RESTORATION OF CANYON LAKE AND BENEFITS TO LAKE ELSINORE DOWNSTREAM

Report to the
Santa Ana Watershed Project Authority

By

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1.0. SUMMARY

Canyon Lake is a small reservoir (A = 383 acres, ~ 10,000 acre-feet) situated on the main inflow to the much larger natural Lake Elsinore (A = 3,000 acres, ~ 35,000 acre-feet). Over 90% of the water flowing into Lake Elsinore enters via Canyon Lake. Based on existing data on P-deposition and loading, Canyon Lake is estimated to intercept 25.1 tons/y of total phosphorus (TP) that would otherwise pass to Lake Elsinore. About 17 tons of P is held in the East Basin and 8.1 tons in the Main Basin for each year. The total retention for both basins amounts to 56% of the external load and 44% of the total average P-loading to L. Elsinore. The East Basin alone intercepts about 38% of the loading. The 25 tons intercepted can be compared with other sources of TP to Lake Elsinore (12.5 tons from summer internal loading; 19-37 tons projected from large volumes of recycled makeup water). A large discrepancy (> 4-fold) exists between TP measured recently and in the past. This report uses the latest values but independent confirmation would be desirable. The P-trapping function of Canyon Lake dominates the external P-budget of Lake Elsinore. Other than the Five-Point Plan to restore Lake Elsinore using Proposition 13 funds, there is no action likely to reduce phosphorus to Lake Elsinore in large amounts from any other sources in the next quinquenium. Since several management actions in the Five-Point Plan to enhance Lake Elsinore require reduction in nutrients within two years, the current existence of a P-trapping mechanism should be considered as much a major benefit to Lake Elsinore as the sediment that carries the phosphorus is a hindrance to Canyon Lake. In essence Canyon Lake acts as a huge sediment detention basin for Lake Elsinore. If Canyon Lake did not exist, a basin with similar sediment trapping abilities would have to be constructed as part of the TMDL process to restore Lake Elsinore

Canyon Lake can be classified as a morphometrically mesotrophic lake but most indicators show aspects of eutrophy (nuisance algae blooms, hypolimnion anoxia, high soluble ammonia and phosphate in the summer hypolimnion, soluble iron and manganese, Secchi depth < 2 m, Chlorophyll *a* > 35 µg/L). Because the nutrient loading to the lake is high, the lake produces abundant algae that sink to the bottom, decay and use up all the deep water dissolved oxygen. The subsequent decline in water quality raises the cost of treating this drinking water supply for Elsinore Valley Municipal Water District. Typical water quality problems for drinking water from Canyon Lake are the presence of soluble iron and manganese, high pH, high turbidity, taste and odor, and possible blue-green algal toxicity. In terms of recreation, low water clarity and nuisance algae are most important in the deeper lake and sediment accumulation interfering with boating, hydrogen sulfide odor and occasional submerged weed growth are most important in the extensive shallow East Bay. Algae in Canyon Lake, like Lake Elsinore, is currently likely to be growth-limited by both P and N depending on season and time of year. However, if biomanipulation and other restoration methods of treating Lake Elsinore are successful, L. Elsinore will revert to strong N-limitation. In practice therefore, both N and P should always be removed.

Restoration of Canyon Lake is possible and would allow it to continue to reduce eutrophication and P-loading to Lake Elsinore. Watershed protection from erosion and external nutrient loading is the ideal solution and should be pursued within the Santa Ana Regional Water Quality Control Board's ongoing TMDL process. However, it will take a long time for any TMDL to be fully effective over such a vast watershed. Thus some in-lake solutions are needed for at least the next 15-30 years. Two main and three minor in-lake solutions are proposed. The two major solutions are deep water or hypolimnion oxygenation and inlet zone dredging. The three minor solutions are spring and fall mixing, local wetland filtration, and biomanipulation. Dredging to balance the current astonishingly high rate of sedimentation (2 to 3 inches per year, over 60 times the rate for a normal lake) will improve use of the lake and will allow future storage space for phosphorus-containing sediments to be stored and kept out of Lake Elsinore. It should be possible to sell some sediment. A pilot program should be undertaken along with some monitoring of the sediment nutrient bioavailability (N & P). Protection of the public drinking water supply in Canyon Lake can be achieved by reducing the amount of algae in the lake, primarily by limiting internal nutrient loading in summer and fall. The installation of a hypolimnetic oxygenation system will reduce the current internal concentration of highly bioavailable soluble phosphate (~ 0.6 mg/L) that is currently exported to Lake Elsinore when releases are made. It is estimated that this loading averages ~2 tons/y to Lake Elsinore. If an oxygenation system is installed in Lake Elsinore to suppress internal P-loading, this addition of 2 tons of bioavailable-P will become more important. Hypolimnetic oxygenation in Canyon Lake will have substantial benefits to use of the lake as a drinking water source since DOC and other undesirable algal products (DOC and THMP, turbidity, neuro- and hepato-toxins) and algae-induced chemicals (iron and manganese, sulfide) will be substantially reduced by oxygenation. Removal of sediment in the East Bay of Canyon Lake will also reduce phosphorus-driven eutrophication in the reservoir by reducing P-loading and shallow water nutrient recycling. Spring and fall mixing to enhance natural bottom oxygenation can make use of existing compressors and would run for a month before and after oxygenation. Local wetland filtration of surface water will remove surface algae but depends on the existence or creation of local wetlands. Wetlands have multiple purposes and could even be use to generate mitigation bank credits as well as increase property values away from the lakeshore. Biomanipulation, with its increase in natural zooplankton to filter lake algae, will occur anyway with the provision of deep oxygenated water refuge for large *Daphnia*. Removal of excess small fish throughout the lake and of carp in the shallow regions will enhance biomanipulation. As the lake water clarity improves, it is likely that submerged weeds will become more common. These weeds will provide refuge for *Daphnia* in the shallow East Bay and can be managed by harvesting.

Dredging costs reflect the high sediment influx and 30 years of Canyon Lake's existence as particulate trap for Lake Elsinore. Removal of the estimated half million cubic yards of sediment trapped by the lake over 30 years would be very costly ($2-5 million, unless sale of sand was possible) but a phased approach removing smaller amounts equal to the annual sediment loading (~17,000 cu yd.) would also work. Annual cost would be $60,000 to $170,000, depending on dredging cost. It is recommended that a pilot project to remove about 20,000 cubic yards be implemented at once to determine overall feasibility of the full-scale cleanup. If the pilot is successful, it is recommended that at least five years worth of sediment and attached phosphorus be removed. Sediment bioavailable-P removal is of interest to The Joint Powers Agency and other agencies interested in the cleanup of the San Jacinto watershed. A sinking fund would then be needed to maintain the new status quo. Capital costs for hypolimnetic oxygenation are $250,000 to $500,000 (construction) and $20,000-$50,000/y for O & M. The minor solutions spring and fall mixing local wetland filtration, and biomanipulation can be expected to be in the $10,000-$25,000 range, excluding any capital cost for land.

