DEEP OCEAN DISPOSAL OF SEWAGE SLUDGE OFF ORANGE COUNTY, CALIFORNIA: A RESEARCH PLAN

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PREFACE

Even though the discharge of sludge into the ocean via an outfall is not now permitted, this research plan has been prepared to show what could be learned with a full scale experimental sludge discharge of 150 dry tons/day by the County Sanitation Districts of Orange County into deep water (over 1000 feet).

To provide a wide range of inputs and evaluation, a broad-based Research Planning Committee was established to advise the Environmental Quality Laboratory on the overall content and details of the research plan. Two meetings were held at EQL on:

March 4-5, 1982:	The entire Committee
July 19-20, 1982:	A working subgroup of the Committee

The entire Committee is listed in Appendix B, with footnotes to indicate meeting attendance. Those unable to come to a meeting were asked to comment on the drafts by mail or telephone. We gratefully acknowledge the members of the Research Planning Committee for their generous help in formulating the research tasks and reviewing report drafts.

The preparation of this volume has been supported by the National Oceanic and Atmospheric Administration (Grant No. NA81RAC00153) and the County Sanitation Districts of Orange County. We thank the representatives of the sponsoring agencies for their valuable assistance, in particular:

NOAA: Alan Mearns, John Calder, Kilho Park, and Lawrence Swanson

CSDOC: Fred Harper, Blake Anderson, and Gregg Pamson

The opinions and judgments expressed in this report are solely the responsibility of the authors. Concurrence of Research Planning Committee members or the sponsoring agencies should not be presumed.

Finally, we thank the EQL staff for their skillful and devoted efforts in assembling this report, often in the face of never-ending changes, in particular, Marcia Nelson for typing, and Theresa Fall for graphics and editorial work.

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CHAPTER 1

EXECUTIVE SUMMARY

A seven-year research program is recommended to study the environmental and possible health effects of a proposed ocean discharge of sewage sludge via a special pipeline to an unprecedented depth of about 1000 to 1300 feet (300-400 meters) off the coast of Orange County in southern California.

Sludge Disposal Problem

Disposal of sludge presents difficult and costly problems for sewage treatment agencies throughout the United States. Land disposal or combustion requires prior extraction of much of the water from the sludge mixture, at a considerable energy expense. Combustion can cause air pollution; land disposal can result in groundwater contamination. Although land and air disposal are usually considered allowable options, ocean disposal is generally not. More specifically, the discharge of sludge through an outfall pipe is prohibited by the Clean Water Act, as amended in 1981, although barge dumping restrictions and prohibitions under the Marine Research, Sanctuaries and Protection Act are being reconsidered in Congress. Despite existing legal and regulatory restrictions, there is nationwide interest in utilizing marine waters for disposal of municipal sludges, as evidenced by a series of recent reports in which such activity is considered (NRC, Commission on Natural Resources, 1978; Goldberg, 1979; NRC, Marine Board, Assembly of Engineering, 1981; NACOA, 1981).

For many coastal cities, ocean disposal is an attractive alternative not only because it is less expensive than land disposal or combustion of sludge, but also because the environmental effects may be less significant than those resulting from other options.

The County Sanitation Districts of Orange County (CSDOC) collects, treats, and disposes of wastewater for two million people. The treated effluent is discharged through a ten-foot ($\sim$3 m) diameter outfall with a multi-port diffuser more than 4 miles (6.5 kilometers) offshore at a depth of 195 feet (60 meters). The mean flow rate is approximately 200 million gallons per day (760,000 m^3/d). The performance of this outfall has been excellent with minimal adverse effects.

Residual solids from wastewater treatment amount to 150 tons (136,000 kg) per day (dry weight) suspended in three million gallons of wastewater (1.2 percent solids by weight). This material consists of anaerobically digested sludge from primary sedimentation tanks and raw waste activated sludge from the secondary treatment process.

Proposed Deep-Ocean Discharge of Sludge

The ocean basins a few tens of miles off the southern California coast drop to depths of over 3000 feet (1000 meters). An earlier Environmental Quality Laboratory report (Jackson, et al., 1979) recommended a depth of about 1300 feet (400 meters), on the side slope of a basin, as the best candidate site for further sludge disposal study. It was felt that environmental effects associated with marine sludge disposal would be minimal at that depth. CSDOC now proposes an experimental discharge of its sludge through a small pipeline terminating 7.5 miles (12 kilometers) from the mouth of the Santa Ana River at a depth of 1000-1300 feet (300-400 m). The pipe (about 18-inches in diameter) would be continuously welded and coated both internally and externally; it could easily be laid from a pipe-laying barge.

Savings attributable to this option would be nearly $10 million per year, including the annualized cost of capital as well as annual operation, maintenance, research and monitoring costs.

The environmental impacts of ocean disposal are expected to be slight, based on what is currently known. We do not anticipate any human health impact or risk. If the research plan presented herein reveals unacceptable impacts, CSDOC will modify or discontinue its ocean discharge operations. Upon termination of the discharge, any sludge-related changes in biological communities are expected to be reversed within only a few years.

CSDOC is currently seeking approval to conduct this experiment through special legislation and/or regulatory actions at both state and federal levels.

Need for Research

Because the CSDOC sludge outfall would be about four or five times deeper than existing wastewater or sludge outfalls, there are special research needs for system engineering and evaluation of environmental effects. The specific goals of this research plan are:

1. To characterize the physical, chemical, and biological properties of the sludge.

2. To recommend: (i) depth and location of the end of the sludge outfall; (ii) in-plant processing of sludge before discharge; and (iii) possible modifications in pretreatment (or source control) programs for trace contaminants.

3. To make pre-discharge predictions of sludge-induced

environmental impacts. These would include changes in water-column oxygen concentrations and benthic sedimentation rates.

4. To observe changes in water column and benthic communities and measure the distribution of important chemicals in the water, in the sediment, and in organisms.

5. To find what human health risks (if any) are associated with deepwater sludge discharge, either directly through human contact with seawater or indirectly through consumption of seafood.

6. To determine the mechanisms by which ecological and chemical changes occur.

7. To assess the predictability of the effects of deep sludge discharge by comparing model predictions with monitoring data.

8. To summarize and recommend methodology for designing systems for sludge discharge into the ocean and predicting the effects.

9. To summarize the effects of the Orange County sludge discharge, and evaluate their significance with respect to marine resources.

Research Plan

To satisfy the goals listed above, a comprehensive research plan is presented, consisting of 41 tasks arranged in nine groups:

Task Group 1. Survey for Discharge-Related Effects (pre- and post-discharge monitoring)
2. Site Characteristics
3. Sludge Characteristics
4. Modeling
5. Preliminary Design
6. Biological Impacts--Laboratory Studies
7. Biological Impacts--*In-Situ* Studies
8. Special Studies
9. Integration, Analysis, and Interpretation

Highlights of the research plan are presented in Chapter 3, and detailed descriptions of individual tasks are in Chapter 4.

Project Organization

The research plan describes the work to be done without regard to who will perform which tasks. Although major parts of the proposed work may be done under grants and contracts to universities and private firms, significant portions would be performed by CSDOC (in-house) and by the Southern California Coastal Water Research Project.

An administrative board, consisting of a representative from each of the funding agencies, would be established to set overall policy to be carried out by a project research administrator selected by the board. Except for in-house work by CSDOC, all the research tasks should be funded through a joint administrative agreement of the various funding agencies (such as NOAA, EPA, the California State Water Resources Control Board and CSDOC). Using funds provided by the sponsoring agencies as a single pool, the project research administrator would carry out the research plan by means of grants and contracts; research proposals would be evaluated with peer reviews.

A research review committee would be established to advise the research administrator on priorities, changes in the research plan, and evaluation of proposals. An annual summary and evaluation of the results would be prepared for the regulatory agencies, CSDOC, NOAA, and other sponsors. Additional administrative details are discussed in Chapter 5.

Thus management of the research project would be independent of CSDOC, the agency which is responsible for building and operating the sludge disposal system. The organizational structure is summarized in Figure 5.1 on p. 94. Regulatory agencies would be responsible for specifying the conditions under which the sludge discharge may continue.

Project Cost

The research project would include two years of predischarge work and five more years of study after the discharge begins. The estimated total research cost is approximately $1.5 to 2 million per year. The breakdown by year and task group is shown in Table 5.1, p.98. These R & D costs are in addition to the usual capital, operation and maintenance costs for the sludge outfall system.

National Significance

National policy for sludge disposal is currently being reviewed, especially with regard to permitting ocean disposal. If the experimental deep-water sludge discharge goes forward as proposed, research and monitoring activities recommended in this report will produce results which are potentially very important to policy-makers. For instance, if related environmental effects are found to be very small, then the ocean discharge option may be viewed more favorably vis-a-vis air and land disposal options.

If ocean discharge of sludge is to be permitted in certain cases, then there is need for better predictive modelling and design methods for deep-water sludge disposal systems. Some of the tasks of this research plan are directed toward developing and improving these capabilities.

CHAPTER 2

PROPOSED DEEP-OCEAN SLUDGE DISCHARGE

The research plan presented in this report is designed to investigate the effects of a proposed discharge of sewage sludge into the ocean at 300 to 400 m depth off the Orange County coast in southern California. Although such a discharge is not now legal, the County Sanitation Districts of Orange County (CSDOC) is seeking approval for a unique research and demonstration project to discharge sludge at that unprecedented depth and to fully study its behavior and effects.

The discharge would consist of 3 million gallons per day of sludge containing about 1.2 percent wastewater solids, or 150 dry tons per day. These solids are very small particles derived from sludge digesters or from the activated sludge process. After discharge, they are expected to sink in the ocean slowly over a wide area.

This chapter is a summary of background technical information related to the proposed research project. Section 2.1 describes the Orange County wastewater and sludge treatment facilities. Section 2.2 discusses the physical and chemical nature of sludge. Characteristics of the receiving water are presented in Section 2.3. Section 2.4 provides a description of oceanographic and chemical processes which determine the fates of sludge and sludge constituents in marine waters. Finally, Sections 2.4 and 2.5 consist of an account, based on existing information, of what will probably happen in an environmental sense if sludge is discharged into the ocean.

2.1 ORANGE COUNTY FACILITIES AND SLUDGE DISPOSAL PLANNING

The County Sanitation Districts of Orange County (CSDOC) serves the wastewater treatment and disposal needs of approximately two million people and various industries in the northwestern portion of Orange County (Figure 2.1). CSDOC operates two treatment facilities -- Treatment Plant No. 1 and Treatment Plant No. 2 which together are known as the "Joint Works." The agency collects and treats an average daily wastewater flow of approximately 200 mgd. All wastewater receives at least primary treatment. A flow of about 125 mgd is also provided with some form of biological treatment (trickling filter or activated sludge). Sludges from these processes are now anaerobically digested and dewatered prior to disposal. Section 2.2 provides a more detailed description of sludge sources and characteristics.

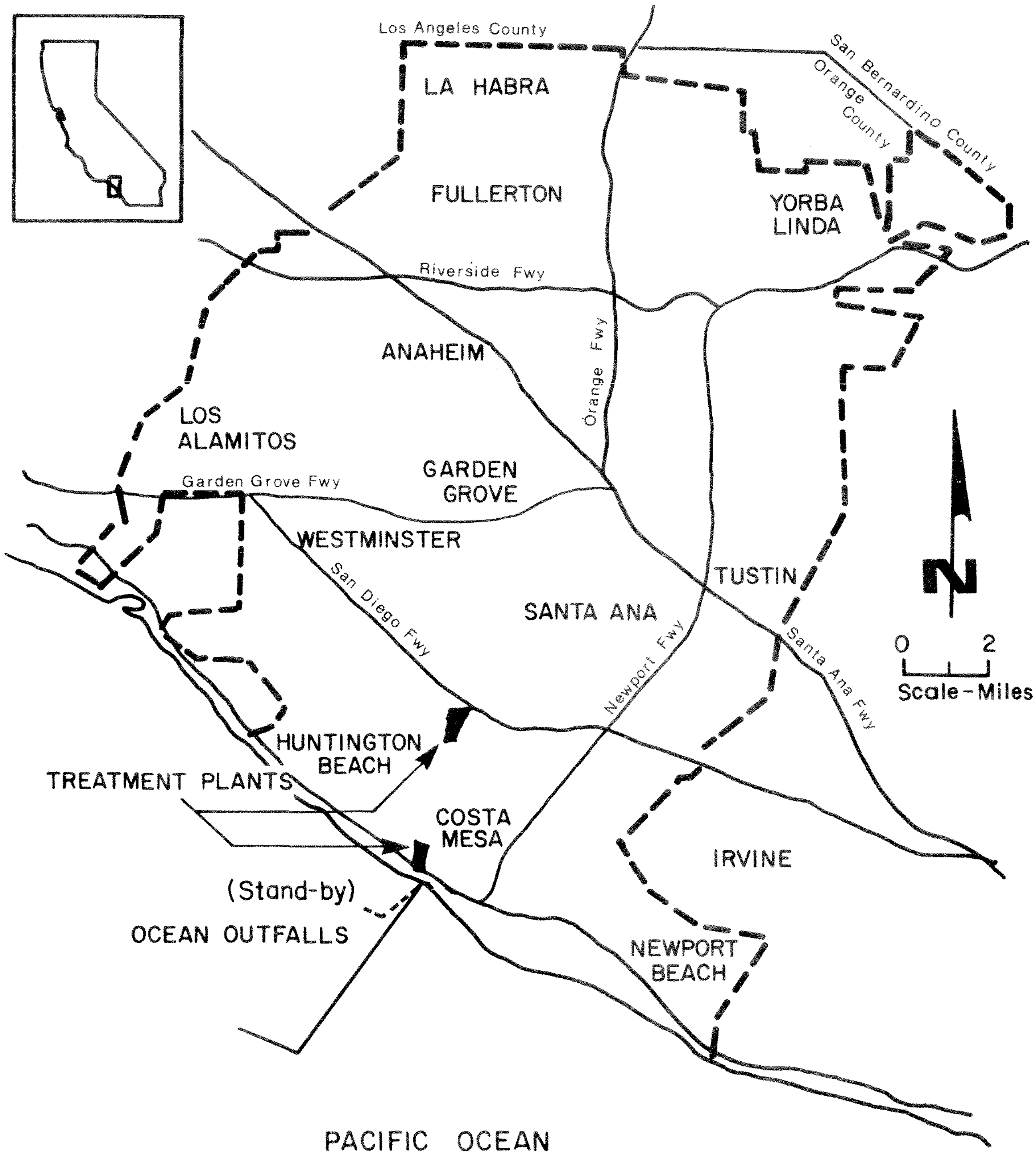


Figure 2.1 Existing CSDOC Boundaries, Treatment Facilities, and Wastewater Outfalls.

Dewatered, dried sludge is trucked to Coyote Canyon Landfill, where the material is further composted to at least 50 percent solids prior to incorporation in the landfill. In 1978, an average of about 120 tons per day of digested sludge (on a dry-weight basis) were disposed of in this fashion. The treated effluent along with centrate from sludge dewatering is discharged to the Pacific Ocean via a 27,400-foot long outfall (including a multiport diffuser which comprises the last 6000 feet of pipe). The discharge depth for treated wastewater is about 195 feet.

In 1974, CSDOC, in concert with other southern California operating agencies, EPA, and the California State Water Resources Control Board, organized the Los Angeles/Orange County Metropolitan Area Sludge Management Project (LA/OMA) to identify and evaluate a wide range of sludge disposal alternatives within the Los Angeles basin. The sludge management program recommended for CSDOC consisted of landfill disposal of digested, dewatered, and composted sludge. The plan carries with it potential environmental costs in terms of land use, groundwater quality, and air emissions associated with truck transport. These and related mitigation measures are discussed at length in the LA/OMA Draft Facilities Plan (1980).

Although much cheaper, ocean disposal alternatives were discarded by LA/OMA (1980) because of (i) federal and state prohibitions against marine sludge disposal (and ineligibility for federal construction grants) and (ii) the need for further monitoring and research to show that environmental impacts would be acceptable. A 400-meter discharge depth was recommended for further study in the EQL report on deep-ocean disposal alternatives (Jackson, Koh, Brooks, and Morgan, 1979).

Research proposed herein will provide a detailed determination of the environmental effects of marine sludge disposal via an outfall to 300 or 400 meters. The program envisioned offers minimal risk of irreversible environmental damage or impacts to human health. Pathways for possible human exposure to trace contaminants or pathogens will be carefully monitored as part of the overall research objective; however, we consider the chances of related health effects to be very remote.

Significant economic benefits would attend marine disposal of sludge instead of land disposal, both to CSDOC and (potentially) to other coastal agencies. Table 2.1 (from Brooks and Krier, 1981) summarizes the estimated capital, annual, and unit costs for land-based and ocean disposal alternatives described previously. The cost of ocean disposal is about one-quarter of estimated costs for the recommended (LA/OMA) land-based alternative.

The reader is cautioned that these are rough cost estimates (in 1981 dollars) which need to be refined by further detailed engineering and planning studies. This report, for instance, estimates that research and monitoring costs would be \$1.5-2.0 million

Table 2.1**

Estimated Costs of Digested Sludge

Disposal Alternatives for Orange County

Sanitation Districts* (150 tons/day)†

	Landfill disposal (by truck)	Ocean disposal (by sludge outfall to to 300m depth)
	$ million	$ million
Capital		
Land	$23-36	
Dewatering, screening	6.0	1.0
Storage	4.5	
Trucking	2.0	
Pipeline		5-10
TOTAL CAPITAL COST	35-48	6-11
Annual costs		
Capital#	4.0-5.3	0.7-1.2
Annual operation and maintenance	6.6	0.25
SUBTOTAL, Capital and O & M.	10.6-11.9	1.0-1.5
Special research and monitoring program	-	0.75-1.25
TOTAL, ALL ANNUAL COSTS ($ million)	10.6-11.9	1.75-2.75
COST PER TON† (dollars)	$82-92	$13-21

* Based on preliminary data provided by Orange County Sanitation Districts, Feb. 1981.

\# Based on 10.25% interest, amortized as follows: land, interest only; storage tanks and outfall pipe, 30 yrs; pumping, dewatering and screening equipment, 10 yrs.; trucks, 7 yrs.

† Actual digested sludge discharge is 150 tons/day which is derived from 350 tons/day of raw sludge. For consistency unit costs are given in costs per ton of original raw sludge.

** From Brooks and Krier, 1981.

per year (1982 dollars), which is about twice the cost given in Table 2.1. However, many of the objectives of this research plan go beyond Orange County's disposal problem and serve national needs; thus assignment of only 50 percent to this particular disposal activity is reasonable for purposes of economic comparison. It should also be noted that the research and monitoring expense will drop sharply after the first five years of discharge if the results are favorable.

The proposed sludge outfall for the Orange County deepwater sludge disposal experiment planned herein will consist of a single pipeline (probable diameter 18 to 24 inches) extending from the shoreline a distance of about 12 km to a depth of 300 to 400 m, as shown schematically in Figure 2.2. The exact depth and location will be determined during preliminary design (Task Group 5). The sludge discharge rate will be approximately 3 mgd (million gallons per day), consisting of a mixture of digested primary sludge (0.8 mgd), unthickened waste activated sludge (2.2 mgd) and a small amount of digested trickling filter humus (0.02 mgd). This material may be prediluted with secondary effluent before discharge (perhaps one or two parts per part of sludge). Predilution will both decrease the resulting concentrations of sludge contaminants and simplify the logistics of maintaining a minimum flowrate through the pipeline.

Under present federal laws (the Clean Water Act) and EPA regulations, the proposed sludge discharge (by ocean outfall) is not permitted. California's Ocean Plan (1978) also prohibits ocean discharge of sludge. Nonetheless, the CSDOC is seeking permission for an experimental discharge over a five-year period. The research plan presented in this report is recommended to evaluate the effects of such a discharge and to produce new scientific and engineering information for national use. If the effects are judged to be acceptably small, CSDOC would continue to dispose of sludge in the ocean. On the other hand, if environmental impacts are considered unacceptable by regulatory agencies, the agency would discontinue or modify its sludge discharge.

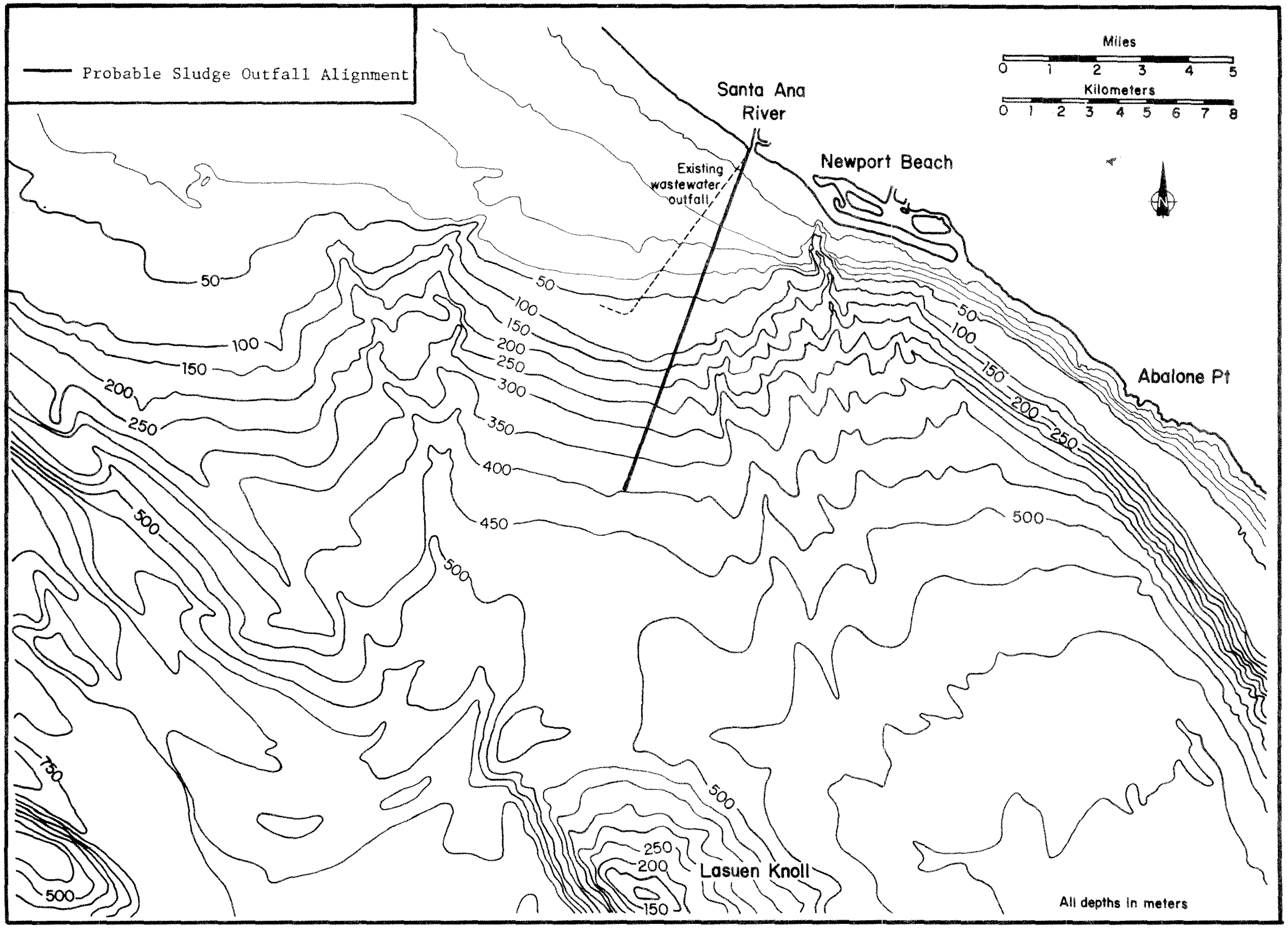


Figure 2.2 Basin Bathymetry off Orange County, California. Existing CSDOC Wastewater Outfall and Candidate Sludge Outfall Alignments.

2.2 THE NATURE OF SLUDGE

As indicated earlier, sewage sludge contains the solids removed during wastewater treatment. Digested sewage sludge is a black liquid containing 2 to 5 percent suspended solids consisting of small organic and inorganic particles in a size range of about 5 to 50 microns. Anaerobic digestion is frequently followed by dewatering and composting. Well composted sludge resembles dark, coarse earth and is sometimes used as a soil amendment.

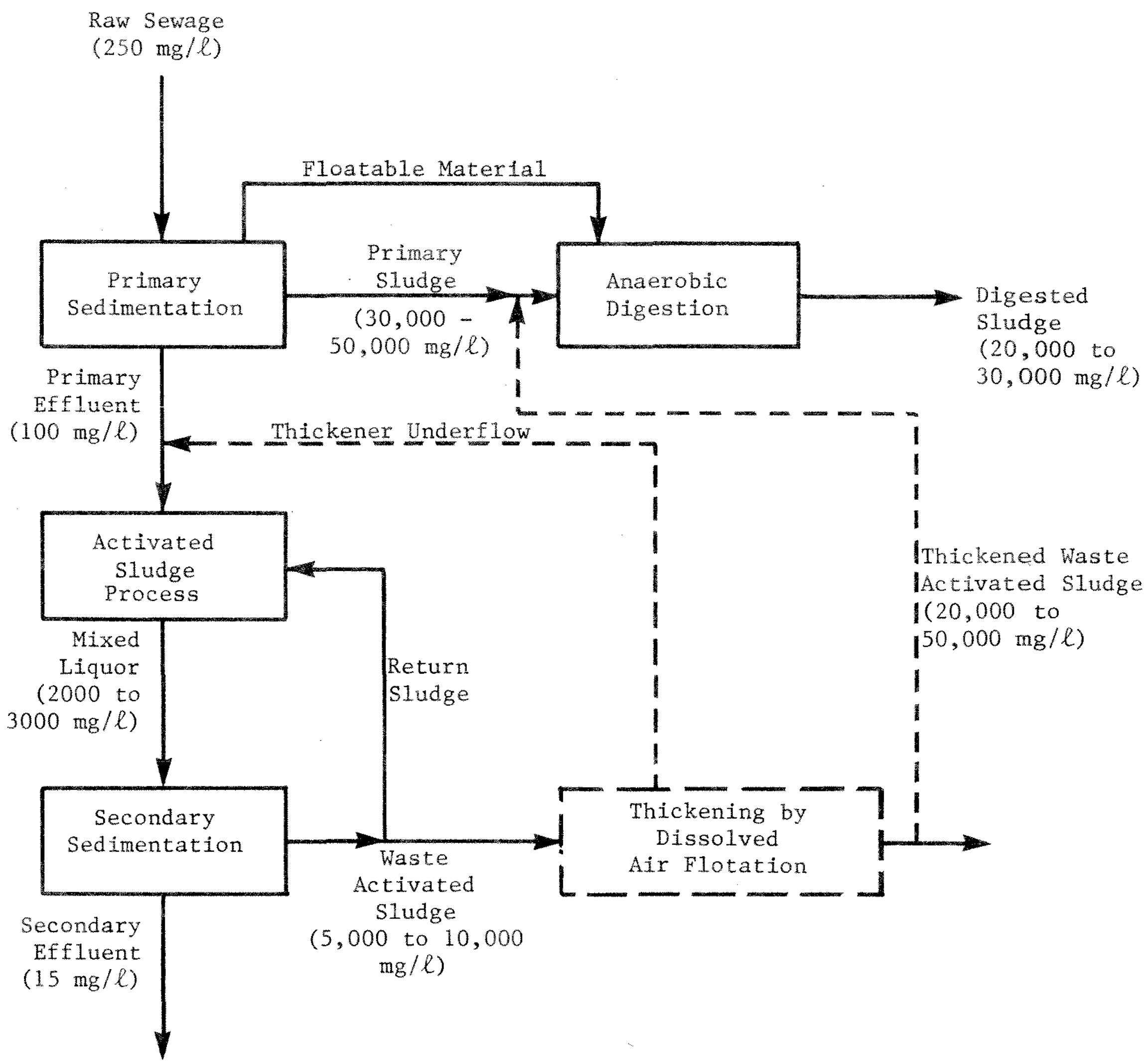
Most municipal sludges, including Orange County's, contain measurable amounts of trace metals and such refractory organics as pesticides and industrial solvents. Neither dewatering nor anaerobic digestion effectively reduces these contaminants. Marine disposal methods would rely on rapid dispersal to ensure that seawater concentrations of such materials are maintained below potentially harmful levels.

