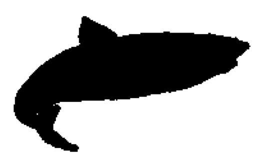
CITY OF ARCATA

ARCATA INTEGRATED WASTEWATER TREATMENT RECLAMATION AND SALMON RANCHING PROJECT

BY



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ARCATA INTEGRATED WASTEWATER TREATMENT, RECLAMATION, AND SALMON RANCHING PROJECT

by

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SUMMARY: Pacific salmon smolts have been reared in saline ponds fertilized with domestic wastewaters. An artificial home-stream is to be created from the discharge of a marsh-lake system to be developed with reclaimed wastewater. This proposed salmon ranching method has the potential for producing food cheaply.

American Society of Agricultural Engineers

St. Joseph, Michigan 49085

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ARCATA WASTEWATER TREATMENT, RECLAMATION, AND SALMON RANCHING PROJECT

George H. Allen, and Robert A. Gearheart

I. INTRODUCTION

Westman (1977) recently reviewed the progress of the United States government in improving the quality of the nation's surface and ground waters under the Clean Water Act of 1972 (PL 92-500). Excessive capital costs in treatment systems being designed to meet nation-wide effluent standards mandated under the law have been a major factor in preventing the program from achieving 1977 goals. Rising energy costs now are contributing to heavy operating expenses required by these treatment systems. Westman also noted a bias in federal and state agencies against innovative wastewater treatment schemes capable of reducing these costs, as well as a reluctance to implement that portion of Section 201 of the law mandating priority to systems that can generate revenue to offset treatment costs by reuse of treated wastewaters in silviculture, agriculture, or aquaculture.

There is a long history in the United States of wastewater reuse on land, particularly in agriculture (Sullivan 1974), but the managed use of treated wastewaters in aquaculture in the United States has been constrained by non-technical considerations (Huguenin and Kildow 1974). Recently, however, there has been a surge of interest in wastewater aquaculture as alternative low-cost treatment systems (Duffer and Moyer 1978). In California alone, two state agencies have recently added wastewater aquaculture research to their programs (Department of Water Resources; State Water Quality Control Board). On a national level, an information bulletin on domestic wastewater reuse has appeared (AWWA Research Foundation 1977), and the Environmental Protection Agency has issued permit regulations for wastewater use in aquaculture.

In 1963, the City of Arcata, located on the north arm of Humboldt Bay (Arcata Bay) (Figure 1), Humboldt County, northern California, approved a proposal to investigate the potential use of domestic wastewaters in aquaculture (fertilizing marine ponds for rearing juvenile salmonids; Allen and Dennis 1974). In the fall of 1977, the first major return of adult coho (silver) salmon[1/] from juveniles reared in this system[2/] were recovered in temporary adult salmon trapping facilities located at the mouth of a small stream (Jolly Giant Creek) which flows through Arcata, entering Arcata Bay adjacent to the

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1/ Appendix I lists all common and scientific names of plants and animals used in this paper.

2/ Appendix II lists unpublished data reports on the juvenile rearing experiments on the use of wastewaters to develop an ocean ranching project, and adult salmon returns to the Arcata pilot project.

salmon rearing ponds. Further development of the utilization of reclaimed waters for the operation of an "ocean ranching" system[3/] is now dependent on the creation on city of Arcata property of a "homestream"[4/] for returning adult salmon. This is to be accomplished by building, adjacent to an existing sewage treatment system, a series of freshwater marshes and a recreation lake. The freshwater marshes will be complementary to salt marshes of a federal wildlife refuge that adjoins the southeastern boundary of the Arcata wastewater treatment plant. The water discharged from the recreation lake will provide the homestream for returning adult salmon. This paper presents the history, present operation, and future plans of the proposed Arcata salmon ranching program as integrated into a wastewater treatment and reuse project.

Specifically we shall:

(1) present a brief history of the events leading up to a proposal by the City of Arcata to integrate wastewater treatment, fish and wildlife enhancement, and eventually an ocean ranching project,

(2) describe the existing wastewater treatment system and evaluate the level of treatment of wastewaters in the existing system as a measure of water quality available for a range of reclamation uses,

(3) outline the proposed fish and wildlife values to be created by utilizing reclaimed wastewaters in marshes and lakes,

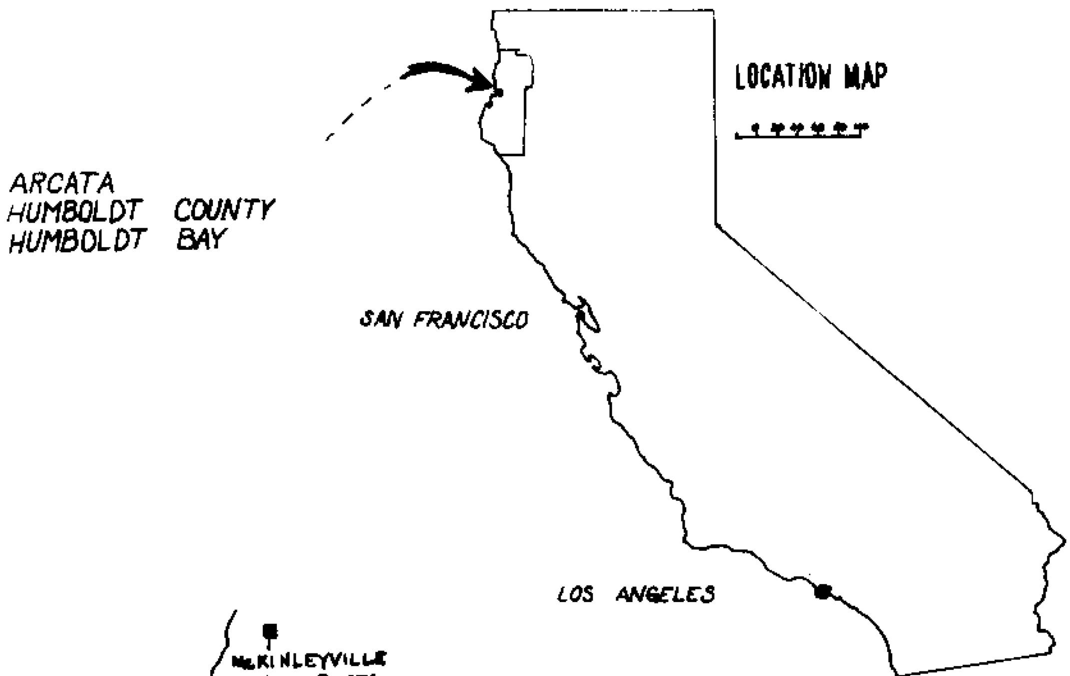
(4) outline the history of a pilot-project on raising juvenile salmon using wastewater-seawater rearing ponds, summarize the results of pond-rearing experiments in this pilot study, and briefly describe the returns of adult salmon to Arcata, and

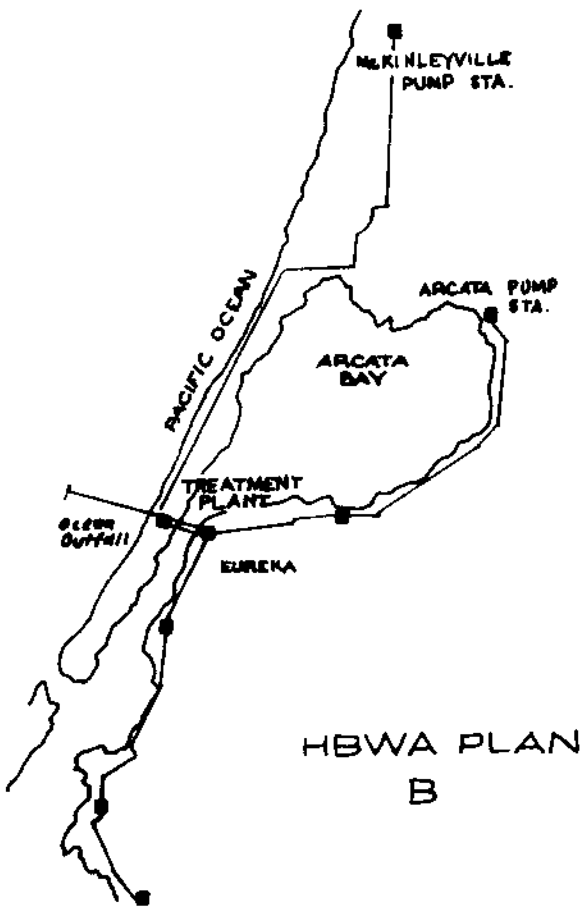
(5) discuss non-technical constraints to implementation of the Arcata wastewater reclamation and ocean ranching proposal, especially a state policy requiring demonstration of "enhancement" of receiving waters which would not have occurred in the absence of a wastewater discharge.

3/ Ocean ranching is a term given to any salmonid hatchery that is operated either by a profit or non-profit entity, in which the hatchery is operated to market (sell) fish captured at the hatchery site (See Joyner 1975).

4/ Mature Pacific salmon return to spawn in the stream (homestream) in which they migrated to sea as smolts or as down-stream migrants. The degree of precision of such return to a homestream varies with species, physiological state of the migrating fish, and local conditions (See Allen 1978, Appendix II).

Figure 1. Location of Arcata, California (A), plan of regional collection and ocean disposal system developed by the Humboldt Bay Wastewater Authority (B), and plan of Citizens for a Sewage Referendum for meeting regional needs for wastewater treatment and control (C). (Maps B and C adapted from: Matthews, M. et al, 1978).


LOCATION MAP
ARCATA
HUMBOLDT COUNTY
HUMBOLDT BAY
SAN FRANCISCO
LOS ANGELES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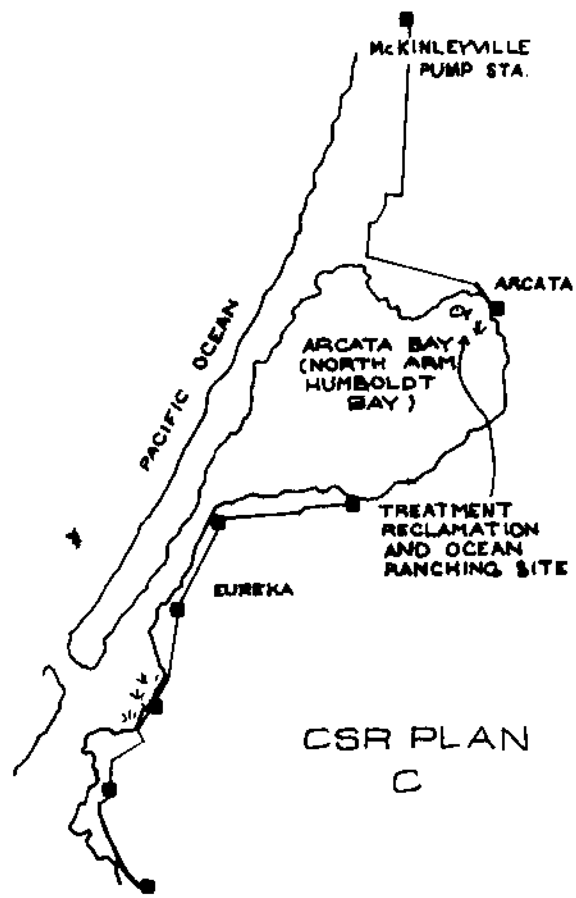
McKINLEYVILLE
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PACIFIC OCEAN
ARCATA
ARCATA BAY
(NORTH ARM
HUMBOLDT
BAY)
TREATMENT
RECLAMATION
AND OCEAN
RANCHING SITE
EUREKA
CSR PLAN
C

II. HISTORY AND BACKGROUND

1. Alternative Wastewater Treatment and Reclamation System

In the fall of 1977, a group of Humboldt County residents (Citizens for a Sewer Referendum - CSR) living within the boundary of a public entity formed to develop a wastewater plan for the watershed surrounding Humboldt Bay (Humboldt Bay Wastewater Authority - HBWA), petitioned the authority to hold an election to approve issuance of revenue bonds to pay for the local share of a proposed regional collection, treatment, and ocean disposal system (Figure 1 - HBWA). The Authority, in not submitting a revenue program to the voters for approval, was exercising a legal option to do so unless petitioned otherwise. The citizen action resulted from concern over the high capital and energy costs of the proposed system ($53 million) and the growth-promoting effects of locating collection lines in green-belt zones on both the east and west side of Arcata Bay. Serious questions were raised about the degree of present and future degradation of Humboldt Bay claimed by water pollution control planners attributable to wastewater treatment plant discharges. HBWA rejected the citizen petition, claiming the petition was filed late, and that it contained less than the required number of registered voters in the district (10 percent). A raw sewage line crossing mid-Humboldt Bay and location of the treatment plant on one of the only deep-water port sites inside Humboldt Bay also was of concern. As of November 1, 1978, CSR challenges to the HBWA rejection of citizen petitions are still in court, thereby preventing HBWA from issuing for public sale revenue bonds to pay non-federal costs of the project ($12 million).

On 18 September 1974, a single public hearing (as then required by state law) was held by the North Coast Water Quality Control Board, on a regional water quality control plan being proposed for the Humboldt Bay area (Coastal Basin Plan 1-B). Considerable public opposition was voiced to the plan with the City of Arcata particularly strong in its opposition. Arcata objected because the plan would force abandonment of the only treatment system in the basin meeting secondary treatment standards, and making an existing 55-acre oxidation pond into a wet storage basin for raw sewage and storm water in the HBWA collection system. Arcata also objected on land-use planning grounds to a sewer line along the east side of Arcata Bay proposed by the HBWA system since this would place enormous pressure to force a strip development of this area of the city which was contrary to its General Plan. Areas adjacent (west) of this east bay pipeline borders a national waterfowl refuge, consequently additional opposition to this element of the collection system came from wildlife interests. In addition, beyond these ecological, social and planning considerations, the City of Arcata faced unknown additional costs to support the construction and operation of the regional collection and treatment system. Thus it was not surprising that Arcata retained a local consulting firm (Environmental Research Consultants 1974a) to challenge all of the assumptions that were presented as justification for requiring a regional collection system as the only alternative for meeting wastewater treatment needs and for protecting the beneficial uses of Humboldt Bay waters (Appendix III). Arcata, in their testimony, proposed an alternative plan which is similar to that preferred by citizen petitioners (CSR - Figure 1). Both the CSR and Arcata plans were originally proposed in the initial planning document developed for the basin (Metcalf and Eddy Inc., 1974, Plan 1B, p 74). In apposition to a basin-wide collection and single treatment plant, Humboldt Bay basin could be divided into two sub-units, with wastewater collected by the northern unit being treated in an upgraded Arcata treatment plant, with treated wastewaters discharged into Arcata Bay.

Wastewater treatment authorities, however, were prevented, possibley psychologically,5/ from any serious consideration of alternative to a regional collection and ocean discharge system by the adoption in 1974 by the State of California Water Quality Control Board of a Bays and Estuary Policy (Appendix IV). The policy was interpreted publicly as strict prohibition against any treated wastewater discharges into specified California bays, although the language was permissive on the basis of adequate protection of existing beneficial uses and proof of "enhancement" of bay waters which would not have occurred in absence of the discharge6/. Faced with such an interpretation from staff and no directives or suggestions on what would constitute "enhancement" by the state board, the regional board in 1974 adopted their staff plan. Without a detailed counter-proposal, Arcata was forced reluctantly into joining HBWA, the agency formed to implement the regional collection system. In 1977, however, prior to offering revenue bonds for sale, HBWA finally was forced to disclose to the general public what the specific wastewater treatment rates would be required to pay back the revenue bonds. Such information catalyzed the public reaction as previously noted. To the City of Arcata, these costs were around $425,000 per year in addition to their own bonded indebtedness still unretired from construction of existing wastewater collection and treatment facilities. It was difficult for the City Council to justify such costs to their constituents. Since a pilot project on rearing of juvenile salmonids in wastewater fertilized salt water ponds had been underway since 1971 (Allen and Dennis, op. cit.), it was suggested to the City Council by the Director of Public Works that a feasibility study could be made on the use of reclaimed wastewater to operate an ocean ranch for salmon. Such a report was prepared (voluntarily) for the city (See Appendix V, Doc. 1). In this initial ocean-ranching proposal, the use of reclaimed wastewater for rearing juvenile fish and to operate a homestream for the returning adult salmon constituted

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5/ "Alternative 1 does not provide the desired degree of flexibility. If at sometime in the future, all bay discharges were prohibited, the con-construction of an interceptor connecting Arcata with Eureka and a regional ocean outfall or the construction of two ocean outfalls, one serving each plant, would be required"(Metcalf and Eddy Engineers 1974; p. 27; see also Appendix III, Statement 6).

6/ Informal discussion by City of Arcata officials drew from wastewater authorities the idea that even wastewater reclaimed to drinking water standards could not be discharged into the bay under the policy.

a case for "enhancement"7/ of Arcata Bay water and thus grounds for continued discharge to the bay under the Bays and Estuaries policy.8/ At about the same time that the City of Arcata was receiving and considering the ocean ranching feasibility study, the State of California Water Quality Control Board was adopting another seminal wastewater management policy. This policy set the guidelines for expanding the beneficial use of reclaimed wastewaters (Wastewater Reclamation Policy as adopted in final form January 1978). With the existence of a state reclamation policy as a basis for trying to define enhancement activities and a feasibility study based upon pilot project data already completed, the Arcata City Council authorized formation of a Task Force under the direction of the Director of Public Works to prepare an alternative plan for Arcata.9/ This Task Force voluntarily produced a plan involving creation of wetlands with wastewater as an enhancement value defined by precedent, and with salmonid aquaculture an enhancement value currently being demonstrated. The Task Force wrote a series of documents and position papers on the plan that provided a data base for public hearings before regional and state boards (Appendix V). These documents contain most of the information on the proposal by the City of Arcata to utilize treated domestic wastewaters in recreation, wildlife, and aquaculture enhancement projects.