2.0 RECOMMENDATIONS

Three immediate actions are recommended for Canyon Lake:

1. <u>Begin a pilot dredging program</u> to remove about 20,000 cubic yards (one year's worth of sediments) to get a realistic idea of the costs of removal of the entire 30 years of sediment and the feasibility of using the East Basin as a long-term sedimentation and removal basin for the upstream regions.

2. <u>Design and install a hypolimnetic oxygenation device</u>. This methodology will offer the best return to improve water quality in Canyon Lake.

3. Independent confirmations of the recent sediment TP data collected by Anderson (2001). This data is so much lower than the previous data that the overall TP budget of Lake Elsinore is affected.

Over the next rainy period the following action is recommended:

4. <u>Watershed nutrient & sediment budgets</u>. The City of Canyon Lake support the efforts of others, including the Regional Board, to determine a P and N budget for the lake and its watershed. A recent study during dry conditions was made by Professor Anderson (UC Riverside) and a similar study in storm conditions should be funded.

Over the next two years the following is recommended:

5. Estimate utility of use of submerged propellers for spring and fall mixing when the hypolimnetic oxygenation device is off
6. Estimate utility of off-line wetlands for temporary summer algae filtration.
7. Estimate feasibility of biomanipulation for long-term sustained algae control.

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3.0. INTRODUCTION

Canyon Lake is a reservoir constructed in 1927 as a railroad canyon dam since train track and trestles covered the now flooded narrow valley bottom. About 1,300 residents enjoy the lake amenities along 15 miles of shoreline with about 1,000 homes built on the waterfront. Main activities are boating, fishing, and water-skiing. Thus the water quality of the lake is of paramount interest to the lake users. In addition the lake is a water source for Elsinore Valley Municipal Water District that also has a strong interest in high water quality. Although both main classes of lake users need high quality water, there specific needs differ. For example the dissolved organic carbon content (DOC) of the water is regulated for drinking water purposes at levels that are unimportant for typical recreational uses. In contrast, certain parts of the lake have become silted in by the storm runoff cause problems for boating but lie above the water elevation used for drinking water storage. Both groups, and the public in general, however, have an interest in the overall health of the lake since shallow water, for example can increase nutrient recycling. In turn, increased nutrients can degrade water quality.

The limnological situation at Canyon Lake can thus be summarized in the following way. The main lake is quite deep and steep sided and would be expected to be mesotrophic or oligotrophic on a morphometric basis. Over time the lake has probably become more eutrophic with more nuisance algae. The cause of eutrophication is excess nutrients from the drainage basin and internal recycling (internal loading). Excess nutrients and sediments from external sources can only be reduced with in the long term via the TMDL process. In the meantime some in-lake restoration is required. Internal sources can be reduced by other in-lake procedures.

Because Canyon Lake is a small reservoir situated at the terminus of a semi-arid drainage the influx of sediment can be large. Areas of low rainfall such as the San Jacinto River generally have large areas of barren or lightly vegetated ground and are susceptible to erosion during the occasional severe storms. Thus the natural watershed contribution to Canyon Lake drainage can be expected to consist of infrequent but large amounts of sediments. The sediment contribution following development in the watershed in the past few decades will have increased substantially over the natural rates. Because phosphorus is strongly bound to sediments in soils, eroded sediment is the major pathway of phosphorus to lakes. However, the Canyon Lake watershed is also developed with dairy farms, some other agriculture and housing. These land uses tend to increase the yield of soluble matter including soluble phosphate and nitrate. The result is that Canyon Lake receives large amounts of sediments in both wet and flood years.

4.0 THE CURRENT STATUS OF CANYON LAKE

4.1 CANYON LAKE AS A STORM DETENTION BASIN: SEDIMENT AND TOTAL PHOSPHORUS RETAINED

Canyon Lake (A = 283 acres) is situated on the San Jacinto River and is a minor volumetric contributor (~7%) to the much larger natural Lake Elsinore (A = 3,000 acres). Lake Elsinore also suffers from eutrophication and considerable efforts are being made to reduce the inflow of nutrients including phosphorus to Lake Elsinore. Although not its original purpose, Canyon Lake dam acts as a storm retention basin for sediments bound for Lake Elsinore. Because of the density of the sediments and the design of Canyon Lake, the majority of sediments build up in the delta of the main inflow and are not distributed over the entire lake or passed downstream of the dam.

East Bay (Salt Creek) Sediments. A survey was made of the sediment depth in the upper reaches of Canyon Lake in 1986 and again in 1997 (Suitt & Assoc., 1998). The difference between the two dates indicates an average annual accumulation of 2 to 3 inches of sediment over an area of 52 acres. Using an annual average value of 2.4 inches, the accumulation is equivalent to an annual sediment load to Canyon Lake of approximately 17,000 cubic yards. Using a density of 1.35 tons/cubic yard the annual weight of sediment deposited is approximately 23,000 tons.

Recently an extensive set of measurements of TP in the sediments of Canyon Lake was made (Anderson, 2000). For the entire lake surface sediment (~ 5 cm) were taken with a Ponar Grab. A total of 23 sites were used and gave a mean concentration of 747 mg/kg with range of 257-1,523 mg/kg. For the East Basin 10 stations gave a mean of 741 mg/kg (range 492 at inlet delta to 1,017 mg/kg as this arm of the reservoir joined the main body of water. Samples in deeper water were similar. However, past measurement of TP in Canyon Lake showed a very much higher value of 4,300 mg/kg (Santa Ana Regional Water Quality Control Board- SARWQCB, October 12, 1995). Thus the amount of TP in the sediments seems to be uncertain and may vary with the different methods used by the two investigators, or in very rapid flux from year to year. Using the more recent and more extensive data from Professor Anderson's University of California at Riverside (741 mg/kg), the amount of TP in the East Bay sediments was 17 tons per year (Table 1). Using the SARWQCB value of 4,300 mg/kg (0.43%), the amount of TP deposited along with the total sediments in the East Bay rises to 99 tons/yr (Table 1).

Main Canyon Lake (San Jacinto River) sediments. Using the same recent report of TP in Canyon Lake, the amounts of TP in the main basin fall considerable from those based on earlier data. The most recent and extensive study (Anderson, 2001) gives a value of about 1,000 mg/kg (0.1%). As before the range of recent TP measurements do not overlap with the previous measurement (4,300 mg/kg). In addition, an estimate of the sediment deposition rate of 1 inch/y was made for the main basin by the USGS. I estimate that the minimum area of hypolimnion sediment is 45 acres. This area is about 12% of the surface area and, although smaller than in most lakes and reservoirs, seems reasonable since Canyon Lake is steep sided. The sedimentation rate is 1 /2.4 = 0.41 or

41% of that in the East Basin and is smaller in size by 45/53 = 0.86. Thus the sediment in main basin is accumulating 0.35 times as rapidly (0.41 x 0.86) as that measured in the East Basin. Based on the above assumptions, the amount of TP retained in the sediments of the main basin of Canyon Lake is approximately 8.1 tons/yr (Anderson, 2000 data, Table 1) or 35 tons/yr (USGS data, 99 x 0.35; Table 1).

