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# OVERLAND FLOW OF OXIDATION POND EFFLUENT AT DAVIS, CALIFORNIA

by

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# AT DAVIS, CALIFORNIA

Oxidation ponds are one of the most commonly employed secondary wastewater treatment systems in the United States for systems with average dry weather flows of approximately 0.2 cu m/sec (5 mgd) and less. Oxidation pond systems are generally easy and inexpensive to operate and maintain but require larger land areas than conventional systems. Thus, they are cost-effective for smaller communities where land is usually less costly than in urban areas.

Oxidation ponds are an effective method of waste stabilization except for the large concentrations of algae carryover in the effluent. This algae is the source of high suspended solids measurements, and decomposition results in oxygen demand in the receiving waters. The EPA definition of secondary treatment requires a 30-day average value of 30 mg/l or less for suspended solids and $BOD_5$. A process for algae removal will enable oxidation pond systems to meet secondary treatment requirements.

This paper reviews the analysis of algae removal alternatives examined for Davis, California, and describes pilot studies of overland flow as a new approach to algae removal. The pilot study was a crucial part of the selection process leading to recommendation of an alternative.

## BACKGROUND

The original sewerage system in Davis discharged effluent, after treatment in an Imhoff tank and rock filter, to the old Putah Creek channel approximately 600 m (2,000 ft) south of the city. In 1950 trunk sewers and pumping stations were constructed and a new plant was constructed about three kilometers (two miles) north of Davis. This plant had primary facilities for domestic flow with a capacity of 0.048 cu m/sec (1.1 mgd) and a total of approximately nine hectares (22 acres) of oxidation ponds. The primary facilities consisted of preaeration and sedimentation tanks, a sludge digester and digested sludge drying beds.

In 1958 separate industrial waste treatment facilities were constructed at this same location to handle tomato and peach processing wastes generated by a local cannery, Hunt-Wesson. These facilities included a 0.6-m (24-in.) industrial waste sewer from the cannery to the treatment plant, a separate industrial waste pumping station, and 50 hectares (122 acres) of waste stabilization ponds.

A 1961 survey of the sewerage system by Brown and Caldwell[1] indicated that the domestic wastewater treatment facilities had reached capacity. In addition to a series of trunk sewer system improvements, a staged expansion of the treatment plant was recommended. However, these improvements were not undertaken.

In 1968 a new sewerage study was prepared by Brown and Caldwell for the City of Davis.[2] In the interim period, both the domestic facilities and the cannery stabilization ponds of the existing 77-hectare (186-acre) site had become significantly overloaded. Because of disadvantages of the existing site and the inability to incorporate existing facilities in alternative treatment plans, the 1968 report recommended a site about eight kilometers (five miles) northeast of downtown Davis.

At the time of the 1968 study, consideration was being given to consolidation of sewerage from the El Macero District, located to the southeast, with that of Davis. Analysis indicated that it would be less costly for both Davis and El Macero to treat their combined flow at this eastern site.

Soon after the 1968 report was issued, the only major industrial contributor, Hunt's Cannery, elected to provide their own separate treatment facilities near the location of the recommended site for the Davis facility. The new Hunt's facility provides screening of raw wastewater at the cannery. Screened waste is conveyed to a 91-hectare (220-acre) overland flow site and applied directly through 1.6 cm (5/8-in.) spray irrigation nozzles. Overland flow effluent from the Hunt's facilities is collected in open ditches at the bottom of terraces and discharged to the Willow Slough Bypass. This facility operates about four months per year. Well water is used for irrigation in other months to maintain the grass. The Hunt's facility has experienced difficulty in meeting effluent limitations during the initial part of their yearly operation because of inherent start-up problems in the overland flow scheme.

Design data for the present Davis treatment plant, completed in 1974, are given in Table 1 and the plant layout is shown in Figure 1. The plant was constructed to accommodate a population of 45,000 with an initial average dry weather flow of 0.22 cu m/sec (5 mgd) and a maximum dry weather flow of 0.44 cu m/sec (10 mgd). The plant is designed for a peak wet weather flow of 0.88 cu m/sec (20 mgd). Provision was envisioned during the 1970 design studies for the site to be able to eventually accommodate a design population of 240,000 by replacing the oxidation ponds with an activated sludge secondary treatment facility.

The initial treatment facilities include coarse screening, prechlorination, influent pumping, comminution, preaeration and grit removal and primary sedimentation. Secondary treatment is provided by three oxidation ponds operated in parallel. Final effluent disposal is through an outfall to Willow Slough Bypass after the oxidation pond effluent is chlorinated. Sludge digestion, with dewatering and disposal in holding basins, is provided for sludge from the primary sedimentation basins. Pumping units are provided for effluent pumping during extreme flooding in Willow Slough Bypass, and postchlorination facilities are available if required.

The three-pond system of 50 hectares (120 acres) includes circulation channels to provide for load distribution as well as initial mixing. Return flow through the ponds of up to six times the influent volume can be attained. With the influent discharged to the channel ahead of the recirculation pumps, intimate mixing is immediately achieved. Both pond inlets from the channel and outlets to the channel are through grated culvert type ports operating partly full so that scum does not accumulate. Outlet ports are downwind so that scum is effectively prevented from forming on the pond and any that does form is redispersed in the circulating water by the pumps. Provision is made so that effluent can be discharged either from the return channel or from the final pond if the ponds are operated in series. The ponds provide a minimum of 39 days detention for design flow conditions.

Water level in the ponds is controlled by a weir in the plant effluent control structure. Effluent spills over the weir and drops about eight feet where it discharges through the outfall to Willow Slough Bypass. Discharging in this

## Table 1. Design Data for Existing Facilities

| Design Factor | Value |
|---|---|
| **Design Flow** | |
| Average dry weather, mgd | 5 |
| Maximum dry weather, mgd | 10 |
| Peak wet wather, mgd | 20 |
| **Design Loadings** | |
| Design population, thousands | 45 |
| Biochemical oxygen demand, 1000 lb/day | 11 |
| Suspended solids, 1000 lb/day | 11 |
| **Raw Sewage Pumps** | |
| Number | 2 |
| Capacity, each, mgd | 20 |
| Total dynamic head, PWWF, feet | 40 |
| Rated horsepower per unit | 200 |
| **Raw Sewage Screening Equipment** | |
| Comminutors, number | 2 |
| Channel width, feet | 4 |
| **Aerated Grit Tanks (preaeration tanks)** | |
| Number | 1 |
| Detention time at avg. dry weather flow, hrs | 0.48 |
| Air supplied, cfm to tanks | 300 |
| Air supplied, cfm to channels | 360 |
| **Chlorinators** | |
| Number | 2 |
| Capacity, each, lb/day | 2000 |
| **Plant Outfall Sewer** | |
| Number | 1 |
| Size, inch diameter | 60 |
| **Emergency Generator** | |
| Number | 1 |
| Generator rating, kw | 300 |
| Engine horsepower | 335 |
| **Sludge Digestion Facilities** | |
| Digesters | |
| Number | 1 |
| Total volume, 1000 cu ft | 78.5 |
| Loading, 1000 lbs dry solids per day | 7.15 |
| Detention at 4 percent solids, day | 27 |
| Gas produced, 1000 cu ft per day | 45 |
| Assumed solids reduction, percent | 40 |
| Digested sludge, 1000 lbs dry solids/day | 4.3 |
| **Sludge Holding Basins** | |
| Number | 2 |
| Net area, acres | 2 |
| Total volume, 10 ft depth, mil cu ft | 0.85 |
| Solids loading | |
| Million lb per year | 1.55 |
| Lb per cu ft | 18.5 |
| Capacity, solids, mil lb | 15 |
| **Primary Sedimentation Tanks** | |
| Number | 2 |
| Detention time at avg dry weather flow, hrs | 1.5 |
| Overflow rate at avg dry weather flow, gal/sq ft/day | 1,060 |
| Mean forward velocity, fpm | 1.36 |
| Maximum hydraulic capacity, mgd | 10 |
| Raw sludge pumps, number | 2 |
| Scum ejectors, number | 1 |
| **Assumed Primary Treatment Efficiency** | |
| BOD removal, percent | 35 |
| Suspended solids removal, percent | 65 |
| **Oxidation Ponds** | |
| Number | 3 |
| Total area, acres | 120 |
| Average depth, feet | 5 |
| Total volume, mil gal | 196 |
| Detention at avg dry weather flow, days | 39 |
| **Pond Circulation Pumps** | |
| Number | 2 |
| Capacity, each, mgd | 15 |
| Total dynamic head, feet | 3.5 |
| Rated horsepower per unit | 15 |
| **Chlorine Contact Tank** | |
| Total volume, 1000 cu ft | 9 |
| Contact time at avg dry weather flow, minutes | 20 |

