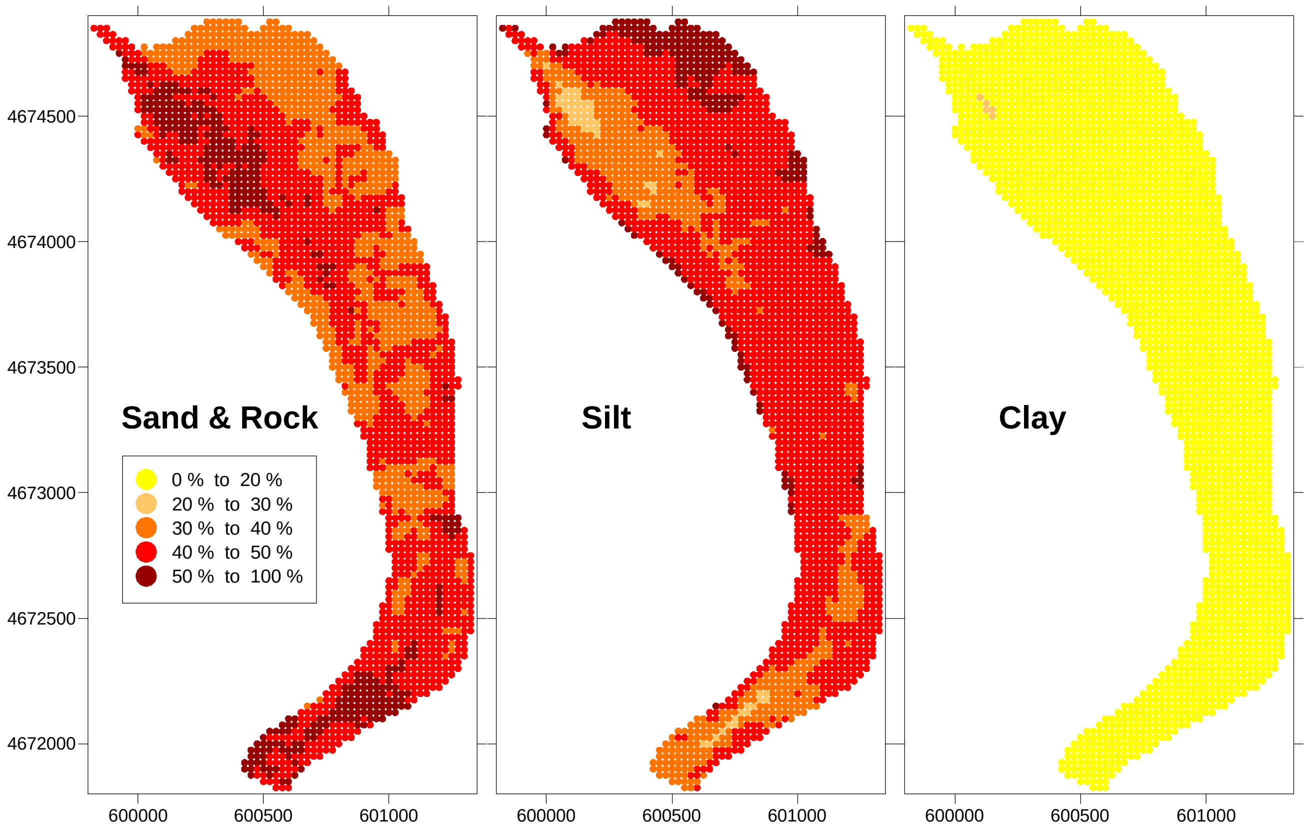

Figure 21. Acoustically classed sediments for Lake Ewauna.