2. Ocean Ranching Project

Salmon culture systems traditionally need a water supply of high quality defined as of good clarity, high in dissolved oxygen content, free of pollutants,

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7/ This first proposal had reclaimed wastewater being delivered continuously through a series of fish-ponds, and with possible dilution along the length of the system with seawater. The plan was technically vulnerable since chlorine disinfection of the discharge would probably have been required. This would have rendered the discharge water useless as a "homestream" for adult salmon since they are notoriously sensitive to this substance and probably would not have entered the discharge stream.

8/ The San Francisco Bay Regional Water Quality Control Board had a Reclamation Policy drafted and under review in which the development of freshwater marshes with reclaimed wastewaters was defined as an "enhancement." In addition the California Department of Fish and Game had also adopted a wastewater reclamation policy which strongly supported wetlands maintenance enhancement and development with properly treated wastewaters. Status of "enhancement" issues as known on December 1, 1978 by the City of Arcata is discussed later.

9/ Task Force members: wastewater treatment - Dr. Robert Gearheart, Associate Professor of Environmental Engineering; waterfowl and wetland - Dr. Stanley Harris, Professor of Wildlife Management; and salmon ranching - Dr. George H. Allen, Professor of Fisheries.

and of suitable temperature (Leitriz and Lewis 1977). This high water quality has been insured in salmonid aquaculture systems by use of spring water, well water, or locating salmon aquaculture systems on tributary streams whose waters are still of high quality. The number of such suitable sites is now limited (Netboy 1958; Scott et al. 1978). Recirculating water systems have been one of the methods employed to overcome lack of natural sites (DeWitt and Salo 1960; Allen 1962). The use of wastewaters, either of domestic or industrial origin, for fish culture has been widely used in most of the world for non-salmonid species (Allen 1969). Such use of wastewaters for trout and salmon culture has been limited due to the sensitivity of salmonids in freshwater to the gaseous (un-ionized) form of ammonia (Brockway 1950; Burrows 1964). Seawater, however, has considerable buffering capacity, and juvenile salmonids reared in seawater-wastewater mixtures have shown much higher rates of survival than would have been expected from reviewing only freshwater studies (Allen and O'Brien 1967; Crawford and Allen 1977). Thus the Arcata wastewater-seawater pond system is a new technique for rearing juvenile salmonids, that if successful, can increase the number of potential salmonid aquaculture sites. To our knowledge, the use of reclaimed wastewater to provide a homestream for adult salmon has never been proposed.

As just mentioned, any wastewater aquaculture system to succeed with salmonids, the sewage source must not contain excessive amounts of recalcitrant toxic substances. Arcata sewage is mainly of domestic origin, with some contribution from light commercial establishments, and lumbering plants. Consequently, the Humboldt State University Fisheries Department started investigating the potential of these wastewaters for aquaculture when the City constructed its first major treatment unit in 1956 (55-acre oxidation pond) (DeWitt 1969). This treatment unit was designed principally to protect a newly emerging oyster industry being developed in Arcata Bay on state-owned lands. Fortunately for the City of Arcata, the professional advice given to the consulting firm hired to develop the initial wastewater treatment unit was heeded (build the pond as large as possible!). Since the total population being served at that time was about 4,200, a 55-acre oxidation pond alone was sufficient to provide wastewater treatment for this population. Bioassay of this water in 1961 with coho salmon fingerlings (Appendix V, Allen 1977a) showed that the quality of the water was meeting a rigorous standard for toxicity as subsequently listed in California's Bay and Estuary Policy adopted in 1974 (Appendix IV). Water quality of undiluted effluent not sufficient for raising salmonids was found mainly in the summer months when high pH values (greater than 8.5), occurring from algal activity produce levels of un-ionized ammonia (NH_3) that are toxic to salmonids (Burrows op. cit.). The successful use of seawater-wastewater mixtures for rearing chinook salmon in laboratory experiments (Allen and O'Brien op. cit.) eventually lead to construction of two 0.15-acre ponds as an experimental project by the California Department of Fish and Game, Wildlife Conservation Board. Experimental rearing from 1971-1976 was funded by the Humboldt State University Coherent Area Sea Grant Program, U.S. Dept. of Commerce, NOAA, National Marine Fisheries Service.

III. SEWAGE TREATMENT SYSTEM

1. Community Background

The City of Arcata is a part of the Humboldt Bay Urban Area and lies between Arcata Bay on the south, Mad River on the north, the Mad River Bottom agricultural lands on the west, and the forested foothills, principally redwoods, to the east. The existing population of Arcata is 19,000 with the 1985 General Plan estimating a population increase to 22,000 people by 1990. Arcata is the home of Humboldt State University. Approximately 7000 of the 19,000 total population are Humboldt State University students and are not in Arcata from June 15 to September 15. About 3,000 students live on campus or in Arcata, resulting in a sewered population of about 19,000 on weekdays and 15,000 at night and weekends.

The City of Arcata recently approved a revenue bond that replaced a major sewer line. In June 1977 citizens gave a 76 percent voter approval to the City's effort to pursue an alternative wastewater treatment system.

2. Development of Existing Sewage Treatment Facilities

Prior to 1949, the City of Arcata discharged directly into Arcata Bay through a 24-inch (24") Vitrified Clay pipe out-fall sewer. In 1949, a primary treatment plant was constructed at a cost of $99,000. This project was funded by the City's General Fund and included a pumping station, pre-aeration unit, primary clarifier, digester and sludge drying beds. The plant at that time had the capacity to treat the effluent of a population of 5000 people. The primary treated effluent discharged directly into Humboldt Bay.

By 1956, the City of Arcata had outgrown the existing plant and the plant was expanded at a cost of $441,000. This plant modification and upgrade was funded by revenue bonds and a Federal Grant under Public Law 660. Two Revenue bonds were required to finance this project. The total bonded indebtedness for these bond issues of 1956 and 1957 was $226,241 (principal and interest). The major new unit added to the treatment system was the 55-acre oxidation pond. The plant at the completion of the 1956 modifications was presumed capable of treating sewage for an equivalent population of at least 20,000. Undisinfected effluent was discharged to Arcata Bay.

In 1966, the City added a chlorine contact basin and chlorinator unit. When this unit was added no provision was made for a high quality processwater to be used in the chlorinators. Since the initial construction of the disinfection facility, other electrical energy demands (heating, etc.) have taxed the original lines installed to the facility.

The treatment plant was again expanded in 1971 at a cost of $395.000. This project was funded by a third revenue bond and a combination of Federal and State funds. The balance of the bonded indebtness for this bond is $1,498,110 (principal and interest). Approximately 85% of this bond issue was devoted to collection system improvements. The improvements included additional headworks capacity, an additional clarifier and an aeration pond preceding the oxidation pond.

In 1974, the City enlarged the chlorine contact basin and chlorination facilities. A dechlorination unit was also added at this time. The project cost approximately $83,000 with funds being derived from sewer revenues and State and Federal Grants.

The City of Arcata is currently a member of HBWA. The Authority is in the process of financing construction of a Regional Wastewater treatment plant which will discharge effluent to the Pacific Ocean through eight miles of sewer main extending from Arcata to the treatment plant (Figure 1-B). The configuration of the secondary waste treatment system and trunk line routing from the north is in the process of being redefined by the Authority, EPA, and State Regulatory Agencies.

Arcata presently has a contract to treat sewage from a neighboring community (McKinleyville) with a projected sewered population of about 6000. The collection line has been completed, with initial deliveries occurring in September, 1978. A Clean Water Grant for $304,000 approved in 1978 will be used primarily to upgrade the disinfection unit of the Arcata treatment system to handle these increased flows.

The design data and current loading for the Arcata wastewater treatment plant is summarized in Appendix VI. The flow diagram for the present Arcata facility is shown in Figure 2. Plan of the Arcata system is shown in Figure 3.

3. Quality of Wastewater

The Arcata wastewater treatment system has had a long history of consistently producing a high quality effluent. With the proposed cellular modification of the treatment unit (Figure 3 - future dikes shown by broken lines), short-circuiting will be eliminated, retention time increased, and an even higher quality water than now exists will be available to enhance and maintain the productivity of the marshes of the proposed reclamation unit to be described. The following sections describe the quality of the water now entering Humboldt Bay as wastewater produced by the treatment unit as existing in the fall of 1978.

In 1974, the City of Arcata was issued a National Pollution Discharge Elimination System (NPDES) permit through the California North Coast Regional Water Control Board. Such permits require monitoring of the effluent quality to insure compliance with federal standards. In addition, discharges which have the potential for contamination of shellfish beds in Humboldt Bay have to meet additional standards, and receive continual scrutiny in overall assessments of the suitability of Humboldt Bay waters for shellfish culture and harvest.

The level of performance of various components in the treatment train of the Arcata plant is assessed from two types of data: (1) analysis of data

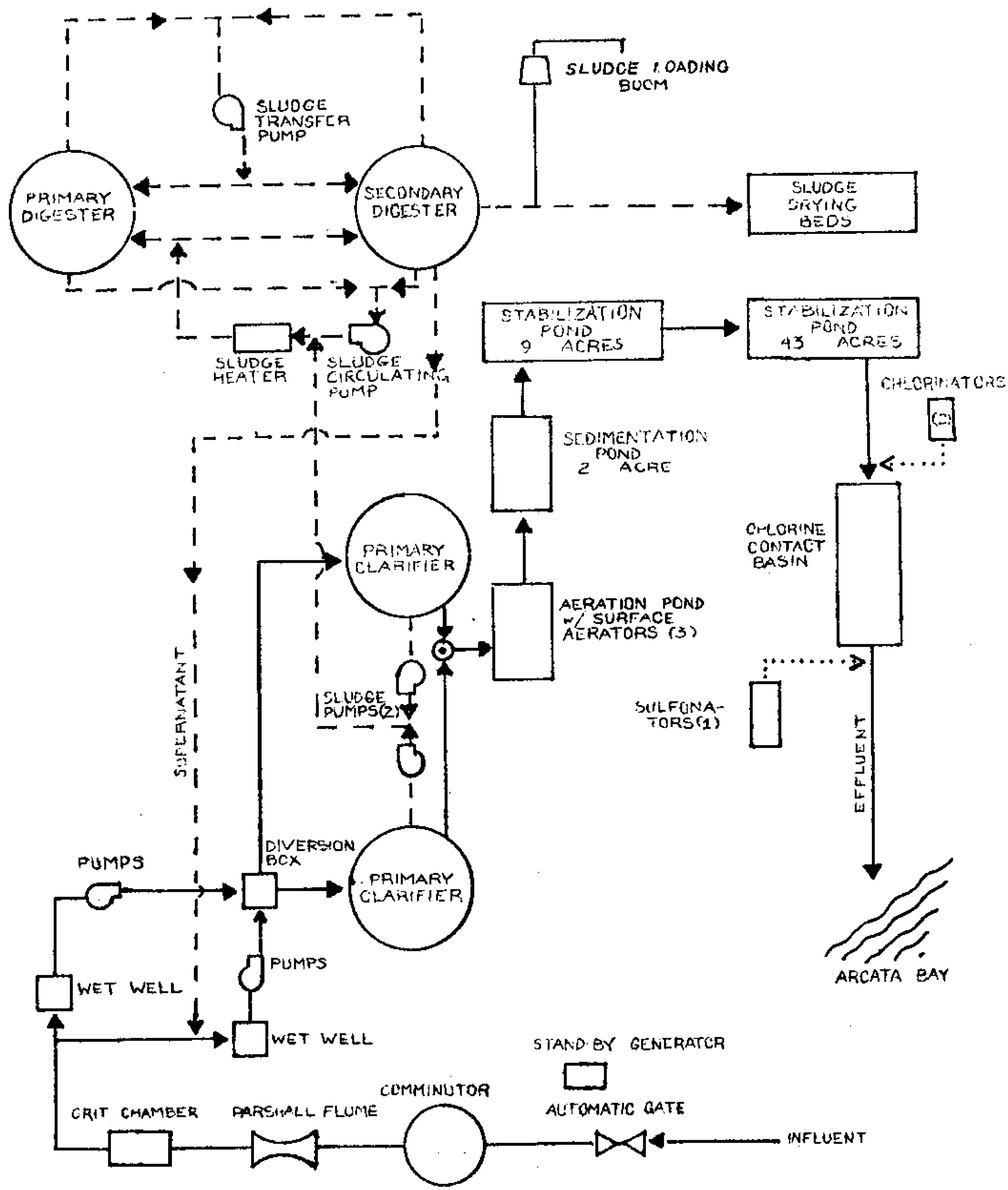


Figure 2. Flow diagram of existing City of Arcata wastewater treatment plant.

Figure 3. Plan of existing units of Arcata oxidation pond system, and proposed improvements.

Legend

T - Primary Treatment Plan

D - Anaerobic Digester

A - Aeration Pond

S - Sedimentation Pond

1-5 - Oxidation Pond Cells

D - Disinfection Unit (Proposed)

6 S - Disinfection Contact and Storage Pond

PU - Pump Station

R - Pump Station to Reclamation Unit

C - Existing Chlorine Disinfection Unit

O - Existing Outfall

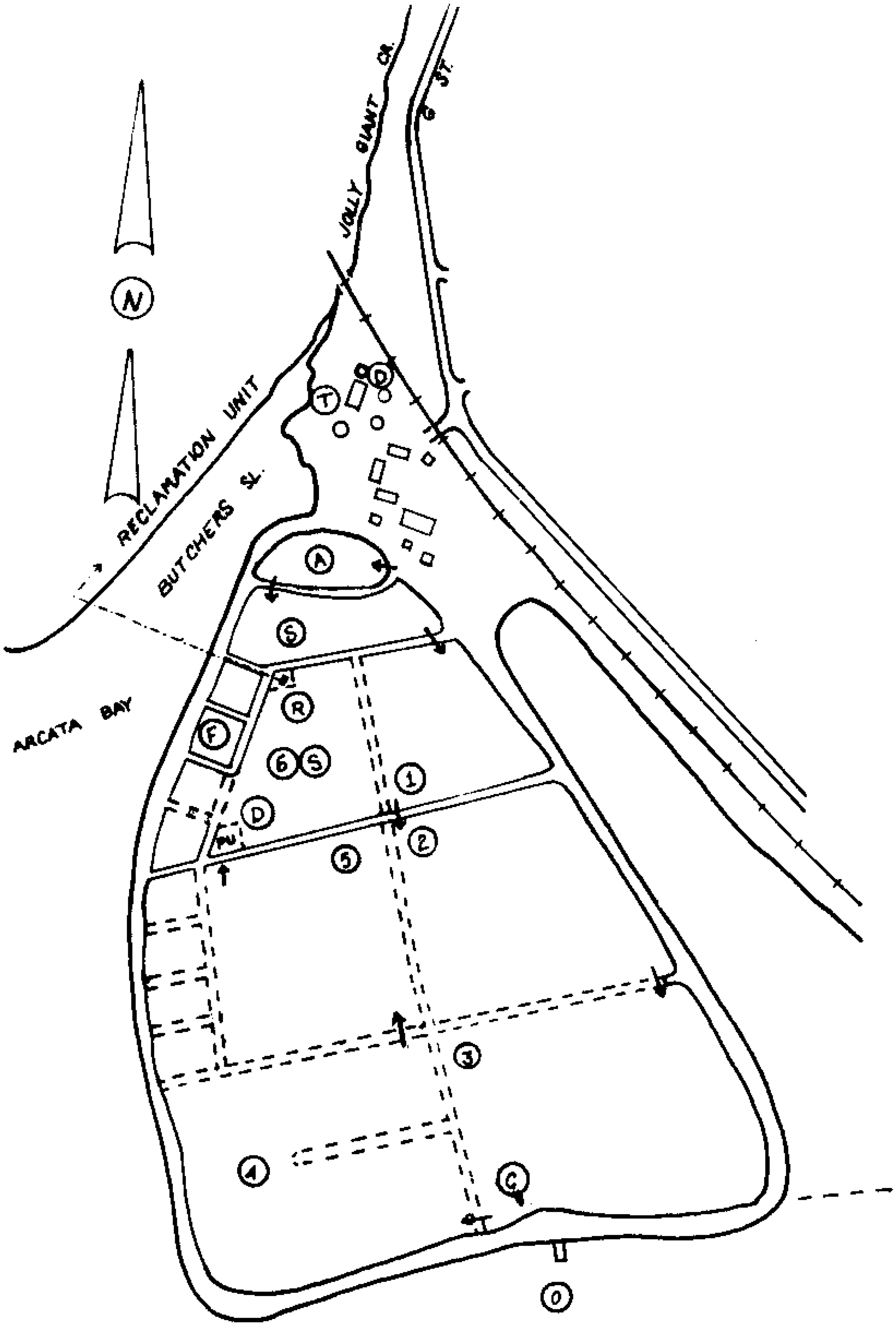
F - Existing Fish Ponds

→ - Direction of Flow Through Proposed System

═ - Existing Levees

== - Proposed Levees

-- - Proposed Wastewater Line to Reclamation Unit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collected in monitoring effluent discharges as required under NPDES permit, and (2) specialized studies undertaken during the summer of 1978 by the City of Arcata and technical staff of the North Coastal Regional Water Quality Control Board.

