PROPOSED LAKE AERATION AND BIOMANIPULATION FOR LAKE ELSINORE, CALIFORNIA

PREPARED FOR:

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EXECUTIVE SUMMARY

Lake Elsinore is a eutrophic, warm polymictic lake. Its eutrophic condition is sustained by a high rate of nutrient recycling and release from sediments, especially phosphorus that is usually limiting. Several severe fish kills occurred at Lake Elsinore since 1990 due to oxygen depletions. Lake Elsinore's sport fishery is poor quality as a result of competition with non-game fishes and bird predation. Threadfin shad (non-game fish) are largely responsible for the poor sport fishery since shad compete with young game fishes for food, reduce game fish survival, and attract fish eating birds that prey on young game fish and further reduce their survival. Shad also reduce population densities of large zooplankters that more efficiently harvest phytoplankton algae. This reduced grazing pressure on algae contributes to greater algal densities, instabilities in algae, and oxygen depletions resulting in fish kills. Objectives of the Lake Elsinore restoration program include preventing fish kills and reducing algal densities. To achieve these objectives, I recommend a combination of biomanipulation and artificial aeration by destratification. Recommended biomanipulation involves stocking 50,000 lbs/yr of 1 to 2 lbs each hybrid striped bass to prey on threadfin shad and provide a trophy fishery at Lake Elsinore. This stocking program will also help improve water quality by reducing predation pressures on large zooplankton, improve sport fishing, and help the local economy. Artificial destratification should prevent oxygen depletions in deep waters, reduce phosphorus loading, reduce algal densities, create better habitat for zooplankton and fish, and reduce the likelihood of fish kills through oxygen depletions. I recommend a destratification system consisting of a combination of axial-flow water pumps and diffuser airlines. This system, especially the air injection component should be controlled using temperature/DO sensors in the lake and on-shore controllers to reduce energy consumption. Capital costs and operating costs for the preferred system (Option C) are estimated at $1.586 million, and between $144,500/yr and $214,000/yr respectively. Options A and B are discussed, but these options have less mixing/aeration capacities. In addition, comments are presented on oxygen demands in Lake Elsinore during worse case oxygen depletions, and on the proposed pump-storage facility at Lake Elsinore. The following table summarizes cost estimates for capital and operating costs for the three lake aeration systems under consideration.

SUMMARY OF CAPITAL AND OPERATING COSTS
FOR THE THREE PROPOSED
AERATION SYSTEMS
FOR
LAKE ELSINORE

COSTS	OPTION A	OPTION B	OPTION C
CAPITAL	**$1,236,000**	**$1,000,000**	**$1,586,000**
OPERATING (yearly for 1st 2 yrs)	**$ 144,500**	**$ 214,000**	**$144,500-$214,000**

TABLE OF CONTENTS

EXECUTIVE SUMMARY 2
1. OBJECTIVES 6
2. INTENDED AND BENEFICIAL USES OF LAKE ELSINORE 7
3. CAUSES OF FISH KILLS 8
3.1. Algal Crashes and Dissolved Oxygen (DO) depletions 8
3.2. Diurnal DO Cycling to Lethal Levels 10
3.3. Overturns 10
3.4. Excessive Numbers of Small Prey Fish 10
3.5. Ammonia 12
4. PREVENTING FISH KILLS 15
5. BIOMANIPULATION 17
5.1. Background and Problem 17
5.2. A Possible Biomanipulation Solution for Lake Elsinore 18
5. LAKE ELSINORE LIMNOLOGY 20
6.1. Stratification Problems 20
6.2. Water Level and Volumes Changes 24
6.3. Seas onal Stratification Frequency 24
6.4. Internal Waves and Seiches 25
6. SIZING ARTIFICIAL AERATION/ OXYGENATION SYSTEMS 28
7.1 Attaining Objectives 28
7.2. Oxygen Demands 29
7.3. Artificial Destratification 30
7. AERATION/OXYGENATION ALTERNATIVES 33
8.1. Lake Destratification Systems 33
8.1.1. Destratification by Air Injection 33
8.1.2. Axial-flow Water Pumps 33
8.2. Hypolimnetic Aeration/Oxygenation 37
8.2.1. Speece Cone 38
8.2.2. Side Stream Pumping 39
9. PROPOSED AERATION SYSTEMS FOR LAKE ELSINORE 43
9.1. Option A 43
9.2. Option B 49
9.3. Option C 51
9.4. Overall costs 56

(continued)

10. Worse Oxygen Depletion Cases **57**
11. Pump Storage Considerations **61**
12. LITERATURE CITED **65**

APPENDIX A. Axial-flow Pump Design Manual
APPENDIX B. Oxygenation Calculations for Air Injection Systems
APPENDIX C. LOX Storage Tank Information

1. **OBJECTIVES**

The overall objectives of this project are to improve recreational and aesthetic uses of Lake Elsinore. These improvements will benefit the Lake Elsinore community both economically and culturally.

Specific objectives include reducing fish kills and reducing problem algal blooms. Achieving these objectives will require a combination of mechanical manipulations and biomanipulation of the food chain through fish stocking.

I will discuss causes of fish kills and current conditions in Lake Elsinore that now degrade its recreational and aesthetic uses, and I will present some alternatives for solving these problems. Lastly, I will present proposed means for accomplishing the primary objectives of this project.

2. INTENDED AND BENEFICIAL USES OF LAKE ELSINORE

A lake's intended and beneficial uses are the main issues determining its management needs. These uses form both the underlying conceptual framework for deciding how the lake should be managed, and they also provide a legal basis or justification for government agencies concerned with water quality issues. The RWQCB (2001) identified a number of intended uses for Lake Elsinore, including;

♦ Warm Freshwater Aquatic Habitat (**WARM**), including recreational fishing.

♦ Body Contact Recreation (**REC1**), or boating, swimming, water skiing.

♦ Non-Body Contact Recreation (**REC2**), including aesthetic enjoyment.

♦ Wildlife Habitat (**WILD**).

The following are not included in intended uses; municipal and domestic water supply (MUN), agricultural water supply (AGR), groundwater recharge (GWR), nor is the lake used for flood control.

3. CAUSES OF FISH KILLS

Fish kills are one of the primary concerns at Lake Elsinore. Fish kills create nuisance conditions at the lake with negative impacts on recreational uses and on the community. Fish kills are usually symptomatic of serious water quality degradation. Furthermore, most fish kills result in selective death of the more desirable recreational fish species. This often results in an imbalance between desirable game fishes and non-game fishes. This imbalance in favor of less desirable non-game fishes reduces fishery values and causes economic losses to the community. There are different causes of fish kills, including the following.

3.1. Algal Crashes and Dissolved Oxygen (DO) depletions.

Algae sometimes die or become senescent quickly (1 to 3 days). This results in much greater oxygen consumption (respiration and oxidation) compared with oxygen generation or recharge (photosynthesis and atmospheric recharge; Fig. 1). DO can decrease to zero or near zero, killing fish and other biota.

Some common causes of these algal crashes included:

a. **Nutrient Depletions.** With intense algal blooms, some nutrient may become limiting, which leads to mass algal mortality.

b. **Calm, Sunny Conditions.** If calm, sunny conditions persist, certain algae will rise to near the water surface and be killed by UV radiation in sunlight (Boyd 1979). This most often occurs with bluegreen algae following normal, windy conditions.

c. **Environmental Changes.** If some change occurs in the physical/chemical environment, this can result in rapid death of existing algae, perhaps as part of a succession process where the algae will be replaced by other algal species. One example of this type of crash is lake “overturn”, when deep water is rapidly mixed with surface waters. The upwelled water may be toxic to algae or otherwise cause algae to die quickly, leading to DO depletion.

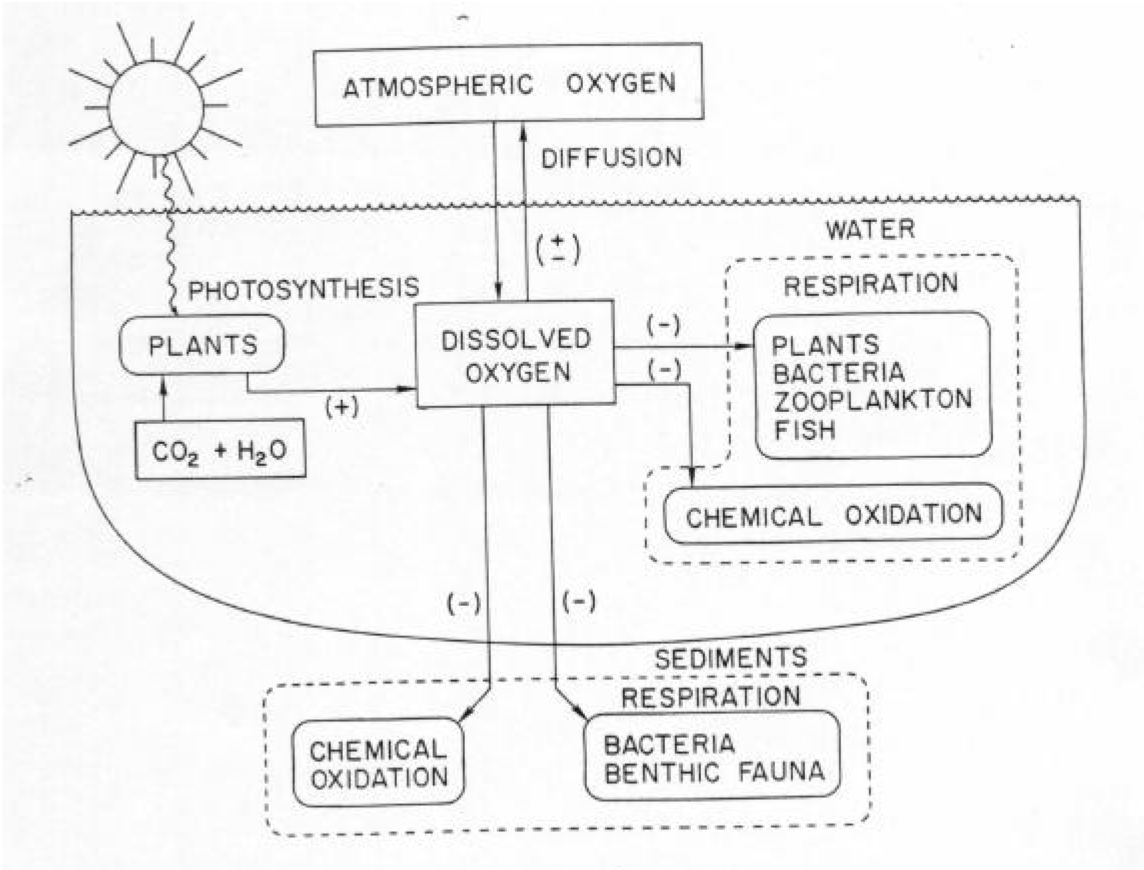

Figure 1. Principal sources and sinks for dissolved oxygen in lakes and ponds (Fast 1986).

3.2 **Diurnal DO Cycling to Lethal Levels** (without algae crashes).

Even if a healthy algal population is maintained, DO can cycle dramatically over the day due to photosynthesis and respiration. During the day, photosynthesis greatly exceeds respiration and DO may exceed 200% saturation, while at night photosynthesis ceases and respiration predominates. These DO cycles increase in amplitude with increasing eutrophication (Fig. 2). The greater the saturation during daylight hours, the lower the saturation values at night. If respiration is great enough relative to DO reserves at sunset, DO may fall to near zero during the night. If low DO persists long enough, fish kills can occur. Fish kills due to DO cycling typically begin between midnight and sunrise.

Fish kills may also occur during overcast conditions even with healthy algal populations. This occurs due to reduced oxygen production (photosynthesis) relative to respiration, and is most often associated with large daily DO fluctuations (Fig. 3).

3.3. Overturns.

In addition to possibly killing algae and thus creating DO depletion through increased DO consumption as noted above, overturns can also upwell substances such as hydrogen sulfide that are toxic to fish. Overturns may also upwell substances with high biological and chemical oxygen demands (BOD and COD) that can rapidly deplete DO due to increased oxygen consumption.

Overturns can thus cause fish kills directly by one or more of three means: kill algae leading to DO depletion; kill fish by toxicants; and/or deplete DO through high consumption by reduced substances.

3.4. Excessive Numbers of Small Prey Fish

Excessive numbers of threadfin shad (small prey fish) herded into shallow waters by predators (game fish and birds) apparently caused at least one fish kill at Lake Elsinore (Pat Kilroy, personal communication, 2001). Threadfin shad respiration may have depleted DO, or death may have been

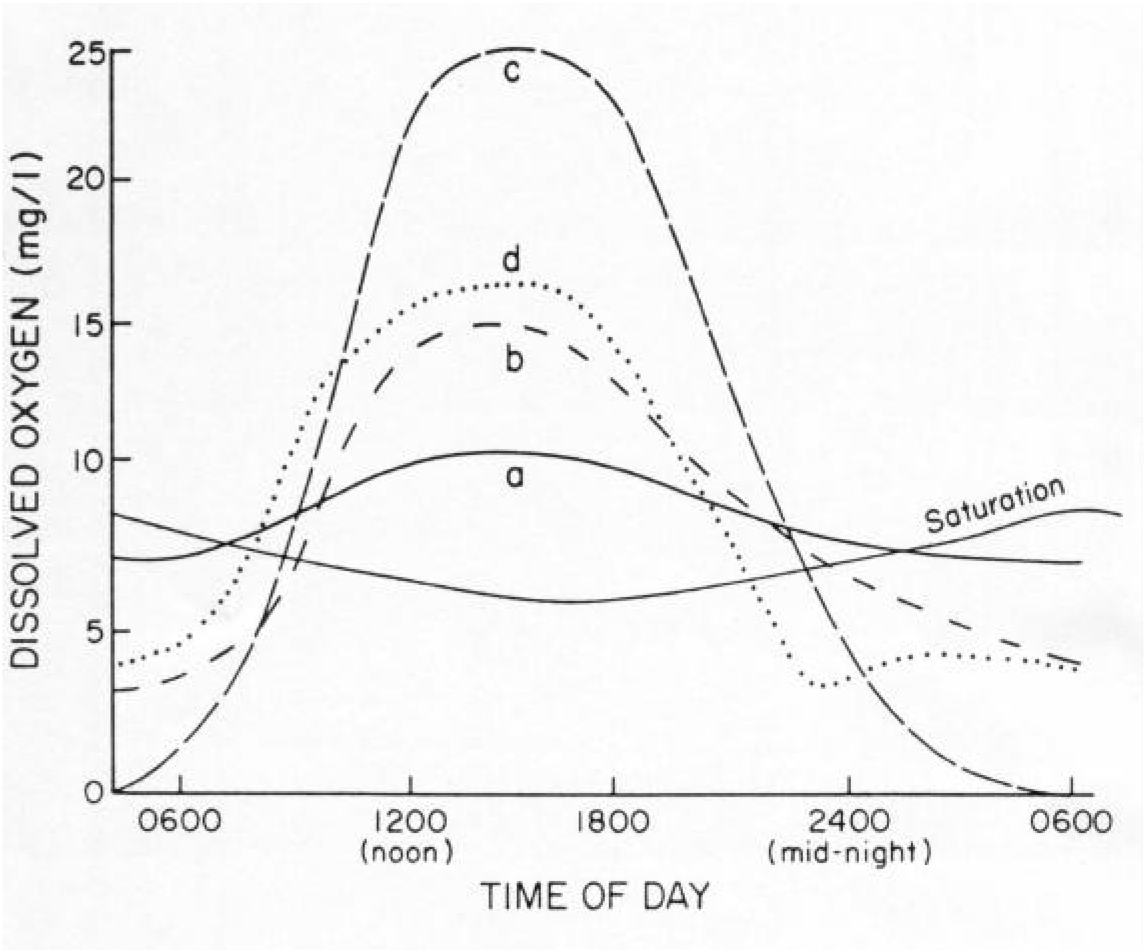

Figure 2. Typical daily dissolved oxygen concentrations in lakes and ponds with; (a) oligotrophic or extensive culture conditions, (b) mesotrophic or semi-intensive culture, (c) eutrophic or intensive culture without aeration, and (d) eutrophic or intensive culture with aeration. Figure from Fast (1991).

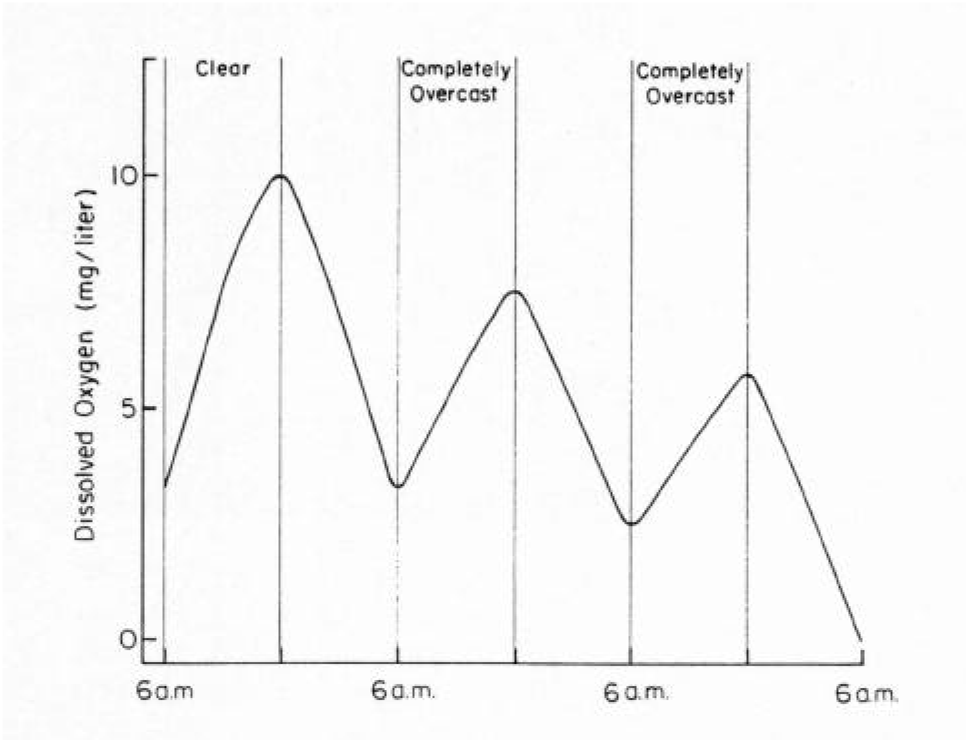

Figure 3. Characteristic dissolved oxygen cycle in eutrophic lakes or intensively managed fishponds during several days of overcast. Maximum DO occurs in the afternoon due to photosynthetic oxygen production, while DO minimums occur at dawn due to nighttime respiration. Overcast weather can reduce photosynthesis and lead to DO depletions and fish kills during the night. Figure from Boyd (1979).

caused by “stress”. This phenomenon was observed in Lake Michigan with alewives[1] during the 1960’s, before the introduction of salmon. Introduced salmon preyed on alewives and greatly reduced numbers of alewives. Massive alewives mortalities have not occurred in Lake Michigan since salmon became abundant.

It is also desirable to reduce threadfin shad densities to reduce predation on zooplankton, as I will discuss below. If zooplankton increase through a combination of reduced predation from threadfin shad, and from greater zooplankton depth distribution due to artificial mixing and aeration, then zooplankton grazing on phytoplankton could be increased.

3.5. Ammonia.

Ammonia is toxic to fish, but there are very few documented fish kills caused by ammonia toxicity in lakes under normal conditions. Normal here means where there is not a sustained source of ammonia or pollution inflow to a lake.

Ammonia exists in two forms in water, un-ionized (NH_3) and ionized (NH_4^+). Only the un-ionized form has much toxicity to fish. The ratio of ionized to un-ionized ammonia is mostly a function of pH and temperature. At pH 6 and 5°C, 1.3% of total ammonia is un-ionized, while at pH 10 and 30°C, 89% is un-ionized. Acute ammonia toxicity depends on several factors such as un-ionized ammonia concentrations, exposure times, fish species, physiological condition of the fish, and possible other stressers such as low DO and/or other toxicants. Chronic ammonia toxicity is more common, but does not typically result in mass mortalities over a short time interval. Even with acute ammonia toxicity, mass mortalities would be expected to occur over a longer time interval than happens with DO induced fish kills, and the kills are more likely to occur in the afternoon when pH is elevated due to photosynthesis.

Fish kills at Lake Elsinore were almost certainly caused by DO depletions in virtually all cases, given the time of day when the kills began and the pattern of fish deaths. These DO depletions were likely caused by algal

[1] Alewives are a small fish similar to threadfin shad that can occur in large schools and feed on zooplankton.

crashes and/or overturns, as well as threadfin shad crowding into shallow water.

4. PREVENTING FISH KILLS AT LAKE ELSINORE

Three major fish kills occurred at Lake Elsinore between 1990 and 1996 (Beutel 2000). All three kills occurred during summer months. Maximum water depths were respectively, 17 feet (July/Aug. 1990), 32 feet (July/Aug. 1992), and 32 feet (June/July 1995). Beutel speculated that these fish kills were associated with more intense stratification during summer months, followed by DO depletions throughout the water columns when the lake destratified. Calm weather of one to two weeks' duration during the summer could result in stable thermal stratification and DO depletions to 0 mg/l below 2 to 3 meters depth. Abrupt mixing of this oxygen depleted water could lower DO throughout the lake to lethal levels for fish, while at the same time causing algal "crashes", thus preventing rapid oxygen regeneration by photosynthesis.

There are a number of possible approaches for preventing oxygen depletions in Lake Elsinore. Reducing algal densities, maintaining healthy algae, and preventing prolonged stratification are some of the more important approaches.

Algal densities could be reduced in Lake Elsinore if nutrient availability to algae could be reduced, and/or if grazing on algae (algal harvest) could be increased. As will be discussed below, transient thermal stratification and DO depletions in bottom waters are responsible for increased phosphorus (P) releases from bottom sediments. If the lake can be artificially mixed or aerated, preventing DO depletions at the mud-water interface, then sediment P releases could be reduced along with algal densities. Reduced algal densities should reduce the amplitude of daily DO fluctuations and DO depletions as shown in Figures 2 and 3. This reduces the likelihood of massive fish kills.

Reducing algal densities through increased grazing by zooplankton can also reduce the probability of oxygen depletions. This will be discussed further below. In addition, and perhaps more importantly, increased algal grazing results in healthier algal populations even if algal densities are not reduced. Healthy algae that are maintained in log-phase growth are much less likely to "crash". Healthy algae produce more oxygen. Increased grazing (harvest) on phytoplanktonic algae can be achieved by promoting survival of large zooplankters that are efficient grazers on algae. The most effective way to favor survival of large zooplankters is by reducing population densities of zooplanktivorous threadfin shad that preferentially feed on large zooplankters, and by creating deep-water sanctuaries for zooplankton. Threadfin shad populations can be reduced by mechanical means (seining), chemical means (fish toxicants), or by stocking large predatory fish. Deep-water sanctuaries for zooplankton can be achieved by artificial aeration/oxygenation or mixing.

Artificial aeration/oxygenation or mixing will also maintain higher DO in deep waters. This reduces the likelihood of oxygen depletions of surface waters during the frequent turnovers at Lake Elsinore. It also reduces the likelihood of upwelling toxicants during turnovers, as discussed above.

Since excessive numbers of threadfin shad could possibly cause localized DO depletions and fish kills, shad population reductions could help prevent fish kills by this means. Again, this can be achieved by mechanical or chemical means, or by stocking large predatory fish to feed on the shad (biomanipulation).

5. BIOMANIPULATIONS

5.1. Background and Problem

During the past 15 to 20 years, managing a lake's water quality by manipulating its biological components has become very popular. This management process is commonly referred to as biomanipulation (Shapiro et al. 1975).

Brooks and Dodson (1965) were some of the first people to document that lakes with small, plantivorous fishes lacked large zooplankters, while lakes without these types of fishes had large zooplankters. Lakes with large zooplankters such as *Daphnia pulex* generally had greater water clarity. The reason for this is that large zooplankton harvest or graze algae much more efficiently compared with small zooplankters. The implications of this were that if zooplanktivorous fishes could be eliminated or at least greatly reduced in numbers, then larger zooplankton could flourish and water clarity would improve. This led to many efforts to demonstrate that this would in fact happen if you reduced densities of zooplanktivorous fishes. Although there can be extenuating circumstances, it is now accepted ecological theory and lake management practice to use biomanipulation of fish populations to manage water quality and fishery benefits (Perrow et al. 1997, Vanni and Layne 1977, Drenner and Hambright 1999, Lammens 1999).

Large populations of non-game threadfin shad and carp now dominate Lake Elsinore's fish populations. Game fishes such as largemouth bass, bluegill and crappie are present, but do not provide a quality fishery due to their small population sizes.

Threadfin shad have been shown to reduce growth of young-of-the-year largemouth bass and bluegill (Fast et al. 1982), presumably through competition for zooplankton, which is the main food item for shad of all ages and young game fishes. If this competition occurs, it would presumably also result in reduced survival of small largemouth bass and other game fishes, which would in turn reduce recruitment of game fishes to the fishery.

In addition to threadfin shad competition with largemouth bass and other game fishes at Lake Elsinore, the presence of a large threadfin shad population also attracts large numbers of fish eating birds such as cormorants, grebes, pelicans and diving ducks. These birds also feed on young largemouth bass and other game fishes, further reducing their recruitment into the fishery. As a result of competition and predation, Lake Elsinore's game fish populations are severely diminished.