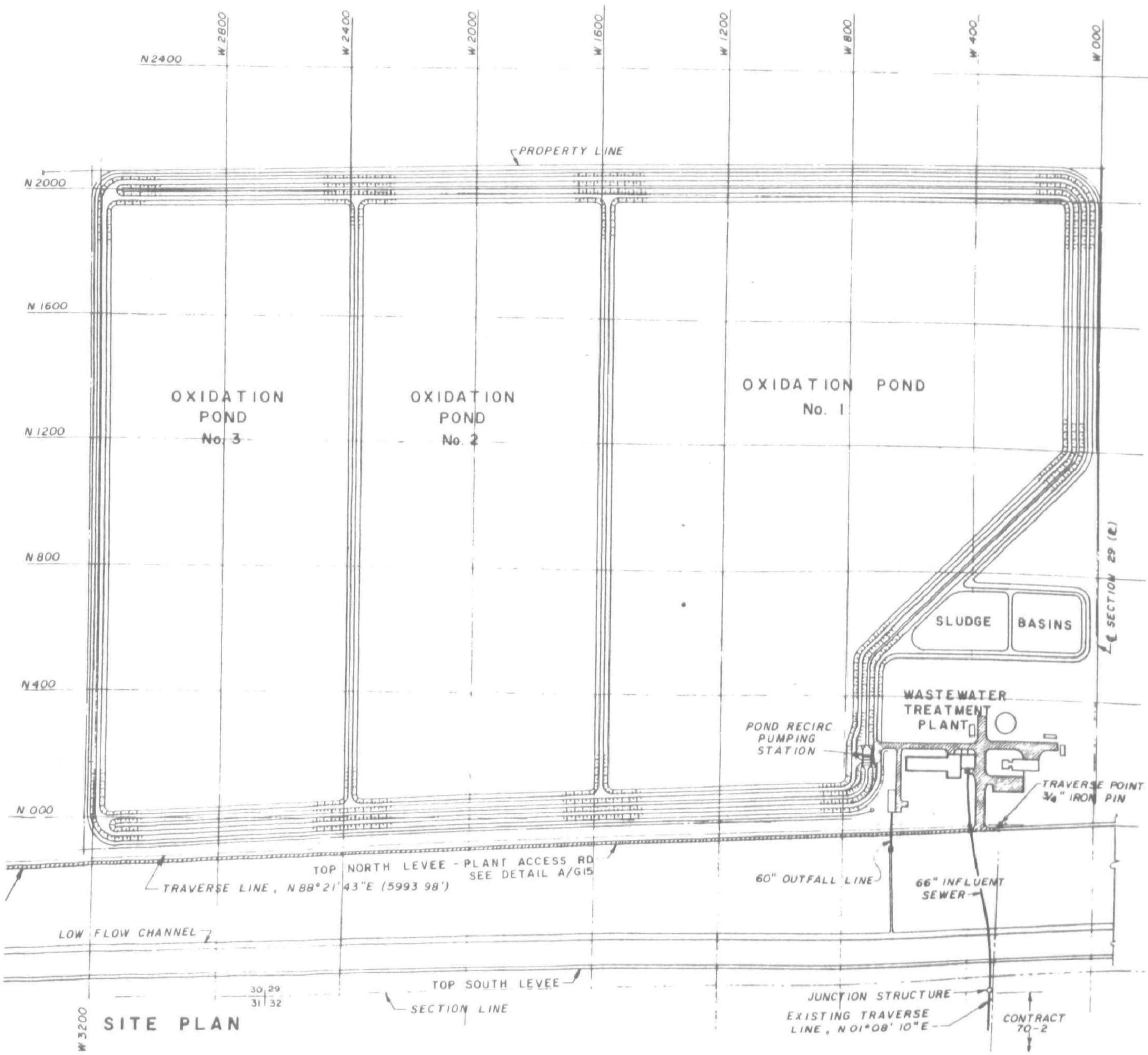


Figure 1 Layout of Existing Davis Treatment Plant

manner is intended to aid photosynthesis in the ponds and to maintain a near-saturation DO in the effluent at all times. The effluent flows east in Willow Slough Bypass a distance of about two miles to Yolo Bypass. The Willow Slough Bypass does not receive flow from Willow Slough during dry weather. It is a shallow ditch during dry weather receiving some agricultural runoff. Dissolved oxygen downstream from the Davis discharges is generally not depleted but tends to remain at near-saturation levels. The waste discharge requirements in effect at the time of the existing treatment facilities design were adopted by the Central Valley Regional Water Quality Control Board on December 1, 1969, by Resolution No. 70-104. The applicable provisions include a receiving water limitation stating that discharge shall not depress dissolved oxygen content of Yolo Bypass waters below 5 mg/l at any time.

The federal definition of secondary treatment was taken into consideration by the Regional Board in establishing 1977 discharge requirements for Davis. The requirements include a limitation of $BOD_5$ and suspended solids to a 30-day average of 30 mg/l. The 30-day median total coliform organism concentration is limited to 23 MPN/100 ml. Average daily dry weather discharge is limited to 18,700 cu m (five million gallons) and pH must be between 6.5 and 8.5. Davis is required to limit mineralization to no more than a reasonable increment and not to cause dissolved oxygen concentration in Willow Slough Bypass to fall below 5.0 mg/l.

In 1975 the Davis pond effluent average suspended solids concentration was 74 mg/l. The average for the highest month (April) was 93 mg/l and the low monthly average (December) was 56 mg/l. Because a significant portion of the effluent $BOD_5$ from oxidation ponds is made up of biodegradable cell solids, the effluent $BOD_5$ values during 1975 were high, although they were still generally below the 30-mg/l level. Average $BOD_5$ for the maximum month was 27 mg/l. Average 1975 $BOD_5$ was 19 mg/l for the pond effluent.

For analysis of alternatives to meet the new discharge requirements, estimates of primary treatment efficiency were based on the design assumptions for the existing facilities, as developed in the 1970 design study. Estimated primary $BOD_5$ removal efficiency is 35 percent. Estimated primary suspended solids removal efficiency is 65 percent. For design conditions, the average peak month outflow at the Davis facilities is estimated to be 0.21 cu m/sec (4.75 mgd), taking into consideration oxidation pond evaporation. Under present conditions of an average dry weather inflow of 0.12 cu m/sec (2.73 mgd), oxidation pond evaporation during much of the late summer and fall allows zero discharge. At design inflow conditions, discharge would occur year-round.

An operations staff of eight people is located at the treatment plant. All wastewater management functions are the responsibility of the director of public works. Total operation and maintenance cost for the 1975/76 fiscal year was $342,300, which included costs for the collection system, treatment facilities, and general administration. Based on an average flow of 0.12 cu m/sec (2.73 mgd), this is a cost of 9.0 cents/cu m (34 cents/1000 gallons). For the treatment facilities only, average operation and maintenance cost for the 1975/76 fiscal year was 5.8 cents/cu m (22 cents/1000 gallons).

## ALTERNATIVES FOR IMPROVED TREATMENT

The principal objective of the planned facilities improvement at Davis is to provide treatment which will produce an effluent suspended solids levels which meets the new discharge requirements. Alternatives were considered under several categories including replacement of existing treatment processes and additions to the existing system.

Alternatives considered for implementation at Davis were compared in several ways. A principal consideration was cost-effectiveness, which includes a monetary cost analysis and an environmental and social impact analysis. Other important factors may also affect an alternative's suitability. Two important categories of criteria are "engineering effectiveness" and "conformance with identified constraints." Engineering effectiveness concerns the ability of an alternative to perform as planned and to be free of mechanical breakdowns. Identified constraints include relevant local, state, and federal laws; administrative guidelines and regulations; and the opinions and goals of the affected community.

Preliminary estimates of construction costs for the alternatives were developed principally from the experience of Brown and Caldwell in designing similar facilities. Supplemental cost information on overland flow and intermittent sand filtration was taken, respectively, from "Costs of Wastewater Treatment by Land Application,"[3] and "Intermittent Sand Filtration to Upgrade Existing Wastewater Treatment Facilities."[4]

Construction cost estimates used in the Davis analysis were based on an ENR Construction Cost Index of 3200, a value expected to be applicable in September, 1977 and which is equal to 97 percent of the San Francisco ENR Index projected for September, 1977. Cost data given herein can be related to current price levels at any time by applying the ratio of the ENR Index prevailing at the time to 3200.

A contingency allowance was also made for uncertainties unavoidably associated with preliminary designs. Such factors as changes in design criteria, necessity for special construction methods, or unusual foundation conditions may increase construction costs, and some allowance must be made in preliminary design estimates. The allowances used for construction contingencies and engineering together were 30 percent of the basic construction cost for categories A and C (described below), and 35 percent for category B alternatives, because less historic cost data was available.