Performance of the sewage treatment system can be judged against federal effluent standards defining secondary treatment level and California effluent discharge standards for protecting shellfish harvesting beds (Table 1).

a. BOD-SS

Eight-hour composite effluent Biochemical Oxygen Demand (BOD) samples are required every week by the NPDES discharge permit monitored by the North Coast Regional Quality Control Board. Over a 2½ year period (January, 1976 to July, 1978), the monthly self reporting showed 104 samples analyzed (Figure 4). During this period, there have been several instances when no discharges to the bay occurred (low flow in summer months or stopping discharges due to emergency conditions). Of the 104 samples, five samples (5%) exceeded the weekly 45 mg/l BOD standard. Both of the two monthly samples that exceeded the 30 mg/l monthly average were taken during periods of late fall or winter algae blooms. One of these samples was during a month (September, 1976) in which only one weekly sample was collected for the month as a result of a no discharge period occurring during the other weeks of the month. The average effluent BOD for the 2½ year period was 16 mg/l. The trend in the data shows lower effluent BOD values in the last year attributable to certain modifications in the operational strategies and the completion of the first cell in the oxidation pond (Figure 3 - dike between cells 1-6 and 2-5).

Concentration of suspended solids (SS) in the effluent were analyzed 104 times during the 2½ year period (Figure 5). Again not all weeks required reporting because of the no-discharge operational plan during periods of algae blooms and emergency conditions. Of the 104 samples, six weekly samples exceeded the 45 mg/l std. which represents 6% non-compliance with weekly standards.

For monthly averages, only two out of the 31 months exceeded the 30 mg/l suspended solids standard which is a 6% non-compliance record. The average suspended solids for the 31 month period was 15.2 mg/l which is less than the required monthly average standard.

The effluent standard for BOD removal is 85% removal of influent BOD based upon a monthly average. Certain conceptual problems were found in the mode of that Arcata plant managers had been calculating this value for the Arcata system. There is approximately 85 million gallons of storage in the aeration pond, sedimentation pond, and oxidation ponds. At an average annual flow of 1.5 million gallons, the residence time through the system is approximately 56 days with no corrections for short circuiting, rainfall, and evaporation. The City is required to take weekly influent and effluent BOD

TABLE 1. EPA secondary treatment standards required for permits to discharge under the federal National Pollutant Discharge Elimination System (NPDES) as published in Federal Register on April 30, 1973 and current standards for Arcata Discharges to Humboldt Bay as required by California North Coastal Regional Water Quality Control Board.

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1. Federal - Domestic (municipal) wastewater

    1. Biochemical oxygen demand (5-day) shall not exceed 30 mg/l as a monthly average and 45 mg/l as a weekly average.

    2. Suspended solids shall not exceed 30 mg/l as a monthly average and 45 mg/l as a weekly average.

    3. Fecal coliform bacteria density shall not exceed 200 MPN/100 ml as a geometric mean and 400 MPN/100 ml as a weekly geometric mean.

    4. pH shall be within the range of 6.0 - 9.0

2. State - Humboldt Bay

    A. Organisms of the coliform group:

    Median total coliform not to exceed 70 MPN/100 ml; no more than 10% in any one day period to exceed 230 MPN/100 ml.

3. State - Arcata effluent discharge permit:

    1. Organisms of the coliform group: median total coliform 23 MPN/100 ml, with daily maximum not to exceed 230, and residual chlorine not to exceed 0.1 mg/l.

    2. Toxicity concentration; 1.5; 90 percentile value - 2.0 units.

    3. Dissolved oxygen in treatment ponds: 1.0 mg/l.

    4. pH : 6.5 - 8.5.

    5. BOD_5 and SS : same as federal standards.

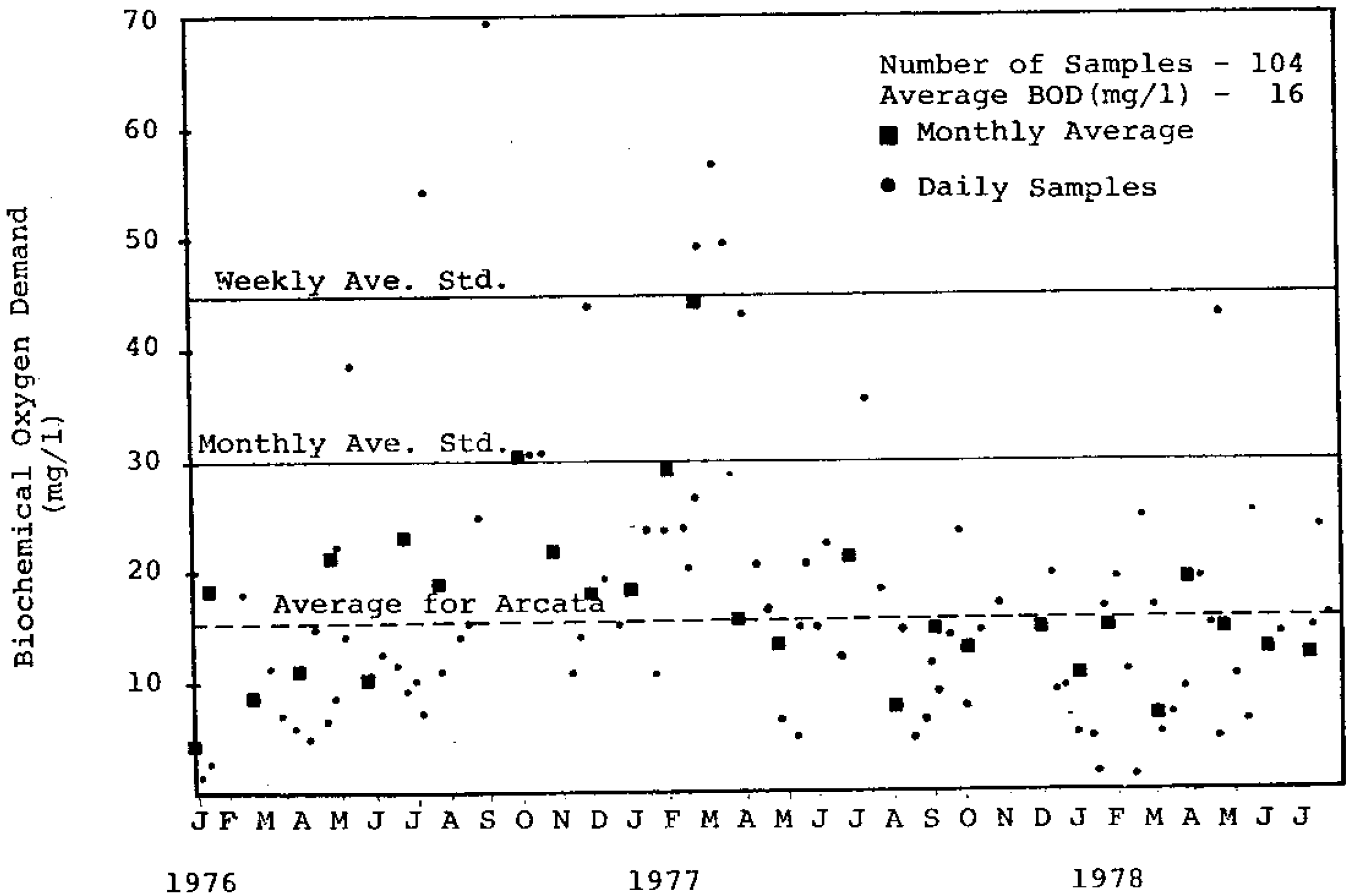
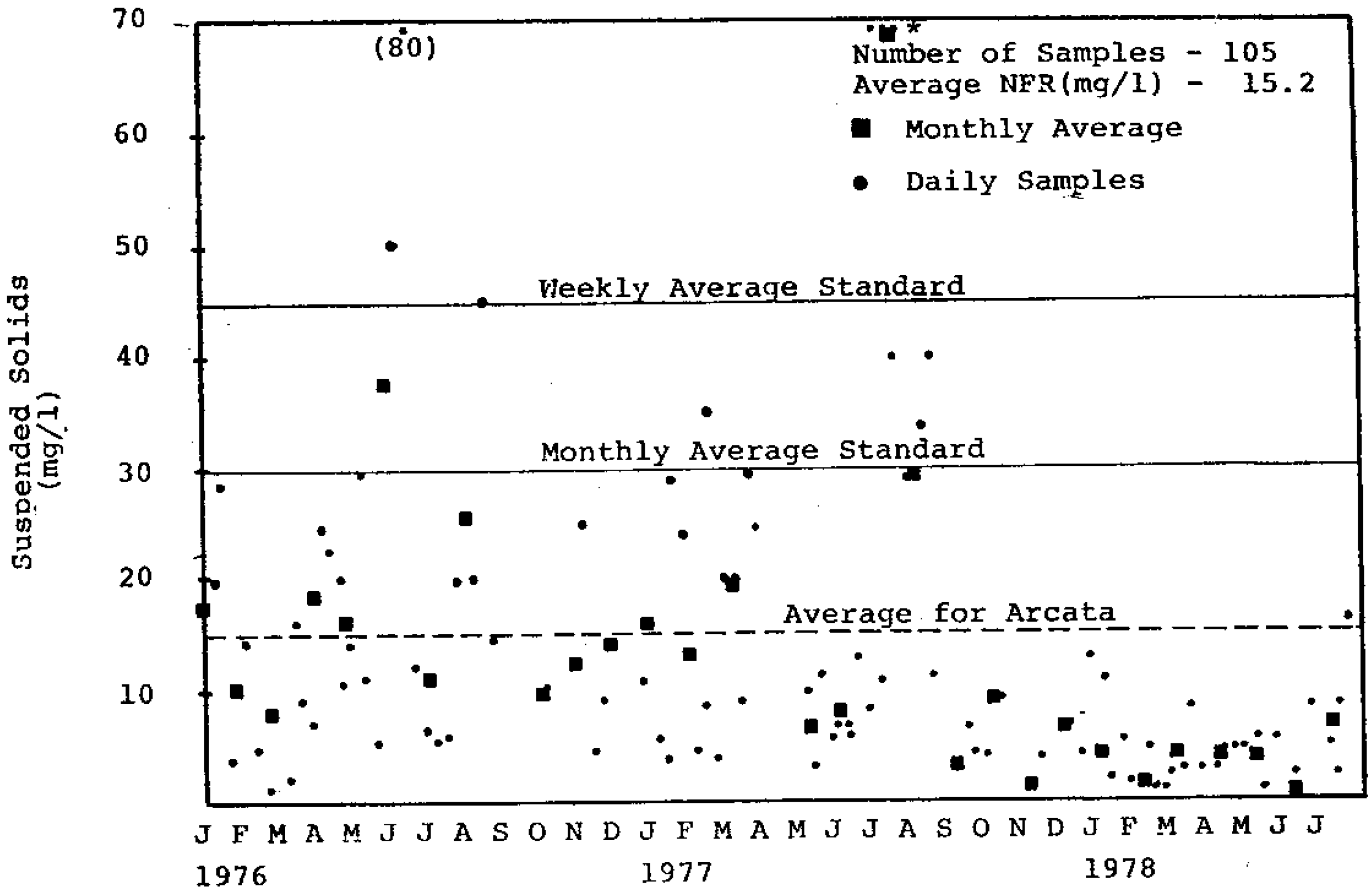


Figure 4. BOD_5 values for Arcata wastewater treatment plant effluent from monitoring required under NPDES permit, January 1976 through July 1978.



*Three values (144, 136, 140 respectively)

Figure 5. Suspended Solid values for Arcata wastewater treatment plant effluent from monitoring required under NPDES permit, January 1976 through July 1978.

values and calculate percent BOD removal in Figure 6[10/]. Of the 30 monthly samples, 10 values were below 85% removal (Figure 6). These were due to a low influent BOD during periods of high volume of inflow water and infiltration, and not due to a high effluent BOD. The average percent BOD removal for the 30 month period was 85 percent removal.

greater than 85 percent removal.

The most complete and representative study to assess treatment performance was an in-depth sampling program for the Regional Water Quality Control Board in August 1978 (Table 2). The results from this study show an 87, 93, and a 97% BOD removal with corresponding effluent suspended solids and BOD concentrations of 11, 8, 11 mg/l and 11, 20, 1.5 mg/l respectively. The 30/30 BOD/SS secondary treatment level was met for all practical purposes by the effluent from the upper oxidation ponds (Figure 3, cell 1-6). This treatment performance occurred during a period when sludge from the City of Eureka sewage plants was being treated temporarily by the City of Arcata. The sludge was introduced directly into the aeration pond.

The present level of BOD reduction is near or better than the current federal standards for secondary treatment. With cellularization of the oxidation pond, this level of treatment can be maintained and even improved despite additional sewage loads from McKinleyville.

b. Total Coliform

Total Coliform analysis is required on a weekly basis or more often if conditions require. In the 2½ year period, 210 coliform samples were taken and reported for the NPDES self-reporting requirement (Figure 7). Of these 210 daily samples, 13 samples exceeded the maximum daily limit of 230 organisms/100 ml. This represented a 6% non-compliance record of the daily maximum standard. Most of these violations occurred during periods of high suspended solids due to high *Daphnia* and algae populations. These are always times of possible effluent violations and procedures are now being developed to eliminate technical violations occurring during periods of increased biological activity in the oxidation pond, and to improve the automatic monitoring of disinfection equipment during nights and weekends.

c. Dissolved Oxygen

The dissolved oxygen concentration is not to be less than 1.0 mg/l under California standards set for the ponds (aeration pond, sedimentation pond, and oxidation ponds). The only consistent data available

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10/ The method of calculating BOD removal required by the NCWQCB is to divide the BOD value of the effluent into the BOD value of the incoming sewage. Since there is no treatment relationship between any one days' influent and effluent values, due to the 30-day time lag through the treatment system, this type of calculation is not a meaningful procedure in assessing removal capabilities. A moving average procedure would be much more appropriate in assessing BOD removal performance.

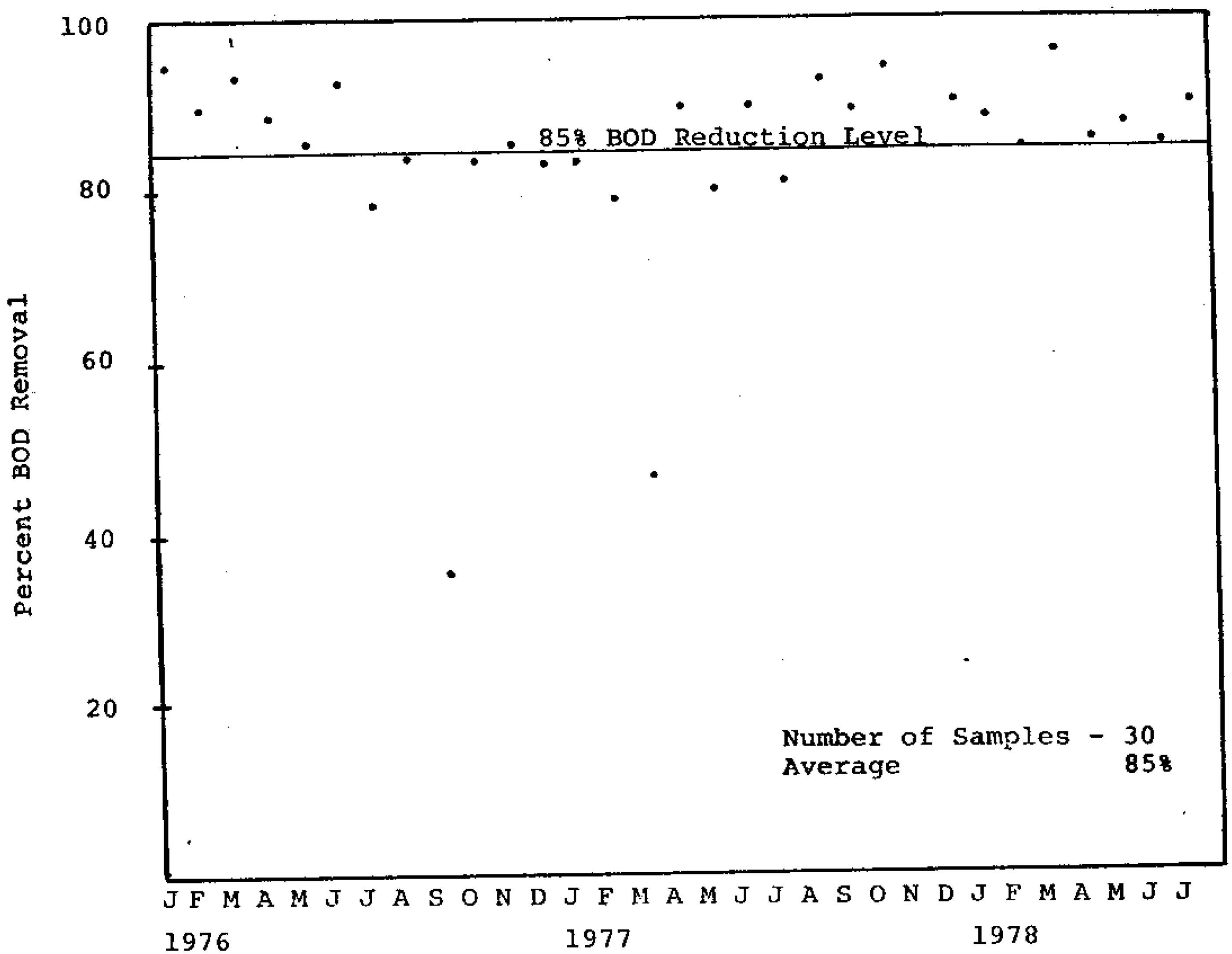

Figure 6. Percent BOD removed by Arcata wastewater treatment system as calculated from NPDES monitoring data, January 1976 through July 1978.

TABLE 2. Results of Arcata wastewater treatment plant survey conducted by North Coastal Regional Water Quality Control Board, August, 1978 (all units mg/l).