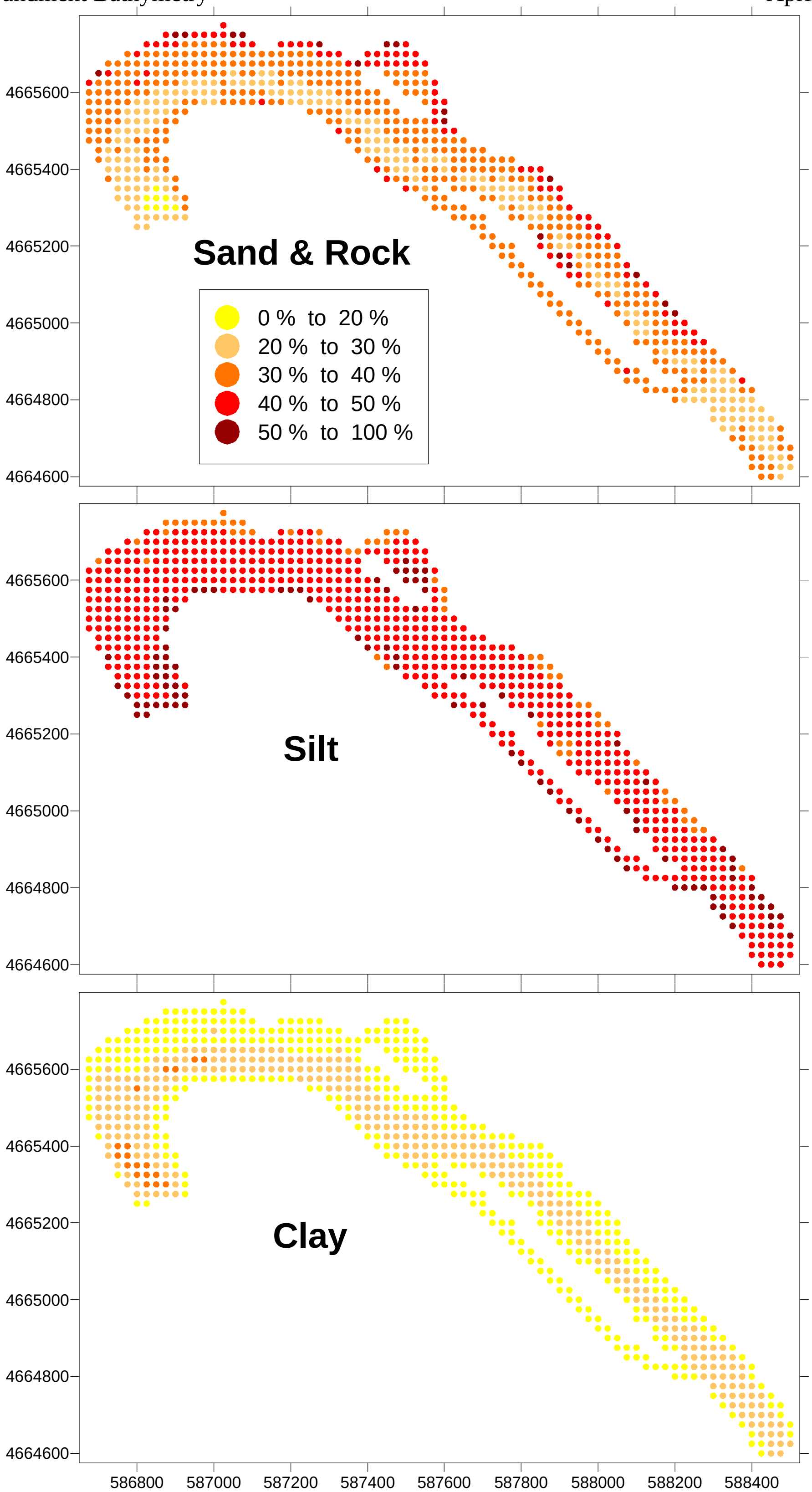

Figure 22. Acoustically classed sediments for Keno Reservoir

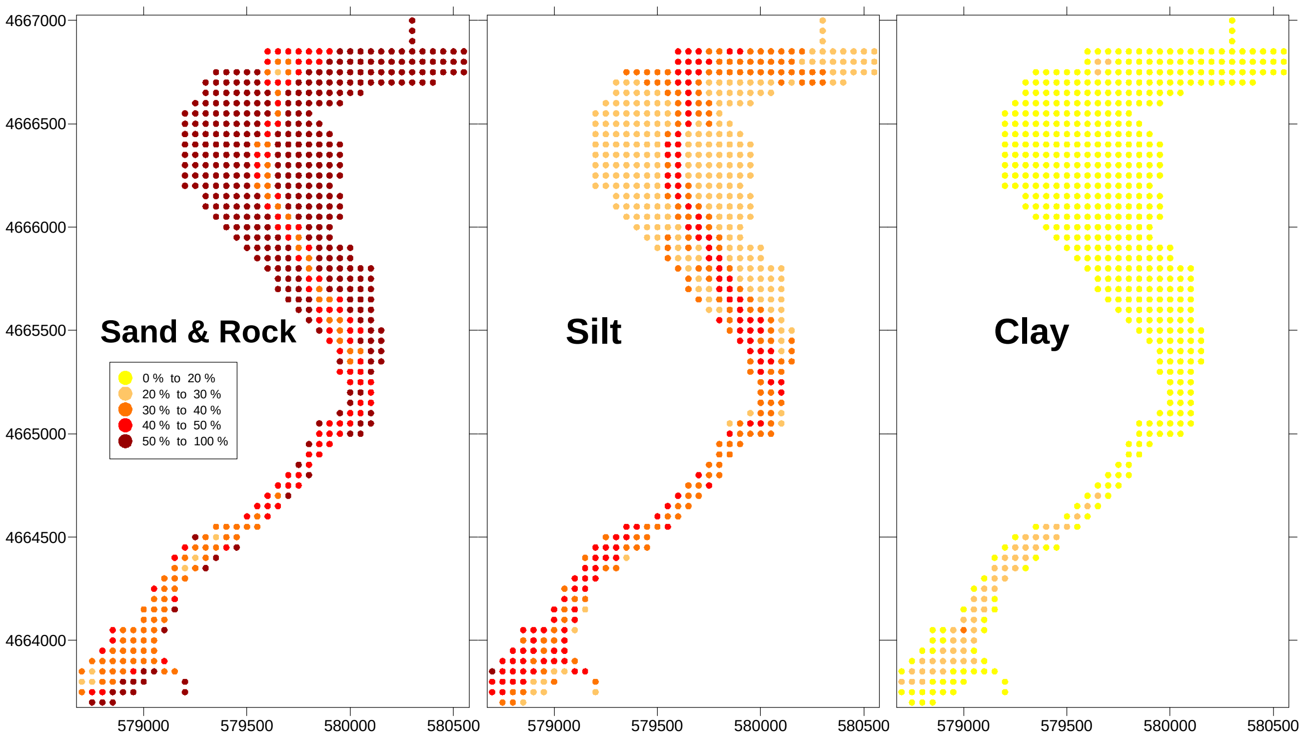

Figure 23. Acoustically classed sediments for JC Boyle Reservoir.

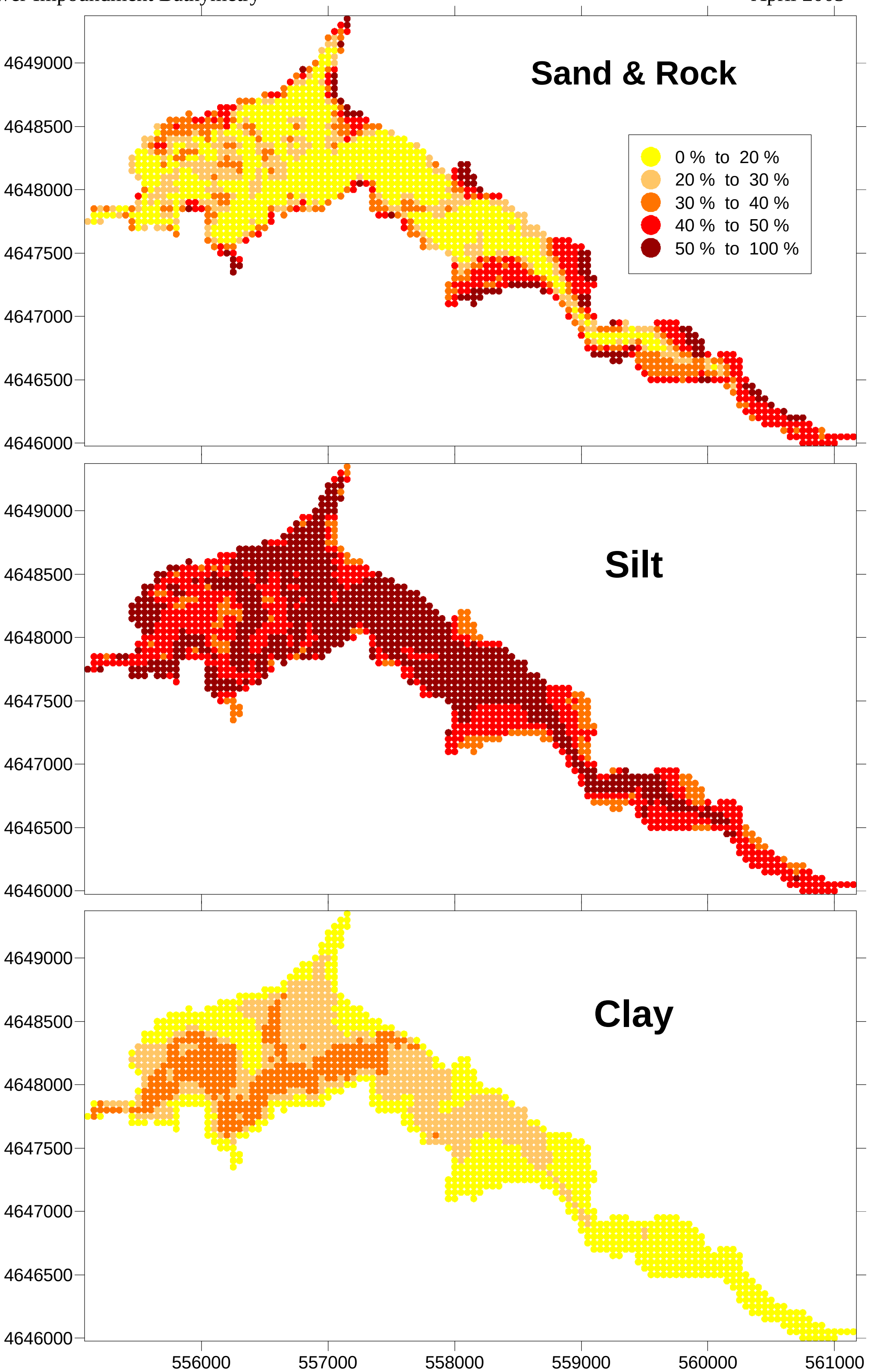

Figure 24. Acoustically classed sediments for Copco Reservoir.