Contribution of both the East Basin and Main Basin of Canyon Lake. The sum of both of these basins in terms of P-trapping is 25 tons/y (17 + 8) using the Anderson (2001) data and 134 tons/y (99 + 35) using the USGS data. The value will be used in the rest of this report will be the Anderson (2001) values. However, an independent check of this data is required.

External Loading to Lake Elsinore. The external loading from the entire drainage is under investigation. Ignoring the small local drainage, the main San Jacinto River below Canyon Lake Dam is estimated to add 20 tons/y to Lake Elsinore (Table 1). The estimate is based on the flood flow measurements in the wet years of 1993 made by Montgomery-Watson (1997) and an assumption of a flood frequency of 10 years. Note that this value would presumably be almost seven times higher if Canyon Lake Dam were removed since any TP trapped behind the dam would pass directly to Lake Elsinore.

Internal Loading to Lake Elsinore. Internal loading is the amount of phosphate released from the sediments into the overlying water in summer. Most internal loading occurs when the sediments in the lake become depleted in oxygen. The resulting anoxia causes chemical changes in the mud that result in the release of soluble compounds such as ammonia, soluble phosphate, iron and manganese. The release of soluble materials can be measured using intact cores of lake sediment incubated in the laboratory under various conditions. Based on summer studies in 2000 by the University of California (Berkeley) and autumn studies in 2000 the University of California (Riverside) the internal loading of phosphate in Lake Elsinore was estimated to be 12.5 tons/y (Montgomery-Watson, December. 2001; Table 1).

Table 1. Phosphorus budget for the San Jacinto Watershed based on extensive summer 2001 sediment measurements (Anderson 2001) and a single October 1995 sediment measurement (SARWQCB).

Source	**1995 data**		**UC Riverside 2001 data**	
	TP retained tons/y	**Percent total P**	**TP retained tons/y**	**Percent total P**
1. Canyon Lake, East Basin (Salt Creek)	99[1]	56	17[6]	30
2. Canyon Lake, Main Basin (San Jacinto Creek)	35[2]	20	8.1[7]	14
3. L. Elsinore (internal loading)	24[3]	13	12.5	22
4. L. Elsinore (external loading)	20[4]	11	20	35
Total overall P-budget	178	100	57.6	100
Total external P-budget	154		45.1	
a. Total retained in Canyon Lake	134	87 (of	25.1	56% of

		external load)		external load
b. Total retained in Canyon Lake	134	76 (of total load)	25.1	44% of total load
Total Bioavailable P loading to Elsinore	147[5]		48.5	

[1] Based on measured sediment deposition of 2.4 inches/y (23,000 tons) at the site (Suitt, 1998) and the single measured TP (0.43%) in the main lake sediment. [2] Based on a single TP sediment measurement (0.43%) in the main basin, the measured sediment deposition rate of 1 inch/y (USGS) and my estimate of the area of hypolimnion sediment (45 acres or about 12% of the surface area since Canyon Lake is steep sided). Value is a ratio of that from E. Basin (see text). [3] Based on UCB and UCR intact core flux measurements in the laboratory (range 17-30 tons/y, Beutel & Horne, 2000, Anderson, 2000) Further studies may modify these flux measurements. [4] Based on 10% of the flood measurements of 200 tons of TP in the 1993 floods (Montgomery-Watson, 1997), assuming one flood per decade. [5] Assuming that 100% of internal P-loading and 80% of external P-loading bioavailable [(99 + 35 + 20) x 0.8 = ~ 123 tons/y + (24 x 1.0 = 24 tons/y)] = 147 tons/y and [(17 + 8.1 + 200 x 0.8 = ~ 36 tons/y + (12.5 x 1.0) = 12.5 tons/yr] = 48.5 tons/y . [6] Based on recent measurements of East Bay sediments of 741 mg/kg TP. [7] Based on recent measurements of sediments in the main body of the reservoir of 1,000 mg/kg TP

Thus in the absence of the Canyon Lake dam 25.1 tons (56% more total phosphorus generated by the San Jacinto drainage would pass directly to Lake Elsinore and increase its eutrophic state. About 17 tons is held in the East Basin, about 8 tons in the main basin. Recently, the Elsinore Valley Municipal Water District (EVMWD) has estimated that Canyon Lake intercepts about half of the annual total P-load to Lake Elsinore. The estimate in this report is agreement with the EVMWD estimate but has the advantage of being based on multiple measured sediment accumulation. The typical removal of particular phosphorus in short-term detention ponds (HRT ~ 0.5 days) is about 50%. Studies of the removal of TP in winter storm flows in the Clear Lake, California rivers was 95% removal in overnight jar tests. Lesser removal would occur in the more wind-mixed and turbulent large retention ponds. Wetlands with several days residence time can remove up to 95% of TP if hydraulic short-circuiting is prevented. Thus the removal of 56% of TP by the deep, long residence time Canyon Lake is feasible. It would be desirable to have an independent check on the TP values of Anderson (2001) and the USGS since the numbers were so disparate. If the higher USGS values were correct the percentage contribution of Canyon Lake to removal of TP flowing into Lake Elsinore would rise to from 56 to 87%. Although there is a large difference in tons per year depending on the TP values used, the percent changes are less affected since Canyon Lake is the only detention basin on the San Jacinto River and it thus the only TP trapping system.

The most important contributors of phosphorus to the San Jacinto watershed were considered by the EVMWD to be dairy farms. There are various sites along the river where sediment could be stored and re-released The complete P-budget of Lake Elsinore is not known but other sources, wind-blown dust, fish stocking, local septic tank leachate, local small sources of storm erosion, and summer nuisance runoff from irrigation are likely to be small relative to the large items just discussed.

Comparison of Canyon Lake P-trapping and other P-sources for L. Elsinore. The 25 tons/y of total phosphorus the settles in Canyon Lake annually (17 tons in East Basin alone) is thus prevented from entering Lake Elsinore. In terms of Lake Ellsinore's phosphorus budget, the 25 tons/y held in Canyon Lake can be compared with the average of 20 tons/y that passes through Canyon Lake and reaches Lake Elsinore and the 12.5 tons/y from Lake Elsinore sediments during internal loading in summer (Table 1). The 25 tons retained by Canyon Lake can also be compared with the 9-39 tons/y that would enter Lake Elsinore from recycled water during normal and total drought years if the lake water make-up program were to be instituted.

In terms of eutrophication and algal growth, all phosphorus is not alike. Although often measured as total phosphate (TP) only soluble inorganic phosphate (PO4) can be used for algal growth. However, much of the TP present in some sources is bioavailable. In this report it was assumed that 80% of the TP in the sediments was bioavailable [this is a reasonable assumption for many types of sediment, but if the sediment-P is dominated by apatite (calcium phosphate), the assumption will be too high since much of the TP will be biologically unavailable]. The amount of bioavailable-P entering from the San Jacinto River the main inflow to Canyon Lake and Lake Elsinore is not known but should be measured by algal bioassay or similar techniques.