Day	Sample Site[1/]	BOD_5[2/] Unfiltered	BOD_5[2/] Filtered	SS	NO_3	NH_4
August 8	1) Influent	160	78	190	-	-
	2) Aeration Influent	130	72	100	0.3	30.0
	3) Sedimentation Pond Effluent	31	17	25	0.1	27.0
	4) 1st Cell Effluent	26	9.1	23	0.3	27.0
	5) Final Effluent	11	8.7	11	0.4	20.0
August 9	1) Influent	160	75	210	-	-
	2) Aeration Influent	110	60	76	0.3	27.0
	3) Sedimentation Pond Effluent	34	15	19	0.1	27.0
	4) 1st Cell Effluent	20	6.5	30	0.2	27.0
	5) Final Effluent	20	4.7	8	0.2	21.0
August 11	1) Influent	140	73	180	-	-
	2) Aeration Influent	110	68	100	0.3	25.0
	3) Sedimentation Pond Effluent	30	7.4	33	0.1	29.0
	4) 1st Cell Effluent	23	4.1	43	0.2	26.0
	5) Final Effluent	1.5	2.0	11	0.2	21.0

1/ Sample locations shown in Figure 3 (points T, A, S, and 6).

2/ Percentage difference in BOD_5 values between influent on August 8, 9 and 10: and final effluent: 93, 88, and 97 respectively.

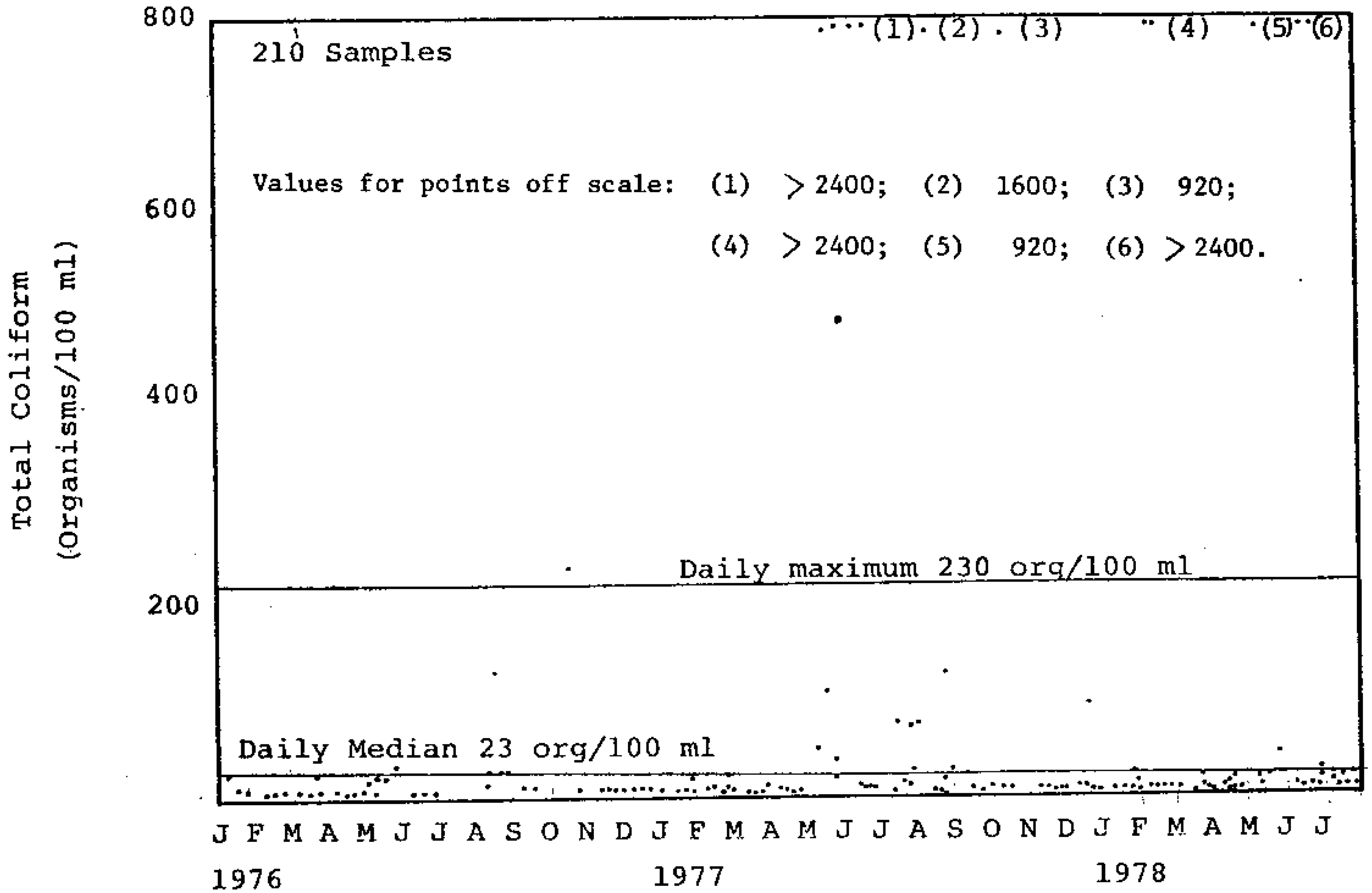

Figure 7. Total Coliform levels in Arcata wastewater treatment effluent as shown by NPDES monitoring, January 1976 through July 1978.

to us was from studies in the final effluent. Of the 86 samples taken, five samples were below 1.0 mg/l for the 30 month period (Figure 8). This represents a 6% non-compliance for final effluent of the dissolved oxygen standard. The actual dissolved oxygen concentration varied from a low of 0.9 mg/l to a high of 15 mg/l during periods of intense algae activity.

d. Toxicity

The State of California requires the determination of the toxicity of effluents as determined by bioassay using a standard test fish and with results expressed as "toxicity" units (State of California Bays and Estuary Policy; Kopperdahl 1976). The test usually is a static bioassay following standard procedures (Amer. Public Health Assoc. 1970).

The Arcata effluent has been tested since the late 1950's for its toxicity by bioassay with salmonids by Humboldt State University fisheries personnel interested in wastewater aquaculture (Allen and O'Brien op. cit.; Allen 1977a, Appendix V). Beginning in 1978, the California Regional Water Quality Control Board required that monthly toxicity tests not be done by personnel with a vested interest in the results and not involving any test fish that may have been grown in the wastewater ponds. As a result bioassays for toxicity testing are now conducted by an independent laboratory (Table 3)[11/].

Previous bioassay studies have shown non-toxic conditions of undiluted effluent occurring primarily in winter months, with toxicity increasing during summer periods. Independent studies beginning in March 1978 (Table 3) showed only one sample with appreciable toxicity, with this sample occurring in June.

Toxicity that exists in the Arcata effluent can be attributed primarily to un-ionized ammonia, a form highly toxic to salmonids (Burrows op. cit.). In 1977, a study of the summer-time characteristics of the Arcata effluent showed the relationships between algal population (as measured by turbidity), pH and forms of ammonia (Figure 9). pH correlated with an increase in turbidity (algal population) since the bicarbonate to carbonate shift occurs with periods of intense photosynthetic activity. As the pH increases a greater proportion of the total ammonia is in the un-ionized form. Total ammonia concentrations fluctuate in oxidation ponds from algal synthesis reactions and bacterial decomposition. During the particular period covered by our study, an increase in algal cells contributed to the removal of total ammonia from oxidation pond water. As the algal population began to decrease the total ammonia began to increase reaching a maximum of 8.2 mg/l on 29 August 1978. The pH at this time was above 9.0, so that most of the ammonia would be in the NH_3 form and would kill salmonids in a bioassay test. Levels of ammonia that produce toxicities in bioassays are rendered harmless to fish life in the bay by the lowered pH of the seawater shifting the ammonia to its non-toxic ionized form and by dilution. Swarms of Humboldt Bay fishes,

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11/ Control water and dilutant water for these tests was freshwater. In tests conducted by City of Arcata personnel, the control water was freshwater, but the dilutant water has been seawater, since this is the medium into which the effluent is discharged.

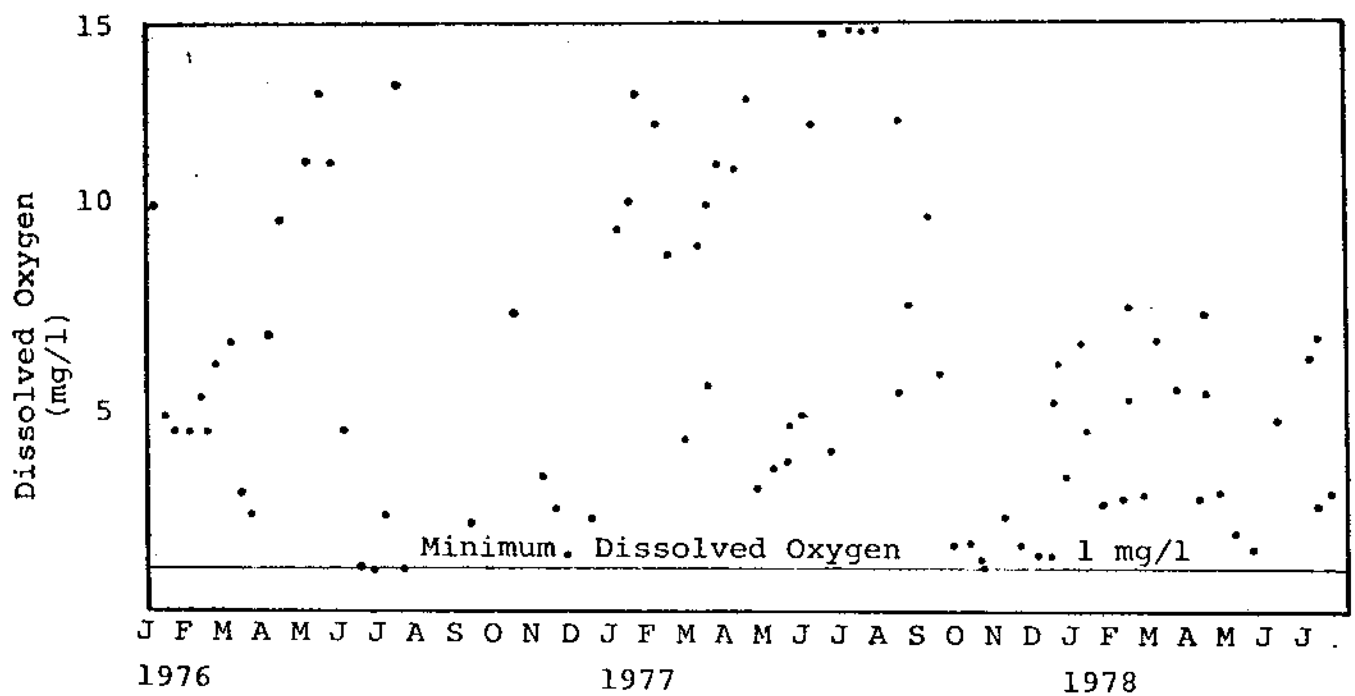


Figure 8. Dissolved Oxygen in Arcata wastewater treatment effluent as shown by NPDES monitoring, January 1976 through July 1978.

TABLE 3. Results of toxicity studies of Arcata effluent using 96-hour static bioassay with rainbow trout fingerlings, March - August, 1978, as conducted by Winzler and Kelley, Inc. laboratories, Eureka, California. (Percent survival by 24 hour periods.)

Month	Test[1/]	24 hrs.	48 hrs.	72 hrs.	96 hrs.
March 1978	Control	100	100	100	100
	100% Sample	100	100	100	100
April 1978	Control	100	100	100	100
	100% Sample	100	100	100	100
May 1978	Control	100	100	100	100
	100% Sample	100	90	60	60
June 1978	75% Sample	60	40	30	10
	85% Sample	40	0	0	0
	95% Sample	0	0	0	0
	Control	100	100	100	100
July 1978	50% Sample	100	90	70	50
	65% Sample	90	80	10	0
	80% Sample	70	60	0	0
	Control	100	100	100	100
August 1978	40% Sample	100	100	100	100
	50% Sample	100	100	100	100
	70% Sample	100	100	100	100
	100% Sample	100	100	100	100
	Control	90	80	80	60

[1/] Dilutant and control was freshwater in these tests.

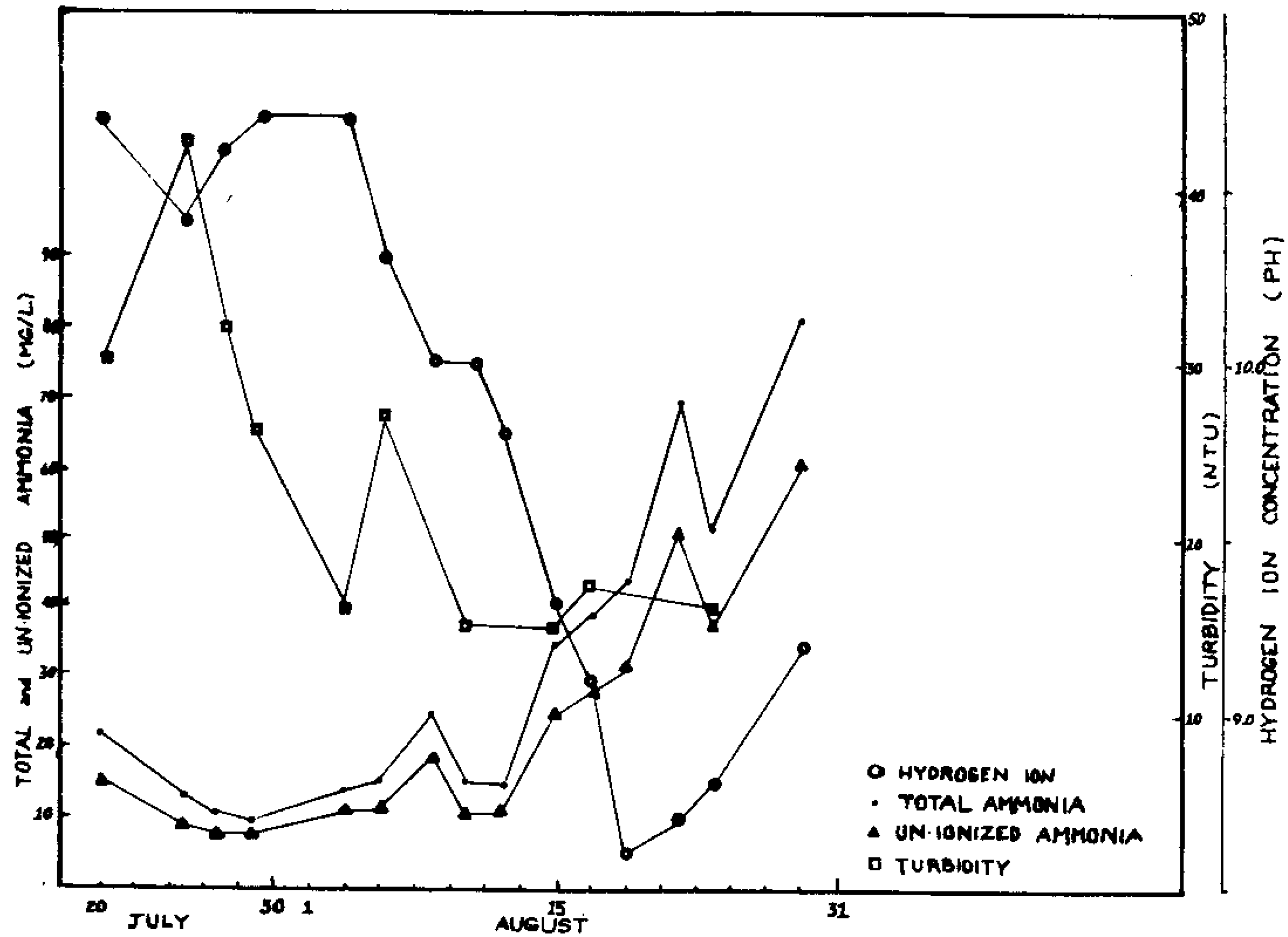


Figure 9. Arcata oxidation pond effluent characteristics, July 20 - August 29, 1977. (Temperature during studies varied only slightly around 15 C, and BOD values ranged between 12-18 mg/1 in July (N = 3) and between 6-9 mg/1 in August (N = 6).

especially jack smelt, occur at the outfall at high tide to feed on invertebrates carried into the bay, particularly Daphnia (water flea). During higher tides, schools of fish will feed within a few feet of the flap gate on the outfall pipe. The only gross difference in external appearance in the fauna near the outfall channel is a lack of barnacles on rocks within a few feet of the outfall. This is probably due to low average salinities directly at the outfall. A single study of benthos of the area showed no difference in mean number per unit area of Capitella capitata (a marine annelid indicator species for areas of high organic content), when compared with a control area away from the influence of wastewater discharges (Heacock 1975).

The major problem with high algal cells or high ammonia levels within the effluent is interference with disinfection using break-point chlorination. The Clean Water Grant received by the City of Arcata in 1978 will aid in rectifying these problems in the disinfection unit as now operated.

IV. RECLAMATION SYSTEM

The reclamation unit (Figure 10) was designed in conformance with the California State Water Quality Board 1977 policy on wastewater reclamation and their 1974 policy requirement of enhancing bay waters. The unit also had to conform with land use policies of the California Coastal Zone Commission. Disinfected wastewater from the treatment unit is proposed for operation of the freshwater marshes and recreation lake. Water discharged from this marsh-lake system will be used to operate a fishway for capturing adult salmon. About 37 acres of city-owned land will be combined with 25.8 acres of privately owned land to construct the reclamation system. Present land uses include an abandoned sanitary landfill, degraded and filled salt marshes and marginal agricultural (grazing) land.

