UPGRADING LAGOONS

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CHAPTER I

LAGOONS IN WASTE TREATMENT

Lagoons are one of the most commonly employed secondary waste treatment systems. In 1968, treatment systems in the general category of stabilization ponds constituted 34.7 percent of the 9,951 secondary treatment systems operating in the United States. These "stabilization ponds" served 7.1 percent of the 85,600,000 people served by secondary treatment plants. These stabilization ponds usually serve small communities; 90 percent were in communities with 10,000 persons or less.[1]

In 1968, Region VIII of the EPA (Montana, Wyoming, Utah, Colorado, North and South Dakota) contained 756 secondary treatment plants, 74 percent of which were stabilization ponds. These ponds served 22 percent of the people that were serviced by secondary treatment plants.[1]

Types of Lagoons

Waste treatment lagoons can be conveniently divided into five general classes according to the types of biological transformations taking place in the lagoon.[a] Two of those types, high rate aerobic ponds and facultative ponds, are also called oxidation ponds.

High Rate Aerobic Ponds. In these ponds, algae production is maximized by allowing maximum light penetration in a shallow pond. These ponds are generally only 12 to 18 inches in depth and are intermittently mixed. The main biological processes are aerobic bacterial oxidation and algal photosynthesis. Organic loadings range from 60 to 200 lbs BOD_5/acre/day. Usually 80-95 percent of the waste organic matter is converted to algae.

Facultative Ponds. Perhaps the most numerous of the pond systems, facultative ponds are deeper than high rate aerobic ponds, having depths of 3 to 8 feet. The greater depth allows two zones to develop, an aerobic surface zone and an anaerobic bottom layer. Oxygen for aerobic stabilization in the surface layer is provided by photosynthesis and surface reaeration while sludge in the bottom layer is anaerobically digested. Loadings generally range from 15 to 80 lbs BOD_5/acre/day, and BOD_5 removal from 70 to 95 percent, depending on the concentration of algae in the effluent. BOD_5 removals as high as 99 percent have been obtained.

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[a] For a complete review of the technology and art of this form of treatment, see 2 and 3.

Anaerobic Ponds. Organic loads are so high in these ponds that anaerobic conditions prevail throughout. BOD_5 loadings are generally in the range of 200 to 1000 lbs BOD_5/acre/day, and BOD_5 removals are limited to about 50 to 80 percent. Anaerobic ponds are usually followed by aerobic or facultative ponds to reduce the BOD_5 in the effluent.

Maturation or Tertiary Ponds. This type of pond is generally used for polishing effluents from conventional secondary processes such as trickling filtration or activated sludge. Settleable solids, BOD_5, fecal organisms, and ammonia are reduced. Algae and surface aeration provide the oxygen for stabilization. BOD_5 loadings are generally less than 15 lbs BOD_5/acre/day but may be higher.

Aerated Lagoons. Aerated lagoons derive most of their oxygen for aerobic stabilization by mechanical means, either air diffusion or mechanical aeration. Photosynthetic oxygen generation usually does not play a large role in the process. Up to 90 to 95 percent BOD_5 removals are obtainable depending on detention time and the degree of solids removal.

Aerated lagoon applications are a relatively new innovation in environmental engineering technology. The Missouri Basin Health Council reports over 100 aerated lagoon installations[3] in the United States (compared to over three thousand stabilization ponds in 1968[1]).

Operating Problems

With increasingly stringent effluent requirements, waste treatment lagoons, like any other waste treatment process, may require modification to meet all objectives. The problems that occur with individual ponds, however, may not be common to all.

Organic Matter in Effluents. An algal-bacteria symbiosis operates in both aerobic and facultative ponds. Bacteria degrade organic matter according to the following simplified transformation:

$$\underset{\text{(organics)}}{CH_20 + 0_2} \xrightarrow{\text{bacteria}} C0_2 + H_2O \qquad (1)$$

Algae, in turn, reuse the carbon (as carbon dioxide), to form algal biomass:

$$CO_2 + 2H_2O + \text{energy} \xrightarrow{\text{algae}} \underset{\text{(algae)}}{CH_2O} + O_2 + H_2O \qquad (2)$$

While these equations oversimplify the transformations, they show the recycling of carbon in ponds. Unless the algae are removed, or the carbon is removed through methane fermentation in an anaerobic sludge layer, little organic reduction may occur.[4]

The fate of algae discharged to receiving waters has received relatively little attention. This may be because severe problems have not developed in most instances. Two studies, however, have shown for two differing aquatic environments that the algae did constitute a BOD load on the receiving waters and decreased the dissolved oxygen levels.[5,6] In these cases, the algae from the pond effluent were in an unfavorable environment for either their maintenance or growth, and they decayed (as in equation 1 above).

Aerated lagoon effluents, while not containing large amounts of algae, may contain biological solids which result from the conversion of a portion of the BOD_5 to biological solids. One aerated lagoon application achieved only 70 percent BOD_5 removal; the insertion of a final clarifier in the process allowed 90 percent BOD_5 removal because of solids removal.[7]

Odors. That lagoons may occasionally emit odors is shown by the very common state requirements concerning lagoon location. These require that lagoons should be located as far from existing or future residential or commercial development as is practical or reasonable. Anaerobic ponds particularly tend to have odor problems due to hydrogen sulfide formation although some methods have been developed for odor control.

Noxious Vegetative Growths. Without maintenance and good design, aquatic growths may develop in ponds. Deeper ponds (greater than 3 feet) will discourage rooted growths, and proper levee maintenance can handle shoreline problems. If not suitably controlled, noxious plants can choke off hydraulic operation and create large accumulations of floatable debris. The debris usually becomes septic and creates odors and conditions detrimental to photosynthetic activity.

Seasonal Performance Variations. In most locales of the United States, there are seasonal changes in both available light and temperature. Typically, in the winter algae activity diminishes. Biological activity may also slow; methane fermentation in facultative ponds may practically cease.[4] Thus, in winter BOD_5 removals may be low. In Michigan, no discharge is permitted until the spring thaw when increased biological activity causes a lower effluent BOD_5.[8]

Despite operating problems, which certainly have not occurred with every lagoon application, lagoons have been providing economical treatment at thousands of locations for decades. Low capital cost, simplicity of operation and low operation and maintenance costs have favored lagoon treatment. However, considering both more stringent water quality criteria and environmental constraints posed by encroaching suburbanization, many lagoons will have to be upgraded in both treatment efficiency and their mode of operation.

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CHAPTER II

TECHNIQUES FOR UPGRADING LAGOONS

Pond Efficiency vs. Pond Loading

Pond Recirculation and Configuration

Feed and Withdrawal

Pond Transfer Inlets and Outlets

Pond Dike Construction

Supplemental Aeration and Mixing

Algae Removal

CHAPTER II

TECHNIQUES FOR UPGRADING LAGOONS

Many of the techniques available for upgrading lagoons treating primary and secondary effluents have already been incorporated in designs at one or more locations--often in the original construction and not as a modification. A well-designed pond will incorporate physical features which minimize upsets, maintenance and nuisances, and maximize operational flexibility, stability and BOD removal. Physical design features which should be considered include configuration, recirculation, feed and withdrawal variations, pond transfer inlets and outlets, dike construction, supplementation of oxidation capacity, and algae removal. These will be discussed in this chapter.

Most of Brown and Caldwell's experience in lagoons concerns those treating primary or secondary effluents. This discussion will center on those applications. Many of the waste treatment lagoons in the United States, particularly in the Midwest, treat raw sewage. One of the ways to upgrade such lagoons is to add primary or primary plus secondary treatment ahead of the ponds.

Pond Efficiency vs. Pond Loading

It is fairly well established that pond process performance is affected by both areal BOD loading[a] and detention time.[6,7] Typical data for canning wastes are shown in Fig. 1. A similar, but not necessarily identical, empirical relationship would apply to domestic wastes. Fig. 1 shows that pond performance can be improved by three techniques:

1. Increasing pond detention time. Increased detention time will increase BOD removal and can be accomplished by deepening the pond. The most probable cause of improvement would be increased algae sedimentation.

2. Decreasing areal BOD loading. Decreased areal BOD loading will increase the BOD removal by decreasing the carbon to be processed (and recycled to algae). This can be accomplished by pretreatment; e.g., placing a primary sedimentation unit before the pond in a system formerly using only raw sewage ponds.

3. Decreasing areal BOD loading and increase detention time. This can be done by increasing the number of ponds in the system (e.g., case 2 in Chapter III).

Pond Recirculation and Configuration

Pond recirculation involves interpond and intrapond recirculation as opposed to mechanical mixing in the pond cell. The effluent(s) from pond cell(s) are mixed

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[a] Except for aerated lagoons, where areal BOD loading is not an appropriate design criterion.

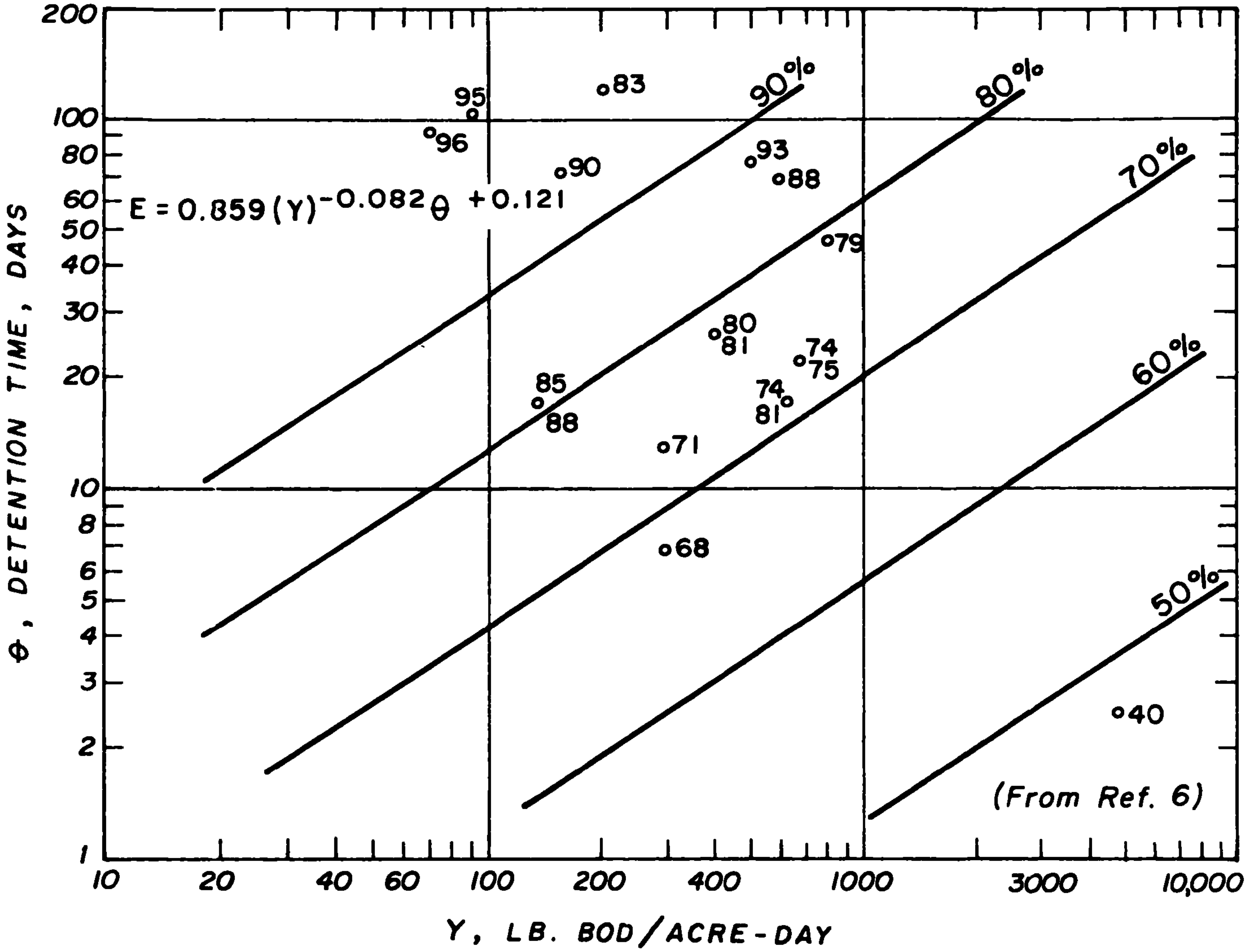


Fig. 1 BOD Removal Relationship for Ponds Treating Cannery Wastes.

with the influent to the cell. In intrapond recirculation, effluent from a single cell is returned to the influent to that cell. In interpond recirculation, effluent from another pond is returned and mixed with influent to the pond (Fig. 2).

Both methods return active algal cells to the feed area to provide photosynthetic oxygen for satisfaction of the organic load. Intrapond recirculation allows the pond to gain some of the advantages that a completely mixed environment would provide if it were possible in a pond. It helps prevent odors and anaerobic conditions in the feed zone of the pond.

Both interpond and intrapond recirculation can affect stratification in ponds and thus gain some benefits ascribed to pond mixing which is discussed later. Pond recirculation is generally not as efficient as mechanical systems in mixing facultative ponds. Both pond mixing and pond recirculation are incorporated in the Sunnyvale case example (Chapter III).

Three common types of interpond recirculation systems (series, parallel, and parallel-series) are shown in Fig. 2. Others have been suggested but seldom used.

One objective of recirculation in the series arrangement is to decrease the organic loading in the first cell of the series. While the loading per unit surface is not reduced by this configuration, the retention time of the liquid <u>is</u> reduced. The method attempts to flush the influent through the pond faster than it would travel without recirculation. The hydraulic retention time of the influent and recycled liquid in the first, most heavily loaded pond in the series system is:

$$T = \frac{V}{(1 + r)F}, \qquad (1)$$

where V is the volume of pond cell, F is the influent flow rate, r or R/F is the recycle ratio, and R is the recycle flow rate.

Another advantage of recirculation in the series configuration is that the BOD in the mixture entering the pond is reduced, and is given by the expression:

$$S_m = \frac{S_{in}}{1+r} + \left(\frac{r}{1+r}\right) S_3 \qquad (2)$$

where S_m is the BOD of the mixture, S_3 is the effluent BOD from the third cell and S_{in} is the influent BOD. Thus, S_m would be only 20 percent of S_{in} with a 4:1 recycle ratio, as S_3 would be negligible in almost all cases. Thus, the application of organic load in the pond is spread more evenly throughout the ponds, and organic loading and odor generation near the feed points are less. Recirculation in the series mode has been used to reduce odors in those cases where the first pond is anaerobic.[3]

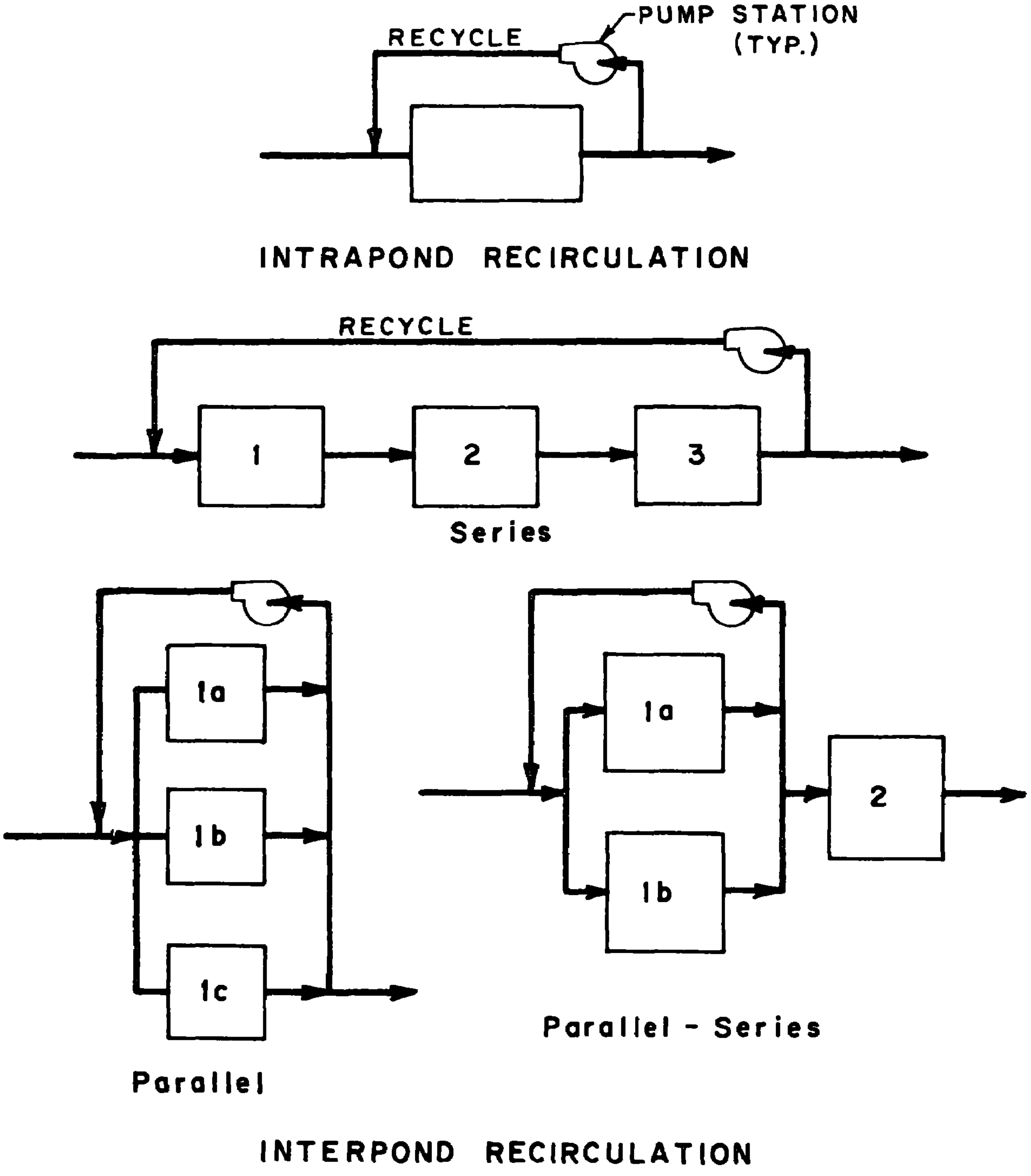


Fig. 2 Common Pond Configurations and Recirculation Systems.