2.2.1 Sludge Sources

Wastewater treatment processes produce a variety of different sludges. Figure 2.3 is a schematic representation of the major process train now used by CSDOC. Typical concentrations of wastewater and sludge solids are indicated at key points. Primary sedimentation removes settleable organic and inorganic materials from wastewater via quiescent settling in large tanks. Floatable materials such as oil and grease are skimmed from the primary sedimentation tanks.

A portion of the primary effluent is treated biologically to capture or oxidize dissolved organic matter and fine particles; resultant biological solids are separated in secondary clarifiers. Secondary sludges (waste-activated sludge and humus from trickling filters) are further thickened and then stabilized by anaerobic digestion in combination with the raw primary sludge prior to dewatering and disposal.

The volume and chemical composition of sludges contributing to the proposed CSDOC ocean discharge are summarized by source in Table 2.2. (Table 2.2(a) gives concentrations, while Table 2.2(b) gives mass emission rates.) CSDOC has proposed to discharge undigested waste activated sludge, but another option would be to thicken and digest waste activated as well as primary sludge before ocean discharge. The latter alternative will be adopted if warranted by projected (estimated) receiving water or sediment oxygen reductions.



Note: Dashed items required only for land disposal of sludge.

Figure 2.3 Simplified flow schematic for activated sludge secondary treatment. (Numerical values represent suspended solids concentrations which are typical of CSDOC system.)

2.2.2 Chemical Properties of Sludge

Sludge chemistry depends upon the nature of materials discharged to the sewer system (i.e., the degree of industrialization within the service area) and the processes used to treat wastewater and sludge. Typically, raw sludge solids within CSDOC are 70 to 80 percent volatile. (Volatile solids are those materials which can be volatilized at 550°C.) Most volatile solids are organic.

Some important contaminants in wastewater are removed by physical, chemical, or biological treatment processes and concentrated in the sludge. More than 90 percent of some trace metals and trace organics from the raw wastewater are found in the sludge. The majority of these, in turn, are associated with particles. Table 2.3 provides typical ranges for trace metal concentrations in sludge as well as data specific to CSDOC. In general, the CSDOC sludges contain levels of major and trace metals which are representative of sludges derived within major U.S. municipalities. Mass emission rates of trace contaminants in CSDOC sludges to be expected following construction of additional secondary treatment capacity are summarized in Table 2.2(b). As indicated in Figure 2.4, mass flow rates of specific trace contaminants have decreased in the CSDOC sewerage system due to recent improvements in industrial waste pretreatment measures.

Nutrients such as nitrogen, phosphorus, and organic carbon are also important sludge constituents. Existing sludge nutrient data are included within Table 2.4.

2.2.3 Physical Properties of Sludge

The physical properties of sludge particles (density, particle size, and settling characteristics) influence their fate subsequent to marine discharge (Koh, 1982; Kavanaugh and Leckie, 1980). The bulk specific gravity of liquid sludge ranges from slightly greater than 1.00 to about 1.02, depending on the solids concentration and type of sludge. Particulate materials within sludge have specific gravities ranging from slightly above 1.0 (biological solids) to about 2.7 (fine sand, silt and clay).

The range of particle sizes in a sludge sample stretches over several orders of magnitude -- from colloids of less than 1 μm in diameter to visible material in the range 50 to 100 μm.

The distribution of particle sizes can vary greatly between samples, depending upon the sludge source and treatment it receives. Figure 2.5 shows a typical cumulative distribution of total volume versus particle size for digested primary sludge. About half the volume of sludge solids (or mass if densities are assumed to be

Table 2.2(a) Projected Quality Characteristics in Various CSDOC Sludge Streams[a]

SLUDGE STREAM	Vol. MGD	TSS mg/l	VSS mg/l	BOD mg/l	Ag mg/l	Cd[c] mg/l	Cr mg/l	Cu mg/l	Ni mg/l	Pb mg/l	Zn mg/l	PCB μg/l	CHC Pesticides μg/l
Plant No. 1, Primary, Digested[b]	0.30	25,000	13,000	2,500	2.0	3.1	14	55	6	17	70	200	5
Plant No. 2, Primary, Digested[b]	0.50	25,000	13,000	2,500	2.5	3.1	10	35	4	17	50	70	9
Plant No. 1, WAS Unthickened, Undigested[b]	0.90	5,000	3,800	1,000	0.15	0.5	3	6	0.3	1.5	7	40	1
Plant No. 2, WAS Unthickened, Undigested	1.30	8,000	6,000	1,600	0.3	0.8	3	7	0.3	2.5	7	20	3
Trickling Filter Humus, Digested[b]	0.02	20,000	16,000	2,000	1.5	8	25	50	2	18	80	500	50
TOTAL	3	11,500	7,000	1,700	0.8	1.4	5	16	1.5	6	20	50	4
Total (mg/kg Dry Weight Basis)					70	110	440	1400	130	500	1700	5	0.4

[a]Projections are based on 1981 influent quality and operational parameters assuming that planned secondary treatment capacity at CSDOC Plant No. 2 is on-line. Source of figures: Enclosure II to Orange County Sanitation Districts' letter, dated 25 November 1981.

[b]Figures are based on data representative of the period July 1979 to June 1981.

[c]The cadmium figures provided are based on current plant operations and reflect industrial waste source control improvements implemented after November 1981. Source control measures planned for 1982-83 are expected to reduce the average cadmium concentration in CSDOC sludge (combined) to approximately 85 mg/dry kg before the end of 1983.

Table 2.2(b) Projected Mass Emission Rates of Sludge Contaminants in Various CSDOC Sludge Streams[a]

SLUDGE STREAM	Volume MGD	TSS MT/day	VSS MT/day	BOD_5(20°c) MT/day	Ag kg/day	Cd[c] kg/day	Cr kg/day	Cu kg/day	Ni kg/day	Pb kg/day	Zn kg/day	PCB kg/day	CHC Pesticides kg/day
Plant No. 1, Primary, Digested[b]	0.30	28	15	2.8	2.3	3.5	16	63	6.8	19	80	0.2	0.006
Plant No. 2, Primary, Digested[b]	0.50	47	15	2.8	4.7	5.9	19	66	7.6	32	95	0.1	0.017
Plant No. 1, WAS Unthickened, Undigested[b]	0.90	17	13	3.4	0.5	1.7	10	21	1.0	5.1	24	0.1	0.003
Plant No. 2, WAS Unthickened, Undigested	1.30	39	29	7.9	1.5	3.9	15	34	1.5	12	34	0.1	0.015
Trickling Filter Humus, Digested[b]	0.02	1.5	1.2	0.2	0.1	0.6	1.9	3.8	0.2	1.4	6.1	0.0	0.004
TOTAL DAILY MASS EMISSION RATE	3.0	133	73	17	9	16	62	190	17	70	240	0.5	0.045

[a]Projections are based on 1981 influent quality and operational parameters assuming that planned secondary treatment capacity at CSDOC Plant No. 2 is on-line. Figures are calculated based on flows and sludge quality characteristics provided in Table 2.2(a).

[b]Figures are based on data representative of the period July 1979 to June 1981.

[c]Source control measures planned for 1982-83 are expected to reduce the average cadmium concentration in CSDOC sludge (combined) to approximately 85 mg/dry kg before the end of 1983. This represents a reduction of about 23 percent below the cadmium figures provided here.

Table 2.3

Trace Metal Concentration Ranges
(mg/kg dry solids)

METAL	CONCENTRATION RANGE	TYPICAL RANGES	TYPICAL CSDOC COMPOSITE
Ag	4 – 150	10 – 50	70
Cd	2 – 1500	20 – 1000	220
Cr	16 – 40000	100 – 1000	440
Cu	52 – 10400	400 – 2000	1400
Fe	6000 – 74000	10000 – 30000	no data
Mn	73 – 39000	100 – 500	no data
Ni	7 – 5300	100 – 500	130
Pb	52 – 26000	200 – 2000	500
Zn	570 – 49000	1000 – 3000	1700

Note: The extremes of concentration on the high side can be traced directly to industrial discharges. The low values generally come from plants receiving only domestic sewage. Values typical of existing CSDOC sludge quality are shown in the third column.

Sources: Camp, Dresser, McKee, 1975; East Bay Municipal Utilities District, 1975; Page, 1974; Shipp and Baker, 1975; Van Loon, et al., 1973; Van Loon and Lichwa, 1973. CSDOC composite figures based on routine Orange County Sanitation Districts monitoring results.

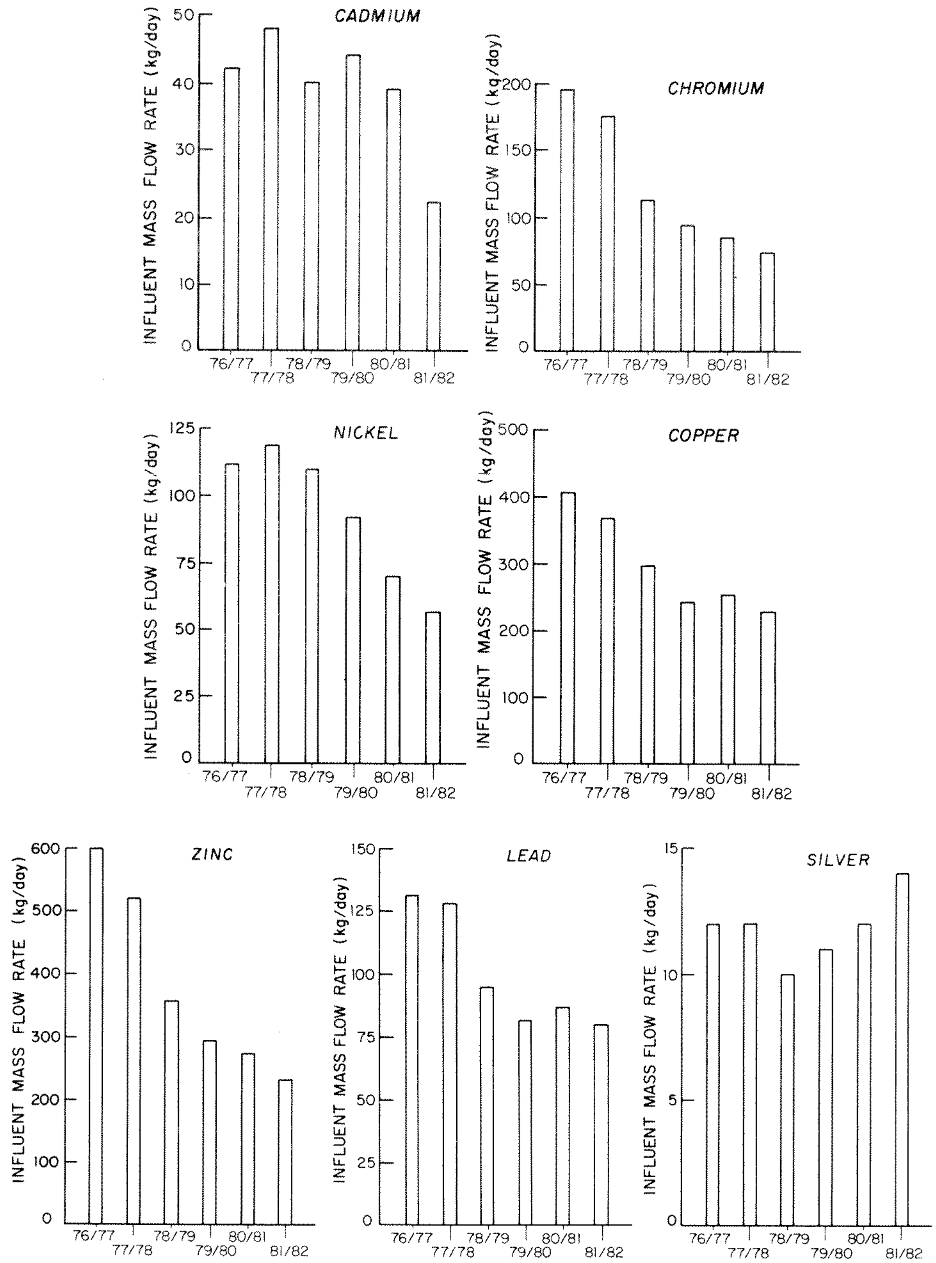


Figure 2.4 Recent Trends in County Sanitation Districts of Orange County Influent Mass Flow Rates (Daily Average) of Selected Trace Metals.[1/][2/]

[1/]Figures are based on routine wastewater monitoring conducted by County Sanitation Districts of Orange County's personnel.

[2/]Observed reductions in influent metals mass flow rates generally attributable to source control improvements among industries tributary to the CSDOC wastewater collection and treatment system.

Table 2.4(a) Typical Concentrations of Volatile Solids, Fat and Grease and Nutrients for Various Sludges

Type of Sludge	Typical values, percent dry solids			
	Volatile Solids	Fat and Grease	Nitrogen, as N	Phosphorus as P
Raw primary	75	6 to 35	2.5	0.7
Waste activated	81	5 to 12	5.6	3.1
Trickling filter solids	64 to 86	6	5 to 15	1.2
Digested sludge	50 to 60	3.0 to 17	2 to 5[a]	1 to 3

a. Includes particulate and dissolved nitrogen.

Sources: (1) US EPA: Process Design Manual for Sludge Treatment and Disposal, September 1978, EPA 625/1-79-001

(2) WPCF Manual of Practice No. 2: Utilization of Marine Wastewater Sludge, 1971.

Table 2.4(b) Typical Concentrations of Volatile Solids, Fat and Grease and Nitrogen in Various CSDOC Sludges

Type of Sludge	Typical values, percent dry solids			
	Volatile Solids	Fat and Grease	Nitrogen, as N	Phosphorus as P
Raw primary	75	25	2.5	
Waste activated (undigested)	80	8		
Waste activiated (digested)	77	6	No data	No data
Trickling filter	65	11		
Digested primary	55	8	3.0	

Sources: Personal communication with Gregg Pamson of CSDOC.

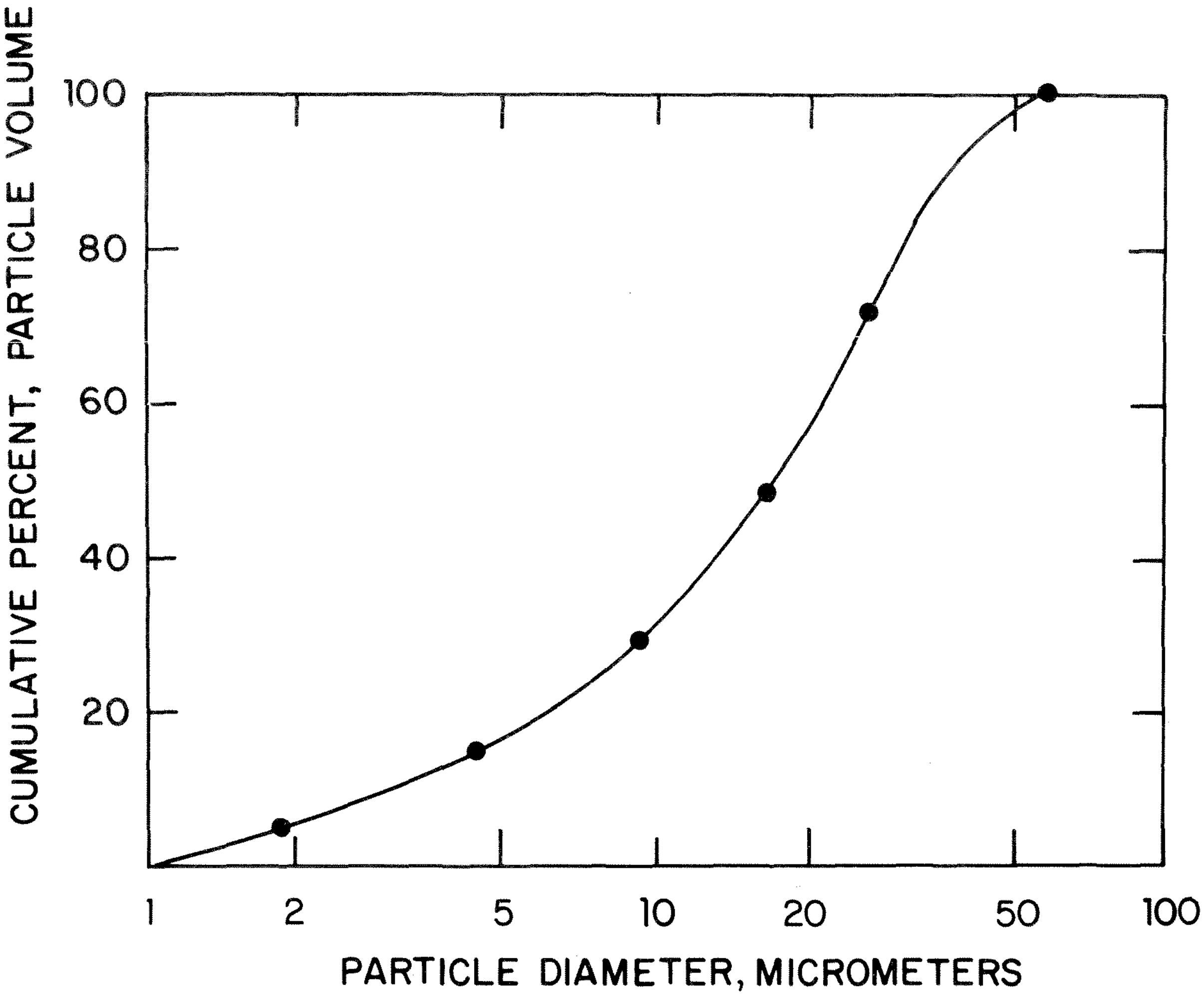


Figure 2.5 Typical particle size distribution for digested primary sludge (Faisst, 1976).

constant) is comprised of particles less than 20 μm in diameter; particles 50 μm and smaller comprise 90 percent of the particle volume.

Prediction of sludge behavior and impacts subsequent to ocean discharge requires information on sludge settling characteristics. Settling is affected by both particle size and density. Measurement of these parameters, however, is difficult, and particle sedimentation is usually characterized with simple settling column experiments. Starting with a uniformly mixed column, sludge concentrations in seawater are sampled over time at a fixed point in the settling column. Changes of solids concentration are then used to develop settling velocity distributions, such as those shown in Figures 2.6 and 2.7 (Faisst, 1980). Figure 2.6 indicates that the mean settling velocity decreases with increased dilution, perhaps due to reduced coagulation effects. They also show that 35 to 70 percent of the sludge particles (by weight) settle with velocities of less than 10^{-3} cm/sec -- less than one meter per day. Thus sludge may spread over wide areas prior to reaching the bottom. It is important to note, however, that two mechanisms participate in the downward migration of sludge particles: (i) gravity settling and (ii) downward diffusion. The second mechanism is significant for particles with small fall velocities ($<10^{-3}$ cm/sec).

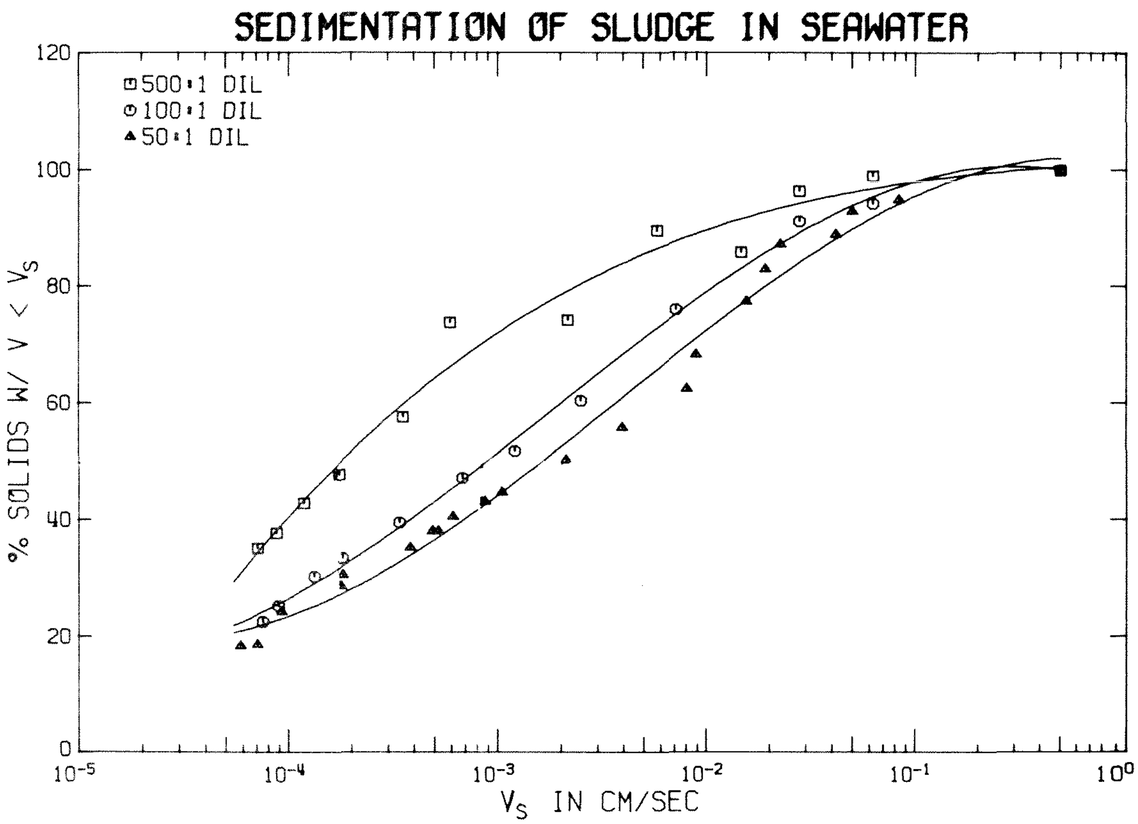


Figure 2.6 Fall velocity distributions for digested primary sludge. Sludges were obtained from the County Sanitation Districts of Los Angeles County and diluted as indicated prior to the start of settling column experiments (from Faisst, 1980).

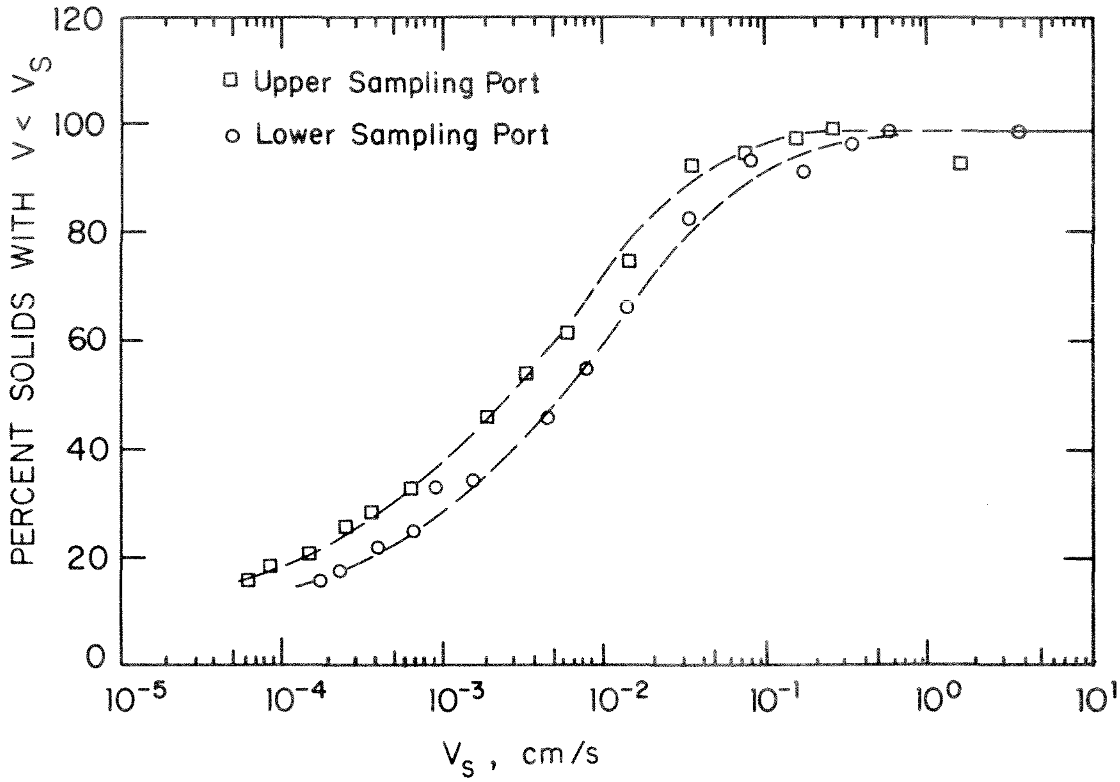


Figure 2.7 Fall velocity distributions for CSDOC digested primary sludge diluted 100:1 with seawater, as determined from samples at two ports along the settling column (Faisst, 1980).

2.3 CHARACTERISTICS OF THE SITE

2.3.1 Bathymetry

The underwater topography off southern California mimics the rugged mountains onshore. The bathymetry is characterized by a number of deep basins with depths of about 1000 meters (Figure 2.8). Deeper portions of these basins are completely surrounded by steep slopes below the sill depths. The various sills connecting the basins vary in depth but are generally several hundred meters deep.

The bathymetry off the Santa Ana River mouth is shown on a larger map in Figure 2.9. Alignments of both the existing Orange County ocean outfall and a candidate deep-water sludge outfall are also shown. The CSDOC effluent outfall is located on a shelf with the diffuser at an average depth of 60 m. Because of the flat slope of the shelf (0.75%), the discharge is nearly 8 kilometers offshore. Beyond 100 m depth, however, the bottom slope becomes much steeper (5%) so that a sludge outfall terminating at 300-400 m depth need only be 12 km in length or about 50 percent longer than the wastewater outfall. Profiles along the lines indicated in Figure 2.9 are shown in Figure 2.10. It is evident that in the alongshore direction (line ABOKL), the candidate sludge outfall terminus is situated on top of a rise, while in the onshore-offshore direction, it is along the slope. Note also that vertical distances are exaggerated 25 times compared to the horizontal scale. One expects advective transport to be mainly in the alongshore direction, i.e., parallel to the bottom contours.

2.3.2 Profiles of Water Properties

Vertical profiles of water properties were measured near the candidate discharge site within the California Cooperative Oceanic Fisheries Investigation (CalCOFI) at their Station 90.28 (in the vicinity of the proposed discharge site) and more recently by the Southern California Coastal Water Research Project (SCCWRP). Profiles representing statistical summaries of CalCOFI data at Station 90.28 (as analyzed by Dr. Tareah Hendricks of SCCWRP) are presented in Figure 2.11. Calculated values for the mean and standard deviation of station measurements, as well as the full range of values encountered within the sampling program, are provided for each parameter. SCCWRP measurements within the preliminary survey described in Appendix A generally fell within the ranges shown in Figure 2.11.

Density stratification in the deeper layer below 150 meters is quite small; the typical gradient of relative density is $2 \times 10^{-6} m^{-1}$, and exhibits little temporal or spatial variation within the basins. The dissolved oxygen concentration decreases steadily with increasing depth to over 400 m. At depths between 300 and 400 meters, concentrations range from 0.5 to 1.5 ml/l (0.7 to 2.1 mg/l).