When the proposed marsh system is operated with wastewater, a variety of difficult water quality control problems will be met simultaneously:

1. domestic (point-source) of wastewaters will be treated to levels beyond current standards.

2. reclaimed wastewater will be used beneficially for fish and wildlife enhancement.

3. nonpoint sources of pollution, as serious in producing water quality degradation in Arcata Bay as point sources, will be treated, and

4. an aquaculture wastewater reuse system capable of producing revenue will be under development.

The following sections describe the proposed fish and wildlife enhancement programs for marshes and recreation lake proposed.

1. Freshwater Marshes

The elimination and degradation of wetland in California, as throughout the United States, has become a serious public concern, not only because of importance of such areas for fish and wildlife habitat, but for their great utility in functioning as a free advanced biological treatment system (Appendix VII). Such wetlands probably are a major factor in maintaining some semblance of normal aquatic life in large sections of our coastal estuaries. Wetland degradation and removal is extremely advanced in Humboldt Bay where only five (5) percent of the original salt marshes remain. It is freshwater wetlands that the California Department of Fish and Game has identified as an even greater habitat limitation for Humboldt Bay area waterfowl. Harris (1977, Appendix V) was able to document the presence of nearly 200 species of birds in the vicinity of the oxidation pond (Table 4) many of which require the freshwaters of the oxidation pond. The oxidation pond is also bordered by riparian vegetation and adjoins saltwater marsh that is now federal waterfowl refuge. The oxidation pond and wildlife refuge contain highly diversified habitats over a relatively small contiguous area. The proposed freshwater marshes will add additional ecological niches and enhance the Humboldt Bay federal waterfowl refuge complex.

Figure 10. Plan of proposed reclamation unit. Existing and proposed portions of the unit shown in legend.

Legend

M - Freshwater marsh area. Southern portions now exist as degraded saltmarsh, upper portions either abandoned mill site or marginal agricultural land.

L - Recreation lake. Basin now exists as a sterile rainwater catch basin.

O - Proposed ocean ranch facilities (discharge channel and fishway, adult holding pond, imprinting ponds). (Existing access road - small and gravelled).

P - Existing Public Parking and Boat Launching Ramp.

F - Fish rearing ponds.

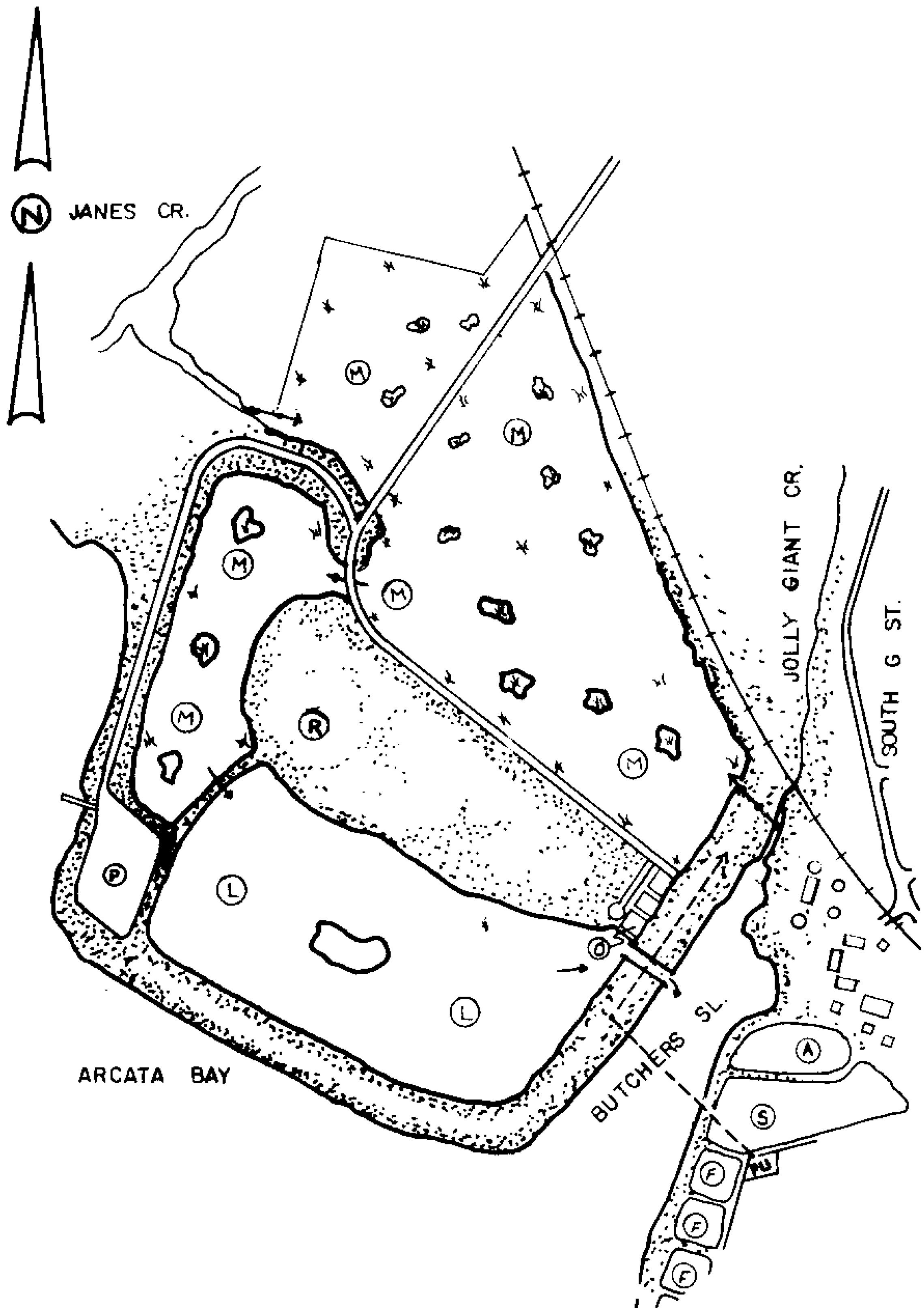
PU - Reclaimed water pump station (proposed).

R - Interpretive and Bird-Watching Area (Existing condition - layer of sterile bay muds over material deposited in abandoned sanitary land-fill refuse disposal site. Area covered by primary plant invaders, mainly over lower slopes).

—•→ - Freshwater Sources

---> - Reclaimed Water Source

——→ - Direction of water flow through proposed reclamation unit.


N
JANES CR.
JOLLY GIANT CR.
SOUTH G ST.
ARCATA BAY
BUTCHERS SL.
M
M
M
M
M
M
R
L
L
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O
A
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F

TABLE 4. Analysis of abundance of birds known to have occurred at Arcata oxidation pond, at site of proposed recreation lake, and on site of proposed marsh (from Harris, AppendixV). (Locations: oxidation pond - Figure 3; recreation lake and marsh - Figure 10).

	Number of Species		
Abundance Status	Oxidation Pond	Proposed Recreation Lake	Proposed Marsh Area
Common	51	21	7
Uncommon	43	22	13
Rare	47	49	21
Casual	37	14	4
Accidental	12	2	1
Total Species	192	108	46

In addition to adding about 35.8 acres of freshwater wetlands to the region's waterflow habitat, the marsh system will act as an advanced biological treatment unit for the secondary treated and disinfected wastewaters, water which under the regional collection and disposal plan would be pumped eight miles for eventual treatment and discharge unused to the ocean. The proposed freshwater marsh should provide considerable advanced biological treatment to incoming wastewater (a grass-bacteria Symbiotic System, Brown 1975). The freshwater marsh-lake chain will act as an ultimate "fail-safe" unit for the wastewater treatment system.

A considerable number of rare or unique species of birds has been recorded on the oxidation pond (Table 4), and these are expected in the proposed freshwater marshes since all of the species of birds recorded in the oxidation pond will be attracted to the new freshwater marsh. Areas of open water and hummocks will be provided to ensure the widest possible range of ecological niches throughout the marsh. Even in its present degraded condition, river otter and black-tailed deer have been observed in the area and would be expected in larger numbers in the improved marsh. Studying the degree of increased utilization and the relative frequency of usage by waterfowl will be part of the biological investigations to be undertaken in order to develop a marsh management needed by the City of Arcata. Plants providing food for waterfowl, such as alkali bulrush, are the species to be favored in marsh development and management.

Restoration of degraded coastal lands for wildlife habitat, conform to policies of the California Coastal Commission, The Humboldt Bay Conservation, Harbor, and Recreation District plans, and the City of Arcata master plan, the three major land use planning agencies having jurisdiction over project lands. Acquisition of non-city owned lands for marsh development is now underway.

2. Recreation Lake

An abandoned sanitary landfill solid waste disposal site will be developed into a recreational lake (Figure 10). During operation of this landfill by Humboldt County, untreated leachate drained into Butcher Slough. To prevent further leaching after site abandonment, the NCRWQCB required that the refuse area be covered with impervious material. For this covering, about a three foot layer of dried mud was dredged from the unused portion of the landfill, resulting in about 17 acres of deepened area of sterile blue mud. The proposed lake to be developed in this basin will be used for waterfowl and fish enhancement programs.

a. Waterfowl

Due to uneven removal of dredge materials as noted above, several broad hummocks were left in the lake. When above water, these areas have served as roosting and loafing sites for thousands of migratory waterfowl. Thus permanent loafing sites (islands) will be created in the lake to improve the amount of loafing areas for waterfowl. Peregrine falcons (an endangered species) have been regularly observed feeding on waterfowl using these loafing sites. Undoubtedly the creation of such permanent loafing islands will insure enhanced feeding activities by this endangered species.

The south side of the protected landfill area will be gently sloped and landscaped with redwood stumps that can serve as bird viewing sites. Access to these viewing sites will be from an interpretative area to be built on the filled portion of the site (Figure 10-R).

b. Trout and Salmon Rearing

At least four distinct trout and salmon programs have been identified for the recreation lake.

a. Trout Fishing

The lake will provide a near-city public fishing area at virtually no cost since a public road to a launching ramp leading to Arcata Bay is already in place at the southwest corner of the lake (Figure 10-P). Trout will be planted into the lake, with sport fishing to be restricted to the south and east banks. These banks are to be crenulated to develop a maximum of picnic and fishing locations.

b. Coastal Cutthroat Trout Enhancement

The second aquaculture program for the lake will be for enhancement of Humboldt Bay's anadromous sport fish runs. The initial target species will be the coastal cutthroat trout. Anadromous coastal cutthroat trout occur in California only in Humboldt and Del Norte counties (DeWitt 1954), and thus can be regarded as a restricted resource in California. Artificial spawning beds (Turman 1972) between marshes will be tested as a means of establishing a self-sustaining run of this species into the system.

c. Salmon Rearing

Pilot project studies on rearing juveniles for use in ocean ranching utilize coho (silver) and fall chinook salmon (Allen and Dennis op. cit.). Juveniles of local stocks of fall chinook salmon move seaward to estuaries in May and June at an age of 3-4 months (Tanaguchi 1970). Recent studies have shown that fall chinook salmon, and probably other stocks of chinook salmon also, remain in brackish waters of estuaries until late fall before entering full-strength seawater (Reimers 1973). During such estuarine residence these salmon probably are subject to considerable natural mortality. By saltwater additions during high tides, the recreational lake can be made into an estuary. Thus, juvenile fall chinook salmon reared in the fish ponds located in the treatment unit (Figure 3-F), can be liberated into the lake to test the estuarine rearing potential of the lake. Survival of juveniles can be monitored in "downstream migrant traps" to be located at the point of discharge into Butcher Slough (Figure 10-O).

d. Artificial Homestream for Ocean Ranch

Water discharging into Butcher Slough from the recreation lake will be used to complete the Arcata ocean ranching project. Juvenile salmon and trout placed in ponds supplied with lake water can be expected to imprint to dissolved organic fractions in the water (Hoar 1976). This imprinting will result in the reclaimed wastewater discharge becoming the homestream for returning adult fish. Returning adult salmon attracted to a fishway to be located in the discharge channel, will be trapped and placed into holding pens, where they will be retained for maturation and spawning. As salmon runs are increased. "jacks" (precocious males) and surplus male salmon can be marketed. When this occurs, the current pilot project will have reached the demonstration stage of ocean ranching of salmon using reclaimed wastewaters.

V. OCEAN RANCHING PROJECT

1. Background, Description, and Results of Juvenile Rearing Experiments

The earliest studies on the potential of the oxidation pond for salmonid aquaculture were by Hazel (1963) and Hansen (1967). These studies indicated, that without modification, the oxidation pond system was not a reliable culture medium for salmonids. In 1963, the first request for experimental use of Arcata's wastewater for mixing with seawater in ponds was granted by the City Council, and a project proposal submitted to the U.S. Public Health Service (USPHS). Matching funds were to be provided by the Humboldt County Board of Supervisors. The project, although approved, never received funding priority by USPHS. In 1964, a serious flood occurring along the west coast of the United States and centering on northern California, resulted in all uncommitted county funds being used for relief and repair work. The USPHS project was subsequently withdrawn. In 1967, the senior author went on sabbatical leave and completed a bibliography on use of wastewater in fish culture (Allen 1969). On returning to Arcata, the wastewater rearing pond project was submitted to the California Department of Fish and Game, Wildlife Conservation Board, for funding of capital construction costs, as a pilot study on new salmon culture techniques. This provided non-federal matching funds for federal support as previously discussed (Allen 1972, Appendix II). The construction of two 0.15-hectare ponds (North and South Ponds) within the periphery of the 55-acre oxidation pond was completed in July 1971 (Figure 3-F).

In the first years of operation, juvenile salmon reared in the ponds were released directly into Humboldt Bay, since facilities were unavailable for holding and marking young fish and an appropriate homestream for project fish had not been identified. Results of freshwater rearing experiments have been published as Data Reports and in the literature (Appendix II). Beginning in 1975, however, holding and marking tanks became available, and marked salmon were released into Jolly Giant Creek, selected as a homestream on a temporary basis. This small urban stream rises in a second-growth redwood forest to the east of the city of Arcata, flows underground in concrete channels under downtown Arcata before emerging into a tidal channel (Butcher Slough) located immediately west of the wastewater fish ponds (Figure 10). Verified returns of salmon planted in the creek began in 1975, with a very successful return in the fall of 1977 (Allen et al. 1978, Appendix II).

A summary of the results of juvenile rearing was developed for hearings before the California State Water Quality Control Board on September 12, 1976, on Arcata's wastewater treatment and reclamation system (Table 5). Of the five species of salmonids reared in the system, the most consistent success has been with fingerling coho salmon reared during a fall-through-spring period. This species in California remains in freshwater during its first summer of life, migrating to the ocean in April-June, roughly 12-14 months after hatching (Shapovalov and Taft 1954). In the Arcata pilot project, juveniles are maintained in standard fish cultural facilities until fall before planting into ponds when water temperatures drop below an 18-20° C range.

TABLE 5. Percent survival of pond- and pen-reared groups of salmon and trout reared in mixtures of seawater from Humboldt Bay and secondarily-treated domestic wastewaters from Arcata oxidation pond during pilot projects studies, 1971-1976.

Type of rearing	Species	Percent Survival[1/]			
		By Individual Groups		By Years	
		Total # groups reared	Range in survivals (1971-76)	Range in mean yearly survivals (1972-76)	Number of years
Pond (free-roaming	Silver salmon	12	0-96	45-87	5
	Chinook salmon	17	0-58	1-34	5
	Rainbow trout	6	0-100	46	1
	Cutthroat trout	1	17	17	1
	Kokanee (sockeye) salmon	1	37	37	1
Pens (either fixed or floating)	Silver salmon	32	0-100	55-91	5
	Chinook salmon	45	0-100	17-56	5
	Rainbow trout	16	16-66	24-50	2
	Cutthroat trout	4	40-100	37	1
	Kokanee (sockeye) salmon	6	0-94	54	1

[1/] The range in survivals for groups of salmonids reared in the system includes the experiments conducted during the first summer of rearing (1971) when all groups reared died. The range in mean yearly survivals, however, excludes 1971 results.

Less success has occurred with fall chinook salmon to which we had directed our initial efforts since we considered the species to have the simplest life history. Fall chinook salmon in northern California migrate into rivers in late summer or fall, normally spawn during October-November, with fry emerging into the streams in mid-winter. The fry then remain in the streams until May-June when they migrate downstream to estuaries (Taniguchi op. cit.). Freshwater juvenile growth therefore, occurs from February-May, with migration to the estuaries in May-June. Rearing in our ponds occurs from February through May, with migratory fingerlings being removed in May before arrival of warmer summer temperatures. Increasing water temperature (above 17-18^{o} C) have been found to inhibit migratory behavior (Hoar op. cit.). Only two of five experiments with fall chinook produced enough migrant fingerling salmon from the fry planted to be considered successful.

Some extended rearing of rainbow steelhead trout, especially during warm-water periods in the summer indicates this species has a potential for successful culture equal to or better than that for coho salmon. A few experiments with coastal cutthroat trout produced mixed success, and a single experiment with sockeye salmon was not successful.

Results in Table 5 involve a wide range of rearing times, seasons, and species, consequently a detailed analysis is not included in this paper.

2. Adult Returns

As previously mentioned, during the initial years of our rearing experiments, juvenile salmon were released directly into the intertidal reaches of Humboldt Bay, either into Butcher's Slough or at the oxidation pond outlet. The fish were released without any identifying marks since we did not have any system for holding juvenile fish for marking. Release into saltwater provided little olfactory imprinting. With completion of juvenile fish-holding facilities, however, project salmon could be given identifying marks (removal of a fin), and held for release into nearby streams, particularly Jolly Giant Creek.