Annual operation and maintenance includes all costs for labor, power, chemical supplies, laboratory control and monitoring, administration, and incidental costs chargeable to various components of the system improvements. Estimates of annual labor requirements for the various alternatives were based primarily on the experience of Brown and Caldwell, with some information for the overland flow alternatives taken from "Costs of Wastewater Treatment by Land Application."[3] It was assumed that the effective annual labor contribution of one man is 1,450 hr, or 6.5 hr per day, with 38 days off for vacation, sick leave, and holidays. The annual cost of one employee was taken as $16,000 per year, including fringe benefits and overhead. Electrical power costs were taken as $0.02 per kwh. Chemical costs were based on current estimates escalated to projected 1978 values.

The feasible alternatives considered for the Davis analysis fall into three main categories. The substitution of conventional secondary treatment processes was considered under the first (category A). The second category (B) considered additional treatment to polish oxidation pond effluent. Land disposal was considered as a third category (C). The remainder of this paper is divided into sections dealing with each category and a concluding section summarizing the comparison of alternatives.

Secondary Treatment Replacement

Under the first set of alternatives (category A), abandoning the ponds and substituting a new secondary treatment process, fall those solutions which can be classified as "traditional" or "standard" approaches to wastewater treatment. These are secondary biological treatment processes which usually follow primary sedimentation; the present primary sedimentation tanks at Davis would be retained for use in the treatment scheme. To fully meet all the discharge requirements at Davis, chlorine disinfection and dechlorination for toxicity removal would follow the biological treatment process. An important characteristic of these processes is that most of them produce an additonal quantity of wastewater solids which must be treated and disposed of. Solids removed in the primary sedimentation tanks at Davis are presently treated by anaerobic digestion and then stored in sludge lagoons before final disposal to land. Because present solids loadings at Davis are lower than anticipated at the time of design, it is believed that the increased solids production resulting from the addition of a biological treatment process could be accommodated by the existing digester. However, to provide for the slightly increased solids loading, a third sludge lagoon would be added.

Three alternatives were considered under category A. These were the conventional activated sludge process, trickling filtration, and the extended aeration variation of the activated sludge process. Because a portion of the existing ponds could be used for aeration basins, and because the extended aeration process produces a very small quantity of biological solids, it was initially believed that this alternative would show up well in the comparison.

Alternative A-1: Activated Sludge. The analysis was based on an aeration tank volume of 3,220 cu m (115,000 cu ft) which would provide a volumetric loading of 0.64 kg $BOD_5$/cu m/day (40 lb/1,000 cu ft per day) and an organic loading of 0.5 kg $BOD_5$/kg MLVSS per day at an MLSS concentration of 1,500 mg/l. Use of a portion of the existing oxidation ponds for emergency and peak wet weather flow storage would allow use of a single two-pass aeration tank and a single secondary clarifier with an ADWF overflow rate of 21.4 cu m/day/sq m (525 gpd per sq ft). Avoiding duplicate, parallel units would reduce the costs for this portion of the plant. It is anticipated that the storage basins could be used whenever the plant flow exceeds 0.44 cu m/sec (10 mgd) or whenever a portion of the secondary treatment process must be shut down.

A third sludge lagoon would be required in order to receive the increased quantity of digested sludge. Capital and operating costs would be reduced substantially by avoiding construction of a second digester.

Estimated capital costs for Alternative A-1 were $3.54 million. The capital cost for the activated sludge process was the highest of the seven alternatives. Additional operation and maintenance (above that required for the existing plant) cost was estimated at $172,000 per year.

Alternative A-2: Trickling Filtration. The trickling filter system would replace the oxidation ponds as the secondary treatment step and would consist of a trickling filter and clarifier with clarifier underflow pumped to the digester. The existing oxidation ponds would be retained to provide wet weather peak flow and emergency storage of primary effluent. A plastic media trickling filter, sized for the average design flow rate of 5 mgd with a 1:1 recirculation, would be designed for an organic loading rate of 1.0 kg $BOD_5$/cu m/day (60 lb per 1,000 cu ft per day). The filter would require a media volume of 3,640 cu m (130,000 cu ft); cost analysis was based on a center shaft rotating distributor system.

The clarifier would be sized for an average flow of 0.22 cu m/sec (5 mgd), with an average overflow rate of 40.7 cu m/day/sq m (1,000 gpd per sq ft). Capital costs for the trickling filtration alternative were estimated at $2.91 million. Additional operation and maintenance costs were estimated at $90,000 per year.

Alternative A-3: Extended Aeration (Pond Modification-Aerated Lagoons). Oxidation pond No. 1 would be modified to contain three extended aeration basins. The mid-depth area of each basin would be 3,260 sq m (35,000 sq ft) in order to provide a total volume of 23,400 cu m (835,000 cu ft). Aeration basins would be situated in the oxidation pond so as to utilize a portion of the existing pond levee. A portion of oxidation pond No. 1 would be used as a storage basin to regulate peak wet weather flows and to provide emergency storage. Activated sludge would be returned from the clarifier to the aeration basins to maintain desired mixed liquor suspended solids concentration. Aeration and mixing in the ponds would be provided by floating surface aerators anchored to concrete pads in the basins. The analysis was based on the assumption of a clarifier designed for an average flow of 0.22 cu m/sec (5 mgd), with a peak overflow rate of 60 cu m/day/sq m (1,400 gpd per sq ft) at 0.44 cu m/sec (10 mgd). Because solids production from the extended aeration process is low, additional anaerobic digestion capacity would not be provided. Sludge lagoon capacity would be increased to receive increased loadings.

Capital costs for Alternative A-3 were estimated at $2.38 million. Operation and maintenance costs were estimated at $170,000 per year. An important component of operating costs is for power to operate the mechanical aerators. In addition to power for oxygenation, sufficient energy must be expended to prevent particles from settling in the relatively large basins. This added requirement increases power costs considerably.

Analysis. The category A alternatives would generally involve construction within the boundaries of the existing treatment plant site, so that environmental impact is localized. The major environmental impact of the alternatives in the A category was a potential negative impact resulting from the reduction in a valuable waterfowl sanctuary created by the oxidation ponds. Maintenance of pond capacity for storm flows was a potential mitigating measure for winter conditions, but the ponds might have had to be drained in the summer to prevent conditions conducive to wild fowl botulism. These alternatives would have continued to support wildlife habitat in Willow Slough Bypass through continued discharge to the bypass.

In terms of reliability to perform as planned, the group A alternatives were rated highest. The activated sludge process, trickling filtration, and extended aeration in aerated lagoons are all well-known conventional treatment processes for which design criteria and operating procedures are well-established. They can be expected to consistently meet the discharge requirements at Davis.

The most likely future change in surface discharge requirements is the imposition of a requirement calling for nitrogen removal. This would occur if future studies indicate that water quality in the Delta-Suisun Bay area is being impaired by high nitrogen levels and that improvements would result from limiting municipal nitrogen discharges. Although such a change may occur, it was considered improbable at the time that the alternative analysis was undertaken.

Of the three group A alternatives, extended aeration/aerated lagoons (A-3) is the one which can accommodate nitrogen removal with the least modification. Because the extended aeration process normally produces a nitrified effluent (nitrogen in the nitrate form), only a denitrification step (conversion of nitrate to nitrogen gas) need be added. For the activated sludge and trickling filtration alternatives, a nitrification step (conversion of ammonia to nitrate) preceding denitrification would also need to be added.

Upgrading of Oxidation Pond Effluent

The second set of alternatives (category B) considered for Davis involves the reduction of the suspended solids level of the oxidation pond effluent. Most oxidation ponds have difficulty meeting the 30-mg/l, 30-day average suspended solids requirement because of the presence of algal cells. Many techniques for algae removal have been proposed. None has a long history of full-scale application, and some are still in the early stages of experimental investigation and development. Nonetheless, in situations where these techniques can be used effectively to reduce suspended solids levels, their capital and operating costs may be significantly lower than for conventional processes.

In category B, three processes were chosen for analysis: coagulation-flocculation-sedimentation, overland flow, and intermittent sand filtration. Several additional processes were evaluated before final selection of these three alternatives for detailed analysis. An example was coagulation-dissolved air flotation. This is similar in concept to coagulation-flocculation-sedimentation, except that finely dispersed air bubbles are used to raise the algae-chemical floc to the water surface, from where it is removed by skimming. Dissolved air flotation usually involves lower capital costs because of shorter detention times and the resulting smaller tanks. Because complicated air dissolution equipment is required, however, operation is more difficult, and this makes air flotation less suitable than sedimentation for use in small and medium size communities. The high chemical costs associated with coagulation-flocculation-sedimentation are also present with dissolved air flotation, making total operation and maintenance costs for this process very high.