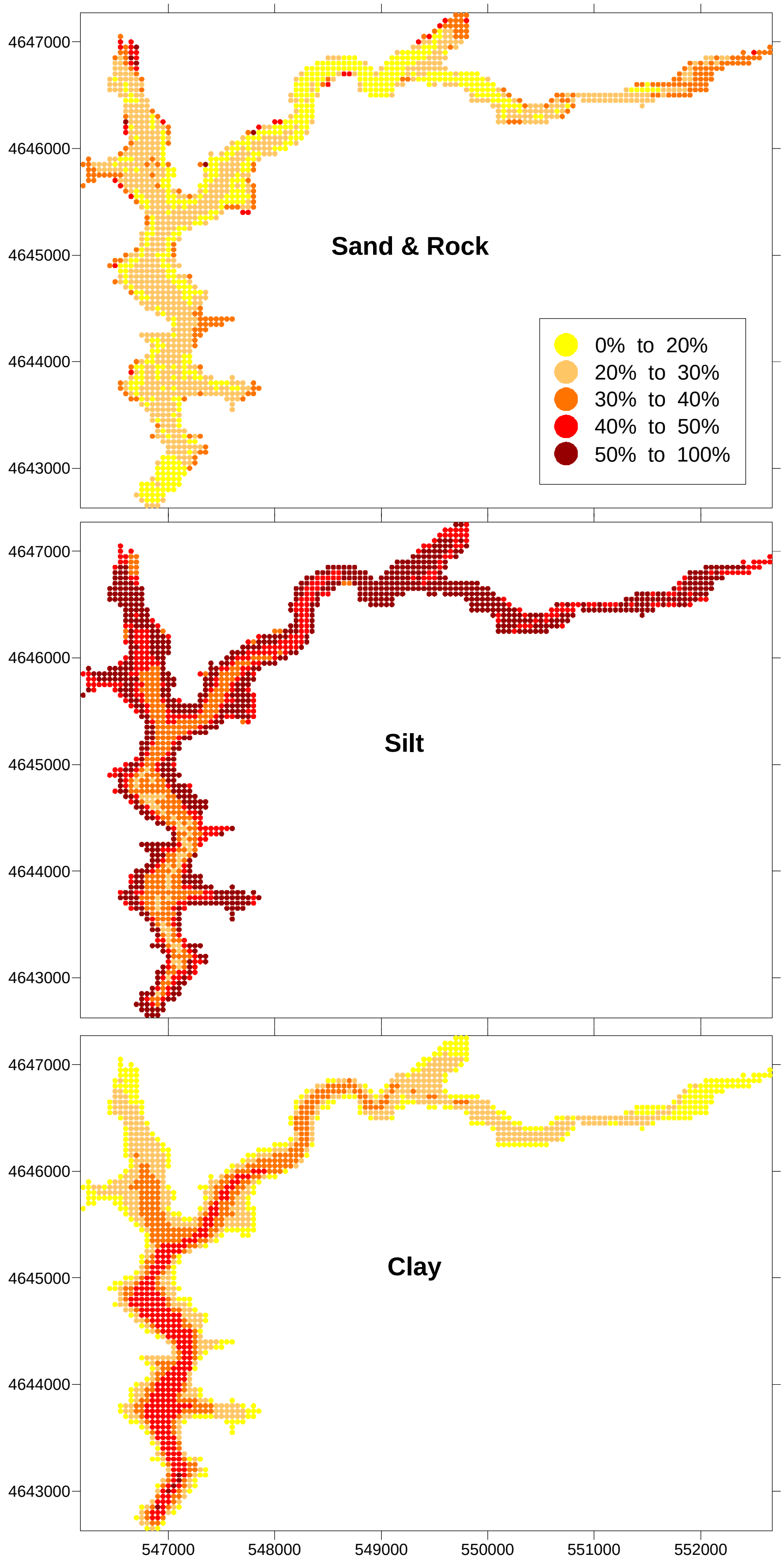

Figure 25. Acoustically classed sediments for Irongate Reservoir.

3. Comparison with Historic Topography

An indication of the amount of sediment accumulated in the impoundments was derived by comparing the current bathymetry with the pre-dam topography of the study sites. Pre-construction topography of the study sites provided by Pacificorp was used to generate a surface which was compared with the current bathymetry. No historic topographic map was provided for Lake Ewauna and thus this site was not included in the historical comparison.

The estimates for loss of lake volume calculated using historic topography for the four impoundments is presented in Figure 26. Pre-construction topography for the study sites is presented in Figures 27-30. The hypsographic curves of the lakes and the historic volumes for the same area were plotted and compared (Figures 31-34).

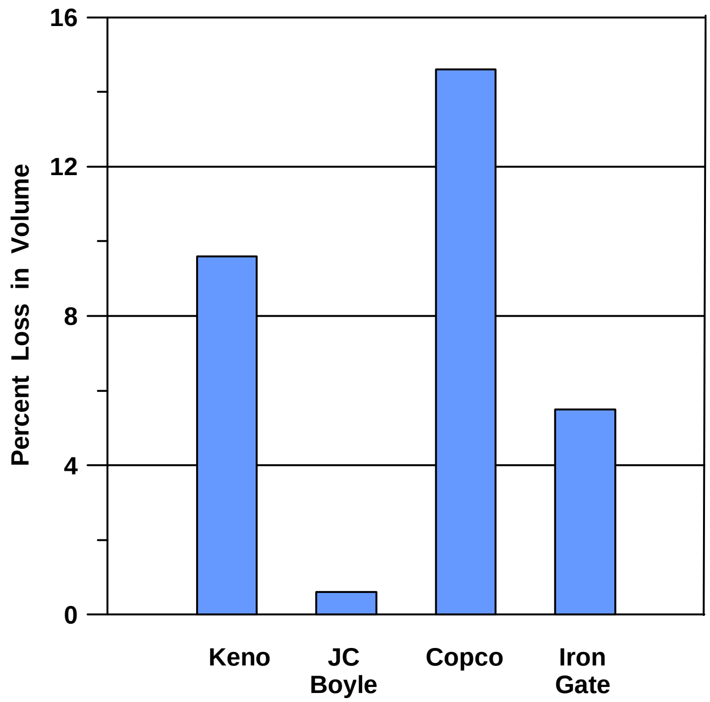

Figure 26. Estimates of loss in reservoir volume based on comparison of current bathymetry with historic topography for four of the five study sites.

There is a considerable disparity in the estimates for volume loss ranging from 0.6 percent in JC Boyle Reservoir to 14.6 percent in Copco Reservoir. The greatest loss in volume, that calculated for Copco Reservoir, appears realistic considering that this is the oldest impoundment in the system, it is deep with a high trapping efficiency, and is situated in a portion of the study area with considerable topographic relief. Irongate Reservoir would be expected to have experienced a considerably lower degree of in-filling because it is relatively recent and it is located immediately below Copco Reservoir. The values computed for Keno Reservoir are also consistent with a shallow, narrow system that would likely have comparatively low trapping efficiency. The values computed for Keno Reservoir are based on the bathymetry of the impoundment prior to dredging in the forebay conducted in 2002. The change in volume estimates for JC Boyle Reservoir are extremely low, well below what would be expected for a system of this type.