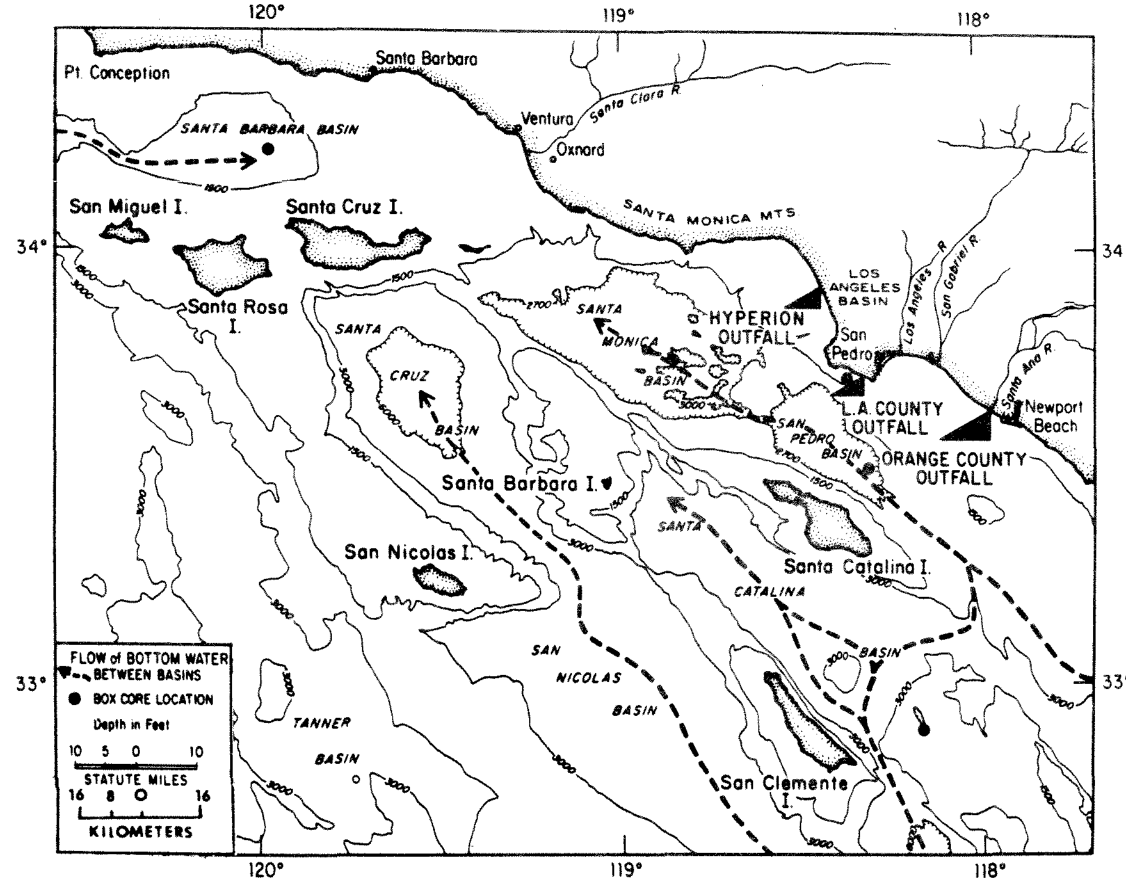


Figure 2.8 The Marine Basins of Southern California (from Bertine and Goldberg, 1977).

2.3.3 Currents

The rugged bathymetry and the hydrodynamic separation of the southward flowing California Current at Point Conception combine to make the current structure in the Southern California Bight, very complex. Satellite imagery has revealed clear evidence of large southward migrating eddies shed off Point Conception. Deep drift currents through the deep basins are generally northward (see Figure 2.8).

Data from the depth range of interest for the sludge outfall experiment are scarce, but measurements are in progress at the proposed discharge site. A special set of current measurements was undertaken by SCCWRP during a previous study by the Environmental Quality Laboratory (EQL) (Jackson, et al., 1979). The current meter depth was at 430 m, 40 meters above the bottom, in the Santa Monica Basin. Results are summarized in Figure 2.12. Currents are predominantly parallel to bottom contours. The onshore-offshore motion constitutes almost white noise with only a small peak in the spectrum at the semidiurnal frequency. In contrast, the along-isobath current component exhibits a marked diurnal peak, with an apparent spring-neap cycle, and a peak amplitude of about 0.1 m/s. In addition, flow "events" of a few days' duration occur, with an amplitude of order 0.3 m/s. The latter are presumably topographic waves propagating along the isobaths. Both the diurnal tide and topographic waves may well be general features of the flow in the depth range where the measurements were taken and may be expected to affect the advection and dispersal of sludge at the proposed outfall site. In particular, pollutant transport and dispersion should be much more intense parallel to the bottom contours than normal to them.

The current sequence shown in Figure 2.12 was not measured at the proposed discharge site, but at a similar location in a neighboring submarine basin. Latest measurements at the proposed discharge site during Spring 1982 (personal communication, T. Hendricks) show that there is a persistent upcoast drift flow on the order of 8 cm/sec, or 7 km/day, at 50 m above the bottom. This indicates that advection will disperse sludge particles over a wide area and minimize buildup in the vicinity of the discharge.

2.3.4 Chemistry and Biology

The chemistry of seawater is closely tied to biological processes. The production of plant matter near the ocean's surface causes a depletion of major nutrients and trace metals; it also releases oxygen into the water. The settling of organic matter and its biodegradation in deeper waters produces opposite effects: concentrations of metals (such as copper, cadmium and nickel)

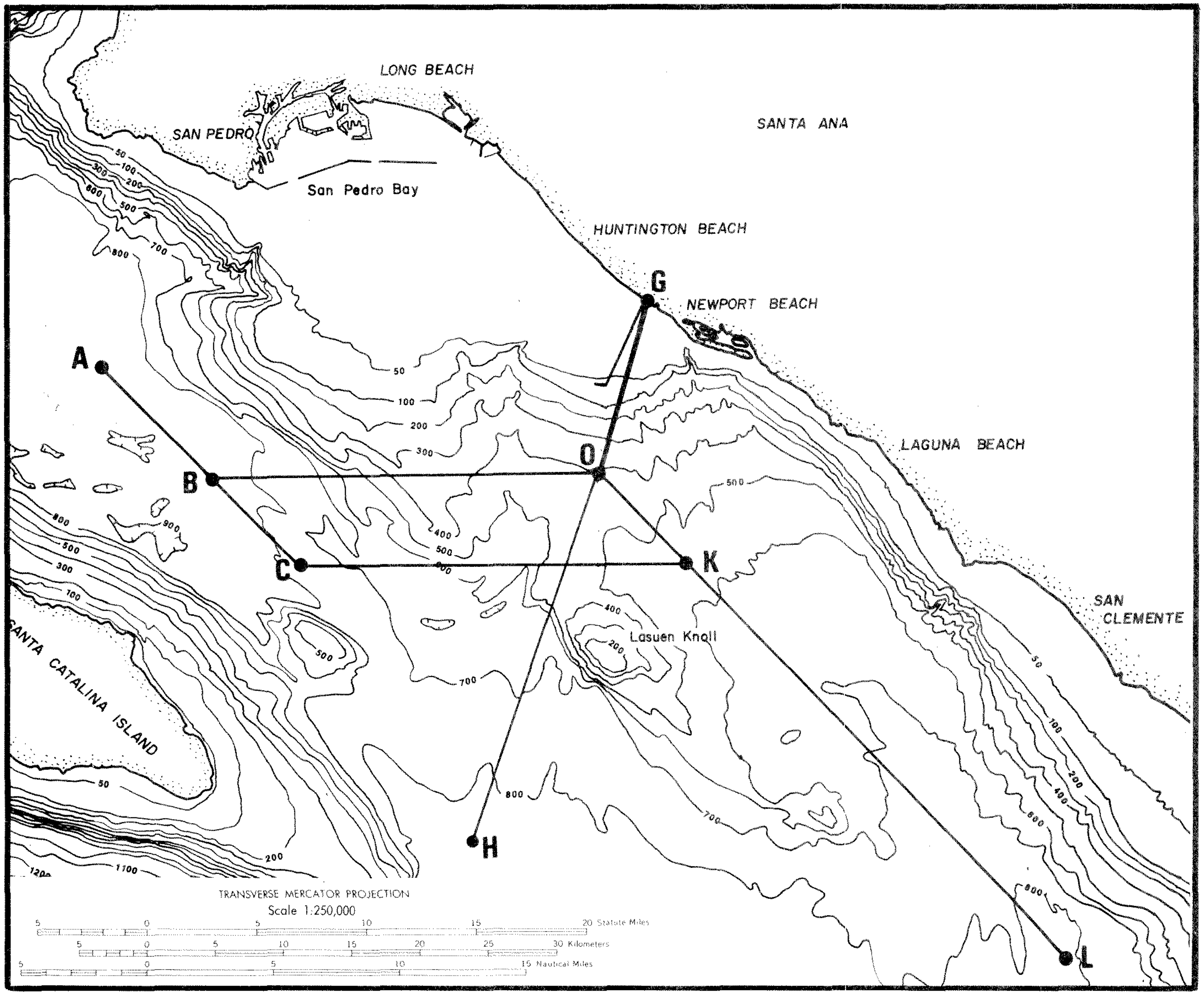


Figure 2.9 Bathymetry of basins near the proposed sludge outfall site. For profiles along the marked lines see Fig. 2.10.

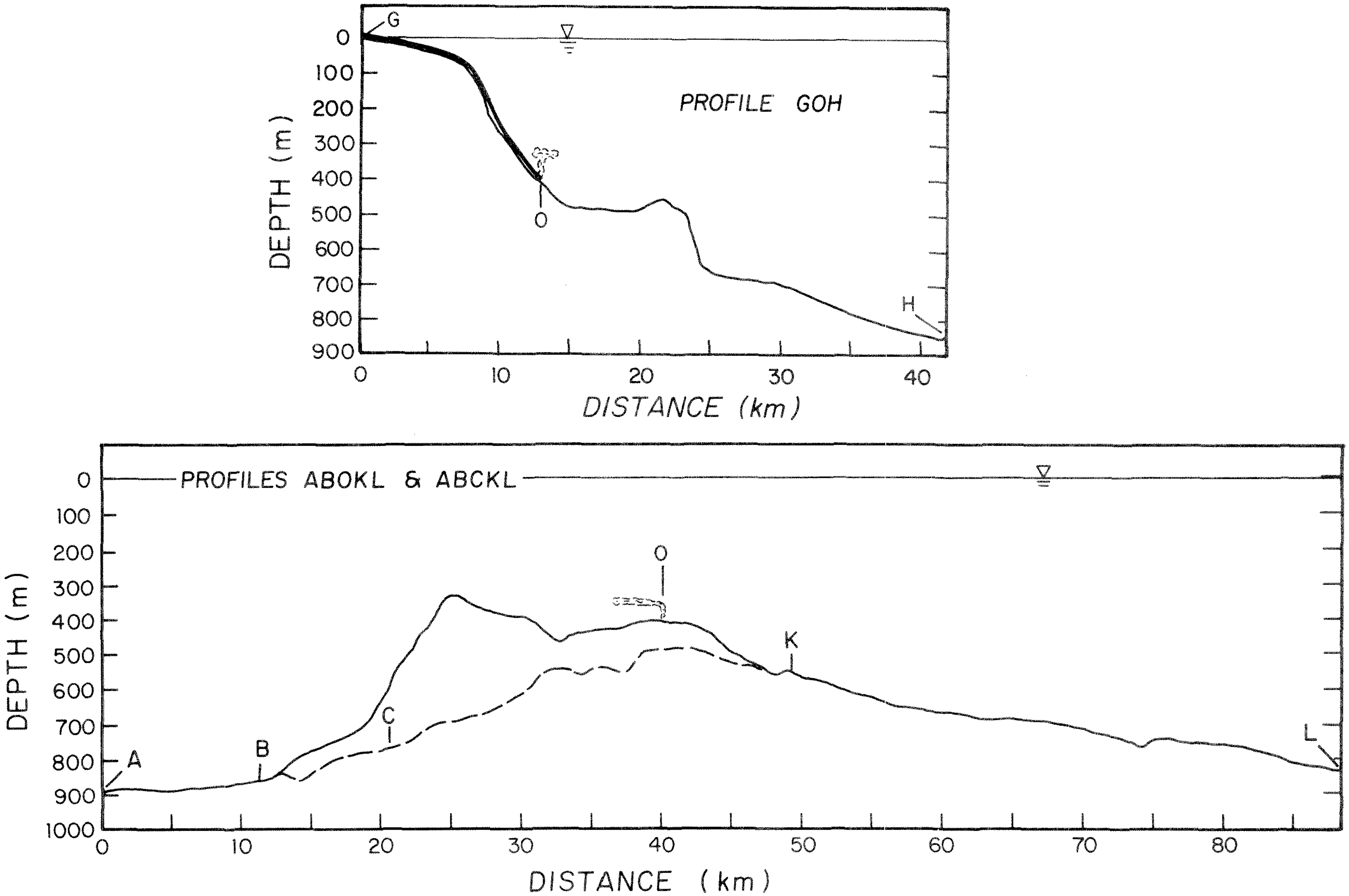


Figure 2.10 Bottom profiles along chosen lines at probable site of deep water sludge outfall experiments (see Figure 2.9 for locations of profiles indicated).

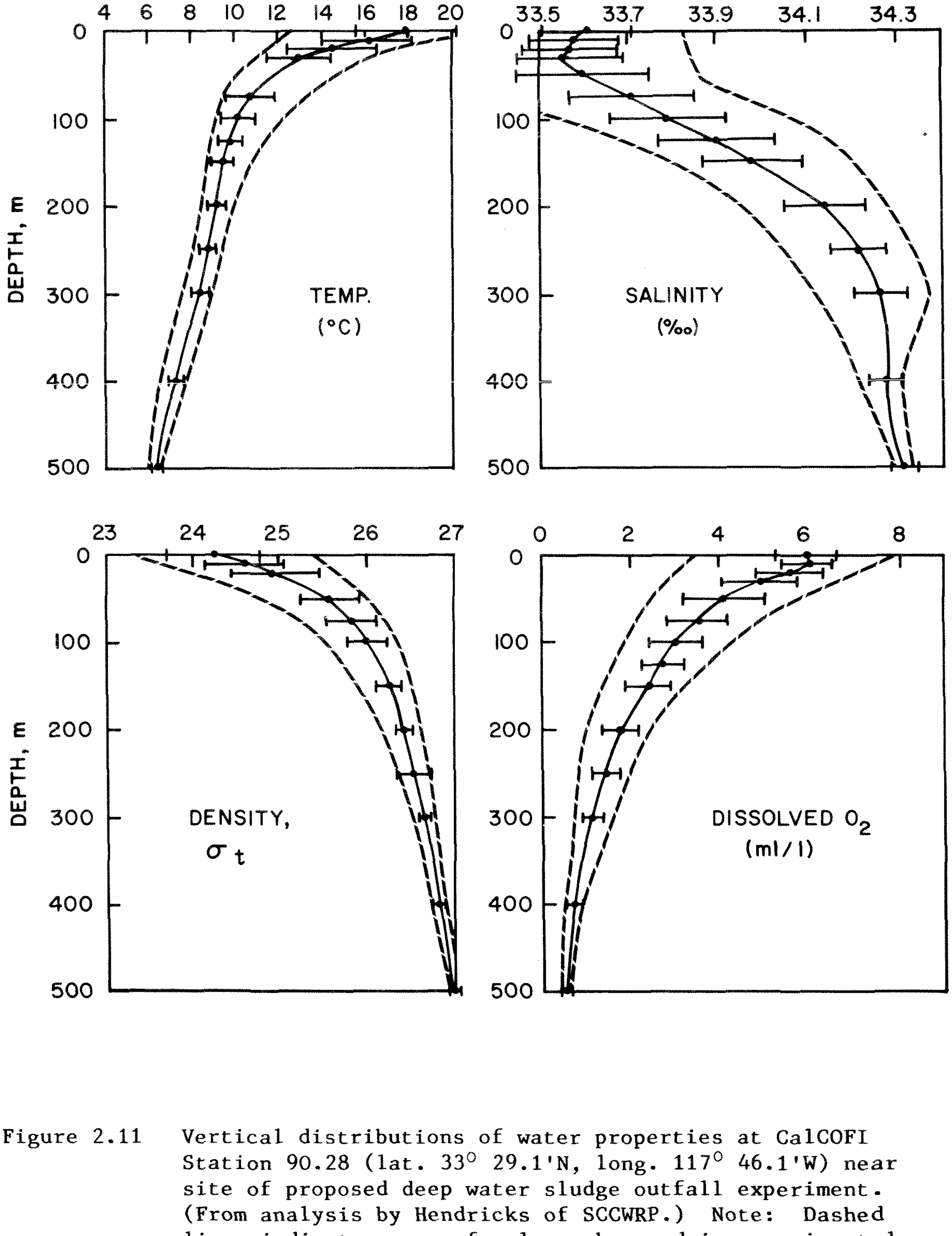
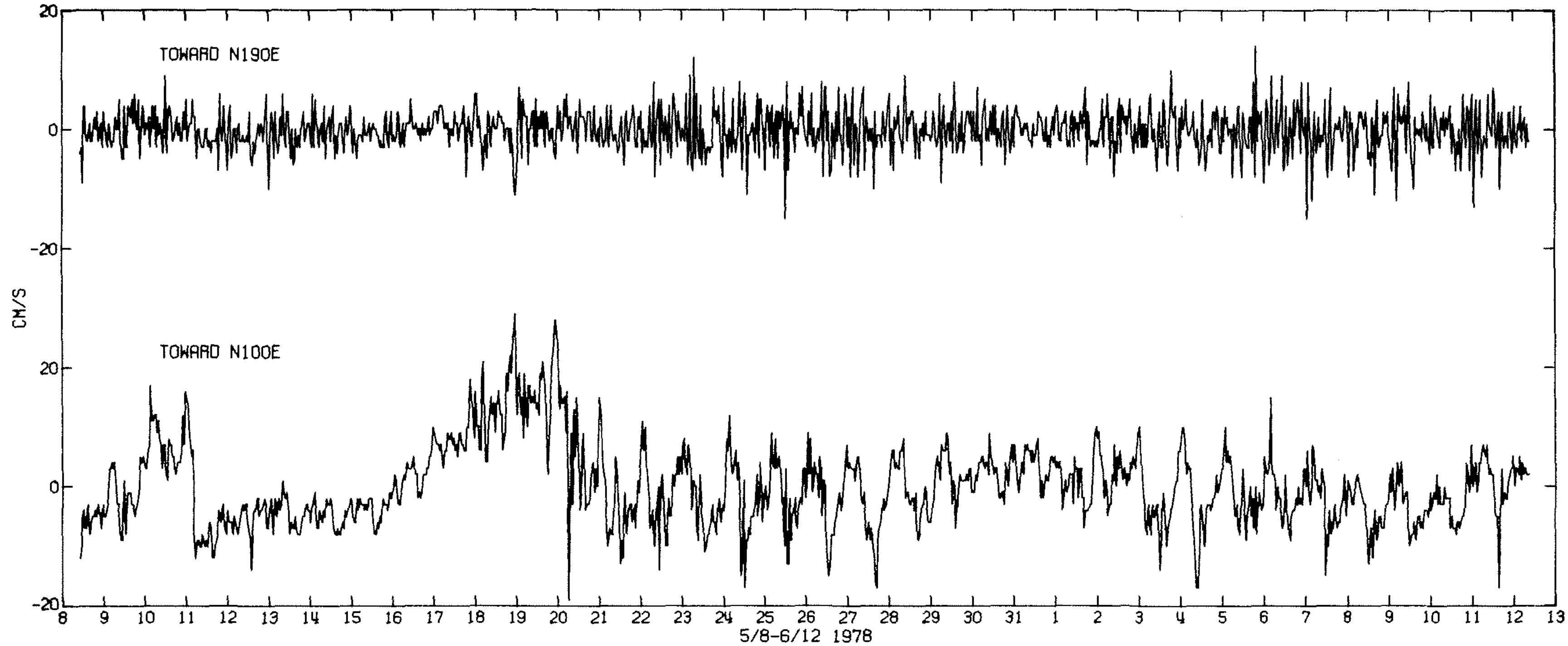


Figure 2.11 Vertical distributions of water properties at CalCOFI Station 90.28 (lat. 33° 29.1'N, long. 117° 46.1'W) near site of proposed deep water sludge outfall experiment. (From analysis by Hendricks of SCCWRP.) Note: Dashed lines indicate range of values observed in experimental programs; ⊢●⊣ indicates width of two standard deviations; and ● indicates mean value.



Figures 2.12 Ocean currents measured on Santa Monica Basin slope in water of 470 meters depth. Meter depth 430 meters. (Jackson et al, 1979.)

generally increase with depth; concentrations of oxygen generally decrease. In the southern California region there is an oxygen minimum in the depth range of 400 to 800 m. Oxygen concentrations at the minimum are about 0.4 ml/l (0.6 mg/l), compared to typical surface concentrations of 6 ml/l (8.5 mg/l) (Figure 2.11). Some of the submarine basins in southern California such as the Santa Monica, San Pedro and Santa Barbara Basins draw their deep water from the oxygen minimum layer, have low exchange rates with outside waters, and have high natural oxygen demand. Consequently, their dissolved oxygen concentrations are at times nearly zero. Waters at the proposed Orange County sludge discharge site are less topographically constrained, leading to higher local exchange rates and oxygen concentrations (typically 0.5-1.0 ml/l (0.7-1.4 mg/l) at 400 m and 1.0-1.5 ml/l (1.4-2.1 mg/l) at 300 m). There is some evidence that trace metal concentrations in this region are higher than expected, a consequence of large anthropogenic inputs. The sediments around the proposed outfall site do not contain significant concentrations of sulfide.

The maximum depth for photosynthesis in the Southern California Bight is about 60 m. As a result, the presence of a sludge plume at 300 to 350 m will probably not affect plants or photosynthetic processes. However, some organisms at 300-400 m do depend on the surface layers for food. Some deepwater pelagic fishes and invertebrates feed directly near the surface, rising up during the night and returning to depths during the day. Others feed directly or indirectly on organic matter settling down through the water column.

Preliminary data collected by SCCWRP (Figure 2.13) show no simple depth-related trend for epibenthic organisms collected between 300 and 627 m depth. The benthic fauna in the area of the proposed outfall are not depauperate.

There are no major fisheries at the depth and location of the proposed outfall site. There is a small sable-fishery in the area, focussed primarily at Lasuen Knoll to the south.

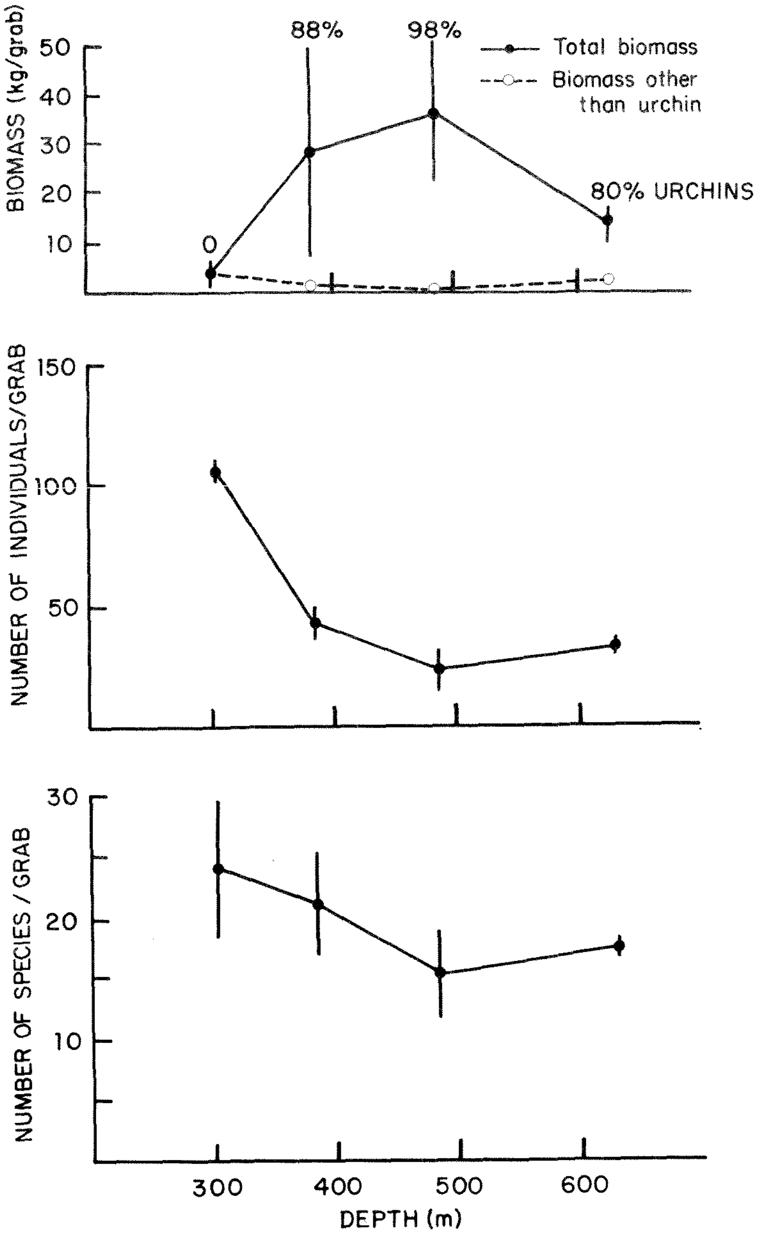


Figure 2.13(a) Depth-Related Trends in Benthic Invertebrate Community Parameters

Notes: (a) Percentages shown indicate the fraction of total biomass which was comprised of urchins.
(b) Figures are the result of Van Veen sediment grabs taken at depths shown along a transect which intersects the expected discharge point.
(c) Vertical bars represent one standard deviation on either side of the mean value (shown as a dot) for parameters indicated. Data were collected within the SCCWRP preliminary site survey.

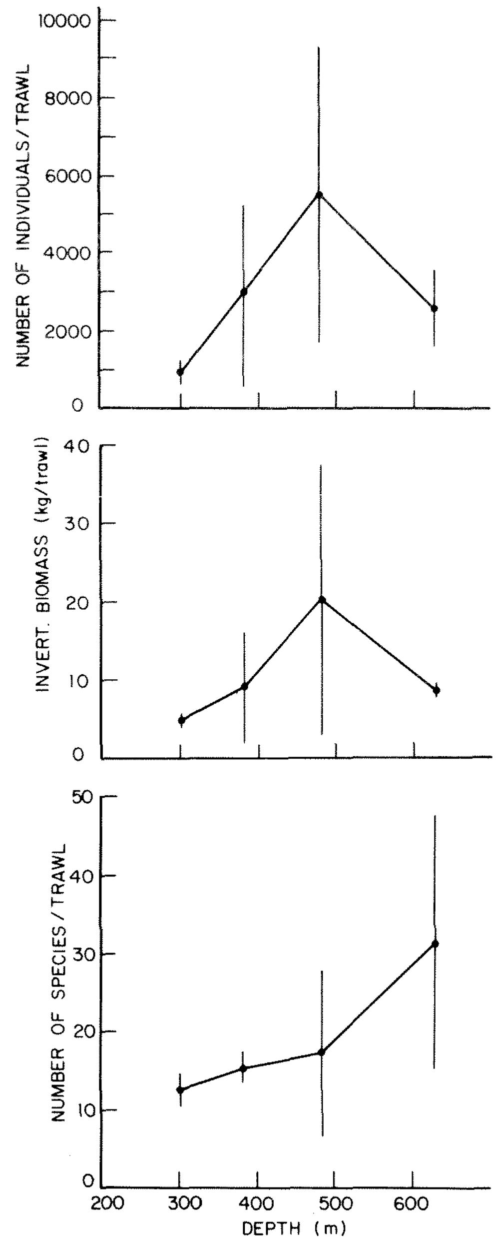


Figure 2.13(b) Depth-Related Trends in Benthic Invertebrate Community Parameters

Notes: (a) Figures are the result of trawl surveys conducted at depths shown along a transect which intersects the expected discharge point. (b) Vertical bars represent one standard deviation on either side of the mean value (shown as a dot) for parameters indicated. Data were collected within the SCCWRP preliminary site survey.

2.4 OCEAN PROCESSES DETERMINING TRANSPORT, FATE AND EFFECTS

2.4.1 The Process-Oriented Approach

In the preceding sections we have described characteristics of the sludge to be discharged and the ocean receiving waters. In this and the following section we describe what we think will happen to the sludge after it is discharged.