The parallel configuration more effectively reduces pond loadings than does the series configuration because the mixture of influent is spread evenly across all ponds instead of the first pond in a series. Recirculation has the same benefits in both configurations.

For example, consider three ponds, either in series or parallel. In the parallel configuration, the surface loading (lbs BOD_5/acre/day) on the three ponds is one-third that of the first pond in the series configuration. The parallel configuration, therefore, is less likely to produce odors than the series configuration.

Recirculation is usually accomplished with high volume, low head, propeller pumps. Fig. 3 presents a simplified cross-section of such an installation. In this design, the cost and maintenance problems associated with large discharge flap gates are eliminated by the siphon discharge. An auxiliary pump with an air eductor maintains the siphon. Siphon breaks are provided to insure positive backflow protection.

Pumping stations of this type can be designed to maintain full capacity with minimal increase in horsepower even when the inlet and discharge surface levels fluctuate over a 3 to 4-foot range. Multiple and/or variable speed pumps are used to adjust the recirculation rate to seasonal load changes.

Pond configuration should allow full use of the wetted pond area. Transfer inlets and outlets should be located to eliminate dead spots and short-circuiting which may be detrimental to photosynthetic processes. Wind directions should be studied, and transfer outlets located to prevent dead pockets where scum will tend to accumulate. Pond size need not be limited, as long as proper distribution is maintained.

Feed and Withdrawal

There is a near unanimity of opinion in the literature that ponds should be fed by a single pipe, usually towards the center of the pond. This design should be used for raw sewage treatment by ponds. We have found that with primary or secondary effluent, a single point of entry into a pond tends to overload the pond in the feed zone, allowing odors to develop. Brown and Caldwell often employs a multiple entry and single exit approach to evenly distribute the organic load throughout the pond cell (Fig. 4). One form of multiple inlet, used for ponds as large as 20 acres, uses inlet head loss to induce internal pond circulation and initial mixing. The inlet pipe, laid on the pond bottom, has multiple ports or nozzles all pointing in one direction and at a slight angle above the horizontal. Port head loss is designed for about one foot at average flow, resulting in a velocity of 8 feet per second. This induces sufficient mass pond movement to permit the pond outlet to be located near the inlet. A second outlet, with low head loss and controlled by an overflow weir, accommodates peak wet weather flow.

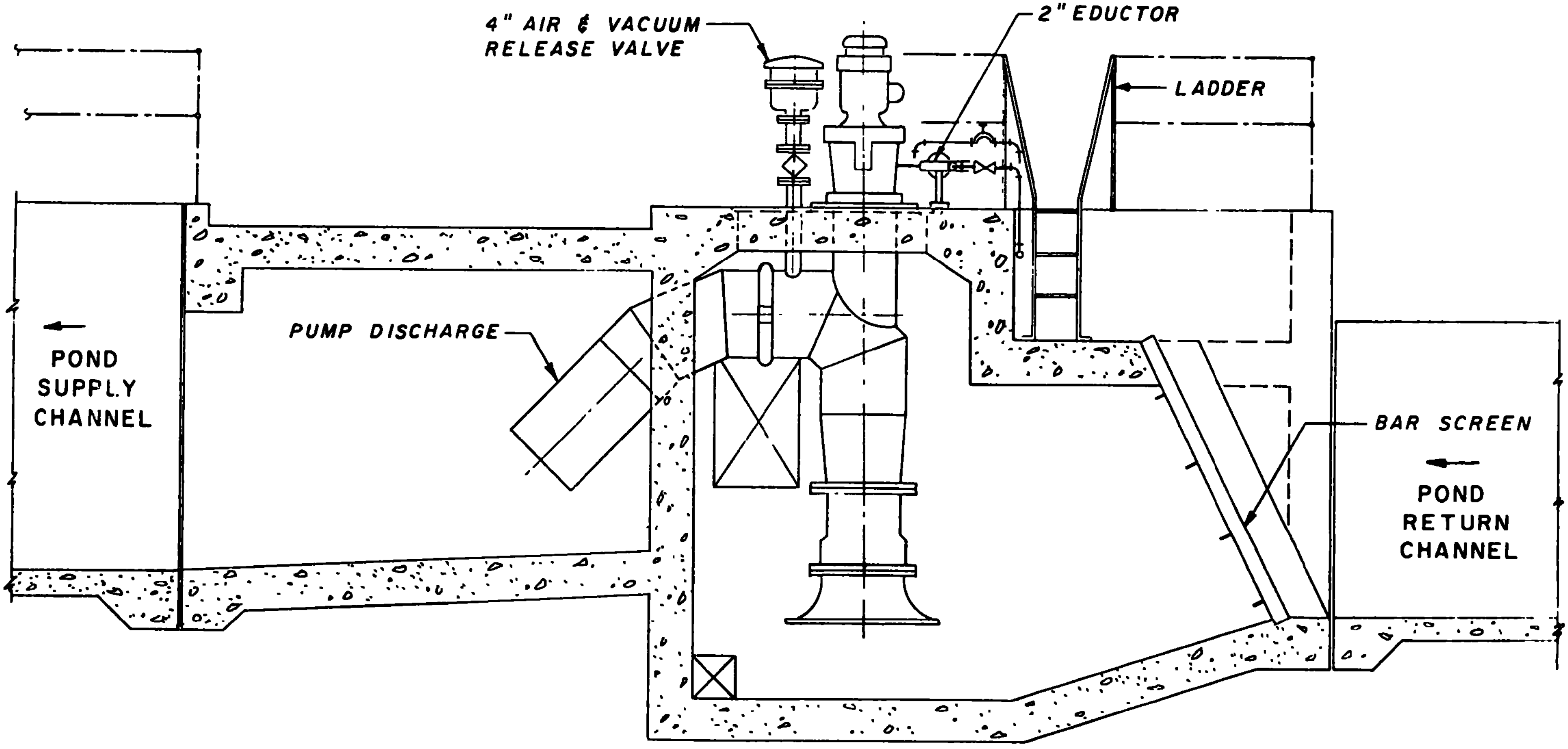
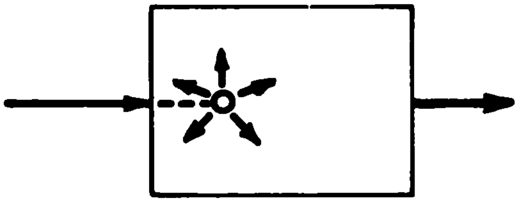
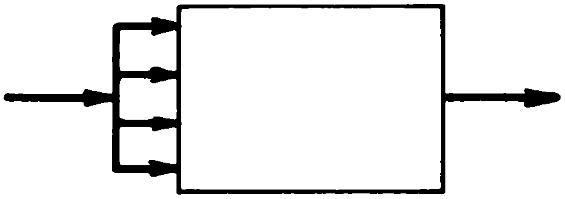


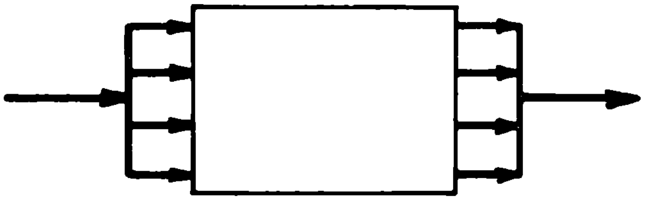
Fig. 3 Cross-section of a Typical Recirculation Pumping Station.



SINGLE ENTRY AND SINGLE EXIT



MULTIPLE ENTRY AND SINGLE EXIT



MULTIPLE ENTRY AND MULTIPLE EXIT

Fig. 4 Methods for Feed and Withdrawal from Ponds.

The multiple-entry, multiple-exit approach has been used in the Stockton, California ponds (case 3 in Chapter III). This system was developed to discourage the development of stagnant surface areas within the pond which can cause development of blue-green algae mats. Such mats can emit odors.

Pond Transfer Inlets and Outlets

Pond transfer inlets and outlets should be constructed to minimize head loss at peak recirculation rates; assure uniform distribution to all pond areas at all recirculation rates; and maintain water surface continuity between the supply channel, the ponds and the return channel.

Transfer pipes should be numerous and large enough to limit peak head loss to about 3 to 4 inches with the pipes flowing about two-thirds to three-quarters full. Supply and return channel sizing should assure that the total channel loss is no more than one-tenth of the transfer pipe losses. When such a ratio is maintained, uniform distribution is assured.

By operating with the transfer pipes less than full, unobstructed water surface is maintained between the channels and ponds. This controls scum build-up in any one area.

Transfer inlets and outlets are usually made of bitumastic-coated corrugated metal pipe, with seepage collars located near the mid-point. This type of pipe is inexpensive, strong enough to withstand rough handling and rapid backfilling, and flexible enough to allow for the differential settlement often encountered in pond dike construction.

Specially-made fiberglass plugs can be provided to close the pipes. The plugs may be installed from a boat. Pond recirculation must be shut down to remove the plugs. Such plugs permit any pipe to be closed without requiring the expensive construction of sluice gates and access platforms at each transfer point. Concrete launching ramps are provided into each pond and channel to assure easy boat access for sampling, aquatic plant control, and pond maintenance.

Pond Dike Construction

Pond and channel dikes can usually be constructed with side slopes between 6 horizontal to 1 vertical and 2 horizontal to 1 vertical. The final slope selected will depend on the dike material and the water erosion protection to be provided. All soils, regardless of slope, will require some type of protection in zones subject to wave action, hydraulic turbulence or aerator agitation. Some examples of turbulent zones are areas around the discharge areas at the recirculation pumping station, and areas around the influent and effluent connections.

If the wind is always in one direction, wave action erosion protection can usually be limited to only those areas which receive the full force of the wind-driven waves. Protection should always extend from at least one foot below the minimum water surface to at least one foot above the maximum water surface.

Protection against hydraulic turbulence should extend several feet beyond the area subject to such turbulence. Protection material should not impede the control of aquatic plant growth.

Pond and channel dikes must be kept completely free from grass and aquatic plants if the ponds are to achieve peak efficiency and operate without odor and insect nuisance. Weeds and aquatic growths are usually controlled by periodic spraying, although cutting and actual physical removal are sometimes necessary. Ponds with luxuriant shoreline growths of cattails and other aquatic plants may seem healthy and beautiful. Closer inspection, however, reveals that such growths harbor heavy accumulation of septic scum, which causes odors and loss of treatment capability.

The tops of the dikes should be at least wide enough for a 10-foot wide, all-weather gravel road. Such a road is essential for pond inspection, and for the control of insects, erosion, and plant growth on the dike surfaces.

Fig. 5 shows some details of dike design.

Supplemental Aeration and Mixing

While intermittent mixing has been applied to shallow, high-rate aerobic ponds,[1] greater attention has been given to mechanical mixing and to aeration within the cells of facultative ponds. Sometimes, when ponds must treat high, seasonal BOD loading, under winter conditions, or when there is no more room for expansion, supplementation of the ponds' photosynthetic oxidation capacity is required. (When no oxygen is supplied by photosynthesis, the system is called an aerated lagoon.)

The supplementation is usually achieved by installing compressed air diffusers or mechanical aerators. When the ponds' extra needs are relatively minor and uniform throughout the year, compressed air aeration may be best. Indeed, if the ponds are located in a cold climate, year-round aeration may be necessary to maintain whatever photosynthetic activity is possible during freezing weather. Preventing surface freezing also allows direct oxygen transfer. When supplemental oxygen requirements are high or when the requirements are either seasonal or intermittent, mechanical aerators are used.

In addition to transferring oxygen to the liquid, aeration breaks up the thermal stratification that normally develops in oxidation ponds. Marais[3] reports that the persistent stratification in ponds diminishes the nonmotile algae population

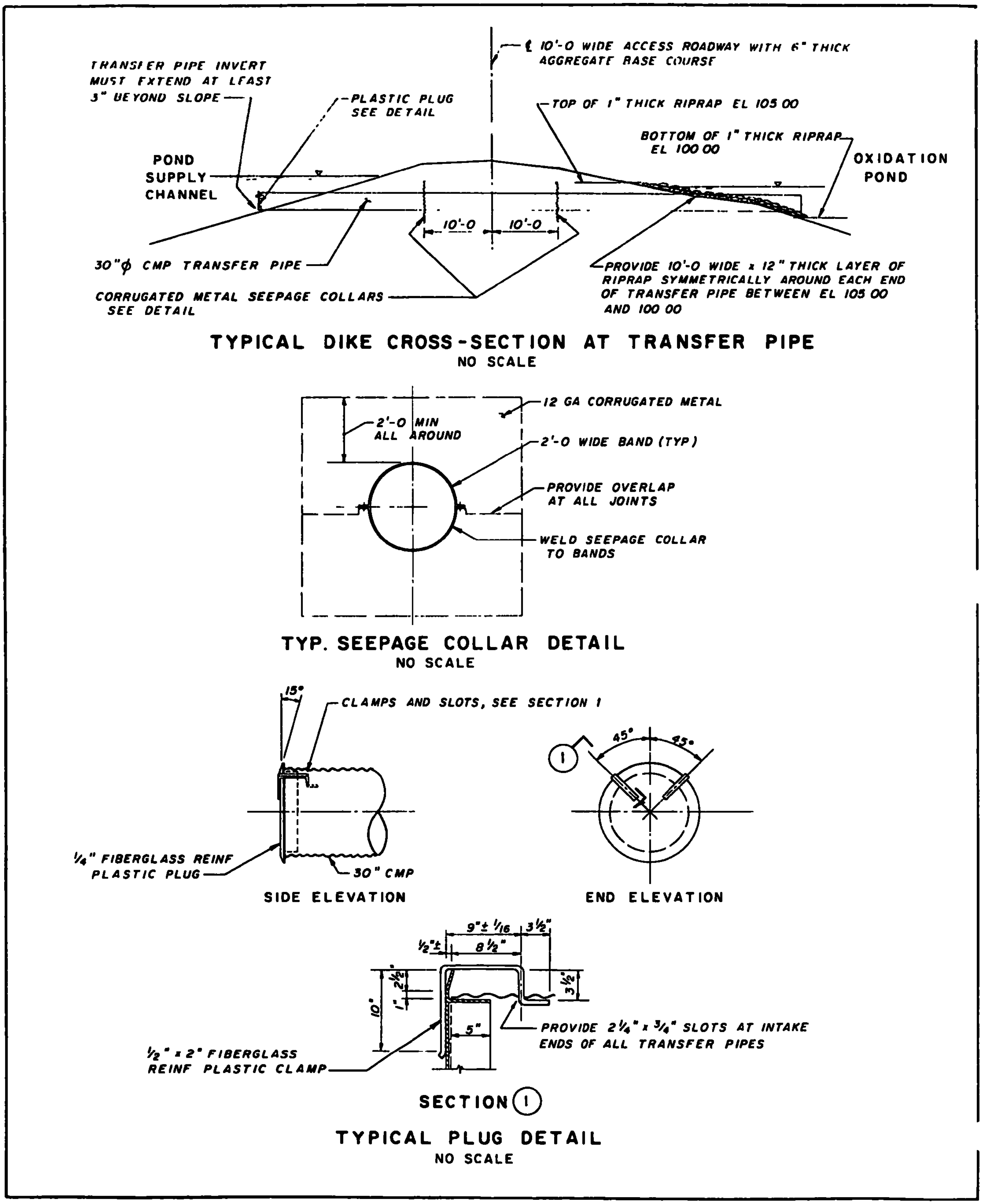


Fig. 5 Details of Dike Design.

because the algae settle below the photic zone and die from lack of light. Mixing tends to increase algae numbers and to maintain aerobic conditions deeper in the pond. By increasing algae numbers, the pond can produce more oxygen, thus increasing its capacity for organic loading.

Surface agitation also breaks up the thin surface layer of slick or scum which forms on calm days. If not destroyed, the scum layer can diminish performance both by decreasing the photosynthetic rates and by decreasing surface aeration.

Mechanical aerators are generally divided into two types: cage aerators (Fig. 6) and the more common turbine and vertical-shaft propeller aerators (Fig. 7). Cage aerators are relatively new in the United States (see Chapter III, case 1) and work particularly well in shallow ponds (less than five feet deep). Propeller aerators require a minimum depth depending on the horsepower of the unit. For shallow ponds a large number of low horsepower units are required, and the cost per horsepower rises.