5.2. A Possible Biomanipulation Solution for Lake Elsinore

The objectives or goals of biomanipulation at Lake Elsinore are to; (1) reduce threadfin shad population densities and thereby cause an increase in large zooplankter densities that will increase grazing pressures on phytoplankton. This increased grazing will help reduce phytoplankton densities and increase water clarity. Whether or not algal densities are reduced and increased water clarity occurs, increased phytoplankton grazing will help maintain phytoplankton in log-phase growth and thereby help prevent fish kills through DO depletions, and (2) reduced threadfin shad population densities will reduce competition with game fishes for zooplankton forage, thus increasing game fish survival, growth and recruitment to the fishery. Furthermore, reduced threadfin shad densities will discourage fish eating birds from visiting Lake Elsinore, thereby reducing bird predation on game fishes. This also will increase game fish survival, growth and recruitment to the fishery.

Threadfin shad can be removed from Lake Elsinore by mechanical means such as seining. However, this approach is inefficient and expensive, and it most likely will not result in measurable improvements in the fishery.

A more desirable alternative for removing threadfin shad from Lake Elsinore is stocking large game fish that will feed on the shad. This approach is not only more efficient[2], but it will also provide a trophy fishery that will attract large numbers of recreational fishermen to Lake Elsinore. This will benefit the local economy and almost certainly more than pay for the stocking program through increased tax revenues.

There are not many choices of large, efficient game fishes that can be legally, politically, and practically stocked in Lake Elsinore. I recommend stocking hybrid striped bass (white bass X striped bass). These fish should be stocked at one to two pounds each such that they are too large for most bird predators, but at the same time will feed on all sized threadfin shad.

[2] These stocked game fish will prey on all sizes of threadfin shad continuously, whereas seining generally selects certain size shad and is not continuous.

The hybrid bass should reach 10 to 15 lbs each within about two to three years of stocking in Lake Elsinore. This will provide a significant and unique trophy fishery and attract large numbers of fishermen to the lake.

I recommend stocking about 5,000 lbs/mo. of hybrid striped bass from October through June each year (50,000 lbs/yr total). These fish will probably cost about $3.50/lb delivered and stocked in the lake[3]. This program should be continued for at least two years, and it should be assessed to determine its efficacy on water quality, the fishery, and on the economy of Lake Elsinore.

[3] Price will be established through competitive bids from fish culturists in California.

6. LAKE ELSINORE LIMNOLOGY

Lake Elsinore is a warm, polymictic lake. This means that the lake experiences repeated cycles of water column stratification and destratification during the year, and is without winter ice cover.

A typical stratification cycle at Lake Elsinore occurs when surface waters warm in the morning due to solar irradiation. Surface waters may increase 2° to 3°C relative to bottom waters. If winds are not strong, this temperature difference or delta-T (ΔT) may intensify over several days with $\Delta T > 3°C$. The greater the ΔT, especially at water temperatures greater than 20°C, the greater the resistance to mixing and destratification. During the evening, surface waters cool. Eventually, through a combination of nighttime cooling and greater wind velocities the lake will mix partially or completely. This stratification-destratification cycle may occur once in 24 hrs, or it may persist for a week or more.

Anderson (2001) found that the bottom waters at Lake Elsinore had low DO ($\leq$ 3 mg/l) on about 33% of the days that he monitored bottom waters. This indicates that stratification often persists for perhaps 7 to 10 days at a time since oxygen consumption rates in bottom waters are about 1 mg/l/day (Anderson 2001). During complete mixing, surface and bottom water DO should be nearly equal at from 6 to 10 mg/l. If bottom water DO decreases at 1 mg/l/day, it would then take from 6 to 10 days for bottom DO to approach zero.

6.1. Stratification Problems

There are several potential or real problems with Lake Elsinore stratification. The first problem relates to phosphorus cycling and eutrophication.

When DO at the deep water, mud-water interface approaches or reaches zero, phosphorus is released from the sediments into the water. Beutel (2000) measured P releases from Lake Elsinore sediments using core samples exposed to DO saturation and anaerobic conditions. He found that P was released both in the presence and absence of DO, but that P release was increased three fold when DO was zero. Anderson (2001) also measured P releases from Lake Elsinore sediments using an *in situ* approach where P concentration gradients were measure from field samples. Anderson also found that substantial amounts of P were released from Lake Elsinore sediments, although he did not correlate P release rates with DO concentrations. Both researchers found that P release rates were much greater during summer months than during the winter, and both concluded that internal P recycling was the primary source of P maintaining Lake Elsinore in a eutrophic condition.

Although phosphorus cycling and pathways are complex and not easily documented, it is safe to say two things about Lake Elsinore's phosphorus situation. First, Lake Elsinore's algae are generally phosphorus limited with excess nitrogen (N) to phosphorus (P) ratios (P:N). Total P:N at Lake Elsinore is 1:18-21 (Anderson 2001), which is above the Redfield ratio for P:N of 1:16 (Redfield et al. 1963). A P:N ratio of 1:10-16 indicates that both N and P are in about the right proportions for phytoplankton growth. A P:N ratio of something like 1:20 means that adding N will not stimulate further phytoplankton growth, but adding P will. Therefore, P additions to Lake Elsinore waters will increase phytoplankton growth, whether P is from internal or external sources. This conclusion was confirmed by recent trials by Anderson (manuscript in preparation) where N and P were added to Lake Elsinore waters. N additions had virtually no effect on phytoplankton densities, but P additions of 0.1 and 0.3 mg/l increased chlorophyll concentrations by 450% and 620% respectively within four days.

Secondly, a substantial portion of the annual phosphorus budget for Lake Elsinore comes from sediment to water P-cycling, rather than P influx from the lake's watershed and from direct rainfall to the lake. This re-cycling is referred to as internal P-loading, as opposed to external P-loading from outside the lake. Internal P-loading apparently accounts for most of Lake Elsinore's annual P budget. Internal P-loading occurs through P release from sediments during stratification and DO depletion at the mud-water interface, and it occurs from re-suspension of particulate P during wind induced water turbulence. It is not clear exactly which process is most important for sustaining phytoplankton growth in Lake Elsinore, but it is clear that a combination of these processes is keeping the lake in a eutrophic condition.

A high P:N ratio also indicates that a lake is less likely to have phytoplankton populations dominated by bluegreen algae that can form floating mats and scum. With low P:N ratios of 1:3 for example, bluegreens would be favored since they can fix atmospheric nitrogen while other algae cannot. At high P:N ratios of say 1:20, bluegreens are not provided a competitive advantage. They can still occur of course, but are less likely to create serious problems. However, high water pH values at Lake Elsinore favor bluegreen algae over other forms since bluegreens are more efficient at using inorganic carbon (carbonates and bicarbonates) at higher pH.

A second problem associated with stratification is its effects on the lake's biota. When Lake Elsinore stratifies and DO is depleted in deep waters, fish and other biota are forced into shallow waters. Threadfin shad, largemouth bass, catfish and probably other species will avoid waters with <3mg/l DO (Miller and Fast 1981; Fig. 4). As DO continues to fall, other fishes that are more resistant to low DO will eventually be forced from the bottom waters. Eventually, zooplankton will also be forced into shallow waters when DO approaches zero. This exclusion creates several problems. First, it results in increased predation on larger zooplankton by threadfin shad and young fishes of all species. Large zooplankters graze more efficiently on phytoplankton then do small zooplankters. This increased predation on large zooplankton reduces grazing on phytoplankton and may result in greater phytoplankton densities and greater instabilities in phytoplankton populations. This is discussed more fully in the section on Biomanipulation. Secondly, midges[4] and certain other benthos that can tolerate zero DO for prolonged periods are not fed upon by fishes when DO is low at the mud-water interface. This can result in excessive population increases in these organisms and nuisance emergence of adult midges that can be very unpleasant for lakeside residents and visitors. Thirdly, forcing fishes into shallow water during deep-water DO depletion increases predation on fishes by piscivorous birds. There are large numbers of these birds at Lake Elsinore, including grebes, cormorants, pelicans, seagulls, and ducks. They are most likely to prey on small game fishes and threadfin shad. This may account in part for the poor largemouth bass fishery at Lake Elsinore.

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[4] Midges are insects with an aquatic larval stage, but with a flying adult stage. The adult looks like mosquitoes, but are non-biting. They can, however, be present in very large numbers under certain circumstances and thus create a considerable nuisance. The larvae live attached to surfaces and/or in bottom sediments. They are sometimes called "blood worms" due to red coloration of some species. The red color is due to hemoglobin, an adaptation to living under very low dissolved oxygen. Midges are readily eaten by a wide variety of fish and other aquatic animals.

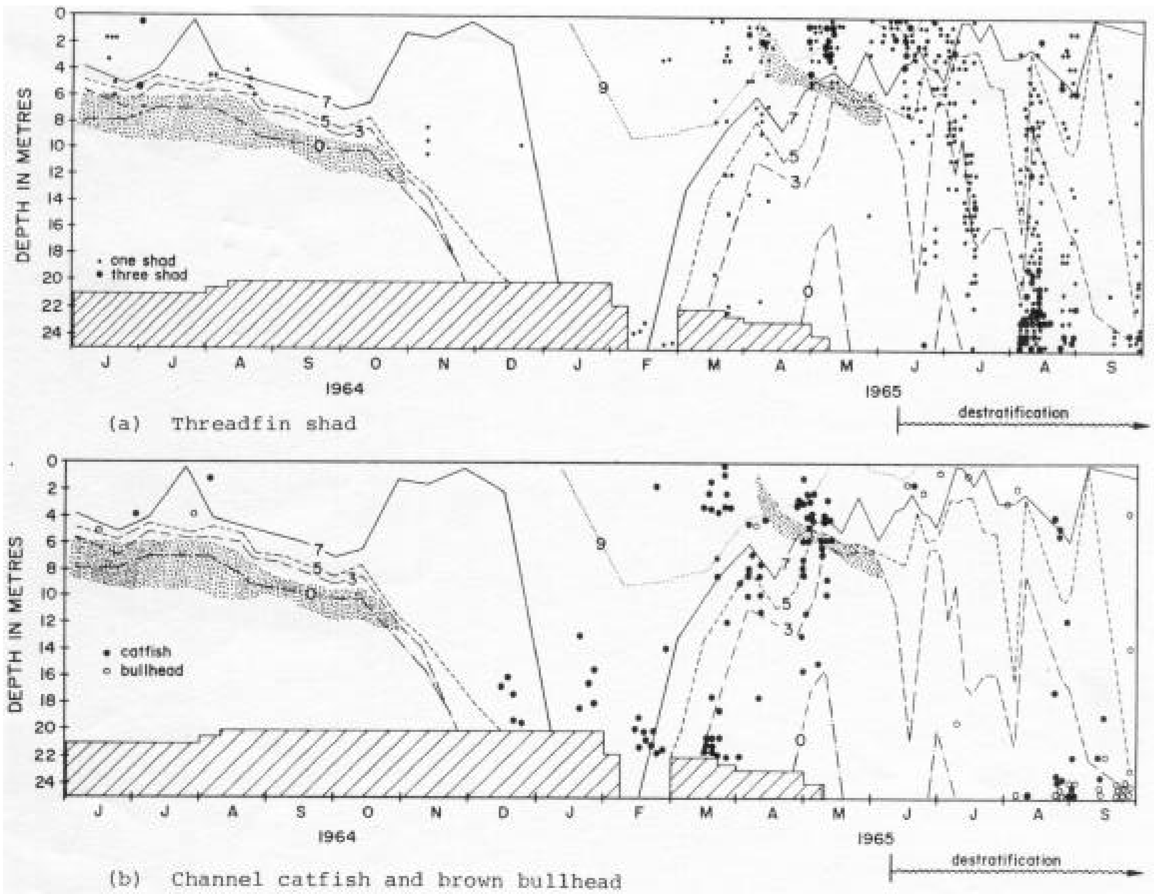

Figure 4. Fish depths and oxygen isopleths at El Capitan Reservoir, California during 1964 and 1965. The reservoir stratified normally during the summer 1964 with zero DO below about 10-m depth. The thermocline is shown by shading each year, while oxygen isopleths are shown in mg/l DO. The lake destratified during the winter from November 1964, and restratified during February and March 1965. The lake was artificially mixed starting in June 1965, bu5 bottom DO did not increase much above 2 mg/l. Fish (threadfin shad in upper panel, and catfish and bullhead in lower panel) tended to avoid water depths with less than 3 mg/l DO.

6.2. Water Level and Volumes Changes

Lake Elsinore's water level is now about elevation 1,238 feet above sea level. At this elevation, it has 19 feet maximum water depth, 2,958 surface acres (A), and 32,632 acre-feet (AF) of water (Table 1). During years with heavy rainfall and runoff, water levels can and have increased to and above spill elevation of 1,255 feet. At flood elevations, water will first spill into Temescal Wash and Santa Ana River at elevation 1,255 feet. At this elevation, the lake's maximum water depth is 32 feet, 3,606 surface acres and 89,114 AF of water. At higher flood elevation, water spills into the wetlands and flood control area above the lake dike at elevation 1,262 feet.

The long-term goal is to stabilize water levels at no less than 1,240 feet elevation, which would mean water depths, area and volumes similar to today's. This stabilization may be achieved through a combination of runoff, well water additions, reclaimed water additions, and perhaps imported water additions. However, during wet years, lake depths and volumes could increase by 50% to 100% more than today's. The impacts of these changes on the lake's limnology could worsen water quality and fishery conditions. In the past, some of the worst fish kills occurred following large runoffs into Lake Elsinore when water elevations were near spill. These runoffs brought in large amounts of P that further increased algal production and most likely led to DO depletions through unstable phytoplankton conditions. In addition, deeper water depths at Lake Elsinore almost certainly leads to longer periods of stratification followed by destratification. Longer stratification could result in even greater DO depletions in deep waters, greater P release from the sediments (increased P cycling), and undesirable effects on the biota noted above.

6.3. Seasonal Stratification Frequency

Anderson (2001, and unpublished data) found that Lake Elsinore experiences transient stratification/destratification cycles all year, but that these episodes may be more persistent and intense during the summer. These cycles may last only 24 hrs, or much longer. It is not clear at this time how often thermal stratification cycles of 5 to 10 days occur, during which large portions of the lake's deep water sediments could experience zero DO at the mud/water interface. Circumstantial evidence indicates that this occurs often (Beutel 2000). When this occurs, larger amounts of P will be released from the sediments and made available for algal growth, thus fueling and maintaining eutrophic conditions. Anderson (2001) observed that low DO (<2 mg/l) occurred at the mud/water interface about a third of the time.

Data from Lake Elsinore are mostly at water elevations of 1,238 to 1,240 feet. Deeper water depths will result in more persistent thermal stratification and greater DO depletions in deep waters. Water quality may therefore worsen at water depths of greater than 1,245 feet.

6.4. Internal Waves and Seiches

Anderson (unpublished data) found that wind driven water currents in Lake Elsinore are complex and strong. Surface water currents often exceed 0.3 m/sec. Bottom currents are typically in the opposite direction and somewhat weaker.

Data collected at the 5.2-m depth (near bottom) in Lake Elsinore during June indicate large temperature and DO changes during very short time intervals (Fig. 5). On Day 59 for example, DO increased from 3 to 11 mg/l in less than an hour in early morning, then abruptly decreased to <3 mg/l. This could have been due to cooling and sinking of surface waters, but it also could be due to internal waves or Seiches. These waves and Seiches could occur when warm surface waters are forced to the leeward shore of the lake by winds, and displacing deep waters in the opposite direction. Then when the winds stop or reverse direction, surface and deep waters are forced in opposite directions again. Daily wind shifts of 180° are common at Lake Elsinore. These events could result in considerable mixing of lake waters from different depths, and in rapid changes in DO at the mud/water interface.

Table 1. Area-capacity table for Lake Elsinore. At elevation 1,223 feet above mean sea level, the lake is dry. Present lake level is about 1,238 feet, while the target elevation for long term maintenance is 1,240 feet. Lake Elsinore overflows into Temescal Wash at elevation 1,255 feet. Note that between elevation 1,240 and 1,255 the lake area increases only 17% while lake volume increases 131%.

Elevation (feet)	Water Depth (ft)	Area (A)	Volume (AF)	
1223	0	0	0	
1225	2	1400	2200	
1230	7	2290	12000	
1235	12	2740	24000	
1240	17	3074	38519	Target elevation
1245	22	3319	54504	
1250	27	3463	71443	
1255	32	3606	89114	overflow to Temescal
1260	37	3882	107877	
1263.3	37.3	3945	120800	100-yr flood elevation

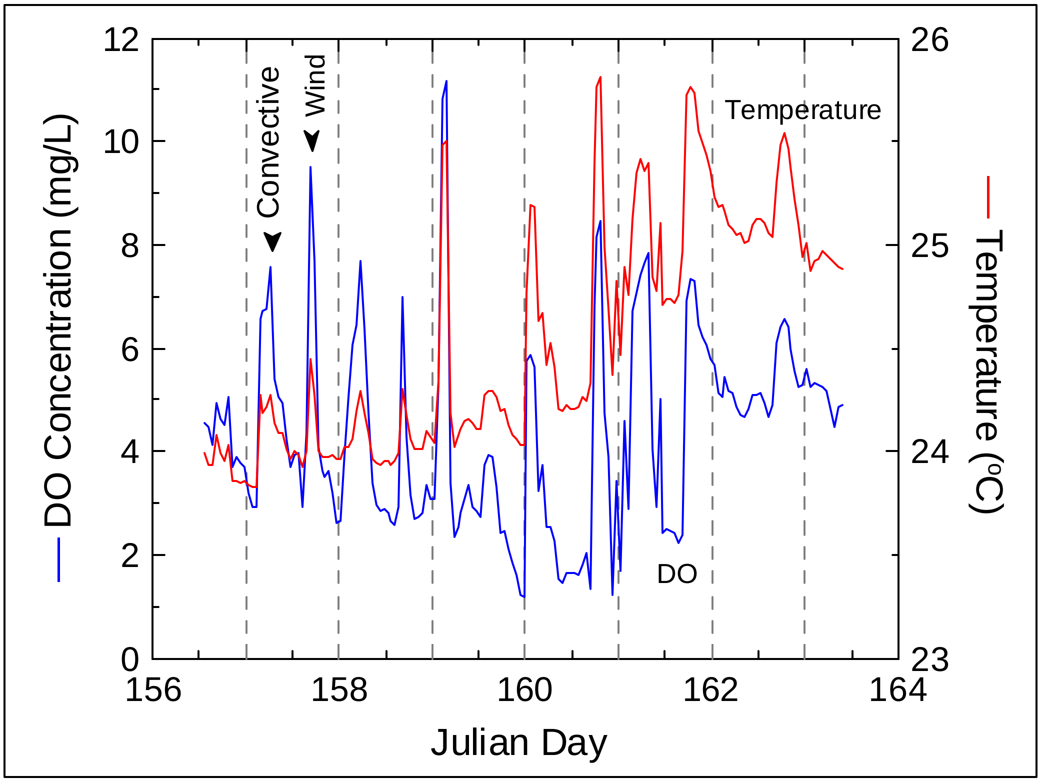

Figure 5. Continuously recorded temperature and DO in Lake Elsinore at the 5.2 m depth during June 2001 (Anderson, unpublished data).

7. ATTAINING OBJECTIVES AND SIZING ARTIFICIAL AERATION/ OXYGENATION SYSTEMS

7.1 Attaining Objectives

Specific objectives of this program include reducing fish kills and reducing algal densities (see Section 1 of this report). These objectives can be achieved through a combination of four processes; namely:

(a) Reduce internal P recycling (loading) from the sediments by maintaining well-aerated conditions at the mud/water interface.

(b) Maintain healthy algae through a combination of increased algal harvest or grazing by zooplankton, and by preventing upwelling of substances toxic to algae.

(c) Prevent lengthy periods of thermal and chemical stratification.

(d) Add DO to bottom waters to prevent DO depletions.

We can accomplish different combinations of these four processes by use of biomanipulation and by using some type of artificial destratification or oxygenation. These can be viewed conceptually as follows:

MANAGEMENT PROCESS	BIOMANIPULATION (fish stocking)	ARTIFICIAL DESTRATIFICATION	HYPOLIMNETIC OXYGENATION
(a)	✕	✕	✕
(b)	✕	✕	✕
(c)		✕	
(d)		✕	✕

I have already discussed the rationale and need for biomanipulation through fish stocking. I consider this as important, or perhaps even more important than use of mechanical mixing or oxygenation systems. In my opinion, this biomanipulation could have an even more profound effect on P recycling and water quality than the mechanical systems. Without question, the proposed fish stocking will have a greater positive economic impact on the Lake Elsinore community. It will also be much less costly than the mechanical systems.

I'll discuss in more detail the types of mechanical systems in the following section of this report. The systems include artificial destratification systems and systems that add oxygen to deep waters without greatly reducing thermal stratification. We will refer to the latter as hypolimnetic oxygenation systems, although strictly speaking Lake Elsinore does not have a hypolimnion, or at least not a long lasting one.

7.2. Oxygen Demands

We will now consider how much oxygen might be needed to maintain stable and adequate DO concentrations in Lake Elsinore. Oxygen consumption or depletion rates include the sum of water oxygen demands (WOD) and sediment oxygen demands (SOD). Beutel (2000) reported WOD in Lake Elsinore ranging from 0.5 to 0.9 mg/l/d from his work, and 1.2 to1.9 mg/l/d from prior reports. He observed SOD of 0.34 to 1.8 g/m^2/d. For a 5-m deep water column, this corresponds to 0.07 to 0.36 mg/l/d. Both WOD and SOD were greater during the summer. SOD was greatly increased (30% to 70% increases) by circulating water over the sediments. On average, 1.0 mg/l/d (WOD + SOD) is a reasonable value for oxygen depletion in deep waters of Lake Elsinore. Surface waters may have a greater net demand at times of algal crash. Anderson (2001) also estimates net oxygen demands in Lake Elsinore's deep waters at 1.0 mg/l/d.

Hypolimnetic oxygen depletion rates in deeper lakes and reservoirs typically range from 0.04 to 0.30 mg/l/day (Lorenzen and Fast 1977), while oxygen consumption rates in shallow (1 to 2 m deep) aquaculture ponds typically range 1.44 to 20.0 mg/l/day (Fast and Boyd 1992). Lake Elsinore's oxygen depletion rates are more similar to shallow, well-mixed aquaculture ponds than to deeper lakes and reservoirs.

Beutel (2000) estimated whole lake oxygen demands at Lake Elsinore of 80 tons/day with 5-m (16.5 feet) average depth and based on WOD of 1.0 mg/l/d and SOD of 1.5 g/m^2/d. If phytoplankton do not provide any net DO addition through photosynthesis, and if atmospheric oxygen recharge is included in the net WOD loss, then 80 tons/day of oxygen would be required to maintain Lake Elsinore's DO at some stable concentration.

If we assume that total oxygen demand is 1.0 mg/l/d at Lake Elsinore, we can then calculate oxygen demands for the whole lake and for the hypolimnion. We will assume here that the top of the hypolimnion occurs at the 3-m (10-foot) depth and extends to maximum depth. At elevation 1,235 for example, maximum depth is 12 feet and the hypolimnion is only 2 feet thick with 2,200 AF (Table 1). With these assumptions, whole lake maximum oxygen demands range from 32.5 to 121.2 tons/day, while hypolimnetic oxygen demands range from 3.0 to 74.1 tons/day (Table 2). At elevation 1,240 (target stabilization level), hypolimnetic oxygen demand is 16.3 tons/day while whole lake demand is 52.4 tons/day.

It is probably impractical to provide enough oxygen additions to Lake Elsinore to meet whole lake demands. At the target lake level of 1,240 feet, this would require 52.4 tons/d (Table 2). At higher elevations of 1,245 and 1,250 whole lake demands are 74.1 and 97.2 tons/day respectively. Perhaps a more reasonable approach is to add enough oxygen to compensate for hypolimnetic oxygen demands when the lake is stratified at about the target lake elevation of 1,240 feet. This would require 16.3 tons/d, which is similar to the 20 tons/d estimate calculated by Beutel (2000) using a different approach. This oxygenation rate would be inadequate to meet entire whole lake demands at any elevation shown in Table 2 (32.6 to 121.2 tons/d), or to meet hypolimnetic oxygen demands much above 1,242 feet. Note that hypolimnetic oxygen demand at 1,245 is estimated at 32.6 tons/d. However, an oxygenation rate of 20 tons/d would offset at least part of a larger oxygen demand and perhaps prevent total oxygen depletion (zero DO) in the lake before destratification and/or until photosynthesis can overcome a net DO loss. With these limitations in mind, I will base the following considerations on an oxygenation rate of 20 tons/d.

7.3. Artificial Destratification

Artificial destratification can prevent DO depletions in deep water by mixing surface waters with high DO concentrations into deep waters with low DO. If compressed air is used for destratification, some oxygen will also be added to under-saturated deep waters, but most DO additions to deep water are through redistribution of surface waters rather than oxygen absorption from air bubbles.

To illustrate the above process, if Lake Elsinore is at elevation 1,240 feet with 3,000 surface acres, the upper 3 feet of the lake contains 9,000 acre-feet of water. If algae in this upper 3 feet produce a net DO “surplus” of even 1 mg/l, this will amount to 24,000 lbs of excess DO that could be mixed into deeper waters. The objective then is to efficiently and adequately mix enough surface waters into deep waters to maintain adequate DO at the mud/water interface. This mixing process also displaces oxygen poor, deep waters upward where they are oxygenated through photosynthesis and atmospheric recharge.