Other algae removal processes which have not been studied sufficiently or which have proved unsatisfactory are submerged rock filtration, centrifugation, and microstraining. In-pond removal systems which have been studied include series pond arrangements, series ponds with intermediate chlorination, intermittent discharge lagoons with chemical addition, and aquaculture, which is the use of an ecological food chain that produces a useful product in the form of fish as opposed to a material requiring further disposal. These in-pond systems also have not been developed sufficiently or suffer from some defect in their operation which would preclude their use at Davis.

Maximum performance and operational ease can be expected from algae removal processes if influent (pond effluent) algae concentrations are minimized. The original plant design allowed simple conversion from parallel to series operation of the oxidation ponds. Series arrangement of the ponds minimizes short-circuiting, and provides about as good a prototype situation for minimizing effluent suspended solids as can be expected.

Over the two-month period of the pilot study (9/9/75 to 11/7/75) discussed in the overland flow section, conversion was made to series operation. However, no evidence of significant autoflocculation was found. In addition, there was not a significant difference in the suspended solids concentrations of the three ponds. The conclusion reached was that autoflocculation would not be a viable process, and that there was no advantage to other (tertiary) treatment processes in using the ponds in series.

Alternative B-1: Coagulation-Flocculation-Sedimentation. In order to reduce the size of the sedimentation tank required for the coagulation-clarification alternative, it was assumed that tube settlers would be utilized which allow a detention time of one hour to be used in design. This reduces capital costs significantly.

Alum ($Al_2(SO_4)_3 \cdot 14H_2O$) would be used as the coagulant chemical. Adjustment of pH through the addition of sulfuric acid ($H_2SO_4$) would be used to maximize alum-algae floc precipitation. Conclusions reached from jar tests conducted in the spring of 1976 were that an alum dose of approximately 125 mg/l, with acid addition of 5 meq/l, would produce the greatest effuent clarity.

Main components of this system would be an influent pumping station, alum and acid storage facilities, a flash mix unit for the addition of alum, flocculation compartments with a detention time of 20 min at design flow, and tube settling basin with a detention time of 60 min. Chlorine disinfection in the existing facility and dechlorination with sulfur dioxide would follow the coagulation-clarification process.

Sludge produced by the process would be returned to the oxidation ponds. It is anticipated this would be the most cost-effective solids disposal method. Steps would have to be taken to prevent autoflotation and to ensure that the sludge is distributed fairly evenly throughout the pond area. Otherwise, no serious operational problems would be anticipated.

Capital and annual operating costs were estimated at $1.51 million and $278,000 per year, respectively. A major fraction of the operating costs would be for chemicals.

Alternative B-2: Overland Flow. For the overland flow alternative, approximaterly 83 hectares (200 acres) of land would be required. There are several tenative sites close to the treatment plant. The 83 hectares (200 acres) include a net application area of 66 hectares (158 acres) based on a loading rate of 2,700 cu m/hectare/day (30,000 gallons per acre per day or gpad) plus additional land to provide for roads, hay drying and buffer zones. A preliminary layout developed for the most likely site would have 14 terraces 44 m (145 ft) wide by 1,070 m (3,500 ft) long. The slope of each terrace would be 2.5 percent. Seven maintenance roads and eight drainage ditches would be included in the layout, with connecting roads at each end and a main drainage ditch at the southern end. Orientation of the terraces in a north-south direction would prevent the prevailing north wind from blowing spray across the roads.

The collection sump would be located at the southwest corner of the plot to receive runoff prior to its discharge to Willow Slough Bypass. Provision would be made to pump runoff back to the oxidation ponds when discharge requirements were not being met. This could occur during start-up following grass harvest.

Costs were based on the assumption that oxidation pond effluent would be sprayed through nozzles from a fixed sprinkler system located along a line near the top of each terrace. Sprinkler spacings of 24 m (80 ft) with discharge pressures of 400,000 to 550,000 Pa (60 to 80 psi) and nozzle flows of 0.0025 cu m/sec (40 gpm) would be typical operating parameters. This would allow for four hours operation per sprinkler each day under design conditions of an application rate of 2,700 cu m/hectare/day (30,000 gad), with the entire system designed to operate over a 24-hr period. A spray radius for the 180 degree nozzles of 152 m (50 ft) would allow overlap and maximum terrace coverage. As a result of the analysis discussed in this paper, overland flow was selected as the recommended project for meeting the new requirements at Davis. When this project reaches the design stage, alternative delivery systems will be considered in more detail. The appendix to the Davis project report contains a discussion by Donald M. Parmalee and Vaughan Sparham of surface delivery systems for overland flow treatment based on experience in Australia and England.[5] This experience will be taken into consideration in optimizing the delivery system design.

Care in design and operation of the overland flow system will be required to minimize conditions allowing mosquito propagation. For example, a thorough dryout will be required prior to harvesting in order to prevent equipment ruts which may become small breeding pools. Gambusia (mosquito fish) would be planted in the runoff collection channels.

Costs for the overland flow alternative are presented in Table 2. Total costs for this alternative were the lowest of the seven studied in detail.

Pilot Studies - As part of the concept development for improving wastewater treatment at Davis, pilot studies of the overland flow process were undertaken. The overland flow studies began one month after seeding of test plots located at the Davis treatment plant. Data collection began on November 11, 1975, and continued through March 27, 1976. The purpose of running the experiments during the winter months was to develop data for the period of the year with the worst operating conditions (maximum flow, lowest temperatures, and greatest precipitation); for all practical purposes it does not rain in Davis during late spring to early fall. Unfortunately, the year was a record drought and no effects of precipitation were developed. This may be a reason for conservatism in scaling up pilot data for design. Consideration of use of the ponds as temporary storage tanks may eliminate the need for oversizing the system, however.

Three test plots, each 15 m (50 ft) wide and 31 m (100 ft) long with a 0.61-m (2-ft) drop were constructed for the overland flow studies. Preparation of the plots included grading, rototilling, flooding with digester supernatant and seeding with annual rye grass. Annual rye grass was chosen because of the speed of germination since plots were not seeded until late, October 1, 1975. Supernatant application was not uniform, and the grass development was both faster and better on plots 1, and 2 than on plot 3. During the five months of applying oxidation pond effluent to the plots the grass grew continually, eventually reaching a height of 25 to 30 cm (10 to 12 in.).

Table 2. Estimated Capital and Operating Costs: Overland Flow Alternative

| Item | Cost |
|---|---|
| Capital costs[a] | |
| Gravity Line to Sump | $ 55,000 |
| Distribution and Runoff Collection Sump | 45,000 |
| Terrace Construction | 250,000 |
| Distribution System | 290,000 |
| Distribution Pumping | 290,000 |
| Runoff Collection | 30,000 |
| Electrical | 45,000 |
| Service Roads | 70,000 |
| Fencing | 120,000 |
| Subtotal | $1,195,000 |
| Engineering and contingencies, 35% | 420,000 |
| Land (200 acres @ $1,800/acre) | 360,000 |
| Total capital cost | $1,975,000 |
| Operation and maintenance costs[b] | |
| Labor | $ 48,000 per year |
| Materials | 10,000 |
| Power | 30,000 |
| Total operation and maintenance costs | $ 88,000 per year |

[a]ENR Index = 3200

[b]For additional facilities only

Pond effluent was supplied from the chlorination basin effluent line at a nominal pressure of 550,000 Pa (80 psig). A separate pressure regulator and solenoid valve was used to control the application rate to each plot. Five shrub type (two 90-degree and three 180-degree) spray nozzles were installed on 0.6-m (24-in.) risers at each plot. Initially the sprays were located on the upper edge of the plots, but were later moved about three meters (10 ft) from the edge because a considerable amount of spray was being blown behind the plots. Windy days are common in Davis with the most common wind direction being from the north. On some days most of the spray was directed off the plots. During these same periods dust was blown off of the access road running below the plots into the sample containers. This factor accounted for several very high suspended solids readings during December, January, and February.

Although the spray heads were designed for use with tap water, very few plugging problems occurred. Those problems that did occur were easily and quickly handled.

From November 7 to February 7 the loading rates and application times were as listed in Table 3. After the first week in February the loading times, and consequently the hydraulic loading rates, were increased on plots 2 and 3. This change was in part because of a desire to determine the effects of higher loading rates and in part because of the lack of rainfall. Some method of estimating the probable effect of rain was needed. Considerable difficulty accompanied this change because of the coincidental plugging of the pressure regulators of plots 2 and 3. Although the application periods were increased during this period the pressures were greatly reduced. This situation was not fully corrected until February 27th. Application rates for the period February 27th to March 28th are given in Table 4.