The cage aerator appears to have an area of influence of as much as 1200 feet (as determined by photographs). While no precise comparison has been made, this device appears to have a much greater pumping capacity than the propeller aerator. The latter device tends to recycle much of the volume pumped, especially in shallow ponds.

Floating propeller aerators are always mounted out in the pond, far enough apart to minimize interference with each other or other pond features. When used for shallow ponds, they require minimum depth pits lined with erosion-resistant surfaces. These surfaces are usually some form of paving, often concrete. Power access is usually via underwater cable while maintenance access is almost always by boat.

Floating cage aerators may be mounted either in the pond or directly off the dike slopes (as at Sunnyvale in Chapter III). When mounted off the dike slopes, they can be close to the pond transfer inlets. The entire dike slope in the immediate area is provided with erosion protection. Units mounted on the slope offer easy access for maintenance and repair, and the extra reliability of above-water power supply.

Most previous pond aeration systems seem to have utilized diffused aeration. For best efficiency these require that the ponds be deepened to 10 feet.[2]

Pond aeration and mixing systems serve mainly to increase the oxidation capacity of the pond. They are useful in overloaded ponds that generate odors.

Algae Removal

Physical removal of the solids in pond effluents will ensure that virtually all of the carbonaceous BOD and most of the nitrogenous BOD in the pond effluent will be removed.

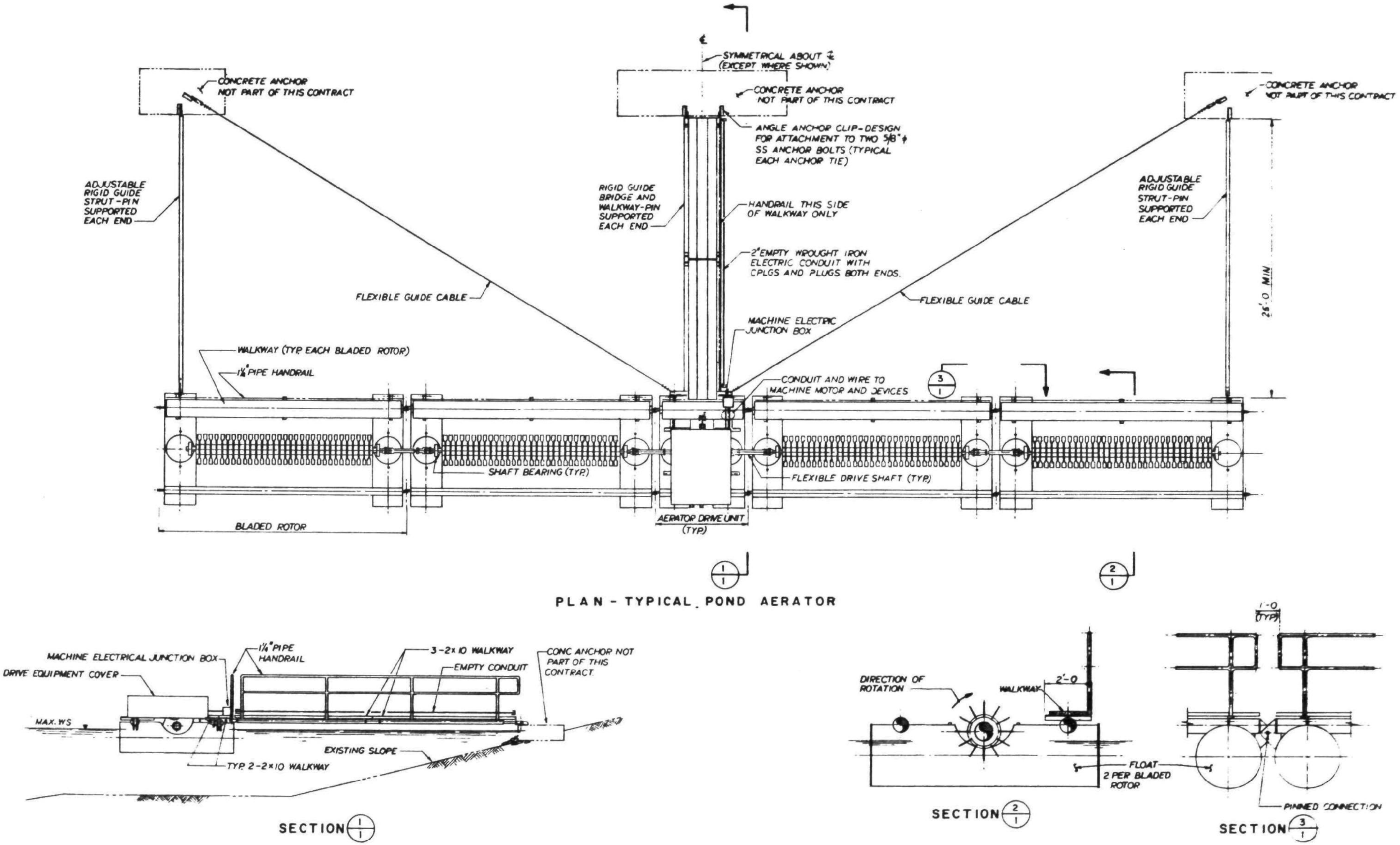


Fig. 6 Floating Cage Aerator.

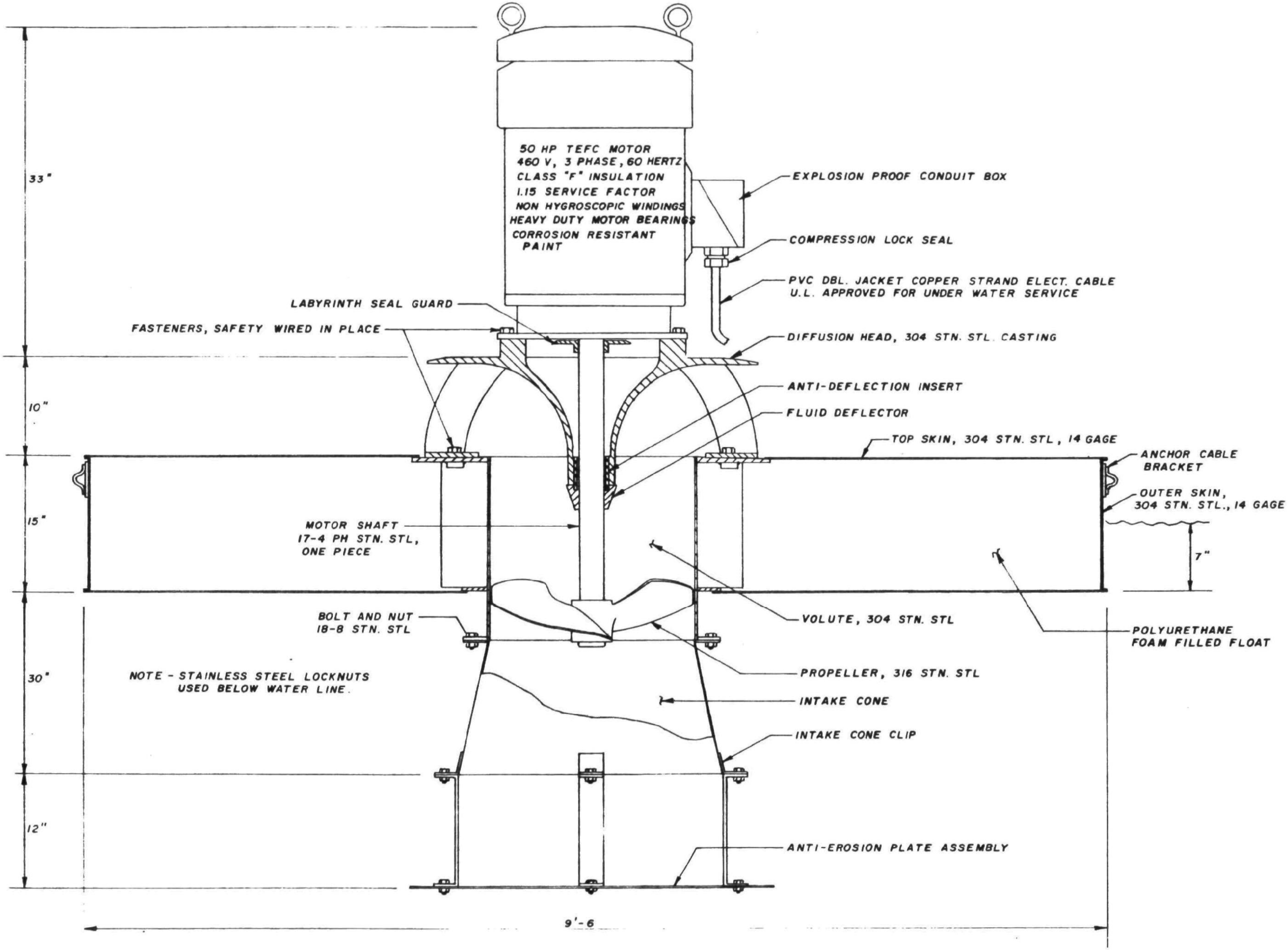


Fig. 7 Floating Propellor Aerator.

Fig. 8 shows the 30-day effluent BOD from the Stockton, California, ponds during the canning season in 1970 (Chapter III, case 3). Physical removal of the algae removed virtually all of the long-term BOD. Very few plant effluents are regulated on the basis of ultimate oxygen demand. If pond effluents are subject to such a rigorous investigation, why look only at lagoon treatment? Fig. 9 shows the 30-day BOD for the effluent of an activated sludge plant in California also receiving a heavy canning load during the summer of 1970. That effluent also has a high 30-day BOD. Much less can be removed by solids separation, presumably because more of the nitrogenous BOD was in the ammonia form and not removable by physical separation.

With proper design and operation of the pond treatment system, the insertion of an algae removal step can produce an effluent which is low in both oxygen demanding materials and nutrients. Table 1 shows recent data obtained by the Napa County Sanitation District[4] from an algae removal pilot plant treating a tertiary pond effluent.[a] The treatment system included lime coagulation, sedimentation, rapid sand filtration, and carbon adsorption. The data shown are for operation in the summer of 1972. As algae activity diminishes in the winter, ammonia levels may rise. However, ammonia discharged to the receiving waters might not stimulate algae growth in the river for the same reasons that pond algae efficiency drops in the winter. Mechanical removal of algae is described further in case 3 in Chapter III.

Nitrogen levels in facultative pond effluents may be quite low for several reasons. Much of the nitrogen in the pond influent may be incorporated into the algae cell. There also appears to be another distinct nitrogen removal mechanism. Nitrification appears to take place in the ponds followed by denitrification in the anaerobic bottom zone.

Recovery of algae for animal feed has been investigated over the years; principal problems lie in developing a market for the product and in finding a means of separating algae in a manner consistent with purpose of obtaining a feed. The use of coagulants such as alum generally diminishes the utility of the product. Dodd, an investigator at the University of California at Davis, has developed a mechanical system in which paper pulp is precoated on a belt filter, and algae are removed on the filter as the belt winds around a micro-strainer drum. The paper-pulp product is vacuum- and heated air-dried to produce an algae-paper that can be shredded to make feed.[9] The algae can provide the protein and the paper can provide roughage for feeding cattle and sheep. Cost data have not been developed yet.

The pond system itself can provide for algae removal. Series ponds (Fig. 2) are recommended by some state regulatory agencies for encouraging algae sedimentation within the pond cells. A parallel-series arrangement (Fig. 2) can also

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[a] Preceded by primary sedimentation and trickling filtration.

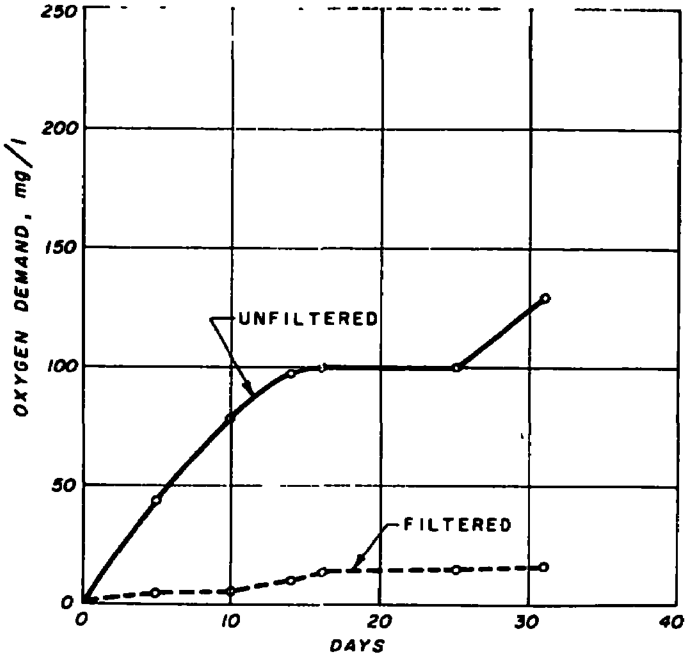

Fig. 8 Oxygen Demand Found in Filtered and Unfiltered Samples of Oxidation Pond Effluent, September 1970

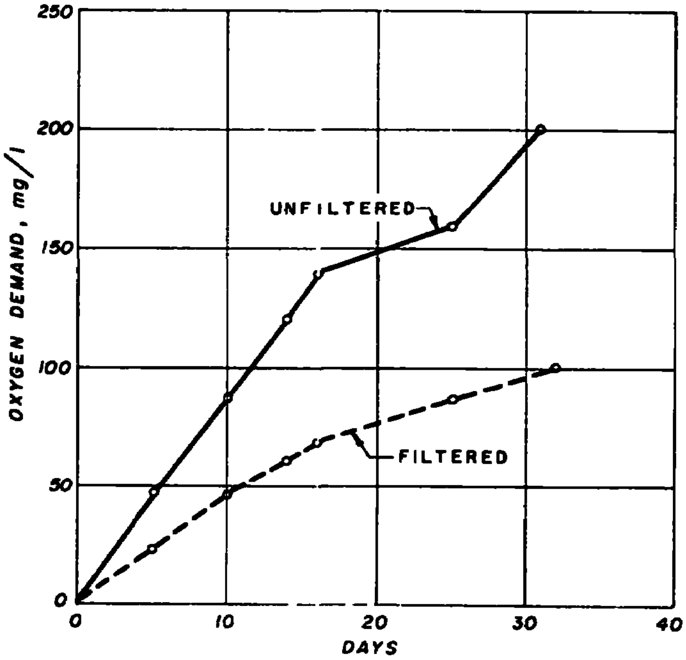

Fig. 9 Oxygen Demand Found in Filtered and Unfiltered Samples of Activated Sludge Effluent, September 1970

Table 1. Treatment of Pond Effluent for Algae Removal

Constituent	Pond effluent, mg/l	Sedimentation tank,[a] mg/l	Multi-media rapid sand filter, mg/l	Activated carbon, mg/l
pH	9.4	10.8	8.0	8.5
BOD	30	3.6	4.3	0.8
COD	158	55	37	13
SS	102	23	6	5.0
Turbidity[b]	42	9	6	3
P	1.7	-	-	-
Org.N	8.3	1.7	1.1	0.46
NO_3	0.16	0.18	0.27	0.18
NO_2	0.18	0.11	0.11	0.11
NH_3	0.21	0.35	0.26	0.17
Total N	9.0	2.2	-	0.7
Chlorophyll A[c]	437	59	-	19

[a] Pond effluent treated with 200 mg/l lime as CaO and 50 mg/l alum as $Al_2(SO_4)_3 \cdot 18H_2O$.

[b] JTU's.

[c] ug/l.

encourage such sedimentation. Sedimentation ponds, however, are limited in efficiency by such factors as wind mixing and species type. Wind prevents sedimentation by mixing the water. The smaller the pond, the less influence wind has on mixing. Sedimentation pond efficiency also depends on species type. Motile algae and crustaceans are not efficiently removed in such ponds.

McKinney, et al,[2] after an extensive review of available data, concluded that, for small ponds (which are used most often), the best method for algae separation was the series arrangement, with the final pond used for algae sedimentation. Oswald, et al,[10] report a series application of ponds where algae sedimentation follows a high rate-aerobic pond;[a] algae settle out in the sedimentation pond which has a detention time of 13 days and a depth of 8 feet. Oswald further reports that while the sedimentation pond initially yielded high algae removals, there has been some deterioration, as blue-green algae grew in the summer of 1972 from nutrients released from anaerobic fermentation of the sludge layer. Oswald recommends removal of the bottom sludges in the sedimentation pond every two years to prevent this problem. The Los Banos case example (Chapter III, case 2) demonstrates a series arrangement to encourage algae removal.

An algae sedimentation pond, unlike a mechanical system, is subject to variable performance caused by wind mixing, nutrient recycle from the sludge layer, and changes in algae removal efficiencies resulting from shifts in algae species. An algae sedimentation pond cannot be expected to operate as efficiently as a mechanical system; however, such sedimentation ponds do have a place in upgrading technology since they are far simpler and more economical than mechanical systems.

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[a] The entire series treatment system consisted of a facultative pond, a high rate aerobic pond, an algae sedimentation pond and two maturation ponds in series.