The first verified return of marked salmon into Jolly Giant Creek were established in 1975 by salmon taken by seining and electro-fishing (Table 6). In the Fall of 1976, a temporary trapping facility was established at an intertidal location on Jolly Giant Creek. In the fall of 1977, a Master of Science student constructed and maintained a salmon weir and trap on Jacoby Creek, a stream entering Humboldt Bay southeast of the oxidation pond. Adult coho salmon from smolts released in the spring of 1976 into upper reaches of Butcher Slough in 1976 (Allen 1976b, Appendix II) were captured in both Jolly Giant and Jacoby creeks in the fall of 1977. An estimated total escapement to the two streams was about 0.5 percent of the smolts released (Allen et al. 1978, Appendix II). Private enterprise salmon ranchers require about a 2.0 percent return of smolts released to the ranch site for a profitable operation. Catch and escapement of coho salmon in California and Oregon in 1977 (1974 brood) was about one-fourth that in 1976 (1973 brood). Rates of return to streams and to hatcheries along the California and Oregon coast were considerably below average, but exact figures were not available for inclusion in this paper. From personal contact with hatchery operators in the spring of 1978, we do know that the return to Arcata of the 1974 coho salmon was at least equal to, if not higher, than return rates to state and federal salmon hatcheries of the California-Oregon coastal region.

TABLE 6. Number of adult Pacific salmon recorded near sites of release of parr and smolts reared in wastewater-seawater aquaculture system, Arcata Humboldt Bay, northern California, 1972-1976.

Years	Coho		Chinook	Remarks
	Jacks[1/]	Adult		
1973	0	2	0	One fish taken in gill net at oxidation pond outlet channel; one carcass recovered from salt marsh east of oxidation pond.
1974	0	0	0	Schools of large fish (thought to be salmon) sighted by wildlife management student in Butcher Slough in late October prior to rainy season. Species identification was not confirmed by project personnel.
1975	3	2	2	The adult coho were taken by gill net in Butcher Slough; other fish were taken about 2 miles inland by seine and electro-fishing.
1976	3	0	1	1 RV coho jack recovered in Jacoby Creek by electrofishing; 1 RV jack and chinook taken in Jolly Giant trap. 1 small salmon carcass was reported early February (by City of Arcata Director of Public Works) on mud bar near mouth of oxidation pond but not recovered for species identification.
1977	0	42	3	Number of adult coho (42) is the number of RV-marked fish recovered in Jacoby Creek, plus all recoveries at Jolly Giant Creek trap. Total estimated recovery of 1974-brood coho salmon was 67 fish (Allen 1978, Appendix II).

[1/] Jacks are precocious males that return after only 1 year in the sea, and are thus two-year-old fish. Adults are coho salmon that have spent one year in freshwater and two years at sea (three-year-old fish).

3. Potential of Project

In May 1977, the United States Department of Commerce, National Oceanic and Atmospheric Administration, issued the "NOAA Aquaculture Plan" (Glude 1977). The plan outlined a method to be used in monitoring progress toward viable commercial aquaculture of selected species of plants and animals (Program Publication and Review Technique - PERT). Progress on the Arcata ocean ranching project using PERT analysis is illustrated in Figure 11. Open circles indicate that the item is either favorable for commercial operations, or that the necessary technological information has been developed. A solid circle, or partially solid circle, indicates information yet to be developed for the task, or that the task indicated has yet to be undertaken. The tasks yet to be completed as shown by the PERT network technique applied to the Arcata ocean ranching proposal are described in Table 7. These tasks are being addressed and their solution is part of the normal time required for the successful development of a new aquaculture venture. Such development time appears to be about a decade (Table 8).

A similar time span can be seen in the development of artificial runs at the University of Washington hatchery located on Lake Washington, Seattle. A little over 100 salmon returned in the fall of 1956 (Donaldson and Allen 1957), with runs being increased to between 1,500 and 5,400 salmon during the 1970-73 migratory seasons (Hines 1976).

In addition to the PERT network for establishing the current status of the Arcata project, the NOAA Aquaculture Plan gives a detailed review of the status of certain "High Priority Species" (Glude op. cit., Appendix A). Both the techniques of Pen Rearing and Ocean Ranching of salmon (a high priority species) are discussed. Major findings with regard to ocean ranching that apply directly to the Arcata ocean-ranching proposal are presented below.

1. Ocean ranching of salmon can be conducted in California under permit from the Department of Fish and Game but local opposition has prevented development of commercial ventures. (Non-profit ventures, however, do not receive overt opposition, e.g. Rowdy Creek fish hatchery on Smith River, Del Norte County; sportsman's fish rearing activities - e.g. Humboldt Fish Action Council on Humboldt Bay, Tyee Club, U.S. Fish and Wildlife Service coho pen-rearing program at Tiburon, San Francisco Bay. Salo (1974) assembled most of the issues upon which local opposition is based (Appendix VIII), and are issues which have to be addressed factually in preparing environmental impact and review statements).

2. Ocean ranching with pink and chum salmon will provide more return to the operator that coho (silver) and chinook salmon, since the latter are actively harvested by sport and commercial fishermen near the point-of-return. (This is not a problem in the Humboldt Bay venture, since this is one of the objectives of the project - to enhance both the catch to the sport and commercial fisheries, with the eventual escapement being the direct return to the ocean ranching venture (Table 7, Item 19. Economic Analysis). Public hatcheries can show favorable benefit/cost ratios, but private enterprise ocean ranching has hardly been tested on a pilot scale basis. Here lies a major attraction of the Arcata proposal - it is doing exactly what has been identified as a major national aquaculture goal).

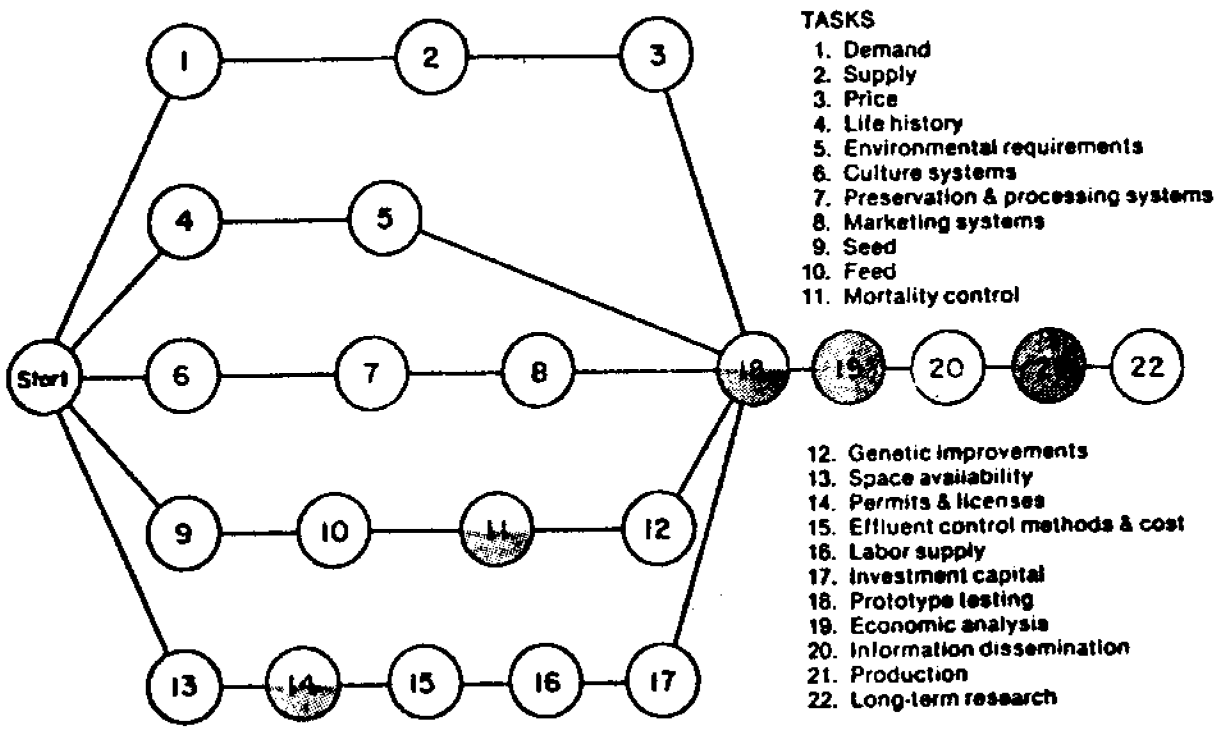

Figure 11. Program evaluation and review technique (PERT) analysis of future tasks required of Arcata salmon ocean ranching system (based on Glude 1977). (Shaded tasks yet to be completed).

TABLE 7. Tasks required before full implementation of ocean-ranching project at Arcata wastewater aquaculture site as based on PERT network (Glude 1977).

PERT network task number	Description of task	Status at Arcata ocean-ranching project
11	Mortality Control	No freshwater diseases have been identified in wastewater-reared juvenile salmonids. The marine bacterium, Vibrio anguillarum, has been positively identified as a major source of mortality. This disease appears highly likely for control by vaccination techniques.
14	Permits and Licenses	The process is very complicated and time-consuming for private enterprise, with the permit process often costing $50,000 to $100,000 with no assurance of all permits. Public or non-profit ocean-ranching ventures have less total problems with obtaining all permits. Presumably pilot or demonstration projects would need permits required for marketing and sale of a product, as would private projects.
12	Genetic Improvements	Not considered a limiting factor in current anadromous salmonid culture, although there is potential for improvement of cultured stocks by genetic programs of selective breeding.
18	Prototype Testing	Freshwater rearing in a seawater-wastewater mixture has been shown as feasible. The development of a point-of-return for adult salmon was never part of the freshwater rearing project Arcata. Testing of prototype adult return and recapture facilities requires discharge of waters (reclaimed or fresh) from the recreation lake into Humboldt Bay.
19	Economic Analysis	Several different types of economic analysis will result from the project: 1. Evaluation of the results based on the premise that the salmon or trout returned to the system should be sufficient to sustain the operation if it were operating as a private enterprise. 2. Evaluation of the contribution of salmon and trout to sport and recreational fisheries and comparison to out-of-pocket costs necessary to provide this contribution (benefit/cost analysis). 3. The value, however defined, of academic instruction and research, public education, and esthetic enjoyment provided by the project.
21	Production	This is the long-term objective of entire ocean-ranching proposal.

TABLE 8. Estimate time required for aquaculture developments in the United States (from Glude 1977, Table 1 footnotes).

Species	Footnote number	Footnote text
Oysters	1	Research on artificial propagation of oysters began about 1950; industry hatcheries became viable about 1970.
Clams	2	Research on artificial propagation of hardshell clams began about 1950; industry hatcheries became viable about 1970.
Pacific salmon Public Hatcheries	3	Artificial propagation of salmon began a century ago - but expanded research on nutrition, disease control, and improved hatchery methods began about 1960 and led to highly efficient hatcheries with favorable benefit/cost ratios by 1970.
Private (pen rearing)	4	Research on pen rearing of salmon in seawater began at low level in 1969. As of 1976, private ventures were approaching viability. The concept of ocean ranching, based largely on research and development related to public hatcheries, was legalized in Oregon in 1971, but may not reach commercial viability before 1980.
Catfish	5	Research on catfish culture began many years ago, but was expanded during the late 1960's. Commercially viable industry developed about 1970.
Freshwater prawn	6	U.S. development of freshwater prawn culture began in 1969 and as of 1976, several private ventures were approaching viability.
Lobster		(No footnote).
Marine shrimp	7	Research on shrimp aquaculture in the United States began at a low level about 1966. Private culture may not become viable before 1980.

3. Egg supply is a major limitation to adadromous salmonid aquaculture, whether public or private. Even though surplus eggs may be available from State hatcheries, State regulations may limit amounts sole to private salmon growers, or other growers such as nonprofit groups. (Past production of surplus eggs may be based on what could have been abnormally good water years. Many hatcheries are now facing serious problems due to inadequate water supplies. Data were not available for this paper on how serious this problem may be, but water shortages are having serious impacts on natural runs in California. Thus development of additional source of eggs by creating new runs to a professionally-operated fish culture facility is a significant contribution to local, state, and national needs).

4. For various reasons, the number of ocean-ranching sites may be limited to only a few locations within a Pacific coast state. (An evaluation of the reasons listed as they apply to the Arcata site is presented in Table 9. The Arcata site has none of the potential limitations to a successful operation).

5. Protection of wild stocks from genetic deterioration or disease from hatchery stocks will be a requirement in obtaining permits from state agencies. This should not be a problem at the Arcata site since the ocean ranching system is located on a small urban stream (Jolly Giant Creek) whose anadromous salmonid stocks had been extirpated by man years ago. A small population of non-anadromous native coastal cutthroat trout still persist in the stream but are only found about a one-half mile section located east of the Humboldt State University campus and isolated from the rest of the stream by an impassable barrier where the stream enters a 2,300 foot highway culvert).

It is obvious that the Arcata ocean ranching site has major advantages, and their realization are contingent on development of an artifical homestream using water discharged from the recreation lake of the reclamation unit of the proposed Arcata system.

TABLE 9. Site sensitivity analysis for ocean ranches as presented in Glude (1977 NOAA AQUACULTURE PLAN) as applied to proposed Arcata ocean-ranching location.

Limitation	Status at Arcata Site
1. Adequate water supply	Juveniles: Pilot project has indicated that the usual concepts of what constitutes adequate water quality for rearing juveniles may be expanded, and may not depend on having water sources from springs, tube wells, or streams with traditional water quality characteristics thought necessary for salmonid culture. The quality of wastewater available for juvenile rearing will increase with upgrading the Arcata system since water will be available from a disinfection unit located immediately adjacent to the juvenile rearing ponds. If ozone could be used, then a totally disinfected, highly oxygenated water could meet EPA standards for rearing animals to be sold directly for public consumption. Adults: The waterflow from the reclamation unit will provide as assured, controlled discharge of water for returning adults. This source of water for adult fish transport and collection is an extremely unique feathre of this system. Another innovative feature is that water flows can be regulated during years of floods, and will not disappear during years of drought.
2. Available land	This is a major attribute of the Arcata location, since it is on land already owned by the city, and has adequate areas for support facilities as the program develops.
3. Minimum interception of returning adults by commercial and sport fisherman	Since the program at Arcata is to provide for the catch of project salmon by all of the ocean fisheries, this is not a problem. Since the site is located on tidewater, the problem of catching a large percentage of adults which have escaped the ocean fisheries is minimized. The immediate approach to the adult trapping facility is entirely on land controlled by the city. This location also minimizes losses of juveniles or adults from pollution, drought, or loss of water possible when an ocean-ranching is site located inland from the sea.

VI. ENHANCEMENT AND PROTECTION OF BAY WATERS

The alternative wastewater treatment, reclamation, and ocean ranching system of the City of Arcata has been proposed as a project that meets the criteria for wastewater discharge into Humboldt Bay as outlined in the State of California Bays and Estuaries Policy (Appendix IV). The City of Arcata has argued before water quality regulatory authorities that the term "enhancement of waters" is undefinable, since there could be no enhancement of water, only the enhancement of properties related to the beneficial uses of such waters. Under state law beneficial values have to be defined since management of water quality to protect such uses is the basis of legal administrative action. The beneficial uses and water quality objectives to protect those uses for the North Coastal Basin Plan 1-B are listed in Appendix IC. A multitude of enhancing values and beneficial uses associated with the proposed project have been documented for formal public hearings and in administrative correspondence with the regional and state water quality control boards (Appendix X). All such statements have been denied since they did not constitute proof of enhancement. In fact, no mutually acceptable definitions to the City of Arcata have been proposed by state or regional authorities on what has to be proven. The latest administrative information to the City of Arcata at the time of this paper is that the regional board could adopt an exemption to the bays and estuaries policy if a limited or unavailable nutrient component in bay waters were provided continued discharge. Thus the project probably would have to show that an enhancing nutrient component is produced (assuming that the system "treats" to the necessary degree, and that no other detrimental component is discharged).

The circular arguments involved in the controversy are amusing, if they were not so costly and confusing to the average sewage treatment rate payer and local authorities trying to navigate with limited financial resources through these administrative seas. An overwhelming argument made for the HBWA regional collection plan was that the bay was in danger of becoming hyper-eutrophic (dying) from nutrient additions. In Humboldt Bay, the mass input of nutrients is primarily from nonpoint sources (wet-weather runoff from agricultural grazing lands, urban areas, and adjacent forest watershed). In highly mixed estuaries, the upper reaches can be one of the most organically productive areas in the marine environment. In Humboldt Bay, the masses of waterfowl feeding on intertidal mud-flats depend upon this high rate of organic production. The bay is a nursery ground for many commercial species in addition to having its own indigenous fish fauna. The oyster-growing industry requires highly productive waters to provide free food to their animals. Clam beds utilize this high organic production to maintain dense population for sport harvest. Eel grass beds and other macrophytes necessary to waterfowl of the bay are maintained at high levels by these nutrients. Thus in order to demonstrate "enhancement" that City appears faced with demonstrating how a nutrient component already known to enhance organic productivity is "enhancing" - but what level is to be considered as enhancing is still left undefined. The implications are that practically no amount of effort or time would allow any such demonstration of enhancement since the term is undefinable, and thus impossible to prove or disapprove12/ The existence of such undefined language in the policy would

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12/ "When _I_ use a work, "Humpty Dumpty said, in rather a scornfultone, "it means just what I choose it to mean - neither more nor less." "The question is," said Alice, "whether you _can_ make words mean so many different things." "The question is," said Humpty Dumpty, "which is to be master - that's all."

suggest only ocean disposal or land disposal of treated wastewaters, regardless of level of treatment. This concept is currently under serious question in California, particularly in the political arena. The high cost of wastewater treatment has become a real issue. This issue will become particularly acrimonious if traditional high-cost wastewater treatment systems prove ineffective in protecting beneficial uses after they are built. In the case of Humboldt Bay, non-point sources of water pollution are controlling water quality values as has been pointed out is the case in large parts of the United States (Westman op. cit.). Thus, discharge of all Humboldt Bay wastewater to the ocean will only marginally improve, if at all, Humboldt Bay water quality. Obviously, once a regional collection and disposal system is built, the range of uses of the water for beneficial uses at the treatment plant site will be severely limited and the wastewater-water quality controversy will be extended to the Pacific Ocean.