For three of the impoundments, JC Boyle, Copco, and Irongate, the historical topography does not include elevation data below the original river channel. This results in underestimating the total loss of volume from sedimentation. For Copco and Irongate Reservoirs, this bias is small because the volume of the historic river channel is small relative to the volume of these large impoundments. For JC Boyle Reservoir, the volume of the original river channel is much greater relative to the volume of the impoundment. The degree to which the loss of lake volume is underestimated in JC Boyle is difficult to assess. However, the sediment sampling in JC Boyle Reservoir showed that much of the original thalweg remained sediment-free through site #7 (mid-way through the lower half of the impoundment), suggesting that the magnitude of the sedimentation bias estimate for this reservoir may not be large.

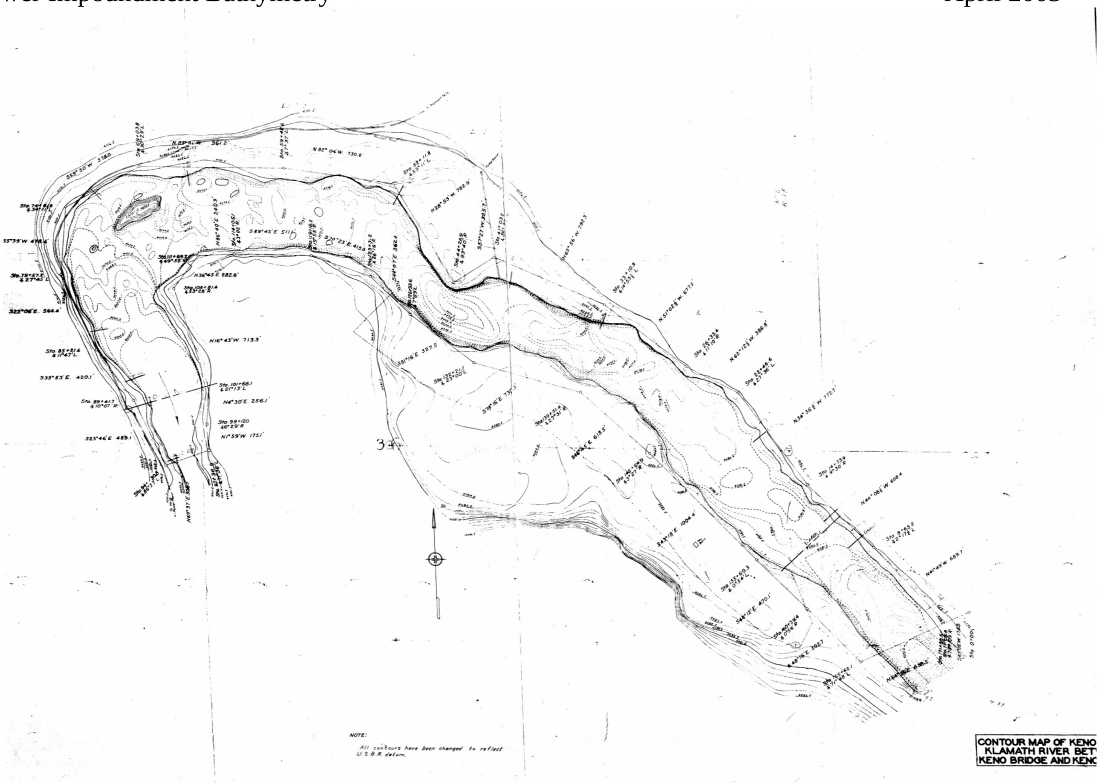

Figure 27. Historic topographic information for the Keno Reservoir area.

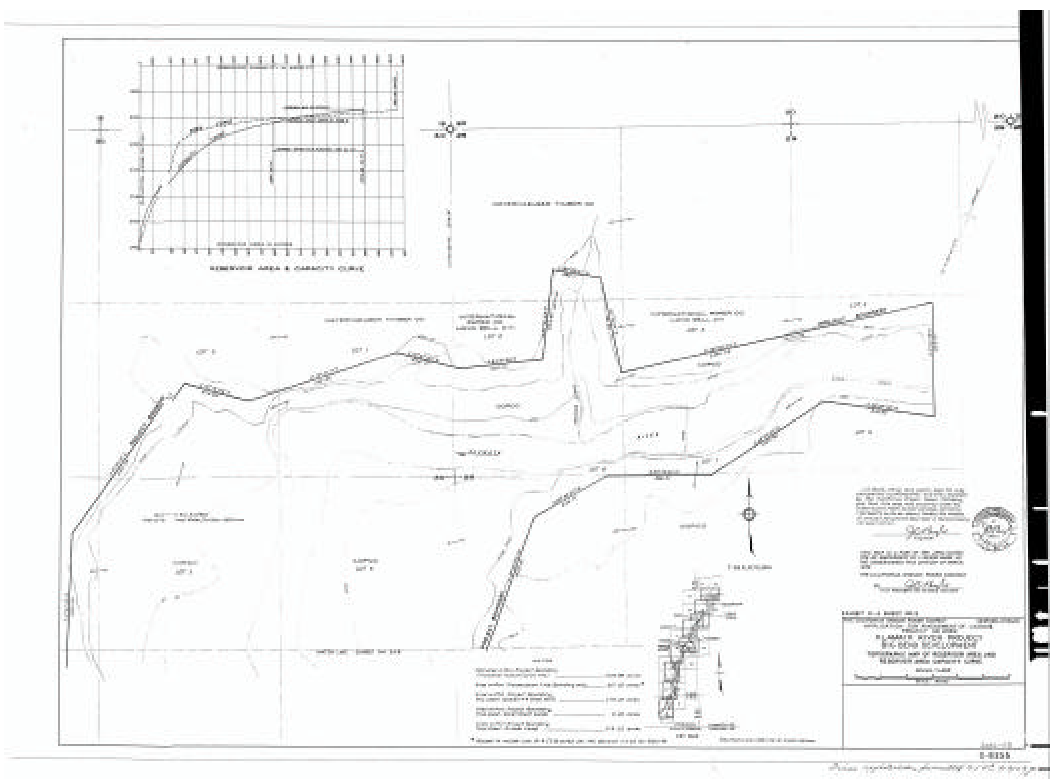

Figure 28a. Historic topography for upper JC Boyle Reservoir area.

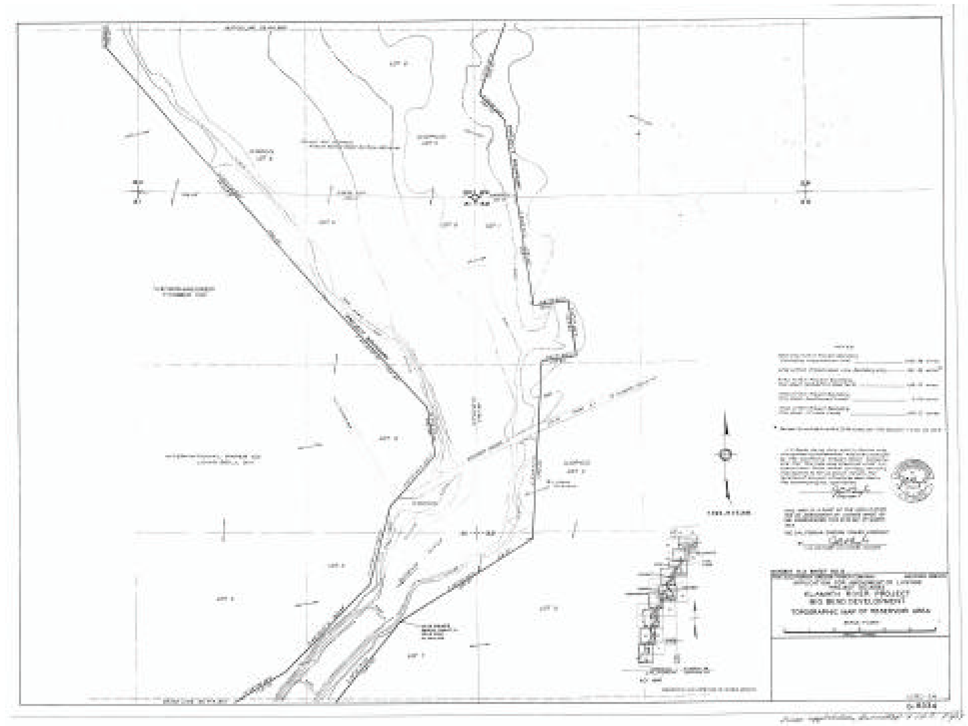

Figure 28b. Historic topography for the middle portion of the JC Boyle Reservoir area.