Lorenzen and Fast (1977) provided guidelines for sizing lake destratification systems that use compressed air injection from a diffuser airline. They recommended air injection rates of about 1.3 SCFM/1 surface acre in order to maintain a relatively well mixed water column with <2°C difference between the surface and bottom, and without any sharp temperature gradients. However, their estimates were based on deep lakes with greater initial temperature gradients and more stable stratification than exists in Lake Elsinore.

Lake Elsinore differs markedly from most lakes that have been destratified by air injection. The primary differences between Lake Elsinore and these other lakes is that Lake Elsinore is polymictic with transient stratification, and Lake Elsinore typically only has 3°C difference between surface and bottom waters when stratified while other lakes typically have 10°C or more difference. In addition, Lake Elsinore is much shallower than these other lakes. With these considerations in mind, I believe that an air injection rate of less than 1.3 SCFM/A would suffice at Lake Elsinore to reduce periods of thermal stratification. I therefore will assume an air injection rate of 1.0 SCFM/A if air injection is the sole means of artificial destratification.

Table 2. Estimated hypolimnetic water volumes, whole lake oxygen demands and hypolimnetic oxygen demands for Lake Elsinore for water elevations ranging from 1,235 feet elevation to 1,255 feet. Hypolimnetic water volumes assume that the hypolimnion begins at the 3-m (10-ft) depth regardless of maximum depth. Oxygen demands estimates assume an average oxygen consumption rate of 1.0 mg/l/day for water and sediment demands combined.

Elevation	Depth (ft)	Lake Vol. (AF)	Hypo. Vol. (AF)	Lake Demand (t/d)	Hypo. Demand (t/d)
1,235	12	24,000	2,200	32.6	3
1,240	17	38,519	12,000	52.4	16.3
1,245	22	54,504	24,000	74.1	32.6
1,250	27	71,443	38,519	97.2	52.4
1,255	32	89,114	54,504	121.2	74.1

8. DESTRATIFICATON AND AERATION/OXYGENATION ALTERNATIVES

There are two broad categories of lake aeration/oxygenation systems. These include **Destratification** systems that reduce or eliminate thermal stratification by mixing surface and deep waters, and **Hypolimnion Aeration/Oxygenation** systems that maintain thermal stratification while adding oxygen to deep waters. I will not review the full range of these two systems, but instead will discuss the systems potentially most relevant for Lake Elsinore.

8.1. Lake Destratification Systems

There are two types of lake destratification systems most relevant for Lake Elsinore. These include air injection systems that destratify a lake by upwelling oxygen poor, deep waters to the surface, and axial-flow pump systems that push oxygen rich surface waters downward. These can be thought of as bottom-up mixing and top-down mixing respectively.

8.1.1. Destratification by Air Injection

The most commonly used lake destratification system uses a diffuser airline installed on the lake bottom with an air compressor on-shore (Fig. 6). In sound sensitive areas, the compressor is enclosed in soundproofing. The airline leading from the compressor to the lake is often of steel and buried, while the airline in the lake is usually plastic. The distal end of the airline is perforated with holes drilled into the plastic. The airline may rest on the lake bottom, or be elevated by floats along the perforated section. One or more airlines can be operated from one or more air compressors.

8.1.2. Axial-flow Water Pumps

Axial-flow water pumps, commonly referred to as Garton pumps have also been widely used for destratifying lakes and reservoirs. These pumps typically consist of a metal frame, float platform, gear box with motor, drive shaft, propeller, shroud around the propeller, and debris shield (fencing) to keep trash from fouling the propeller (Fig.'s 7 & 8). These pumps are designed to move large water volumes at low cost. Propellers typically range in diameter from 1.5 to 8 feet. Propellers turn at low speed (30 to 60

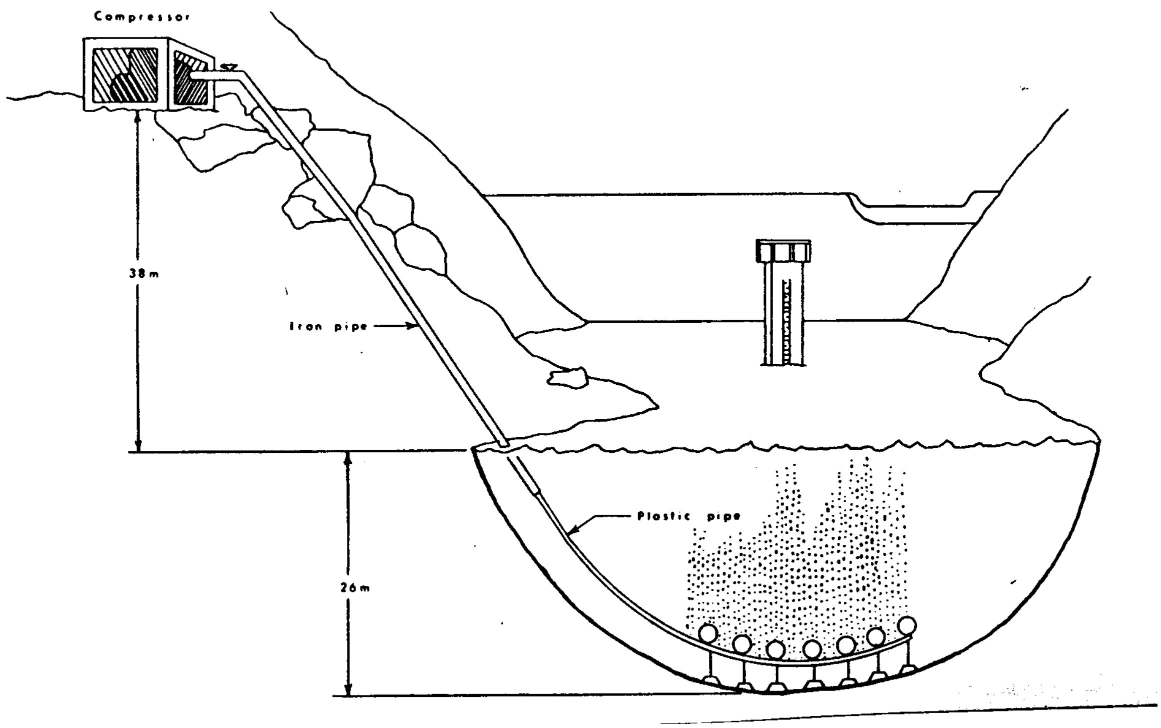

Figure 6. A commonly used diffuser airline destratification system. Sketch is from such a system used at El Capitan Reservoir, San Diego County (Fast 1968).

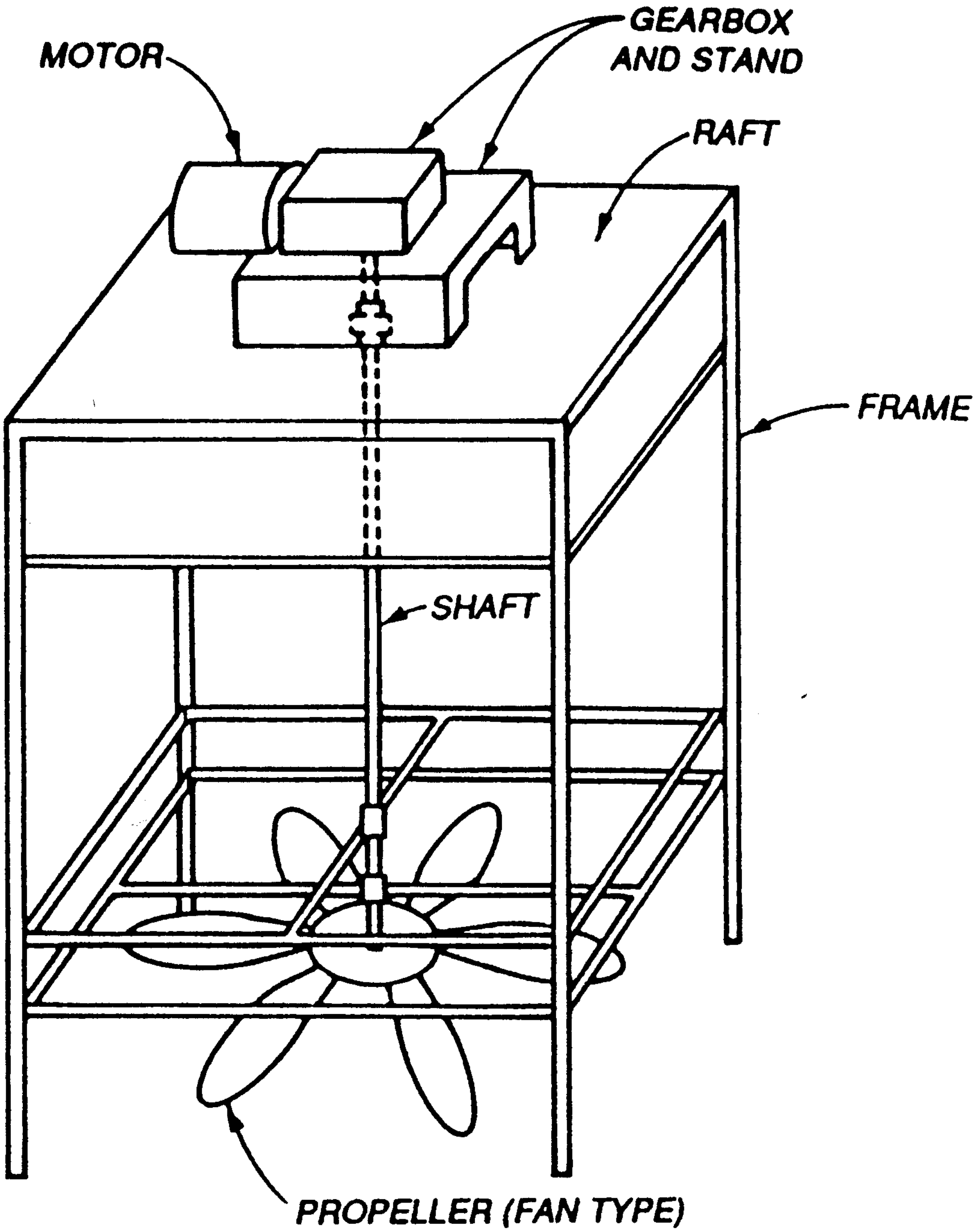

Figure 7. Sketch of axial-flow water pump without shroud or debris shield. Sketch taken from Punnett (1991).

Figure 8. Photograph of a commercially available axial-flow water pump with 6-foot diameter propeller blade and 3-HP motor.

rpm). One commercially available pump has a 6 foot diameter propeller, rotates at 35 rpm, 3-HP electric motor, and pumps >30,000 gpm.

Axial-flow pumps have been used to thermally destratify lakes and reservoirs by pumping warm surface down where it mixes with deeper waters. This approach is especially effective where there is relatively small ΔT differences between surface and bottom waters (<4°C), the lake is shallow (<30 feet deep), and where wind mixing will help destratify the lake as the ΔT is decreased by pumping. These characteristics exist at Lake Elsinore.

Punnett (1991; Appendix A) details design, sizing and other aspects of using axial-flow pumps to destratify lakes and reservoirs. Based in part on his specifications, I believe that at water elevations of 1,240 to 1,245 feet that 16 axial-flow pumps of 3-HP each could help achieve project objectives at Lake Elsinore, as discussed above. Namely, axial-flow pumps could reduce periods of stratification, thus reducing oxygen depletions in deep waters. These pumps can be clustered in rafts with 4 pumps/raft, or 4 rafts total.

8.2. Hypolimnetic Aeration/Oxygenation

Hypolimnion aeration/oxygenation is a process whereby bottom waters of a lake are aerated or oxygenated, but thermal stratification is maintained. This can be achieved using either air or pure oxygen injection techniques. However, air injection systems are generally much less efficient at shallow water depths such as Lake Elsinore, and not compatible with large water level fluctuations. I will therefore consider only oxygen injection systems here.

There are three types of oxygen injection systems that have been widely used in lakes and reservoirs (Lorenzen and Fast 1977, Fast and Lorenzen 1976, Beutel and Horne 1999). One system is similar to the airline system shown in Figure 6, except that garden soaker hose is often attached to the airline and pure oxygen is injected through the hose. This system is most appropriate in deep lakes and/or just in front of a dam penstock. It is not applicable for Lake Elsinore. The other two systems include the Speece Cone and Side Stream Pumping.

8.2.1.Speece Cone

The Speece cone (down-flow bubble contactor) is a unique hypolimnetic oxygenation system that includes a submersible pump that pumps hypolimnetic water through an inverted funnel (Fig. 9). Pure oxygen is injected at the top of the funnel (cone). The downward flowing water prevents oxygen bubbles from rising out of the cone, while water velocity decreases in the cone in a downward direction thus preventing oxygen bubbles from being swept out of the cone bottom. This process greatly prolongs bubble/water contact time and results in nearly 100% oxygen absorption depending on circumstances. Oxygen enriched water then flows out of the cone through a diffuser pipe and back to the hypolimnion. A Speece cone design for Lake Elsinore has been proposed that would add about 20 to 27.5 tons/d of oxygen to the lake's deep waters (Montgomery Watson 2000). Because of shallow water depths at Lake Elsinore, this design would require modification to include excavating a deep well (35 to 70 feet deep and 16 feet diameter) into Lake Elsinore's lake bed (Fig. 10). Well construction would presumably require construction of a temporary cofferdam, and lining the well with a concrete liner. After constructing the well, the Speece cone would be brought to the well by barge and installed with a crane, then the cofferdam removed. A 200-HP submersible pump would be required with a 35-foot deep well, and a 100-HP pump with a 70-foot deep well. Liquid oxygen (LOX) would be stored or produced onshore and pumped to the cone for injection. Operating costs for a 10-12 ton/d Speece cone system at Camanche Reservoir, Calif. exceeded $1,000/day[5], including $605 for LOX and $323 for electric power (including operation of 170-HP submersible pump).

Capital costs for this Speece cone installation were estimated at $1.5 million (Montgomery Watson 2000). My opinion is that capital costs could exceed $3 million, but I have no data to support this opinion. Detailed yearly operating costs were not provided, but would depend on how often the system is operated (hrs/day and days/yr), oxygen use (tons/yr), and on system maintenance. Operating costs would include electrical energy to operate the 100 or 200-HP submersible pump and oxygen[6] purchase or generation.

[5] Costs provided by Bill Faisst at Dec. 6, 2001 workshop on "Aeration and Oxygenation in Lakes and Reseroirs to Improve Water Quality", at SAWPA, Riverside, Calif.

[6] Energy costs to produce one ton of LOX used to be 800 kw-hr (Fast et al. 1976). At $0.10/kw-hr, energy costs alone to produce 1-ton of LOX would be $80. At 20 tons LOX/day = $1,600/day

The Speece cone proposed for Lake Elsinore has the advantages that it is completely submersible, and will inject oxygen near the bottom where it is most beneficial. Disadvantages are that the costs (capital and operating) are not well defined, and could be much higher than some of the other alternatives. Maintenance of submerged hardware could also be difficult and expensive, and this system would not reduce duration of stratification cycles. In addition, no suggestions were provided about system operations during times when the lake would be well mixed and oxygen injection would be wasteful.

8.2.2. Side Stream Pumping (SSP)

Another hypolimnetic oxygenation system that uses LOX and maintains thermal stratification is SSP (Fast et al. 1975). This system consists of a shore-side water pump and oxygen source (Fig. 11). Hypolimnetic water is drawn to the pump through a suction line, oxygen is injected just downstream from the pump and water is pumped back to the hypolimnion. Oxygen absorption is usually greater than 90%. This system has been used in several lakes, rivers and is a common industrial process technique.

A SSP system capable of injecting 20 tons/d of LOX at Lake Elsinore would probably need a 900-HP water pump based on a pumping efficiency of 1.5-lb O_2/kw-hr (Fast et al. 1976). Pipe dimensions would probably exceed 24 inches diameter on the suction line and 20 inches on the discharge line. Capital costs would probably be less than any of the other alternative aeration/oxygenation systems, but operating costs for the water pump and LOX would be very high.

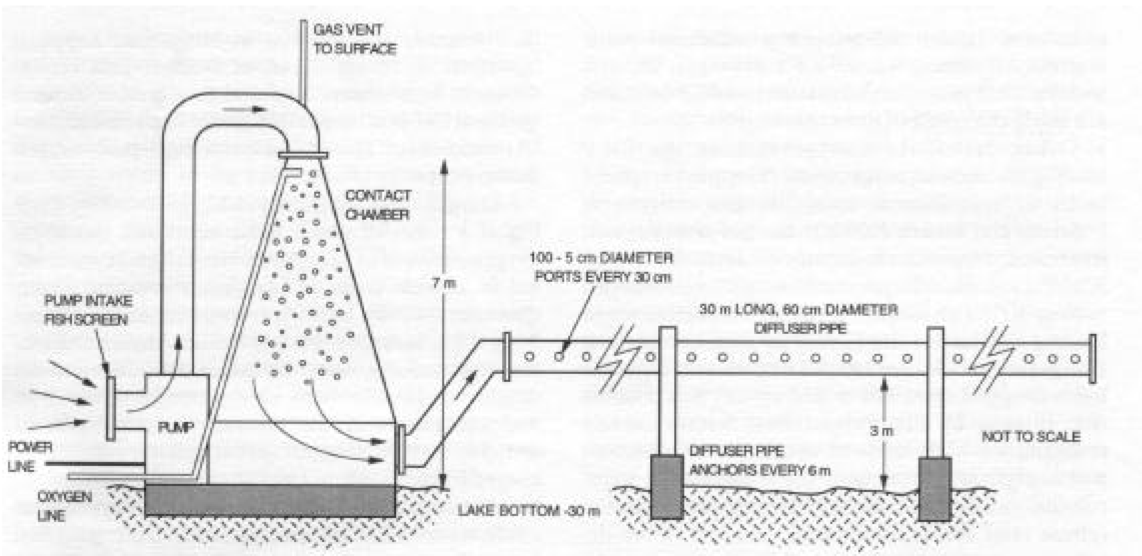

Figure 9. Speece cone system of hypolimnetic oxygenation (Beutel and Horne 1999).

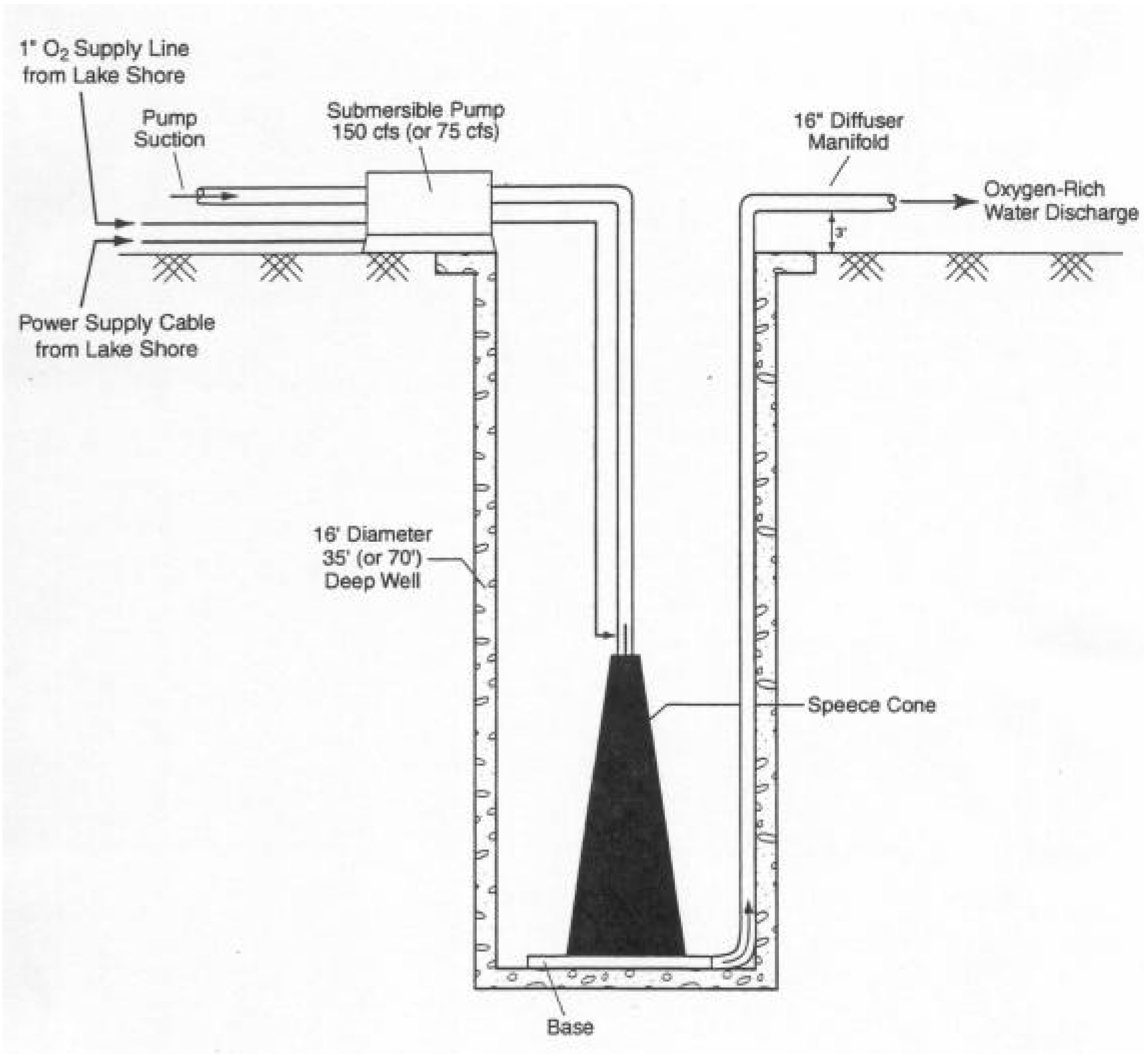

Figure 10. Modified Speece cone system of hypolimnetic oxygenation proposed for Lake Elsinore (Montgomery Watson 2000). The oxygenation chamber (cone) is placed in a deep well dug in the lakebed.

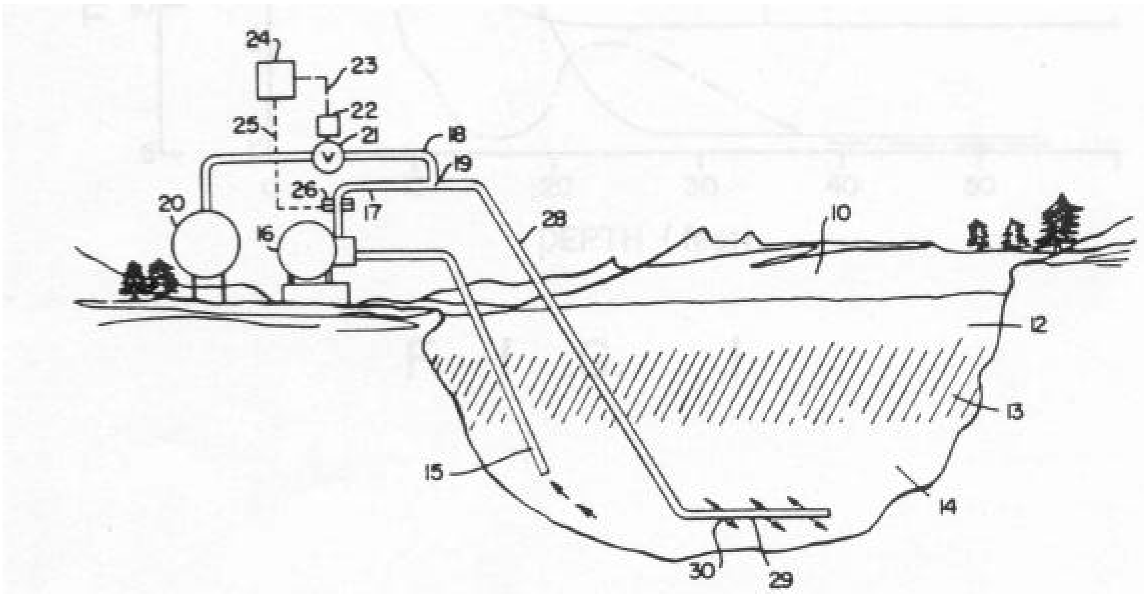

Figure 11. Side Stream Pumping (SSP) system of hypolimnetic oxygenation (Fast et al. 1975).

9. PROPOSED AERATION SYSTEMS FOR LAKE ELSINORE

Many of the aeration/oxygenation systems described herein and elsewhere could be made to meet project objectives. The main issues then are capital costs, operating costs, impacts on recreational use, and operational flexibility. With these considerations in mind, I've described below three options for achieving project objectives. The first two options (Options A and B) should be adequate in most cases when Lake Elsinore is less than full, which is most of the time. Option C has greater mixing capacity and should be adequate at all lake water volumes.