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CHAPTER III

EXAMPLES OF UPGRADING PONDS

Case 1: Sunnyvale Water Pollution Control Plant

Case 2: Los Banos Sewage Treatment Plant

Case 3: Stockton Main Water Quality Control Plant

CASE 1:

SUNNYVALE WATER POLLUTION CONTROL PLANT

CASE 1:

SUNNYVALE WATER POLLUTION CONTROL PLANT

Sewage treatment facilities for the City of Sunnyvale, California, were first placed in operation in September 1956. They included: a primary treatment plant having an average daily capacity of 7.5 million gallons of domestic sewage and nonseasonal industrial wastes, and a holding pond with a capacity of 200 million gallons, for seasonal wastes from two large canneries which processed fruit and vegetables. Effluents from the primary plant and the holding pond were discharged directly to Guadalupe Slough (which is a tributary to south San Francisco Bay).

By 1960 the domestic sewage flow had reached the capacity of the primary plant, and conditions in Guadalupe Slough, because more effluents were discharged from the treatment facilities, had deteriorated so much that they failed, at times, to comply with the minimum requirements established by the Regional Water Quality Control Board. In a study authorized by the city, Brown and Caldwell recommended doubling the capacity of the primary plant and adding an oxidation pond. The facilities were not completed until 1967.

Growth of both domestic and industrial wastes since 1960, and the more stringent requirements of the Regional Water Quality Control Board required further improvement of the plant. This was completed by the canning season of 1971; three more primary settling basins were added (for a total of 9), and aerators were added to the two ponds. The addition of aerators is the primary concern of this discussion.

Originally, the large pond (325 acres) had been used as an oxidation pond for secondary treatment of the domestic wastewaters. The wastewater from the canneries was put directly in the smaller holding pond (100 acres). This pond was designed to operate anaerobically, with odors controlled by calcium or sodium nitrate additives. A considerable quantity of nitrate was required and resulted in high operating costs during the food processing season. Attempted close control of nitrate addition resulted in insufficient amounts being added at times so that hydrogen sulfide odors did occur.

Design provided for the effluent from the holding pond to be discharged to the oxidation pond at a rate which would maintain aerobic conditions in the oxidation pond. Seasonal wastes increased in quantity and strength beyond expectations and the holding pond did not have sufficient capacity to contain the waste for the entire canning season. Since 1960 it was necessary to discharge some of the holding pond contents to Guadalupe Slough during the canning season.

During the past few years, attempts were made to improve the situation by putting the cannery waste through the primary plant and operating the two lagoons in parallel. The small pond received heavier loadings, however, and continued to produce odors. Also, hydrogen sulfide odors continued to develop in Guadalupe Slough.

In an upgrading step, floating cage aerators were placed near the inlets to the ponds to increase their oxidation capacity. The aerators are used only during the canning season when supplemental oxygenation capacity is required. Fig. 6 shows a drawing of the aerator and Fig. 10 a diagram of the ponds. The influent and the recirculation flows are mixed in the channel. The flow is then discharged to the ponds through a series of pipes along their edges. The aerators are generally near the transfer pipes (however, no pipes are located near the last two aerators of the large pond). Near the last two aerators the discharge line leads from the pond to the chlorine contact chamber, and then to Guadalupe Slough. These two aerators prevent short-circuiting of wastewater.

Operating the ponds in this manner has substantially improved effluent quality. The ponds and Guadalupe Slough contain dissolved oxygen at all times and are odor-free; fish have returned to the slough. Tables 2 and 3 give design data for before and after upgrading (1967 and 1971). Table 4 shows operating data for 1970 and 1971. Capital costs for pond upgrading is given in Table 5. Table 6 shows the operating cost changes caused by plant expansion.

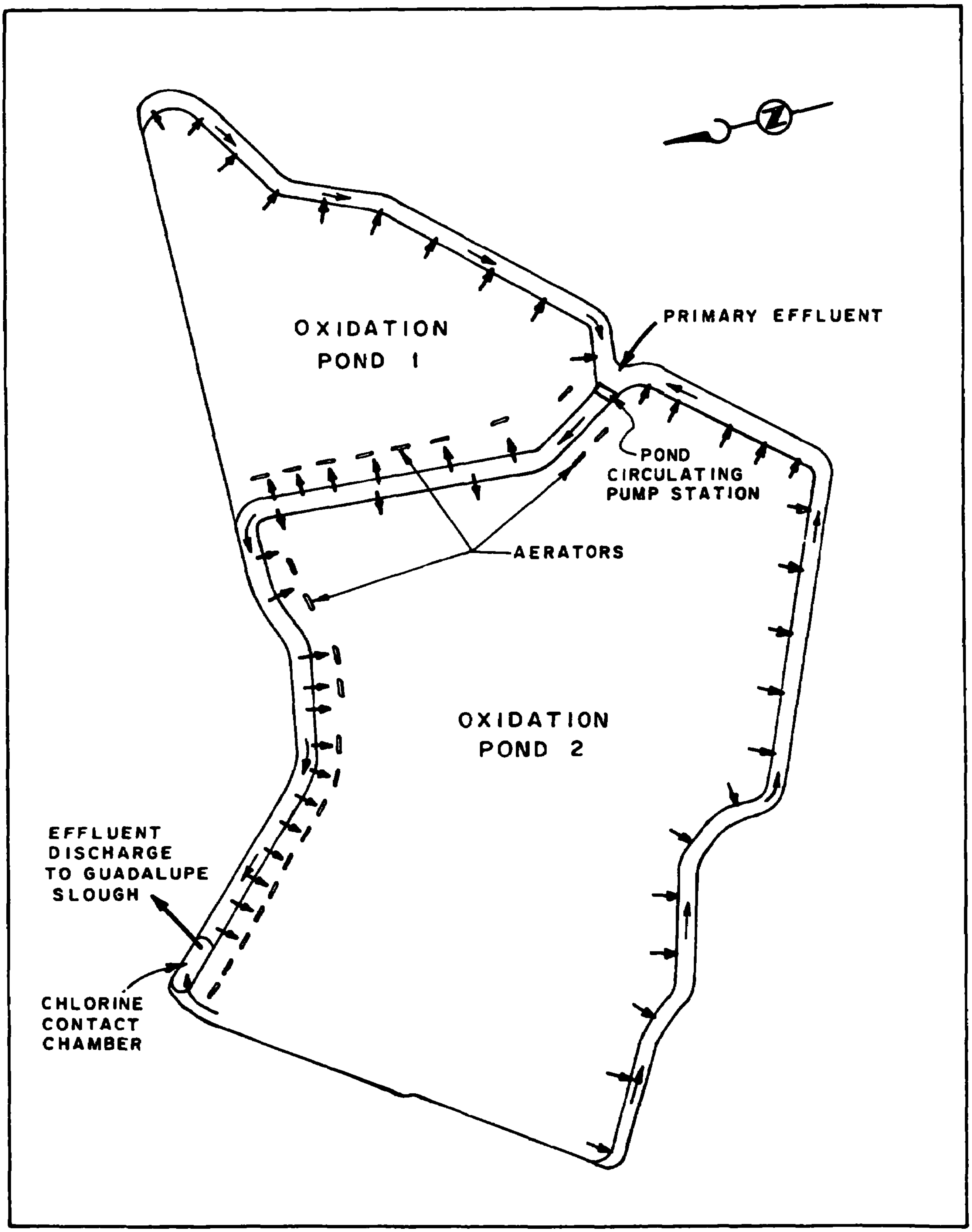
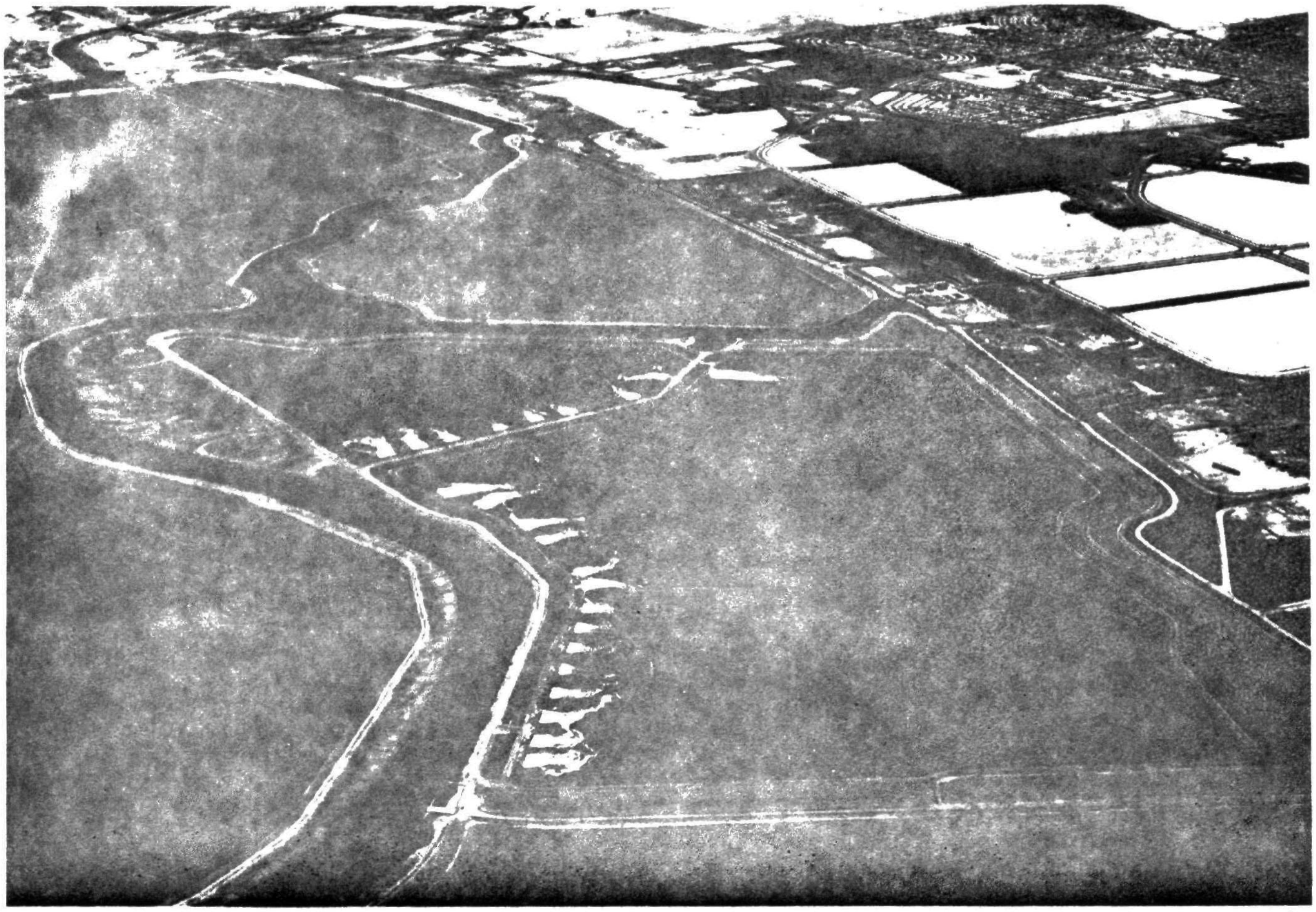
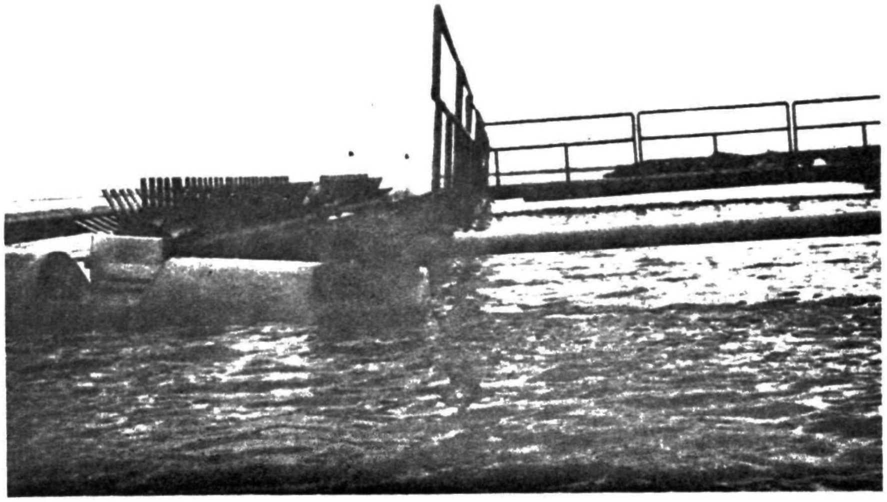


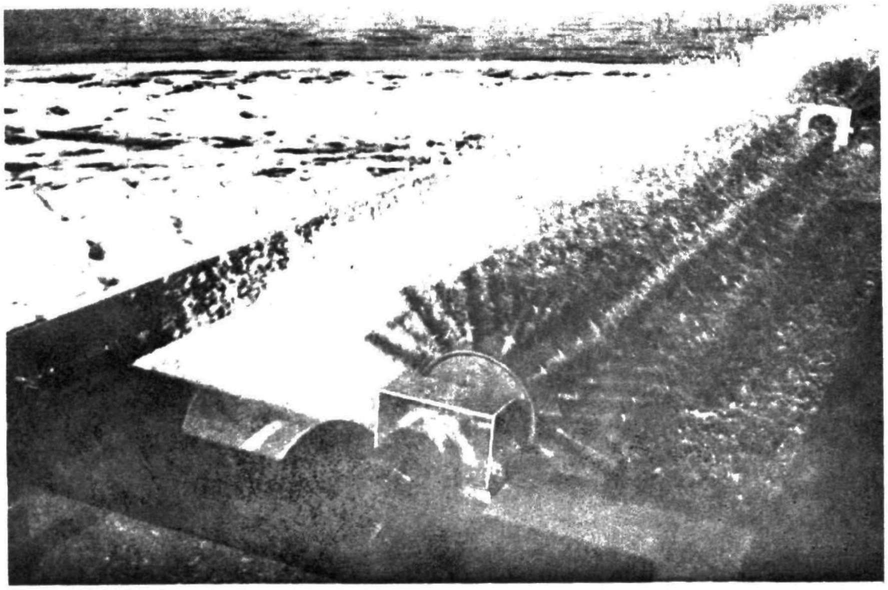
Fig. 10 Diagram of Sunnyvale Ponds.



Sunnyvale Sewage Treatment Works. 1969 Enlargment



Cage Aerator



Cage Aerator in Operation

Table 2. Sunnyvale Water Pollution Control Plant Design Data, 1967

Design loadings	
Domestic	
Daily average flow, mgd	15
BOD, mg/l	270
BOD, lbs/day	33,600
Suspended solids, mg/l	300
Suspended solids, lbs/day	37,400
Industrial waste (seasonal)	
Daily average flow, mgd	8.0
BOD, mg/l	1,800
BOD, lbs/day	120,000
Suspended solids, mg/l	500
Suspended solids, lbs/day	33,000
Preaeration tanks (domestic sewage only)	
Number	6
Width, ft	19
Length, ft	35
Average water depth, ft	10.5
Detention time, hrs	0.5
Air supplied per tank, cfm	300
Air supplied per tank, cf/gpm	0.17
Maximum hydraulic capacity per tank, mgd	6.75
Maximum hydraulic capacity bypass channel, mgd	50
Sedimentation tanks (domestic sewage only)	
Number	6
Width, ft	19
Length, ft	110
Average water depth, ft	10
Effluent weir per tank, ft	164
Detention time, hrs	1.5
Mean velocity, fpm	1.2
Overflow rate, gal/sf/day @ daily avg flow	1,200
Maximum hydraulic capacity, mgd	6.75
Maximum hydraulic bypass channel, mgd	50

Table 2 (cont'd)

Primary treatment (domestic sewage only)	
Assumed BOD reduction, percent	35
BOD reduction, mg/l	95
BOD reduction, lbs/day	11,800
Assumed suspended solids reduction, percent	60
Suspended solids reduction, mg/l	180
Suspended solids reduction, lbs/day	22,400
Primary effluent (domestic sewage only)	
BOD, mg/l	175
BOD, lbs/day	21,800
Suspended solids, mg/l	120
Suspended solids, lbs/day	15,000
Oxidation pond (domestic sewage only)	
Number	1
Area, acres	325
Loading, 5-day BOD, lb/acre/day	67
Detention, days	36
Circulation pumps	
Number	4
Capacity each, gal/min	44,000
Head, ft	3.5
Engine-generators	
Number	3
Rated output, kw	223/167
Speed, rpm	1,000/750
Frequency, cycles per second	66/50
Industrial wastes holding pond	
Net water area, acres	100
Maximum water depth, ft	6
Maximum capacity, mg	200