Plot effluent characteristics are summarized on a monthly basis in Figures 2 and 3. The monthly averages are useful in noting how the effluent quality changed with season and with some of the operating parameter changes. Requirements set on the discharge by the Regional Board are based on running 7- and 30-day averages, however. These values were calculated in the pilot study.

Several samples exceeded the 90-mg/l maximum set by the Regional Board. All of these samples were taken on extremely windy days. In several cases it was noted on the raw data sheet that there was considerable silt in the sample. Finally, if the true suspended solids reading were high the $BOD_5$ value should be correspondingly high. This was not the case. It can therefore be concluded that wind-blown dust was the cause of these extremely high suspended solids readings.

Limited nitrogen data was developed in the study. Some nitrogen was taken up by the grass, but there is no clear evidence of the quantity. Because the 1977 discharge requirements do not include any nitrogen limitation, it was decided to defer those studies until such time as a limitation was imposed. Then, studies for optimum nitrogen removal could be conducted using the full-scale system.

From the pilot studies, it was concluded that:

1. Loading rates up to 290 cu m/hectare/day (32,000 gal/acre/day) (3.00 cm/day or 1.18 in./day) are suitable for process design. The data from the pilot studies appear to be good, and support the above value for design use.

Table 3. Pilot Study Application Rates, 11/7/75 through 2/7/76

| Plot | 1 | 2 | 3 |
|---|---|---|---|
| Time of Application, hrs. | | | |
| morning | 3 | 2 | 1 |
| afternoon | 3 | 2 | 1 |
| Application Rate gal/acre/hr[a] | 3476 | 3350 | 3716 |
| Average Daily Flow | | | |
| gal/acre day[b] | 20,856 | 13,400 | 7430 |
| in/day[c] | 0.77 | 0.49 | 0.27 |

[a]gal/acre/hr x 0.0091 = cu m/hectare/hr

[b]gal/acre/day x 0.0091 = cu m/hectare/day

[c]in/day x 2.54 = cm/day

Table 4. Pilot Study Application Rates, 2/27/76 through 3/28/76

| Plot | 1 | 2 | 3 |
|---|---|---|---|
| Time of Application, hrs. | | | |
| morning | 3 | 4 | 12 |
| afternoon | 3 | 4 | |
| Application Rate gal/acre/hr[a] | 5530 | 5500 | 4630 |
| Average Daily Flow | | | |
| gal/acre/day[b] | 32,000 | 44,000 | 56,000 |
| in/day[c] | 1.18 | 1.62 | 2.07 |

[a]gal/acre/hr x 0.0091 = cu m/hectare /hr

[b]gal/acre/day x 0.0091 = cu m/hectare/day

[c]in/day x 2.54 = cm/day

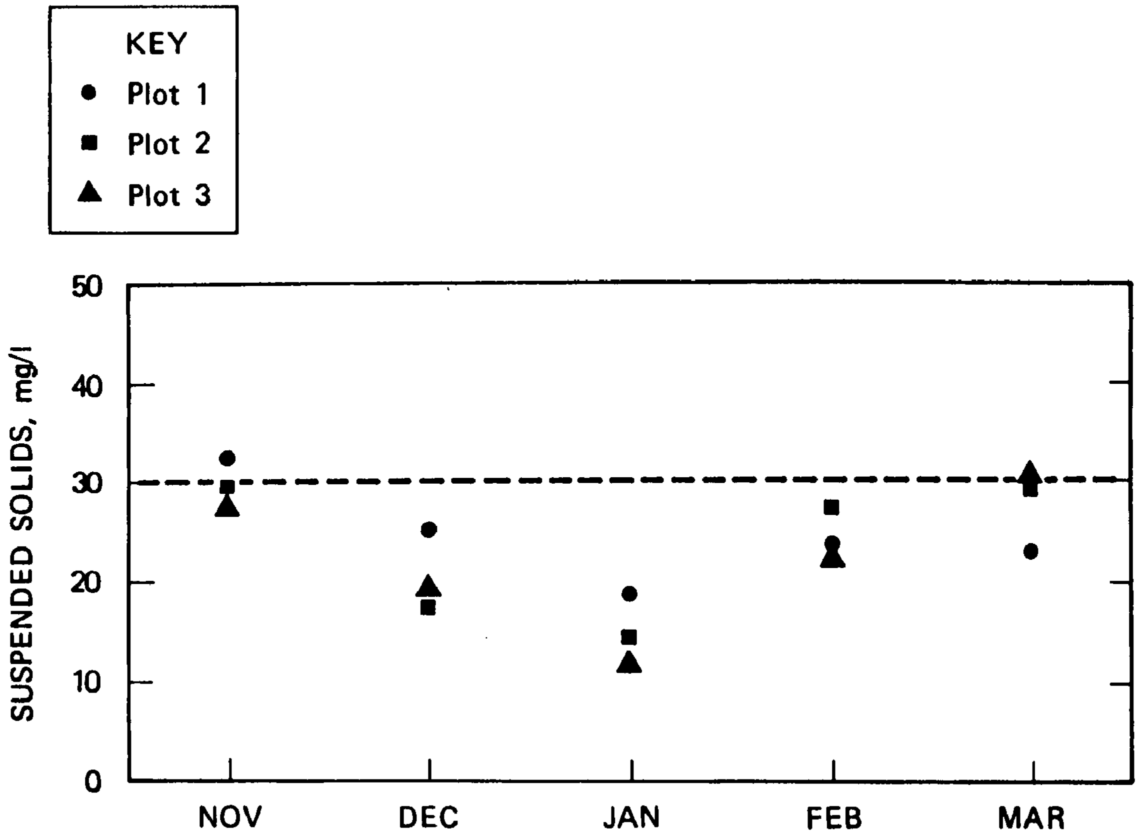


Figure 2 Effluent Suspended Solids Concentrations from Study Plots

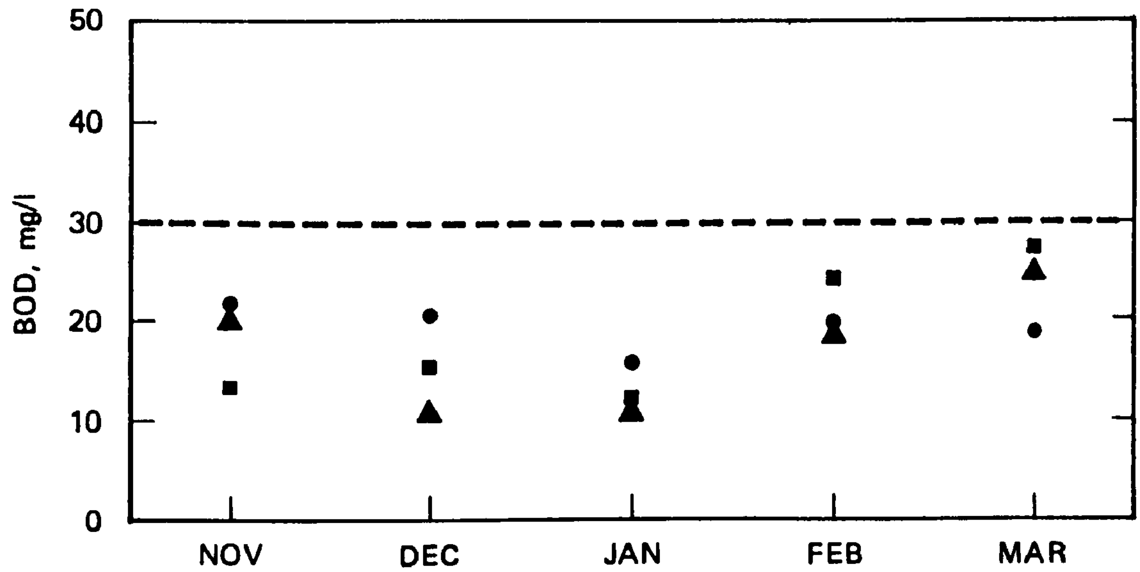


Figure 3 Effluent $BOD_5$ Concentrations from Study Plots

2. Loading rates studies above 290 cu m/hectare/day (32,000 gal/acre/day) resulting in effluent quality very close to the minimum required. Using these values would leave little margin (perhaps none) for natural process variation.

3. Rye grass would be a suitable cover for prototype land treatment systems. This conclusion was based upon the observations made in this study and those reported in the literature.[6]

4. Application times up to 12 hours per day resulted in excellent grass growth. Twelve hours was the maximum application period and it is not known if longer periods would be satisfactory also.

5. Meeting $BOD_5$ requirements with an overland flow treatment process designed for suspended solids removal will not be a problem.

6. Chlorinated effluent will not damage the grass.

7. Data developed in the study provide conservative estimates of prototype operation. As the grass root zone develops, effluent quality may continue to improve and stabilize.

8. The fact that grass grows well in Davis during many winters may provide a method of year-round nutrient removal from wastewater. Additional studies need to be made year-round to determine the extent of possible nutrient removal.