Interim Conclusion. The P-trapping function of Canyon Lake thus appears important compared with either the external loading budget or the internal P-budget of Lake Elsinore (Table 1). It is vital that better data be collected for the San Jacinto River, although the recent dry years have handicapped any collections. Thus the P-trapping in Canyon Lake should be considered as much a benefit to Lake Elsinore as the sediment containing the phosphorus is a hindrance to Canyon Lake. In terms of constructing sediment detention ponds upstream the P-trapping function of Canyon Lake saves a considerable amount of construction and maintenance upstream. It is also not clear at what time in the future actual storm water detention ponds would be constructed since there is no fixed implementation schedule for most TMDL construction projects at present.

4.2. WATER QUALITY PROBLEMS AT CANYON LAKE

Deeper, thermally stratified part of the lake. The main water quality problems at Canyon Lake are related to the large annual influx of sediments and other nutrients that enter the lake. Canyon Lake has two main sections: a shallow upstream area and a deeper section that extends back from the dam where water depth reaches about 50 feet.

The main deeper water section of Canyon Lake could be expected to have moderate to good water quality based on its shape. Normally, deep steep-sided lakes have good water quality since the nutrients entering in the summer are trapped in the deeper water. So only a spring algae bloom occurs with relatively good water quality for the remainder of the year. The magnitude of the spring bloom depends on the amount of nutrients carried in each winter together with nutrients mixed in from the deeper water. It is important to note that flushing of nutrients from lakes by winter storms or summer releases has generally little effect on the lake's trophic state.

The main problems in the deeper water of Canyon Lake are due to algae, which in turn are fed by excessive nutrients (Table 2). The winter supply of nutrients and sediments that contain nutrients is one cause. The second cause is that nutrients are regenerated in the sediments in deep water in the summer. Sediment nutrient generation or internal loading is primarily caused by a lack of oxygen in summer in the deep-water hypolimnion.

Table 2. Examples of water quality problems in the deeper water section of Canyon Lake in 1995-2000 (Data from Dr. Cindy Li, Santa Ana Regional Water Quality Control Board).

Parameter	**Measured value**	**Depth/date**	**Desirable value**
Dissolved oxygen	0.2 mg/L	42 feet/Sept.	2-7 mg/L
Soluble phosphate	1.3 mg/L	Hypolimnion/Aug	20-50 ug/L
Ammonia	4.3 mg/L	Hypolimnion/Aug	20-100 ug/L
Chlorophyll a	37 ug/L	Surface water	10-20 ug/L
Iron	1.4 mg/L	Hypolimnion, summer	0.05 mg/L
Manganese	0.35 mg/L	Hypolimnion, summer	0.05 mg/L
Blue-green algae	Surface blooms	Fall	No visible blooms

The upper shallow keys section of the lake. The main problems for the shallow area of the lake are that they are becoming shallower more rapidly. Shallow water in some parts of the lake can degrade the entire lake by increased nutrient recycling and by allowing the growth of macrophytes (waterweeds). Submerged aquatic plants can produce odors that are undesirable in a drinking water supply both directly and by providing a site for attached blue-green algae. Submerged weeds, if extensive are also a nuisance for swimmers and boaters, especially if the propulsion unit becomes entangled in long stringy weeds. An outbreak of submerged weed did occur about 10 years ago but so far weeds have not been a nuisance. It is not clear why this is so but shallow waters usually become dominated with weed when the water is shallow. As the water becomes clearer if other cleanup measures such as hypolimnetic oxygenation are put into operation, then increase submerged macrophyte growth is probably inevitable.

The increase in sediment in Canyon Lake is very large indeed, especially in the 15% of the East Bay and inlet regions. A survey of the lake bathymetry was made in 1986 and 1997 at five stations in the East Bay section (Table 3).

Table 3. Thickness and increase in sediment over 11 years in the East Bay section of Canyon Lake.

Site location	**Thickness of deposited organic clay, sand and gravel, Dec 1986 (feet)**	**Sediment increase in 11 years to Sept. 1997 (Feet)**	**Total thickness of alluvial sediments**
1	6.5	+2.6	9.1
2	2.2	+2.1	4.3
3	2.7	+1.8	4.5

4	1.4	+1.8	3.2
5	1.2	+2.3	3.5

The bottom elevation was found to have increase from 1.8 to 2.6 feet over the eleven years, a rate of 2-3 inches/year (4.6-6.9 cm/y; Suitt & Assoc. Feb 17 1999). Total sedimentation in the East Bay over the 30 years life of the reservoir was estimated at 3.2 to 9.1 feet or 1.3 to 3.6 inches per year (3 to 8.4 cm/y (Table 3).

The amount of sediment retained in upper East Bay Canyon Lake can be compared with the values found elsewhere. A range of sediment values is shown in Table 4.

Table 4. Rate of sedimentation in the East Bay section of Canyon Lake compared with other sites. Values based on surveys. It was assumed that the East Bay section covered 52 acres or 14% of the entire lake.

Rate of sedimentation	Inches/ year	cm/yr	Comments
Based on East Bay			
Based on last 11 years	2-3	5-7.5	Based on survey of 52 acres in E. Bay
Based on 30 years	1.3-3.6	3.2-9	As above
Averaged over entire lake			
Based on last 11 years	0.27-0.41	0.68-1.0	Assumes E. Bay sediment spread through the lake
Based on 30 years	0.18-0.49	0.44-1.2	As above
Values elsewhere			
Typical lake		0.1	Mostly winter silt and dead summer algae
Strumpshaw Broad, UK		0.5	Heavy agricultural loading
Small Michigan lake		0.6	Very eutrophic lake
Mountain Lake, SF, recent years		1.9	Result of a road built through the lake
Daguerre sediment dam	30	75	Built to trap hydraulic mining debris in early 1990s. Was filled in six years.

The sedimentation rate found in the East Bay of Canyon Lake are astoundingly high and are about 65 times more than would occur in a normal lake. Even if the influx of sediment had been spread over the entire lake the rate is eight times the normal rate. Such very high sedimentation rates have been approached in Mountain Lake in the Presidio in San Francisco only because a road was constructed through the lake. The sand deposited to form the roadbed spread over the lake, filling it in several feet in a few years. Only deliberate sediment traps such as the Daguerre Dam on the Yuba River in northern California show higher deposition rates than the East Bay of Canyon Lake (Table 4). However, there are some other reservoirs in highly erosive conditions (e.g. Lake Pillsbury on the Eel River) that have experienced severe filling of side arms.

The high sedimentation rate in Canyon Lake has been questioned by the City of Lake Elsinore (Kilroy, 2001) based on the Salt Creek flow and estimates based on TP concentrations in typical winter flows. Kilroy estimates that only 0.11 tons/yr of TP would be deposited in the East Bay, rather that the direct measurement of 17 tons/yr. The difference between Kilroy's estimate and that of this report is thus 155 fold (17/0.11). If translated into annual sedimentation, Kilroy estimates that instead of 2.4 inches/yr (5.8 cm/y) sediment deposition would be 0.015 inches/yr (0.036 cm/y). The measured sedimentation rate of 2.2 feet over the last 11 years would thus be only 0.014 feet or 0.17 inches. It seems unlikely that any boat dock user would notice a change in water depth of less than a quarter of an inch over 11 years. Since there is ample visual evidence that the dock and East Basin has become noticeably shallower over the past 11 years, some sedimentation much greater than that estimated by Kilroy must have occurred.