Table 3. Sunnyvale Water Pollution Control Plant Design Data, 1971

Design loadings	
Domestic	
Average daily flow, mgd	22.5
BOD, mg/l	270
BOD, lbs/day	50,000
Suspended solids, mg/l	300
Suspended solids, lbs/day	56,000
Industrial waste (seasonal)	
Average daily flow, mgd	8.0
BOD, mg/l	1,800
BOD, lbs/day	120,000
Suspended solids, mg/l	500
Suspended solids, lbs/day	33,000
Preaeration tanks	
Number	7
Width, ft	
Six at	19.0
One at	20.7
Length, ft	
Six at	20.5
One at	58.7
Average water depth, ft	
Six at	10.5
One at	11.0
Average daily flow, mgd	
Six at	2.5
One at	7.5
Detention time, hrs	
Six at	.29
One at	.32
Air supplied per tank, cfm	
Six at	130
One at	250
Air supplied per tank, cf/gal	
Six at	.074
One at	.048
Max hydraulic capacity per tank, mgd	
Six at	6.75
One at	20
Max hydraulic capacity bypass channel, mgd	50

Table 3 (cont'd)

Sedimentation tanks:	
Number	9
Width, ft	19
Length, ft	110
Average water depth, ft	10
Effluent weir per tank, ft	164
Detention time, hrs	1.5
Mean velocity, fpm	1.2
Overflow rate, gal/sq ft/day	1,200
Max hydraulic capacity per tank, mgd	6.75
Max hydraulic capacity bypass channel, mgd	50
Primary treatment efficiency (domestic only)	
Assumed BOD reduction, percent	35
BOD reduction, mg/l	95
BOD reduction, lbs/day	17,000
Assumed suspended solids reduction, percent	60
Suspended solids reduction, mg/l	180
Suspended solids reduction, lbs/day	34,000
Primary effluent (domestic only)	
BOD, mg/l	175
BOD, lbs/day	33,000
Suspended solids, mg/l	120
Suspended solids, lbs/day	22,000
Oxidation ponds	
Number	2
Area, acres	425
Average depth, ft	4.25
Mechanical aerators	
Number	24
Maximum power, input to rotors, hp	1,800
Efficiency, lbs O_2 input/hp hr	1.86
Oxygen input, lbs/day	76,500
Loading, 5-day BOD	
Total, lbs/day	
Noncanning season	33,000
Canning season	141,000
5-BOD reduction capacity	
Noncanning season (winter months)	
Photosynthetic	
Unit, lbs/acre/day	80
Total, lbs/day	35,000

Table 3 (cont'd)

Canning season (summer months)	
Photosynthetic	
Unit, lbs/acre/day	175
Total, lbs/day	77,000
Mechanical aeration, lbs/day	59,000
Photosynthetic plus mechanical aeration, lbs/day	136,000
Detention, days	
Noncanning season	27
Canning season	20
Circulation pumps	
Number	4
Capacity each, mgd	63.5
Head, ft	3.5

Table 4. BOD_5 Removals During Canning Season by Ponds Before and After Installation of Aerators

	Pond influent BOD		Pond effluent BOD		Percent removal[a]
	mg/l	10^3 lbs/day	mg/l	10^3 lbs/day	
July 8 - Oct.1, 1970 (before aerators)	347.2	67[b]	64	7[c]	89
June 30-Oct.2, 1971 (after aerators)	405.5	64[d]	29	4	94

[a] Based on mass emission, lbs/day.

[b] Maximum value 102,000 lbs/day; effluent value is fairly consistent.

[c] Does not include BOD in effluent from industrial holding pond.

[d] Maximum value 121,000 lbs/day.

Table 5. Summary of Capital Costs for Sunnyvale Aerators

Aerators (24)	$ 587,000
Levee riprap	40,000
Aerator anchor blocks (4.5 cu yd per aerator)	28,950
Pond transfer pipes (6 installed; more may be needed at other installations)	32,000
Pond power load centers (5)	138,710
Direct burial cable	140,000
Main switch gear	24,000
Unload, position, and hook up aerators	31,900
	$1,022,510

Table 6. Operating Costs Associated with Pond Upgrading

	1970 (before aerators)	1971 (after aerators)
Gas and electricity[a]	$15,000	$58,000
Chemicals[b]	54,000	0
Labor[c]	0	10,000
Total	$69,000	$68,000

[a] Includes power for remainder of plant which was also expanded in 1971.

[b] Calcium and sodium nitrate, phosphoric acid, and anhydrous ammonia.

[c] One employee added in 1971.

CASE 2:

LOS BANOS SEWAGE TREATMENT PLANT

CASE 2:

LOS BANOS SEWAGE TREATMENT PLANT

The Los Banos Sewage Treatment Plant, in Los Banos, California, was constructed in 1961 for two reasons: the treatment system was too small and in disrepair; and the system could not meet recent discharge requirements set by the California Water Quality Control Board. Treatment then consisted of a two-compartment, 125,000-gallon capacity septic tank originally designed to serve 700 people. Population at that time was 6,800, and the average daily flow was 2.5 mgd. Hydrogen sulfide gas had deteriorated the concrete so much that the system was inoperative.

In 1960 the Regional Water Quality Control Board established effluent requirements for discharge to Mud Slough, the receiving water for the plant effluent. The pertinent portions of the requirements were:

1. DO in the receiving waters was not to be reduced to less than 5.0 mg/l for 16 hours in a 24-hour day.

2. Settleable solids were not to exceed 0.5 ml/l/hr.

The treatment facility was constructed to meet these requirements. A concurrent plan was effected to reduce stormwater infiltration, and divert cooling water from the milk processing industry that was tributary to the plant, thus reducing the plant influent flow to 0.5 mgd (ADWF). The facility included a pump station, a comminutor, and two 85-acre raw sewage lagoons (Fig. 12). BOD_5 removal was 85 percent on filtered effluent samples.

In 1972 the Regional Board added more constituent requirements:

1. Median BOD_5 must be less than 40 mg/l
2. Median settleable solids must be less than 0.2 ml/l
3. Median MPN must be less than 50/100 ml
4. Chlorine residual must be less than 0.5 mg/l
5. pH must be between 6.5 and 8.5

Since 1969, shock loads of organics had periodically turned the first pond anaerobic, causing it to give off odors. The Regional Board's requirements stipulated that DO in the ponds must not be less than 1.0 mg/l. Additionally, it required that discharges should not lower the DO concentration in the receiving waters below 5.0 mg/l for 16 hours, and never less than 3.0 mg/l.

The proposed two-stage plan expands and alters the existing facility. Stage I calls for addition of a third pond of 170 acres which will double the pond area (see Fig. 13). Mechanical aerators will be installed in the first pond cell and recirculation will be increased to alleviate initial septicity. The long detention time of 250 days and the good climate should promote crustacean growth. The crustaceans devour the algae, encouraging clarification and sedimentation. Disinfection will be accomplished by chlorination. The plant effluent now contains between 20 and 90 mg/l BOD_5, and little or no settleable solids. If algae removal is effective the BOD_5 of the effluent should be quite low. DO levels in the receiving waters is presently adequate and should remain so. Settleable solids should decrease.

If operating experience indicates inadequate algae removal, the construction of an algal removal facility is proposed (as Stage II). Tables 7 and 8 show design criteria and operating costs for Stage I.

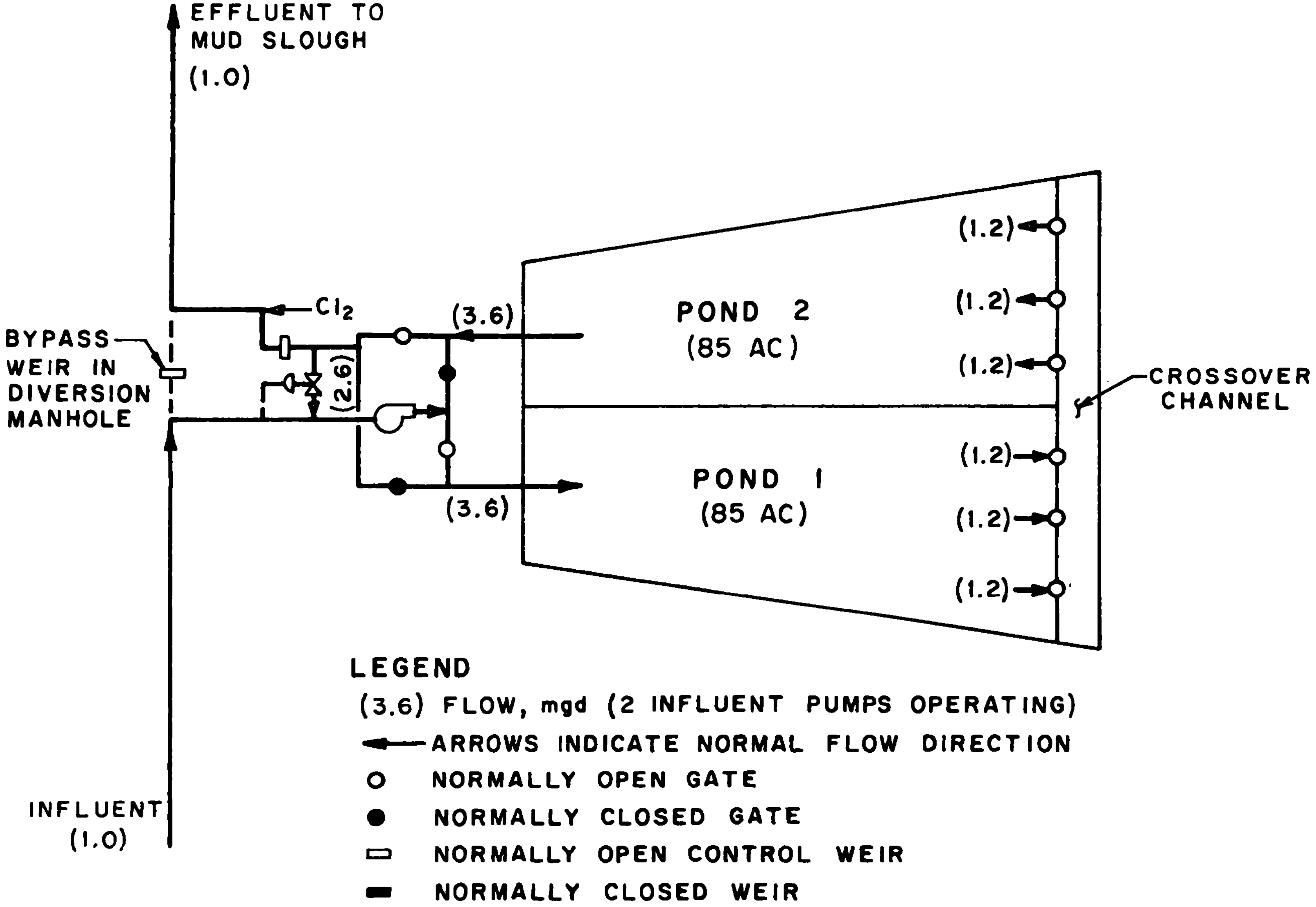


Fig. 12 Flow Diagram for Existing Conditions (at 1.0 mgd-Summer, ADWF).

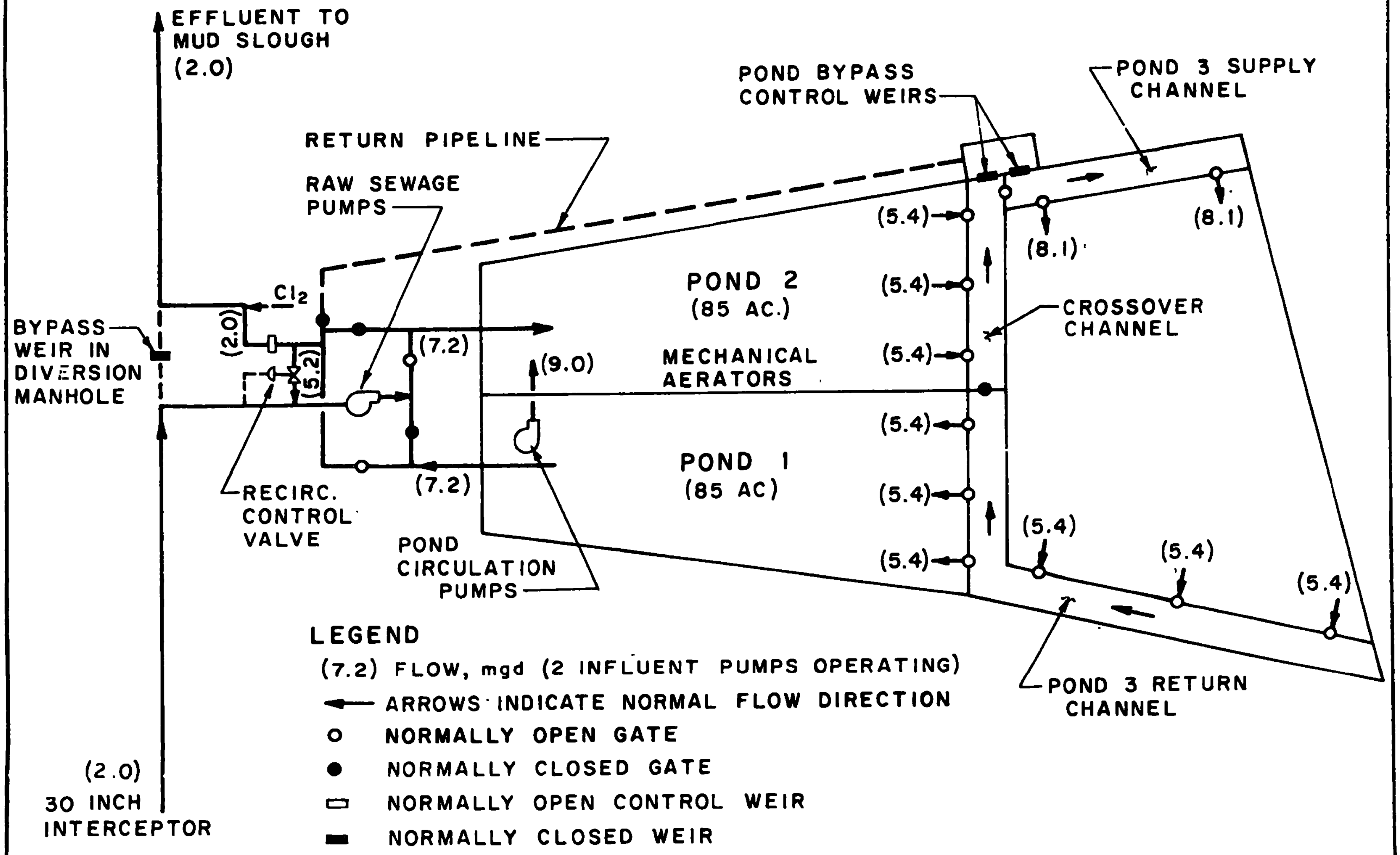


Fig. 13 Flow Diagram for Stage I Design (at 2.0 mgd-ADWF).

Table 7. Los Banos Design Data

Component	1959	1972	Design
Basic loading data			
Flow, mgd, average			
During summer season	2.5	1.0	2.0
During winter season	1.8	0.7	1.4
Wet weather flow, mgd			
BOD_5,1000 lbs/day	4.8	4.0	6.9
During summer season	6.7	4.6	9.0
During winter season	4.1	2.8	5.6
Influent pumps			
Number	-	2	3
Capacity, each, mgd	-	3.6	3.6
Capacity, one unit out of service, mgd	-	3.6	7.2
Oxidation pond system			
Ponds			
Number	-	2	3
Area, net water surface, acres	-	170	340
Volume, mg	-	280	560
Allowable loading during summer season			
BOD, lb/surface acre/day	-	40	40
BOD total, 1000 lbs/day	-	6.8	13.6
Allowable loading during winter season			
BOD, lb/surface acre/day	-	20	20
BOD total, 1000 lbs/day	-	3.4	6.8
Mechanical aerators			
Number	-	-	3
Total horsepower	-	-	60
Total capacity, 1000 lb[a] of BOD/day	-	-	2.2
Pond circulating pumping units			
Number	-	-	2
Total capacity, mgd	-	-	9.0
Chlorination			
Chlorination rate, lbs/day[b]	-	84	167
Chlorination capacity, lbs/day	-	400	400

[a] Based on motor shaft horsepower of 0.27 for each pound of BOD stabilized per day.

[b] Based on summer flow and dosage of 10 mg/l.

Table 8. Operation and Construction Costs

Component	Existing	Stage I[1]
Construction cost (incl. Cont., Eng., Legal, Admin.)	885,000	490,000
Annual costs		
O & M	4,000	16,300
Capital cost	20,000	50,400
Total annual cost	24,000	66,700

[1] Estimated.

CASE 3:
STOCKTON MAIN WATER QUALITY CONTROL PLANT

IMPROVING POND EFFLUENT BY ALGAL REMOVAL

What do you do when you have 630 acres of recently expanded ponds in your treatment system and a regulatory agency tells you to meet tough new requirements? The answer: Incorporate them into an advanced waste treatment system and accomplish the objective.

The City of Stockton, California, is located near the confluence of the San Joaquin and Sacramento Rivers and has an unusual water quality problem that requires a unique solution. The cities of the San Joaquin Valley, and Stockton in particular, have historically been agriculturally oriented. This has resulted in industries which produce unusually heavy loadings at the city's main water quality control plant during peak canning periods.

Stockton faces the problem of serving six canners and six other major wet industries, including food processors, in its municipal system. These industries caused a peak monthly flow to the City's main water quality control plant in the summer of 1970 of 35 million gallons per day (mgd); biochemical oxygen demand (BOD) loading during that same time reached a high of 3,200,000 lbs/month. Flows during the remainder of the year are 15 mgd with 945,000 lbs/month of BOD. Unfortunately, these peaks occur at the period of critical water quality and low flow in the San Joaquin River, a tidal estuary of San Francisco Bay into which the plant's effluent is discharged.