9. The effect of precipitation on the effectiveness of a prototype process could not be predicted from the results of the study because there was almost no precipitation during the study period. The response of the plots to very large increases in loading during March was sluggish. This leads to the conclusion that precipitation will not dramatically affect effluent quality from the prototype system unless the storm is very intense.

Alternative B-3: Intermittent Sand Filtration. For the intermittent sand filter alternative, a design application rate of 5,500 cu m/hectare/day (0.6 million gallons per day or mgad) was assumed. Sixteen 0.21-hectare (0.5-acre) filter basins would be required. It was assumed that each basin would be 46 m (150 ft) square, and the basins would be located in a double row in order to provide access for cleaning. An area of approximately 10 hectares (25 acres), located along the east side of the present treatment plant site, would be required if this alternative were implemented.

In determining the intermittent sand filter design requirements, it was assumed that a filter run would be 28 days. With 16 basins, one basin could be cleaned each day during a regular five-day work week, with four days during each four-week period allotted to other maintenance items. The influent supply line and main drain would run along the spine between the rows of basins. The influent line would be sized for hydraulic loading of each filter for two hours with a maximum of four basins being loaded at a time. Loading would be rotated automatically by a timer-controlled valve. Under design conditions it would be possible to load all the basins within an eight-hour period. When the total amount of applied effluent fails to drain through the filter within 22 hr, the filter would be considered plugged and would require cleaning.

It was assumed that the filters would be contained by soil embankments paved with asphalt along the sides to facilitate cleaning. The basin tile drains would be covered with about one-third meter (one foot) of graded gravel from 0.6 cm (0.25 in.) minimum diameter to a maximum diameter of 4.0 cm (1.5 in.). The filter medium placed on top of the gravel would consist of one meter (three feet) of sand with an effective size approximately 0.50 to 0.75 mm. Cleaning would be accomplished by removing the top two to five centimeters (one to two inches) of sand and replacing with clean sand. Sand would be washed and reused. Sand wash water, after passing through a sand sedimentation basin, would be returned to the oxidation pond. Effluent from the intermittent sand filter basins would be drained to a sump and then pumped to the chlorine contact tank before discharge to Willow Slough Bypass.

Capital costs for intermittent sand filtration were estimated at $3.52 million. Operation and maintenance costs were estimated at $79,000 per year. The chief uncertainty in the cost estimate was the amount of labor required for sand cleaning. This results directly from the lack of adequate information for designing intermittent sand filters for wastewater characteristics and effluent quality requirements similar to those at Davis.

Analysis. All the alternative methods of effluent improvement have similar environmental impact on the service area. There are significant differences in the immediate vicinity of the treatment plant. The overland flow alternative has a favorable environmental impact. Wildlife habitats in the vicinity of Davis include croplands, pasture, riparian and water surfaces. Rodents, small mammals and birds use these habitats. Water surfaces are heavily used by both resident and migratory waterfowl. Varying amounts of riparian habitat exist along the Yolo Bypass, Willow Slough Bypass, Putah Creek and other stream and slough banks. Riparian vegetation, considered one of the most valuable wildlife habitat types, is a concentration point for a variety of game and nongame species and provides excellent feed and cover. The Davis Audubon Society has identified the Hunt's Cannery overland flow treatment site, located about two kilometers (one mile) east of the central treatment plant, as one of the best wildlife habitats in the Davis area and considers that the recommended overland flow project will significantly enhance the wildlife habitat. A wildlife inventory from the vicinity of the treatment plant is discussed in the summary section.

Because the group B alternatives all involve algae removal, all provide some removal of nitrogen, which is incorporated into algal cells in the oxidation ponds. Of the three group B alternatives, overland flow can be expected to provide the greatest removal of unassimilated nitrogen. The principal mechanisms are crop uptake and nitrification-denitrification in the soil.

## Reclamation/Irrigation

The third major alternative investigated (category C) was to apply the effluent to land, either as a reclamation program for crop irrigation or simply as a method of disposal. Advantages to this approach are, in general, that crop irrigation is a beneficial use (if reclamation is practiced), less costly treatment is required, and the possibility of future upgrading being required to meet more stringent discharge requirements is less likely. Disadvantages are that large tracts of land are often required, wastewater storage during wet portions of the year is usually required, and care must be taken to prevent degradation of groundwater aquifers. Reuse of reclaimed wastewater for industrial purposes may be undertaken in some situations, but the lack of industrial demand at Davis made this infeasible.

The wastewater effluent from the Davis facility has a sodium adsorption ratio of 10. This high concentration of sodium in an irrigation supply can reduce soil permeability by causing clay minerals to swell. The SAR value of 10 classifies the plant effluent as potentially leading to severe soil permeability problems. Using effluent as the source of water on soils around the treatment plant where permeability is already low without any mitigating measures would, in time, produce this sealing effect. This is unsuitable for irrigation but ideal for overland flow where water infiltration into the soil profile beyond the grass root zone is not desirable. Due to the high SAR value, the wastewater must be blended at a ratio of 1:1 with local irrigation water for long-term irrigation. It is estimated that an application area of 400 to 600 hectares (1,000 to 1,500 acres) would be needed.

Because irrigation is a seasonal use at Davis, storage of effluent would be required during the winter months. It was determined that a storage reservoir with a capacity of approximately five million cubic meters (4,000 acre-ft) would be required. A 200-hectare (500-acre) parcel, probably located to the east of the existing plant site, would be purchased and used as the storage reservoir site. Flow from the storage reservoir and existing ponds would be delivered by pressure pipeline to the irrigation systems of local farmers.

In order to assure a reuse demand for the Davis effluent, it would be necessary to develop long-term (e.g., 15-year) agreements with local farmers to receive the effluent. An alternative would be to purchase land and lease it to farmers on the condition that they use the effluent for irrigation. This would add $2,000,000 to $2,500,000 to the capital cost. Resulting savings in other areas might result from reduced storage and conveyance costs. Operating costs would be reduced by the rent payments received for the leased land.

An important aspect of irrigation reuse is control of subsequent runoff from irrigated fields. A probable Regional Board requirement would be that such drainage not reach surface waters (unless it has been treated to meet surface discharge requirements). This would require collection of drainage waters and return either to the treatment plant or to the irrigation system. This could also add to the estimated costs. Estimated capital costs were $3.24 million. Operation and maintenance costs were estimated at $40,000 per year for the additional facilities.

Summary of Alternatives Analysis

Cost-effectiveness, including environmental and social impact analysis, and project suitability were considered for the seven alternatives. Alternatives were compared on the basis of equivalent annual cost, using a discount rate of 7 percent and a 20-year planning period, conforming to state and federal guidelines for cost-effectiveness analyses. The annual cost is computed by applying a capital recovery factor, available from standard interest tables, after first taking into account any facilities salvage value at the end of the 20-year planning period. No depreciation was assumed for the value of land, so that capital recovery factor used for land was equal to the interest rate. The results of the monetary cost analysis is depicted graphically in Figure 4.