It should be kept in mind, however, that all three proposed aeration systems will not add sufficient quantities of DO to Lake Elsinore to prevent fish kills during worse case DO depletions. Requirements to achieve that are discussed in more detail in Section 10 of this report (below). The axial-flow pumps will add little or no DO. The injected air will add some DO as described in Appendix B, but this is insufficient to prevent DO depletions during worse case conditions. The proposed aeration systems are intended to reduce duration of thermal and DO stratification by reducing thermal differences between the lake's surface and bottom, thus allowing wind action to more easily and thoroughly mix the lake. Results of this increased mixing should include much shorter stratification cycles, overall increased DO throughout the water column, less P release from sediments, improved habitats for fish and zooplankton, greater grazing on algae by zooplankton, and healthier algal populations. These conditions should reduce the probability of DO depletions and fish kills.

As discussed below (Section 10), an oxygenation system capable of preventing DO depletions under all cases would involve extra-ordinary capital and operating costs. The proposed systems are a reasonable compromise between risk reductions for fish kills, etc. and costs.

9.1. <u>OPTION A</u>

Option A consists of two in-lake aeration components, axial-flow pumps and diffuser airlines.

<u>Component A1.</u> This component consists of 16 axial-flow pumps as described in Section 8.1.2. of this report. Each pump would have a 6 foot diameter propeller, 3-HP electric motor and pump >30,000 gpm (>132

AF/d). At lake elevation 1,240 feet, hypolimnetic volume is 12,000 AF. The axial-flow pumps would pump this equivalent volume in 6 days, which is less than the 8 days recommended by Punnett (1991). At greater lake elevations, pumping rates would exceed 8 days, but should still contribute substantially to lake mixing, destratification and aeration of deep waters.

I recommend that these 16 axial-flow pumps be clustered in rafts of 4 pumps per raft. This would mean 4 rafts in the lake positioned across a centerline stretching from the SE shore (Fig. 12). These rafts should consist of a special float such that each axial-flow pump can be inserted or removed from the raft independent of the other pumps and without disrupting operations. This allows for maximum flexibility in operation and maintenance since one or more pumps can be removed and taken to shore for servicing. After insertion in the raft, the pumps should be secured to prevent their movement and damage. There should also be a simple ON/OFF switch for each pump on each raft.

Each raft should be conspicuously identified to prevent collisions with recreational boaters. These identifications should include appropriate colors and visual aids, as well as strobe and other lights. The rafts should also contain attachments to discourage bird roosting.

An underwater cable stretching from the on-shore, control house along the lake bottom (Fig. 12) would provide electricity to each raft. This cable should be armored and/or otherwise protected to prevent damage and injury from/to recreational users. The cable and rafts should be designed such that they will remain in position without damage to the cable at lake elevations that could fluctuate as much as 34 feet (elevations 1,230 to 1,263.3 feet; Table 1).

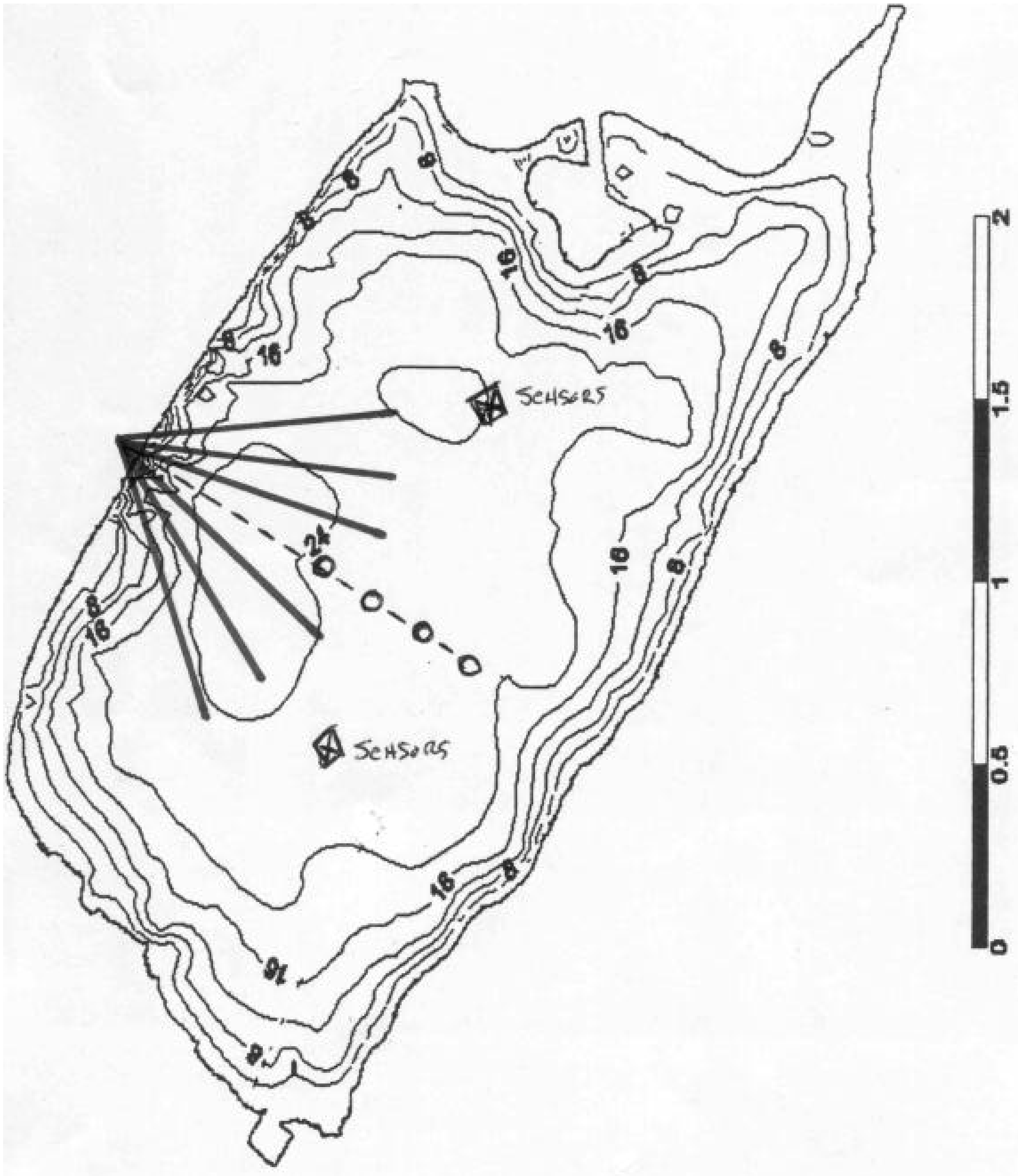

Figure 12. Option A layout of diffuser airlines (6 lines) radiating from compressor building, and four rafts of 16 axial-flow water pumps (circles). Each raft contains four 3-HP pumps. Water depths are in feet when lake elevation was 1,243 feet. Scale is in miles.

Pump Operation. Although these pumps could be controlled by an in-lake sensor and on-shore controller system (described below), I believe they should be operated continuously at least during the first few years. Thereafter, and after experience is gained, they may be included in the automated control system described below for the air injections system. Costs for operating the axial-flow pumps continuously are much less than with the other aeration/oxygenation systems so continuous operation is not a large expense.

Disadvantages/Advantages. The main disadvantage of these axial flow pumps is that they create potential interference with recreational boaters. However, with proper identification this should not pose a major problem. There is not much difference between these rafts and comparable sized boats or barges that are allowed to anchor in Lake Elsinore and other recreational lakes. If anything, these rafts will be much more conspicuous. The main advantages of these pumps are that they are simple, easy to maintain and operate, relatively inexpensive to construct or replace, and relatively inexpensive to operate.

Cost Estimates Component A1. Actual costs will be determined through more detailed design and cost analysis, and ultimately through a bid process. Cost estimates here are first approximations and for conceptual uses only.

Capital Costs:

18 pumps (2 extra) @ $16,000/pump	$288,000
4 rafts w/anchoring systems @$20,000/raft	80,000
Electric cable and controls	200,000
-side Building (hollow block), including electric service to bldg., (also used by compressors)	50,000
Total	$586,000

Operating Costs (yearly):

Electricity (16 pumps)(3-HP/pump)(1 kw-hr/HP) ($0.11/kw-hr) (24 hrs/day)(365 days/yr)	$46,000/yr[7]

Component A2. This component consists of a air injections system with a airline diffuser similar to that shown in Figure 6, but much larger. The air

[7] Electrical operating costs could be much less since pump draws <1 kw-hr/pump (Punnett 1991)

diffuser system for Lake Elsinore (Option A2) would consist of six airlines radiating from the SE shore from a central air source (Fig. 12). The airlines should be at least 2 inches ID, about 4,000 feet long each, plastic, adequately anchored, and perforated along their distal ends to provide upwelling of deep waters. Air supply should be provided by an oil-free rotary screw compressor (s) delivering about 2,000 SCFM of air at about 50 psi. Compressors should contain soundproofing to reduce noise to 80 decibels. The compressors and controllers should also be enclosed in a hollow block building, further reducing noise. The compressor will need about a 200-HP electric motor.

Compressor Operation. Because of the large electric consumption of this air injections system, it should only be operated when needed. Its ON/OFF operation should be controlled using a sensor and controller system described below. If operated in conjunction with the axial-flow pumps (continuous pump operation) as described above, I believe operating times for the air injection system could range from 10% to 20% of the time on an annual basis with properly configured automated controls for air injection. This is based in part on Anderson's (2001) observation that bottom DO was depleted or low about one third of the time. For budgeting purposes, I will assume that compressor operation with Option A2, as described would be 20% of the time, or 73 days/yr (1,752 hrs).

Disadvantages/Advantages. Perhaps the main disadvantage of the air injection system is the cost to run the air compressor. However, this cost could be reduced through an appropriately designed and operated sensor/controller system. The main advantages of airline destratification are that it is simple, easy to service, and has been widely used for a long time.

Cost Estimates Component A2. Actual costs will be determined through more detailed design and cost analysis, and ultimately through a bid process. Cost estimates here are first approximations and for conceptual uses only.

Capital Costs:

Compressor and airlines, including installation at lake.	$400,000
Shore-side building (included with A1)	---

Operating Costs (yearly):

Electricity (200-HP)(1 kw-hr/HP)($0.11/kw-hr) (24 hrs/day)(73 days/yr)	$38,544/yr

Component A3. Sensor/Controller System. The air compressors (A3) should be operated in an ON/OFF mode controlled automatically using an in-lake sensor array and on-shore controllers (A3). The in-lake sensors should consist of temperature sensors at 3-foot intervals from the lake surface to bottom and a DO probe just above the bottom of the lake. These sensors should be suspended from a raft, with two sets of sensors and two rafts as shown in Figure 12. Data should be collected on some appropriate time interval (e.g. 15 to 30 min.), and sent via wireless transmission to a on-shore computer. The computer could be located in the on-shore compressor building, or perhaps more appropriately in an operator's office. Data should be recorded for later interpretations, and it will be used in real time to make decisions about ON/OFF compressor operation. This will require development of decision logic and computer programs specific to Lake Elsinore. Refinement of this controller system could take two years, but is well worth the investment. With Option A, continuous compressor operation could cost $200,000/yr, and $400,000/yr with Option B (see below). If operation time can be reduced to 20% or less with Option A and 50% or less with Option B, substantial yearly savings will result.

Capital Costs:

Sensors, rafts, anchoring system, controller, Computers, telemetry	$250,000

Operating Costs (yearly):

a. first 2 years during system refinement	$70,000
b. year 3 and thereafter	$10,000

9.2. OPTION B

Option B consists of in-lake diffuser airlines and compressed air injection.

Component B1.

Component B1 includes two air injection systems similar to the one discussed in Option A2 above. Component B1 includes air compressors on opposite sides of Lake Elsinore installed in two on-shore buildings (Fig. 13). Each compressor would have 6 airlines. Total air capacity would be 4,000 SCFM and require 400 HP.

Disadvantages/Advantages. The main disadvantage of this option is the cost to run the air compressors. While this cost could be reduced using sensors/controller, I believe that compressor operation might be required 40% to 50% of the time. The main advantages of this system are that there are no surface obstructions, it is simple, easy to service, and has been widely used for a long time.

Cost Estimates Component B1. Actual costs will be determined through more detailed design and cost analysis, and ultimately through a bid process. Cost estimates here are first approximations and for conceptual uses only.

Capital Costs:

Compressors and airlines, including installation at lake.		$650,000
Two on-shore buildings		100,000
	Total	$750,000

Operating Costs (40% time, yearly):

Electricity (400-HP)(1 kw-hr/HP)($0.11/kw-hr) (24 hrs/day)(146 days/yr)	$154,176/yr

Component B2.

Same as Component A3 discussed above, with same costs.

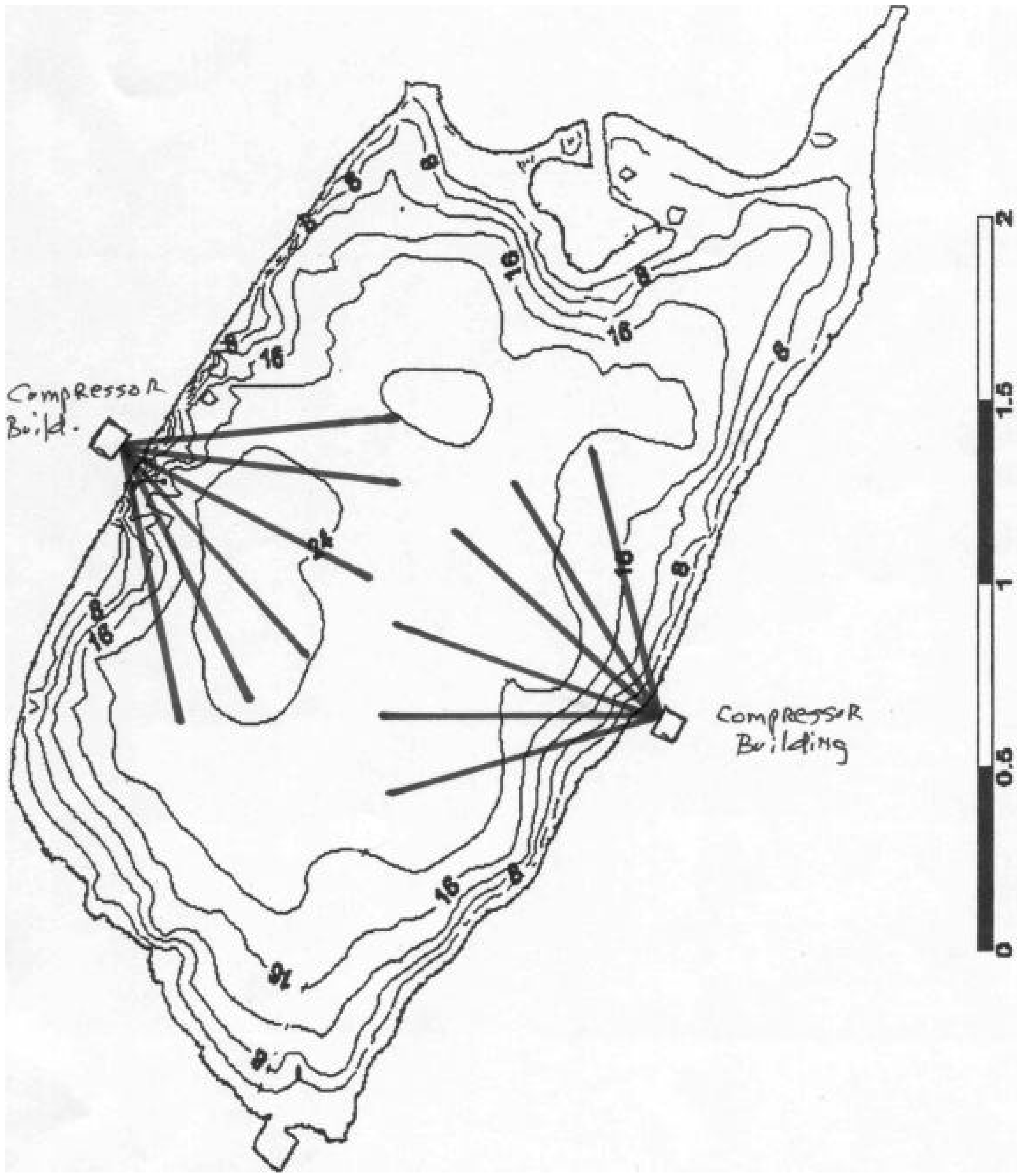

Figure 13. Option B layout of diffuser airlines (6 lines per compressor, 12 lines total) radiating from compressor buildings. Water depths are in feet when lake elevation was 1,243 feet. Scale is in miles. Note that sensor rafts are not shown in this figure but should be the same for all three options.

9.3 OPTION C

Alternative aeration system options A and B for Lake Elsinore were described previously (Fast, Feb. 2002)[8]. Based on subsequent discussions with the project Technical Advisory Committee on Feb. 26, 2002, I have prepared a description of a third option, OPTION C (below). This option combines elements of Options A and B and increases destratification capacity such that OPTION C should provide adequate mixing at all lake levels. Provided that an appropriate sensor and control system is designed and used to operating the mixing systems, energy consumption and costs for Option C should be similar to Option A at reduced lake water volumes, and intermediate between Options A and B when Lake Elsinore is near capacity. Required hours of operation should change based on lake elevation. The proposed automated control system should sense this automatically and adjust operations accordingly. Since OPTION C has greater mixing capacity, it should not need to operate as much as either Option A or B to accomplish the same degree of destratification, thus offsetting higher operating costs per unit time for OPTION C.

***Overall System Description*:** Option C aeration/destratification system for Lake Elsinore consists of three components; axial-flow water pumps, air injection from diffuser airlines, and a sensor/control system that will automatically determine ON/OFF operations of the water pumps and air injection. The air injection system consists of two compressor sites located on opposite sides of Lake Elsinore (Fig. 14). Six diffuser airlines (4,000 feet each) radiate from each compressor site. The axial-flow pumps are clustered in rafts with four pumps per raft and four rafts total. A total of sixteen, 3-HP axial-flow pumps will be used. An underwater cable will deliver electricity to the rafts and pumps. The last component consists of in-lake temperature and dissolved oxygen (DO) sensors suspended from two rafts near opposite ends of Lake Elsinore. Temperature and DO will be measured at about 15 minute intervals and sent telemetrically to an on-shore computer for data storage and analysis. This data analysis will determine ON/OFF operations of the water pumps and air compressors. Different decision logic will be used for each system.

[8] Fast, Feb. 2002, Proposed lake aeration and biomanipulation for Lake Elsinore, California, 51 pgs. + append.

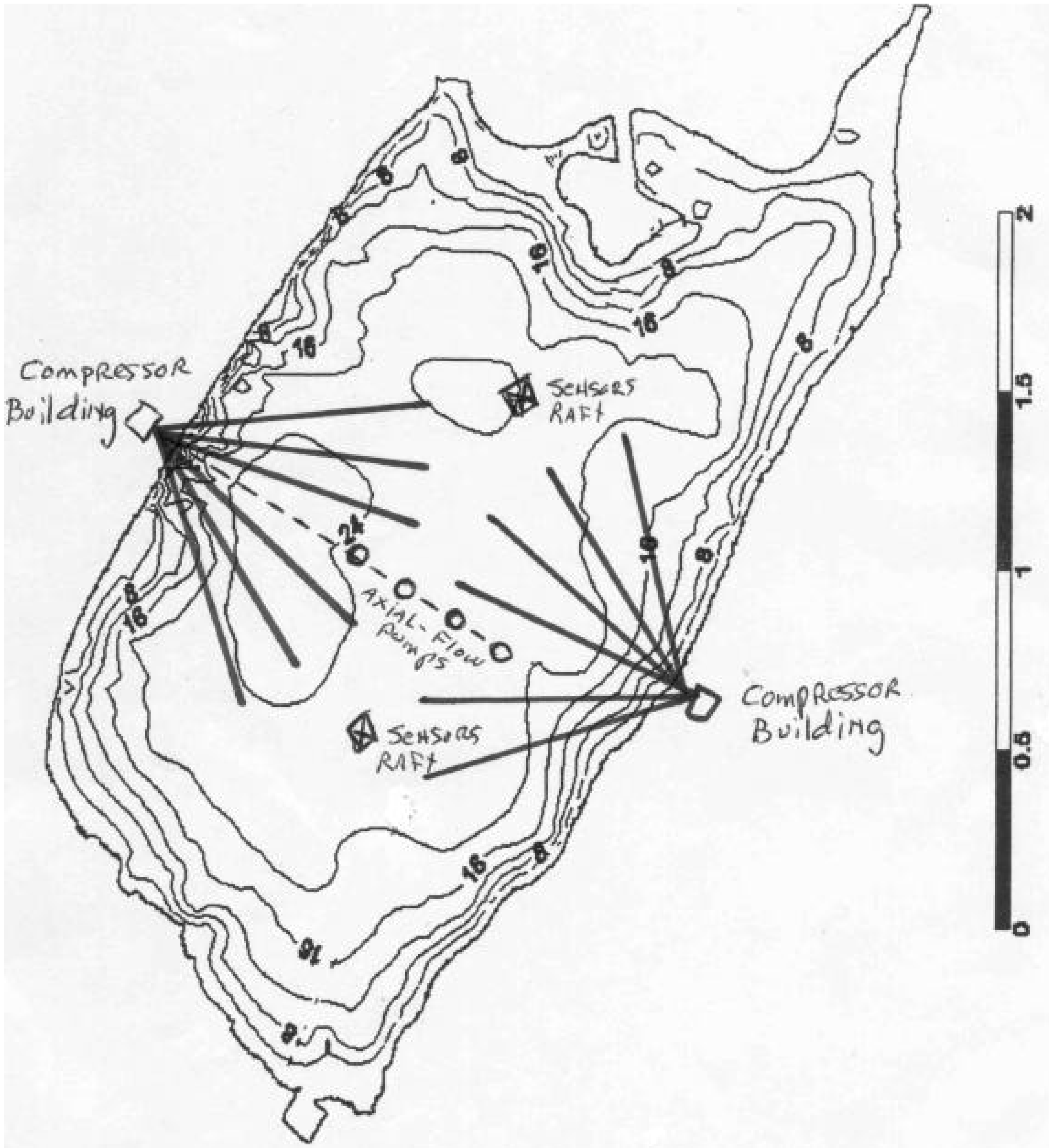

Figure 14. Option C: Aeration system consists of two air compressor sites located on opposite sides of Lake Elsinore with six diffuser airlines radiating from each compressor site, and four rafts of axial-flow water pumps (circles). Each raft contains four, 3-HP pumps. Two sensor/control rafts are located at opposite ends of Lake Elsinore. These sensors will be used to collect temperature and oxygen data used for decision making about ON/OFF operation of water pumps and air compressors. Water depths are in feet when lake elevation was 1,243 feet. Scale is in miles.

COMPONENT C1. AXIAL-FLOW WATER PUMP DESTRATIFICATION SYSTEM.

This component consists of 16 axial-flow pumps as described above. Each pump would have a 6 foot diameter propeller, 3-HP electric motor and pump >30,000 gpm (>132 AF/d). At lake elevation 1,240 feet, hypolimnetic volume is 12,000 AF. The axial-flow pumps would pump this equivalent volume in 6 days, which is less than the 8 days recommended by Punnett (1991). At greater lake elevations, pumping rates would exceed 8 days, but should still contribute substantially to lake mixing, destratification and aeration of deep waters.

I recommend that these 16 axial-flow pumps be clustered in rafts of 4 pumps per raft. This would mean 4 rafts in the lake positioned across a centerline stretching from the SE shore (Fig. 14). These rafts should consist of a special float such that each axial-flow pump can be inserted or removed from the raft independent of the other pumps and without disrupting operations. This allows for maximum flexibility in operation and maintenance since one or more pumps can be removed and taken to shore for servicing. After insertion in the raft, the pumps should be secured to prevent their movement and damage. There should also be a simple ON/OFF switch for each pump on each raft.

Each raft should be conspicuously identified to prevent collisions with recreational boaters. These identifications should include appropriate colors and visual aids, as well as strobe and other lights. The rafts should also contain attachments to discourage bird roosting.

An underwater cable stretching from the on-shore, control house along the lake bottom (Fig. 14) would provide electricity to each raft. This cable should be armored and/or otherwise protected to prevent damage and injury from/to recreational users. The cable and rafts should be designed such that they will remain in position without damage to the cable at lake elevations that could fluctuate as much as 34 feet (elevations 1,230 to 1,263.3 feet).

Pump Operation. Pump operation should be controlled using Component C3 (below), where the intensity and duration of thermal and DO stratification is measured, then a decision is made using computer driven devices regarding ON/OFF operations of both Components C1 and C2. Axial-flow pump operation should have a lower threshold for ON operation since its operating costs are much less than for air injection. Axial-flow pumps may be operated perhaps 3 of 4 days during the year, although they may not operate 24 hrs/day in all cases when they are in operation. Their operation should greatly reduce the intensity and duration of stratification, thus reducing the need for higher cost air injection.

Disadvantages/Advantages. The main disadvantage of these axial flow pumps is that they create potential interference with recreational boaters. However, with proper identification this should not pose a major problem. There is not much difference between these rafts and comparable sized boats or barges that are allowed to anchor in Lake Elsinore and other recreational lakes. If anything, these rafts will be much more conspicuous. The main advantages of these pumps are that they are simple, easy to maintain and operate, relatively inexpensive to construct or replace, and relatively inexpensive to operate.