The Central Valley Regional Water Quality Control Board has established discharge requirements which include the following provisions:

1. The waste discharge shall "not cause the dissolved oxygen of the receiving waters to fall below 5.0 mg/l at any time".
2. The waste discharge shall "not cause the total nitrogen content of receiving waters to exceed 3.0 mg/l".

A study of the dissolved oxygen dynamics of the Stockton Ship Channel, which provides a deep water link to San Francisco Bay, established the assimilative capacity of the channel for oxygen demanding materials discharged from the Stockton main plant.[1] The long-term oxygen demand was found to be principally associated with algae; therefore, physical removal of the algae from the pond effluent eliminated most of the long-term BOD. A projection of long-term BOD loads compared to the assimilative capacity of the water indicated that algal removal would permit the dissolved oxygen (DO) criterion to be met. At the same time, algal removal would also accomplish nitrogen removal, since most of the nitrogen is in the organic form and associated with algae.

By: Denny S. Parker, Project Engineer, Brown and Caldwell - James B. Tyler, Supervising Chemist, Environmental Quality Analysts - and Thomas J. Dosh, Public Works Director, City of Stockton.

To meet the new requirements, Stockton is currently undertaking enlargements and modifications to its main water quality control plant. A phased design and construction program has been prepared which will enable the city to be in compliance with waste discharge requirements by February 1974. This program involves improvements to the entire plant including the following elements: (1) preliminary treatment, (2) primary sedimentation, (3) secondary treatment (trickling filtration), (4) tertiary treatment (oxidation ponds and algal removal facilities), (5) disinfection, and (6) solids treatment.

As a part of this program, pilot algal removal studies were conducted during the summer of 1971 to provide design and operating criteria.

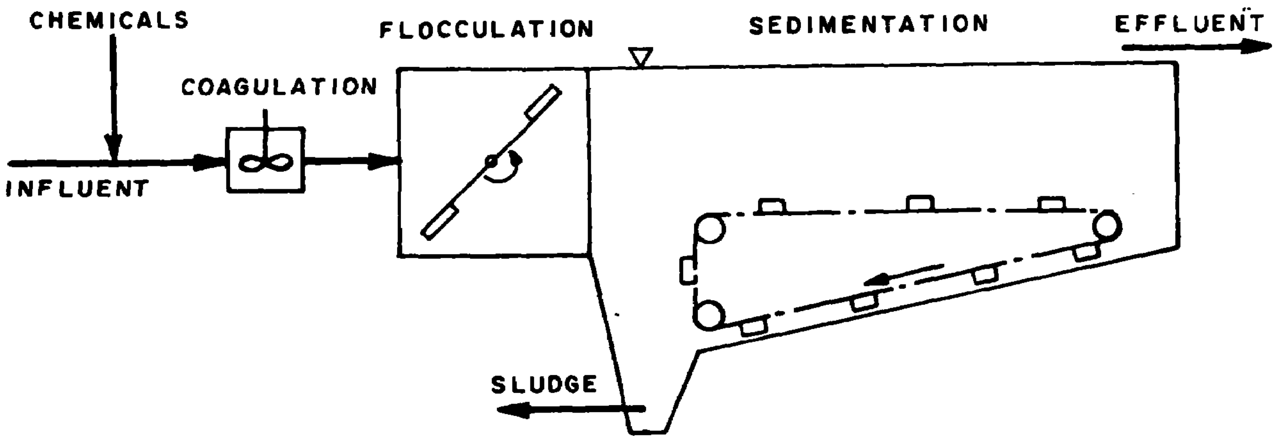
Alternative Means for Removal

Algal removal can be accomplished in two stages: a first stage consisting of chemical coagulation and gravity separation and a second stage of multimedia, rapid sand filtration. The first removal stage accomplishes separation of the bulk of the algae (60-90 percent) and produces an effluent that can be applied to filters without excessive backwashing. The first stage can utilize either flotation (in several modes) or sedimentation. In either case, the well coagulated and flocculated solids are removed, leaving only dispersed solids in the first stage effluent. The second stage separation process then removes residual materials and usually involves the use of a polymer coagulant aid to enhance removals.

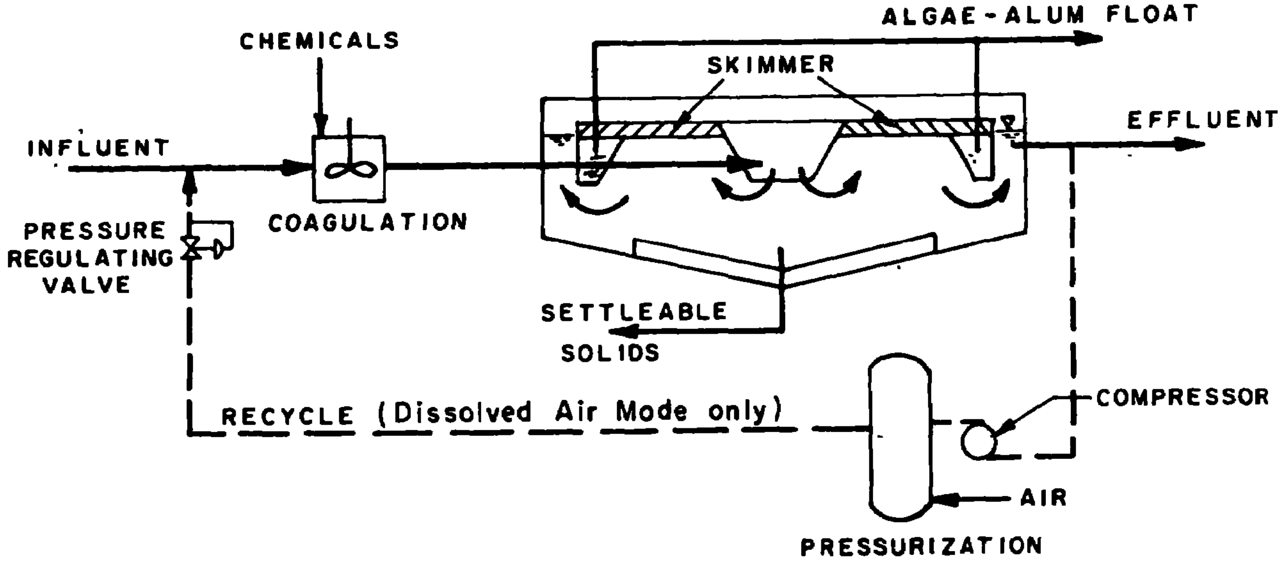
Sedimentation is widely used to clarify many suspensions. When used for the removal of algae, it is first necessary to chemically coagulate the algae in order to remove the repelling charges which stabilize the individual particles. The treated particles are then aggregated to form particles large enough to settle out in the sedimentation tank. Sedimentation thus involves three stages: chemical coagulation, flocculation, and sedimentation, as shown in Fig. 1.

When flotation is used, separation depends on the formation of fine bubbles which are physically attached to the algae causing them to float to the tank water surface where they are collected and removed. Chemical coagulation enhances the effect in the same manner as in sedimentation. It is the algae-bubble-chemical matrix that is desired for good flotation, rather than large aggregates of chemically bound algae needed for rapid sedimentation. No separate mechanical flocculation step is provided in flotation.

Two modes are available for the formation of the fine bubbles: dissolved air flotation and autoflotation. In dissolved air flotation, a portion of the effluent or influent is pumped to a pressure tank where the liquid is agitated in contact with high pressure air to supersaturate the liquid. When this pressurized stream is released into the influent, fine air bubbles are formed. These bubbles are then coagulated with the algal cells by the rapid addition of chemicals. The algae-chemical-bubble "float" is then removed at the surface of the tank. Autoflotation differs only in that no pressurization is required for the formation of the fine bubbles.



SEDIMENTATION



FLOTATION

Fig. 1. Alternatives for First Stage Algal Removal

Flotation with alum coagulation and rapid sand filtration has proved successful in Windhoek, South Africa.[2,3,4,5] The flotation stage produced a reduction in the five-day BOD from 27.3 to 9.5 milligrams per liter (mg/l) using an alum dose of 350 mg/l. In another test, the suspended solids were reduced from 280 mg/l to 94 mg/l. Float solids ranged from 1.4 to 3.7 percent total solids.

In the Windhoek studies, it was found that flotation could be obtained without pressurization, a process termed "autoflotation". In order for this to be effective, the dissolved oxygen content of the pond effluent must be at a supersaturated level and exceed 14 mg/l. The supersaturation is released by providing aeration or carbon dioxide addition and turbulence. The presence of the suspended algae or alum-algae floc catalyzes the formation of small oxygen bubbles which results from the change in oxygen partial pressure. The bubbles then attach themselves to the floc and rise to the surface. When insufficient dissolved oxygen was present, it was found that flotation could be achieved by aeration of the water under pressure followed by pressure release. Carbon dioxide was used in conjunction with alum for two purposes: (1) to promote a change in the partial pressure of oxygen and encourage gas release, and (2) lower pH to the 7.0 to 6.5 range which is optimum when alum is used as a flocculant.

The advantages of flotation cited by the Windhoek investigators are: the separation can be accomplished in shallow flotation tanks with residence times as low as 6 to 20 minutes as opposed to 3.5 hours in sedimentation, the sludge is more concentrated than from a sedimentation unit, and higher tank overflow rates can be used.

The other alternative first stage separation technique, sedimentation, has been thoroughly evaluated by Dryden and Stern.[6] In jar tests, alum proved to be a more effective coagulant than either lime or ferric sulfate. Jar tests showed that a pH of 6 and an alum dose of 300 mg/l was necessary to attain turbidities less than 10 Jackson units and total phosphate less than 0.1 mg/l. A pilot plant of sedimentation-rapid sand filtration produced an effluent equivalent to that of a parallel pilot facility incorporating a pressurized dissolved air flotation and filtration sequence. Autoflotation was not observed. At the Interagency Agricultural Waste Water Treatment Center at Firebaugh, California, laboratory tests have shown that the flocculation-sedimentation process could remove 90 percent of the algae. However, sludge could be concentrated in the sedimentation tanks to only one percent.[7]

Golueke and Oswald[8] found in field scale studies of algal removal by sedimentation that a pH of 6.5 and an alum dose of 105 to 120 mg/l were required. Algal removals of 94 to 100 percent were obtained in a sedimentation tank with 2 to 3 hours residence time. Underflow solids concentration averaged 1.5 percent.

Incentive for Pilot Study

Both flotation and sedimentation have been established as workable, dependable processes for the first stage removal of algae by both pilot-scale and field-scale tests. Both processes have been tested successfully on a long-term basis. A review of past work indicates that flotation may be economically superior to sedimentation, because higher overflow rates and lower residence times can be used, equivalent removals can be obtained for approximately the same chemical dose, and greater sludge concentration is attained.

Given the projected advantages of flotation in the first stage, it was deemed desirable to operate a pilot-scale process to determine if flotation was applicable to Stockton's waste and to develop design concepts and criteria for a full-scale unit. Of special interest was the comparison of pressurized dissolved air flotation to the Windhoek mode of oxygen release under supersaturated conditions (autoflotation).

Pilot Plant

A circular pilot flotation unit was rented for the study and located next to the final pond at the main plant. The pilot plant was modified to allow transfer from recycle stream pressurization for dissolved air flotation operation to autoflotation by simple valve changes.

Normal values for the various operating criteria are indicated in Table 1. As can be seen, the pilot unit was operated at fairly high overflow rates (2 to 2.7 gpm/sq ft) and fairly low residence times (17 to 22 minutes). These rates can be compared to values for the alternative sedimentation tank design of 0.9 gpm/sq ft for overflow rate and a detention time of 165 minutes.

Table 1. Operating Criteria for Pilot Study

	Autoflotation without pressurized recycle	Dissolved air flotation with pressurized recycle
Influent flow rate, gpm	29	29
Recycle, percent	0	33
Recycle flow rate, gpm	0	10
Area for clarification, sq ft	14.5	14.5
Area for thickening, sq ft	9.5	9.5
Volume, gallons	650	650
Recycle pressurization, psig	-	35-60
Air rate, scfm	-	0.36
Surface loading rate, gpm/sq ft	2.0	2.7[a]
Hydraulic residence time, minutes	22	17[a]

[a] Including recycle

Test Period

Flotation was studied from July 9 through September 24, 1971. Pond conditions during the test period were affected by canning operations and are illustrated in Figs. 2 and 3. It was observed that suspended solids in the pond effluent increased when wind stirred up the pond. Alkalinity, after fluctuating in July, rose steadily in August and September. The pH varied both daily and hourly.

Pond solids during initial operations were lower than desired for meaningful test work so the first 9 runs prior to July 22 were used for equipment checkout and modification and establishment of procedure. Between July 22 and August 25, the autoflotation mode was evaluated exclusively and from August 26 to September 25, operation was in the dissolved air flotation mode.

Autoflotation

The principal concern in the study of autoflotation was to establish whether it could be used to dependably accomplish algal removal in the face of fluctuating pond conditions at Stockton.

Successful autoflotation is related to dissolved oxygen concentrations in excess of dissolved oxygen saturation levels (the saturation level is approximately 9 mg/l and depends on liquid temperature). It was found on two occasions that the autoflotation process would not function at all when the dissolved oxygen concentration fell below 8 mg/l. Once the dissolved oxygen concentration was above 13-15 mg/l, the autoflotation process functioned. Since dissolved oxygen levels drop below saturation levels in the night and early morning, autoflotation was inoperative for portions of each day.

The jar test work indicated that pH adjustment is essential for optimum autoflotation performance. The reasons for this appear to be two-fold: (1) alum flocculation is optimum in the pH 6 to 7 range, and (2) a drop in pH increases the level of carbon dioxide (CO_2) in solution. An increase of the CO_2 level in solution will increase the partial pressure of CO_2 and, therefore, increase the probability of bubble formation due to combination of dissolved oxygen and CO_2 to form a bubble.

Adjusting the pH with CO_2 in autoflotation proved to be more effective than pH adjustment with acid. Suspended solids removals with CO_2 for pH adjustment averaged 79 percent; with acid, the suspended solids removal averaged 44 percent (runs 12 to 19). Alum dose ranged from 75 to 200 mg/l, acid, when used, ranged from 1.5 to 2.3 meq/l.

In summary, autoflotation exhibited a potential for algal solids removal, but performance was erratic. Autoflotation depends on the algal system to produce sufficient supersaturation of dissolved oxygen to allow the release, under proper conditions, of fine bubbles. However, this process is not continuous and, therefore, autoflotation could not be relied upon as the only means of algal solids removal. The field evaluation of autoflotation will allow the positive aspects of the phenomenon