Environmental scientists analyze problems like this in terms of processes -- physical, chemical, and biological. Some processes, such as the turbulent mixing in the discharge jet, happen very rapidly and in a small space (in just a few minutes over a few tens of meters), and others, like bioaccumulation in the food web, may take years and affect many square kilometers. The rough classification of processes according to "near-field" vs. "far-field", and "short-term" vs. "long-term" emphasizes the range of length and time scales to be considered.

To understand the overall effects of sludge discharge in deep-water in any meaningful way, we must distinguish among the various processes at work. Safe, intelligent use of the ocean for waste disposal will ultimately depend upon mathematical characterization of important oceanographic processes in terms of their effects on waste dispersal and assimilation. The research plan is directed, in part, toward that goal.

As used here, the phrase "transport, fates, and effects" is a shorthand reference to such a process-oriented perspective on waste assimilation. Naturally, our discussion will focus on processes relevant to sludge discharge in the ocean. "Transport" includes those phenomena that move suspended or dissolved materials from one place to another; "fates" is the group of processes that convert water constituents from one form to another and/or cause them to be removed from the aquatic system of interest; and "effects" covers all the biological responses (including those involving human health) which are in some way related to the discharge.

Out of this focus on processes comes the method of analysis called "critical pathways." As the various processes are identified and understood, we can determine which are the most important ones linking a source with an effect -- i.e., the critical pathways. This approach has been used successfully in setting environmental standards for radioactivity, and is now being widely used for other persistent contaminants (e.g., control of PCBs in fish for human consumption).

2.4.2 Description of Potentially Important Oceanographic Processes

This subsection is a qualitative overview of the various processes which may materially affect marine sludge disposal at 300 to 400 m. Although the research plan presented in Chapter 4 consists of 40 separate tasks, it is important to remember that they are all designed either to directly measure environmental impacts in the CSDOC sludge disposal setting or to characterize physical, chemical, and biological processes which bear on these impacts. Figure 2.14 may help in visualizing both the mechanisms described and interrelationships among the processes of interest; however, this figure is not intended to be all-inclusive, nor is it drawn to scale.

(1) Initial dilution is the immediate entrainment of ambient seawater into the turbulent, buoyant jet issuing from the end of the pipe. The process is normally considered complete when the initially buoyant jet either achieves neutral buoyancy and ceases to rise in the water column, as shown in Figure 2.15, or the plume reaches the surface. Plume submergence (trapping below the surface) depends upon ambient density stratification. For the deep-water sludge disposal experiment, the plume would always be trapped because an adequate degree of density stratification persists throughout the year. Both the magnitude of initial dilution and the maximum height of plume rise can be predicted with reasonable accuracy using discharge and receiving water characteristics as inputs to existing mathematical models (Fischer, et al., 1979). At the completion of the initial dilution process, the sludge-seawater mixture is a neutrally buoyant, drifting cloud, hereinafter referred to as a wastefield.

(2) Passive advection due to ocean currents is the primary means by which the wastefield is transported away from the discharge site following initial dilution. The strength and persistence of currents at the maximum height of plume rise will have profound effects on the ultimate fate of sludge and, in turn, on the viability of the proposed disposal scheme.

(3) Lateral spreading and additional wastefield dilution accompany the advection process. Spreading and diffusion of the sludge-seawater cloud is caused by: (a) gravitational effects (the cloud gets thinner as it pushes out horizontally at the level of neutral buoyancy); (b) shear dispersion (the current speed and direction vary with depth, tending to pull the sludge cloud apart); and (c) diffusion due to turbulent eddies. These three effects are not easily separated, but they all contribute to dilution and dispersal of the waste.

(4) Sedimentation of sludge particles occurs simultaneously with passive wastefield advection and lateral spreading. While sedimentation further reduces the wastefield concentration of particle-affiliated contaminants, the process leads to accumulation of those materials among marine sediments. The particles essentially

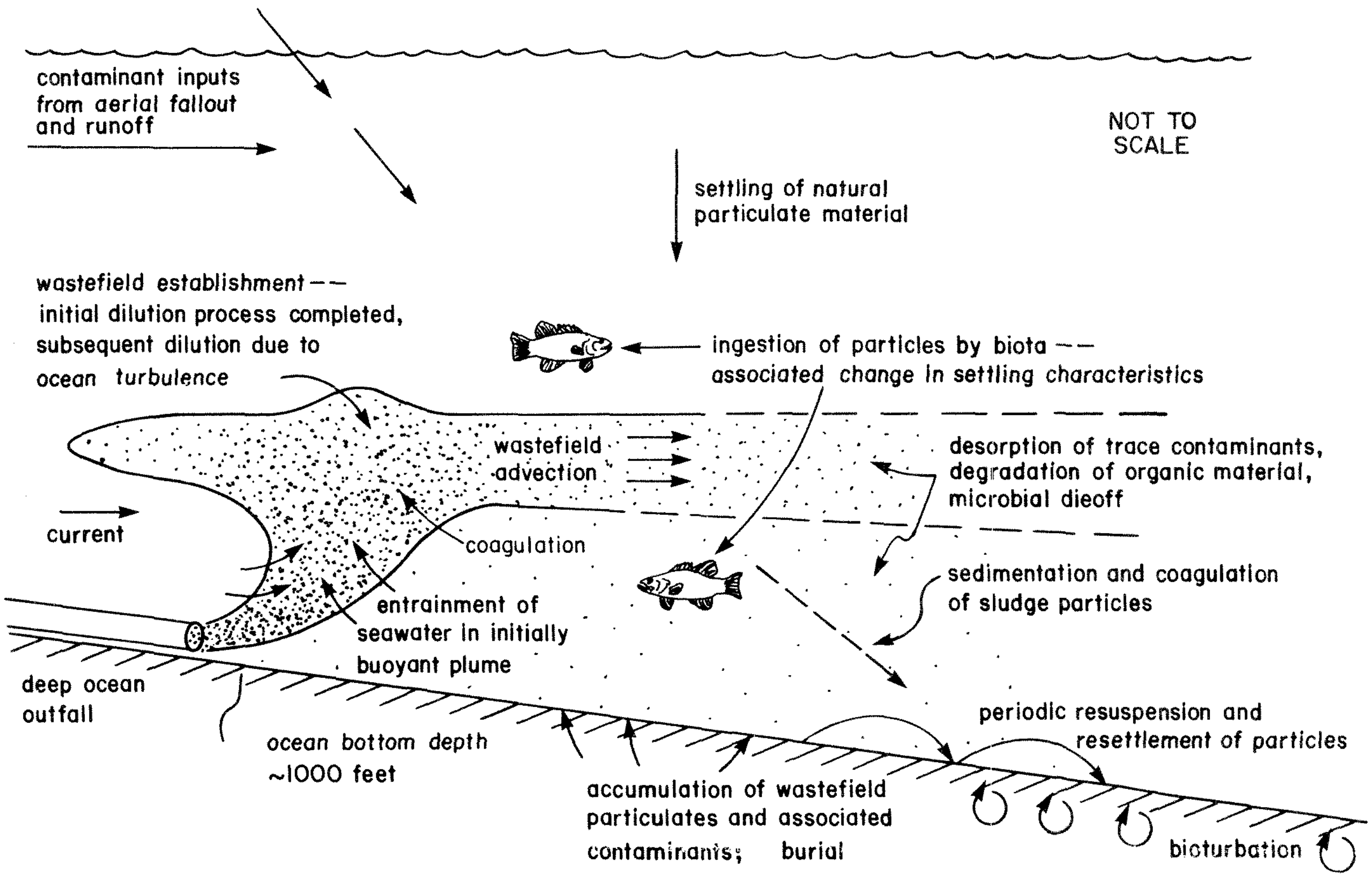


Figure 2.14 Factors affecting particulate fluxes and contaminant fates in marine waters.

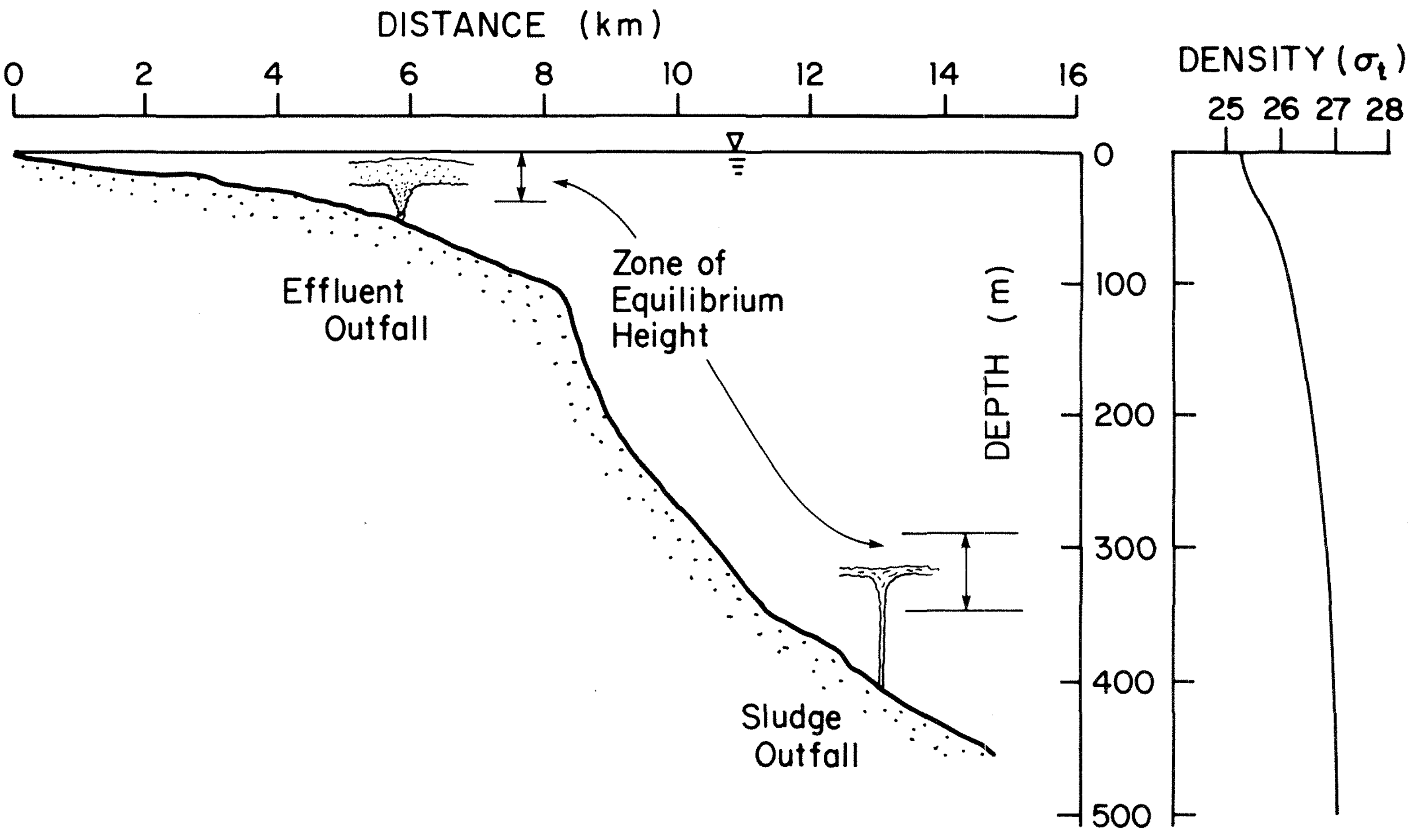


Figure 2.15 Implication of Proposed Discharge Depth on Wastefield Height of Rise and Intrusion of Waste Into Surface Waters -- Contrasting Geometries between Proposed Sludge Outfall and Existing Wastewater Discharges at 60 meters

"rain out" of the dilute wastefield as it drifts downcurrent. Under the conditions envisioned, fifty percent (by weight) of discharged sludge solids will have fall velocities of less than 10^{-3} cm/sec (<1 m/day). Therefore, it is likely that the process occurs over a long period, during which particles may be transported tens of kilometers. Although sludge particle sedimentation is expected over a large area, sediment accumulation rates will be low outside a small region near the outfall terminus (perhaps within one kilometer) where the small percentage of relatively large, fast-settling particles (>10^{-1} cm/sec or 100 m/day) will collect.

Any particles or oil droplets lighter than seawater will of course rise toward the surface. There is a small fraction of such material in sludge (as yet not determined), but efforts will be made in the treatment plants to eliminate floatable material to the maximum extent possible.

(5) Coagulation (or flocculation) of sludge particles (or sludge with natural marine particles) is a process whereby small particles coalesce into larger, faster settling solids. Coagulation is poorly understood in the ocean, but shear currents and small-scale turbulence enhance the process, whereas high dilution impedes it (because of lower particle concentration and less frequent collisions). The increased ionic strength resulting from the dilution of sludge with seawater probably favors coagulation and accelerates particle sedimentation.

(6) Microbial dieoff (or disappearance) occurs in marine waters due to the combined effects of sedimentation, wastefield dispersion, and bacterial or viral mortality (the sea is a hostile environment to many microorganisms). Because the proposed discharge site is about 12 km offshore and the plume will not immediately impact the surface, there is almost no credible avenue by which pathogens can reach shore, except by gradual upwelling and mixing over periods of days or weeks. During such a period, pathogen concentrations would be reduced to very low levels. Microorganisms attached to particles will be co-transported--gradually sinking for the most part; if there is buoyant material in the sludge discharge (e.g., oil and grease), associated pathogens may reach the ocean surface, and then be advected toward shore by wind-driven currents.

(7) Zooplankton feeding on sludge particles at depth may impact the plankton community or associated food chain in ways which are as yet unidentified. Zooplankton feeding may also accelerate the deposition of sludge constituents by "packaging" them in rapidly settling fecal pellets. The resultant sedimentation pattern for these constituents would be smaller in area, but peak fluxes of particulates and outfall-related contaminants would be higher.

(8) Bacterial degradation of particles and dissolved organics of sludge origin will consume dissolved oxygen in the water column. If currents carry sludge into the deeper basins, particles may have to

settle several hundred meters in order to reach the bottom. During this long settling period, a significant fraction of the particulate organic carbon discharged may be oxidized to carbon dioxide with attendant oxygen consumption (Jackson, 1982).

Oxygen consumption kinetics at the relatively cold temperatures (<10^{o}C) typical of the proposed discharge depth are not yet characterized. Laboratory tests will yield data needed to develop water column dissolved oxygen predictions. The proposed discharge depth (300 to 400 meters) represents a compromise. Based on previous analyses (Jackson, 1982), this is the deepest water in which ambient dissolved oxygen levels assure satisfaction of discharge-related oxygen demand without risking unacceptably low water column oxygen concentrations.

(9) Mobilization of trace contaminants from sludge particles into the water column will probably result from dilution of sludge with seawater. The oxidation of some environmentally significant trace metals (present in anoxic sludge in their reduced forms) favors dissolution of insoluble metal-sulfide and metal-hydroxide compounds with release of metals into the water column. Desorption and mobilization of metals and refractory organics are also promoted by waste dilution and breakdown of particulate organics. Although this sounds ominous, the net environmental effect of contaminant mobilization may be positive. Expected fluxes of various trace contaminants in CSDOC sludge would be modest (see Table 2.2 (b)), and mobilized metals, etc., could be transferred from the Southern California Bight to the open ocean before unacceptable concentrations develop among local waters or sediments. That is, mobilization of trace contaminants into the water column reduces the rate at which these materials accumulate among local sediments.

(10) Sediment resuspension and bioturbation also play important roles as determinants of sediment character in the vicinity of the discharge. Bottom currents at the discharge site will periodically reach speeds capable of resuspending surface sediments. Such events will tend to destroy the chronology of sediment deposition (by winnowing away or redepositing lighter material on the top), oxygenate surface sediments, deplete bottom-water dissolved oxygen levels and gradually transport sludge materials away from the discharge point toward deeper sediments. Bioturbation by burrowing animals reduces the degree of vertical stratification among sediments and permits sediment oxygenation and other exchanges with the water column by increasing sediment porosity. Together, resuspension and bioturbation may greatly accelerate the release of contaminants from the sediments to overlying waters.

(11) The benthic community structure changes in response to sludge-enriched substrate, favoring a few species at the expense of less pollution-tolerant organisms. Echinoderms and crustaceans are expected to be negatively affected in the vicinity of the outfall terminus. Total biomass may be enhanced significantly

and species diversity reduced over a considerable area. Local patches of surface anoxia may develop in the most highly impacted areas if the transport of oxygen from the overlying water to the sediment surface is insufficient for the requirements of aerobic respiration. Under such circumstances, hydrogen sulfide (toxic to most marine species) may be generated.

(12) Sludge constituents may be a source of chronic toxic effects among populations of organisms which live or feed on the bottom near the discharge site. Signs of chronic toxicity which have been attributed to existing southern California marine outfalls in the past include the incidence of fin erosion and liver enlargement among fish. Acute toxic effects are not expected because of high dilution and wide dispersal of sludge solids.

(13) Although bioaccumulation of specific trace contaminants (e.g., DDT and PCBs) is anticipated among marine organisms exposed to sludge contaminants, the relatively low levels of critical contaminants in CSDOC sludge are not expected to result in unacceptable fish tissue concentrations (in excess of FDA limits, State standards, etc.). Neither will there be adverse ecological effects due to biomagnification in the marine food chain. DDT emissions from the Whites Point outfall system, which endangered local pelican populations a decade ago (prior to elimination of the industrial inputs to the sewer system), were about 6000 times greater than the anticipated mass emission rates from the proposed sludge outfall (Goldberg, 1979, and Table 2.2(b)).

The physical, chemical, and biological processes enumerated above are interconnected in terms of their relevance to marine disposal and waste assimilation issues. Some of them will prove to be unimportant as determinants of contaminant fates and effects in the context of this study. The research proposed in Chapters 3 and 4 will improve our understanding of important natural marine processes so that intelligent decisions can be made in other ocean waste disposal settings, as well as off Orange County.

2.5 ANTICIPATED EFFECTS OF PROPOSED SLUDGE DISCHARGE

With the qualitative discussion of fates and effects (Section 2.4) as background, we can provide a quantitative description of environmental conditions following initiation of the proposed sludge discharge. In this section, we will emphasize near-field mixing behavior, which at this point is more predictable than other aspects of pollutant transport, fates, and effects. Since we do not have the data necessary (currents and fall velocities) to make far-field predictions, our discussion of the far-field is limited to the results of order-of-magnitude calculations.

Figure 2.2 indicates a candidate alignment for the proposed deep-water sludge outfall. It terminates at a depth of 400 m, and will probably consist of a single open-ended pipe of interior diameter 18 or 24 inches. The flow rate of sludge will be 3 mgd (million gallons per day) containing a mixture of digested primary sludge (0.8 mgd); unthickened, undigested waste activated sludge (2.2 mgd); and a small amount of digested trickling filter humus (0.02 mgd). Treated wastewater may be mixed with the sludge to maintain flow velocity and prevent solids deposition in the outfall.

The bulk density of the mixture will be slightly greater than that of fresh water, perhaps 1.005 to 1.01 gm/cc. Nonetheless, it will rise in the midst of the denser seawater at the discharge depth as a buoyant plume. Due to ambient density stratification (see Figure 2.11), the plume will stop rising after reaching its neutral buoyancy level, as illustrated in Figure 2.15. Because of ambient density stratification, the dilute sludge cloud will always be trapped in deep water, never intruding into shelf waters (less than 100 meters deep and within 8 km of shore). The location of the CSDOC wastewater outfall terminus and its rising plume are also shown in Figure 2.15 for purpose of comparison; the wastewater plume remains submerged, again due to density stratification, except during occasional periods in winter.

Calculations using the measured density profile, projected sludge characteristics, and assumed range of predilution (mixing sludge with secondary effluent) indicate that under weak current conditions the plume will rise to a height on the order of 100 meters above the discharge point. The dilution at that point would be on the order of 500:1. When there is a current, the equilibrium height of rise would be smaller and the dilution larger. Over longer periods (it takes only a few minutes for the plume to rise to its equilibrium height), it seems evident that the diluted sludge will spread into the receiving water column over a range of depths due to varying currents. In the expected range of current speeds (see Figure 2.12), the height of plume rise will vary from about 40 meters (relatively strong current, no predilution) to 110 meters (no current, one-to-one predilution with secondary effluent). The dilution of the discharge jet with seawater is found to be relatively insensitive to the degree of predilution.

Assuming a one-to-one predilution, the diluted sludge is expected to rise in the receiving water to between 50 and 110 meters above the discharge point or, equivalently, to depths of 350 to 290 m (for discharge at 400 m). Seawater dilution of the already prediluted sludge would vary between 450 and 750. If we take a value of 600 and assume that secondary effluent has negligible BOD while the sludge has a five-day BOD of 1700 mg/l, then the BOD in the layer due to the sludge discharge would be 1.4 mg/l ($\sim$1 ml/l). Total oxygen consumption given unlimited time might be 50 percent greater, or 2.1 mg/l (1.5 ml/l). As indicated in Figure 2.11, the dissolved oxygen content at those depths is of the same approximate magnitude, indicating that local impacts might be significant. Other sludge constituents will also be reduced by a factor of 2x600=1200; for example, suspended solids will be reduced from about 12,000 to 10 mg/l, a value which is probably several times background.

Following plume rise, further mixing occurs as the plume drifts with the current. We expect the motion to be largely horizontal, and parallel to local bottom contours. Turbulent diffusion at those depths is likely to be slower than near the surface. If we assume that the horizontal diffusion coefficient at depth is 10 percent of surface values, then, using results from Brooks (1960), turbulent mixing will provide additional dilution by a factor of two or three within 12 hours, and a corresponding further reduction of BOD to 0.5 to 0.7 mg/l.

Jackson, et al. (1979) estimated sludge degradation rates under these temperature conditions as 1 percent per day. If the ambient **oxygen** concentration is 0.5 ml/l, total BOD is 1.5 ml/l, and no mixing occurs subsequent to initial dilution, biological degradation would halve the oxygen concentration of the sludge-seawater mixture in 18 days. Particle removal by settling and mixing processes will decrease this impact on oxygen concentrations.

Based on these calculations, it seems possible that the naturally low ambient dissolved oxygen concentrations will be slightly depressed locally in the diluted sludge field near the discharge point. However, the sludge discharge system will be specifically designed to prevent significant oxygen depletion by various methods during the design phase as more predischarge oceanographic information becomes available. Among the methods of controlling DO depletion are: (1) the BOD mass emission rate can be reduced by digesting the waste-activated sludge component; (2) the outfall depth can be reduced to get the plume into water with more dissolved oxygen; and (3) larger predilutions of sludge with effluent can be employed.

The areal extent of discharge-related impacts among local benthos will depend on many factors, only some of which are now understood. At present, we can state that sludge particles will be widely dispersed in the environment. The bulk of this material may be dispersed throughout the Southern California Bight since typical particle fall velocities are of the order of 1 meter per day, while characteristic rates of net horizontal advection at the plume height-of-rise are about 7 km per day. Hence benthic impacts are expected to be minor except in a relatively small region near the discharge point. However, we do not have enough information to make quantitative predictions regarding changes in sediments due to sludge particle deposition.

In summary, we can estimate reasonably the short-term fate of sludge near the discharge point. Our capacity for long-term estimation of fates and effects is much poorer and will benefit greatly from information generated within the accompanying research plan.

CHAPTER 3

OVERVIEW OF THE RESEARCH PLAN

3.1 GOALS OF THE RESEARCH PROJECT

The motivation for discharging sludge at an ocean depth three-to-four times deeper than any previous project is to place this material in a location which is farther removed from biologically productive waters and more isolated from human interaction. The proposed location at 300 to 400 meters depth presents possible risks because biota there are less understood than those near the surface and because the low ambient oxygen concentration at that depth ($\sim$1 mg/l) could make the high BOD of the sludge (1700 mg/l, 5-day demand at 20^{o}C) more disruptive there than near the surface.

The research project should be designed to clarify aspects of the behavior and effects of the deep sludge discharge and to provide information to make future decisions regarding sludge discharge to the ocean. The specific goals are:

1. To characterize the physical, chemical, and biological properties of the sludge.

2. To recommend:

   - depth and location of the end of the sludge outfall;
   - in-plant processing of sludge before discharge; and
   - possible modifications in pretreatment (or source control) programs for trace contaminants.

3. To make pre-discharge predictions of sludge-induced environmental impacts. These would include changes in water-column oxygen concentrations and benthic sedimentation rates.

4. To observe changes in water column and benthic communities and measure the distribution of important chemicals in the water, in the sediment, and in organisms.

5. To find what human health risks (if any) are associated with deepwater sludge discharge, either directly through human contact with seawater or indirectly through consumption of seafood.

6. To determine the mechanisms by which ecological and chemical changes occur.

7. To assess the predictability of the effects of deep sludge

discharge by comparison of model predictions with monitoring data. Effects to be determined from the monitoring program include sedimentation patterns, alteration of biota, and changes in water and sediment chemistry. It is pertinent to ask how well the fate of discharged materials can be accounted for in mass-balance analyses.

8. To summarize and recommend methodology for designing systems for sludge discharge into the ocean and predicting the effects.

9. To summarize the effects of the Orange County sludge discharge, and evaluate their significance with respect to marine resources.

3.2 RESEARCH PLAN HIGHLIGHTS

3.2.1. Task Groups

With the overall goals described above in mind, we have developed a research plan of 41 tasks arranged in nine groups according to the general objectives. The detailed enumeration and descriptions of tasks are presented in Chapter 4. The research plan has been developed on the basis of the work to be done without regard to which organization would be performing which tasks (for further discussion of administration, see Chapter 5).

The major task groups, which are interrelated as shown in Figure 3.1, are briefly summarized below:

Task Group 1. Survey for Discharge-Related Effects (9 Tasks)

Comparison of important water quality and benthic parameters measured near the outfall and at control stations, both before and after discharge starts, is the basic method for detecting and documenting the effects of the discharge. With this monitoring data, predictive models can be calibrated and improved. Predischarge monitoring data also contribute to the design of the sludge discharge system. In terms of total effort and cost, this group will be by far the largest.

Task Group 2. Site Characteristics (3 Tasks)

In addition to the usual water quality monitoring data, a predischarge survey of bathymetry and currents is necessary for siting the outfall and the network of sampling stations and for interpreting and modelling the observed discharge-related effects (Task Group 1).

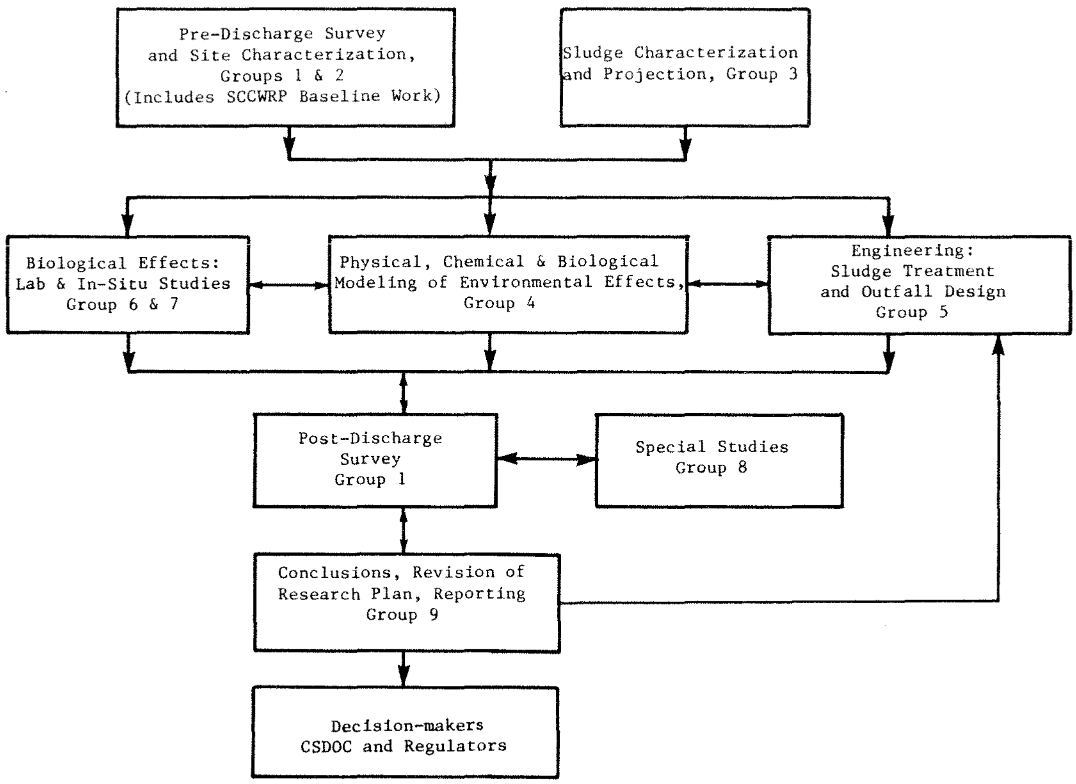


Figure 3.1 Relationships among Generalized Tasks Comprising the Overall Sludge Disposal Experiment.