The most likely explanation for the discrepancy between the estimate of sediment and TP accumulation and that made the City of Lake Elsinore (Kilroy, 2001) lies in the transport of sediment in normal winter storms and that in the 10 or 50-year storms. Kilroy based his estimates on normal winter storms. Typically, major storms carry about 100 times more particulate matter, such as particulate phosphate than normal storms. The logarithmic shape of the relationship between water velocity and sediment transport explains the difference between the directly measured sediment accumulation and that found from estimates made in relatively low water velocities. Thus increasing the winter storm flow by ten fold, the sediment carried will increase by about 100 fold. The lack of good measurements in major storms is possibly the greatest problem in TMDL calculations and lake P and sediment budgets. However, it is often very dangerous to make water quality and quantity measurements in large floods. Automatic equipment is often destroyed by debris or clogged with silt while boating in such waters is usually inadvisable. Only where there are convenient bridges is it usually possible to collect samples across the width and at several depths in a flooded river.

Nonetheless, Kilroy makes some useful comments both in the 2001 memo and verbally in Technical Committee meetings on the Canyon/Elsinore. It would thus be advisable to make measurements of storm transport of particulate and soluble nutrients similar to those made by Professor Anderson in the last few years during drought conditions.

4.3. ALGAL GROWTH LIMITING NUTRIENT IN CANYON LAKE AND LAKE ELSINORE

The most successful method to improve water quality in almost all drinking water and recreational lakes and reservoirs is to reduce the amount of algae (Cooke et al., 1999). In turn, in deeper lakes such as Canyon Lake, direct reduction of nutrients such as nitrate or phosphate has been shown to be effective in reducing algae (Horne & Goldman, 1994). The situation in shallow lakes is complicated by the need to ensure reduction in sediment recycling which is probably best ensured by biomanipulation combined with strong initial nutrient reduction.

Algae in Canyon Lake, like Lake Elsinore, are currently likely to be growth-limited by both P and N depending on season and time of year. However, if biomanipulation and other restorations of L. Elsinore are successful, it will revert to strong N-limitation. In practice therefore, both N and P should always be removed in future projects. The combination of wetlands and settling basins provides methods for N and P removal, respectively. Thus the P removal capacity of Canyon Lake (sedimentation) will always be needed to assist Lake Elsinore but should be combined with N-removal, by oxygenation for example.

The rates of phosphate flux from the sediments of Canyon Lake have been recently measured for both shallow and deep water by Professor Anderson (Anderson, 2001) using isolated cores incubated in the laboratory. The results showed that between 2.4 and 4.8 $mg/m^2/d$ (mean 3.7 $mg/m^2/d$) were released in cool conditions simulating those of the hypolimnion in Canyon Lake. The shallow and warmer sediments of the epilimnion released more phosphate (range 9 to 13 $mg/m^2/d$). These rates are within the ranges found for eutrophic lakes elsewhere. The very high phosphate concentrations measured in the hypolimnion of Canyon Lake must be due to these sediment releases.

Hypolimnetic oxygenation has been shown to reduce the amount of internal loading for nitrogen and phosphorus by an average of about 50%. Reductions as high as 95% have occurred for phosphate in some lakes. The amount or soluble iron in the water and the ability of sediments to bind iron may control the differences found among lakes for phosphorus removal when oxygenating lakes and reservoirs.

5.0 SOLUTIONS TO CANYON LAKE'S WATER QUALITY PROBLEMS

5.1. SELECTION OF THE METHODS FOR ENHANCEMENT OF CANYON LAKE

The problems that can be addressed by watershed and lake management for Canyon Lake are shown in Table 5. The chief problems are too much sediment and nutrients from the watershed and too much internal loading in summer in the lake itself.

Table 5. Current problems in Canyon Lake and their probable causes.

Problem to be addressed	Probable cause	Other possible causes
Eutrophication	High nutrients from runoff & high internal loading of nutrients	
Algae	Excessive nutrients from watershed & anoxic lake bed	Sedimentation in East Bay enhances nutrient fluxes from shallow sediments
High internal nutrient loading	Anoxia on lake bed & hypolimnion	
DOC/THMs*	Algae extra-cellular products	
Iron & manganese	Anoxia on lake bed	
Sulfides & odors	Anoxia on lake bed	
Silting in of lake	Sediment from watershed	

*Dissolved organic carbon (DOC) can produce Trihalomethanes (THMs) when if DOC is high (> ~ 4-6 mg/L) when the water is chlorinated for disinfection during drinking water treatment. THMs have been linked with human health problems including birth problems and possibly cancer.

Eutrophication and sedimentation in lakes and reservoirs can be reversed by two methods:

1. Watershed actions – Five methods of reduction of nutrients and sediment in the inflows
2. In-Lake actions – 17 lake management techniques and technologies

5.2. WATERSHED ACTION TO REDUCE EUTROPHICATION AND SEDIMENTATION IN CANYON LAKE

There are five general methods of watershed action that can be taken. These are:

Treat sewage
Divert non-point sewage (move from septic tanks to sewers)
Decrease landscape/agricultural fertilizer input
Block entry of storm runoff & sediment out particles
Use of wetlands as "biological filters"

Applicability of five watershed treatment methods for the Canyon Lake drainage basin

Treat sewage. Secondary treatment is currently provided for the residents and shoreline homeowners in Canyon Lake. No sewage treatment plant effluent is discharged directly into Canyon Lake. There is thus little room for improvement in the local region. However, treated sewage and animal wastes form part of the flow of the San Jacinto River that flows into Canyon Lake from its vast watershed of over 500,000 acres.

Divert non-point sewage. Most homes outside cities are permitted to use septic tanks for sewage disposal so long as the land area and soil types are adequate. Septic tanks contribute nutrients and can cause eutrophication downstream. In addition, agriculture of both row crops and livestock contribute nutrients downstream that can also cause eutrophication. Non-points of diffuse sources of nutrients are generally septic tanks or farms and ranches. Septic tanks are adequate methods of treatment for the reduced oxygen-demanding components of sewage and if they are sited on large plots. However, septic systems are ineffective for nutrient removal of all waste components even if there are sufficient trees in the leach line to remove soluble nitrate. In the winter trees do not take up water from the ground allowing soluble nutrients to flow to the local groundwater and eventually the lake. One method to reduce diffuse septic tank pollution is to connect the septic tanks to sewers.

Decrease landscape/agricultural fertilizer input. The other main diffuse source of nutrients in most drainages is “nuisance flows” from landscaping irrigation and runoff from farms. Reduction or elimination of row crop fertilizer runoff or groundwater seepage and livestock wastes can be accomplished with retention/treatment ponds and nutrient removal wetlands. Unfortunately, these actions are difficult in a large watershed. However, there is hope that the TMDL process will eventually reduce upstream diffuse pollution. Until that time some other, probably in-lake methods will be needed.