Capital and Operating Costs: Same as for Option A1

COMPONENT C2. AIR INJECTION DESTRATIFICATION SYSTEM

The air injection system for Lake Elsinore consists of air compressors on opposite sides of Lake Elsinore installed in two on-shore buildings (Fig. 14). Each compressor would have at least 6 airlines radiating from the shore from each air compressor. The airlines should be about 3 inches ID, about 4,000 feet long each, plastic, adequately anchored, and perforated along their distal ends to provide upwelling of deep waters. Air supply should be provided by oil-free rotary screw compressors delivering about 4,000 SCFM of air at 40-50 psi. Compressors should contain soundproofing to reduce noise to 80 decibels. The compressors and controllers should also be enclosed in a hollow block building or other shelter, further reducing noise.

Compressor Operation. Because of the large electric consumption of this air injections system, it should only be operated when needed. Its ON/OFF operation should be controlled using a sensor and controller system described below. If the control system is properly designed and operated, and air injection is operated in conjunction with the axial-flow pumps as described above, I believe operating times for the air injection system could range from 10% to 20% of the time on an annual. This is based in part on

Anderson's (2001) observation that bottom DO was depleted or low about one third of the time.

Disadvantages/Advantages. Perhaps the main disadvantage of the air injection system is the cost to run the air compressor. However, this cost could be reduced through an appropriately designed and operated sensor/controller system. The main advantages of airline destratification are that it is simple, easy to service, and has been widely used for a long time.

Capital and Operating Costs: Same as for Option B2, except that the air compressors should operate less than with Option B due to use of both the axial-flow pumps and air injection. Operating costs should therefore be intermediate between Options A and B.

<u>COMPONENT C3.</u> AUTOMATED, PROGRAMABLE SENSOR AND CONTROL SYSTEM FOR BOTH AIR INJECTION & AXIAL-FLOW PUMP SYSTEMS

The air compressors should be operated in an ON/OFF mode controlled automatically using an in-lake sensor array and on-shore controllers. The in-lake sensors should consist of temperature sensors at about 3-foot intervals from the lake surface to bottom and a DO probe just above the bottom of the lake[9]. These sensors should be suspended from a raft, with two sets of sensors and two rafts as shown in Figure 14. Data should be collected on some appropriate time interval (e.g. 15 to 30 min.), and sent via wireless transmission to a on-shore computer. The computer could be located in the on-shore compressor building, or perhaps more appropriately in an operator's office. Data should be recorded for later interpretations, and it will be used in real time to make decisions about ON/OFF axial-flow pump and compressor operations. This will require development of decision logic and computer programs specific to Lake Elsinore. Refinement of this controller system could take two years, but is well worth the investment. With Option C, continuous compressor operation could cost $400,000/yr or more. If operation time can be reduced to 20% or less, substantial yearly savings will result.

[9] Some other sensor configuration may be appropriate as well. This example gives some idea of the type of monitoring required.

Capital and Operating Costs: Operating costs should be the same as shown for Options A3 and B3.

9.4. OVERALL COSTS

Overall costs for Options A, B and C are shown below.

	OPTION A	OPTION B	OPTION C
CAPITAL COSTS	$1,236,000	$1,000,000	$1,586,000
OPERATING COSTS (yearly for 1st 2 yrs)	$ 144,500	$ 214,000	$144,500-$214,000

10. ESTIMATED OXYGEN NEEDS TO MEET WORST CASE DISSOLVED OXYGEN DEMANDS AT LAKE ELSINORE FOR PREVENTING FISH KILLS

Assumptions:

1. Net maximum daily dissolved oxygen (DO) demand will be 1 mg/l/day. At lake elevations 1,235 to 1,255 feet, total oxygen (O_2) needs to meet this demand range from 32.6 to 121.2 tons O_2 per day (Table 1).

   Note: Oxygen demand could exceed 1 mg/l/day. We could expect an unusually high O_2 demand in cases where an intensive algal bloom developed creating a large algal biomass, then the algae die or shutdown photosynthesis at about the same time. This could happen in which case daily O_2 demand could well exceed 1 mg/l/day.

2. Even with a net daily O_2 demand of 1 mg/l/d caused by an algal bloom crash, the algae will recover within three days with a net positive effect on the lake's DO budget. In other words, emergency O_2 additions would not exceed three days per event.

   Note: It is possible that algae might take longer than three days to recover. In this event, an even larger supply of liquid oxygen (LOX) would be required than discussed below, or provisions would need to be made to replenish supplies before they are exhausted.

3. Lake managers will have a continuous monitoring system in place that can and will predict a possible fish kills before they occur. This early warning system should be able to predict when lake-wide DO will fall to below 3 mg/l, thus allowing sufficient time to begin emergency O_2 injection.

Note: The proposed sensor and monitoring system for the destratification systems at Lake Elsinore should provide such an early warning of a pending fish kill due to low DO. However, this system will monitor DO at only two locations. Therefore, when this system detects a potential problem, additional DO measurements should be made at many additional locations in the lake.

Table 3. Estimated hypolimnetic water volumes, whole lake oxygen demands and hypolimnetic oxygen demands for Lake Elsinore for water elevations ranging from 1,235 feet elevation to 1,255 feet. Hypolimnetic water volumes assume that the hypolimnion begins at the 3-m (10-ft) depth regardless of maximum depth. Oxygen demands estimates assume an average oxygen consumption rate of 1.0 mg/l/day for water and sediment demands combined.

Elevation	Depth (ft)	Lake Vol. (AF)	Hypo. Vol. (AF)	Lake Demand (t/d)	Hypo. Demand (t/d)
1,235	12	24,000	2,200	32.6	3
1,240	17	38,519	12,000	52.4	16.3
1,245	22	54,504	24,000	74.1	32.6
1,250	27	71,443	38,519	97.2	52.4
1,255	32	89,114	54,504	121.2	74.1

EMERGENCY OXYGENATION SYSTEM AT LAKE ELSINORE

With the above assumptions and considerations in mind, I believe that an O_2 injection system of 100 tons/day capacity and storage capacity of 300 tons of LOX would be needed.

Because of the massive amounts of O_2 that must be quickly dissolved in Lake Elsinore to meet the above O_2 demands, pure O_2 injection is the only approach that has much merit. Furthermore, this O_2 should be stored at the lake as LOX for when it is needed. Other systems for dissolving these large amounts of O_2 in water would be too massive and too expensive to install and maintain.

An O_2 injection system with capacity of 100 tons/day is about five times larger than the ones I discussed in my February 2002 report[10]. These systems included the Speece cone and side stream pumping (SSP). Of these two systems, SSP would be the system of choice since it would require much less capital expense to install and maintain. It would require much larger

[10] Proposed Lake Aeration and Biomanipulation for Lake Elsinore, California. Feb. 2002.

water pumps than the Speece cone, but these pumps would not operate very often. Therefore, operating costs will be relatively low for either system on an average annual basis. In other words, capital costs are the main issue.

Basically, five SSP systems would need to be installed around the periphery of Lake Elsinore, or one large installation at one location. I previously estimated that one system with a 20 ton/day injection capacity would require a 900-HP water pump, 24 inch diameter water intake line, and 20 inch diameter water discharge line. LOX storage for a 20 ton/day system with a three day supply (60 tons total) could be provided by one TM-3000 tank and one TM-11000 tank (Appendix A). One TM-11000 tank can store more than 105,000 lbs of LOX. This vertical tank has dimensions of 10.2 feet wide by 31.6 feet high. Six TM-11000 tanks could provide storage capacity for the entire 300 tons of LOX.

I do not have any accurate installation costs for such a large SSP system. I believe, however, that capital costs would range between $15 million to $20 million. Operating costs would be relatively small since based on past history of fish kills at Lake Elsinore, this system may only need to operate about once every five years. Operating costs would include system maintenance, LOX replacement due to evaporation from storage, and occasional operation of the system when DO becomes critical (i.e. <3 mg/l lake-wide).

PUMP STORAGE ALTERNATIVES AND OPPORTUNITIES

In my separate report[11] I discussed some aspects of the proposed pump storage project that relate to providing improved DO in Lake Elsinore and preventing fish kills. These include oxygenating the return pump storage flows into Lake Elsinore, or creating re-aeration structures either at Lake Elsinore or at the storage reservoir to maintain waters at or near 100% oxygen saturation.

Provided that the pump storage project is constructed and operated, this probably represents the less costly and most effective means for preventing fish kills due to oxygen depletion in Lake Elsinore. It is, however, important to make sure that appropriate provisions are provided in the pump storage

[11] Lake Elsinore Advanced Pump Storage Project, Comments on Some Water Quality and Fishery Issues. March 2002.

system design before it is constructed. If this is not done soon, it will be difficult to get these included in the design. Retrofitting the system later may not be likely.

I have also recommended in my comments on the pump storage facility that this facility provide mitigation for fishery loses. Appropriate mitigation, in my opinion, would be stocking of hybrid striped bass to compensate for sport fishery losses caused by pumped storage. I recommend at least 50,000 lbs of striped bass be stocked in Lake Elsinore yearly. These fish should be at least 1 to 2 lbs each.

11. LAKE ELSINORE ADVANCED PUMP STORAGE PROJECT: Some Comments on Some Water Quality and Fishery Issues

The proposed pump storage project is described in the April 2001report, "Initial Stage Consultation Document", prepared by The Nevada Hydro Company Inc. As described, water is pumped from Lake Elsinore at elevations between 1,240 to 1,249 feet during the night to an upper storage reservoir at elevation 2,740 feet (a vertical rise of about 1,500 feet). Water would then be discharged back to Lake Elsinore during the day. Energy is consumed during the pumping cycle when excess electrical energy capacity exists (nighttime), and generated during daytime when energy demand is much greater and shortages may occur. Both the intake from and discharge to Lake Elsinore are subsurface as presently configured. Water levels in Lake Elsinore will rise and fall as much as 12 to 18 inches daily. Water volumes withdrawn from and discharged to Lake Elsinore will be about 5,000 acre-feet (AF) cycle, or from 7% to 13% of lake volume depending on lake surface elevation. The project report indicates that pump storage will increase dissolved oxygen (DO) in Lake Elsinore, but makes no mention of how this will occur based on proposed configurations and equipment. There is insufficient description and analysis of potential impacts of the proposed pump storage project on the plant and animal life in Lake Elsinore.

As described, it is unclear how the pump storage operation will add any DO to Lake Elsinore. Water will be drawn from Lake Elsinore during the night from some depth, perhaps near maximum depth. DO will be lowest in the lake at depth at night. This water is then pumped to the upper storage reservoir without any mention of aeration or oxygenation. Some oxygen may be absorbed from atmospheric exchange and photosynthesis in the storage reservoir, but this may be minimal since water is released back to Lake Elsinore starting most likely the next morning. Water flows into Lake Elsinore from the pump storage operation are again subsurface without aeration or oxygenation. My conclusion is that the pump storage operation, as presently described will not materially add any DO to Lake Elsinore.

Possible Improvements in Lake Elsinore DO from Pump Storage Operations:

Option 1. Oxygen can be added to Lake Elsinore water during the pumping cycle if water is cascaded into the storage reservoir over an aeration structure as it leaves the pumping system and enters the reservoir. This would involve construction of some type of aeration structure (e.g. step or baffle configuration) over which all water entering the reservoir must cascade. This should result in water entering the storage reservoir being at or near 100% saturation with DO. Water drawn from the reservoir for discharge back to Lake Elsinore during the energy generation cycle will then be at or near DO saturation. This process will be most beneficial to Lake Elsinore if water is drawn from maximum depth in Lake Elsinore, and discharged back to Lake Elsinore at maximum depth. This will result in aeration of the deep waters with lowest DO concentrations. The cascade aeration structure at the storage reservoir may require a 30 to 50 foot vertical drop, which is trivial relative to the total pumping head of 1,500 feet. The cascade aerator is a "passive" system that requires no special mechanical equipment and would be functional for the life of the facility.

Option 2. This option involves discharging water over a cascade aeration structure just before the water flows back into Lake Elsinore on the energy generation cycle. This influent water to Lake Elsinore would then be at or near 100% saturation. Again, the cascade structure may have to have a 30 to 50 foot vertical fall. Water intake from Lake Elsinore for this option should be at or near maximum depth in the lake so that low DO water is replaced with high DO water.

With both options 1 and 2, water inflows to Lake Elsinore should help with the mixing process and thereby help distribute DO throughout the water column. Both options also require separate intake and discharge structures at the locations where the cascade structure is located. This will increase construction cost somewhat, but should be more than offset by improvements in Lake Elsinore DO conditions. Also, cascade structures will probably reduce the efficiency of power generation, but this may be again offset by improvements in Lake Elsinore DO conditions.

Note: If cascade aerators (either at the storage reservoir or at Lake Elsinore) reduce pump storage efficiencies too much, an alternative is to divert water over these aeration structures only when DO concentrations in Lake Elsinore drop below some critical threshold (e.g. 3.5 mg/l). Other times, water can by-pass the cascade aerators. Aeration may only be required once a year or less. The automated sensor/control system proposed for Lake Elsinore's destratification system could also be used for operation of the pump storage aeration system.

Option 3. This option involves injecting pure O_2 from a liquid source into the intake from the storage reservoir, but only during times when DO is at or below some critical minimum level in Lake Elsinore (e.g. 2 to 3 mg/l). With Lake Elsinore at elevation 1,250 feet and a DO depletion rate of 1 mg/l/day, this would require 100 tons of O_2 per day to prevent further DO reduction. Assuming that a negative DO depletion would continue for three days, 300 tons of liquid O_2 would need to be stored continuously near the O_2 injection location. Note that DO would not increase in Lake Elsinore under these conditions, but would be prevented from further depletion provided that DO depletion rate is no more than 1 mg/l/day. With a properly designed O_2 injection system, 100% of the injected O_2 would be dissolved in the influent water to Lake Elsinore. With total water inflow rates of 5,000 AF/day and 100 tons/day of O_2 injection, DO concentrations in the discharge water would be increased by about 15 mg/l.

Even with the LOX system for adding O_2 to Lake Elsinore via the pump storage return water, a cascade aerator would greatly increase total DO inputs to Lake Elsinore. For example, if Lake Elsinore DO is 3 mg/l when a fish kill is threatening, water pumped to the storage reservoir would also be 3 mg/l. If no aeration were provided in this water, the return flow to Lake Elsinore the next morning would also be at about 3 mg/l. The LOX injection system would add 15 mg/l, for total DO in return water of 18 mg/l. However, if a cascade aeration structure is installed at the storage reservoir, pumped water DO would increase from 3 mg/l to about 8 mg/l. The return flow to Lake Elsinore would consequently increase to 23 mg/l (8 mg/l plus 15 mg/l).

Cost of this option would include O_2 storage tanks (300 tons), O_2 makeup (boil off makeup), O_2 evaporators, O_2 injection (diffusers) and plumbing, and process controls. There would also need to be an in-lake continuous monitoring system that would alert the system operators of a pending critical DO condition in Lake Elsinore that might need intervention with O_2 injection.

EFFECTS OF LAKE ELSINORE PUMP STORAGE ON LAKE ELSINORE FISHERY AND WATER QUALITY

The proposed pump storage facility at Lake Elsinore is likely to cause detrimental effects on the lake fishery and water quality. This could occur since the pump storage operation will entrain large numbers of fish eggs, larval fish, and zooplankton. These impacts were not thoroughly investigated or analyzed in the document referenced above.

Most or all of the fish and zooplankton will be killed by the large pressure changes as water flows through the pump storage facility and by water shear forces at the turbine. With 7% to 13% of the lake volume passing through the pumped storage facility twice each day, the equivalent of 100% of the lake volume will pass through the facility twice every 8 to 14 days. The effects on Lake Elsinore's fishery are likely to be negative since these impacts will reduce both game fish densities as well as forage for gamefish. Forage includes small forage fishes and zooplankton. The effects on Lake Elsinore's water quality could also be negative if zooplankton populations are reduced, thus reducing grazing pressure on phytoplankton by the zooplankton.

Mitigation. As partial mitigation for negative impacting the Lake Elsinore fishery by the pump storage facility, hybrid striped bass should be stocked in Lake Elsinore to compensate for sport fishery losses and losses to recreational and other businesses at Lake Elsinore. I recommend that at least 50,000 lbs/yr of hybrid striped bass be stocked at 1 to 2 lbs each as mitigation for these losses. Annual stockings of hybrid striped bass should continue at 50,000 lb/yr for the life of the pump storage facility.

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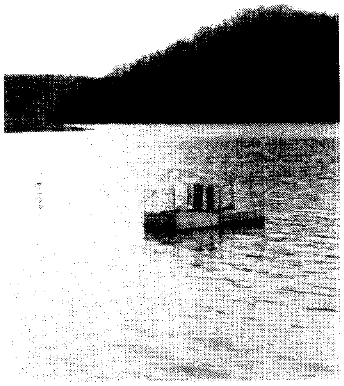
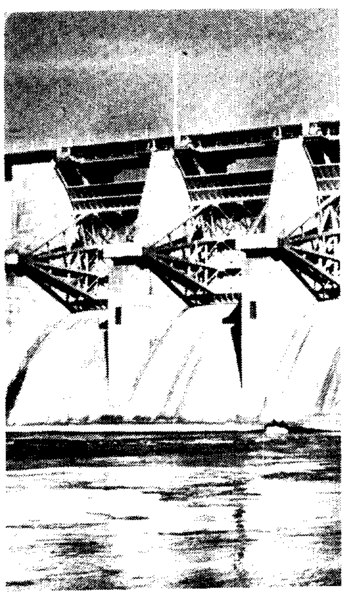
APPENDIX A

Axial-flow Pump Design Manual (Punnett 1991)

US Army Corps of Engineers





WATER QUALITY RESEARCH PROGRAM

INSTRUCTION REPORT W-91-1

DESIGN AND OPERATION OF AXIAL FLOW PUMPS FOR RESERVOIR DESTRATIFICATION

by

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13. ABSTRACT *(Maximum 200 words)*

This report presents information on design considerations, construction, installation, and operation of axial flow pumps for either localized mixing or lake destratification. When used for localized mixing, the pump displaces the hypolimnetic water in the withdrawal zone of a low-level intake with epilimnetic water. When used for lake destratification, the pump moves the surface water downward to mix with the bottom water and eliminate thermal stratification. The pump consists of a frame, flotation platform, motor, gearbox, drive shaft, bearings, and a large-diameter propeller. An example of the design procedure used for destratification of Beech Fork Lake is given.

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PREFACE

The work reported herein was conducted as part of the Water Quality Research Program (WQRP), under the work unit "Hydraulic and Pneumatic Mixers and Aerators in Principle and Practice." The WQRP is sponsored by the Headquarters, US Army Corps of Engineers (HQUSACE), and is assigned to the US Army Engineer Waterways Experiment Station (WES) under the purview of the Environmental Laboratory (EL). Funding was provided under Department of the Army Appropriation No. 96X3121, General Investigation. The WQRP is managed under the Environmental Resources Research and Assistance Programs (ERRAP), Mr. J. L. Decell, Manager. Mr. Robert C. Gunkel was Assistant Manager, ERRAP, for the WQRP. Technical Monitors during this study were Mr. David Buelow, Mr. James Gottesman, and Dr. John Bushman, HQUSACE.

The report was prepared by Dr. Richard E. Punnett, Chief of the Reservoir Control Section, Engineering Division, US Army Engineer District, Huntington, Huntington, WV. Technical review of the report was provided by Dr. James E. Garton, Professor Emeritus, Oklahoma State University.

The report was prepared under the supervision of Dr. Richard E. Price, Reservoir Water Quality Branch (RWQB), Hydraulic Structures Division (HS), Hydraulics Laboratory (HL), WES, and under the general supervision of Dr. Jeffery P. Holland, Chief, RWQB, and Mr. Glenn A. Pickering, Chief, HS. Mr. Frank A. Herrmann, Jr., was Chief, HL.

COL Larry B. Fulton, EN, was Commander and Director of WES. Technical Director was Dr. Robert W. Whalin.

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CONTENTS

	Page
PREFACE	1
CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT	3
PART I: INTRODUCTION	4
PART II: DESIGN OF AXIAL FLOW PUMPS	7
Theory of Design	7
Sizing of Pumps	9
PART III: CONSTRUCTION	12
Generalized Parts and Construction	12
Drive Train	14
PART IV: INSTALLATION	16
Launching and Site Location	16
Anchoring	16
PART V: OPERATION AND MAINTENANCE	18
PART VI: SUMMARY	20
REFERENCES	21
APPENDIX A: BEECH FORK LAKE PUMP DESIGN	A1
APPENDIX B: SPECIFICATIONS FOR AXIAL FLOW PUMPS	B1

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic feet	0.02831685	cubic meters
degrees (angle)	0.01745329	radians
feet	0.3048	meters
gallons (US liquid)	3.785412	liters
horsepower (550 foot-pounds (force) per second)	745.6999	watts
inches	2.54	centimeters

DESIGN AND OPERATION OF AXIAL FLOW PUMPS
FOR RESERVOIR DESTRATIFICATION

PART I: INTRODUCTION

1. As lake surfaces in temperate regions warm during spring and summer, lakes become thermally stratified. The resulting stratification can dramatically affect the water quality in eutrophic lakes. Thermal stratification is not of itself undesirable; however, without the benefit of surface to bottom mixing, dissolved oxygen (DO) is often depleted in the lower layers of the lake, and the water quality deteriorates. In the absence of DO, high concentrations of hydrogen sulfide, iron, manganese, and ammonia nitrogen often persist. As temperatures moderate in the fall, the thermal differences in the lake are reduced, and the lake eventually becomes isothermal (destratified). When isothermal conditions exist, the lake water quality parameters are improved as the lake naturally mixes and DO is increased throughout the water column.

2. Lake destratification by man-made means has been demonstrated to be effective in improving water quality (Quintero and Garton 1973; Steichen, Garton, and Rice 1974; Strecher 1976; Punnett 1978, 1988; Garton and Punnett 1980; Robinson, Garton, and Punnett 1982; Price and Sneed 1989). The two principal methods of mixing to cause destratification are diffused-air pumping and mechanical pumping. Diffused-air pumping is used for direct aeration of the bottom waters and for inducing lake mixing by entraining bottom waters in the rising bubbles. Mechanical pumping may be performed to pump the oxygen-rich surface waters downward to mix with the lower lake levels. Both methods can be used for either localized or whole lake destratification. Localized destratification by mechanical mixing can be used to improve the outflow water quality from a lake by displacing the bottom waters with surface water in the vicinity of the intake structure, which withdraws predominantly from the hypolimnion (Givens 1978; Moon, McLaughlin, and Moretti 1979; Busnaina, Lilley, and Moretti 1981; Robinson, Garton, and Punnett 1982; Price and Sneed 1989). Laboratory tests indicated that a maximum of about 80 percent surface water pumped downward can be released downstream from a bottom intake using localized mixing.

3. For a particular application, the best method can be selected after

evaluating the following considerations: cost, operation and maintenance, lake depth, degree of stratification, and areal extent of destratification. Mechanical pumping systems are often cheaper than diffused-air pumping systems. Mechanical pumping is generally inexpensive in daily operation and can be easily maintained. However, mechanical pumping is often not feasible in deep lakes that have a strong stratification pattern because of buoyant forces that inhibit the downward penetration of the lighter surface water.

4. A specific type of mechanical pump that has been applied successfully to mechanical pumping is the axial flow pump, often referred to as the Garton pump. The axial flow pump consists basically of a frame, flotation platform, motor, gearbox, drive shaft, and propeller (Figure 1). The pump is designed for moving large volumes of water with a low power input. A propeller, such as a cooling tower fan (Figure 2), is suspended below the water surface and rotated to pump surface water downward. Even though a low-head, low-velocity jet is produced, the large-diameter propellers (up to 5.2 m) pump a large volume of water (up to 4.5 m^3/sec). The design of such a system is discussed in the next section.