Task Group 3. Sludge Characterization (4 Tasks)

To understand the transport, fates, and effects in the ocean we must know the quantity and quality of sludge being discharged; the settling (or flotation) behavior of the particles in seawater; the degradation of the particles during their slow descent; and release of trace contaminants within the water column. The properties of the sludge may change with time due to population and industrial growth, pretreatment or source control measures, and improvements in treatment processes.

Task Group 4. Modeling (5 Tasks)

The behavior of the waste stream in the ocean is predicted by a series of conceptual and computer models; each model focuses on particular processes and scales. For example, the initial dilution model covers only the first few minutes following discharge, during which the buoyant plume rises from the end of the outfall, producing initial dilutions of several hundred to one; on the other hand, particle deposition models attempt to describe a process that probably takes months. Such models form a basis for predicting effects, not only for this project but also for future projects.

Task Group 5. Preliminary Design (2 Tasks)

Before the demonstration experiment can proceed, decisions must be made regarding treatment of the sludge and the location and terminal depth of the outfall. These choices involve treatment and pipeline technology and costs, as well as water-quality effects predicted with the models and pre-discharge surveys. Preliminary modeling (Jackson, et al., 1979) favors discharge at approximately 300-400 m depth through an 18 to 24-inch diameter pipe.

Task Group 6. Biological Impacts -- Laboratory Studies (4 Tasks)

Because routine field surveys are not sufficient to understand biological processes, specific laboratory experiments are necessary to investigate biologically-mediated pollutant transformations and biological sensitivities to pollutants. Results of such experiments yield important parameters which are needed for developing good predictive models for sludge effects.

Task Group 7. Biological Impacts -- In-Situ Studies (5 Tasks)

The purpose of field experiments is similar to that for Task Group 6, but there are some experiments which simply cannot be done outside the natural system (e.g., benthic oxygen consumption). Because of the large depths involved, in-situ experiments are difficult and costly, and can be pursued in the latter part of the research program as required, funds permitting. In the next few years, there may also be significant advances in experimental techniques and equipment.

Task Group 8. Special Studies (4 Tasks)

This group includes special studies and unanticipated tasks which do not fit in other categories. Tracer studies and extrapolation from the Hyperion sludge outfall experience at 100 m depth are examples. Very near to the outfall discharge (within about 200 m) the similarity with the Hyperion discharge will be closest, and the Hyperion experience provides a valuable qualitative insight into the sedimentation of the larger particles and the resuspension and flushing process.

Task Group 9. Integration, Analysis, and Interpretation (5 Tasks)

The results of individual tasks and task groups do not stand alone, but must be woven into an overall picture to fulfill the goals of the project and summarize the results. This group of tasks includes cross-disciplinary interpretation of modelling data, comparison of model predictions with data, and revision of the research plan. Summaries and recommendations will be prepared annually to assist the regulatory agencies and Orange County Sanitation Districts in making decisions about continuation of the sludge discharge.

3.2.2. Strategy and Priorities.

The various tasks have to be done in a logical sequence, and will have different priorities at different times. After the project is approved by Congress and/or the cognizant regulatory agencies, we estimate a seven-year duration for this research program including 2 years of pre-discharge work, and 5 years after the start of discharge. Some work is now being done and will continue on an ad hoc basis pending project approval.

Estimates of cost by task group and year are given in Chapter 5 (Table 5.1). The total cost is estimated at approximately $1.5 to 2 million per year for seven years (in 1982 dollars). Not all of this expense is incremental because some activities (e.g., sludge characterization) have to be done anyway. It is absolutely essential to emphasize that these costs are not based on actual proposals or task-by-task estimates, but represent only educated guesses to assist the funding agencies. Furthermore, as the project progresses there may be very substantial additions and/or deletions of research tasks or changes in priorities, depending on results obtained in earlier research.

CHAPTER 4

DESCRIPTION OF RESEARCH AND MONITORING PROGRAM

INTRODUCTION

The individual research tasks, presented in this chapter, are divided into nine broad categories or areas of effort as explained in Chapter 3. These are functionally related as indicated in Figure 3.1. Elements from several of these areas might be focused on specific environmental questions such as biological impacts attributable to oxygen depletion in the vicinity of the proposed discharge.

It is not possible to specify each task with the same degree of detail. Where monitoring or modeling techniques are well established, a relatively complete task description is provided. On the other hand, in a few cases we are able to specify only a research objective and suggest means for its pursuit. Research tasks which are in advance of existing experimental or analytical procedures are included only if they serve project goals and have a reasonable probability of being successfully carried out.

In arriving at these individual tasks, emphasis was placed on those areas in which discharge-related effects are more likely to be detected. During the course of the study, investigators should recommend changes in the program whenever: (1) measurements specified in the research plan offer no further utility for understanding environmental impacts or verifying model predictions; or (2) monitoring stations are found to be incorrectly located, or sampling frequency is improper.

All the individual tasks are listed in Table 4.1.

Table 4.1

List of Research Tasks

Table 4.1 (continued)

Task No.	Title	Page No.
Group 5	PRELIMINARY DESIGN	77
5.1	Evaluation of In-plant Design Alternatives	77
5.2	Selection of Discharge Site and Submarine Pipeline Technology	78
Group 6	BIOLOGICAL IMPACTS -- LABORATORY STUDIES	79
6.1	Effect of Sludge Particles and Organics on Zooplankton Feeding	79
6.2	Dependence of Zooplankton Respiration on Ambient O_2 Concentration	80
6.3	Microbial Decomposition of Water Column Organics	80
6.4	Sea Urchin Toxicology -- Lab Study	81
Group 7	BIOLOGICAL IMPACTS -- <u>IN SITU</u> STUDIES	82
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7.2	Rates of Particle Ingestion by Macrobenthos	83
7.3	Effect of Sludge Particulates on the Feeding Habits of Marine Fauna-- Baited Camera Experiments	83
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Group 8	SPECIAL STUDIES	85
8.1	Identification of Sludge Tracers	85
8.2	Remote Tracking of Wastefield	86
8.3	Extrapolation from Hyperion Sludge Disposal Experience	87
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Group 9	INTEGRATION, ANALYSIS AND INTERPRETATION	89
9.1	Analysis and Interpretation of Survey Data	89
9.2	Comparison of Model Predictions with Observations	90
9.3	Effects of Organic Enrichment on the Dynamics of Midwater plankton Communities	91
9.4	Revision of the Research Plan	91
9.5	Annual Summaries of Project Results, Conclusions and Recommendations	92

Task Group 1 SURVEY FOR DISCHARGE-RELATED EFFECTS

The heart of the sludge disposal experiment lies in comparison of pre- and post-discharge oceanographic survey data as an indicator of environmental impacts. In addition, baseline (pre-discharge) monitoring data will be used to develop rational environmental models, without which generalization of observations would be very difficult, and post-discharge data will permit model verification.

Some of the baseline work listed herein is already underway, chiefly due to efforts of the Southern California Coastal Water Research Project (SCCWRP). A description of the SCCWRP predischarge sampling program is provided as Appendix A. To maintain program continuity, uniform sampling and analytical techniques will be employed whenever practicable throughout the monitoring programs specified in this section. Surface waters should be examined for sludge particles, oil and grease, and coliforms. Sampling stations will be selected to ensure that survey results generated during the course of the experiment satisfy program objectives at minimum cost. Post-discharge data will include measurements within suitable control areas.

The California Cooperative Oceanic Fisheries Investigation (CalCOFI) has an extensive record of hydrographic and biological properties in southern California waters. There are plans to change the CalCOFI sampling program, increasing the frequency and intensity of measurements and reducing the number of grid points. CalCOFI monitoring and this program should be coordinated with respect to sampling times, stations, and methods of analysis. Such cooperation may assist in estimation of any sludge-related, far-field effects within the water column.

Task 1.1 Measurement of Water Quality Characteristics

Purpose: To measure receiving water quality before and after the initiation of sludge discharge. For convenience, water quality measurements are considered either "routine" or "non-routine". The former category is comprised of general parameters influencing nutrient and dissolved oxygen status of the water column (e.g., nutrients, temperature, DO, etc.). The latter consists of trace contaminant concentrations potentially influencing ecosystem and human health (e.g., selected trace elements, chlorinated hydrocarbons, etc.). Pre-discharge measurement of these parameters in the study and control areas will permit evaluation of baseline conditions and seasonal variations in DO status, nutrient-influenced productivity, and trace-contaminant concentrations. Post-discharge water-column measurements seek to identify discharge-related impacts on DO, nutrient enrichment, and trace contaminant availability. In addition, mathematical techniques for estimating wastefield dilution and dissolved oxygen concentration rely upon data related to several receiving water quality parameters. A special measurement program will acquire data needed to verify initial dilution and water column dissolved oxygen models. (See Task 9.2.)

Because water column oxygen depletion or eutrophication may accompany marine sludge disposal, receiving water oxygen concentrations will be monitored carefully throughout the study. Although some oxygen depression may not be harmful to marine life, water column monitoring will provide a prompt warning should waters in the vicinity of the discharge threaten to become anaerobic (which is considered unlikely).

Description: Routine water-column measurements will be made quarterly over at least a two-year pre-discharge period. To the extent possible, cruises should be coordinated with those of the CalCOFI program. During periods of outfall operation, water-column parameters are to be monitored seasonally. Pre- and post-discharge measurements will provide bottom-to-surface profiles of salinity, temperature, DO, and indicators of water clarity (e.g., turbidity). Parameters to be measured in near-bottom waters, 50 meters and 100 meters above the bottom, and above and below the thermocline include dissolved organic nitrogen, particulate organic nitrogen, dissolved organic carbon, particulate organic carbon, nitrate, nitrite, total ammonia, total phosphorus, soluble reactive phosphorus, soluble reactive silica, total and fecal coliforms, and pH. Surface waters should be examined for sludge particles, oil and grease, and coliforms. Sampling stations will be selected to cover the full extent of sludge-related water quality impacts anticipated on the basis of water quality modeling results. Appropriate control stations will also be selected, although station positions cannot be recommended at this time.

Based on water quality monitoring experience in other marine disposal settings, the station grid will extend perhaps 25 km in the westerly (downcurrent) direction and 15 km eastward from the discharge point. It is anticipated that post-discharge water column stations will outnumber those in the pre-discharge monitoring grid.

Water quality data should be analyzed for evidence of intrusion of sludge constituents into local surface waters. Aerial surveys for chlorophyll among surface waters should be considered in this regard.

Non-routine measurements of selected trace metals and trace organics should be made two (2) times per year (∿March and September) over a reduced sampling grid consisting of perhaps six stations. Samples should be taken from the depths described above.

Prevention of sampling error and post-sampling contamination will be critical in this program. Analytical techniques must be state-of-the-art to provide needed sensitivity, accuracy, and precision. An appropriate quality assurance plan will be adopted.

Samples will be taken at two sites (study area and control) in each season at prescribed water-column depths to determine the distribution of trace metals and organics between particulate and dissolved phases. These measurements will permit determination of biotic exposures, loss terms, and transport characteristics. Trace metals and organics to be considered will include at least those listed in Table 4.2. Additional measurements may be required on the basis of sludge analyses for priority pollutants and pesticides. As in other areas of the research program, elements of the water column monitoring effort may be dropped if it is evident that they are not necessary to protect marine biota or assess compliance with applicable water quality criteria.

TABLE 4.2

Trace Constituents

Group I: Trace Elements		Group II: Trace Organics
Arsenic	(As)	PCBs
Cadmium	(Cd)	t-DDT (and derivatives)
Chromium	(Cr)	BHC
Copper	(Cu)	
Iron	(Fe)	Toxaphene
Lead	(Pb)	Hexachlorobenzene
Manganese	(Mn)	Chlorinated benzenes
Mercury	(Hg)	
Nickel	(Ni)	
Silver	(Ag)	
Tin	(Sn)	
Zinc	(Zn)	

Trace contaminants listed will form the basis of routine chemical measurements in CSDOC sludge, receiving waters, and sediments. They are included by reference at numerous points in the accompanying text. Additional analyses may be required based on measurements of priority pollutant concentrations in CSDOC sludges.

Task 1.2 Water Column Biological Monitoring

Purpose: To establish levels of discharge-related impact among local communities of zooplankton and pelagic fish.

Description: Routine midwater biological monitoring will consist of zooplankton capture and hook-and-line fishing programs. Plankton will be taken at two depths -- near-bottom and 50 meters above the bottom -- at each of four stations. Zooplankton biomass will be measured routinely, individuals counted, and samples archived. In a few samples only, animals will be classified to the species level. The catch should always be examined for gross unexpected features or signs of environmental impact. Individuals will be preserved for possible subsequent trace contaminant analyses. All fish taken will be identified, counted, and measured, and stomach contents will be sampled and preserved for subsequent analyses. Pre-discharge zooplankton and hook-and-line surveys will be conducted. Post-discharge monitoring of zooplankton will be semi-annual, and the fishing program will be carried out annually.

The CalCOFI program has produced a 30-year record of zooplankton biomass at midwater depths. Spatial coherence among these data indicates that, in the absence of local perturbations, measurements of zooplankton biomass throughout California Current waters exhibit a uniform pattern of variation. That is, vast areas apparently respond to the same environmental stimuli in the absence of overwhelming local influences. The CalCOFI record may be used to advantage to illustrate the magnitude of natural variation among southern California zooplankton populations. Furthermore, CalCOFI data collected concurrent with water column biological monitoring for sludge-related effects may provide useful control information.

Task 1.3 Inventory of Local Sport and Commercial Fishing Activities

Purpose: To compare pre- and post-discharge fishing success as a measure of environmental impact. Sport and commercial fishing are obvious beneficial uses of shelf waters and must be protected. Comparison of pre- and post-discharge commercial and sport fishing success will provide a reasonable estimate of fishery impacts.

Description: Records of the California Department of Fish and Game will be examined biennially throughout the experiment for significant changes in sport fishing and commercial catches taken near the proposed sludge outfall. Observed variation will be normalized via comparison with catch figures in one or more control areas to separate effects unrelated to sludge discharge.

Task 1.4 Trawl Monitoring Program

Purpose: To establish levels of discharge-related impacts among trawl-caught fish and invertebrates.

Description: The pre-discharge trawl program is to be a one-time effort conducted at two depths (bottom and 50 meters above the bottom -- see Appendix A, Figure A-3 for station locations). After start of discharge, trawl stations will be selected based on the probable extent of sludge-related impacts, direction of bottom contours or prevailing currents, and the positions of pre-discharge trawl stations. In light of associated expense and environmental damage, trawls should be conducted infrequently, perhaps annually, at two depths during each year of post-discharge study. Trawl-caught animals will be identified, counted, measured and weighed. Results will be analyzed to identify, if possible, any outfall-induced changes in fish and invertebrate assemblages. Gut contents of one or two indicator species will be analyzed. Trawl-caught fish will be examined for external signs of diseases such as fin rot, tumors, discoloration, etc. One or more control sites will be sampled at the same time as the discharge area to test hypotheses relative to the source of observed changes.

Levels of trace metals and chlorinated hydrocarbons (Table 4.2) will be analyzed in liver and muscle tissue of three trawl-caught species. If tissue levels prove to be uniformly low, routine monitoring for body burdens of trace contaminants will be discontinued. Liver tissue from the same species will be sectioned and examined for indications of disorder at the cellular level. Investigators will devise a set of qualitative standards based upon experience in other monitoring efforts or early results in this program for use in this regard. An effort should be made to correlate histopathological observations with tissue levels of specific trace contaminants. Tissue preparations will be photographed and photos archived as slides to permit convenient reference and comparison among sequential observations.

To the extent practicable, common trawling equipment, procedures, and analytical measures will be used throughout the program.

Task 1.5 Benthic Surveys

Purpose: To establish the intensity and extent of changes in the local benthic environment attributable to marine sludge disposal practice. Activities described under this task heading are arbitrarily limited to analyses of sediment surface samples and cores measuring physical, chemical, and biological conditions in marine sediments surrounding the outfall site. Post-discharge bottom trawls and near-bottom chemical measurements are described elsewhere (Task 1.4 and 1.1, respectively).

Description: There should be an intensive survey area around the discharge site plus an extensive line of stations along the 350 m isobath, up and down the coastline for perhaps $\pm$ 30 km or more. The stations used by SCCWRP in the initial baseline survey are shown in Appendix A, Figure A-2; to this near-outfall array, it will be necessary to add a line of far-field stations up- and down-coast.

Sediment samples will be obtained using equipment which satisfactorily preserves the order of material taken without losing the lighter sediment at the top of the sample. Physical and chemical measurements will include grain size analyses (at selected stations) and more extensive measurement of volatile solids, total organic carbon, total organic nitrogen, selected hydrocarbons, and selected trace metals per Table 4.2 (indicators of sediment organic enrichment or the presence of sludge-related contaminants). A few (e.g., three) deep cores will be extracted and stored for subsequent age-dating and analysis. The existing community of benthic macroinvertebrates will be characterized via a set of bottom sediment samples. The same set of samples will serve as the basis for chemical measurements. Parameters representative of community structure (e.g., biomass, number of species) will be generated for comparison with subsequent monitoring results.

Pre-discharge sediment redox conditions will be characterized via a one-time sampling program consisting of surface sediment (top 5 cm only) samples and analyses for indictors of sediment DO status. Prior to the introduction of sludge into the area, there is little reason to expect a significant degree of seasonal variation in these parameters, and a baseline program designed to expose natural variation of longer time scale is not feasible. Samples for redox measurements are to be taken from about 12 stations comprising a subset of baseline sediment sampling points. Stations will be sufficiently widespread to provide a broad sampling of locations and natural environmental conditions.

Throughout the discharge period, representative sets of sediment samples (at least the top 5 centimeters) will be taken from potentially impacted sediments at six-month intervals. In addition, a one-or-two-time sampling program may be required to augment routine measurements immediately following discharge initiation, during the period when related changes in sediment quality are expected to change most rapidly. The sampling grid will overlay, to the extent practicable, the pre-discharge grid (Appendix A, Figure A-2) although the number and location of stations will be selected to reflect the full intensity and extent of predicted outfall-related effects. Sediment quality models will be consulted in the selection of stations. Because of the suspected influence of bottom topography on currents, it is anticipated that sampling points will follow bottom contours up- and downcoast from the discharge transect. A trade-off is necessary between extensive spatial mapping with few replicates versus limited spatial coverage with greater sample replication. As in the pre-discharge survey, care will be taken to preserve sediment order and avoid loss of material at the top of the core in all sediment samples. Physical and chemical tests will include, as a minimum, analyses of grain size and measurements of the sediment surface layer volatile solids, total organic carbon, total organic nitrogen, selected hydrocarbons and trace metals. Both sediment particulate material and pore water will be analyzed for trace organics and metals in order to answer remobilization questions. In addition, indicators of DO status measured in the pre-discharge program will again be monitored to characterize post-discharge redox conditions.

Benthic infauna taken in the samples will be identified, counted, and weighed. Results will be analyzed using such parametric indicators as biomass, species diversity, number of species, and other appropriate measures.

Gonadal tissue from prominent urchins taken from both impacted and control areas will be sectioned and examined microscopically for evidence of abnormality at the cellular level. Investigators will devise a qualitative scale with which to evaluate the histopathological well-being of organisms studied in this fashion. In this area, initial monitoring results will be used to devise an appropriate strategy (in terms of geographic extent, frequency, and repetition) for subsequent measurements. Efforts should be undertaken to correlate these results with measured physical and chemical sediment characteristics. Tissue preparations will be photographed and photos archived as slides to permit convenient reference and comparison among sequential observations.

Task 1.6 Age Dating and Chemical Analyses of Sediment Cores by Layers

Purpose: To compare pre- and post-discharge sediment cores as an indication of sludge particle deposition rate and fate. Bioturbation depth may also be determined from profiles of isotope concentrations.

A number of natural processes play potentially important roles in determining the local rate of sediment deposition and degree of stratification within a given sediment core. In addition to the numerous factors affecting sedimentation rates, bottom currents periodically achieve strengths necessary for sediment resuspension. Such events may cause a winnowing of fine or organic particles from the accumulating sediment and upset the chronology of deposits by restratifying particles in a way which favors redeposition of relatively light or fine material at the surface.

Description: Comparison of pre- and post-discharge core characteristics will permit estimation of net solids accumulation rates as a function of position relative to the discharge point. The pre-discharge cores may reveal geological markers beyond the reach of surface sediment disturbances which will prove useful as reference points. In this regard, full advantage will be taken of existing cores and results of previous sediment measurements. A sequence of analyses will shed light on the relative importance of natural processes, such as sediment resuspension, biological mixing, and contaminant mobilization in pore water, as determinants of sediment quality. Sediment quality models can be calibrated on the basis of core data and routine benthic surveys (Task 1.5). Comparison of core data with the CSDOC sludge quality records will provide the basis for mass balances and first-order estimates related to the fates of specific contaminants in the marine environment (see Table 4.2).

Appropriate age-dating techniques (e.g., Pb-210, Cs-137, C-14 concentrations) should be used to date layers in both pre- and post-discharge cores. The post-discharge coring grid will cover the full geographic extent of sludge-related impacts. Changes in sediment quality characteristics will be most apparent in the direction of the prevailing sub-thermocline current at the discharge depth. However, the foci of chemical and biological changes may gradually shift offshore due to sediment resuspension and redeposition.

Box-coring devices will be used to collect sediments for chemical analyses. During the first two years after discharge initiation, cores will be taken annually. Thereafter, a full set of samples need only be taken every three years. The overall program should include a one- or two-time core extraction following significant storms to assess the importance of isolated events as determinants of overall sediment quality characteristics. Selected cores are to be age dated, and all will be analyzed by layers for trace metals and selected hydrocarbons known to be present within the CSDOC sludge (Table 4.2). The output of the sediment analyses should include estimation of sedimentation rate, depth of mixed zone, and profiles of trace contaminant concentrations.

Layer thickness may be varied within the sediment column but should be selected to minimize the number of separate analyses without sacrificing resolution of variation in important parameters. Naturally, intervals should be smallest where the rate of change in contaminant concentration is greatest. It is also anticipated that at some point in the program, analysis of material from below the mixed zone can be discontinued since this material may be considered permanently buried (barring some catastrophic event) and subsequent analyses would provide only duplication of previous findings.

Task 1.7 Measurement of Sedimentation Rate via Sediment Trap Deployment

Purpose: To compare the sludge-related fluxes of organic and inorganic material with background sedimentation rates. Near-bottom sediment traps will provide the means for estimating gross solids accumulation rates. Similarly, trapped material provides a reasonable estimate of the upper limit of deposition rates for oxygen-demanding materials and/or potentially deleterious trace contaminants. Differences between pre- and post-discharge sediment trap data will provide the basis for estimating outfall-related sediment enrichment of these contaminants.

Sediment traps may also support development of dissolved oxygen models for receiving waters and local sediments. Traps deployed within the water column can be used to estimate natural or discharge-related fluxes of oxygen-demanding material as a function of depth.

Description: As part of the pre-discharge monitoring program, midwater sediment traps will be deployed via attachment to current meter moorings. Traps will be placed at 100-meter vertical intervals from 100 meters below the surface to the bottom. The upper traps will measure "natural" particle fluxes while the lower traps will help in determining particle resuspension rates. At each mooring, a trap will be placed in the near-bottom waters to provide an estimate of gross sedimentation rate as a function of position relative to the proposed discharge site. Although there is little reason to expect strong lateral gradients in the pre-discharge distribution of particulate flux, the post-discharge sedimentation pattern should clearly reflect the position of the outfall and local current characteristics. For this reason, the sediment trap program should be enlarged during the post-discharge monitoring period. Because current meters will be removed after local currents have been adequately characterized, deployment of post-discharge traps will require additional moorings. Sampling stations will be oriented about the discharge point to highlight effluent-related variation in sedimentation rate in directions parallel and perpendicular to local bottom contours. Trap contents collected at selected moorings will be analyzed for trace contaminants known to be present in the CSDOC sludge (see Table 4.2).

The continuation of this task will be contingent upon a demonstration that the experimental technique is working properly for this application.

Task 1.8 Bioaccumulation of Trace Contaminants

Purpose: To measure the bioconcentration of trace contaminants (Table 4.2) in the marine food web during pre- and post-discharge periods. Although persistent chemicals represent one of the areas in which a marine sludge disposal is potentially linked to human health, mechanisms for trace contaminant accumulation in marine biota are not well understood. Bioconcentration studies to be carried out in this research are empirical in nature. They are based on measurement of pre-discharge biotic burdens and water/biota partitioning of trace contaminants, prediction of post-discharge burdens based on bioconcentration partitioning theory, and post-discharge biotic measurements to evaluate predictions and assess discharge effects. Predictions based on various discharge scenarios and post-discharge measurements should provide a clear warning if contaminant problems are to occur. The approach taken should provide a framework with which to anticipate food web impacts in other marine disposal settings.

Description: Selected species of dominant phytoplankton (surface waters only), zooplankton, benthic macroinvertebrates and commercial fish will be analyzed for specific trace contaminants present in CSDOC sludge and potentially accumulated in the food web. Historical studies should be considered in designing this program, as well as the several related measurements carried out in the SCCWRP baseline survey (Appendix A). Pre-discharge monitoring will consist of annual measurements to determine biotic burden, and will be tied to water-column analyses for selected trace contaminants (Table 4.2). In this way, bioconcentration factors and ecological magnification can be assessed. Post-discharge sampling will be conducted annually at sites in the study and control areas not yet determined. Based on a review of bioconcentration and magnification literature (including relationships between bioconcentration factor and other measures of trace organic accumulation - i.e., octanol water partition coefficient), contaminant partitioning coefficients and biotic burdens resulting from sludge discharge will be estimated. Post-discharge measurements will be used to verify projections and complete model development.

A review of the literature on bioaccumulation and existing data for the Southern California Bight, coupled with the relatively low fluxes of trace contaminants in this discharge (see Tables 2.2 and 2.3), may indicate that this task should be reduced in scope.

Task 1.9 Designation of Control Sites for Water Column and Sediment Monitoring

Purpose: To select, if possible, one or more control sites for measurement of natural fluctuations in water and sediment quality during the post-discharge period. Identification of a control site is critically important if variation in environmental conditions due to sludge disposal is to be separated from other potential sources of variation in the marine environment. Control sites should be minimally impacted by the sludge discharge and by any other source of pollutants which does not affect the study site in a similar fashion. Furthermore, the physical characteristics of the control site should be essentially identical to the pre-discharge features of the study site. That is, the control location should have similar depth and bottom characteristics (e.g., sandy, silty, etc.), dissolved oxygen profile and other water mass characteristics, prevailing current, and so forth.

Description: The pre-discharge monitoring program will include an abbreviated benthic and water column sampling effort designed to expose the general characteristics of potential control locations. Control areas will be sought primarily in the downcoast (southerly) direction. Areas sampled should be unaffected by other major sources of pollutants such as oil seeps, river or harbor discharges, or marine discharges. The abbreviated sampling program should include such parameters as sediment organic content and biomass and water column profiles of temperature, salinity, density, and dissolved oxygen concentration. Water column monitoring at the control site should be conducted at approximately the same time as the measurement of water-column characteristics at the study site.