In the dry climate of Canyon Lake, runoff from agriculture is likely to occur only in winter following storms. However, although occasional, such flow can contain enormous amounts of nutrient and pathogen waste. There are several dairies and other agricultural operations in the vast watershed. It is recommended that control of agricultural and other diffuse nutrient sources be mainly directed through the ongoing Santa Ana Regional Water Quality Control Board’s TMDL process.

Block entry of storm runoff & sediment out particles. Soil particles are bathed in soil water, which contains nutrients at much higher concentrations than even eutrophic lake waters. An exception is the summer anoxic waters of Canyon Lake where ammonia and soluble phosphate probably exceed the amounts sorbed to the sediments. The removal of storm flow particles is important since they contain sorbed nutrients that are released when the particle meets the lower nutrient milieu of the lake. In addition, once in the lake, sediments particles are decomposed by bacteria releasing nutrients in summer and adding to the lake's internal nutrient loading.

Best Management Practices (BMPs) are used to control sediment losses. Contour plowing, better road cutting, and enforcement of house construction are examples of BMPs commonly used. Constructed detention ponds and wetlands to hold urban and agricultural runoff are examples of structural BMPs. It is recommended that BMPs be also considered in the TMDL process not directly dealt with in the management of Lake Elsinore.

Use of wetlands as "biological filters". Wetlands in wet or dry conditions have proven effective at removing particles and soluble nutrients as well as heavy metals, organics, pesticides and pathogens. However, a detention time of one to four weeks is needed for soluble nutrient removal. Only a few hours is needed to sediment particles in wetlands.

In conjunction with the TMDL process it is recommended that wetlands be employed in the drainage basin where possible. It is unlikely that riparian wetlands will contribute much in terms of nutrient removal in storm flows. However, flat vegetation-filled wetlands upstream of Canyon Lake would assist in the reduction of eutrophication in the lake. Wetlands do consume water (~ 3-5 feet per acre per year in this region) so the water quality improvements must be balanced against water losses.

5.3. IN-LAKE TREATMENTS

There are 17 commonly accepted methods for the reduction of eutrophication in lakes using know technologies and management strategies. Some methods are well known while others are just beginning to be used for most lakes and reservoirs. The methods are shown immediately below and their possible application to Canyon Lake are shown in Table 5.

A. Physical methods

Common and widely applicable methods
1. Dredging
2. Water level draw down & water level fluctuation
3. Destratification & lake mixing
4. Macrophyte (water weed) harvesting
5. Wetland algae filters (off-line wetlands)

Minor or restricted methods
6. Algae (phytoplankton) harvesting
7. Selective withdrawal of hypolimnion water
8. Dilution/flushing
9. Sediment sealing (fabric liners, barriers)

B. Chemical methods
10. Herbicides (for algae or macrophytes)
11. Oxygenation or aeration
12. Shading (dyes)
13. Sediment sealing (chemical; alum, phosloc for PO_4 binding)

C. Biological methods
Direct
14. Pathogens of algae or macrophytes (virus, bacteriophages, bacteria)
15. Grazers on algae of macrophytes (, grass carp, Talapia, beetles)
16. Nutrient harvesting (fish, minor method, unlikely to work)

Indirect
17. Biomanipulation (top down controls to favor algae-filtering *Daphnia*). Includes harvesting excess small fish and bottom-grubbing carp.

The 17 methods were listed above and the utility for Canyon Lake are summarized in Table 6.

Table 6. Review of the applicability of the in-lake methods for Canyon Lake, southern California.

Method	**Applicability for Canyon**	**Use?**
Dredging	Use in East Bay to remove up to 9 feet of sediment. Carry out in stages? Will remove main source of P to Canyon Lake (& Lake Elsinore). Cost is high for complete removal	Yes
Water level draw down & water level fluctuation	East Bay already too shallow for draw down, no weed problems (yet). Most of shoreline is bulkhead with no weed potential	No
Summer destratification & lake mixing	Will likely increase algae, possibility of odors. Climate too warm to make this method energy efficient. Replace with hypolimnetic oxygenation.	No
Spring & fall short term destratification & lake mixing	Will reduce blue-green algae in spring and fall by extending natural winter mixing when mixing is energetically feasible.	Yes
Macrophyte (water weed) harvesting	No weeds at present, possible need in future	Maybe
Wetland algae filters (off-line wetlands)	Not feasible due to pumping costs? Need to explore possible sites and other values of wetland	Maybe
Algae (phytoplankton) harvesting	Cost is high and effectiveness low for small Canyon Lake. Algae must accumulate predictably	No
Selective withdrawal of hypolimnion water	No spare water to lose, water is withdrawn at present from hypolimnion. Water quality problems and smells with summer releases.	No
Dilution/flushing	Possible flushing with Colorado River since volume of Canyon Lake is small. Water not always available and would be required most years in absence of other methods.	Maybe
Sediment sealing (fabric liners, barriers)	No weed problems at present. Could be used if weeds grow alongside docks & swim areas	No
Herbicides (for algae or macrophytes)	Most cannot be used in a drinking water supply. Copper sulfate or similar are used but should be kept for emergencies	Limited
Oxygenation or aeration	Main in-lake method to reverse eutrophication by reducing internal nutrient loading	Yes
Shading (dyes)	Lake too large for this method, lasts only few months.	No
Sediment sealing (alum, phosloc)	High cost, would be ineffective following first storm. Lake is N limited not P-limited so effect not as good as in some other sites.	No
Pathogens of algae or macrophytes	Ineffective for blue-green algae due to resistance buildup. None known for macrophytes	No
Grazers on algae or macrophytes	Not applicable except within concept of biomanipulation (see below)	No
Nutrient harvesting from fish or other biota	N and P removal very small compared to other nutrient sources. Fish stocking may balance harvesting.	No
Biomanipulation	Successful in shallow lakes, less so in deeper lakes. Needs hypolimnetic oxygenation for a refuge from fish predation for the algae grazing zooplankton.	Yes

6.0 RECOMMENDED METHODS OF WATERSHED AND IN-LAKE TREATMENT FOR CANYON LAKE

Two main approaches are recommended. These are:

- Installation of a hypolimnetic SDCO oxygenation system (Submerged Downflow Contact Oxygenator or similar device)
- Phased dredging of the shallow East Bay sediments

Three minor approaches are recommended. These are:

- Extended winter mixing in early spring and late fall using compressed air
- Examination of local regions for algae-filtering wetlands
- Biomanipulation: Small fish stock reduction and carp removal

6.1 Installation of a submerged hypolimnetic oxygenation system

The installation of a hypolimnetic oxygenation system is the most cost-effective way to improve the drinking water quality of Canyon Lake while also improving the water quality for recreational uses (see review by Beutel & Horne. 1999). The SDCO (e. g. Speece Cone) is one example that has been used for eight years and there are other less efficient systems that use Venturi or oxygen bubbles to achieve similar results. The Speece Cone is not a proprietary device but is the general name for a submersible oxygen-water mixing system originally devised by Professor Richard Speece at Vanderbilt University in Tennessee. Various SDCO devices and other similar systems have been used in the Tennessee Valley Authorities Reservoirs, in Camanche Reservoir on the Mokelumne River (East Bay Municipal Water District, Oakland, CA) and in Washington State. At this time the exact size and oxygen demand of the reservoir is not known so the sizing is based on similar sized systems elsewhere. In particular the large SDCO operating in Camanche Reservoir since 1993 has been used for operation and maintenance estimates and the design of several yet to be built cones for smaller reservoirs has been used for capital costs and installation. The actual system for Canyon Lake should be specifically designed for the lake's own shape and depth. Because there are new innovations in hypolimnetic oxygenation devices Professor Speece (Department of Civil & Environmental Engineering, Vanderbilt University, Tennessee) or some other experts (e.g. Mark Mobely, private consultant formerly at TVA. Dr. Marc Beutel or Bill Faisst, both at Brown & Caldwell, Walnut Creek CA) should be requested to assist with the design. It is vital to note that aeration and oxygenation expertise is not the same and persons with experience at oxygenation are more useful than those familiar with the more common aeration methods.