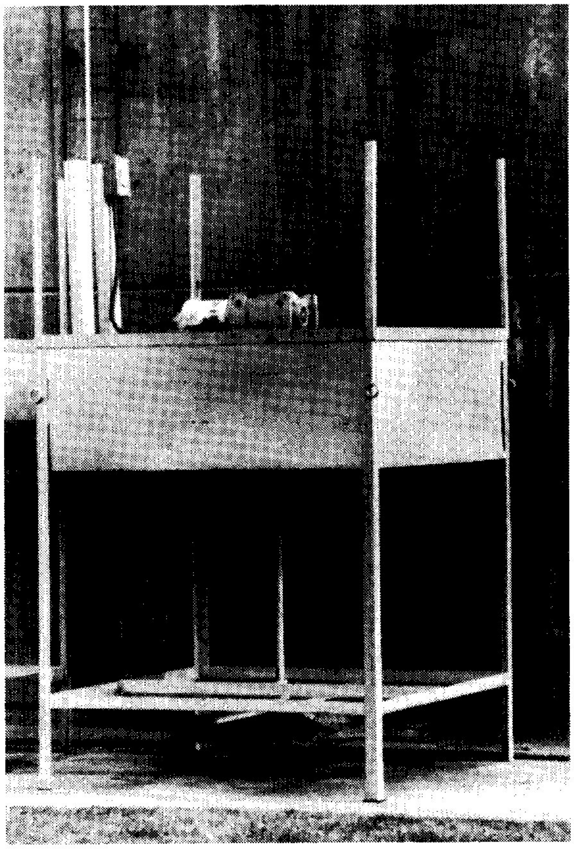

Figure 1. Garton pump

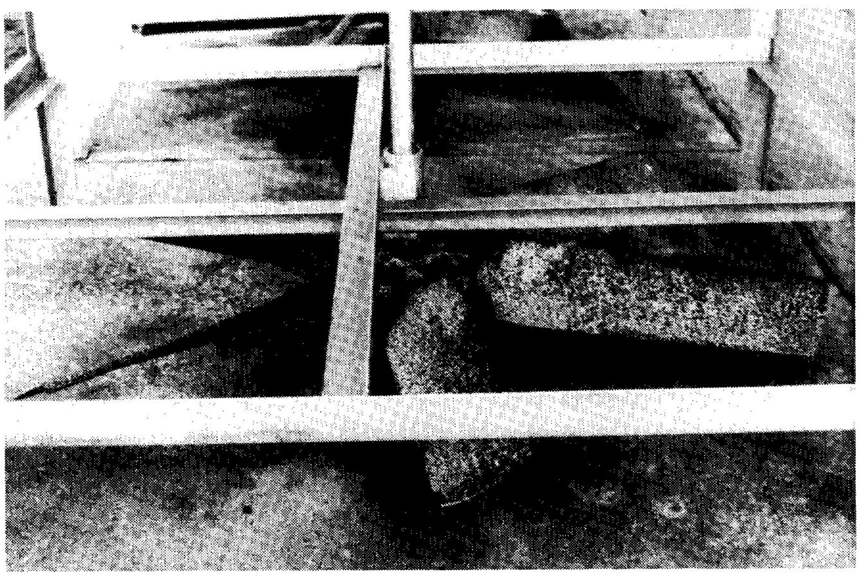

Figure 2. Pump propeller

PART II: DESIGN OF AXIAL FLOW PUMPS

Theory of Design

5. As surface water is pumped downward into the hypolimnion, a plume of warm (light-density) water is formed within the lower layers of cold (heavy-density) water. Buoyant forces acting upon the plume impede the downward velocity of the plume until a relatively stable mixing depth is established. The plume must penetrate to the desired depth in order to be effective. The desired depth would be the lake bottom if lake destratification is the objective or to the intake invert if localized destratification is the objective. Several equations have been developed by Punnett to predict the depth of plume penetration for axial flow pumps (Punnett 1984), the best nondimensional form of which is

$$\frac{H_p}{D} = 0.176 \frac{V^2}{g(\Delta\rho/\rho_o)} + 0.756 \frac{H_e}{D} \qquad (1)$$

where

H_p = length of plume, m

D = pump diameter, m

V = initial jet velocity, m/sec

g = gravitational constant (9.81 m/sec^2)

$\Delta\rho$ = difference in density between surface and desired depth of penetration, kg/m^3

ρ_o = average density of pumped water

H_e = length from pump to thermocline, m

6. In Equation 1, the first term on the right side accounts for plume penetration into dissimilar density strata. The second term on the right side accounts for penetration within the epilimnion where little buoyant resistance is encountered. The depth of the thermocline (for the above equation) was considered to be from the pump propeller to the depth at which the first major increase in density (or temperature) occurred. In a case where no apparent thermocline exists but there is a thermal gradient, the midpoint between the pump and the desired depth of penetration should be used. Other predictive equations have been developed (Holland 1984, Punnett 1984) for surface pumps;

however, Equation 1 was derived from field tests specifically designed to determine the best penetration equation for axial flow pumps.

7. The values for density can be obtained from a lake temperature profile and water density tables. In the absence of chemical-density gradients, the density of water (ρ , in kilograms per cubic meter) can be calculated using Equation 2 (Ford 1983), and the average density of pumped water (ρ_o) can be calculated using Equation 3:

$$\rho = 1{,}000 - \frac{(T - 3.98)^2 (T + 283)}{(503.57)(T + 67.26)} \qquad (2)$$

where T is the temperature of water (°C),

and

$$\rho_o = \frac{(\rho_s + \rho_1 + \rho_2)}{3} \qquad (3)$$

where

ρ_s = density of water at the surface

ρ_1 = density of water at 1 m below the surface

ρ_2 = density of water at 2 m below the surface

8. Early work (Robinson, Garton, and Punnett 1982; Steichen, Garton, and Rice 1974) concluded that the following fan laws provide an effective means of predicting the pump performance in water from the available data based on air tests for a constant diameter:

$$\frac{Q_1}{Q_2} = \frac{N_1}{N_2} \qquad (4)$$

$$\frac{P_1}{P_2} = \frac{N_1^3 \rho_1}{N_2^3 \rho_2} \qquad (5)$$

where

Q = pump flow rate

N = rotative speed, rpm

P = blade input power, kw

Note:

1 = air

2 = water

$$\frac{\rho_1}{\rho_2} \approx 1.22 \times 10^{-3}$$

9. Using Equations 4 and 5 and a manufacturer's propeller performance curve developed for a specific propeller in air, the performance in water can be determined. The power in Equation 5 represents the power required by the propeller; motor sizing should also include calculations of power losses in the bearings and gearbox. An example application of the above equations is given in Appendix A.

Sizing of Pumps

10. For use as a design factor, Equation 1 can be used to solve for the design velocity assuming a pump diameter. For large-diameter propellers normally manufactured for operation in air, the maximum design velocity should be less than about 1.0 m/sec because the propeller hub is designed for stresses related to high-speed, low-resistance operation. A good target velocity is about 0.5 to 0.8 m/sec. A propeller designed for operating in water, such as a ship's propeller, can be operated at higher velocities than the target velocity.

11. The pump diameter and number of pumps required are determined by considering the flow rate needed to be pumped. The flow rate (Q , in meters per second) is calculated by

$$Q = 0.785D^2V \qquad (6)$$

12. Because the pump velocity has important design limitations, and because only discrete pump diameters are available, there is no

straightforward approach to solving for the velocity and diameter simultaneously. However, an iterative process will quickly lead to a solution. Propeller diameters of 1.22, 1.83, and 2.44 m are generally available from manufacturers of cooling tower fans. Assuming a propeller diameter and using Equation 1 to determine the required velocity, Equation 6 can then be used to determine the flow rate. If the required flow rate is greater than what the 2.44-m pump will yield, multiple pumps generally will be required. Use of multiple pumps also allows for more operating options and, if required, permits pump maintenance without complete shutdown. Aircraft propellers have been used for pumps having a propeller diameter of 5.2 m.

13. If localized destratification is desired for the purpose of improving the outflow water quality, the pumping flow rate is a critical design parameter as well as the depth of penetration. Too little flow will not produce the desired results; too much flow may cause a greater mixing action, which can give less than maximum benefits. Some site-specific tests have shown that the maximum benefit is achieved by pumping about half of the release rate (Robinson, Garton, and Punnett 1982).

14. If lake destratification is desired, an evaluation of the required flow rate is difficult. Factors such as wind action, basin morphometry, size and shape of the lake, volume of hypolimnion, degree of stratification, time of year, and pump location have major influences on the required pumping rate. The pumping rate in early summer is much greater than that required in late summer because the larger influx of heat attempts to restratify the impoundment. As pumping occurs, the warm water being forced downward mixes with the cold bottom waters. The mixed water, which has an intermediate temperature and density, rises to the depth of approximately the thermocline (or to a depth of equal density). As pumping continues, the zone of mixed water spreads horizontally and begins to widen vertically in a "lens" fashion. The rate of spreading may be limited by the pumping rate or by the hydrodynamic and buoyant forces associated with mixing water of dissimilar densities. Pumping a flow rate that is too low will limit the amount of water available for mixing. Pumping a flow rate that is too high may set up a recirculating cell around the pump, resulting in excess operating costs. Ideally, the pumping rate would equal the maximum rate at which the mixed buoyant pumping plume would spread throughout the lake.

15. In Ham's Lake (40 ha, surface), Oklahoma, a 1.83-m-diam pump

completely destratified the lake within a 1-week period (Quintero and Garton 1973; Steichen, Garton, and Rice 1974; Strecher 1976). The 1.1-kW pump was placed near the middle of the lake, and its flow rate was about equal to pumping the volume of the hypolimnion once every 4 days. However, successful destratification was achieved using smaller pumps that pumped the volume of the hypolimnion once every 8 days. In Beech Fork Lake (291 ha), West Virginia, the same ratio (volume of the hypolimnion pumped in 8 days) of pumping did not have the same success (Punnett 1988). Beech Fork Lake has a bifurcated shape, and the pumps were placed within 30 m of the dam. Unlike the Ham's Lake project, the pumps were not located in the middle of Beech Fork Lake, which meant the mixed lens of water could not spread in a full radial fashion. Unpublished observations by the author indicate that the pumping rate was too great for the rate at which the mixed water would spread throughout the lake; thus, much of the pumped water was being recirculated in a localized cell around the pumps. Although Beech Fork Lake was not completely destratified until the heat input moderated in late August, the thermocline was lowered throughout the lake and the temperature difference within the lake was reduced to about 3° C for most of the summer.

PART III: CONSTRUCTION

Generalized Parts and Construction

16. The construction of an axial flow pump requires only basic shop functions, but machining of the drive shaft ends is sometimes required. The pumps can be constructed using a welded metal frame, flotation platform, motor, right-angle gearbox, drive shaft with couplings, bearings, and a propeller. The axial flow pump has been constructed in-house as well as commercially. Many pumps have been constructed by college students in a university shop. From a generalized parts list and a hand sketch, a machine shop in Point Pleasant, WV, constructed the main components for four axial flow pumps (1.83-m-diam with a single hermetic steel tank for flotation) for about $24,000 in 1986 (Figures 3-5). The pump sizing calculations, actual design specifications, generalized parts list, and sketch used by the machine shop are given in Appendix A. E. C. Baker & Sons, Inc., Sigel, IL, markets axial flow pumps that are completely equipped for about $11,000; delivery and installation are available at additional cost.

17. The flotation platform can be made either with foam blocks or with hermetic containers. If hermetic containers are used, some flotation material should be put inside, in case the containers develop a leak. After estimating the weight of the pump, the platform should be designed to float the pump with

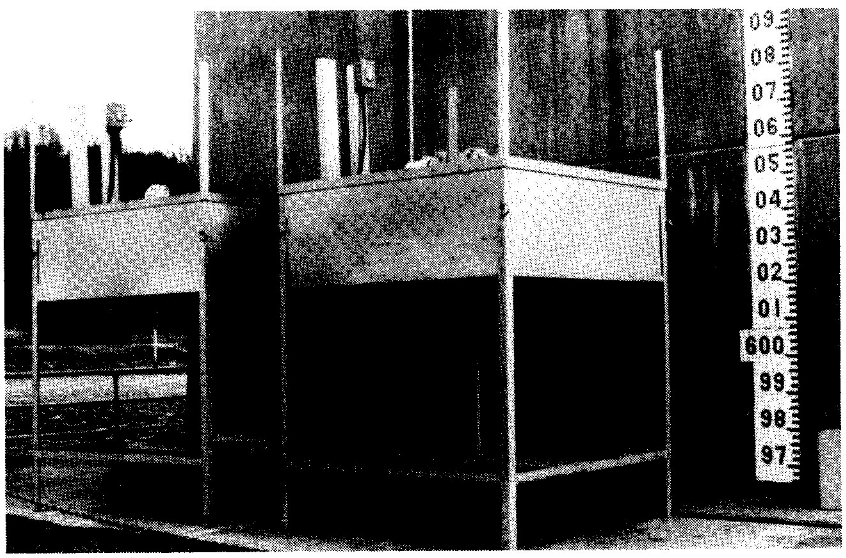

Figure 3. Two assembled pumps

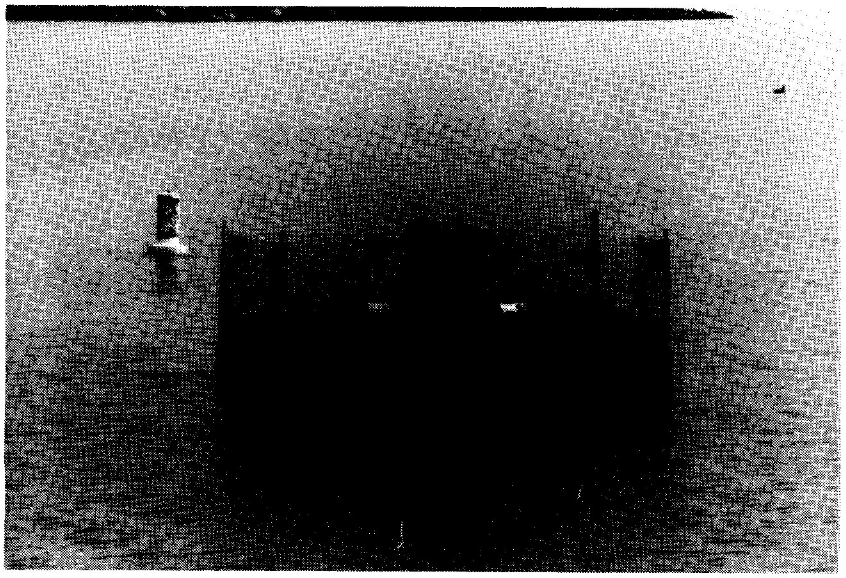

Figure 4. Two pumps in operation

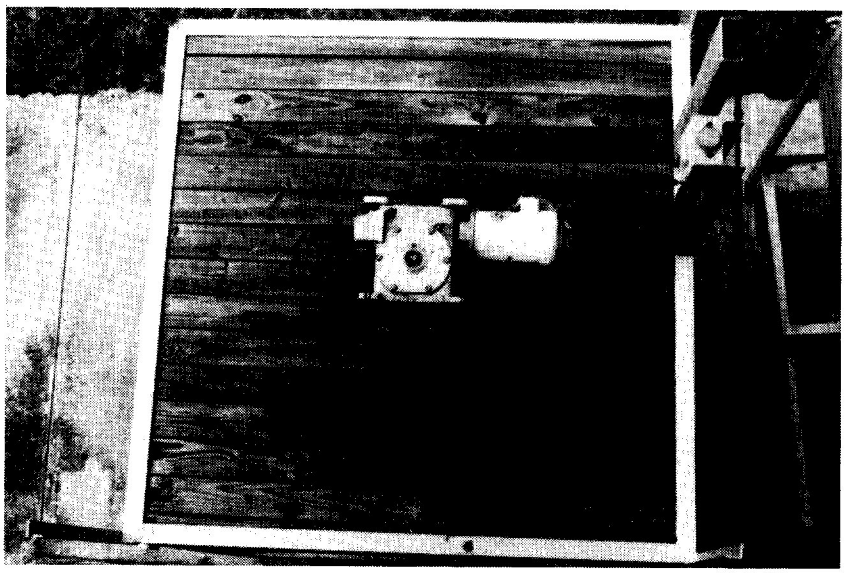

Figure 5. Pump gearbox, motor, and switch

about 0.5 m freeboard. If flotation blocks are used, protection from waterfowl may be necessary.

Drive Train

18. Both diesel and gasoline engines have been used to power the pumps where electrical connections were not feasible; however, electrical motors are much easier to operate. The use of fuel not only dramatically increases operational expenses and hardships, but can deteriorate some flotation materials and create environmental concerns.

19. If an electric motor is used, the electrical connections consist of individual switch boxes for each motor as well as a central starter switch station for a cluster of pumps. The motor selection should include adverse-environment casing (specified TEFC, total enclosed fan cooled) and be consistent with the available power source. In case of power failure, a manual starter switch can prevent multiple pumps from automatically starting simultaneously. Delay circuits are available which allow the pumps to restart sequentially, thus avoiding a possible overloading of the power lines. Generally, the power line runs from the source onshore, along the lake bottom, and up to the pumps.

20. The gearbox should be designed for continuous operation under adverse environmental conditions. A high-quality, heat-resistant gear oil should be used. The reduction ratio of the gearbox is dependent upon the input speed of the motor and the required drive shaft speed of the propeller. The gearbox should be mounted on an elevated frame above the platform surface so that the coupling joining the drive shaft is serviceable from the top of the flotation platform. This is a critical consideration if a gearbox requires replacement while the pump is anchored in the lake.

21. A suitable drive shaft material is cold-rolled steel. Stainless steel shafts are unnecessarily expensive. A stress analysis should be made to determine the necessary diameter. A 3.8-cm-diam shaft has been used successfully for a 1.83-m propeller, and a 5.1-cm-diam shaft has been used successfully for a 2.44-m propeller. The shaft length should allow the propeller to be suspended about 1.5 to 2.0 m below the water surface for propellers less than 2.5 m. The ends of the shaft may require machining to attach the coupler and propeller. Key slots are often required. If a rigid coupler is used, the

gearbox can generally handle both the weight of a suspended propeller and the upward thrust forces when operating. If a flexible coupling is used, shaft bearings (or bushings) will need to handle the vertical forces as well as stabilize the shaft horizontally.

22. The actual blade configuration (shape and number) of the propeller seems to be of little consequence to the penetration performance of the pump. Aerovent, Inc., Piqua, OH, manufactures six-bladed cooling tower fans that perform well as propellers for an axial flow pump (Figure 2). The propeller pitch is adjustable so that the flow rate can be set for a given rate of rotation. The blades are also reversible. Care should be given to ensure a proper blade setting; the blade angle should be greater at the hub than at the blade tips. An improperly installed blade produces unpredictable pumping results. A propeller shroud, designed to improve pumping efficiency by guiding the flow and reducing entrance losses, is optional.

23. Once all the material and parts are gathered, approximately 80 man-hours (engineer and/or technician) is required for construction of the major components. If a pump is built on contract and is no greater than 2.44 m wide (highway limitation), the major components should be assembled by the contractor and delivered as a complete unit. If a pump is larger than 2.44 m, delivery of the components and site assembly may be best.

24. Where public access could be a problem, fences have been installed around the flotation platform. To prevent debris from entering the propellers, fencing has been installed below the flotation platform. Warning signs, indicating high voltage, have been used. Yellow flashing lights have been installed where a potential nighttime boating hazard existed. High-performance epoxy base paints have been successful in preventing corrosion of metal parts. Wheels have been installed on some pumps to facilitate loading from a boat launch area.

PART IV: INSTALLATION

Launching and Site Location

25. With the possible exception of fencing, the pumps should be complete and ready for operation before installation since most tasks are more difficult while the pumps are floating. The most efficient method of installation is to place the assembled pump in the lake using a crane. If wheels have been installed on the base of the pump frame, a cable to control the rate of descent down the ramp should be attached as low as possible on the frame (near the wheels). Because of the deep draft of the pump, the ramp depth should be checked for suitability. Loading from a boat launch area will require personnel who are ready and able to skin dive. After a pump is in the lake, it can be easily pushed by a small boat (in barge fashion) to the pumping site. Generally, three people are able to install one pump in about 2 hr.

26. The location of the pump site is an important issue that involves not only lake mixing considerations, but also common logistics such as the availability of power, potential boating hazards, likelihood of vandalism, and access for maintenance. The best location, for lake mixing concerns only, is over the deepest site that is centrally located. In lakes with extensive dendritic patterns or where the hypolimnion may be partitioned by submerged topography, several locations may need to be evaluated. For localized mixing, the pump should be placed just upstream of the intake port. Pump location and configuration (Price and Sneed 1989) for a three-pump, localized destratification operation at J. Percy Priest Reservoir indicated the location in front of the intake can have a significant influence on system efficiency.

Anchoring

27. Generally, pumps are anchored in position, but some have been secured to an existing structure. The two main concerns are the ability to accommodate changes in surface elevations and to compensate for induced torque. In the case of anchoring, some slack should be left in the anchor lines to accommodate expected lake rises. The torque induced by the turning propeller will cause slack lines to partially wrap around the pump (or cluster of pumps) until all lines are taut. This is a useful side effect since the

pump(s) will "unwind" as the lake level increases and "rewind" as the lake lowers, thereby maintaining position. In the Beech Fork application (Punnett 1988), a cluster of four 1.83-m-diam pumps was held in position by four anchors and 0.635-cm steel cables. The anchors were made by cutting 55-gal* drums in half and filling with concrete. A short piece of heavy-gauge chain was set in the concrete so that the cable was easily attached. The anchors were positioned off the corners of the square cluster of pumps far enough away so that the taut cables formed a 45-deg angle with the lake surface.

28. The total weight of the anchors should not exceed the floating capacity of the platform in case of extreme lake rises. If it appears that the anchors may be lifted because of an imminent extreme rise, the pump(s) should be shut off. An auxiliary anchor with a longer cable could hold the pumps near the site if it is important to maintain the relative position.

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

PART V: OPERATION AND MAINTENANCE

29. For localized destratification, the pumping activity should commence with declining water quality conditions in the lower strata of the lake and coincide with the release schedule. One of the benefits of localized mixing is that the pumps need only to be operated during a period of hypolimnetic releases (e.g., hydropower generation or summer flood control).

30. For lake destratification programs, significant stratification can be prevented in lakes if pumping begins early, thereby possibly avoiding anoxic conditions in the hypolimnion. In the late spring and early summer, the lake surface temperatures may increase rapidly, and the full pumping capacity should be used. Although the system is designed to pump the volume of the hypolimnion in a given time, full pumping capacity is not needed until the maximum heat loading to the lake occurs. If start-up of the system is delayed or solar input is much more than design condition, complete destratification may not be achieved.

31. The effect of pumping is to warm bottom waters to surface temperatures. There may be a slight cooling of surface temperature, but it does not appear to be significant. As the heat input moderates (about mid-August), only a minimal amount of pumping is required to maintain isothermal conditions. The pumping schedule depends primarily upon weather conditions. By early September, pumping may not be needed even though the lake would normally stay stratified until November.

32. The success of the pumping effort can be easily determined using temperature and DO profiles. Profiles of temperature and DO, taken immediately beside the pump(s), will reveal whether the pump jet is penetrating to the proper depth. The temperature in the pumped plume will be relatively constant (at surface values) until the depth of penetration is reached. At that point, readings become erratic; readings below the penetration depth become stable at a colder temperature. Changes in release water temperature and DO, as monitored downstream, will quickly indicate the success of a localized pumping effort.

33. In the case of whole lake destratification where pumping begins early (e.g., April), weekly profiles are usually sufficient for monitoring progress. If pumping commences after stratification has been established, profiling every other day would be important until nearly isothermal

conditions prevail; then, weekly profiles become sufficient. To identify all the changes caused by lake destratification, an expensive and intensive program is needed; however, to assess the success of the pumping effort, temperature and DO are usually sufficient indicators. A program to identify all changes would include a study, both inlake and downstream, of benthos, plankton, chemistry, and fish.

34. For localized destratification, three sampling stations may be sufficient to monitor the pumping program: one station upstream of the dam to monitor lake profile conditions, one station within the pump plume, and one station immediately downstream of the dam. For lake destratification, several stations should be considered in addition to those identified for localized destratification. The shape and bottom contour of the lake are important considerations in determining sampling station locations. Stations located in the thalweg will usually give the best indication of destratification success.

35. Maintenance needs of the axial flow pump, with an electric motor, are relatively minor. An axial flow pump driven by a fuel engine will be essentially as reliable as the engine. The gearbox requires an occasional oil-level check, about every 2 months of operation. An oil change after a specified operation time, such as once a year under continuous operation, is recommended. The gear oil should be of high quality and heat resistant; in some cases, oils have "baked" and allowed gear failure. In gearboxes, a brass gear might require replacement if worn excessively. The gears should be checked at least once a year. Pumps have been left in the water for 3 years without problems. A good maintenance plan would require pump removal every other year for inspection, cleaning, and repainting. The expected useful life of a pump with proper maintenance would be limited by the life of the gear box and motor, assuming rust problems do not develop. Based on previous destratification projects, 5 to 10 years of operation can be anticipated. If fencing was used below the water surface, replacement of the fencing each year may be necessary due to corrosion. If a pump is removed from the lake for winter storage, the anchor cables can be attached to a single buoy and left in place.

PART VI: SUMMARY

36. This report discusses design and construction methods for axial flow pumps used for localized mixing and lake destratification. The theory of design along with computation procedures for sizing of pumps is given. Construction methods, including materials and parts, are discussed. The propellers used in the design are cooling tower fans with variable pitch to achieve a desired flow rate. Installation information includes location of the pumps on the reservoir and anchoring techniques. A section on operation and maintenance gives techniques for monitoring the success of a localized mixing or lake destratification project. Maintenance needs, although minimal, are based on operation of the pump during the stratified season. The design computations used for construction of the Beech Fork Lake destratification system are given in Appendix A. Specifications for axial flow pumps are presented in Appendix B.

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APPENDIX A: BEECH FORK LAKE PUMP DESIGN

Introduction

1. Beech Fork Lake is located on a tributary of Twelvepole Creek in northwestern West Virginia. This 750-acre lake, with a maximum depth of 35 ft, is used for recreation and fish and wildlife enhancement. Thermal stratification during the summer results in a shallow epilimnion (about 2 m) and anoxic conditions in the hypolimnion. This limits habitat available to the fishery, as well as biological productivity. To increase the habitat available to the fishery, a destratification project was initiated in 1987.

Destratification Objective

2. The major objective of the destratification was to increase the depth of the epilimnion and thereby increase the available habitat for the fishery. This was accomplished using four Garton-type pumps to mix the lake. These pumps were operated to pump epilimnetic water through the thermocline into the hypolimnion. The epilimnetic water mixed with the hypolimnetic water to produce a volume of water with a temperature near the thermocline temperature. Thus, the mixed water moved throughout the lake as a layer in the thermocline region. As pumping continued, this layer increased in length and thickness until both the warm and cold water were mixed and the lake was isothermal.