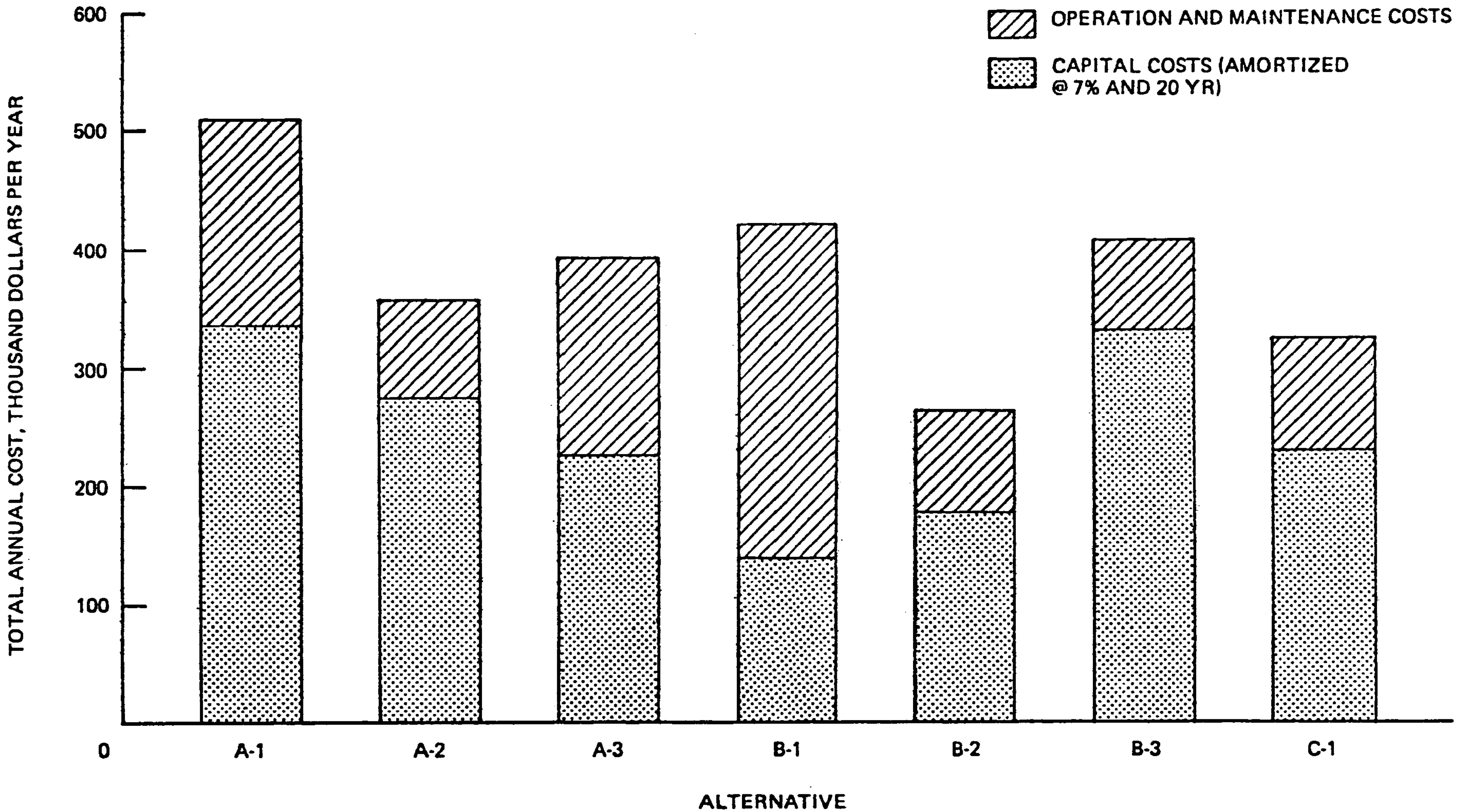


Figure 4    Monetary Cost Analysis for Project Alternatives

The most notable aspect of the costs is range of values. The most costly alternative, the actived sludge process (A-1), is nearly 90 percent higher than overland flow (B-2). Overland flow and reclamation/irrigation (C-1) are the two lowest-cost alternatives, and are significantly less expensive than the others.

In terms of operation and maintenance costs, which must all be borne locally, reclamation/irrigation has the lowest cost, $40,000 per year, and trickling filtration (A-2), overland flow (B-2), and intermittent sand filtration (B-3) are in the $48,000 to $90,000 per year range. The remaining three alternatives have much higher operating costs. Activated sludge (A-1) has high labor and power costs. The extended aeration alternative (A-3) has lower labor and materials cost, but requires more power to keep all the particulate material in suspension in the aerated lagoons. Coagulation-flocculation-sedimentation has the highest operating costs; this results from the large quantities of alum and sulfuric acid which must be used.

The alternatives have significantly different environmental impacts. Due to the general dryness of the area and the absence of major water bodies, aquatic resources are limited within the study area. Water quality in Willow Slough Bypass is poor, consisting in the summer of agricultural return flows and treated wastewater effluent. Water quality in the fall, between the end of the irrigation season and the beginning of the rainy season, is especially poor. Nutrients contained in the agricultural runoff support excessive algae growth in the Bypass drainage; algae decompositon consumes the oxygen supply. Most warm water fish species are absent. California Department of Fish and Game personnel indicate that some bluegill and catfish may inhabit the water course.

The major value of the Willow Slough Bypass is the riparian habitat it provides. Vegetation in the vicinity of the treatment plant is sparce, reflecting the dry climate. Most of the area is under cultivation. Dense primary riparian vegetation along the Willow Slough Bypass provides food, nesting, dens and escape sites for muskrats and other water-related mammals, amphibians, and ducks. Bottom lands of the bypass provide habitat for rodents and upland birds such as pheasant. These species attract and supply food to hawks and other raptors. Category A and B surface water disposal alternatives would support the continuation of this habitat.

The oxidation ponds are one of the most valuable wildlife habitats in the study area. These ponds provide a sanctuary for several species of waterfowl and shore birds. The treatment area is surrounded by a high chain link fence, and the operation of the oxidation ponds is automated so that the waterfowl are well isolated from man's activities. These ponds are always occupied by large numbers of several species of waterfowl. Category B and C alternatives would maintain this valuable habitat.

The reclamation alternative, C, would involve irrigation during the summer and storage of effluent during the winter. There would be no discharge to Willow Slough Bypass. Storage would create 170 hectares (400 acres) of additional waterfowl habitat from land currently devoted to irrigated agriculture.

The overland flow alternative would create 80 hectares (200 acres) of habitat very favorable to wildlife, as indicated by the use of the Hunt's overland flow area. Table 5 shows a wildlife inventory in the vicinity of the Davis treatment facility.

# Table 5. Wildlife Inventory for Treatment Plant Vicinity

| Hunt-Wesson overland flow site | Treatment plant oxidation pond | Riparian area | Agricultural areas: Rice | Agricultural areas: Wheat, Corn, Hay |
|---|---|---|---|---|
| **Birds** | **Birds** | **Birds** | **Birds** | **Birds** |
| Mallard (UC-AY) | *Pied-billed grebe (C-AY) | Great blue heron (UC-AY) | Great blue heron | Sparrowhawk |
| Turkey vulture (C-S,W,F) | Whistling swan (C-W) | Green heron (UC-AY) | American bittern | Swainson's hawk |
| White-tailed kite (C-AY) | Canada goose (C-W) | *White-tailed kite (UC-AY) | Mallard | Ring-necked pheasant |
| Red-tailed hawk (C-AY) | White-fronted goose (C-W) | *Sparrowhawk (C-AY) | White-tailed kite | White-tailed kite |
| Swainsons hawk (UC-Su) | Snow goose (C-W) | *Marsh hawk (UC-AY) | Red-tailed hawk | Rough-legged hawk |
| Rough legged hawk (UC-W) | *Mallard (C-AY) | *Ring-necked pheasant (C-AY) | Marsh hawk | Common crow |
| Marsh hawk (C-AY) | Gadwall (UC-W) | **Virginia rail | Sparrowhawk | Greater yellowlegs |
| Prairie falcon (Rare-W) | Pintail (C-W) | **Sora rail | Ring-necked pheasant | California gull |
| Sparrow hawk (C-AY) | Greenwinged teal (UC-W) | *Killdeer (C-AY) | Killdeer | Herring gull |
| *Ringnecked pheasant (C-AY) | Cinnamon teal (C-W) | *American Arocet (C-Su) | American arocet | Ring billed gull |
| *Killdeer (C-AY) | American widgeon (C-W) | *Black-necked stilt (C-Su) | Black-necked stilt | Brewers blackbird |
| Long-billed curlew (C-AY) | Shoveler (C-W) | *Mourning dove (C-AY) | Black tern | Cow bird |
| Whimbrel (Rare-W) | Canvasback (C-W) | *Brown owl (C-AY) | Cliff swallow | |
| Mourning dove (C-AY) | Ruddy duck (C-W) | *Long-eared owl (Rare-AY) | Barn swallow | |
| Barn owl (UC-AY) | *American coot (C-AY) | *Western kingbird (C-Su) | Tree swallow | |
| Burrowing owl (UC-AY) | Wilsons phalarope (UC-Su) | *Mockingbird (C-AY) | Brewers blackbird | |
| *Short-eared owl (UC-AY) | Northern phalarope (UC-Su) | Water pipet (C-AY) | | |
| Western kingbird (C-Su) | Herring gull (C-W) | *Loggerhead shrike (C-AY) | | |
| Horned lark (C-F,W,Sp) | California gull (C-AY) | *Red-winged blackbird (C-W) | | |
| Tree swallow (C-Su) | Ring-billed gull (C-AY) | Yellow throat | | |
| Barn swallow (C-Su) | Blacktern (UC-Su) | **,*Long-billed marsh wren | | |
| Cliff swallow (C-Su) | Lesser nighthawk (UC-Su) | *Brewers blackbird (C-AY) | | |
| Common crow (C-AY) | Tree swallow (C-Su) | Brown-headed cowbird (C-AY) | | |
| Water pipet (C-W) | Barn swallow (C-Su) | | | |
| Loggerhead shrike (C-AY) | Cliff swallow (C-Su) | | | |
| *Western meadowlark (C-AY) | | | | |
| Brewers blackbird (C-AY) | | | | |
| Brown-headed cowbird (C-AY) | | | | |
| House finch (C-AY) | | | | |
| American goldfinch (C-AY) | | | | |
| Lesser goldfinch (C-AY) | | | | |
| Savannah sparrow (C-F,W,Sp) | | | | |
| **Mammals** | | **Mammals** | **Mammals** | |
| Ornate shrew | | Ornate shrew | Muskrat | |
| California mole | | **Racoon | | |
| Black-tailed jackrabbit | | California vol | | |
| **Audubon cottontail | | Muskrat | | |
| California ground squirrel | | | | |
| Valley pocket gopher | | | | |
| Deer mouse | | | | |
| Meadow mouse | | | | |
| Striped skunk | | | | |
| **Reptiles** | | **Reptiles and amphibians** | **Reptiles** | |
| Coachwhips | | Common garter snake | Garter snake | |
| Long-nosed snakes | | Western water garter snake | | |
| Common kingsnake | | Western toad | | |
| Gopher snake | | California newts | | |
| Western terrestrial garter snake | | | | |
| **Western fence lizard | | | | |