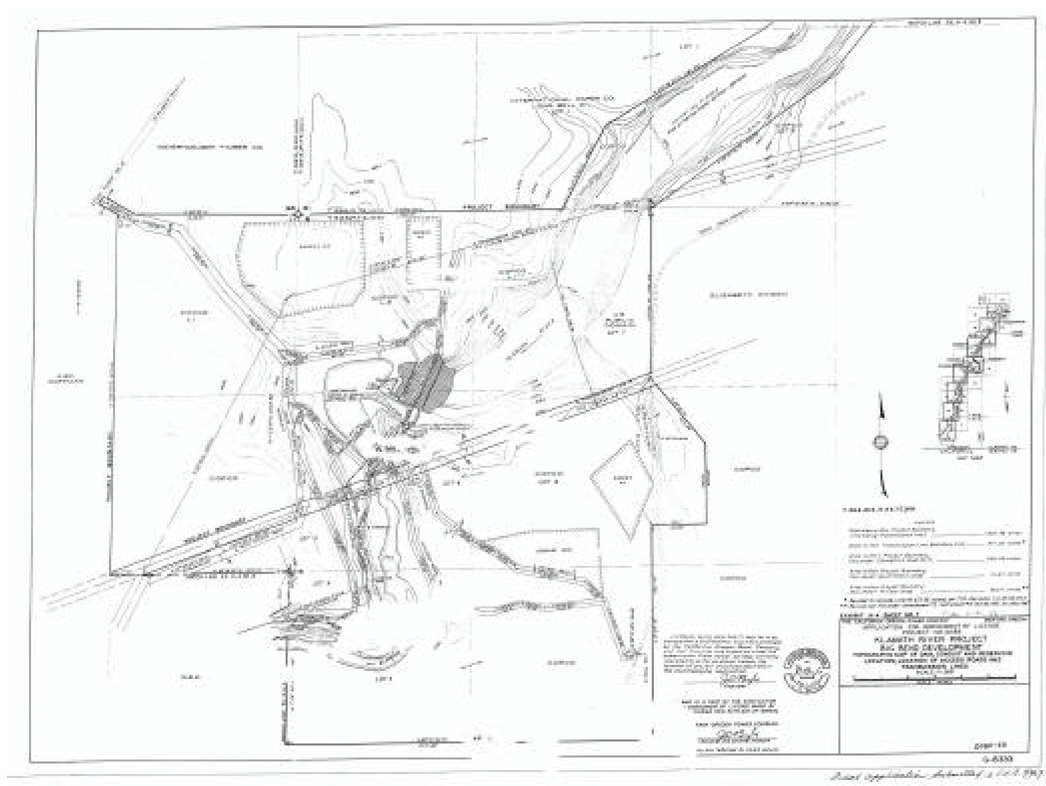

Figure 28c. Historic topography for the lower portion of the JC Boyle Reservoir

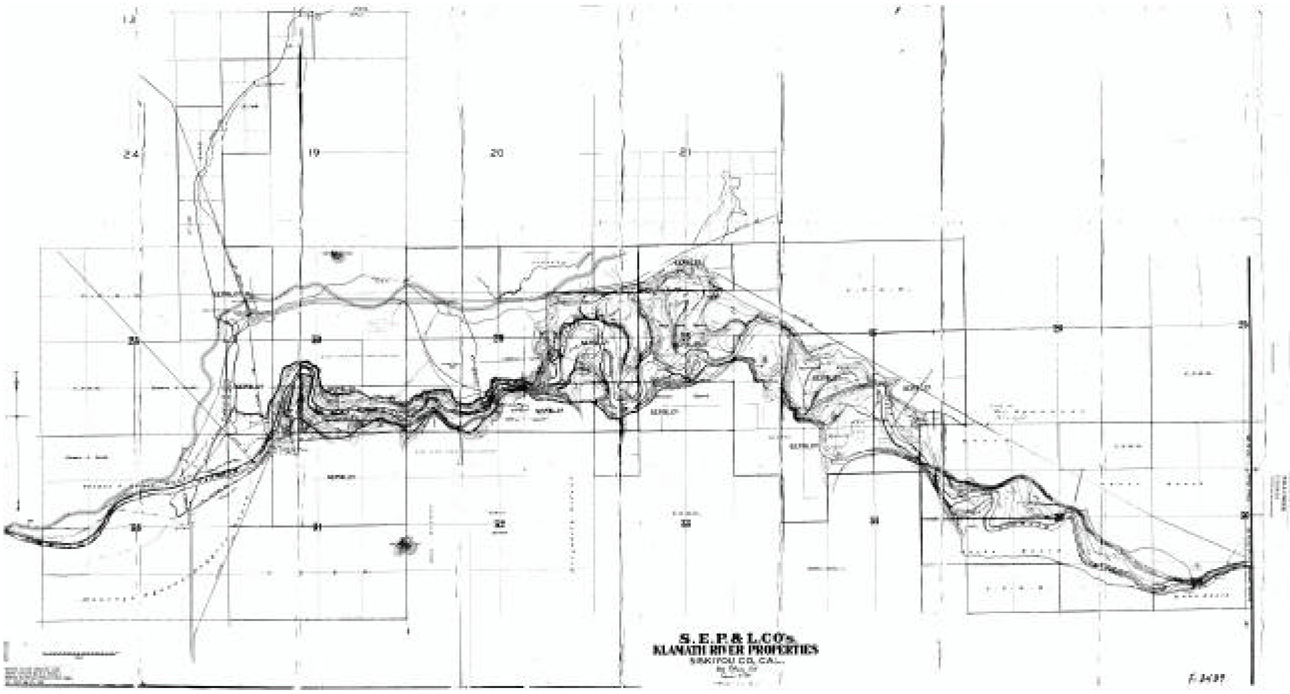

Figure 29a. Historic topography for the Copco Reservoir study area.