Since selection of a true control site may prove difficult, several potential sites should be examined. In this regard, pre-discharge sediment monitoring at the far-field stations described in Task 1.5 may provide helpful data. Furthermore, a control area for water column measurements may be inappropriate as a control for benthic monitoring. Designation of control sites cannot precede at least the initial results of the post-discharge monitoring programs.

Task Group 2 SITE CHARACTERISTICS

Major portions of the pre-discharge survey described in Task Group 1 are devoted to characterization of the proposed sludge discharge site. To avoid duplication, these monitoring efforts are included here only by reference (Tasks 1.1 through 1.8). The only new work described in this section consists of the investigation of ocean currents and bottom conformation in the outfall region. If an adequate record is obtained during the pre-discharge period, additional detailed current measurements may be unnecessary because sludge discharge effects on the current structure will be negligible.

Task 2.1 Measurement of Local Currents

Purpose: To characterize the movement of water masses in the vicinity of the proposed outfall. A comprehensive current monitoring program is recommended to characterize currents in terms of intensity, persistence, and temporal and spatial variation. This information is necessary for modeling the transport and fate of discharged sludge, and interpreting post-discharge monitoring results.

Description: Stations and meter depths described subsequently may be modified by those drafting the final current monitoring program provided such changes are designed to satisfy monitoring objectives at minimum cost. An uninterrupted (so far as practicable) series of current measurements will be obtained at 3, 4, or 5 depths at each of at least four different moorings. See Figure 4.1 for approximate mooring locations. Three moorings should be deployed at the 100-meter, 350-meter, and 500-meter isobaths on a transect which intersects the proposed discharge site. A fourth string of four current meters should be placed approximately 15 km west of the proposed outfall terminus on the 350-meter isobath. Depth permitting, meters should be placed two meters above the bottom, 350-meter depth (500-meter isobath only), 200 meters, 100 meters, and near-surface (about 10 meters below the surface). The shallow (100-meter) mooring will carry only three meters -- surface, mid-depth, and bottom. Proven equipment which is generally accepted within the oceanographic community is to be utilized.

Thermistor chains should be placed on the 350-meter and 500-meter moorings in the main transect, covering the top 200 meters with thermistors at 10 to 15-meter intervals. Sediment traps should also be provided at several depths along each of the moorings (see Task 1.7 for details).

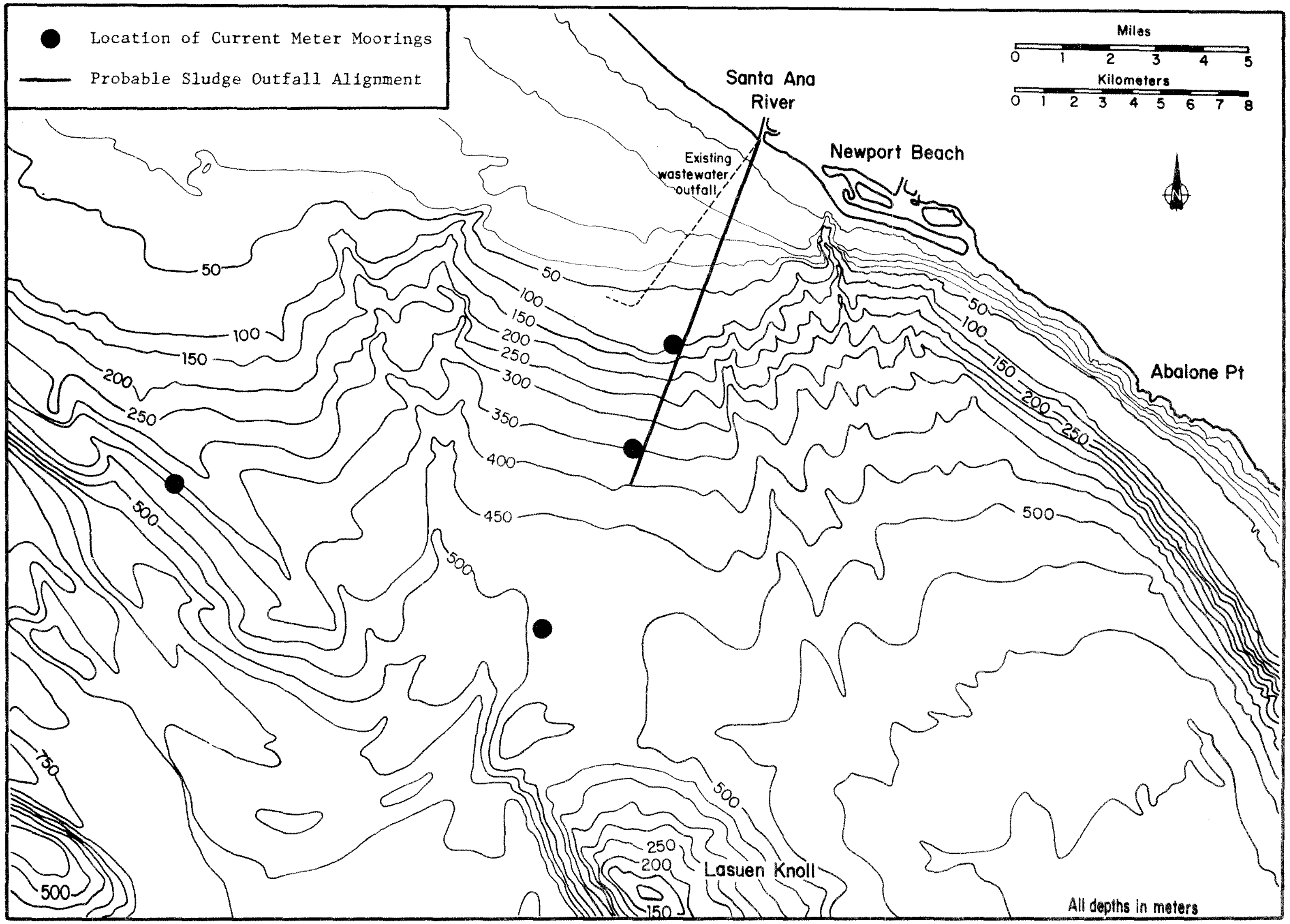

Figure 4.1 Proposed Current Meter Mooring Locations.

Half-hourly (vector) averaged data are to be collected and analyzed statistically for inferred daily excursions, displacements during periods of unidirectional flow, joint distributions of current speeds and directions, vertical isotherm movement, and such other characteristics as may clarify the circulation, advection, and density structure of the water column.

A much less extensive current meter sampling program (e.g., one or two current meters at the discharge site) should be continued throughout the discharge period to characterize long-term variations.

Task 2.2 Hydrographic Surveys for Determination of Geostrophic Currents

Purpose: To calculate the geostrophic currents in a broad region surrounding the discharge site by measurement of water column density transects. Such information will complement the current meter records and assist in estimating the direction and extent of discharge-related, far-field effects within the water column and on the bottom.

Description: The distribution of salinity, temperature, density, and such other properties as may be of interest should be measured along at least three transects perpendicular to the depth contours. Cruises are envisioned to sample water properties from the ocean surface to the bottom. At least three transects are to be located at such positions as

(1) along the proposed outfall alignment out to approximately 40 km offshore,

(2) about 30 km north i.e., approximately off Point Fermin out to the shelf on Santa Catalina Island, and

(3) about 30 km south of the outfall, i.e., approximately off Dana Point.

Each of the transects should be surveyed at least two times per year (March and September). This should be done at least once, and preferably in two successive years to indicate year-to-year variations.

An adequate number of observations should be made to resolve the horizontal and vertical structure of property distributions. The data should be presented in contoured cross-sections. Geostrophic velocities perpendicular to the transects should be calculated relative to the bottom.

In addition, measurements should also be made at several stations located at each of the basin sill areas to facilitate data interpretation.

Task 2.3 Site Bathymetry

Purpose: To establish bathymetric characteristics in the vicinity of the proposed outfall. Accurate bathymetric information is essential to the design of any submarine works. Available bottom soundings may be inaccurate and should be updated using modern survey equipment.

Description: A bathymetric survey will be carried out covering the area surrounding the proposed outfall location. The survey should encompass all the sampling sites in the monitoring effort and extend at least 20 km up- and downcoast from the discharge point and to the middle of the basin in the offshore direction. Equipment chosen will be capable of accurate determination of both depth and horizontal positioning. The survey lines may be set quite far apart initially (e.g., 0.5 km). If results check with existing charts, additional measurements will be unnecessary until design is initiated. If discrepancies are found, however, then additional lines should be surveyed to obtain the correct bathymetry.

Task Group 3 SLUDGE CHARACTERIZATION

Experiments described in this task are designed to characterize sludges from the CSDOC treatment plants in terms of selected, environmentally significant parameters; determine how sewage treatment and industrial waste pretreatment (source control) alternatives might impact those sludge characteristics; and finally, to investigate the behavior of sludge particles and associated trace contaminants when placed into marine waters. Of special interest are the settling properties of sludge particles and the fractionation of trace contaminants such as metals and pesticides between the dissolved and particulate phases. Each subtask is designed to promote a rational understanding of transport and transformation processes (see discussion, Chapter 2) which actively determine the fates of pollutants discharged to the marine environment or to provide input data for predictive water and sediment quality models described in Task Group 4. Sludge characteristics are requisite to development and application of such predictive models and to rational analysis of events observed following initiation of sludge discharge.

Task 3.1 Measurement and Projection of Sludge Quality Parameters

Purpose: To characterize CSDOC sludge mass flow and chemistry throughout the life of the experiment. Determination of discharge characteristics is the first step in estimating water quality impacts associated with marine sludge disposal. Historic sludge quality analyses carried out by CSDOC will be considered in specifying additional study. Detailed information, including estimates of central tendency and variation, should be developed for each contaminant of potential environmental or health-related import. Factors affecting sludge quantity and quality projections at Orange County include (a) industrial waste pretreatment regulations on industries tributary to the CSDOC wastewater treatment system; (b) planned growth in the Orange County service area including projected industrial growth; (c) wastewater treatment processes; and (d) sludge treatment processes (e.g., digestion, screening). Studies to evaluate (c) and (d) are proposed in Task 3.2.

Description: The results of previous CSDOC sludge quality analyses will first be collected, evaluated, and parameterized. The ongoing, routine analytical program will be scrutinized and augmented as necessary to provide a minimum data base. Whenever possible analyses are to be conducted on sludge samples receiving treatment comparable to that anticipated for sludges destined for marine disposal.

(i) Sludge volume will be measured daily for at least 12 consecutive months. Because sludge production is dependent upon the level of wastewater treatment provided, sludge volume and other measurements described subsequently are strictly valid only under operational conditions similar to those anticipated during the conduct of the sludge disposal experiment. However, when projected operational conditions cannot be created as part of the sludge characterization program, extrapolation from existing quality data will be necessary.

(ii) Sludge concentrations of total and volatile solids, important trace metals, common pesticides and synthetic organics, major anions, chemical oxygen demand, five-day biochemical oxygen demand (BOD), organic nitrogen, ammonia, and pH will be measured in 24-hour composites taken several times per week during the first three to six months of sampling. Thereafter, single 24-hour composites will be taken monthly. Measurements will be made on both particulate and dissolved fractions.

(iii) Initially, monthly grab samples of treated sludge will be analyzed for total and particulate organic carbon and for fatty acids and carbohydrates in dissolved and particulate fractions. The program will be discontinued when observed variation in these parameters is considered well characterized.

(iv) On at least three occasions prior to the initiation of sludge discharge, sludge samples will be analyzed for the complete list of priority pollutants, as designated by current EPA regulation. Analyses should be carried out in both dissolved and particulate fractions.

(v) Appropriate toxicity testing will be carried out on at least two occasions.

(vi) The effect of temperature on BOD kinetics will be investigated by monitoring oxygen demand in seawater-diluted sludge maintained at a series of temperatures ranging from minimum ambient seawater temperature at depth to 20^{o}C. Experimental results should permit development of a functional relationship between the first-order rate constant for BOD exertion and temperature.

In projecting sludge quality characteristics at CSDOC, efforts will be made to (i) extrapolate from past trends, (ii) consider the effect of planned changes in treatment levels or operational procedures anticipated at CSDOC wastewater treatment plants, and (iii) estimate the impact of EPA industrial waste pretreatment regulations and/or industrial growth on sludge quality. Reasonable efforts will be made to identify major point sources of priority pollutants tributary to the CSDOC treatment system. The effect of specific discharge prohibitions will be estimated for pollutants felt to play a potentially critical role as determinants of marine environmental health. Despite obvious uncertainties, Orange County sludge quality characteristics should be projected over at least a ten-year period.

Task 3.2 Evaluation of In-Plant Unit Operations Affecting Sludge Characteristics

Purpose: To develop relationships between sludge treatment processes and sludge volume and quality. A number of in-plant sludge treatment operations will be considered including anaerobic digestion, sludge screening to remove the largest particulate fraction, and skimming of quiescent sludge to remove floatables. Exclusion of specific sludge fractions from digestion (e.g., waste activated sludge) or separate disposal of particularly worrisome material (e.g., skimmings from primary clarifiers) is also possible. When practicable, full scale operations should be utilized directly for related studies. If such facilities do not exist or experiments are impractical, bench scale tests may be used to estimate attendant sludge quality improvements.

Description: The effect of anaerobic digestion on sludge characteristics will be investigated directly by comparing the qualities of digested versus undigested waste-activated sludges in full-scale operation. In at least six consecutive months, raw and digested waste activated sludges should be analyzed across a single, representative digester for total suspended solids, trace metals, pesticides, specific anions, five-day BOD, COD, organic nitrogen, and ammonia. Raw sludge samples should consist of flow-weighted, 24-hour composites of digester influent. Digested sludge samples may be flow-weighted composites over any period representative of digester pumping operations. Trace metals and pesticide concentrations will be measured in both the particulate and dissolved fractions of raw and digested sludge samples.

During at least six consecutive months, grab samples of raw and digested sludges are to be analyzed for concentrations of total organic carbon (TOC), particulate organic carbon (POC), fatty acids and carbohydrates. The effect of digestion on critical priority pollutants (those observed in high concentrations during analyses for priority pollutants, per Task 3.1) should also be investigated via analysis of raw and digested sludge grab samples.

Bench scale or pilot studies are recommended for evaluation of sludge screening and skimming benefits. Care should be taken to ensure that studies are representative of full scale capabilities in terms of screen size, period of quiescence for separation of floatables, etc. Screenings and skimmings are to be analyzed directly for total solids, trace metals, pesticides, five-day BOD, TOC, POC, fatty acids and carbohydrates.

Task results will be used in water quality models to generate a rational basis for sludge processing decisions.

Task 3.3 Measurement of Sludge Particle Size Distribution, Settling Characteristics, and Coagulation Effects

Purpose: To determine particle fall velocities in seawater for subsequent use in predictive models and interpretation of post-discharge monitoring results. Most sludge particles are heavier than seawater and will sink slowly back toward the seabed following establishment of a passive wastefield. Consequently, the rate at which waste materials accumulate among local sediments should depend upon (among other things) the settling characteristics of sludge particles following initial dilution with seawater. Since discrete settling velocity is primarily determined by the density difference between a particle and its surroundings (hard to measure) and particle size (relatively easy to measure), experiments should be constructed to determine both settling velocities and particle size distributions following seawater dilutions representative of the initial dilution process. The program should be sufficiently extensive to permit establishment of relationships between particle size distribution and settling velocity and to characterize variation in particle size distribution.

The role of coagulation as a determinant of time-dependent particle size distribution within the established wastefield is not well understood. Introduction of an essentially freshwater waste into a saline environment is expected to destablize particles by at least partially offsetting their mutual repulsion. Thus the marine environment provides circumstances favorable to particle growth and accelerated deposition. Understanding how coagulation affects particle settling will permit more rational estimation of particulate fluxes to local sediments.

Description: Bench-scale column experiments are recommended for establishment of particle settling characteristics and investigation of coagulation effects. Experiments will be run on representative dilutions of sludge samples. Techniques for such experiments have not been thoroughly worked out, and latitude must be afforded the experimenter. Technical difficulties have typically attended attempts to initiate particle settling from a single vertical position in the column, as opposed to starting the sedimentation process within a well-mixed column. Particle size distribution measurements should be conducted within the fluid mixture representing wastefield conditions immediately following completion of the initial dilution process. Because turbulent shear which accompanies sludge discharge and mixing of the initially buoyant jet is expected to enhance coagulation and change the distribution of particle sizes in the passive wastefield, column experiments and particle size measurements will be conducted on samples subjected to rates of shear typically encountered within the initial dilution process. (For description of previous fall velocity studies of digested sludge diluted in seawater, see Faisst (1976).)

Task 3.4 Mobilization of Trace Contaminants within the Water Column

Purpose: To measure the exchanges of various trace contaminants between particulate and dissolved phases when sludge is diluted with seawater. The extent to which decomposition and desorption processes will favor the liberation of sludge-related trace contaminants in the water column is not well understood. The discharge of sludge into the marine environment represents a major discontinuity in redox conditions for particles and associated trace contaminants. The rapid shift from anoxic to oxic conditions may cause an environmentally significant change in equilibria governing the distribution of metals and potentially toxic refractory organics between the dissolved and particulate phases. Previous work indicates that higher oxidation state tends to favor the desorption of several (though not all) trace metals present among sludge particulates. The situation is complicated by the dependence of toxicity (exhibited by some metals) on oxidation state and poorly understood desorption kinetics.

Description: Experiments designed to investigate the mobilization of trace contaminants from discharged sludges will be preceded by a survey of related scientific literature. Reliable analytical results generated elsewhere will be used to limit the scope of original research undertaken within this program. Necessary chemical desorption or adsorption studies will be carried out using well characterized sludges maintained under anoxic conditions until rapidly mixed with seawater in a manner which simulates the initial dilution process. Following dilution the sludge-seawater mixture will be maintained as a well mixed aerobic solution. The distribution of trace contaminants between dissolved and particulate phases will be measured periodically to characterize the extent and time dependence of the desorption reaction (or adsorption, as appropriate). Experiments will also yield estimated degradation rates for specific synthetic organics in the marine environment.

Task Group 4 MODELING

Predictive models are useful tools for understanding processes, mechanisms, pathways, and cause-and-effect relationships in complex phenomena. They often form a basis for integration and synthesis of information from several sources or disciplines. Within the present research plan, mathematical models will be used to

(i) estimate mixing and transport of discharged sludge within receiving water,

(ii) estimate values of water quality indicators such as dissolved oxygen concentration in the water column,

(iii) predict the fallout pattern of sludge particles among local sediments, and

(iv) calculate trace contaminant concentrations and oxygen distribution in the sediment.

The baseline survey and sludge characterization studies will provide input data for model development. Since improvement in existing modeling procedures is expected to be an outgrowth of the overall program, model configurations cannot be fully anticipated at this time. Predictions will be utilized in both outfall design and selection of appropriate sludge treatment operations and industrial waste pretreatment measures.

Task 4.1 Initial Dilution and Height of Plume Rise

Purpose: To calculate the magnitude of initial dilution and height of plume rise during the first few minutes after discharge. Several good models exist for estimating dilution under specified conditions of receiving water density stratification, current strength, outfall configuration, discharge characteristics, etc. Such models also predict the equilibrium height of rise of the wastefield -- the height at which the diluted sludge discharge achieves the same average density as its surroundings. Thus initial dilution models can be used to predict wastefield concentrations of sludge contaminants and locate the wastefield within the water column when initial dilution is complete. Because dilution and equilibrium height of rise depend on several variables within the control of the design engineer, these models should be run to develop a disposal strategy during preliminary outfall design. Model output will be used as initial conditions for other water quality models.

Description: Any one of several models may be used for estimation of initial dilution and equilibrium height of rise. The sensitivity of results should be tested by varying input data (currents, receiving water density stratification, sludge flow) throughout their feasible ranges. Pre-discharge water column measurements (Task 1.1) will provide necessary input data. Care should be taken to identify and model worst case conditions.

Model results are to be combined with projected sludge characteristics to predict wastefield concentrations of specific contaminants. Wastefield concentrations so calculated will serve as the basis for predilution and industrial waste pretreatment recommendations.

Task 4.2 Estimation of Water Column Dissolved Oxygen Concentrations

Purpose: To predict changes in water column dissolved oxygen concentrations for impact assessment and comparison with post-discharge measurements. Since maintenance of receiving water dissolved oxygen levels is biologically important, development of a midwater dissolved oxygen model will receive priority within the project. A successful predictive oxygen model would be of general value for estimating water column dissolved oxygen deficits within other marine waste disposal scenarios. The effects of dissolved oxygen reductions on zooplankton respiration will be investigated separately in Task 6.2.

Description: Development of a midwater dissolved oxygen model of the following form is anticipated:

(i) Model inputs will consist of initial wastefield concentrations of dissolved oxygen and oxygen-demanding materials (outputs from the initial dilution model) in addition to ambient dissolved oxygen concentrations and temperature from predischarge monitoring.

(ii) The model should consider the kinetics of oxygen demand (including temperature effects) and dilution due to turbulent diffusion subsequent to wastefield establishment.

(iii) Model output will include minimum wastefield dissolved oxygen concentration as a function of time following initial dilution (i.e., following a patch of the passive wastefield in the Lagrangian sense). The model should also be run assuming that the discharge has no associated biochemical oxygen demand. Comparison of these cases will permit estimation of oxygen deficit due to the exertion of waste-related oxygen demand, as opposed to plume-induced upwelling of low dissolved oxygen bottom waters.

Task 4.3 Estimation of Particulate and Trace Contaminant Fluxes to Local Sediments

Purpose: To predict the outfall-related pattern of particulate deposition in the vicinity of the proposed sludge discharge. Dissolved oxygen in bottom waters and trace contaminants in sediments depend upon deposition rates of outfall-related particulates. The flux of particulates and associated contaminants to the ocean floor is governed by processes such as sedimentation, diffusion, advection, particle dissolution and aggregation, and contaminant mobilization from particles in the water column.

A series of current measurements can be combined vectorially to simulate the position of advecting water masses as a function of time. This form of analysis is limited geographically by the proximity of current meters and spatial coherence of currents. By repeating the procedure a sufficient number of times, one can estimate the probability of finding a puff of wastewater at any position (x,y) from the discharge point, given that time t has passed since discharge of the puff. Such information can be combined with discharge characteristics, settling velocity data, effects of eddy diffusion, particle decomposition rates, and contaminant remobilization data to estimate average rates of gross particulate and trace contaminant deposition as a function of position relative to the discharge point.

Description: Current meter and settling velocity data will be used to simulate wastefield trajectories. A set of probability density functions representing the probability of sludge particles reaching the sediments at any position (x,y) from the discharge point will be developed from the wastefield trajectories. The number of potentially important phenomena which can be handled rationally within this model is not yet known and will depend upon results generated elsewhere within the sludge outfall study. The model is to consider, as a minimum, the concurrent effects of wastefield advection and particle settling. Should the data base support their mathematical treatment, ocean turbulence, coagulation, decomposition of particulate organics, and desorption of specific contaminants will be included. Model calibration will be based on sediment trap data collected as directed elsewhere in this report (see Task 1.7).

Task 4.4 Sediment Concentrations of Dissolved Oxygen and Sludge-Related Contaminants

Purpose: To develop modeling techniques and predict sediment and pore water concentrations of dissolved oxygen and sludge-related contaminants in the vicinity of the proposed outfall site; and to predict the areal extent of sulfide bearing sediments.

Sulfide generation results from the bacterial oxidation of organics in the absence of molecular oxygen and oxidized nitrogen forms. Oxygen depletion leads to reductions in species diversity and biomass. Only a few specialized benthic organisms persist in the presence of hydrogen sulfide. Development of a sound sediment dissolved oxygen model will also provide an important boundary condition for the water column dissolved oxygen model (see Task 4.2).

Contaminants such as trace metals and synthetic organics are possible sources of biological anomalies in the vicinities of several major marine outfalls in southern California. As such, prediction of sediment concentrations of such materials could improve pre-discharge estimates of environmental impacts in a variety of disposal settings.

Description: Factors to be considered in sediment dissolved oxygen and trace contaminant models include:

(i) the fluxes of oxygen-demanding materials (natural and outfall-related) or trace contaminants (Table 4.1) to local sediments as a function of position from the discharge point (output from Tasks 1.7 and 4.3);

(ii) rates of BOD exertion at the sediment-seawater interface (necessary in DO model only) as a function of benthic biomass, sediment organic content, and dissolved oxygen concentration at the interface (see Task 7.1);

(iii) effects of biological mixing and periodic sediment resuspension on sediment profiles of dissolved oxygen, organics, and Table 4.1 trace contaminants;

(iv) diffusion of molecular oxygen through the oxygen boundary layer and pore water near the sediment surface;

(v) chemical mobilization of trace contaminants from sediments including the effect of redox potential on mobilization; and

(vi) temperature effects.

Several of these processes have resisted rational mathematical representation in the past. Should rational dissolved oxygen models prove ineffective, it may be possible to correlate local surface oxygen deficit with the flux of outfall-related, oxygen demanding material to the sediments. Monitoring results from the City of Los Angeles' Hyperion sludge outfall and the Los Angeles County Sanitation Districts' Whites Point outfall system may be used for this purpose.

Dissolved sulfide concentrations among sediment pore waters will be predicted using a chemical equilibrium model, input data from the monitoring program (Task 1.5), and sediment quality models discussed above. Under reducing conditions, the formation of metal-sulfide precipitates can limit dissolved concentrations. Consequently, iron content will be measured within the sediment quality monitoring program.

Task 4.5 Biological Models.

Purpose: To develop methods for predicting the intensity and geographic extent of sludge-related changes among local biota. Several other important tasks are devoted to characterizing the fauna in the vicinity of the proposed discharge site and developing exposure data (receiving water or sediment concentrations of sludge contaminants) via model application or direct measurement. Task 1.8 may yield relationships between exposures and tissue concentrations of these contaminants. It remains, then, to relate estimates of waste-related exposures, body burdens of contaminants, or dissolved oxygen depression (also calculated -- see Task 4.2) to changes in population characteristics observed within the monitoring program. Models capable of predicting the severity and extent of biological anomalies attributable to a given waste disposal scenario will permit comparison of marine disposal impacts with those of other alternatives (land, air) on a more rational basis. The environmental impacts of other disposal methods should be developed via parallel studies.

Description: Development of rational, predictive biological models is encouraged although techniques cannot be suggested at this time. An effort should be made to understand the methods by which individuals and populations of organisms protect themselves against adverse environmental conditions and the limitations of those mechanisms. Previous biological models have been premised on empirical relationships between waste discharge and/or receiving water characteristics and observed biological anomalies, and additional effort along these lines is encouraged. Post-discharge monitoring should be constructed to yield such relationships.

Task Group 5 PRELIMINARY DESIGN

Characteristics of both the discharged sludge and the initial mixing process in the ocean are within the control of the design engineer. Available alternatives, both in the treatment plant and in the submarine discharge structure, will be examined in terms of their effects on sludge quality, initial mixing, and sludge behavior subsequent to discharge.

Discharge depth is of prime importance in outfall design. Based on previous modeling (Jackson, et al., 1979) the anticipated sludge discharge depth is in the 300-400 m range. At such a depth, the resultant plume will be trapped well below the surface under all oceanographic conditions, and surface water quality will be protected. At the same time, the discharge will be shallow enough to avoid oxygen exhaustion among naturally low DO waters of the deep basins.

Task 5.1 Evaluation of In-Plant Design Alternatives

Purpose: To evaluate various treatment and control processes which affect sludge quality characteristics and recommend measures appropriate to marine sludge discharge. For example, trace contaminant concentrations in sludge can be reduced through discharge prohibitions and pretreatment requirements. The sludge solids content and the concentrations of oil and grease and large solids may be manipulated by controlling materials added to the digester or sludge processing subsequent to digestion. The amount of degradable organic carbon in the discharge is functionally related to digester detention time and fraction of discharged solids which have been anaerobically digested. All of these sludge characteristics carry implications for receiving water quality. A more complete list of treatment and control measures to be evaluated is provided in Task 3.2.