The basic principle of a SDCO system is that water is pumped from the very deepest part of the reservoir into the top of a small steel cone (~ 10 feet high for Canyon Lake) that has been dropped to the bottom of the lake on a concrete base. The anoxic water flows down the cone and is met by a stream of bubbles of pure oxygen that, since they are buoyant, are floating towards the top of the cone. The countercurrent thus established is a very efficient way to dissolve all of the oxygen with no waste and no bubbles escaping. The water, now fully saturated with oxygen at the high pressure of the lakebed, is forced out of a manifold set just above the lakebed. The high oxygen water meets with lower oxygen water and entrains about 10 times its own volume within a few feet of the manifold. The manifold jets are set horizontally since it is the lakebed that is most important in eutrophication reduction using oxygen. A new innovation is that the manifold size can be considerably reduced in size making the entire system very compact.

Hypolimnetic oxygenation device system in Canyon Lake. There are several possible devices for this purpose including a SDCO or other devices that achieve the same result. A system should be installed near the dam in the deepest section of the lake to take advantage of the reduction in power required. In deep water the pressure of the water increases the amount of oxygen dissolved, reducing the amount of water to be pumped to the cone. Oxygen is pumped from the lakeshore either as evaporated liquid oxygen that is stored in a tank at the lakeshore or gaseous oxygen that is made by PSV compressors on the lakeshore. The location of the oxygen station, electrical controls for the pump and the evaporator for the liquid oxygen is not critical and can be set in a convenient spot away from the public view.

Costs of a hypolimnetic oxygenation device. The size of the system is not known at this time. It is anticipated, by analogy with other reservoirs, that between 0.25 and 2 tons of oxygen per day will be needed. Overall estimated cost will also depend on the mix of capital options (for example the PSV on site oxygen generator) versus bi-weekly liquid oxygen deliveries. Other yet to be decided costs are the length and cost of the electrical supply to the underwater pump. The location of the underwater entry is critical to reducing costs. Overall a preliminary estimate of $250,000 to $500,000 can be made

6.2. Phased dredging for Canyon Lake

Dredging of the East Bay of Canyon Lake is the only feasible way to restore that section of the lake to recreational use. In addition, the removal of large amounts of phosphorus that will recycle in the shallow water would benefit drinking water quality in the lake. For example areas that were nine feet deep at low water a decade ago are now about a foot deep. The environmental geologists who recently surveyed the site state that "…portions of the East Bay could be dry or elevated should a low water event occur within the next three to five years." (Suitt & Assoc. 1998).

The water depth cannot be raised without flooding the lakeside homes, so the only option for these shallow water lakeside homes is to remove some of the accumulated sediments. The erosion upstream that created the shallow water is not the fault of the Canyon Lake residents and some redress from upstream actions that have accelerated the erosion seems fair. In addition, the action of Canyon Lake in trapping sediment and especially about 45 tons per year of bioavailable phosphorus has a beneficial effect on Lake Elsinore downstream.

The ideal solution would be construct sediment traps and storm water detention basins upstream and relieve Canyon Lake of the sediment and phosphorus load. However, such detention basins have not even been proposed and may be part of a future TMDL. In the next decade or two it might be appropriate for the residents and users of the entire upstream region to use the East Bay of Canyon Lake as an already constructed sedimentation basin. In this way some of the large costs for dredging could be shared for the public benefit and for Lake Ellsinore's protection as well as assisting the residents of Canyon Lake.

Sediment removal and cost of removal. The total amount of sediment that has entered Canyon Lake since its construction about 30 years ago is not known. However, the amount of heavier sediment that has settled near the inflow in the East Bay section has been estimated to be in excess of 500,000 cubic yards (17,000 cubic yards annually over 30 years). This is a very large amount of sediment to have accumulated in such a short time as was noted above. Typical current costs for sediment removal range from $3.50 to $10 per cubic yard giving a cost range for dredging of $2 to $5 million. These costs assume that the sediments do not contain any toxicants such a heavy metal (copper, zinc, lead etc.) and that disposal sites can be found locally. The costs also do not include any profit that could be made from the sale of some dredged material such as sand.

Phased approach. Given the high cost of removing the entire sediment accumulation, a phased approach may be most appropriate. The initial sediment removal project should target those areas that are most likely to go dry in the next five years. There is no doubt that some of the burden of cost should be born by the Canyon Lake dwellers, perhaps in proportion to the amount of sediment that would have arrived at the lake under natural undisturbed conditions. The sediment TMDL for the watershed will determine this amount.

Two immediate actions are recommended:

- **Chemical and soils testing of the recently accumulated sediment** in the East Bay. Needed will be a particle size analysis, measurements of heavy metals (17 can be measured simultaneously with plasma methods, and mercury can be tested separately), and estimation of the quantity and bioavailability of the sediment phosphorus and nitrogen.
- Beginning a pilot program to remove about one year's worth of sediments to get a realistic idea of the costs of removal of the entire 30 years of sediment and the feasibility of using the East Basin as a long-term sedimentation and removal basin for the upstream regions.

Over the next rainy period the following action is recommended:

- The City of Canyon Lake support the efforts of others, including the Regional Board, to determine a P and N budget for the lake and its watershed.

The 25 tons of phosphorus contained in the sediments and withheld from Lake Elsinore is a valuable contribution to making Lake Elsinore less eutrophic than it otherwise would be. In addition, the projects proposed using State Proposition 13 funds, which will be used to restore Lake Elsinore, would be much less successful if 25 tons of additional phosphorus was not held back by Canyon Lake Dam. Of this phosphorus retained in Canyon Lake, about 17 tons/y is held in the East Basin. Its rapid silting in testifies to the amount of silt and thus phosphorus retained.

Following the results of the pilot-dredging program, a regular program of dredging the East Bay of Canyon Lake may be implemented as the best long-term solution for both lakes and their eroding watersheds. The Canyon Lake group should begin to consider setting up a sinking fund to provide matching funds for other grants that will fund the dredging of the lake.