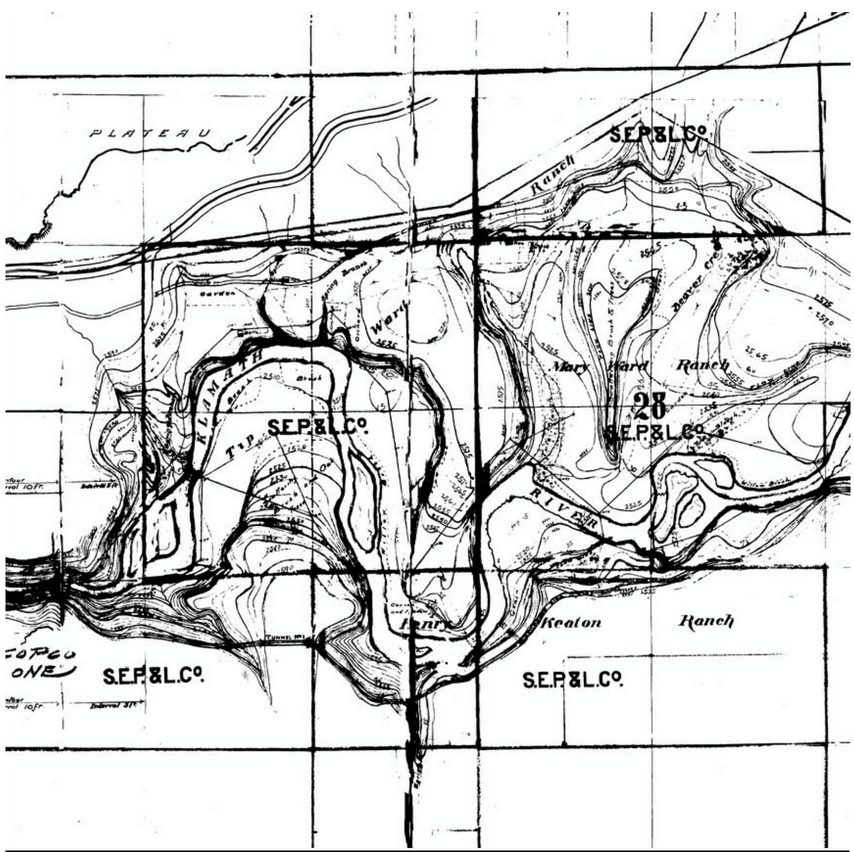

Figure 29b. Historic topography for the central portion of the Copco Reservoir area, shown at a larger scale.

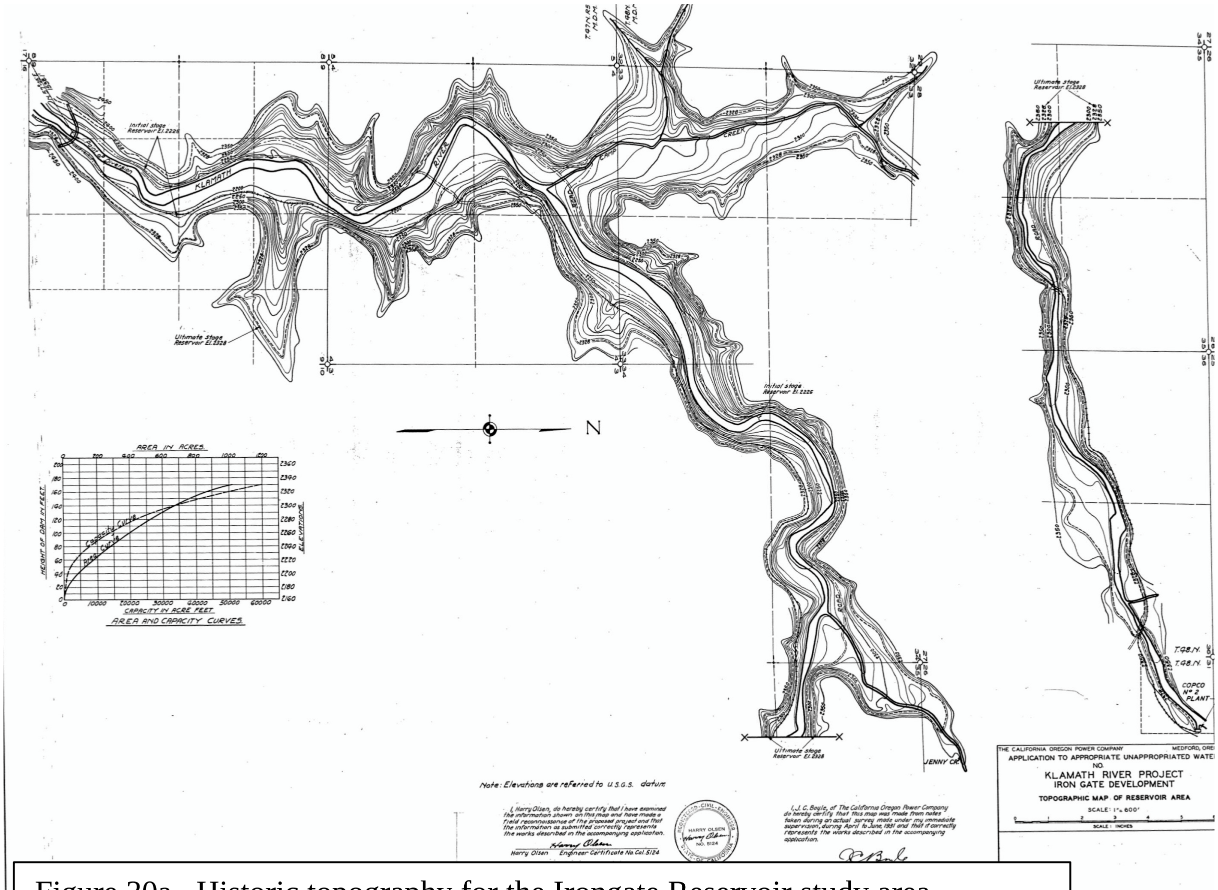

Figure 30a. Historic topography for the Irongate Reservoir study area.

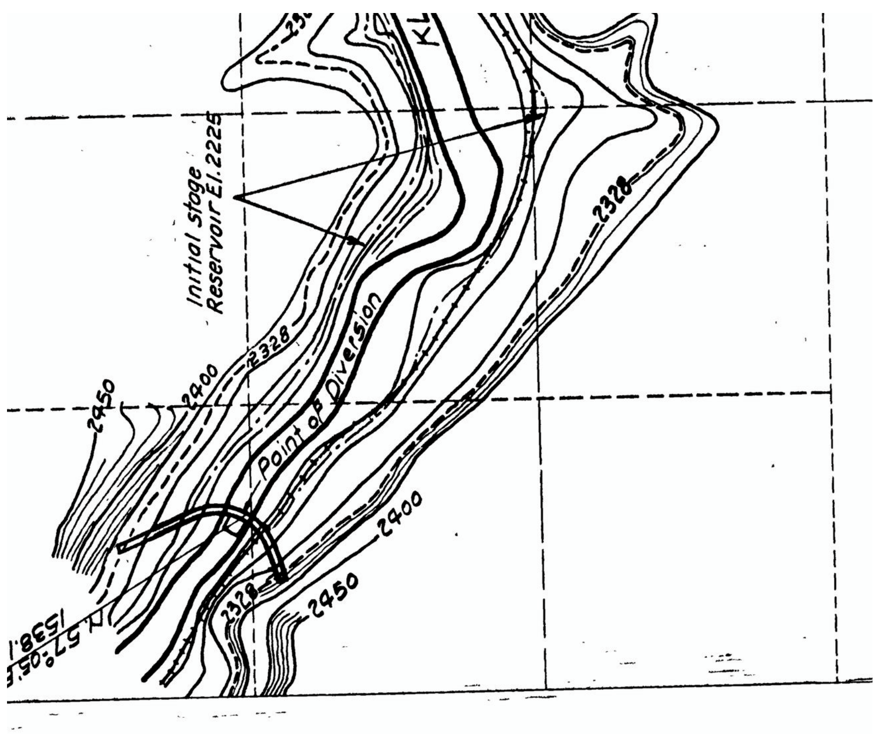

Figure 30b. Expanded scale of the historic topography for the forebay of the Irongate Reservoir area.