Probably the most critical issue for the Arcata proposal, however, is in assessing the degree to which the wastewater treatment and reclamation systems will provide virtually absolute protection to the shellfish resources of the bay. Of most immediate concern is a large commercial oyster industry located in Arcata Bay on state leased-land, and, to a lesser degree, clam beds used by sportsmen spread throughout all reaches of the bay. For the Arcata proposal we have predicted that the proposed system will discharge to the bay, water that will meet raw drinking water standards. Based on die-off rates for viral particles reported in the literature, the percent of such particles entering the wastewater treatment plant that would pass through both the treatment and reclamation units of the system and enter the bay was calculated for the maximum average daily flow predicted to enter the treatment plant (3 MGD) (Allen and Gearheart 1977, Appendix V). This percentage was less than 2.3×10^{-5}. A study of the current Arcata treatment system during a wet-weather period (February 1978, Musselman et al. 1978) showed excellent treatment, although the study only dealt with organisms that are indicators of potential pathogenic viral particles[13/]. However, there is a possibility that the actual discharge water may contain numbers of indicator organisms currently employed to monitor shellfish beds (total coliforms) in excess of discharge requirements placed on a normal treatment plant effluent discharging directly to the bay. This would be expected since the recreational lake is to have bird-loafing areas constructed adjacent to the discharge point. Waterfowl are known to produce high levels of the indicator organisms used to monitor quality of shellfish waters (Geldrich 1966).

13/ FDA certification of shellfish waters is based on total coliform, fecal coliform, and fecal streptococci counts, and on total coliform counts on shellfish meats (Musselman et al. 1978). Standard techniques employed by regulatory agencies for these microorganisms (Amer. Public Health Assoc. 1970) cannot distinguish between human and non-human sources of these forms, and need not do so in their effective application in the protection of drinking water supplies for which the tests were originally designed. Although chlorination, the most commonly utilized disinfectant in the United States, effectively kills bacteria, it is not totally effective in deactivating viral particles. Fortunately for the type of system proposed by Arcata, treatment lagoons in series have shown to be efficient at containing viral particles (Carpenter et al. 1974).

TABLE 10. Pathogen levels in Arcata sewage treatment system and Jolly Giant Creek's estuary as determined by FDA Shellfish Sanitation Branch, Northeast Technical Services Unit, February 8-11, 1978 (from Musselman et. al. 1978, p. B-6 and B-12). (Values MPN/100 ml).

Water Sampled	Water Pathogen Indicator: Total Coliform, Range in Values	N	Fecal Coliform, Range in Values	N	Fecal Steptococci, Range in Values	N
Raw Sewage	$11 \times 10^6 - 17. \times 10^6$	2	$3.1 \times 10^6 - 7.9 \times 10^6$	2	5.4×10^5	1
Lagoon[1/]	$<2 \times 10^4 - 1.7 \times 10^5$	2	$4.5 \times 10^3 - <2.0 \times 10^4$	2	-	-
Effluent[2/]	7.8 - 20	9	<2.0 - <20	9	<2.0	3
Jolly Giant Slough[3/]	$2.3 \times 10^3 - 1.6 \times 10^5$	18	$<200 - 1.7 \times 10^4$	18	$78 - 1.6 \times 10^4$	13

[1/] Exact location not specified.

[2/] After chlorination.

[3/] Off wooden bridge at site of adult salmon trap (see Allen et. al 1978, Figure 2A).

High counts of indicator organisms have historically been recorded entering Humboldt Bay from nonpoint sources, principally drainages from pasture lands during wet-weather conditions. Such high counts now exist in Jolly Giant Creek (Table 10) and represent the typical conditions being found for nonpoint pollution sources coming from urban areas (Bonigiorno et al. 1976). For Arcata, such water quality problems will continue no matter which treatment system is developed for the collected sewage, since protection of bay waters from dispersed pollution is dependent on different management strategies[14/].

The inability of the City of Arcata to obtain an official definition of what constitutes "enhancement of bay waters," plus implied allegations that the proposed system will not protect the bivalve resources of the bay, have posed difficult constraints to the immediate implementation of the project as proposed.

14/ Westman (1977) has suggested as a management strategy in treating nonpoint source of pollution the holding of stormwater generated by the first one-third to one inch of rainfall on urban areas. Development of the freshwater marshes with water from two urban streams (Jolly Giant Creek and Janes Creek) will provide a unique opportunity at Arcata to assess the technique for controlling urban runoff contamination threatening the bay's shellfish producing beds.

VII. DISCUSSION

The positive attributes of the proposed Arcata wastewater treatment, reclamation, and salmon ranching project with regards to meeting legal mandates, acceptable benefit-cost ratios, water quality protection, and public acceptance are summarized in Appendix XI. Only those innovative features and enhancement aspects of the ocean ranching portion of the aquaculture program will be discussed here.

Aquaculture development mainly occurs through incremental advances and changes in established techniques. Using treated domestic wastewaters in an ocean ranching system for rearing juveniles and for developing an artificial homestream for returning adults is an example of minor changes in technique that can lead to major advances in aquaculture art. The Arcata project has passed through laboratory experimentation and pilot project stages. With good survival of juveniles in the ocean now documented, with viable eggs having been taken from returning adults, the major task now facing the project is to construct and operate a permanent adult collection and holding facility.

The location of the proposed permanent adult collecting facility at the point of discharge from the recreational lake into Butcher Slough has many advantages. It is the only location on Arcata city property that provides adequate space for support facilities (fishway, holding and sorting ponds, spawning shed, processing shed, smolt imprinting ponds, incubator shed, parking space etc.). The discharge channel will end in subtidal water, and since water can be stored in the recreational lake for operation of the fishway at any time of the year, a wide choice of species and stocks of salmonids will be possible to insure maximum utilization of the facilities.

The point of discharge proposed for the recreational lake will provide an excellent opportunity to study salmonid imprinting and precision of return to an artificial homestream. The principal place of straying for salmonids released into Butcher Slough will be Jolly Giant Creek that can be monitored readily for returning adult fish.

Integrating a salmon ocean ranching scheme into a wastewater treatment and reclamation system greatly reduces the capital and operating costs to the salmon aquaculture venture. Facilities primarily required for wastewater treatment can be used by the aquaculture project. There is no cost for water. There are only minimal costs associated with collecting and storing fish food organisms produced in the oxidation ponds of the wastewater treatment plant. There are no costs for rent since the operation is entirely on public property. Much equipment and materials useful for pond construction and maintenance are available free or at reduced cost.

Recent droughts in California have curtailed the operation of several trout and salmon hatcheries. It appears reasonable to assume the wastewater-based ocean ranching system will be able to function during the severest of droughts. This would be so since domestic needs always will have the priority for any available water resources.

The proposed Arcata integrated system, over and above its relatively inexpensive sewage treatment costs, will always show a public benefit. These benefits derive from the fact that the area will provide for public education and scientific research, that salmon and trout reared for ocean ranching purposes will contribute heavily to the catches by sport and commercial fishermen in Humboldt Bay and the Pacific Ocean, and that all the aquaculture projects will be enhancing depleted salmonid runs in Humboldt Bay.

Probably the most significant aspect of the ocean ranching project is that it has a very high probability of meeting the mandate under the Clean Water Act of 1972 (PL 92-500) of developing revenue-generating projects that utilize reclaimed wastewaters. While so doing, it will be meeting local, state, and national responsibilities for preserving, restoring, and enhancing stocks of salmon and anadromous trout, and meeting a national aquaculture goal:

> "In the long run, prospects are good for expansion of Pacific salmon production by ocean ranching. If permits can be obtained, private ventures could add 40 million pounds (18,000 metric tons) to the salmon supply by 1985." (Glude op. cit. p. 12).

The status of the Arcata proposal as of November 1978 is still tentative (Appendix XII). However, the rising cost of energy, the need for increasing low-cost food resources, the relative cheapness of treating a unit volume of sewage in the Arcata system, and the variety of beneficial uses of treated wastewaters in the proposed system, may all combine to allow the project to be developed *ad seriatum*.

VIII. ACKNOWLEDGEMENTS

We would like to acknowledge the North Coast Regional Water Quality Control Board technical staff for providing results of their study of the Arcata sewage treatment plant, August 1978. Mrs. Ellen Spurling (Humboldt State University Cooperative Fisheries Unit, U.S. Fish and Wildlife Service) provided much timely assistance with typing manuscripts. Support for construction of existing elements of the system is greatefully acknowledged: California Small Crafts and Harbor Commission - access and parking lot adjacent to proposed recreation lake; Humboldt County - diking around reclamation site and excavating proposed recreation lake to seal land-fill; State of California Wildlife Conservation Board - original grant for experimental fish ponds; Department of Commerce, National Oceanic and Atmospheric Administration, Sea Grant Program - funding juvenile rearing studies; California Coastal Conservancy - selecting the Arcata marsh enhancement element to serve as a demonstration project on freshwater wetlands restoration and development. To the many governmental and private agencies, and individual citizens who have constantly supported the concept, and lent their support, particularly the California Office of Appropriate Technology, we give our sincere thanks. Juvenile fish and eggs have been provided to the project by the California Department of Fish and Game, and Humboldt County Prairie Creek fish hatchery.

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APPENDIX I. Common and scientific names of plants and animals listed in text.

Kind	Common Name	Scientific Name
Fish	Coho (silver) salmon	*Oncorhynchus kisutch*
	Chinook salmon	*Oncorhynchus tshawytscha*
	Sockeye salmon	*Oncorhynchus nerka*
	Pink salmon	*Oncorhynchus gorbuscha*
	Shum salmon	*Oncorhynchus keta*
	Rainbow steelhead trout	*Salmo gairdneri*
	Cutthroat trout	*Salmo clarki*
Birds	Snowy egret	*Leucophoyx thula*
	Great egret	*Casmerodius albus*
	Great blue heron	*Ardea herodias*
	Black-crown night heron	*Nycticorax nycticorax*
	Forster's tern	*Sterna forsteri*
	Bonaparte's gull	*Larus philadelphia*
	Kingfisher	*Megaceryle alcyon*
	Peregrine falcon	*Falco peregrinus*
	Pied-billed grebe	*Podilymbus podiceps*
Plants	Alkali bulrush	*Scirpus paludosus (robustus)*
Mammals	River otter	*Lutra canadensis*
	Black-tailed deer	*Odocoileus hemionus*

APPENDIX II. Annotated list of published literature and unpublished data reports on performance of the Arcata wastewater-seawater salmon rearing ponds.

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Allen, G.H. and R.L. Carpenter. 1977. The cultivation of fish with emphasis on salmonids in municipal wastewater lagoons as an available protein source for human beings. In: Carpenter, R.L. (Chr.), Proceedings of the Inter. Conf. on the Renovation and Recycling of Wastewater through Aquatic and Terrestrial Systems, Bellagio, Italy, July 16-21, 1975. New York, Marcel Dekker, Inc.: 479-528. (Detailed report on Experiment VII, with selected results from Experiments IX and X.)

Allen, G.H. 1975. Rearing salmon in saltwater ponds fertilized with domestic wastewater July-September, 1974. Humboldt State Univ., Coherent Area Sea Grant Program. Data Report. 42 pp. (Detailed report on Experiment VIII.)

Allen, G.H. 1976a. Rearing Pacific salmon in saltwater ponds fertilized with domestic wastewater September 1974-November 1975. Ibid: HSU-SG-10: 92 pp. (Detailed report on Experiments IX-XI.)

Allen, G.H. 1976b. Rearing Pacific salmon in saltwater ponds fertilized with domestic wastewater October 1975-August 1976. Ibid: HSU-SG-11: 99 pp. (Detailed report on Experiments XII-XIII, with first results on selective-trapping of smolts from rearing ponds.)

Allen, G.H., J. Miyamoto, and W. Harper. 1978. Rate of straying in adult coho (silver) salmo (Oncorhynchus kisutch) from smolts released at an intertidal location. Calif. Coop. Fish. Res. Unit, Res. Rept. 78-1: 44 pp. (Report on adult salmon recaptures in Jolly Giant Creek and closely adjacent areas, and importance of proper salmon smolt imprinting required in future ocean-ranching operations.)

APPENDIX III. List of statements justifying a regional collection and disposal system as only plan for meeting Humboldt Bay area-wide needs for wastewater treatment and control as challenged by Environmental Research Consultants (1974) representing the City of Arcata at public hearing, Eureka, California, September 18, 1974 (See also: State Water Resources Control Board and Regional Water Quality Control Board, 1974, p. 17).

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1. "The California Department of Fish and Game has concluded that discharges of municipal effluents have adversely affected the Bay in the past."

2. "The California Department of Public Health has found that discharges of municipal effluent in the Eureka and Arcata areas threaten the shellfish growing beds in Humboldt and Arcata Bays, particularly during wet weather periods when incompletely treated effluent is being discharged. Some areas of the Bay have been closed to shellfishing as a result of the threat posed by these existing discharges."

3. "The Federal Water Pollution Control Act as amended in 1972 states the national objective of zero discharge of pollutants to the nation's waters by 1985, a requirement for secondary treatment by 1977, and a requirement for "best practicable" treatment by 1983. This can logically be interpreted for the Humboldt Bay situation to mean that: a) the primary treatment plants discharging at Eureka must be abandoned or upgraded almost immediately b) that secondary treatment provided at Eureka today to discharge to the Bay would have to be further upgraded by 1983 and perhaps abandoned by 1985, but c) that secondary treatment will probably be judged as the best practicable treatment prior to ocean discharge for many years to come."

4. "Parts of Humboldt Bay have recently been named as a National Wildlife Refuge by the Federal Bureau of Sports Fisheries and Wildlife. It is reasonable to expect discharge prohibitions to be introduced into the management of this area; mush as the State of California now prohibits discharges to Areas of Special Biological Significance."

5. "The facilities plan recommended and described in some detail provides for early removal of the major discharges of effluent from the Bay, with complete removal of all discharges by 1985. This plan has the lowest total cost and the lowest local cost of the alternatives studied, primarily because the consolidate facilities provide economy of scale advantage to all communities. Facilities will also be less expensive in earlier years than in later years."

6. "The State Water Resources Control Board is expected to adopt in early 1974 a proposed Water Quality Control Policy for the Enclosed Bays and Estuaries of California, wherein Humboldt Bay is named explicitly, which policy will require elimination of municipal waste discharges to such bays and estuaries at the 'earliest practicable date'."

APPENDIX III. (continued)

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7. "From Table 6 it can be seen that two relatively fragile beneficial use types, namely WILD and RARE, are specified for Humboldt Bay, whereas they are not specified for the coastal ocean waters."

8. "Treatment plant reliability industry-wide is about 50 to 70 percent. Eighty percent reliability is considered very good. The open ocean must be considered more amenable to transient plant operation disruptions than is an enclosed bay with fragile ecosystem populations."

APPENDIX IV. Pertinent language of State of California Water Quality Control Board policy on discharge of wastewaters to enclosed bays and estuaries of California as adopted 1974.

"It is the policy of the State Board that the discharge of municipal wastewaters and industrial process waters (exclusive of cooling water discharges) to enclosed bays and estuaries, other than the San Francisco Bay-Delta system, shall be phased out at the earliest practicable date. Exceptions to this provision may be granted by a Regional Board only when the Regional Board finds that the wastewater in question would consistently be treated and discharged in such a manner that it would enhance the quality of receiving waters above that which would occur in the absence of the discharge.[3/]"

"3/ Undiluted wastewaters covered under this exception provision shall not produce less than 90 percent survival, 50 percent of the time, and not less than 70 percent survival, 10 percent of the time of a standard test species in a 96-hour static or continuous flow bioassay test using undiluted waste. Maintenance of these levels of survival shall not by themselves constitute sufficient evidence that the discharge satisfies the criteria of enhancing the quality of the receiving water above which occur in the absence of the discharge. Full and uninterrupted protection for the beneficial uses of the receiving water must be maintained. A Regional Board may require physical, chemical, bioassay, and bacteriological assessment of treated wastewater quality prior to authorizing release to the bay or estuary of concern."

APPENDIX V. List of unpublished documents on the Arcata alternative wastewater treatment, reclamation, and ocean ranching project by City of Arcata Task Force and by individual members, 1977-1978.

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1. Allen, G.H. 1977. Ocean-Ranching - A preliminary feasibility study for a demonstration system using reclaimed municipal wastewaters. Prepared at the request of the City of Arcata. Submitted 14 February 1977. 23 p. plus appendices.

2. Klopp, F.R. No Date. Preliminary Draft. City of Arcata Wastewater Treatment, Water Reclamation, and Ocean Ranching. Proposal. Outline of project for City Council review. 21 p.

3. Klopp, F.R. No Date. Draft. City of Arcata Wastewater Treatment, Water Reclamation, and Ocean Ranching. Task Force document prepared for review by appropriate agencies and for initial formal appearance before Regional Water Quality Control Board to obtain a hearing on the proposed upgrading of the Arcata treatment system and development of wastewater reclamation uses. 101 p. including appendices.

   Appendix A. California State Water Resources Control Board January 1977 Policy and Action Plan for Water Reclamation in California.
   Appendix B. California Regional Water Quality Control Board, San Francisco Bay Region January 1977 Policy and Guidelines on the Use of Wastewater to Create Marshlands.
   Appendix C. Water Reclamation Policy of the California Department of Fish and Game, August 10, 1976.
   Appendices E-H.