Pump Design

3. The design of the Garton pumps was accomplished using the design equations and guidance provided in the main text. Pertinent data from Beech Fork Lake are given in Table A1.

Table A1

Pertinent Data, Beech Fork Lake, West Virginia

Parameter	Value
Surface area	293 ha
Maximum depth	10.7 m
Extreme thermal conditions	
Surface	24° C
1 m below surface	22° C
2 m below surface	21° C
10.7 m (bottom)	14° C
Minimum depth to top of thermocline	2.1 m
Volume of anoxic hypolimnion	6.0×10^6 m^3

4. Using Equations 2 and 3 of the main text, the densities associated with the thermal stratification are

$$\rho_{24} = 997.3 \text{ kg/m}^3$$
$$\rho_{22} = 997.8 \text{ kg/m}^3$$
$$\rho_{21} = 998.0 \text{ kg/m}^3$$
$$\rho_{14} = 999.3 \text{ kg/m}^3$$

$$\rho_o = \frac{(997.3 + 997.8 + 998.0)}{3} = 997.7 \text{ kg/m}^3$$

$$\frac{\Delta\rho}{\rho_o} = \frac{(999.3 - 997.7)}{997.7} = 0.0016$$

5. For whole lake destratification, the pump plume should penetrate to the lake bottom at the pump site. Assuming a propeller diameter of 1.83 m, Equation 1 is solved for the velocity:

$$\frac{10.7 \text{ m}}{1.83 \text{ m}} = \frac{0.176V^2}{9.81(0.0016)} + \frac{0.756(2.1 \text{ m})}{1.83 \text{ m}}$$

Therefore,

$$V = 0.67 \text{ m/sec}$$

6. Using Equation 6 to find the associated flow rate yields

$$Q = 0.785\ (1.83)^2\ (0.67) = 1.76 \text{ m}^3\text{/sec}$$

From the manufacturer's propeller performance curve (as shown in Figure A1), for a 6-ft-diam propeller having six reversible blades, a blade pitch of 22 deg, and a rotation rate of 50 rpm, the flow rate is about 3,600 cfm at a low head (static pressure). After conversion, the flow rate is about 1.70 m^3/sec. For this project, an electric motor with an input rotation rate of about 1,750 rpm was used. To produce 50-rpm output to generate 1.70 m^3/sec of flow, a gear ratio of 35:1 would be needed. Since a gearbox with a ratio of 50:1 was readily available, the adjusted propeller performance was calculated.

7. Using Equation 4 to determine the flow rate for the same propeller at 35 rpm yields

$$\frac{1.70 \text{ m}^3\text{/sec}}{Q_2} = \frac{50 \text{ rpm}}{35 \text{ rpm}}$$

therefore

$$Q_2 = 1.19 \text{ m}^3\text{/sec}$$

8. The blade power requirement is computed (assuming the density ratio of air to water is 1.22×10^{-3}), using the manufacturer's propeller performance curve (Figure A1) and Equation 5:

$$\frac{0.0015 \text{ hp}}{P_2} = \frac{(50 \text{ rpm})^3}{(35 \text{ rpm})^3}\ 1.22 \times 10^{-3}$$

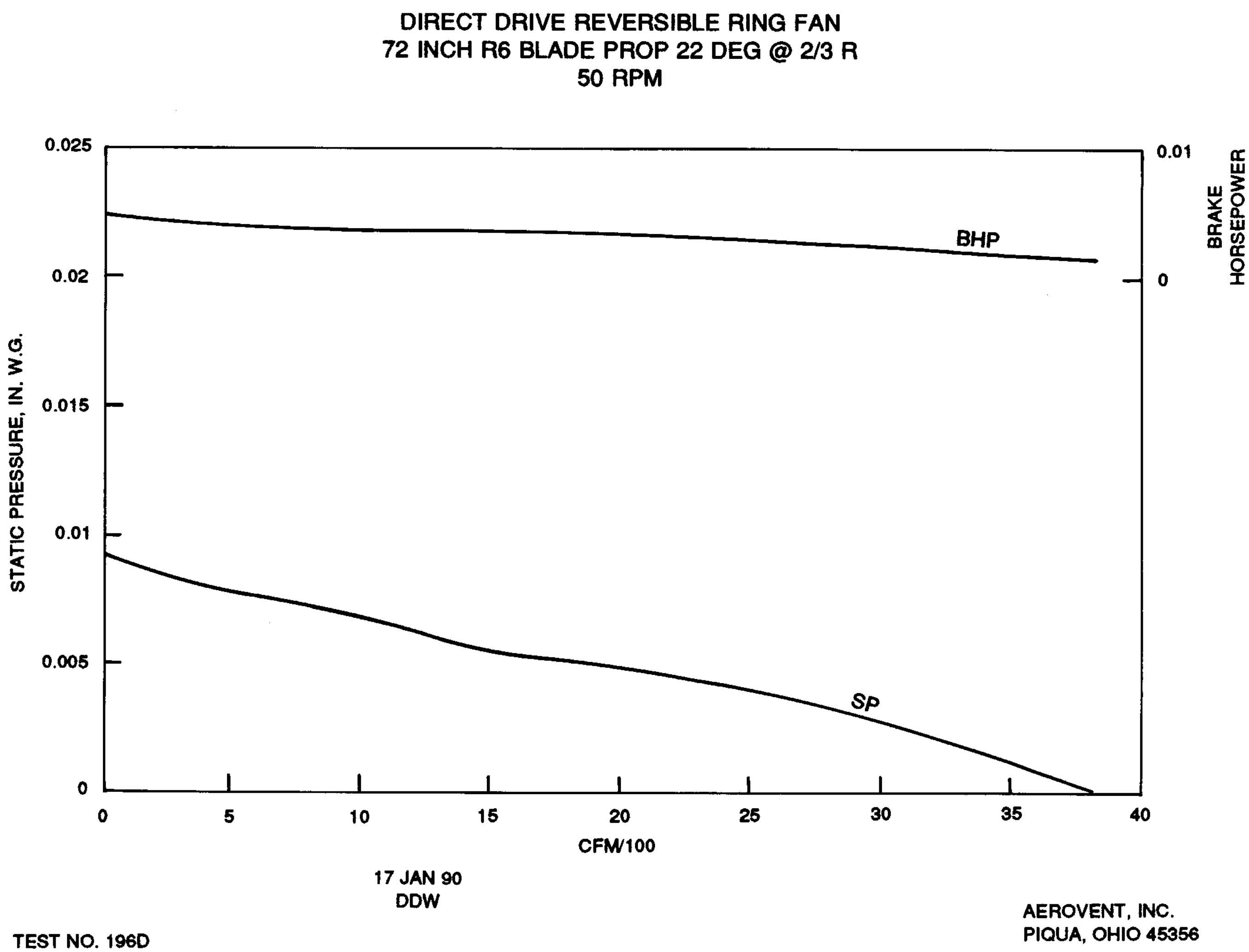


Figure A1. Propeller performance curves

Therefore,

$$P_2 = 0.42 \text{ hp (or 0.31 kw)}$$

9. Using the curves for specific blade pitch settings as provided by the manufacturer (Figure A1) and the information above, the same propeller at different blade pitch settings has the following performance at 35 rpm:

Blade Pitch deg	Flow Rate m^3/sec	Velocity m/sec	Blade Power kw
22	1.19	0.45	0.31
30	1.95	0.74	0.67
32	2.12	0.80	0.82

10. To determine the approximate flow rate necessary for whole lake destratification, the normal volume of the anoxic hypolimnion should be used. From the author's previous experience at Ham's Lake, the required flow rate for destratification of the lake is about equal to pumping the volume of the hypolimnion every 8 days. With a volume of the hypolimnion of approximately 6×10^6 m^3 and a recommended destratification time of 8 days, a flow rate of 8.7 m^3/sec is required.

$$6 \times 10^6 \text{ m}^3 \times \frac{1}{8 \text{ days}} \times \frac{1 \text{ day}}{86{,}400 \text{ sec}} = 8.7 \text{ m}^3/\text{sec}$$

11. Using the above performances of a 1.83-m propeller at 35 rpm, 4.4 pumps will be required at a blade angle of 30 deg; 4.1 pumps will be required at 32 deg. The design specifications for four pumps having the 1.83-m propeller at 35 rpm were written. Appendix B provides copies of the actual specifications, parts list, and drawing supplied to contractors for bids and ultimately for construction of the pumps.

Conclusions

12. A detailed discussion of the destratification system is given by Punnett (1988). Conclusions from that report were as follows:

- a. The epilimnion was increased (the major objective).
- b. The pumps were sufficient for destratifying Beech Fork Lake even though a strong thermal-density difference existed prior to the start of pumping.
- c. Mixing occurred throughout the lake, even though the shape of the lake did not appear to be suited to mixing and pumping was conducted at only one location.
- d. The water in the vicinity of the dam did not become anoxic. Although at times the overall DO was low, only less than 1 percent of the lake volume became anoxic for a short period.

APPENDIX B: SPECIFICATIONS FOR AXIAL FLOW PUMPS

General Description

1. These specifications are for the construction of four axial flow (fan-type) pumps. Each pump consists of a flotation raft and support frame, electric motor, right-angle drive gearbox, shaft and bearings, and a 6-ft-diam fan (propeller). The motor and gearbox are mounted on the raft. The support frame, suspended below the raft, is used to stabilize the shaft and propeller as well as provide a base when the pump is on dry land. A sketch is provided as Figure B1; a generalized parts list is given in Table B1.

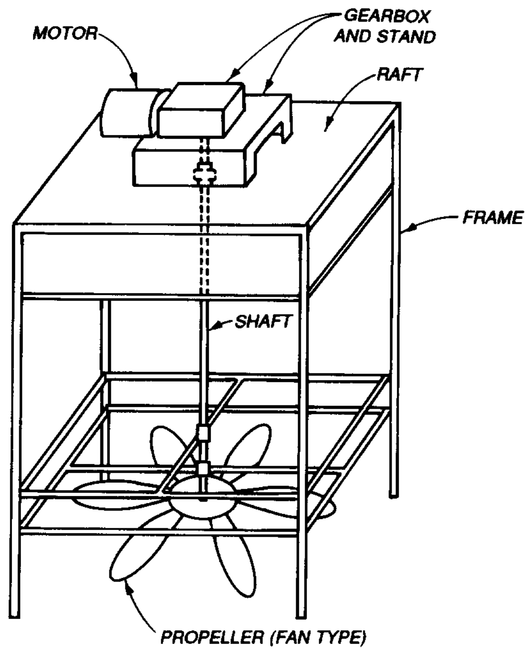


Figure B1. Axial flow pump (shown without optional shroud)

Technical Description

2. The raft shall be constructed of pressure-treated wood (approved by US Environmental Protection Agency for water use) or a steel hermetic container, with at least a 6.5-ft square deck. The raft shall be supported with sufficient flotation to give the pump a freeboard of about 18 in. above the waterline. The flotation material, if used, shall be gas and oil proof, and enclosed for protection from waterfowl. The frame shall be constructed of

metal and painted with high-performance epoxy paint. The electric motor shall be a 3-hp, 3-phase, 240-volt, TEFC (total enclosed fan cooled) motor. The motor shall be mounted directly on the gearbox. The right-angle gearbox shall have a 50:1 reduction and be rated for continuous operation. The shaft shall be made of 2-in.-diam, cold-rolled steel (about 8 ft long), and painted with a high-performance epoxy paint. The coupler that connects the gearbox output shaft to the propeller shaft can be either a steel sleeve type or a flexible, chain-type coupler. The propeller shall be six-bladed, 6 ft in diameter, with a variable pitch (e.g. Model 72R6xx from Aerovent, Inc., Piqua, OH). The propeller shall be suspended about 6 ft below the water surface and sufficiently supported with guide and thrust bearings to be stable under full speed (about 35 rpm). The pump will be used in a lake and subject to weather; therefore, the construction and all components shall be compatible with an adverse environment.

Table B1

Generalized Parts List

Part	Description
Frame	Metal, designed to stand on dry land as well as provide a stable support for the shaft and propeller while operating. The metal should be painted with a high-performance epoxy paint unless made of corrosion-resistant metal.
Flotation	Hermetic container or styrofoam (or equivalent) that is gas and oil resistant and enclosed for protection from waterfowl.
Motor	3-hp, 3-phase, 240-volt, weatherproof, continuous operation.
Gearbox	Right-angle drive (horizontal input, downward output), 5-hp input, weatherproof, continuous operation, 50:1 reduction, motor-mount flange and coupling.
Coupler	Steel sleeve or flexible, chain-type.
Shaft	2-in.-diam, about 8 ft long, cold-rolled steel, high-performance epoxy coating (painted).
Bearings	For 2-in.-diam shaft, submersible, with thrust bearings if needed.
Propeller	Fan-type, 6-ft-diam, six-bladed, adjustable pitch (e.g. Model 72R6xx from Aerovent, Inc., Piqua, OH). Shroud optional.

APPENDIX B

Calculated oxygen absorption in lake waters from air injection at Lake Elsinore

March 8, 2002

TO: David Ruhl
FROM: Arlo W. Fast
REGARDING: Potential oxygen contribution to Lake Elsinore's oxygen demands from air injection

During our meeting last month we discussed the potential amount of oxygen that could be dissolved in Lake Elsinore from the proposed air injection system. The main objective of this system is to reduce stratification and to redistribute DO from surface waters into deeper waters. DO in surface waters is mostly from photosynthetically produced oxygen, as well as from atmospheric recharge if DO is under-saturated. There is some DO added from the compressed air injection. I've calculated below what it might be.

Air Injection Rate: 4,000 SCFM
Air @ 1 atm. and 20ºC = 1.2047 g/l
Air = 21% oxygen

4,000 SCFM air = 300 lbs air or 63 lbs/min oxygen

During one day (1,440 min), 90,752 lbs (45 tons) of oxygen is injected.

The amount of oxygen dissolved in the lake relates to DO content of the water[12], air injection depth, bubble size, temperature, etc. With lake water at about 3 mg/l DO, we might expect from 10% to 20% of the oxygen in the compressed air to be dissolved in lake water. This yields:

10% = 9,075 lbs or 4.5 tons/day
20% = 18,150 lbs or 9 tons/day

As you can see, this is much less than we are talking about if the lake experiences a severe DO depletion. However, it does contribute to a positive DO balance and should not be dismissed.

[12] If the water is 100% saturated with DO, no oxygen is dissolved. If it is super-saturated, oxygen is lost to the atmosphere, while if it is under-saturated then oxygen is dissolved from the air bubbles into the lake water.

APPENDIX C

LOX Storage Tanks Literature

Standard Line Tankage

**A COMPLETE RANGE
OF STANDARD LINE TANKAGE
FOR CRYOGENIC LIQUIDS**

UNION CARBIDE CRYOGENIC PRODUCTS

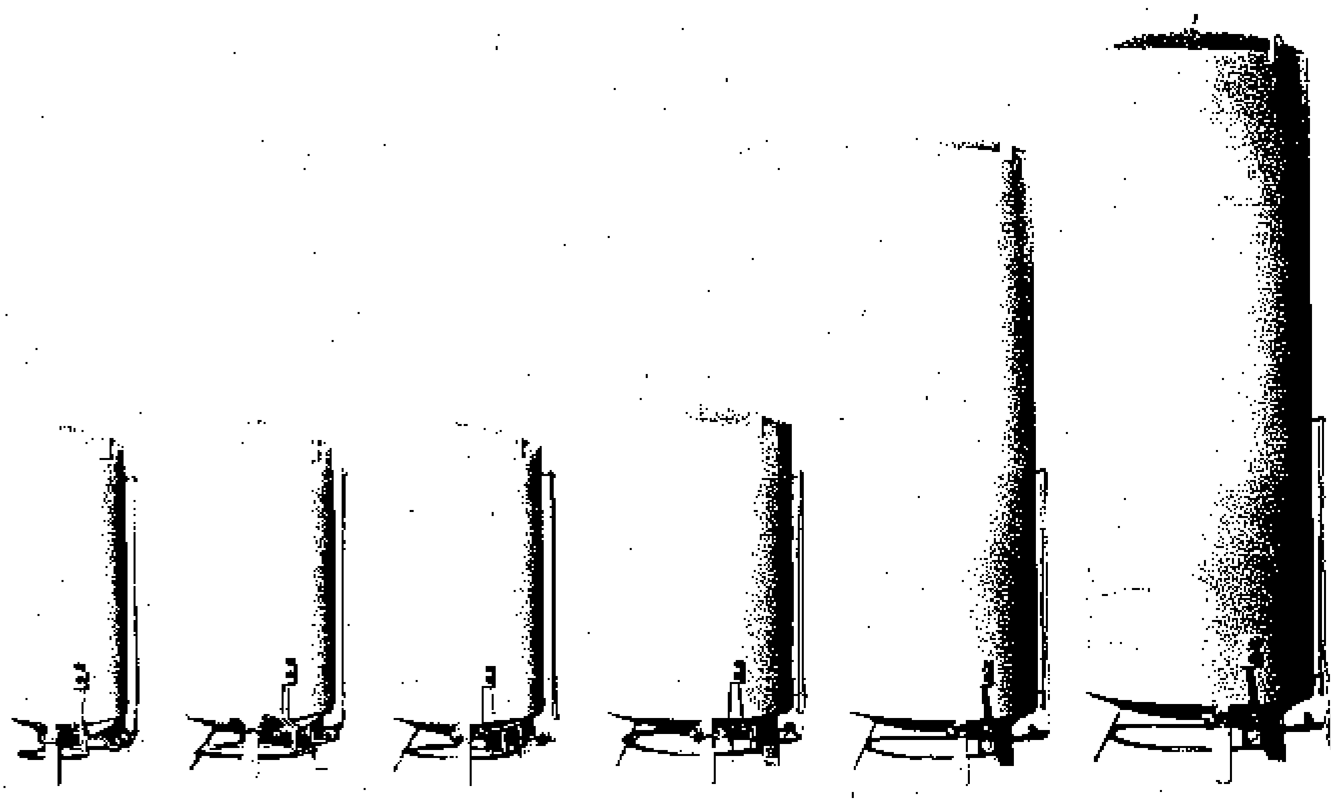
Union Carbide Corporation offers to industry a standard line of cryogenic customer stations specially designed to provide a flexible choice of storage and withdrawal capabilities for cryogenic fluids. Ranging in size from 500 to 11,000 gallon capacities, these customer stations can be used for either withdrawal of liquid product or the supply of medium pressure gas (250 psi maximum working pressure) through the use of vaporizers and control equipment. The unique flexibility of this tank line has been achieved by standardization of construction and by combining rugged construction with the economies of mass production. Identical control systems are used on all tanks except the TM/TL 11000.

An experienced engineering department coupled with expanded production facilities have enabled Union Carbide's Cryogenic Products Department to offer 100 combinations of optional accessory items for use with the Standard Tank Line. For example, a series of vaporizers are available for gas flows ranging from 2,000 to 100,000 cfh.

These units are all of vertical design. Thus, they take up less space, require considerably smaller installation pads, and need less fencing than the horizontal types.

The control system for these Standard Tank Line units has been designed and tested to provide the utmost reliability. Standardization and positioning of the controls have resulted in a minimum amount of piping and joints. The pressure building coil, control components, and safety devices are located at the bottom of the tank. Also, the filling flange and fill valves are conveniently located near the bottom of the tank. The result of this arrangement is to make all parts readily accessible for operation and maintenance.

All controls are of the non-electrical type. Therefore, no on-site power supply is required for industrial installations, except when an alarm is required for hospital or similar use.



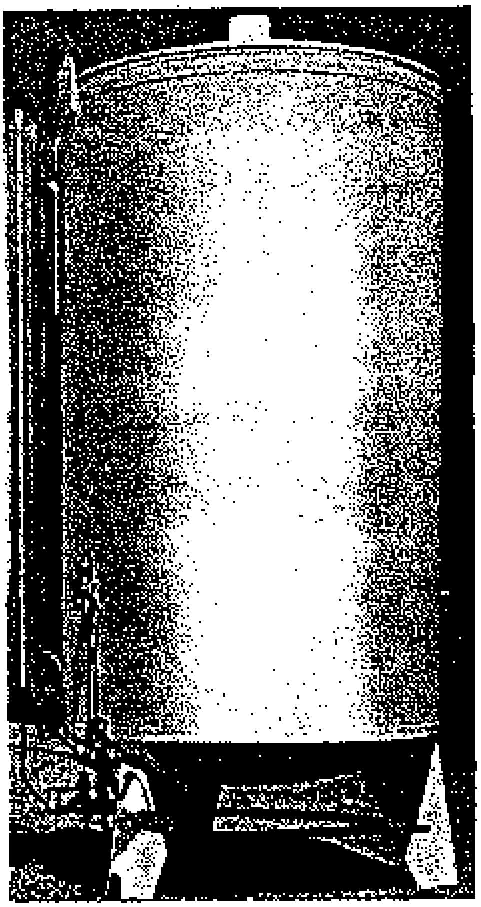
TM-500 TM-900 TM/TL-1500 TM/TL-3000 TM/TL-6000 TM/TL-11000

STANDARD LINE TANK SPECIFICATIONS

TL—"tank low pressure" (70 to 125 psi)
TM—"tank medium pressure" (250 psi)

	TM-600	TM-900	TM-1500	TL-1500	TM-3000	TL-3000	TM-6000	TL-6000	TM-11000	TL-11000
Height	15'6"	15'9"	15'9"	15'9"	16'	15'11"	25'9"	25'9"	31'7"	31'7"
Width	60"	78"	78"	78"	96"	96"	96"	96"	122"	122"
Warm Water Volume, Gallons	568	956	1611	1615	3117	3133	6022	6036	11,290	11,290
Net Capacity, Gallons	530	904	1517	1523	3000	3016	5889	5903	11,000	11,000
Net % Per Day Evaporation Loss	0.5	0.4	0.4	0.4	0.5	0.5	0.3	0.3	0.25	0.25
Working Pressure, psig	250	250	250	125	250	83	250	77	250	65
Weight Empty, Pounds	5,450	9,700	10,300	8,940	15,500	11,400	28,600	20,700	47,000	34,300

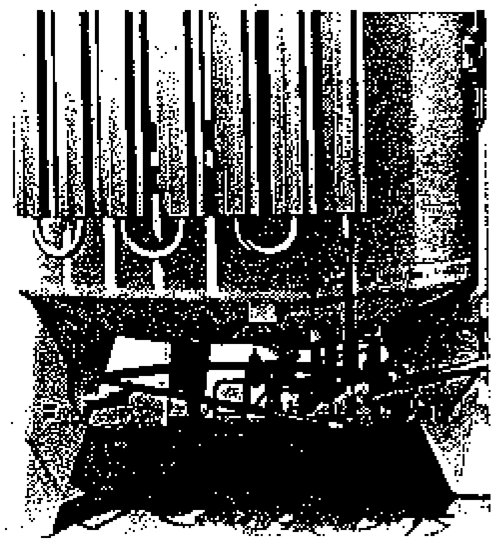
What makes the STANDARD LINE so different?



Standardized Construction and Components

A high degree of standardization has resulted in many new benefits, among these the ability to equip five of the six models with identical controls and vaporizers. The TM-500 through the TM-6000 all have the same controls. This means the same spare parts kit can be used to service all units except the TM-11000. Hence, the spare parts inventory can be kept to a minimum where a variety of sizes are used. Even on the TM/TL-11000, all parts except five are the same as on the other models, and then those differ in size only. Functionally, all parts are the same.

Not only is maintenance simplified because of interchangeable components, but standardization has reduced the tank operating procedures to a single program. Mass production of the Standard Tank Line has produced cost savings that are reflected in the competitive prices of these units.

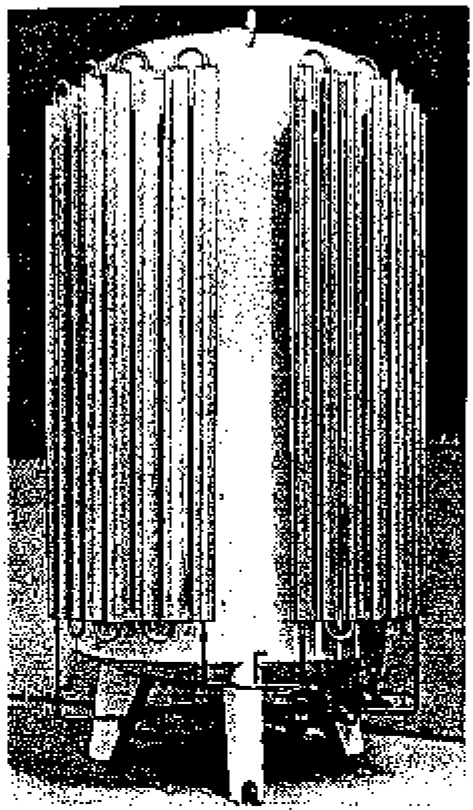


Simplified Control System

Innovation has made possible a significant reduction in the number of pipes, valves, and connections previously necessary for safe, reliable operation. The number of threaded joints has been kept to a minimum thereby increasing the reliability of the system. Also, by positioning the control components below the tanks, the need for an external control cabinet has been eliminated.

Fewer components simplify maintenance, allow parts to be more easily installed and reduce the number of points where the need for maintenance might occur. The reduction in the number of components has also enabled the controls to be located for maximum convenience during operation. The new control systems reduce and even eliminate the need for extensive driver instruction in the filling operation.

Most controls and accessories are fitted to the containers at the factory, reducing field assembly and installation costs and allowing for quicker handling of orders.