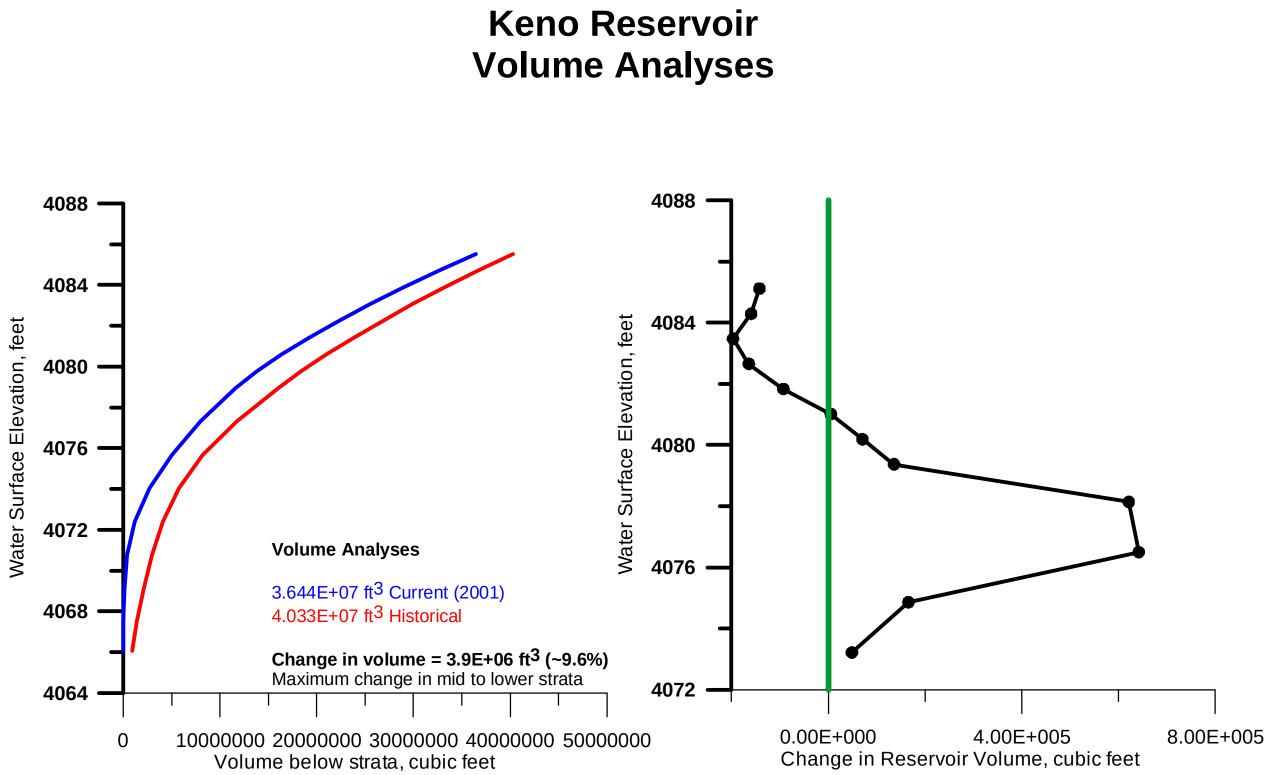

Figure 31. Current and historical hypsographic curves for Keno Reservoir and an estimate of the distribution of the change in lake volume as a function of lake depth.

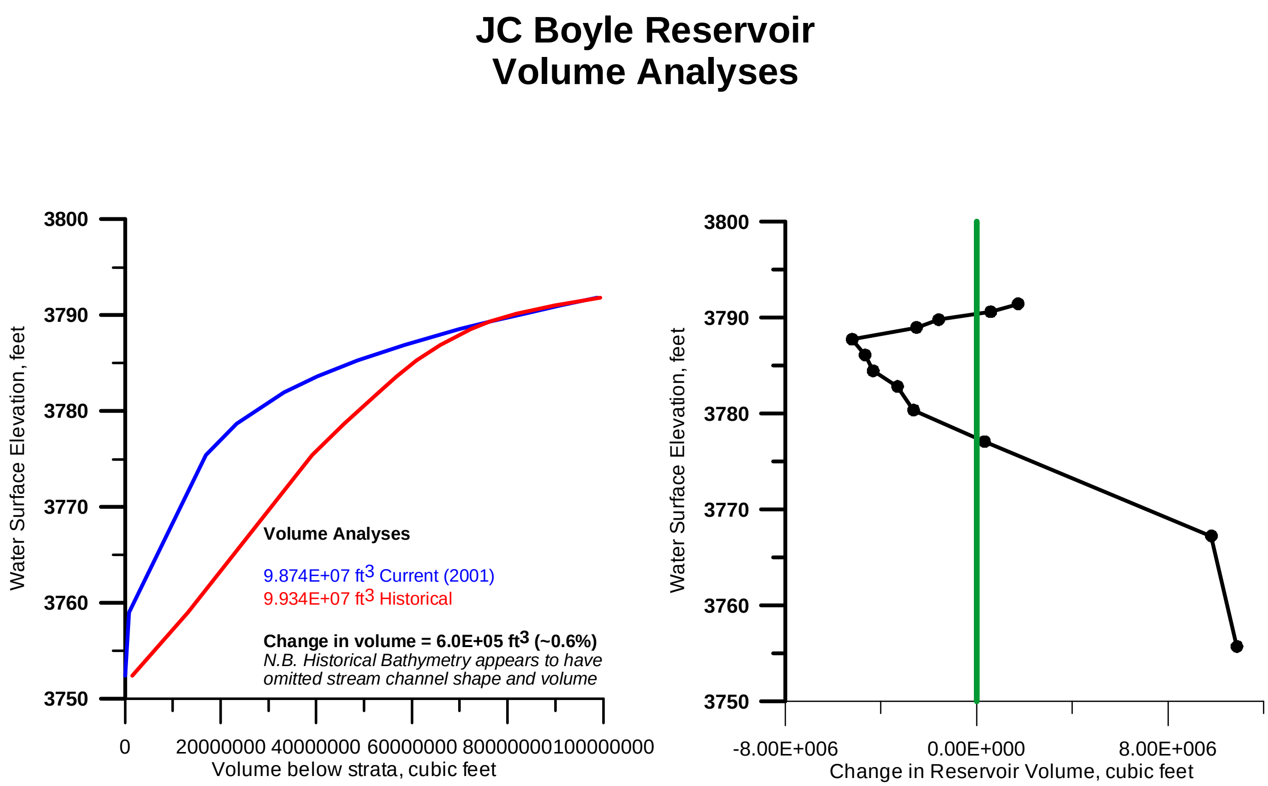

Figure 32. Current and historical hypsographic curves for JC Boyle Reservoir and an estimate of the change in lake volume as a function of depth.