LEGEND

- * - nesting
- ** - identification is uncertain
- C - common
- UC - uncommon
- AY - all year
- Sp - spring
- Su - summer
- F - fall
- W - winter

The relative abilities of alternatives to meet engineering effectiveness criteria and to conform to identified constraints may strongly affect selection of the recommended plan. The effectiveness criteria include reliability, flexibility, flood protection and bypass prevention. Constraints include ability to meet discharge requirements, conformance with the basin plan, compatibility with "best practicable treatment" requirements, reclamation potential, ability to implement, and public acceptability. All of the alternatives were judged to be fairly reliable. None would be affected greatly by power outages or process shutdowns. Retention of the oxidation ponds, as emergency storage for the A alternatives and as part of the treatment process for the B and C alternatives, would provide adequate storage capacity for several days in the event of a process shutdown. Emergency power for influent pumping is provided by gas engines. Resource commitments for the various alternatives are summarized in Table 6.

Alternatives B-2 (overland flow) and C-1 (reclamation/irrigation) were rated as being the most flexible. They would be least affected by a future nitrogen limitation, and both have low capital costs, a portion of which is for land, which does not depreciate as structural or mechanical components do. In addition, the reclamation/irrigation alternative would not be affected by any future requirement mandating land disposal (although this was considered quite unlikely). The activated sludge (A-1) and trickling filtration (A-2) alternatives were rated the least flexible: a high capital investment would be required, and major additions would be needed to provide nitrogen removal.

As a result of the analysis, an overland flow system was recommended. A summary of the project alternative analysis, taken from the Environmental Impact Report,[7] is given in Table 7. A more detailed discussion of the alternatives is contained in the EIR and in the Project Report.[5]

The consideration of alternatives at Davis may be generally applicable to small communities which have existing oxidation pond systems. This may be especially true where existing capacity is sufficient to meet anticipated growth for the intermediate future, but where upgrading of effluent quality is required. As more experience is gained in the United States with overland flow systems, it is expected that the positive environmental aspects will be recognized.

## Table 6. Estimated Resources Commitments of Alternatives

| Alternatives | Land (acres) – Direct – Treatment site | Land (acres) – Direct – Buffer | Land (acres) – Indirect – Agriculture | Power kilowatt hours – Annual | Power kilowatt hours – Maximum month | Chemicals (tons/year) – Alum | Chemicals (tons/year) – Sulfuric acid | Chemicals (tons/year) – Chlorine | Chemicals (tons/year) – Sulphur dioxide | Materials – Construction ($1,000,000) | Materials – Annual operation & maintenance ($1,000) | Personnel (man-days) – Construction | Personnel (man-days) – Annual O&M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A-1 Activated sludge | 0 | 0 | 0 | 2,100,000 | 175,000 | 0 | 0 | 40 | 16 | 3.5 | 172 | 7,800 | 2,200 |
| A-2 Trickling filtration | 0 | 0 | 0 | 900,000 | 75,000 | 0 | 0 | 40 | 16 | 2.9 | 90 | 6,500 | 1,100 |
| A-3 Extended aeration (aerated lagoon) | 0 | 0 | 0 | 3,300,000 | 275,000 | 0 | 0 | 40 | 16 | 2.4 | 170 | 13,400 | 1,825 |
| B-1 Coagulation | 0 | 0 | 0 | 500,000 | 50,000 | 950 | 2,000 | 40 | 16 | 1.5 | 278 | 3,300 | 1,100 |
| B-2 Overland flow | 170 | 30 | 0 | 1,500,000 | 150,000 | 0 | 0 | 40 | 0 | 2.0 | 88 | 6,700 | 1,100 |
| B-3 Intermittent sand filtration | 15 | 10 | 0 | 350,000 | 35,000 | 0 | 0 | 40 | 16 | 3.5 | 79 | 11,700 | 1,100 |
| C-1 Reclamation | 450 | 50 | 1,200 | 500,000 | 65,000 | 0 | 0 | 55 | 0 | 3.2 | 40 | 10,700 | 550 |

## Table 7. Comprehensive Evaluation of Project Alternatives

| Considerations | A-1 | A-2 | A-3 | B-1 | B-2 | B-3 | C-1 | No project |
|---|---|---|---|---|---|---|---|---|
| ENGINEERING/INSTITUTIONAL | | | | | | | | |
| Regulatory compliance | Good | Good | Good | Good | Good | Good | Acceptable | Unacceptable |
| Implementation | Marginal | Marginal | Marginal | Marginal | Good | Marginal | Marginal | Unacceptable |
| Reliability | Acceptable | Acceptable | Acceptable | Acceptable | Good | Marginal | Acceptable | - |
| Flexibility | Marginal | Marginal | Marginal | Marginal | Good | Marginal | Good | Good |
| Flood protection | Good | Good | Good | Good | Acceptable | Good | Good | - |
| SOCIAL - ECONOMIC | | | | | | | | |
| Public Health | Enhance | Enhance | Enhance | Enhance | Enhance | Enhance | Enhance | Slight |
| Archeological/Historical | None | None | None | None | Insignificant | Insignificant | Insignificant | None |
| Project cost | 3,540,000 | 2,910,000 | 2,380,000 | 1,510,000 | 1,975,000 | 3,515,000 | 3,235,000 | - |
| Annual operation, maintenance cost | 172,000 | 90,000 | 170,000 | 278,000 | 88,000 | 79,000 | 40,000 | - |
| Cost per household/month | 4.29 | 3.48 | 4.15 | 5.03 | 3.35 | 3.48 | 3.76 | 2.35 |
| Public acceptance | Unacceptable | Unacceptable | Unacceptable | Unacceptable | Good | Acceptable | Acceptable | Marginal |
| ENVIRONMENTAL | | | | | | | | |
| Surface water supply | Enhance | Enhance | Enhance | Slight | Slight | Slight | Moderate | Slight |
| Surface water quality | Enhance | Enhance | Enhance | Enhance | Enhance | Enhance | Slight | Slight |
| Groundwater quality | None | None | None | None | Insignificant | None | Slight | None |
| Soils | None | None | None | None | Slight | None | Moderate | None |
| Wildlife habitat | Moderate | Moderate | Moderate | None | Enhance | None | Slight | None |
| Air quality | Slight | Slight | Slight | Slight | Slight | Slight | Slight | Insignificant |
| Environmental rating (1 is highest) | 6 | 6 | 6 | 2 | 1 | 3 | 4 | 5 |
| OVERALL RATING | 8 | 6 | 7 | 4 | 1 | 2 | 3 | 5 |

**ENVIRONMENTAL EVALUATION**
- Severe
- Moderate
- Slight
- Insignificant
- None
- Enhance

**ENGINEERING/INSTITUTIONAL EVALUATION**
- Unacceptable
- Marginal
- Acceptable
- Good

## REFERENCES


1. Brown and Caldwell, City of Davis Sewerage Survey, December 1961.

2. Brown and Caldwell, City of Davis Sewerage Study, December 1968.

3. Pound, C.E., D.W. Crites and D.A. Griffes, Costs of Wastewater Treatment by Land Application, U.S. EPA, Office of Water Program Operations, Technical Report No. EPA-430/9-75-003, June 1975.

4. Marshall, G.R. and E.J. Middlebrooks, Intermittent Sand Filtration to Upgrade Existing Wastewater Treatment Facilities, Utah State University, College of Engineering, Utah Water Research Laboratory, PRJEW115-2, February 1974.

5. Brown and Caldwell, City of Davis, Project Report, Algae Removal Facilities, February 1977.

6. Overman, A.R. and H.C. Ku, Effluent Irrigation of Rye and Ryegrass, Proceedings ASCE, JEED, Vol. 102, 475 (April 1976).

7. Brown and Caldwell, City of Davis, Draft Environmental Impact Report, Algae Removal Facilities, February 1977.