6.3. Spring and fall extended winter lake mixing for Canyon Lake

Lakes in Mediterranean climates tend to mix top-to-bottom (holomixis) for only two or three winter months. The time that atmospheric oxygen is stirred naturally by the wind over the anoxic sediments is thus short. In more northern climates holomixis may last for up to six months. In addition, Canyon Lake is quite sheltered from winds and is deep for its surface area. It is not possible to stir lakes in Mediterranean or tropical climates in summer using compressed air or similar devices. The sun is simply too strong and sets up too large a temperature gradient for mechanical mixing to be efficient. However, in spring and fall the sun is lower and the thermal gradient is easier to overcome using mechanical means. Assuming that the lake is in good condition due to installation of the Speece Cone hypolimnetic oxygenation system, additional mixing for a month in early spring and late fall using the existing air compressor would befit the water quality of the lake.

During the warm summer stratified period the stratification is used to the lake users benefit and maintained. In the March-April and November months, the Speece Cone system should not operated but will be replaced with the holomixis device. The results from tests of operating the reservoir in holomixis mode in early spring and late fall should be evaluated using chlorophyll a, Secchi depth, bottom oxygen levels, and blue-green algae as one set of indicators.

Cost of spring and fall holomixis. A large compressor is already installed in Canyon Lake. Previous attempts to use compressed air bubbles to destratify the lake, without first oxygenating the hypolimnion, produced less than ideal results. In addition, it is working against nature to destratify such a strongly stratified lake. Working against the sun is inefficient when one can work with it (hypolimnetic oxygenation makes use of the stratified layer). Cost for operating the current system for two months per year is estimated in the $5,000 range.

6.4. Local wetlands as algae filters in summer at Canyon Lake

One sure method to reduce nuisance algae growths is to filter them out directly using a wetland with a few days retention time. It is not clear that there is any land available, but considering the large benefits gained in property values situated near wetlands, sites may be available away from the water's edge but close enough that pumping costs are minimized. Various solar and wind devices are available for the pumping to be at least partially renewable energy. Up to 95% of the algae can be removed. The method has been employed in large Lake Apopka in Florida and is proposed for Lake Elsinore.

Cost of local wetlands filtration. The main cost in wetlands construction is the purchase of the land. In the case of Canyon Lake 20-50 acres would be needed. This land could be away from the lake and the wetland, which can also be designed to look like a lake with islands, could be the focus of a housing development. The cost of the land is thus variable and could even be free if a wetland mitigation bank were set up. The other cost for the lake filtration would be pumping the lake surface water up to the lake. Obviously the elevation and distance of the lake to the wetlands would decide the pumping costs. The amount of water to be pumped is equivalent to about 10% of the lake epilimnion.

6.5. Biomanipulation

Wetlands filtration is an effective method to filter out algae that requires energy. Biomanipulation can serve a similar function but is essentially self-sustaining, once in place. The method uses the filtering ability of small animals in the water, the zooplankton to remove algae. These zooplankton, particularly the large individuals of the genus *Daphnia*, are already present in the lake. The essence of the lake manipulations needed is to make large Daphnia more abundant by providing better conditions for them. If the method is successful, large *Daphnia* can filter the upper lake water layer in about a week. Large *Daphnia* are more desirable in biomanipulation because they can filter a lot more water and algae than smaller forms.

The main requirement for the lake manager is to adjust the reservoir habitat to favor large *Daphnia*. A single factor controls the survival and abundance of these highly useful small animals; a safe refuge from small fish predation during daylight hours. If large zooplankton are present in open water when it is light enough for small fish to see them, they will be eaten.

Hypolimnetic oxygenation. One component needed for *Daphnia* survival will be provided if a SDCO oxygenation system is installed. Daphnia will be able to migrate down the water column into healthy but dark hypolimnion water during the day. At present the hypolimnion of Canyon Lake has no oxygen so the zooplankton cannot take refuge there. For example, even at 18 feet down there was only 0.2 mg/L dissolved oxygen at station 7 near the dam in September 2000. Zooplankton can survive, probably uncomfortably at about 2 mg/L oxygen but fish cannot. Thus the conversion of the hypolimnion to about 5 mg/L dissolved oxygen will provide a zooplankton refuge.

Fish population balancing. Even with an oxygenated hypolimnion, fish grazing pressure at dawn and dusk can decimate zooplankton when they are migrating from deep to shallow water. Severe reductions in useful zooplankton occur when there are too many small fish and too few large ones. Such a situation with an excess of stunted small fish often occurs in reservoirs and is frequently managed to improve fishing. In Canyon Lake the removal of excess small fish by summer netting is the major active lake management action required. It is not necessary to remove all the small fish, just sufficient to balance the lake to a more natural ratio. Also always useful for biomanipulation is to reduce or eliminate introduced carp. The adult carp stirs nutrients from the lakebed, especially in the shallows and increases eutrophication. Netting or fishing out any large carp is almost always beneficial to the lake.

Biomanipulation in the shallow East Bay. The East Bay is too shallow, even if dredged back to its original depth, to be permanently stratified. Water quality is poor at present with less than three feet of water clarity. The East Bay must be cleaned up if the entire lake is to become much less eutrophic so water transparency will improve with oxygenation. However, there is the problem of how to provide a refuge for *Daphnia* if the water is clear to the sediments.

Under clear water conditions aquatic macrophytes are likely to grow. Although submerged weeds can be a nuisance if they interfere with boating, aquatic vegetation in the right place provide a daytime refuge for *Daphnia* and also improve the fishing. It may be necessary to control submerged weeds as the lake water quality improves from dredging and oxygenation. There are several methods for control but mechanical weed harvesting may be the most appropriate action in a drinking water reservoir where use of chemical is problematic.

Costs of biomanipulation. The costs of biomanipulation are small, that is one of the most attractive features of the technique. The costs of fish populations balancing, primarily small fish removal, is estimated at $15,000 for the first year will smaller amounts in following years. Not all years will require fish population balancing and cooperation with the local California Fish and Game Department is good. In addition, local schools and colleges may wish to use the project as part of class or research exercises. For example, the fish population in the lake could be measured before and after manipulation using experimental gill nets with various sized openings.

7.0. SPECIALIZED TERMS USED IN THIS REPORT

The use of some specialized terms is inevitable in a technical report. The following terms are commonly used and have no common term equivalents:

Eutrophic – a lake with high amounts of algae and nutrients (literally a "well-fed").
Oligotrophic – the opposite of eutrophic, a lake with few algae and nutrients.
External loading – nutrients flowing to the lake from external, watershed sources.
Internal loading – nutrients flowing to the lake from its own sediments (internally recycled nutrients).
Epilimnion – The upper warmer and less dense layer of water formed in summer but not present in winter.
Hypolimnion – the lower, cooler and denser layer of water formed in summer but not present in winter. This layer is normally used as a drinking water source.
Stratification – the process of separation into epi- and hypolimnion that occurs by solar warming in spring. Thermal stratification separates the sunlit water where algae can grow from the nutrient-rich deeper waters.
Destratification – the process of destruction of stratification that occurs during the autumn cooling period. If destratification occurs in summer, increases in algae often result.

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