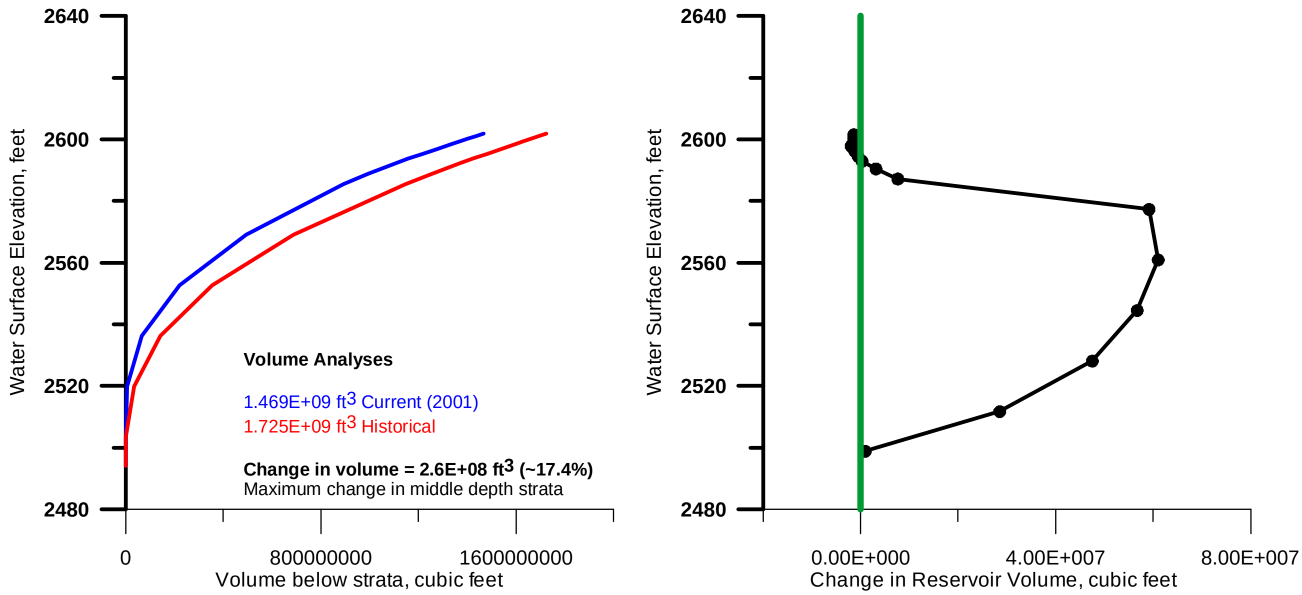

Figure 33. Current and historical hypsographic curves for Copco Reservoir and estimate of change in lake volume as a function of depth.

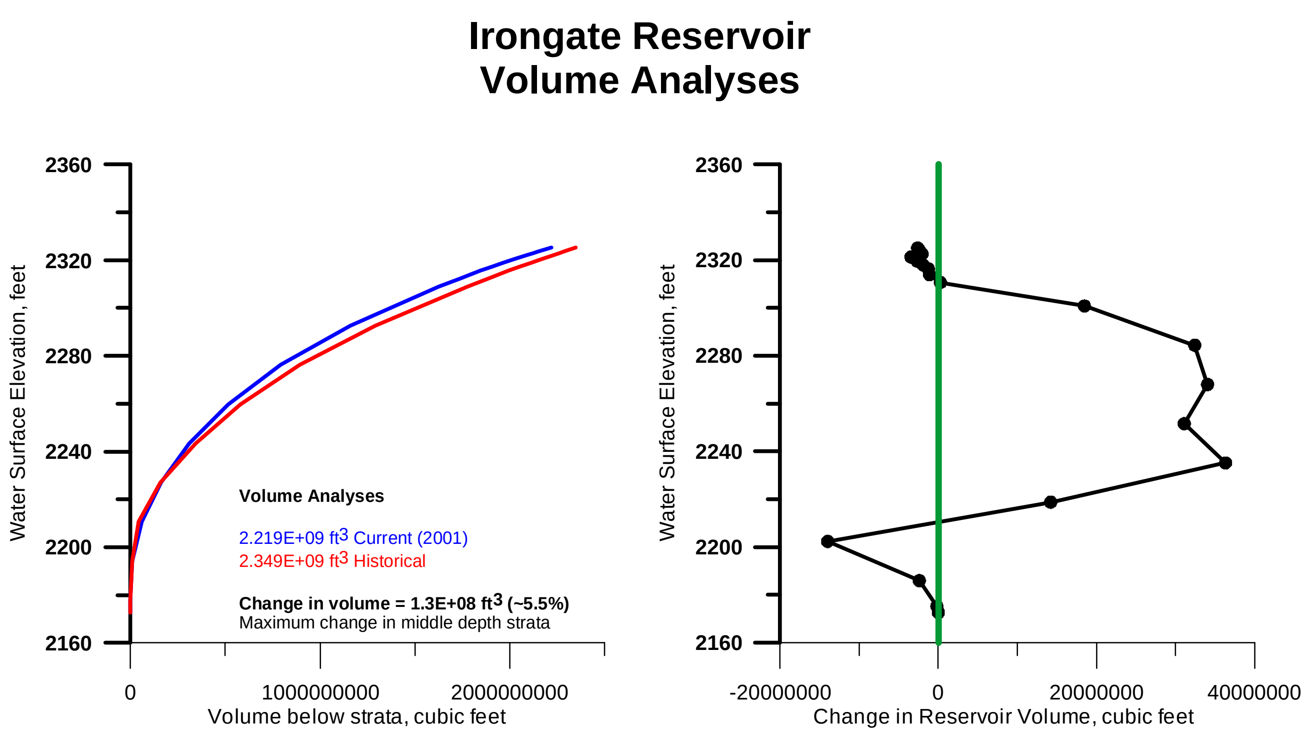

Figure 34. Current and historical hypsographic curves for Irongate Reservoir and an estimate of a change in lake volume based on depth.

DISCUSSION

Bathymetry for all of the impoundments was conducted and the results showed that the current bathymetry of the impoundments does not differ greatly from the historical topography. The estimated maximum loss of lake volume was calculated for Copco Reservoir, the oldest and most likely impoundment in the system to have accumulated the greatest amount of sediment. The least loss of volume was calculated for JC Boyle Reservoir, although anomalies in the historical topography for the upper portion of the reservoir cast doubt on the estimate for this system. Sediment composition in the impoundments consisted of a relatively high proportion of hard substrate, although deep sediments had a high proportion of silt and clay. Deltaic formation at the mouths of tributaries entering the impoundments was relatively sparse, reflecting the low rates of sediment production in the Project area.

Sediment classification using hydroacoustic analysis in some portions of the impoundments appeared to be affected by somewhat unusual sediment conditions. For example, in the northeastern portion of Lake Ewauna, buried wood fiber in the sediments appeared to promote reflectivity of the sediments to a degree greater than expected based on the soft matrix of the material in the area. In Keno Reservoir, the presence of shallow accumulations (~ 2cm) of soft sediment over the hard basaltic base rock appeared to dampen the hydroacoustic signal to a significant degree. Regardless of these minor anomalies, the bathymetric analysis provides managers with a reasonable basis for assessing current and future conditions in the study impoundments.

The chemical analysis of the sediments indicated that carbon content was relatively low throughout the system, with the exception of sites in and below Lake Ewauna that had high wood-fiber content. Thus despite the influx of lake water with high phytoplankton densities, the sediment in the Project area are principally inorganic.

ACKNOWLEDGEMENTS

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APPENDICES

Data files provided in attached CD.