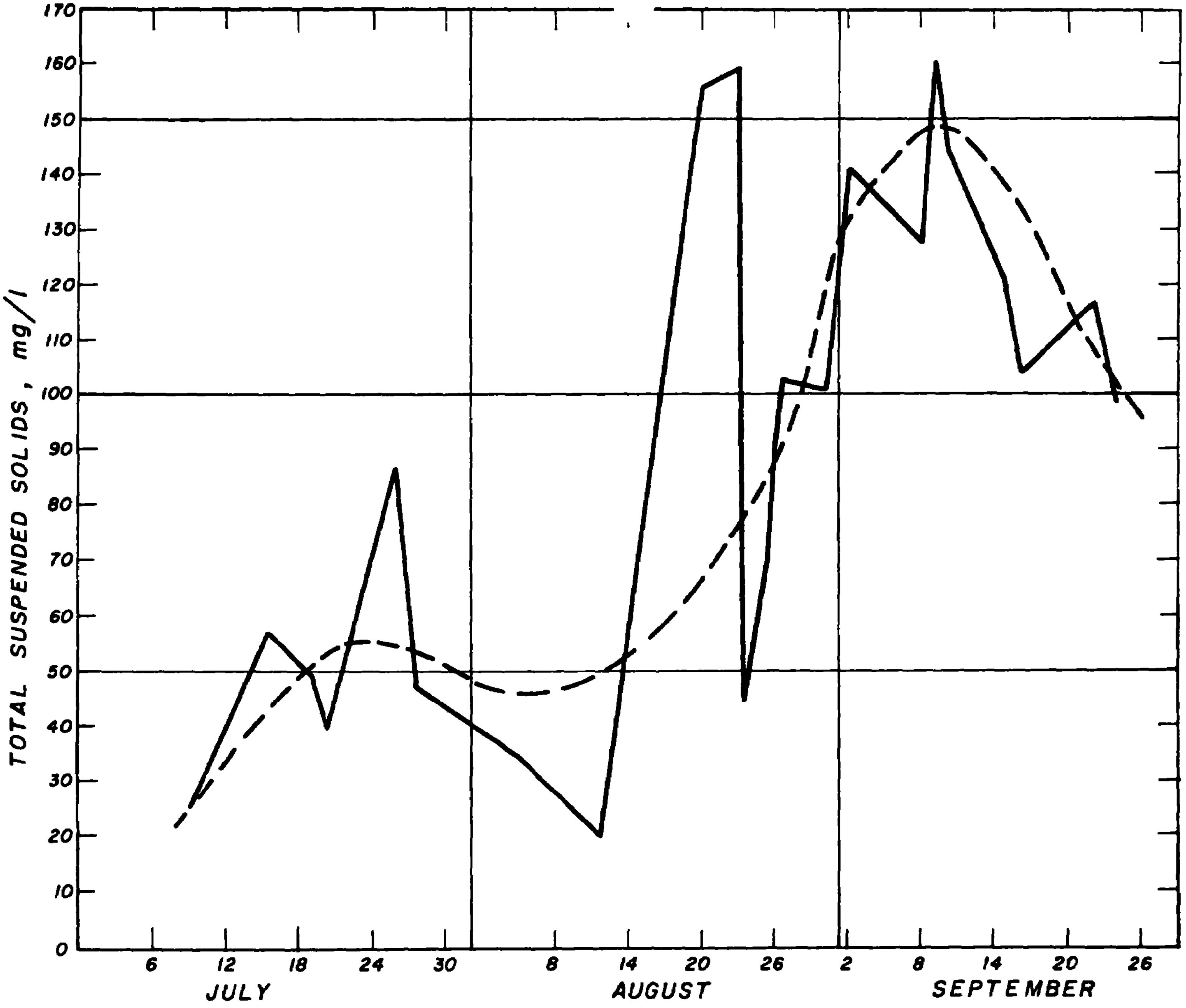


Fig. 2. Suspended Solids in Pond Effluent

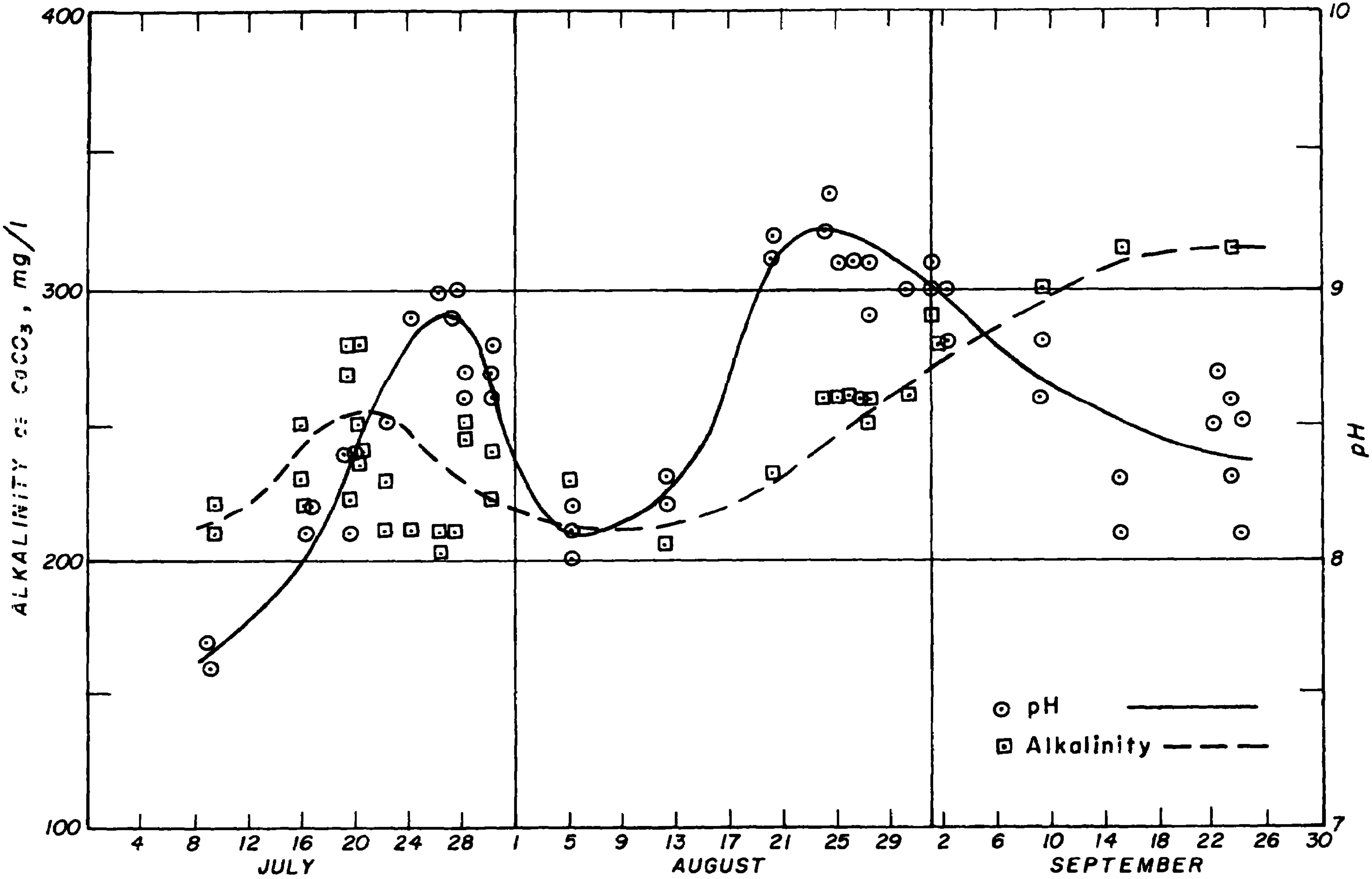


Fig. 3. Pond Alkalinity and pH

to be utilized in the plant design and the negative aspects to be avoided. For instance, autoflotation can be used to assist dissolved air flotation. However, if flocculation-sedimentation is chosen to be the first stage separation process, special efforts would have to be undertaken to avoid the formation of fine bubbles prior to sedimentation and thus avoid flotation in the sedimentation unit.

Dissolved Air Flotation

After the period of somewhat erratic algal separation performance with autoflotation, attention was turned to the evaluation of dissolved air flotation. This involves the mechanical saturation of dissolved air in a portion of the liquid stream (influent or effluent recycle). The release of the dissolved gases to form fine bubbles in the influent stream while adding alum or other coagulants allows the separation of suspended materials to take place by flotation.

Five runs involved the use of alum alone without pH control or coagulant aids. The alum doses ranged from 75 to 225 mg/l and suspended solids removal averaged 72 percent. The highest alum doses were generally associated with high suspended solids concentrations in the pond. Solids levels ranged from 53 to 142 mg/l.

Four runs involved pH control with acid and higher alum doses to demonstrate the ability of flotation to achieve higher removals than were attained when no pH control was used. Suspended solids removal averaged 87 percent for an alum dose of 200 to 250 mg/l and acid addition of 2.0 to 2.7 milliequivalents per liter (meq/l). The acid level was adjusted to yield the optimum pH of 6.4 to 6.5. Suspended solids in the influent during this period ranged from 94 to 152 mg/l.

In summary, once initial operating difficulties were resolved, dissolved air flotation proved to be an effective process for the first stage separation of algae. The separation efficiency is closely related to chemical dose. Since the purpose of the first stage separation process is the preparation of an effluent that is suitable for filtration, the first stage process must be flexible enough to respond to changes in influent quality while maintaining consistent effluent quality. A significant variation in suspended solids can be expected through the canning season (Fig. 2). When suspended material in the pond effluent is low, alum alone in a dose range of 75 to 150 mg/l will yield sufficient suspended solids removal (on the order of 60 to 70 percent) prior to filtration. In portions of August and September when increased canning loads cause an increase in pond effluent solids, the alum dose will have to be increased to 150 to 250 mg/l range with acid pH control in a dose range of 1.5 to 2.7 meq/l. This will increase flotation removals to 85 to 92 percent and yield an effluent suitable for filtration.

Long-Term BOD Removal Efficiency

Samples of flotation influent (pond effluent) and flotation effluent during September were subjected to long-term oxygen demand analyses. Both total and soluble BOD was determined for the influent and effluent samples (Fig. 4). During the peak of the canning season, most of the BOD is associated with the suspended matter. Removal of the suspended material by coagulation and flotation, caused the total effluent BOD to be low and nearly equal to the soluble BOD. The difference between filtered influent and effluent BOD may have been due to the coagulation of colloidal materials.

Float Recovery

In addition to its primary objective of removing the suspended algal material from the liquid stream, flotation demonstrated a unique capability of concentrating the separated materials as float to a much greater extent that can be obtained in sludge concentration by the sedimentation process alone. There are two reasons for this.

First, float removal from the flotation unit takes place on the liquid surface where the operator has good visual control over the thickening process. He, therefore, can see the immediate effects of changes in operating variables such as the speed of the float skimmer, float skimmer submergence, and float blanket depth. Second, thickening of the float takes place by drainage of the liquid from the float. This mechanism has a greater driving force promoting thickening than the mechanism of thickening in sedimentation which involves setting and compaction of the loose algae-alum floc.

During the experimental work, it was found that variation in thickening operation did yield improvements in float concentration. For instance, initial float concentration was improved from 0.13 percent to values averaging 2.45 percent by decreasing the float skimming frequency from 2-3 minutes to 15-30 minutes. A further improvement in float concentration was attained by altering the float skimmer submergence so that the skimmer was positioned slightly above the water surface level to minimize inclusion of water in the float. This increased float concentration to an average concentration of 3.6 percent. This was attained despite the fact that skimming frequency was simultaneously reduced to 7 to 8 minutes.

It was found that an anionic polymer, Dow A-23, could significantly increase float concentration even further (runs 27 to 29). As little as 0.25 mg/l of A-23, employed as a coagulant aid, increased float concentration to 5.3 percent. No improvement in effluent clarity was obtained over the use of alum alone. A cationic polymer, Dow C-31 was also tried, but did not improve either float concentration or effluent clarity when used in conjunction with alum.

In summary, flotation has demonstrated an in-process ability to achieve significant thickening of the algae-alum sludge produced. Such initial thickening has a beneficial impact on the economics of further solids processing, since processing will not require an extra initial thickening step.

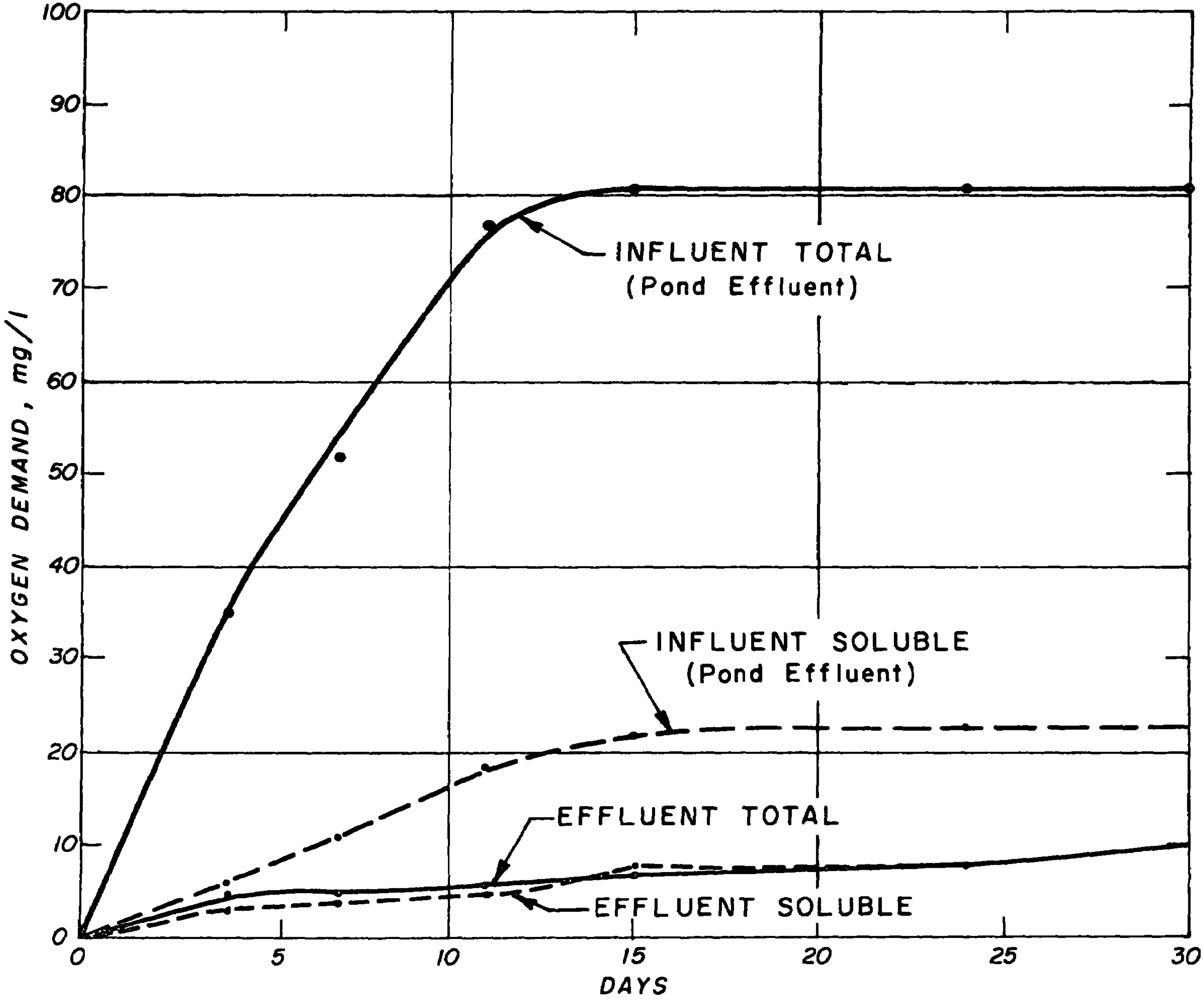


Fig. 4. Oxygen Demand of Flotation Unit
Influent and Effluent

Solids Processing

Solids samples were collected and subjected to alternative treatment processing by various processes on a batch scale.

Heat treatment by the Porteous process at temperatures ranging from 380 to 415°F improved the slurry dewaterability on a vacuum filter, but the process was disappointing in terms of both filter yield and cake concentration. Filter yield was uniformly low in the range of 0.9 to 2.5 pounds per square foot per hour (lbs/sq ft/hr). The highest cake concentration achieved was 21.6 percent total solids with a low value of 8.3 percent, which is not a great improvement over the feed concentration of 4 percent. At these cake concentrations, incineration of the cake would be expensive in terms of fuel costs.

Zimpro low oxidation at temperatures ranging from 180 to 220°C, yielded vacuum filter cake concentrations ranging from 15 to 19 percent total solids at filter yield ranging from 0.67 to 3.05 lbs/sq ft/hr. Incineration of the filter cake under these conditions would still be costly.

Zimpro wet air oxidation was also investigated as a process which would lead directly to ultimate disposal of the sludge. In evaluating this process, cake concentration and filter yield were marginal, indicating that ultimate disposal should incorporate lagoons. In this process, the reduction of volatile solids is the important step in producing a stable end product. The high oxidation process removes about 97 percent of the volatile suspended solids from the sludge. Although some of the volatiles are solubilized in the liquid, the final solids are stable and would be suitable for lagoon storage.

Two other processes investigated were chemical oxidation schemes which employ chlorine as the oxidant. Both of these processes, Pepcon and Purifax, were capable of achieving stabilization of the sludge and yielded a product that could be dewatered on sand drying beds or in a lagoon.

Conclusions

Field tests have proved that dissolved air flotation is a viable alternative to sedimentation for algal removal at Stockton. Further, capital costs will be less owing to the much smaller tanks required for flotation than for sedimentation. If sedimentation facilities were to be designed for canning season use, special attention would have to be given to providing facilities to prevent autoflotation.

The facilities at Stockton will be designed as dual purpose units so that the tanks can be used for sedimentation during the low flow, non-canning period. The system employing flotation and filtration is currently under design. Four 80-ft diameter circular flotation units are planned. By 1974, Stockton will be operating a 55 mgd algal removal facility, the largest of its type in the world.

Acknowledgments

The City of Stockton treatment plant staff, under the direction of Mr. Art Vieira, Utilities Division Superintendent, made all field modifications to the pilot unit and conducted most of the chemical analyses. Certain special analyses were made by Environmental Quality Analysts, Inc., a division of Brown and Caldwell. The flotation unit was rented from the Eimco Division of The Envirotech Corporation.

Test work on solids processing alternatives were run by the Envirotech Corporation, Zimpro, Inc., Pacific Engineering and Production Co. of Nevada, and BIF.

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APPENDIX I:

DESIGN CRITERIA FOR TERTIARY FACILITIES AT STOCKTON

The existing Stockton plant consists of the following sequence of processes: preliminary treatment, primary sedimentation, trickling filters, secondary sedimentation, tertiary ponds, and effluent chlorination. Solids treatment is by digestion and sludge lagoons.

Improvements will be made to all treatment stages. Data summarized here are concerned only with upgrading of the tertiary ponds by algae removal.

Design data for the existing ponds, the algal removal facility, and chlorine contact channel are shown in Table 2, while the process flow diagram is shown in Fig. 5.

The chlorine contact channel is a multipurpose unit serving for chlorine contact, backwash water storage, ammonia removal by superchlorination, dechlorination with sulfur dioxide, and post-aeration.

The original cost estimate for the tertiary facilities (excluding the ponds) was $3,600,000 (December 1972 prices), but was for a facility using sedimentation rather than flotation. The revised design required smaller tanks: four 85 ft. diameter flotation tanks with 7 ft. side water depth instead of four 130 ft. diameter sedimentation tanks with 20 ft. side water depths. A revised cost estimate has not been completed by November 1, 1972.