Description: In this task, we will estimate sludge quantity and quality characteristics resulting from several feasible wastewater treatment and industrial waste pretreatment combinations. Planned secondary treatment facilities within the CSDOC sewerage system will be considered as well as sludge quality improvements attributable to treatment operations such as anaerobic digestion, sludge screening, skimming, etc. These evaluations will be based on experimental results generated in Task 3.2. Here we will recommend source control and in-plant treatment measures designed to produce a sludge of acceptable quality for marine disposal.

Task 5.2 Selection of Discharge Site and Submarine Pipeline Technology

Purpose: To make a final recommendation on outfall location and depth. The technology required for construction and operation of a deepwater sludge outfall has been developed over the past two decades, both through the construction of submarine oil and gas pipelines and from the operation of the Hyperion sludge outfall. This task is focused on defining engineering design criteria for the proposed discharge and selecting a suitable discharge location.

Description: The proposed discharge site will be selected after a review of available oceanographic data and model applications. Initial and subsequent dilution calculations and related modeling will be carried out to simulate plume behavior after discharge. Maintaining dissolved oxygen at acceptable levels is a key objective. Sludge flow rates and gross density will reflect a degree of predilution of sludge with wastewater effluent. Preliminary calculations will be carried out to size the outfall and determine pumping requirements. Deepwater submarine pipeline construction techniques will be reviewed to select appropriate technologies for laying pipe to the anticipated 300-400 meter depth.

Requirements of the discharge permit (to be established by regulatory agencies) will, of course, be met by a combination of in-plant processes and outfall design.

Task Group 6 BIOLOGICAL IMPACTS -- LABORATORY STUDIES

Supplementary biological studies will be used to investigate biologically-mediated pollutant transformations and biological sensitivities to pollutants. Biological experiments are divided into two groups -- those which can be carried out effectively under laboratory conditions and those which must be performed *in situ* on natural systems. Laboratory studies are proposed in this section and field studies in Task Group 7.

Sludge particle-organism interactions will start in the water column when planktonic animals and bacteria first encounter the freshly mixed sludge-seawater mixture and continue in the sediments following particle deposition. Water-column and near-bottom particles might act as food, as poisons, or simply as environmental "noise" to the plankton overwhelming chemical cues used to find food. In turn, numerous biological factors affect the fates of sludge constituents in the environment.

A brief explanation of chemical and biological determinants of contaminant form and behavior in the marine environment is provided within Chapter 2 of this report.

Task 6.1 Effect of Sludge Particles and Organics on Zooplankton Feeding

Purpose: To determine how sludge particles affect zooplankton feeding. Sludge particles could supplement the zooplankton food supply or interfere with normal feeding activity by masking chemical cues. If zooplankton ingest sludge, they could reduce the concentration of water column particles by "packaging" material in rapidly settling fecal pellets. The mechanisms could change sediment quality characteristics near the discharge. Experiments can show the importance of these interactions and provide information for sediment and water quality models.

Description: Zooplankton used in these experiments will be captured in the vicinity of the sludge plume. Animals used should include demersal zooplankton collected near the sediment/water boundary. Maintenance of these animals following capture will depend upon temperature and perhaps pressure control. Captured, acclimated zooplankton will be exposed to a range of sludge particle concentrations in the presence and in the absence of food. Disappearance of sludge particles from the water and their appearance as fecal pellets would indicate feeding on the sludge; change of regular feeding activity with increased sludge concentration would indicate interference. Zooplankton will be observed for outward signs of physical or behavioral anomalies and analyzed for body burdens of sludge-related contaminants at the close of the experiment.

Task 6.2 Dependence of Zooplankton Respiration on Ambient O_2 Concentration

Purpose: To investigate relationships between midwater organism metabolisms and dissolved oxygen concentration. A potentially important impact of sludge disposal at 400 m is depression of relatively low ambient oxygen concentrations. Experiments designed to see if midwater organisms can adapt to a low dissolved oxygen environment are also described.

Description: As in Task 6.1, experiments depend upon the capture and acclimation of suitable zooplankton species. In all cases, relationships will be sought between oxygen concentration and rates of oxygen consumption. It may be possible to carry out a crude adaptation test using zooplankton taken from the outfall-affected region at various times following initiation of marine sludge disposal. Oxygen consumption experiments conducted on these specimens can then be compared with the results of pre-discharge experiments.

Task 6.3 Microbial Decomposition of Water Column Organics

Purpose: To measure the rate of organic decomposition as a function of bacterial biomass, temperature, dissolved oxygen, pressure, and level of organic material present. Rates of microbial decomposition and related oxygen demand will provide data for development of a water column oxygen model.

Description: Marine water samples will be taken from midwater, near the proposed discharge site, and maintained at *in situ* temperature throughout the course of the experiment. While it is recognized that maintenance of ambient pressure under lab conditions will require specialized equipment, a few such experiments should be included within a minimum program. If it becomes apparent that pressure effects are not critical to microbial respiration, high pressure tests should be discontinued. Sludge additions to a series of water samples will bracket the range of expected sludge strengths following initial dilution. Periodic measurements in all samples will include concentrations of organics, dissolved oxygen, and microbial biomass (or an acceptable substitute parameter). The rate of sludge decomposition will be calculated from these data.

Task 6.4 Sea Urchin Toxicology -- Lab Study

Purpose: To investigate the toxic response of deepwater sea urchins upon exposure to sludge constituents. The benthic community over much of the southern California slope, including the proposed discharge site, is dominated by two species of sea urchin, *Brissopsis pacifica* and *Allocentrotus fragilis*. Marine waste disposal experience in southern California indicates that sea urchins endemic to shallower waters are particularly sensitive to waste discharge, despite the fact that under some conditions sludge particles sustain urchin populations when their preferred food sources are exhausted. Toxicological studies will be designed to establish the response of dominant urchins (both adult and larval forms) to varying concentrations of sludge-related contaminants.

Description: Methods must be developed to capture and sustain viable deepwater urchins. Maintenance of *in situ* temperatures may be critical to their survival under lab conditions. Urchins will be exposed to a series of sludge/seawater dilutions of strengths designed to induce both acute and chronic toxic effects. Oxygen concentration may be varied in any or all of the dilutions. Experiments should yield an estimate of the 96-hour LC_{50} as well as levels representing the onset of such pathological and behavioral effects as loose spines, eviscerated organs, reduced feeding and oxygen consumption, etc. LC_{50} determinations should be conducted on *Allocentrotus* larval and adult forms. Organisms used in chronic toxicity tests should be analyzed for body burdens of specific contaminants known to be present in sludge. These results should be used as the basis of experiments designed to test the response of the same species to specific toxicants. Urchins will be exposed over long periods to a range of concentrations of these contaminants and observed for physiological or behavioral anomalies, as above. Body burdens of trace contaminants will again be established in an effort to correlate observed effects with exposure and bioaccumulation data.

During the course of chronic toxicity tests, organisms will be removed periodically for histopathological study involving tissue (gonadal) sectioning and observation at cellular level. An effort should be made to relate such observations to the qualitative scale devised on the basis of benthic monitoring results (see Task 1.5). Investigators should try to correlate histopathological information so obtained with exposure and bioaccumulation data.

Task Group 7 <u>BIOLOGICAL IMPACTS -- IN SITU STUDIES</u>.

Field studies allow one to observe the effects of sludge on a community of organisms as opposed to individuals or single species. Direct *in situ* manipulation permits ecologists to study the mechanisms of ecological change.

The technology for working at 300 to 400 m depth is not totally established. Well developed systems are available for such proposed experiments as the benthic respiration measurements of Task 7.1 and baited camera observations in Task 7.3. In other experiments, however, such as the various manipulations discussed in Task 7.5, related technology is changing rapidly. Late developments include such systems as one-atmosphere dive suits. This equipment is expensive but may permit a more direct investigation of mechanisms behind sludge impacts. Decisions relative to manipulation studies that rely on the one-atmosphere dive suits or other recent technological developments should be postponed pending accumulation of monitoring results.

Task 7.1 <u>Benthic Oxygen Consumption</u>

<u>Purpose</u>: To find relationships between physical, sludge-related impacts and rate of oxygen consumption in the benthic environment. Sediment oxygen demand is an important component of the overall oxygen balance among marine bottom waters. Sludge discharge will increase the rate of sediment oxygen demand, decreasing bottom water and sediment pore water dissolved oxygen concentrations. Direct measurement of pre- and post-discharge sediment oxygen demand will improve the qualities of sediment and near-bottom dissolved oxygen models and, ultimately, improve our ability to predict biological impacts in similar waste disposal settings.

<u>Description</u>: The proposed program for monitoring benthic oxygen consumption will be carried out using grab respirometers equipped with oxygen probes and syringes for sample withdrawal. Benthic monitoring stations will be selected based on preliminary modeling results to cover the full range of expected impact intensities. A typical respirometer measures dissolved oxygen concentration continuously over an incubation period withdrawing samples for calibration at the beginning and end of the monitoring period. At the close of the experiment, the sampling device removes a grab sample of sediment for chemical and biological measurements and identification of species. Based on these results, correlations will be developed between such

parameters as total biomass or oxygen concentration (independent variables) and rate of oxygen consumption (dependent variable).

Task 7.2 Rates of Particle Ingestion by Macrobenthos

Purpose: To observe the effects of sludge and dissolved oxygen concentration on particle ingestion rates. Important sediment characteristics such as grain size and organic content are dependent upon rates of sediment ingestion and particle degradation by macrobenthos. Here we propose to measure particulate ingestion rates as a function of sludge and dissolved oxygen concentration. Results may be used in sediment quality or dissolved oxygen models described elsewhere in this report.

Description: Per Task 7.1, grab respirometers will be used to carry out related experiments. Here, however, dye or isotope-labelled sludge particles will be injected into the respirometer chamber. A representative period will follow for ingestion of labelled substrate, after which samples will be retrieved and the gut contents of organisms analyzed for tracer. Dissolved oxygen concentration will be measured throughout the experiment and surface concentrations of total organic carbon will be determined in sediment grabs. Measurement of total benthic biomass is also required. Although not expressly described in Task Group 6, *in situ* particle ingestion experiments described here should be supplemented with a laboratory study constructed along the same lines.

Task 7.3 Effect of Sludge Particles on the Feeding Habits of Marine Fauna -- Baited Camera Experiments

Purpose: To observe directly the effects of sludge discharge on feeding habits of marine fauna. Baited camera experiments are the *in situ* counterparts of laboratory efforts to observe sludge impacts on fish and microinvertebrate feeding and will serve the same overall purpose.

Description: A dead fish bait in the presence and absence of sludge will be used to determine scavenger feeding preferences among midwaters 50 to 100 meters above the proposed discharge depth. It has been suggested that at sufficient concentration sludge particles interfere with chemical cues upon which zooplankton and fish depend for finding food. Baited camera experiments will be designed to test that hypothesis.

Task 7.4 <u>Field Observation of Zooplankton Feeding in the Presence of Sludge Constituents</u>.

<u>Purpose</u>: To determine whether or not zooplankton are inclined to feed on sludge particles.

<u>Description</u>: Comparison of gut fullness and analyses of gut contents in zooplankton taken from study (proximate to the outfall) and control areas offer the most direct sources of evidence. The Hyperion sludge discharge could be studied in this regard during the pre-discharge period.

Task 7.5 <u>Other Biological Experiments</u>

<u>Purpose</u>: To be defined as needed based on the results of post-discharge monitoring.

<u>Description</u>: The monitoring program described in Task Group 1 of this report is designed to register unanticipated as well as anticipated impacts of marine sludge disposal. Consequently, monitoring results will, in all probability, suggest additional field or laboratory manipulations which are not warranted at this point. The class of experiments in which divers directly manipulate elements of the local benthic environment has already been noted. Due to the expense of equipment rental and because potential advantages are not well defined at present, tasks which require the use of deep water diving equipment have been at least temporarily omitted. Monitoring results may justify their reconsideration during program revisions.

Task Group 8 SPECIAL STUDIES

In a broad multidisciplinary research effort, it is expected that the research plan may have to be modified periodically as the need for new tasks becomes apparent. As such, Task Group 8 will grow during the course of the experiment. This section contains those tasks which do not fall into any other category, including:

8.1 Identification of Sludge Tracers
8.2 Remote Tracking of Wastefield
8.3 Extrapolation from Hyperion Sludge Disposal Experience
8.4 Assessment of Potential Public Health Impacts.

Additional tasks may be included within this group in future program revisions.

Task 8.1 Identification of Sludge Tracers

Purpose: To identify tracers for direct tracking of sludge plumes and positive delineation of the depositional area. Recent advances in dilution modeling have not been matched by improved field verification techniques. Field measurements are impeded by the lack of an effective tracer. An ideal tracer should:

(i) behave in the same way as the material of interest,
(ii) not be found under natural conditions,
(iii) be detectable in very low concentrations, and
(iv) be harmless to the environment.

Dyes, radioactive tracers, and other measures all fall short in terms of these criteria. Other possibilities should be investigated.

Description: A number of substances have been suggested as tracers of wastefield dispersion and particle fallout in the marine environment. The feasibility of using these and other tracers for the purposes outlined above will be examined.

(i) Relatively heavy substances found in sludge (e.g., tomato seeds, gritty contaminants) but not in unimpacted sediments have been suggested to trace the fallout pattern in the immediate vicinty of the outfall.

(ii) Sludge refractory organics detectable in low concentrations may be used to determine the lateral and vertical limits of effluent-related suspended materials and sediment deposits. Suggested tracers which fit this description include halogenated hydrocarbons, natural hydrocarbons such as aromatic or other cyclical compounds, and coprostanol.

(iii) Similarly, the trajectories and sediment distribution of sludge particulates can be measured using isotope ratios (e.g., $^{13}C/^{12}C$, $^{15}N/^{14}N$, $^{34}S/^{32}S$). The utility of such measurements lies in differences between ratios characteristic of natural and sludge-related particulates.

(iv) Inorganic materials present at higher concentrations in sludge than in nature, e.g., trace metals, may be used to estimate the contribution of effluent particles to local sediments. The utility of trace metals in this regard has been fairly well established through wastewater monitoring. Unfortunately, metal concentrations after initial dilution are normally so close to background levels or so near detection limits that their use as tracers of dissolved contaminants is not promising.

(v) Artificial tracers may be added to the sludge discharge if they can be detected in very low concentrations. Candidates include fluorescent plastic beads a few microns in diameter. While such tracers may have the advantage of detectability, the interpretation of related data is nebulous because the sludge discharge can only be "marked" during some relatively short time interval. The site at which measurements are taken always holds a mixture of marked and unmarked sludge. Such experiments offer a qualitative indication of the area invaded by sludge particles, provided that the beads and sludge solids are transported in the same way.

Task 8.2 Remote Tracking of Wastefield

Purpose: To locate the near-field sludge plume using an acoustic device. Among detection methods, remote sensing is by far the most efficient. Acoustic tracking may provide a convenient means for locating the established wastefield. Because marine zooplankton can be detected in this manner, zooplankton avoidance or attraction to the wastefield may be monitored acoustically.

Description: The feasibility of locating the wastefield from shipboard using acoustic equipment will be investigated during water quality monitoring cruises. If successful, the technique can be used during field verification of initial dilution and water column dissolved oxygen models.

Task 8.3 Extrapolation From Hyperion Sludge Disposal Experience

Purpose: To apply oceanographic data and insight gained via monitoring efforts at the City of Los Angeles sludge discharge site in Santa Monica Bay. For years, Los Angeles has operated an outfall dedicated to the discharge of digested sewage sludge to the marine environment. The structure, known as the Hyperion sludge outfall, terminates 11 kilometers from shore near the head of the Santa Monica Canyon at 100 m depth. Keeping in perspective the similarities and differences between the Hyperion sludge outfall and the proposed deep water outfall for Orange County, it is natural to extrapolate from the Hyperion experience to the present situation.

Description: A number of field surveys and evaluation studies have been conducted on the impact of the Hyperion sludge outfall (SCCWRP, 1974 through 1978; Bascom, 1981; Koh, et al., 1977). These data and all relevant publications will be reviewed to extract information which can be applied to the Orange County situation. Hyperion sludge is discharged in shallower water with greater potential for transport and mixing in waters of higher dissolved oxygen concentrations. Consequently, Hyperion field survey results should not be applied within the context of the Orange County study without considering these and other differences (e.g., current patterns). Los Angeles monitoring experience will permit rough projection of impact magnitudes at the Orange County site.

Task 8.4 Assessment of Potential Public Health Impacts

Purpose: To insure that no significant public health impacts result from sludge disposal practice. The primary avenues for potential discharge-related impacts to human health involve either direct contact of humans with waste and associated pathogens or ingestion of contaminated seafood from an impacted area.

Description: There is reason to expect, largely based on marine wastewater disposal experience, that detrimental effects related to direct human exposure to pathogens will not result from deepwater sludge disposal. The flux of pathogens to the environment (total number of organisms) due to sludge disposal will be significantly lower than that which results from wastewater disposal. The proposed sludge outfall is about five times deeper than the existing CSDOC wastewater outfall and will terminate farther from beaches and shellfishing areas. It is anticipated that the sludge plume will be trapped well below the ocean surface for long periods of time -- considerably longer than is necessary for destruction of enteric microorganisms. A modest program of water column coliform sampling will be carried out to confirm that hypothesis (see Task 1.1). In the event sludge-related coliforms are found to persist among receiving waters, the program can then be expanded to include sampling over a broader area and measurement of pathogen concentrations. Consideration will also be given to potential pathogens such as pathogenic amoebae.

The potential for human exposure to toxicants of sludge origin will be assessed using monitoring and bioconcentration data developed in Tasks 1.5 and 1.8, respectively. That program should be expanded to include periodic measurements of liver and muscle concentrations of Table 4.2 contaminants among species known to be taken (commercially or for sport) from potentially impacted areas. Annual sampling frequency is recommended. Results can be compared with FDA limits for edible tissue, state standards, EPA guidelines, etc., in light of commercial and sport fishing catch statistics to determine the significance of related impacts on human health.

Task Group 9 INTEGRATION, ANALYSIS AND INTERPRETATION

As explained in Chapter 3, the research tasks fit into a conceptual structure designed to develop information on important coastal oceanographic processes and effects of the proposed deep-water sludge discharge. Task Groups 1 through 8 above will produce a wealth of related information. The purpose of this ninth group of tasks is to integrate the new knowledge within the existing scientific framework, draw conclusions, make recommendations, and revise the study plan based on the research results. Group 9 includes the following individual tasks:

- Task 9.1 Analysis and interpretation of survey data
- Task 9.2 Comparison of model predictions with observations
- Task 9.3 Effects of organic enrichment on the dynamics of midwater plankton communities
- Task 9.4 Revision of research plan
- Task 9.5 Annual summaries of project results, conclusions and recommendations.

Task 9.1 Analysis and Interpretation of Survey Data

Purpose: To correlate data from various tasks and develop an overall understanding of the interplay among physical, chemical, and biological processes important to the transport, fates, and effects of the sludge contaminants. Although investigators will be encouraged to interpret the results of individual tasks, integration of their findings is an indispensable function without which the overall study objectives cannot be satisfied.

Both individual investigators and those groups or individuals responsible for synthesis and interpretation of project results are to review related scientific findings generated outside the CSDOC research project to avoid duplication of effort, assist in formulation of hypotheses and experimental techniques, and interpret new information within the most relevant and complete framework possible.

Description: Accumulated data will be integrated into a suitable data bank and library collection for archival purposes, available to all investigators for work on their respective tasks. However, in this task the investigator(s) should expressly search for causal relations between observed effects and characteristics of the sources and the ocean. For example, is the observed depositional zone (or "footprint") consistent with current measurements and particle fall velocities? Or, is the lack of detectability of some trace contaminants due to unexpected sinks, or are the dilution and dispersion so great that the expected concentrations are below the measurement thresholds?

Mass balances will play an important role in the synthesis of program results. Can we develop overall scenarios of how and where the BOD of the sludge particles is exerted? What fraction of the organic carbon in the particles is oxidized before the particles reach the bottom? Does the integral of the areal distribution of carbon deposits match the input minus losses within the water column? What fraction of discharged metals is trapped in the sediments compared to that which is flushed out of the area?

These questions are intended to be suggestive, as the most pertinent issues for study should not be predetermined. Part of the interpretation of the post-discharge monitoring data will entail identifying measurements or sampling stations which may be discontinued and, conversely, defining areas in which the research effort can be profitably expanded.

Task 9.2 Comparison of Model Predictions with Observations

Purpose: To verify predictive models using observations of dilution, transport, fates and effects of the sludge discharge. The future success and acceptance of marine discharge of any waste depends on good predictive models, so that engineered disposal systems may be undertaken with reasonable understanding of what the environmental impacts will be. This task will provide model calibration and opportunities for further model development in an effort to reach that goal. The results will thus have national significance for future waste disposal policy.

Description: Mathematical models developed in Task Group 4 will be evaluated both step-by-step and in terms of their overall accuracy. Input data will be adjusted in light of new research results, and models rerun as needed. If predicted results still disagree with observations, some parametric studies may be undertaken to see what input values yield better predictions. For example, it may not be possible to get a proper laboratory evaluation of particle fall velocities including the effects of shear-induced coagulation. Under these circumstances, it may still be possible to back-calculate the settling velocity using the sedimentation model described in Task 4.4 and sediment trap data obtained per Task 1.7.

Overall, this may be a large task, and may illustrate the need for modifications or additions in other tasks in order to achieve a predictive capability which is adequate for engineering purposes.

Task 9.3 <u>Effects of Organic Enrichment on the Dynamics of Midwater Plankton Communities</u>

<u>Purpose</u>: To assess carbon balance impacts among local receiving waters attributable to the discharge of sludge. The effect of sludge-related organic carbon on midwater zooplankton community ecology should be investigated quantitatively (to the extent feasible) in light of both (1) the scale of the carbon source represented by the proposed discharge and (2) the scarcity of existing data relevant to waste-related impacts among marine zooplankton. Disruption or alteration in the flow of carbon within the plankton community may be one of the primary effects of sludge (nutrient) enrichment in the pelagic ecosystem.

<u>Description</u>: Results of several related tasks described elsewhere will be integrated to yield a carbon budget within the potentially impacted zooplankton community. Analytical and/or experimental work to be considered in devising such a budget includes results of the following tasks:

Task 1.1 -- Measurement of water quality characteristics (dissolved organic carbon, particulate organic carbon, nutrients, etc.).

Task 1.2 -- Water column biological monitoring (changes in the distribution and abundance of zooplankton in relation to the presence of sludge-related materials within the water column).

Task 6.1 -- Effect of sludge particles and organics on zooplankton feeding (laboratory measurement of carbon utilization by zooplankton in the presence of sludge particles).

Task 6.3 -- Microbial decomposition of water-column organics (laboratory measurement of microbial organic carbon decomposition in the presence of varying sludge particle concentrations).

Task 7.4 -- Field observation of zooplankton feeding in the presence of sludge constituents.

Task 9.4 <u>Revision of the Research Plan</u>

<u>Purpose</u>: To revise the research plan annually (approximately) accounting for new scientific information, changing needs and priorities, and availability of funds.

Description: The research plan must be sufficiently flexible to respond to changing circumstances -- i.e., to permit "mid-course corrections". Examples of situations which will necessitate adjustments include:

1. Changes in water quality regulations governing this proposed sludge discharge;

2. New scientific discoveries elsewhere;

3. Unexpected research results ("surprises") which need more investigation;

4. Evidence that environmental effects are geographically restricted to the near-field and undetectable in the far-field;

5. Changing research priorities and availability of funds;

6. Changes in sludge quality or volume due to source control (or pre-treatment) and unit processes in contributing treatment plants;

7. Research results which indicate that further work on a particular task is not needed or, conversely, that program expansion is required.

Because of all these factors, a group or committee should be formed which is responsible for plan review at about one-year intervals.

Task 9.5 Annual Summaries of Project Results, Conclusions and Recommendations

Purpose: To summarize, draw conclusions, and make recommendations annually and at the end of the research project.

Description: For policy-makers this is perhaps the most important task in the research progam. It should produce a consensus (or range of views) within the scientific community regarding what was learned and what the implications are for continued sludge discharge by Orange County Sanitation Districts, or for national policy.

CHAPTER 5

PROJECT ORGANIZATION

5.1 INTRODUCTION

In this chapter we turn our attention to management questions: who does the work, how much will it cost, who provides funds, how is it managed, and how are the results evaluated? At this stage, we can only recommend some general principles for management and provide some rough cost estimates.

The research plan in Chapter 4 describes the work to be done, without regard to who will perform which tasks. Although major parts of the proposed work may be done under grants and contracts to universities and private firms, significant portions will be performed by the County Sanitation Districts of Orange County (in-house) and by the Southern California Coastal Water Research Project. NOAA, EPA, and the California Water Resources Control Board may also have some direct roles in conducting the research as well as funding it. There obviously needs to be strong coordination, while still encouraging innovative research.

Finally, there must be procedures for reporting the conclusions and recommendations to the regulatory agencies and CSDOC on a regular basis, so that decisions can be made regarding continuation of the ocean discharge of sludge.

5.2 RESEARCH ADMINISTRATION

The suggested organization for research administration, which is summarized in Figure 5.1, will be separate from CSDOC and its normal operating functions. Except for in-house work by CSDOC, all the research tasks should be funded through a joint administrative agreement of the various funding agencies. An administrative board representing the sponsoring agencies would appoint a well qualified scientist or engineer to be the project research administrator. This person should have experience in both oceanographic research and waste disposal problems. Using funds provided by the sponsoring agencies as a single pool, the project research administrator would carry out the research plan by means of grants and contracts and disseminate the results. The research administrator might be a career scientist drawn from one of the sponsoring agencies (such as NOAA or EPA), but while on his assignment, he would be responsible only to the administrative board. He would also operate independently of the Orange County Sanitation Districts, but maintain close technical liaison.