Vaporizers

TM's 500, 900, and 1500 can be shipped with an extruded aluminum finned-tube 2000 cfh atmospheric tank mounted vaporizer. A second 2,000 cfh vaporizer is available as a factory installed option on TM's 900 and 1500. These vaporizers could also be added in the field at a later date if required.

The larger units, TM's 3000 and 6000, are delivered with the provisions for attaching one or two 2000 cfh vaporizers. The vaporizers are shipped separately and installed at the site in a few minutes.

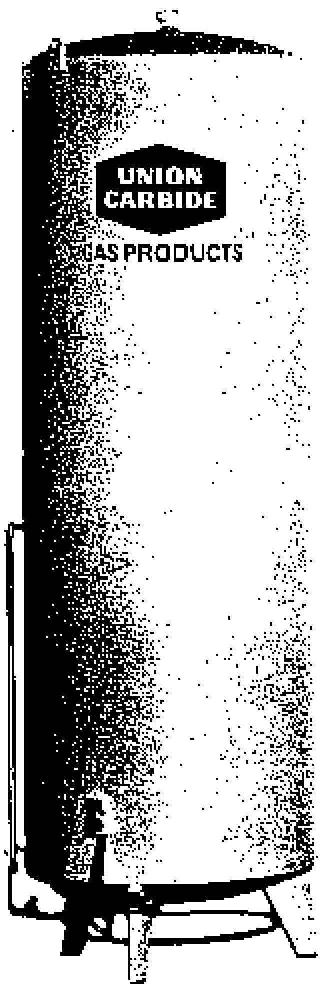
No attachment lugs for tank mounting of vaporizers are provided on the TM-11000. For the TM-11000, as well as other tanks requiring higher capacity vaporizers, single or dual ground-mounted atmospheric vaporizers (capacities of 5,000 or 10,000 cfh), and pressure-building steam vaporizers (with capacities up to 100,000 cfh) are available.

Vacuum Quality Construction and Components

Standard tank line units are of proven construction and are the culmination of Union Carbide's 30 years experience in the design and manufacture of cryogenic storage and distribution equipment.

The units are rigidly built. The inner container is fabricated of nine percent nickel steel. All seams of the inner container are short arc welded and 100% x-rayed to insure meeting ASME code requirements. The outer container is constructed of high strength carbon steel. The seams here are also welded to insure a leak-proof vacuum space. The area between the inner and outer containers is filled with a high quality evacuated powder insulation pumped to a high vacuum. The vacuum is factory sealed and each tank is equipped with a factory installed adsorbent trap which aids in maintaining the vacuum.

TM-6000



The TM-6000 is unmatched as a reliable supply unit for industrial withdrawal of cryogenic fluid — either as a liquid or as a gas. Its modern, clean appearance identifies one of the most dependable sources of high-purity oxygen, nitrogen, or argon available to industry today.

Tank Capacity .... 5,889 gallons
Maximum Working Pressure .... 250 psig
Withdrawal Connection .... 5/8-in. ODT
Empty Tank Weight .... 28,600 pounds

Optional atmospheric, steam, and electric vaporizers are available to suit any gas flow requirement.

CUSTOMER REQUIREMENTS

Proposed for: ______________________

Fluid Requirements ______________________

Projected Monthly Volume ______________________

Max. Delivery Pressure Required ______________________

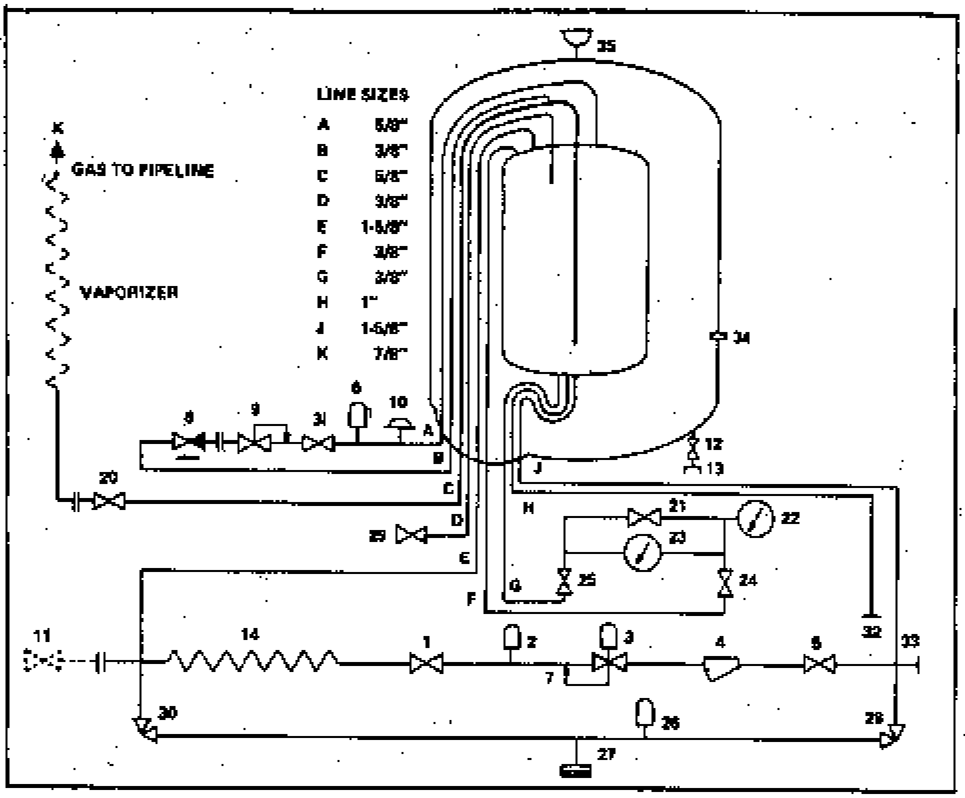
Max. Flow Rate Required ______________________

	☐ OXYGEN	☐ NITROGEN	☐ ARGON
Tank Contents	677,700 cubic feet*	546,100 cubic feet*	662,000 cubic feet*
Weight of Liquid	55,770 pounds	39,540 pounds	68,350 pounds
Average Volume per Fill (75% of Capacity)	508,300 cubic feet*	411,100 cubic feet*	496,500 cubic feet*
Reserve Supply at Time of Average Fill	169,400 cubic feet*	137,000 cubic feet*	165,500 cubic feet*

*NTP (70 F, 14.7 psi absolute pressure)

UNION CARBIDE

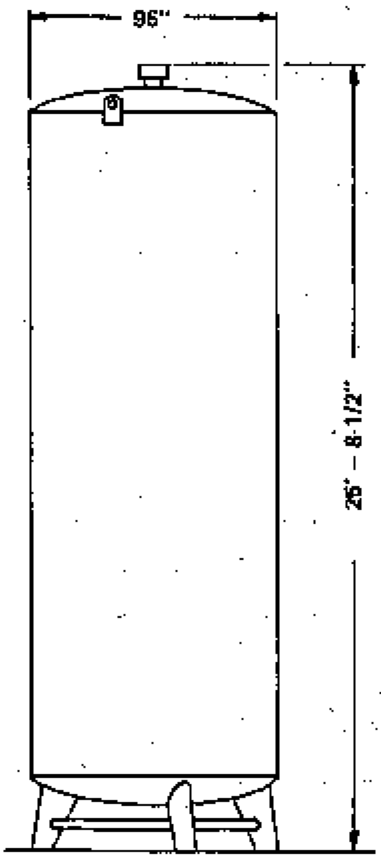
LINDE DIVISION

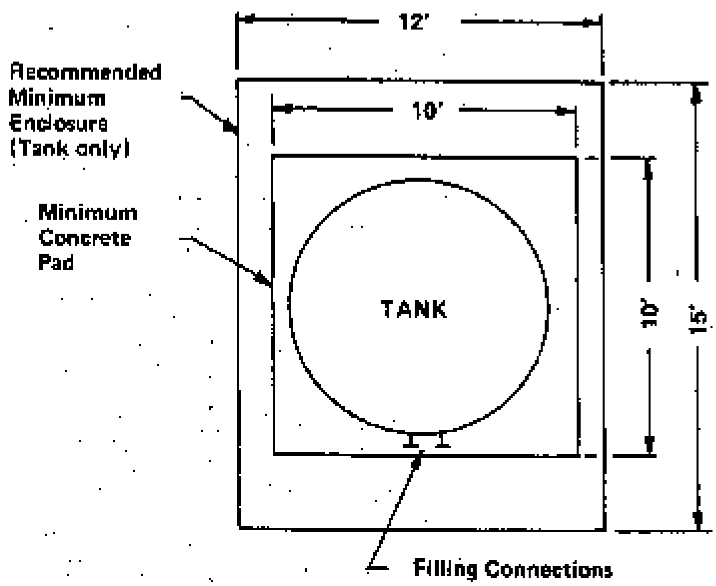


LEGEND

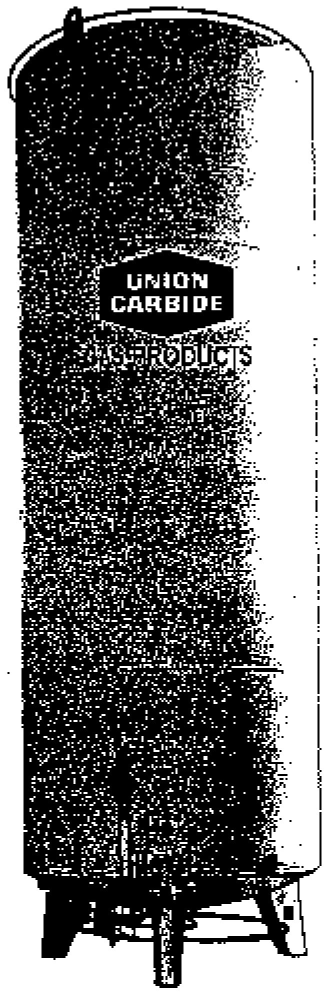
1 ISOLATION VALVE
2 LINE RELIEF VALVE, 400 PSI
3 REGULATOR RELIEF VALVE, 400 PSI
4 STRAINER
5 PRESSURE BUILDING VALVE
6 SAFETY VALVE (ASME), 250 PSI
7 PRESSURE BUILDING REGULATOR
8 ECONOMIZER LINE CHECK VALVE
9 ECONOMIZER RELIEF VALVE
10 BURSTING DISK, 330-367 PSI
11 BLOWDOWN VALVE
12 VACUUM GAUGE TUBE VALVE
13 VACUUM GAUGE TUBE
14 PRESSURE BUILDING COIL
20 LIQUID WITHDRAWAL VALVE
21 BYPASS VALVE
22 PRESSURE GAUGE
23 CONTENTS GAUGE
24 ISOLATION VALVE
25 ISOLATION VALVE
26 RELIEF VALVE, 400 PSI
27 FILL CONNECTION
28 BOTTOM (LIQUID SIDE) FILL VALVE
29 FULL TRYCOCK
30 TOP (GAS SIDE) FILL VALVE
31 ISOLATION VALVE
32 LIQUID WITHDRAWAL CONNECTION (PLUGGED)
33 LIQUID WITHDRAWAL CONNECTION (PLUGGED)
34 EVACUATION CONNECTION
35 CASING BURSTING DISK

FLOW DIAGRAM — TM-6000





TM - 9000



The TM-9000 is unmatched as a reliable supply unit for industrial withdrawal of cryogenic fluid — either as a liquid or as a gas. Its modern, clean appearance identifies one of the most dependable sources of high-purity oxygen, nitrogen, or argon available to industry today.

Tank Capacity . . . . 8,900 gallons
Maximum Working Pressure . . . . 250 psig
Withdrawal Connection . . . . 5/8-in. ODT
Empty Tank Weight (Est.) . . . . 37,000 pounds

Optional atmospheric, steam, and electric vaporizers are available to suit any gas flow requirement.

CUSTOMER REQUIREMENTS

Proposed for: ______________________________

Fluid Requirements ______________________________

Projected Monthly Volume ______________________________

Max. Delivery Pressure Required ______________________________

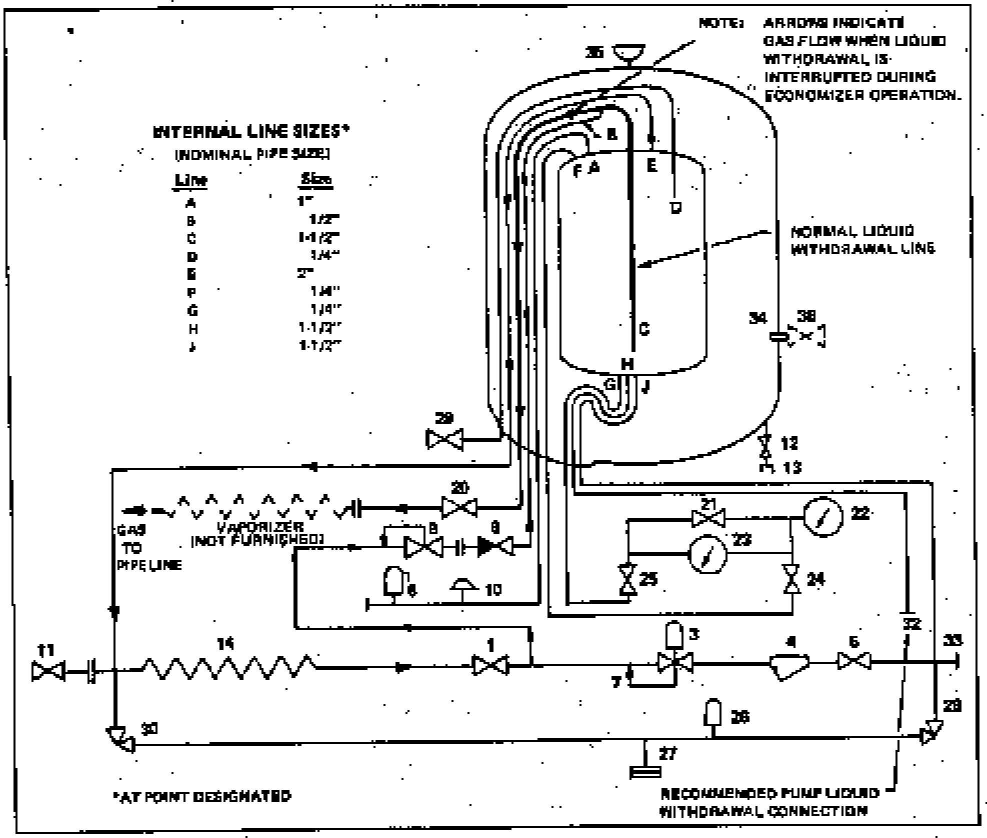
Max. Flow Rate Required ______________________________

	☐ OXYGEN	☐ NITROGEN	☐ ARGON
Tank Contents	1,023,910 cubic feet*	828,000 cubic feet*	1,001,830 cubic feet*
Weight of Liquid	84,760 pounds	60,000 pounds	103,590 pounds
Average Volume per Fill (75% of Capacity)	767,933 cubic feet*	621,000 cubic feet*	751,373 cubic feet*
Reserve Supply at Time of Average Fill	255,977 cubic feet*	207,000 cubic feet*	250,457 cubic feet*

*NTP (70 F, 14.7 psi absolute pressure)

UNION CARBIDE

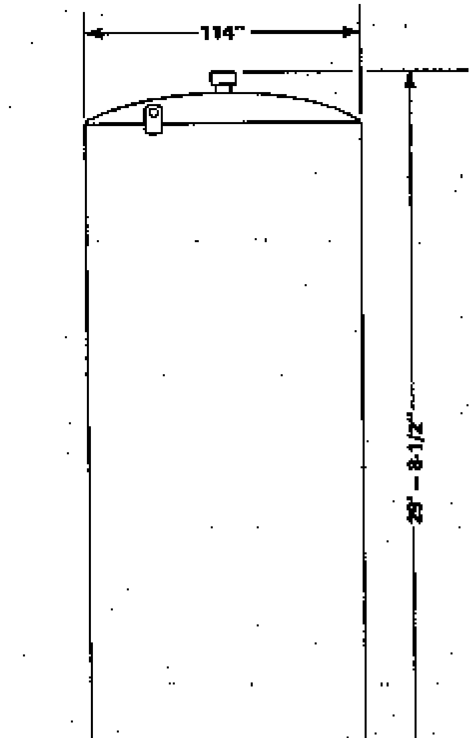
LINDE DIVISIO

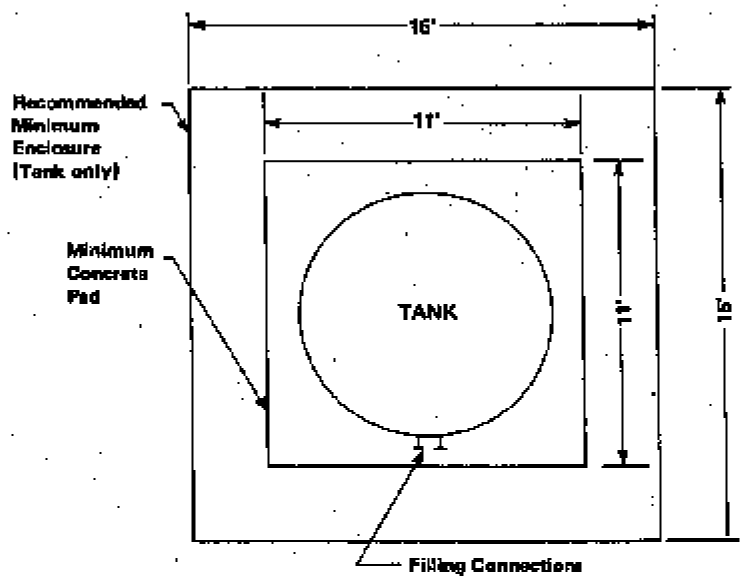


LEGEND

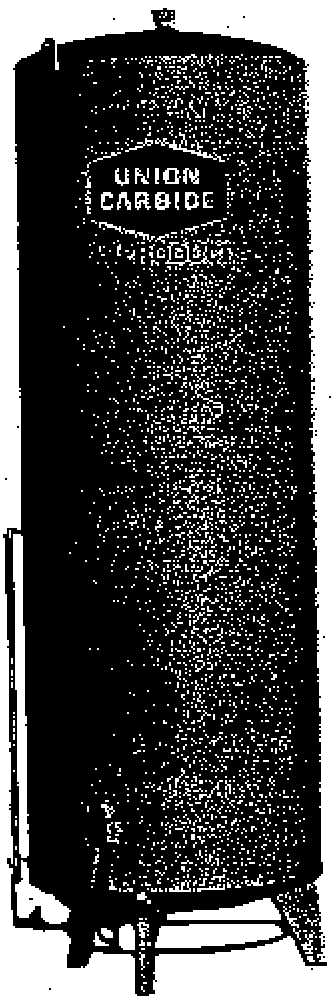
1 ISOLATION VALVE
3 REGULATOR RELIEF VALVE, 400 PSI
4 STRAINER
5 PRESSURE BUILDING VALVE
6 SAFETY VALVE (ASME), 250 PSI
7 PRESSURE BUILDING REGULATOR
8 ECONOMIZER LINE CHECK VALVE
9 ECONOMIZER RELIEF VALVE
10 BURSTING DISK
11 BLOWDOWN VALVE
12 VACUUM GAUGE TUBE VALVE
13 VACUUM GAUGE TUBE
14 PRESSURE BUILDING COIL
20 LIQUID WITHDRAWAL VALVE
21 BYPASS VALVE
22 PRESSURE GAUGE
23 CONTENTS GAUGE
24 ISOLATION VALVE
25 ISOLATION VALVE
26 RELIEF VALVE, 400 PSI
27 FILL CONNECTION
28 BOTTOM (LIQUID SIDE) FILL VALVE
29 FULL TRYCOCK
30 TOP (GAS SIDE) FILL VALVE
32 HIGH WITHDRAWAL RATE LIQUID CONNECTION (PLUGGED)
33 AUXILIARY LIQUID WITHDRAWAL CONNECTION (PLUGGED)
34 EVACUATION CONNECTION
35 CASING BURSTING DISK
36 VACUUM VALVE

FLOW DIAGRAM — TM-9000





TM-11000



The TM-11000 — the largest of LINDE's Standard Line Tankage — is unmatched as a reliable supply unit for industrial withdrawal of cryogenic fluid — either as a liquid or as a gas. Its modern, clean appearance identifies one of the most dependable sources of high-purity oxygen, nitrogen, or argon available to industry today.

Tank Capacity .... 11,080 gallons
Maximum Working Pressure .... 250 psig
Withdrawal Connection .... 1-1/2-in. ODT
Empty Tank Weight .... 47,000 pounds

Optional atmospheric, steam, and electric vaporizers are available to suit any gas flow requirement.

CUSTOMER REQUIREMENTS

Proposed for: ____________________

Fluid Requirements ____________________

Projected Monthly Volume ____________________

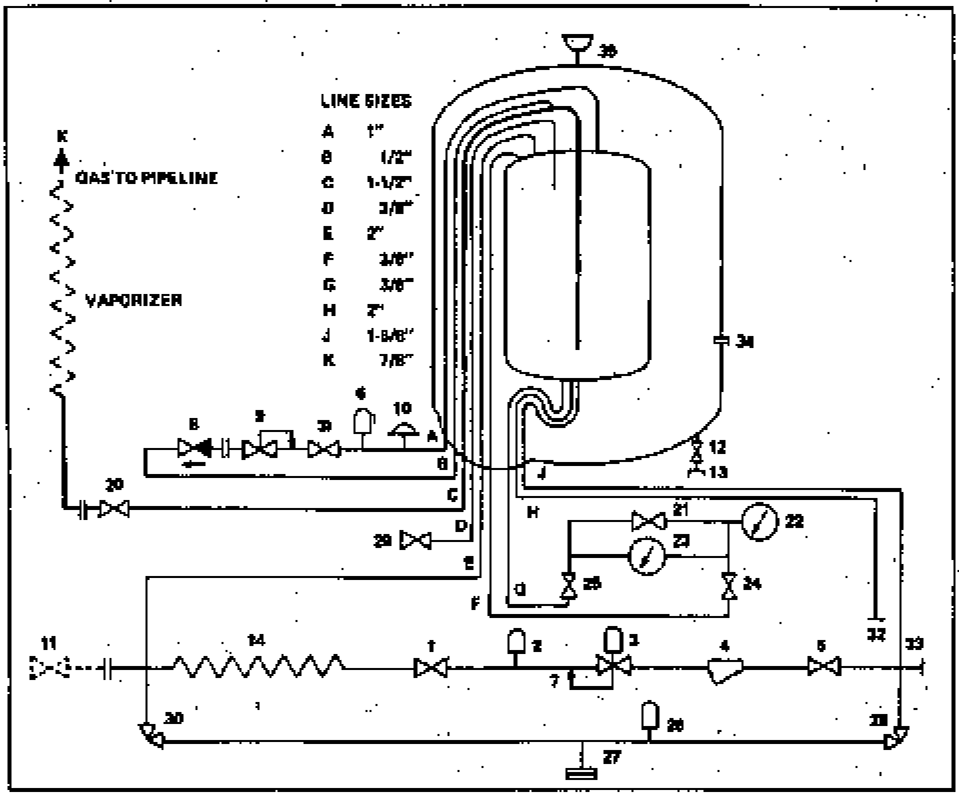
Max. Delivery Pressure Required ____________________

Max. Flow Rate Required ____________________

	☐ OXYGEN	☐ NITROGEN	☐ ARGON
Tank Contents	1,266,000 cubic feet*	1,024,000 cubic feet*	1,237,000 cubic feet*
Weight of Liquid	105,120 pounds	74,360 pounds	128,630 pounds
Average Volume per Fill (75% of Capacity)	949,500 cubic feet*	768,000 cubic feet*	927,700 cubic feet*
Reserve Supply at Time of Average Fill	316,500 cubic feet*	256,000 cubic feet*	309,300 cubic feet*

*NTP (70 F, 14.7 psi absolute pressure)

UNION CARBIDE



FLOW DIAGRAM – TM-11000

LEGEND

1 ISOLATION VALVE
2 LINE RELIEF VALVE, 400 PSI
3 REGULATOR RELIEF VALVE, 400 PSI
4 STRAINER
5 PRESSURE BUILDING VALVE
6 SAFETY VALVE (ASME), 250 PSI
7 PRESSURE BUILDING REGULATOR
8 ECONOMIZER LINE CHECK VALVE
9 ECONOMIZER RELIEF VALVE
10 BURSTING DISK, 300-387 PSI
11 BLOWDOWN VALVE
12 VACUUM GAUGE TUBE VALVE
13 VACUUM GAUGE TUBE
14 PRESSURE BUILDING COIL
20 LIQUID WITHDRAWAL VALVE
21 BYPASS VALVE
22 PRESSURE GAUGE
23 CONTENTS GAUGE
24 ISOLATION VALVE
25 ISOLATION VALVE
26 RELIEF VALVE, 400 PSI
27 FILL CONNECTION
28 BOTTOM (LIQUID SIDE) FILL VALVE
29 FULL TRYCOCK
30 TOP (GAS SIDE) FILL VALVE
31 ISOLATION VALVE
32 LIQUID WITHDRAWAL CONNECTION (PLUGGED)
33 LIQUID WITHDRAWAL CONNECTION (PLUGGED)
34 EVACUATION CONNECTION
35 CASING BURSTING DISK