Annual operating costs of the tertiary facility (excl. ponds) are estimated at $40 to $45/MG, based on year-round operation of the tertiary facilities (1972 costs prorated to design year flows).

Table 2. Design Data for Stockton Tertiary Facilities

Component	Quantity
Tertiary ponds (existing)	
Number	4(4)
Area, net water surface, acres	630
Volume, mg	1,320
Loading during noncanning season	
BOD total, 1000 lbs/day	3.2
BOD lb/surface acre/day	5
Loading during canning season	
BOD total, 1000 lbs/day	57
BOD lb/surface acre/day	90
Detention during noncanning season, days	57
Detention during canning season, days	23
Circulation pumping units	
Number	3
Capacity, each, mgd	65
Circulation ratio (at peak)	3.4
Flotation tanks (new)	
Peak weekly flow rate, mgd	55
Number	4
Diameter, ft	85
Sidewater depth, ft	7
Surface loading rate gallons/sq ft/day (incl. pressurized flow)	2.7
Solids loading rate, lbs/sq ft/day	6.8
Pressurized flow, percentage of total	26
Pressurized, psig	40
Alum dosage, mg/l, peak rate	250
Polymer dosage, mg/l, peak rate	1
Acid dosage, peak, ml/l	3
Assumed float concentration, percent	3
Assumed float weight, lbs/cu ft	41
Float collection arms, number each tank	4
Float collection troughs, number each tank	2
Peak float discharge rate, gpm	600

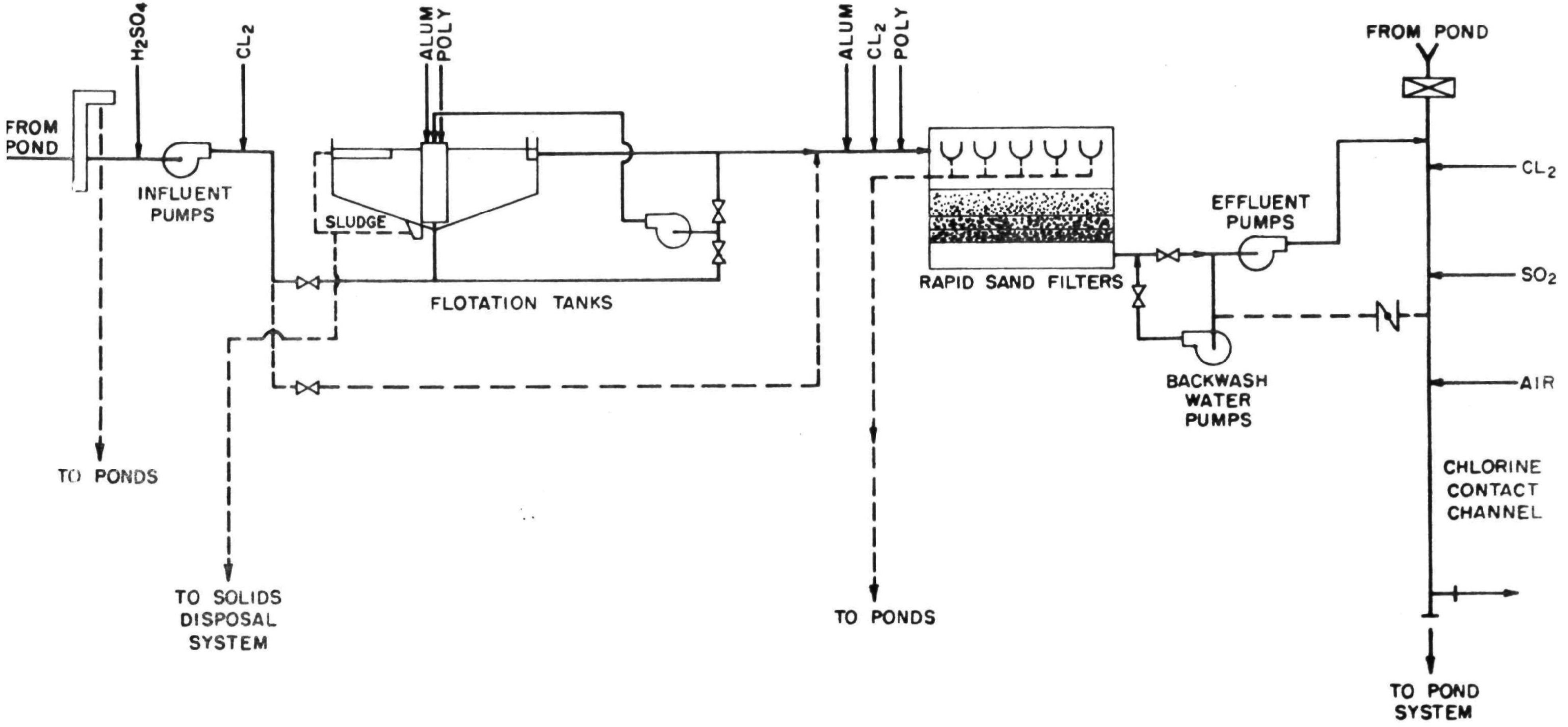


Fig. 5 Tertiary Algal Removal Facility

Table 2 (cont'd)

Component	Quantity
Filters (new)	
Number	4
Area per filter (bifurcated), sq ft	1,700
Design filtration rates, gpm/sq ft	
All filters in service	5.6
One filter backwashing	7.4
Anthracite coal	
Depth, ft	4
Effective size, mm	2.4-4.8
Sand	
Depth, ft	1.5
Effective size, mm	0.8-1.0
Pea gravel	
Depth, ft	0.62
Backwash	
Air	
Rate, cfm/sq ft	4
Pressure, psig	5
Water	
Wash rate, gpm/sq ft	
Minimum	10
Maximum	20
Chlorine contact canal (new)	
Length, ft	1,000
Depth, ft	6
Average width, ft	27
Residence time, peak flow, min	30
Chlorine disinfection dosage rate, mg/l	15
Chlorine for NH_3 removal, lbs Cl_2 per lb ammonia (NH_3)	12
Sulphur dioxide dosage, peak, mg/l	5
Reoxygenation, mg/l	5

COUNTY SANITATION DISTRICTS
OF
LOS ANGELES COUNTY

2020 BEVERLY BOULEVARD
LOS ANGELES, CALIFORNIA 90057

JOHN D. PARKHURST
CHIEF ENGINEER AND GENERAL MANAGER

TELEPHONE
(213) 484-1370

13 October 1972

Denny Parker
Brown and Caldwell
66 Mint Street
San Francisco, California 94103

Dear Mr. Parker:

This letter is in reply to your phone request for data concerning the Lancaster Tertiary Treatment Plant.

Construction Cost: $243,000
Design Flow: 0.5 MGD

Processes:
- Coagulation
- Sedimentation
- Filtration
- Chlorination

Operation Costs:	70-71 (11/23/70 to 6/30/71)	71-72 (7/1/71 to 6/30/72)
Cost of Operation	$19,033	$28,273
Cost per MG Treated	256	199
Cost per MG Delivered	325	238
Total Water Treated(MG)	74	142
Total Water Delivered(MG)	59	119
Overall Plant Efficiency(%)	79	83

Also enclosed is a Monthly Summary of Operation Report for August 1972. If you desire any other information do not hesitate to contact the Districts.

Sincerely yours,

John D. Parkhurst
Chief Engineer & General Manager

By
Kip Payne, Supervisor
Monitoring Section
Technical Services Department

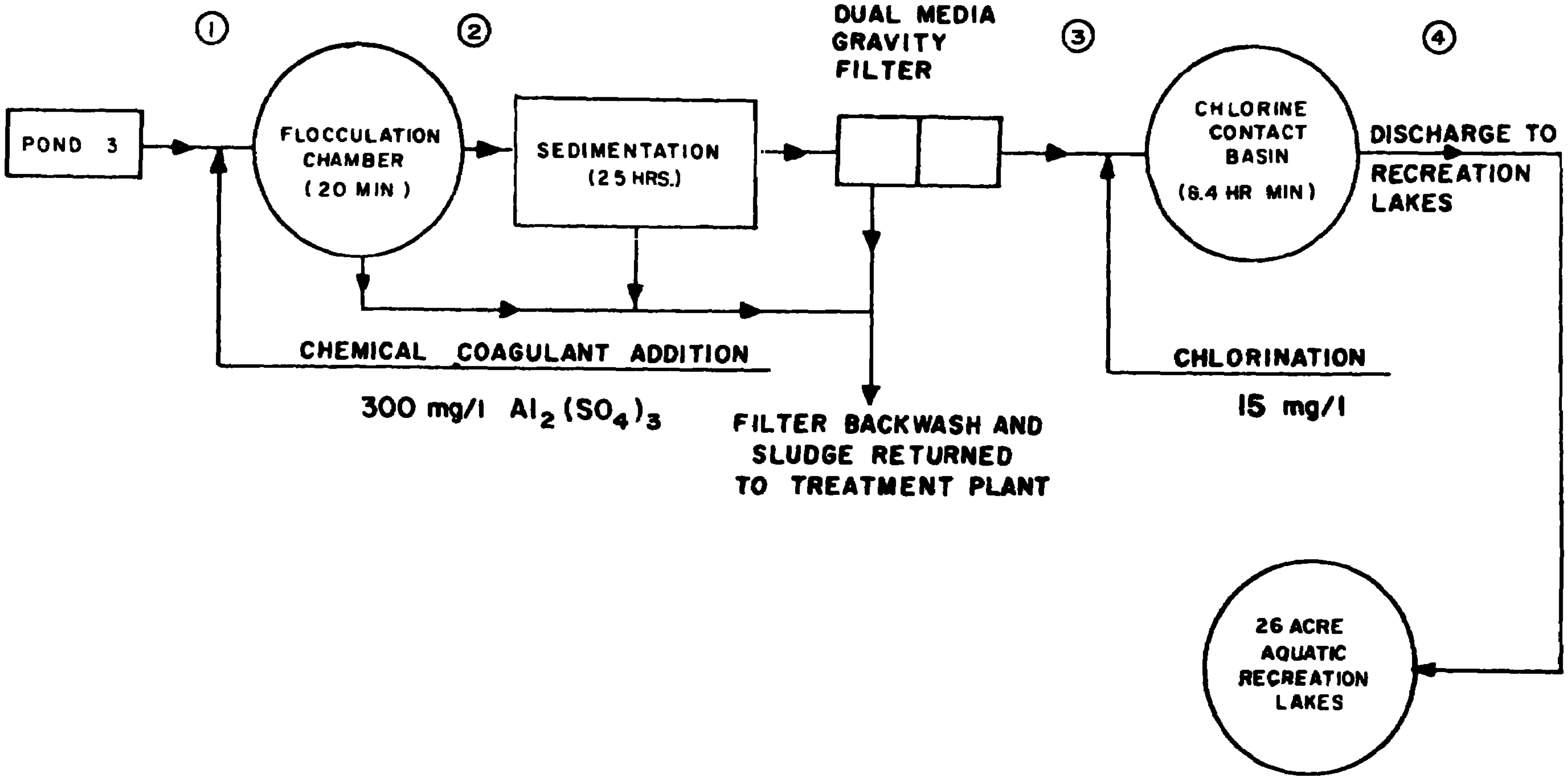
JDP:KP:vic
Encl.

APPENDIX II:

LANCASTER TERTIARY TREATMENT PLANT

PROCESS FLOW DIAGRAM

FLOW = 500,000 GALLONS PER DAY



ANTELOPE VALLEY TERTIARY TREATMENT PLANT

LANCASTER 1/1

COUNTY SANITATION DISTRICTS
OF LOS ANGELES COUNTY, CALIF
JOHN D PARKHURST - CHIEF ENGINEER & GENERAL MANAGER

MONTHLY SUMMARY OF OPERATION

DATE AUGUST 1972
MONTH

DATE	FLOW						SAMPLE		pH		ALKALINITY AS $CaCO_3$	SUSP SOLIDS	AMMONIA AS NH_3	TOTAL PHOSPHATE AS PO_4		TURBIDITY	CHLORINE		SLGE	ALUM USED	BACKWASH	CHLORINE #/DAY INF	CHLORINE #/DAY FILT EFF	INF TEMP °F	PLANT SHUTDOWNS- TIMES & REASONS	DATE
	INF MGD	ALUM DOSE mg/l	EST'D INF FLOW MGD	EST'D ALUM DOSAGE ppm MGD	FINAL EFF MGD	DOWN TIME HRS	TYPE	TIME	INF	FLOC CHAMB	INF mg/l	INF mg/l	INF mg/l	INF mg/l	EFF mg/l	EFF JTU	DOSE #/DAY	RESID ppm	GPM	GAL/24 HRS	DURING LAST 24 HRS					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24		
1	0.618	330			0.521	0	Grab	8 AM	9.20	6.13	250	214	0	34.84		4.8	70	0.7		330	1	40	30	76°		1
2	0.578	359			0.501	0			9.20	6.14		128		30.15		1.9	70	0.7	77	350	2	40	30			2
3	0.621	319			0.535	0		8 AM	9.21	6.13	252	100		32.06		1.4	70	0.7		310	0	40	30	71°		3
4	0.630	357			0.526	0			9.35	6.12						1.2	70	0.8		350	1	40	30			4
5	0.460	380			0.382	8.0			9.20	6.15						1.0	70	0.7		270	1	40	30		Electrical power failure	5
6	0.619	320			0.515	0.5			9.11	6.09						1.4	70	0.7		310	1	40	30		Electrical power failure	6
7	0.653	338			0.567	0		8 AM	9.15	6.11	250	188	0	30.82		1.4	70	0.5		360	1	40	30	75°		7
8	0.628	337			0.524	0.5			9.20	6.13		182		40.80		1.4	70	0.6		330	1	40	30		Chlorine analyzer failure	8
9	0.689	307			0.571	0			9.30	6.15		186		34.17		1.4	70	0.7	76.5	330	1	40	30			9
10	0.580	287			0.476	0.3		8 AM	9.25	6.15	262	184		36.36		1.2	70	0.7		260	1	40	30	73°	Chlorine ran out	10
11	0.554	462			0.577	0			9.40	6.18						1.4	70	0.7		400	1	40	30			11
12	0.683	352			0.546	0			9.10	6.10						0.8	70	0.7		350	2	40	30			12
13	0.734	327			0.594	0			9.20	6.10						1.0	70	0.7		375	2	40	30			13
14	0.645	348			0.515	0		8 AM	9.30	6.12	248	152		26.80	0.20	0.8	70	0.7	72	350	2	40	30	71°		14
15	0.695	308			0.563	0		8 AM	9.40	6.18		152	0	28.14	0.20	0.9	70	0.8		335	1	40	30			15
16	0.712	297			0.578	0		8 AM	9.38	6.18		120		28.14	0.21	1.0	80	0.6	75	330	2	40	40			16
17	0.724	326			0.598	0		8 AM	9.38	6.18		128		26.80	0.17	0.8	80	0.7		370	1	40	40			17
18	0.715	305			0.571	0		8 AM	9.38	6.20	250	120		28.14	0.20	0.9	80	0.8		340	2	40	40	66°		18
19	0.736	308			0.623	0		8 AM	9.40	6.20		116		27.47	0.20	0.8	80	0.7	66	355	1	40	40			19
20	0.716	308			0.603	0		8 AM	9.32	6.20		132		30.82	0.18	0.8	83	0.8		345	1	40	43			20
21	0.676	303			0.581	0		8 AM	9.42	6.20	248	116	0	31.50	0.18	0.8	83	0.8		320	0	40	43	67°		21
22	0.712	319			0.597	0.1			9.10	6.22						1.2	83	0.6		355	2	40	43		Duck in influent meter	22
23	0.730	303			0.602	0		8 AM	9.28	6.20		124		26.80	0.32	0.8	83	0.7	64	345	2	40	43			23
24	0.672	319			0.562	0.1		8 AM	9.30	6.12	252	136		28.14	0.10	0.5	83	1.0		335	1	40	43	69°	Duck in influent meter	24
25	0.751	298			0.641	0		8 AM	9.38	6.20	250	116		25.46	0.12	1.0	90	1.5		350	1	40	50	68°		25
26	0.758	284			0.648	0.5		9 AM	9.30	6.20		124		28.81	0.28	1.0	83	0.7		335	1	40	43		Electrical power failure	26
27	0.302	280			0.246	10.0		10 AM	9.35	6.20		144		27.47	0.36	0.9	35	0.5		140	1	17	18		Electrical power failure	27
28	0.729	271			0.615	0			9.25	6.20	250	104		25.46	0.28	1.1	90	1.6	65	310	1	40	50	71°		28
29	0.697	322			0.583	*1.0			9.20	6.45						1.1	90	2.3		350	1	40	50			29
30	0.505	270			0.321	*10.0			9.20	6.48						0.8	56	2.0		220	1	24	30			30
31	0.769	296			0.657	0		10 AM	9.10	6.50		124		26.80	0.14	1.0	83	0.9		355	1	40	43			31
SUM																										SUM
AVG	0.654				0.546																					AVG

REMARKS:

- * Cleaned chlorine contact chamber, installed variable speed motor on flight drive, and installed baffle between flocculation chamber and sedimentation tank.