A research review committee of scientists and engineers would be appointed by the research administrator with concurrence of the

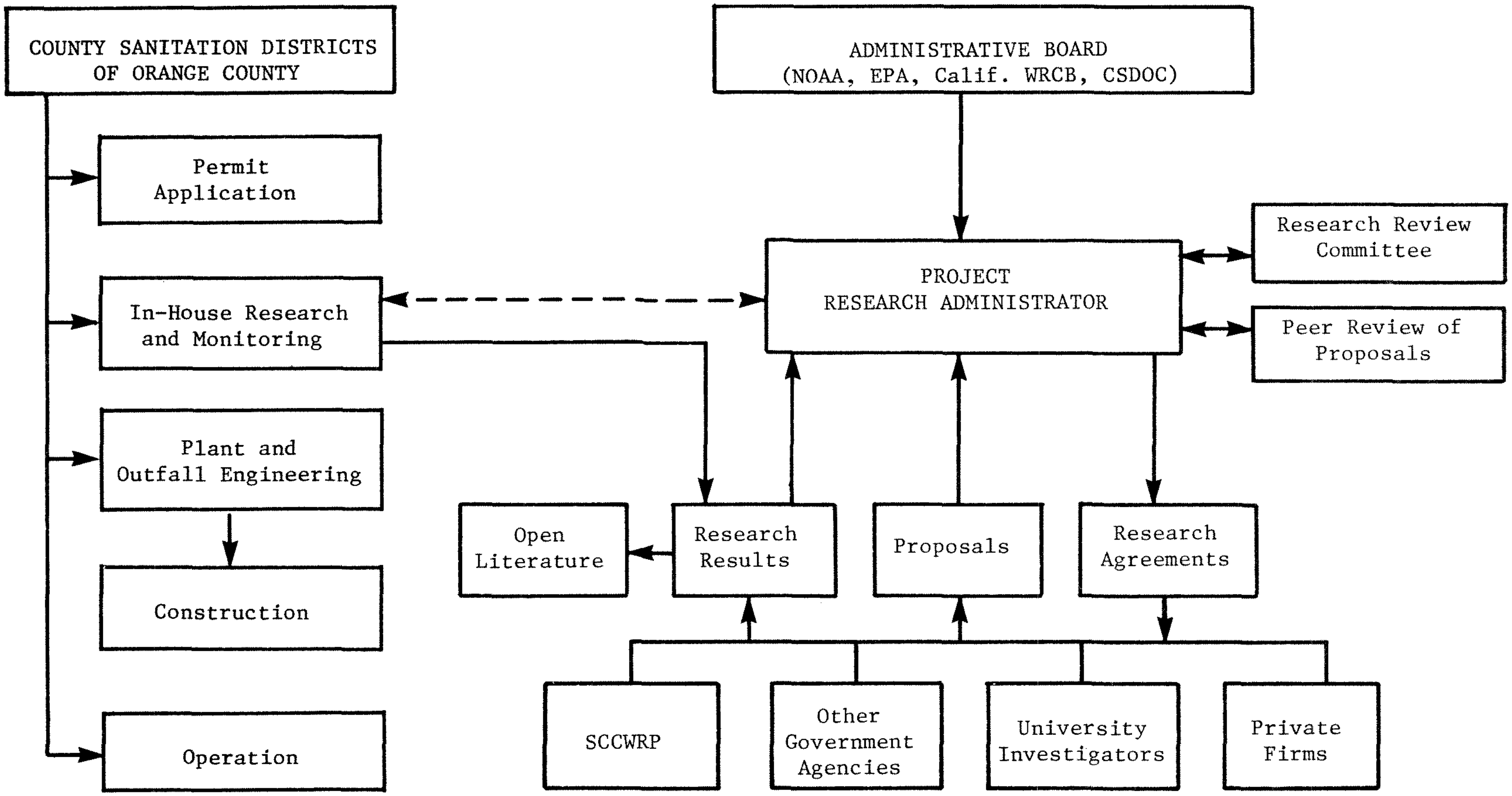

Figure 5.1 Suggested organization for research administration. Arrows indicate main lines of responsibility, but do not show all the communication links needed for coordination and utilization of results.

administrative board. Membership of this committee would be based on professional qualifications, rather than organizational affiliation or geographical location. The functions of this research committee, in collaboration with the research administrator, would be to:

(1) Approve the research plan and all revisions;
(2) Establish priorities among research tasks;
(3) Approve procedures for solicitation of proposals and award of grants and contracts;
(4) Evaluate research proposals submitted by organizations who wish to perform the work, and recommend awards;
(5) Prepare an annual summary of the findings and evaluate their significance.

The procedures for receiving and processing proposals (function (3) above) should vary depending on the type of task and the type of investigator. For some work, unsolicited grant proposals should be accepted, while for others well-defined requests for proposals (RFPs) may be issued. The award of research funds may be by grant, contract, or cooperative agreement, depending on which is most appropriate to the circumstances. With grants, the individual investigators are given the maximum discretion and encouragement to generate new ideas, while contracts imply a more closely prescribed and pre-determined scope of work. In short, the award mechanisms should be flexible and should not be constrained to just one procedure.

When processing proposals (function (4) above), the administrator and the research review committee will be assisted by a system of external peer review of proposals by individual experts. For renewal of grants or contracts, peer review would include evaluation of the proposer's performance under previous agreements for the sludge disposal experiment.

Investigators would be required to submit progress reports at least annually to the research administrator and a final report at the end of the research agreement. The technical components of these reports should be available to all researchers and the public. Publication in peer-reviewed professional journals ("open literature") should be encouraged and should be considered in evaluations by the research review committee.

The research administrator will also make proper arrangements to see that the basic data and research results are properly archived for easy retrieval. Updating the research plan and preparing annual summaries (part of functions (1) and (5) above) have been included in the list of research tasks (Tasks 9.4 and 9.5, respectively, in Chapter 4). The research administrator may decide to award a grant or contract for these activities in order to provide inputs for action by the research review committee.

The most important purpose of this research project is to provide information and guidance to decision-makers in the regulatory agencies and CSDOC. They will need to review the project results during the five-year post-discharge observational period and at the end of the research program to decide whether or not the sludge discharge should be continued. Factors involved in these decisions go beyond the scientific evaluation of the effects of ocean discharge, and involve impacts and costs of alternative sludge disposal systems, legal constraints, and political perceptions. Thus, while the research review committee has the major responsibility for evaluating environmental impacts, it is clearly not the proper group to be charged with the final decision on continuance of the discharge of sludge to the deep ocean.

5.3 RESEARCH PROJECT COSTS

Although cost estimation is difficult and risky at this stage, it is necessary to give some indication of the scale of proposed work. For this purpose, we established a time line originating at the date of approval of this project concept (by legislative and/or administrative actions). This date is, of course, very uncertain (or it may never occur), but it is the logical reference point for both construction and research activities. For construction of the outfall and associated in-plant facilities for sludge processing and pumping by the County Sanitation Districts of Orange County, the following schedule is anticipated:

Year	Month	Activity
0	0	Project concept approval
0	1	Site selection, start design
0	3	Filing of permit application
1	0	Complete outfall design
1	4	Complete design of on-shore facilities
1	4	Permit granted by regulatory agencies
1	4	Advertise construction projects for bids
1	7	Award construction contracts
2	4	Complete all construction, start testing facilities
2	6	Start regular continuous discharge

Thus, it is expected to take 2 1/2 years from project concept approval to start of discharge. During this period, the research project would be formally started, and two years of predischarge work would be conducted. After discharge, five years of observation are planned, making a total of seven years for the research project.

The estimated costs for each of these years ranges from about $1.5 to 2.0 million (in 1982 dollars). In Table 5.1 we show the estimated annual amounts and the percentage allocation of funds to the nine task groups described in Chapter 4. An allowance of 13 percent of the total has been included for administrative costs (equivalent to 15 percent of total direct costs of Tasks 1 through 9). No attempt has been made to further disaggregate costs to the level of individual tasks within the groups.

The final allocation of funds will of course be the responsibility of the project research administrator and the research review committee when the time comes. The present estimates are given only to illustrate how the priorities and areas of emphasis shift over the course of the project.

Before the deep-ocean sludge discharge concept is approved (<u>before</u> time zero), there is still need for considerable activity in Tasks 1,2,3,4, and 5 in order to acquire oceanographic data and do the analyses required to support the concept development and permit application. Such work is already under way with limited funding from CSDOC and NOAA and includes: a one-year baseline oceanographic survey by SCCWRP (see Appendix A); chemical characterization of sludge (in-house by CSDOC); measurement of sludge particle fall velocities by EQL, Caltech; and this research planning study, also by EQL, Caltech. Because of the indefinite length of this pre-approval period and the uncertainty of near-term funding arrangements, we have <u>not</u> attempted to include this work in the cost estimates. Some interim administrative arrangements will also be required, which we have not attempted to define.

The estimates in Table 5.1 are subject to substantial uncertainty. Furthermore, cost figures will change depending on how the project progresses and what the early research results are. The costs assume a rather thorough investigation, even though some members of the Research Planning Committee believe the effects of the sludge discharge will be minimal. The objectives, however, reach beyond CSDOC's immediate needs, to include improvements in predictive modeling of deep-water disposal and contributions of useful information for state and federal policy-makers. Because of the national objectives involved, we expect that funding responsibilities will be shared by federal agencies (NOAA, EPA), the California Water Resources Control Board, and the County Sanitation Districts of Orange County.

Table 5.1

Estimated Cost of Research Project

	Predischarge		Post-discharge				
Year	1	2	3	4	5	6	7
Estimated total cost (millions of 1982 dollars)	$2.0	2.0	1.5	1.5	1.8	1.9	1.9
Percentage allocations by task groups:							
1. Survey for discharge-related effects	21%	21%	32%	30%	23%	20%	15%
2. Site characteristics	11	11	0	0	0	0	0
3. Sludge characterization	10	7	8	4	3	3	3
4. Modeling	8	9	8	7	7	9	9
5. Preliminary design	5	0	0	0	0	0	0
6. Biological impacts--lab studies	12	13	12	19	16	16	11
7. Biological impacts--*in-situ* studies	7	10	8	8	16	16	15
8. Special studies	7	7	8	8	10	10	9
9. Integration, analysis and interpretation	6	9	11	11	12	13	25
Administration	13	13	13	13	13	13	13
	100	100	100	100	100	100	100

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APPENDIX A

DESCRIPTION OF THE SCCWRP PREDISCHARGE OCEANOGRAPHIC SURVEY

Introduction

The Southern California Coastal Water Research Project (SCCWRP) was organized in 1969 to study the environmental effects of municipal wastewater disposal in southern California marine waters. Its efforts are currently funded jointly by several major southern California wastewater treatment agencies, including the County Sanitation Districts of Orange County (CSDOC).

This appendix describes the scope of preliminary deep-ocean monitoring undertaken by SCCWRP in support of the Orange County proposal for a deep-ocean sludge disposal experiment. This work represents a first step toward establishment of baseline conditions in waters and sediments likely to be affected by the sludge discharge. The SCCWRP program, financed by CSDOC, is now in progress; results will be reported separately by SCCWRP in early 1983. When complete, SCCWRP measurements will provide: (i) a basis for estimating environmental impacts attributable to the proposed sludge discharge, and (ii) data which partially satisfy baseline oceanographic survey requirements outlined in Chapter 4. In order to avoid costly repetition, SCCWRP results, station selection, etc., should be carefully considered before proceeding with the project baseline survey (see Task Group 1, Chapter 4).

The zone under study within the SCCWRP investigation extends to a depth of >600 meters and some 20 km alongshore from the suggested discharge site. The program is designed to provide three kinds of information:

1. Physical measurements of receiving water density structure and currents. (Table A-1)

2. Chemical measurements in receiving waters, surface sediments, and some animal tissues. (Table A-2)

3. Biological measurements within the benthic and pelagic communities. (Table A-3)

The SCCWRP oceanographic survey, including sampling points and frequencies, is described in the text, tables, and figures which follow. The reader is referred to the forthcoming SCCWRP survey report for details relative to sampling procedures and equipment.

Table A-1. Physical Studies by SCCWRP

Type	Technique	Number of Sampling Periods (duration if cont.)	Number of Stations	Comments
Currents	current meters	continuous for 1 year	1	Three depths (1, 51, 101 m above bottom) read every 15-30 minutes
	"	60 days	1	51 m above bottom
	"	60 days	1	101 m above bottom
Density structure	Literature			Review profiles for years 1952-1969
	STD recorder	3	4	continuous surface to bottom
	thermography	60 days (continuous) in each of 3 seasons	1	at three depths (with continuous current meters)
Sediment grain size analyses	Pipet and sieve	1	8	Stations sampled comprise a subset of the sediment stations along a transect across the discharge site.

Table A-2. Chemical Studies by SCCWRP

Sample type	Number of Sampling Periods	Number of Stations	No. samples & depths	Analyses to be done
Sediment grabs	1	49	Subsamples from grab of upper 2 cm	archives wet - Volatile Solids, BOD, HEMs, TOC, TON organic - chlorinated hydrocarbons metals - Ag, Cu, Cd, Cr, Pb, Zn, Ni, Hg
Sediment Core	1	3	1	Archives
Water column dissolved oxygen	3	4	~50 m intervals	
Animal tissue	1	8	2 to 4 species from trawls	5 composites each of liver and muscle for metals and chlorinated hydrocarbons

Note: Sediment analyses indicated were performed on samples obtained at subsets of the 49 (total) grab sampling stations.

Table A-3. Biological Studies by SCCWRP

Animals	Technique	Number of Sampling Periods	Number of Stations	Work to be performed
Bacteria	Bottom Samples	1	8	Counts; ATP/biomass
Plankton	Auriga and Bongo nets	1	4 4 stations 2 depths	Zoo and ichthyoplankton to be identified and enumerated. (near bottom and 50 m above bottom)
Benthic infauna	Grabs	2	49/8	Identify, count, weigh benthic animals
Benthic epifauna (fish and inverts)	Otter trawl	2	8	Identify, count, weigh trawl-caught animals
Demersal fish and inverts	Photographic survey	1	3	Identify animals seen in photos
Fish	Long line	1	4	Identify, count, weigh, preserve stomachs
Food webs	Gut analyses of trawl and grab-caught animals	none specified		

Physical Oceanography

The program objective in this area is to characterize currents and water-column density structure in the vicinity of the proposed outfall. These data will permit prediction of initial dilution, plume height-of-rise, pattern of local particulate sedimentation, and the rate of exchange of water overlying the outfall-influenced sediments.

Current meters have been deployed at several elevations above the bottom at each of three stations (see Figure A-1). A string of meters is to record currents in the vicinity of the proposed discharge site (300-meter depth) continuously for about a year at 1, 51, and 101 meters above the bottom. Meters are to be deployed at two other sites to establish the continuity of currents. The first of these "secondary" stations is located 10 km upcoast from the proposed outfall, and the second is displaced in the offshore direction. To date, the current-meter program has been hindered by equipment loss. As a result, program results may represent somewhat different periods than originally envisioned.

Information on the density structure of the ocean in the vicinity of the outfall will be obtained from three sources: (1) historical data, (2) profiles measured using an STD (salinity/temperature/depth) recorder, and (3) temperature fluctuations recorded at three different elevations.

Water column salinity and temperature data obtained within the CalCOFI program will be used to provide a long-term history of the density profiles. The history includes: (1) the variability between stations; (2) seasonal variability, and (3) the inter-annual variability.

Density profiles at the proposed discharge site, as well as inshore, offshore, and in San Gabriel Canyon will be collected once during each of three oceanographic seasons. These profiles will be obtained using a recording STD. Water samples at the surface and at the bottom of the profile will also be collected to verify the STD calibration.

Surface sediments will be analyzed for grain size distribution at eight stations. Sampling points comprise a subset of the sediment monitoring stations which lie along the transect across the discharge site.

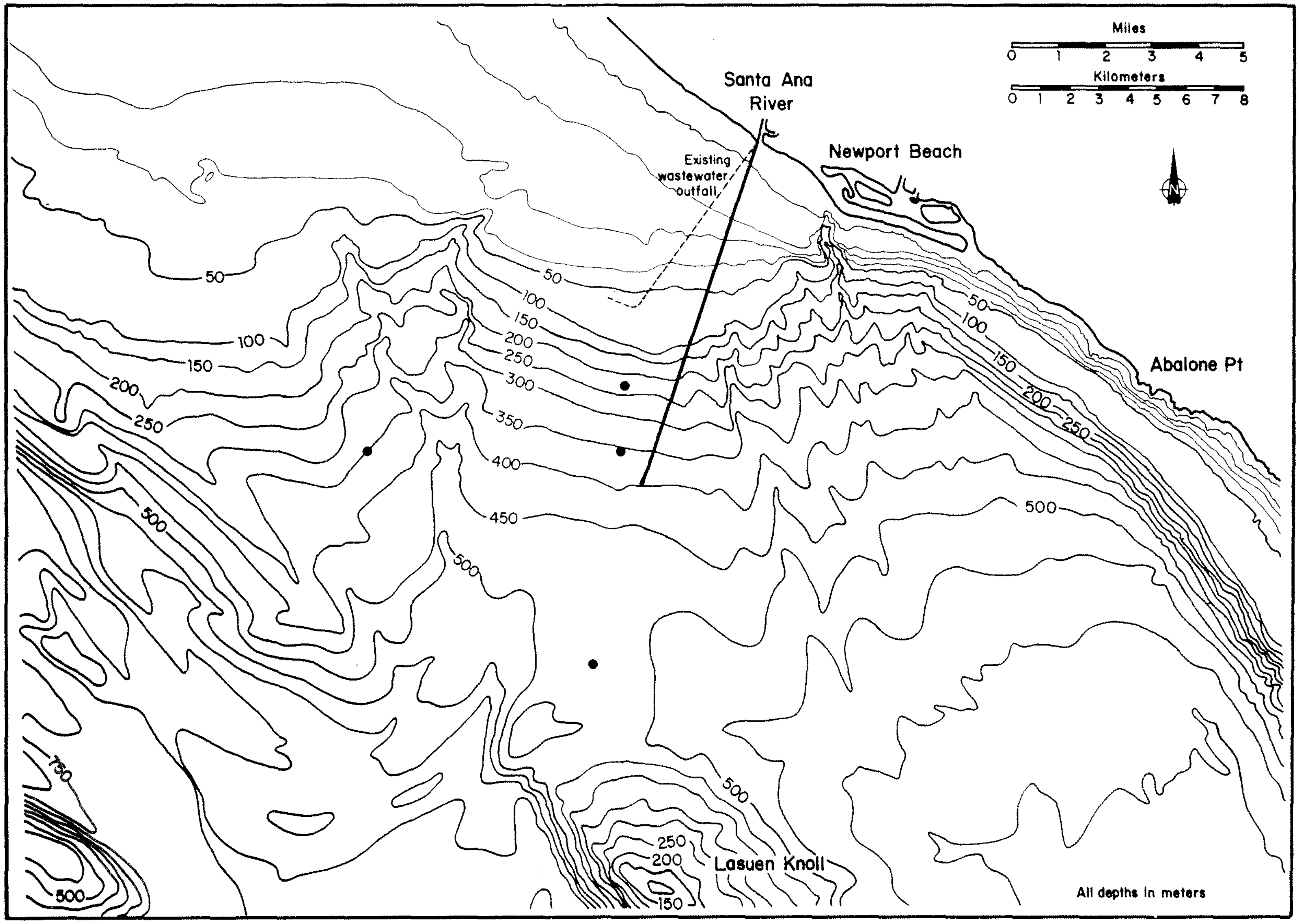

Figure A-1 SCCWRP Predischarge Baseline Survey -- Location of current monitoring stations. Note, positions shown are approximate; LORAN C coordinates are available from SCCWRP.

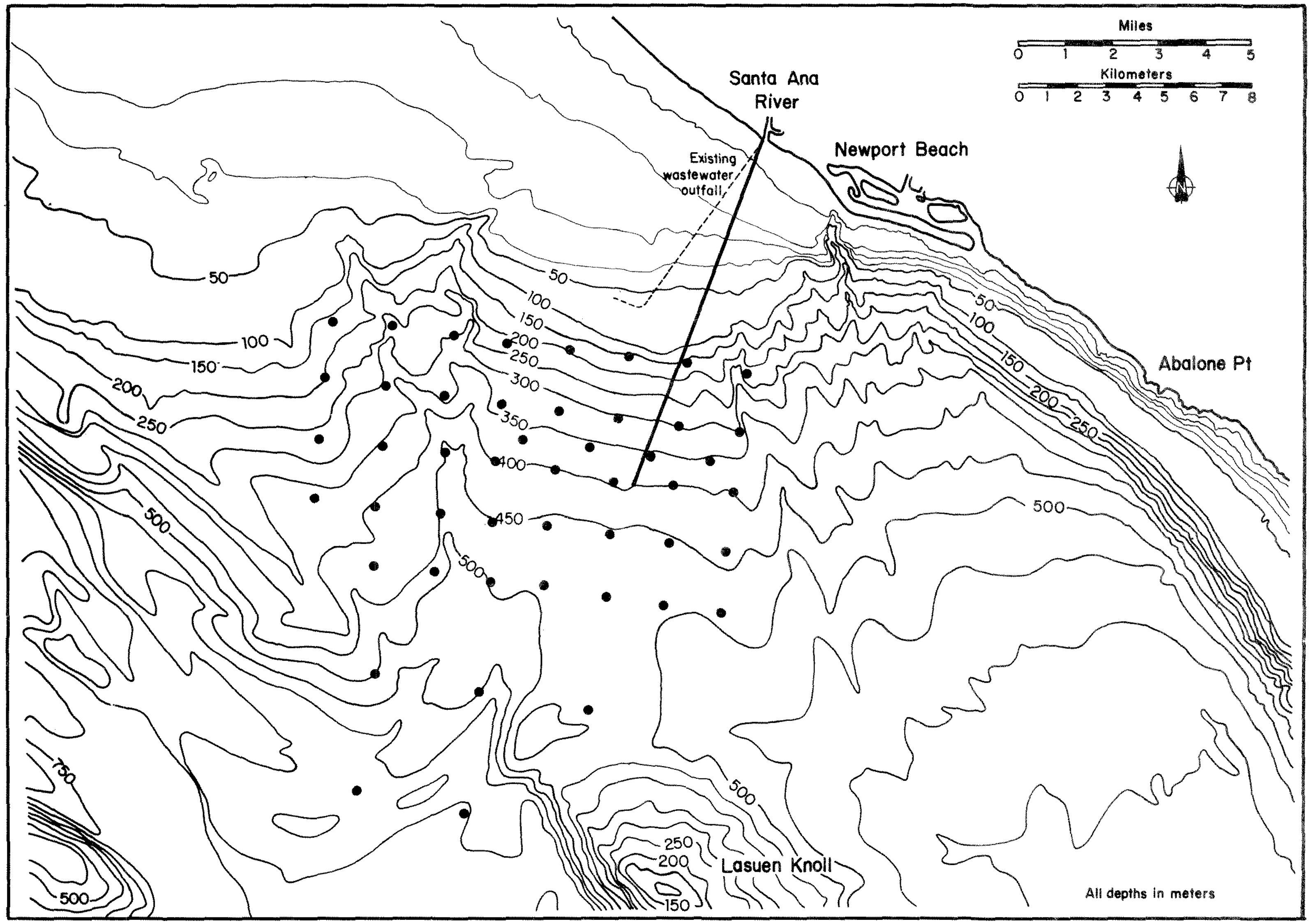

Figure A-2 SCCWRP Discharge Baseline Survey -- Location of benthic grab stations. Note, positions shown are approximate; LORAN C coordinates are available from SCCWRP.

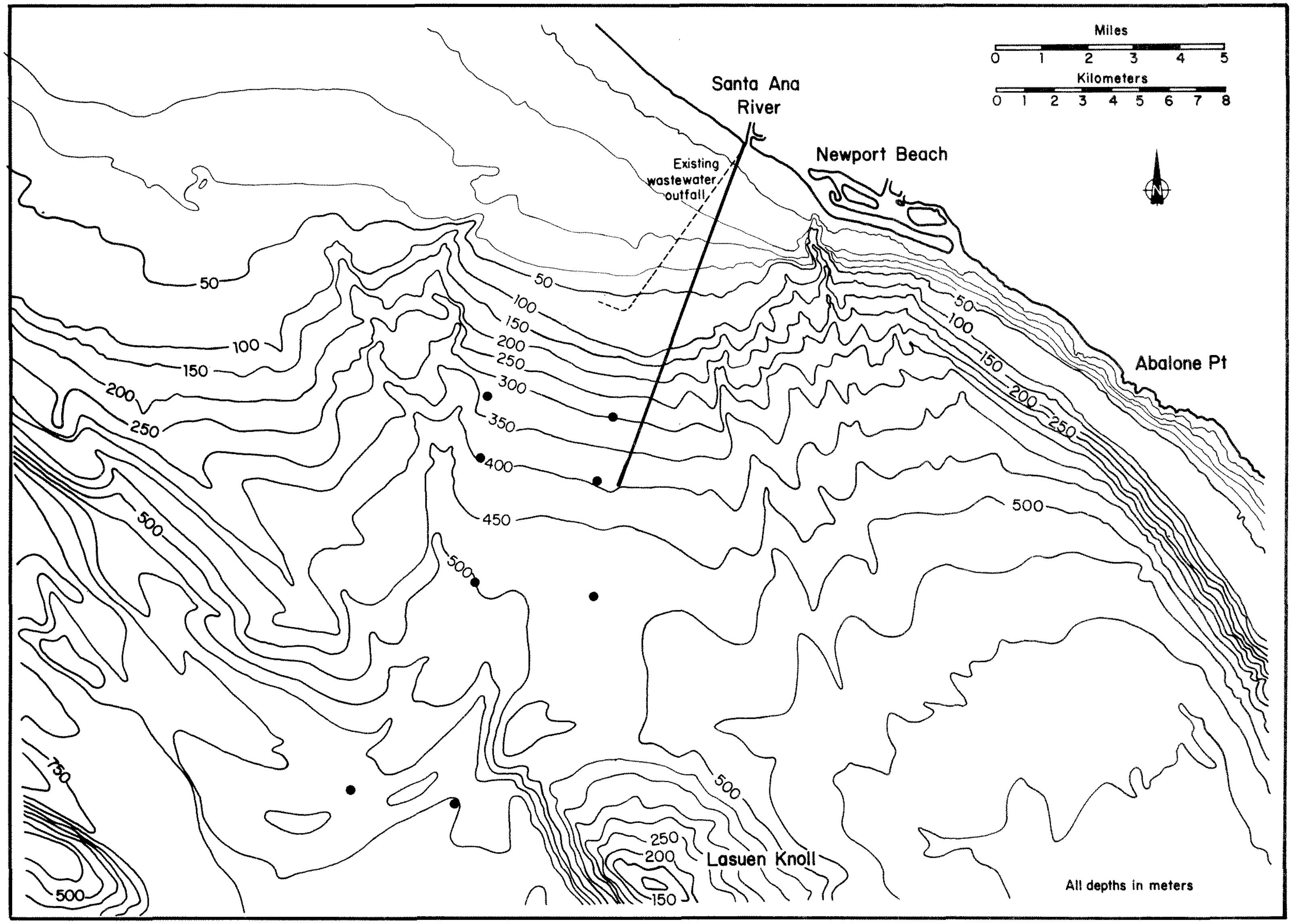

Figure A-3 SCCWRP Predischarge Baseline Survey -- Location of stations serving trawl, plankton, and long-line monitoring programs. Note, positions shown are approximate; LORAN C coordinates are available from SCCWRP.

Chemical Measurements

Sediment concentrations of specific nutrients, metals, chlorinated hydrocarbons and petroleum hydrocarbons will be measured at some of the 49 stations (see Figure A-2) in the region surrounding the suggested discharge site. These will establish background chemical conditions likely to be affected by the proposed discharge. A replicate subsample from each station will be frozen and archived by CSDOC to permit subsequent (post-discharge) analyses for constituents which may have been overlooked initially. Three sediment cores (about 50 to 100 cm deep) will also be taken and archived.

Dissolved oxygen will be profiled to characterize predischarge receiving-water concentrations. Samples will be taken at four stations (approximately 50-meter vertical interval) during each of three seasons.

Liver and muscle tissue concentrations of metals, organic mercury, and chlorinated hydrocarbons will be measured in several trawl-caught animal species. Analyses will be carried out on composites of 5 animals (if possible) to establish baseline tissue levels for these contaminants.

Table A-2 is a summary of chemical measurements to be carried out within the SCCWRP predischarge survey.

Biological Studies

Biological surveys will be used to establish the kind and number of organisms inhabiting the slope area at depths which may be affected by the proposed sludge outfall (200 to 600 meters depth). Identification and characterization of indigenous species in this zone may permit anticipation of ecological impacts attributable to the proposed discharge.

Zooplankton and larval fishes will be collected at each of eight stations (see Figure A-3) using an opening/closing bongo or auriga net towed for five minutes near the bottom and 50 meters above the bottom. Resultant data will be used to determine the biomass and community composition of zoo- and ichthyoplankton populations in deep water.

The benthic invertebrate community will be studied via a program of bottom samples to be collected at the 49 sites specified in Figure A-2. A Van Veen grab sampler will be employed. Animals retained on a 1.0 mm screen will be identified and counted. Total biomass and Infaunal Trophic Index will be calculated and plotted as extensions of existing survey results.

Epibenthic invertebrates will be taken in bottom (otter) trawls conducted using standard procedures (8-meter net width, 1.1 m/sec speed of advance for 10 minutes) and results compared with data collected in shallower water.

Fishes may be impacted by community changes at lower trophic levels. The objectives of the SCCWRP fish study will be to (1) add to existing data on the diversity and abundance of fishes in the San Pedro Basin region and (2) study the feeding habits of several species collected. Fish abundance will be measured via several methods. Otter trawls will be conducted at the stations shown in Figure A-3. In addition, a photographic survey of the bottom and long-line collections will be made at three and four stations, respectively.

Acknowledgment

We are grateful to SCCWRP personnel for providing information on which Appendix A is based. In particular, we thank Willard Bascom (SCCWRP Director), Bruce Thompson, and Terry Hendricks for their assistance.

APPENDIX B

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