4. City of Arcata, 1977. Facility Plan and Project Report. Document requested at suggestion of regional board staff for formal hearing on Arcata proposal held June 24, 1977, by North Coast Regional Water Quality Control Board, Ukiah, California. 243 p.

   Harris, S.W. Analysis of Scarce Resources Freshwater Marsh. pp. VII-33 through VII-73.
   Allen, G.H. Analysis of Scarce Resources Salmon and Trout. pp. VII-74 through VII-111.
   Allen, G.H. 1977. Statement on Aquaculture to North Coast Regional Water Quality Control Board. 10 p. Friday, June 24, 1977, Ukiah, California.

5. Documents prepared for appeal hearing, State of California Water Quality Control Board, September 12, 1977, Sacramento, California:

   Allen, G.H. and R.A. Gearheart. 1977. Expected deactivation of human pathogens in proposed Arcata wastewater treatment and reclamation system. 38 p.
   Allen, G.H. 1977a. Prediction of toxicity of discharge to Humboldt Bay from proposed Arcata wastewater treatment and reclamation system. 14 p.
   Allen, G.H. 1977b. Statement on aquaculture to State of California Water Quality Control Board. 14 p.

APPENDIX VI. Design capacity and loadings for Arcata wastewater treatment system, 1 November 1978.

Type: secondary treatment - aerated lagoon	Design data	Current loading
Basic Data		
Population	--	12,500
Avg sewage flow, mgd	2.6	1.54
Peak sewage flow, mgd	6.0	6.46
BOD_5 load, lb/day	--	1,580
Comminutors		
Number	2	2
Max hydraulic capacity, mgd	7.0	7.0
Grit channel		
One, mechanically cleaned		
Max hydraulic capacity, mgd	7.0	7.0
Primary clarifiers		
One 26-ft. diam. and one 60-ft. diam.		
Overflow rate at avg flow, gpd/sq ft	770	460
Detention time at avg flow, hr	2.67	4.5
Effluent weir rate at avg flow, gpd/ft	9,600	5,700
Aerated lagoon (See Fig. 3-A)		
One with 3 mechanical aerators, 15 hp ea		
Area, sq ft	49,000	49,000
Avg depth, ft	7.35	7.35
Detention time, hr	24.8	42.0
BOD_5 applied, lb/day	--	1,025
BOD_5 loading, lb/day/1,000 cu ft	--	2.9
Capacity of aerators, hp	45	45
Sludge digestion tanks		
Primary, 45 ft diam x 28 ft SWD		
Volume, cu ft	45,000	45,000
Capacity, cu ft/capita	--	4.75
Solids loading, lb/cu ft/day	--	0.027
Secondary, 26 ft diam x 28 ft SWD		
Volume, cu ft	15,000	15,000
Capacity, cu ft/capita	--	1.58
Stabilization pond complex		
One 54-acre pond 5.5 ft deep		
Avg retention time, day	37	63
Organic loading lbs BOD/acre/day	--	10

APPENDIX VI (Continued)

Type: secondary treatment - aerated lagoon	Design data	Current loading
Sedimentation (See Fig. 3-5)		
Depth (ft)	4.5	--
Area (ft^2)	79,000	--
Volume (ft^3)	355,500	--
First cell (See Fig. 3-1, 6)		
Depth (ft)	4.5	--
Area (ft^2)	392,040	--
Volume (ft^3)	1,764,180	--
Second cell (See Fig. 3-2, 3, 4, 5)		
Depth (ft)	4.5	--
Area (ft^2)	1,873,080	--
Volume (ft^3)	8,428,860	--
Chlorination (See Fig. 3-c)		
Number of chlorinators	2	2
Total capacity, lb/day	400	400
Volume of detention basin, cu ft	12,800	12,800
Detention time at avg flow, hr	0.88	1.50
Detention time at peak flow, hr	0.38	0.35
Sludge drying beds		
4 beds totaling 9,600 sq ft		
Area provided, sq ft/capita	--	1.01
Sulfonators		
Number of sulfonators	--	1
Total capacity	--	200 lbs.

APPENDIX VII. Selected recent literature on advanced biological treatment provided by marshes and wetlands used to predict the utility of the marsh reclamation unit as a tertiary treatment device providing ultimate "fail-safe" capacity for Arcata wastewaters proposed for use in reclamation system.

Berg, G. 1971. Removal of viruses from water and wastewater. Proc. 13th Water Quality Conference. Virus and Water Quality: Occurrence and Control. Urbana-Champaign. University of Illinois, Department of Civil Engineering, and Illinois Environmental Protection Agency: 126-336.

Carpenter, R.L., H.K. Malone, A.F. Roy, A.L. Mitchum, H.E. Beauchamp, and M.S. Coleman. 1974. The evaluation of microbial pathogens in sewage and sewage-grown fish. In: Wastewater use in the production of food and fiber - proceedings. U.S. Environmental Protection Agency, Environmental Protection Technical Series, EPA-660/2-74-941: 46-55.

De Jong, J. 1976. The purification of wastewater with the aid of rush or reed ponds. In Tourbier and Pierson: 133-139.

Furia, E.W. 1976. Biological alternatives in perspective: more than academic curiosities. In: Tourbier and Pierson, 1976: 1-4.

Geldreich, E.E. 1966. Sanitary significance of fecal coliforms in the environment. Federal Water Pollution Control Administration, U.S. Department of Interior, Publication No. WP-20-3.

Gosselink, J.G., E.P. Odum, and R.M. Pope. 1974. The value of the tidal marsh. Louisiana State University, Center for Wetland Resources. LSU-SG-74-03.

Seidal, K. 1976. Macrophytes and water purification. In: Biological Control of Water Pollutions. University of Pennsylvania Press: 109-121.

Small, M.M. 1977. Natural sewage recycling systems. U.S. Department of Commerce, Natural Technical Information Service BNL-50630: 36 p.

Spangler, F.D., W.E. Sloey, and C.W. Fetter, Jr. 1976. Wastewater treatment by natural and artificial marshes. U.S. Environmental Protection Agency, Environmental Protection Technical Series EPA-600/2-76-207: 171 p.

Tourbier, J. and R.W. Pierson, Jr. 1976. Biological Control of Water Pollution. University of Pennsylvania Press, 340 p.

Valiela, I.S. and J.M. Teal. 1976. Assimilation of sewage by wetlands. In: Wiley, M. (Ed.): Estuarine Processes: Uses, Stresses, and Adaptations to the Estuary. New York, Academic Press: 234-253.

APPENDIX VII. (Continued)

Wellings, F.M., A.L. Lewis, and C.W. Mountain. 1977. Survival of viruses in soil under natural conditions. In Wastewater Renovation and Reuse. New York, Marcel Dekker: 453-478.

Whigham, D.R. and R.L. Simpson. 1976. The potential use of freshwater tidal marshes in the management of water quality in the Delaware River. In Tourbier and Pierson, 1976: 173-186.

Woodwell, G.M. 1977. Recycling sewage through plant communities. American Scientist 65(5): 556-562.

APPENDIX VIII. List of concerns or possible problems associated with development of ocean ranching systems as applicable to Arcata site as listed in Salo (1974).

1. Ranch locations confound hatchery and wild stocks,
2. Technical incompetence of salmon ranchers.
3. Local stocks of salmon only should be used.
4. Genetic and disease controls needed.
5. Hatchery smolts not moving quickly to ocean, thus competing with wild stocks.
6. Ocean ranch sites should not be located inland.
7. Ocean may be saturated with salmon, but more likely bays and estuaries may be saturated with smolts.
8. Since the U.S. has claimed the right to salmon on the high seas, the ocean rancher will claim the same right for himself.
9. It may be difficult to mass-produce large quantities of hardy juveniles at low cost.
10. Poor quality, or spent, mature salmon will compete with and depress price of troll-caught fish.
11. Ocean ranchers will be subsidized by government.
12. Only big business will have technical competence and financial resources for ocean ranching.
13. Indian rights could allow additional harvesting right up to the return facility.
14. Salmon could be harvested by international fleets.
15. Salmon ranching threatens independence of independent commercial fisherman.
16. Private industry could end up controlling vast amounts of state waters.
17. Possible lower salmon prices will not produce a greater demand, thus forcing commercial fisherman out of business.
18. Dumping poor quality salmon on market will hurt seafood industry.

APPENDIX IX. List of beneficial uses for Humboldt Bay and water quality standards to protect beneficial uses adopted by North Coastal Regional Water Quality Control Board. (Beneficial uses enhanced by Arcata alternative plan underlined).

Water Quality Standard	Beneficial Uses of Bay Waters
A. Organisms of the Coliform Group: (See Table 1).	I. Industry
B. Dissolved oxygen shall fit the following constraints: Minimum 6.0 mg/1; 90% value 6.2 mg/1; Median 7.0 mg/1	II. Commercial Fisheries III. Shellfish
C. Hydrogen ion concentration: the pH shall not be depressed below natural background nor increased above 8.5.	IV. Science V. Aesthetics VI. Marine Habitat
D. Toxic or other deleterious substances: minimum compliance 96 hour bio-assay - survival of aquatic life in surface waters subjected to a waste discharge or other controllable water quality factors shall not be less than that for the same water body in areas unaffected by the waste discharge (toxicity concentration (Tc) expressed in toxicity units and not to exceed 0.05 units). Waters shall not contain taste or odor producing substances.	VII. Fish Spawning VIII. Fish Migration IX. Water Contact Recreation X. Non-Water Contact Recreation XI. Navigation
E. Biostimulartory substances: shall not contain biostimulatory substances in concentrations that promote aquatic growths to the extent that such growths cause nuisance or adversely affect beneficial uses.	
F. Turbidity: shall not be increased more than 10% above naturally occurring background levels. Exceptions allowed.	
G. Radionuclides: shall not be present in concentrations which are deleterious to human, plant, animal or aquatic life, or accumulate in the food webb. (Limits given).	
H. Temperature: shall comply with limitations necessary to assure protection of beneficial uses.	

APPENDIX X. List of specific examples of how the Arcata alternative wastewater treatment, reclamation, and salmon ranching project will enhance the beneficial uses of Humboldt Bay waters as listed for Coastal Plan 1-B, Humboldt Bay, North Coastal Regional Water Quality Control Board.

Category of Beneficial Use	Example of Specific Beneficial Use
Scenic Enjoyment (Aesthetics)	New area for aquatic bird populations by adding scarce freshwater wetland habitat from a degraded unproductive salt marsh. The area has direct public access and will contain an interpretative area.
Fish and Wildlife Habitat	In addition to marsh-dependent bird life, marsh mammals and reptile populations will also be created. Recreation lake will provide habitat for trout and salmon, and will develop a population of non-salmonid estuarine species of fish as have occurred in the wastewater aquaculture ponds.
Water-Oriented Recreation	Fishing and wading will be the major beneficial uses provided by the recreation lake. Picnicking, beachcombing, sunbathing, hiking, and marine life studies are additional activities requiring minimal or no water contact that will be provided by the system.
Recreational Fishing, Commercial Fishing, and Fish Migration	Recreational fishing will occur in the lake. Ocean troll fishery will catch salmon produced by the salmon ranch. Water issuing through the fishway will be the route of migration of cutthroat trout to the recreational lake and of adult salmon to holding facilities of the ocean ranch. Food organisms developed in the lake will provide forage for marine species in Arcata Bay.
Shellfish Harvesting	Phosphorus, nitrogen, detritus, and zooplankton, phytoplankton, and benthic organism will enter Arcata Bay similar to such discharges from pristine marshes that originally existed around the perimeter of the bay. This flow of material provides a nutrient base for food chains supporting native and commercially-introduced bivalve populations. Productive estuaries are not nutrient deficient.
Education Studies	Heavy use of the existing system has been made by educational institutions of the surrounding area, especially as an area for research and laboratory projects by Humboldt State University personnel. Additional studies will be generated by the Arcata project, especially those associated with the freshwater wetlands. Water quality parameters occurring at each stage of the wastewater treatment train, and through the units of the reclamation portion of the system will be of special scientific interest, since the system will be monitored constantly by the well-being of the plant-animal communities.

APPENDIX XI. Overview attributes of Arcata wastewater treatment, reclamation, and salmon ranching project.

1. Legal Requirements

Meets the Presidential policy of May 1977 on energy, wastewater reclamation, and wetland preservation and enhancement.

Meets the Congressional mandate under PL 92-500 for revenue producing reclamation projects.

Meets the Congressional mandate under PL 92-500 for designing and locating wastewater treatment facilities that will allow for future beneficial uses of reclaimed wastewaters.

Meets the California Department of Fish and Game policy on the beneficial use of reclaimed wastewaters, especially in creating new fish and wildlife resources in controlled and managed wetlands.

Meets the State Water Quality Control Board policy on reclamation of wastewater and on discharges to bays and estuaries by providing maximum protection to estuarine water quality and providing enhancement through aquaculture, marsh reclamation, waterfowl protection and enhancement, and controlled enhancement of estuarine productivity.

Meets the guidelines of the Marsh Reclamation Policy of the San Francisco Bay Regional Water Quality Control Board. This is the only guide as to what is enhancement since the State Board has not yet developed specific guidelines for implementing its reclamation policy or defining enhancement.

Meets all land use and zoning requirements.

2. Benefit-Cost Ratio

Utilizes substantially existing conventional wastewater treatment facilities for the project which reduces capital costs.

Minimizes energy use and cost since system is primarily gravity flow.

Minimizes capital outlay costs for diking since dikes already in existence can be used for both treatment and reclamation activities.

Provides an extended write-off period for most of the system since earthen dikes require minimum maintenance.

Capital cost for treating wastewaters to equivalent quality levels is about 1/7 that of alternative methods.

Annual estimated operating cost for the system, including the enhancement elements, is about ½ that of the most feasible alternatives, which have no enhancement benefits.

APPENDIX XI. (Continued)

3. Water Quality

Disinfected, advanced secondary-level treated reclaimed water will be available for operation and maintenance of the reclamation unit.

The wastewater treatment is provided with a system maximum in "fail-safe" features by:

1. Possesses a large storage volume within the system available for storage of peak wet-weather flows.

2. Under maximum inflow periods, provides at least 50 days retention time before reclaimed wastewaters from system enters Humboldt Bay.

3. Has the ability to halt discharges of water either to the reclamation unit or to the bay for considerable periods of time in any season of the year to correct water quality or other problems.

4. Provides advanced biological treatment in the reclamation unit by macrophyte (marsh) plants.

System provides maximum opportunity for sequestering and monitoring toxic materials, heavy metals, and pathogens.

System provides the maximum opportunity for monitoring water quality by bioassay and pathogen studies at at least ten control points throughout the system.

Possesses a maximum ability to withstand natural disasters like floods since it has already withstood two 100-year floods, and the existing stabilized dikes are not likely to break under earthquake stress such as can occur with buried pipe and concrete works.

4. Public Acceptance

Full support of Arcata City Council, staff, and Arcata citizens. No opposition has appeared at any staff, planning, or City Council meeting.

Strong support from most public agencies requested to review the plan. The only technical questions have been limited to possible pathogens release to existing oyster-growing beds. This opposition admittedly was developed prior to review of Facilities Plan and Project Report, and was apparently totally unaware of the water treatment capacity of marsh-wetlands to be developed in the reclamation unit.

A strong local civic support resulting from:

1. Long well publicized history with a pilot-project wastewater aquaculture project.

APPENDIX XI. (Continued)

2. Knowledgeable group of local citizens that understand ecological principles involved in the Arcata biological treatment system.

3. Willingness of citizens to support a local governmental entity that refused to accept administrative fiats at face value.

4. Obvious reduction in cost to the sewage rate payer of the Arcata proposal over other alternatives.

5. Obvious enhancement and other beneficial uses that will accrue to the citizenry from the Arcata plan as opposed to shipping natural resources for dispersal in the Pacific Ocean.

APPENDIX XII. Status of development of Arcata proposal as of November 1978.

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1. McKinleyville has been connected to the Arcata sewage treatment plant, and a Clean Water Grant has been obtained to make improvements to the treatment system to insure handling of the increased flows to the Arcata plant. This will assist in upgrading the treatment system as envisioned in the original proposal.

2. The California Coastal Conservancy has adopted for funding the development of the Arcata freshwater wetlands proposed in the system using non-wastewater sources. Development of the marshland will provide water for the recreation lake, and thus a water discharge to Butcher Slough for completing an ocean-ranching demonstration project.

3. The State of Califronia Water Quality Control Board is providing support for a study to examine the reliability of a freshwater marsh to provide consistently high quality water to the recreation lake and to other areas where the public will come in direct contact with reclaimed wastewaters. Satisfactory demonstration of this capability could lead to use of wastewaters for sustaining and enlarging wetlands in the reclamation unit, and for enlarging the volume of water to operate adult fishway.

4. Negotiations continue on what is to be demonstrated as "enhancing" bay waters by a treated wastewater discharge.

5. CSR is being joined by other citizen's groups, particularly in Eureka, in opposing the regional collection system as the only plan that can meet the basin's wastewater treatment needs.

6. HBWA is unable to place it's revenue bonds on the market since the courts have still to decide at the appelate levels the legal suits before it is as filed by CSR.

7. Some modifications in the regional collection plan are being negotiated within HBWA, which requires mutual agreement, under it's operating charter, of all members to any action.

8. The Food and Drug Administration is threatening to modify it's conditional approval to Humboldt Bay for shellfish harvesting, and alleging all present treatment systems are inadequate for protecting shellfish resources on Humboldt Bay.

9. The City of Arcata has established a limited aquaculture budget to continue the capability of carrying out all salmon ranching activities with city facilities, and is seeking outside funding for a demonstration salmon ranching project.
