FINAL REPORT

ENGINEERING AND ENVIRONMENTAL FEASIBILITY EVALUATION OF WASTE DISPOSAL ALTERNATIVES

StarKist Samoa, Inc.

CH2M HILL

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PREFACE

This Engineering and Environmental Feasibility Evaluation of Waste Disposal Alternatives was prepared by CH2M HILL for StarKist Samoa, Inc. The report is presented in two separately bound volumes: a Final Report, and Final Report Appendixes. This Final Report contains an Executive Summary and Sections 1 through 7. The Appendixes contain supporting technical information for the Final Report.

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EXECUTIVE SUMMARY

REASON FOR STUDY

In June 1990, StarKist Samoa, Inc. (StarKist), entered into an agreement with the American Samoa Government (ASG) to implement certain waste management practices with the purpose of complying with ASG's water quality standards by March 7, 1992.

As part of the agreement, StarKist agreed to conduct an engineering study to evaluate the feasibility of extending its existing wastewater outfall. StarKist retained the professional services of CH2M HILL to conduct such a study. This report presents the results and supporting documentation of the study.

PURPOSE OF STUDY

The purpose of this study was to evaluate the following waste disposal alternatives:

- Modify the existing outfall in the inner harbor
- Extend the outfall to the middle or outer harbor through either a land or marine route
- Extend the outfall beyond the mouth of the harbor

EFFECT OF HIGH-STRENGTH WASTE SEGREGATION

On August 6, 1990, both canneries (StarKist and Samoa Packing) in American Samoa commenced segregation of their high-strength wastes (cooker juice and press liquor), which contain high levels of nitrogen and phosphorus. These wastes, together with the cannery sludge, are being disposed of at an EPA-designated ocean disposal site.

Scientists from CH2M HILL visited American Samoa during the week of October 23, 1990, and collected water quality samples at historical sampling stations in Pago Pago Harbor. Results from these samples show that the water quality of Pago Pago Harbor has improved significantly since initiation of high-strength waste segregation. Both total nitrogen (TN) and total phosphorus (TP) concentration values measured were as much as 70 to 90 percent lower than the historical mean values. These results are corroborated by the monthly harbor monitoring results taken by ASG. Such improvements in the harbor water quality are consistent with and attributable to the practice of high-strength waste segregation.

OUTFALL LOCATION CRITERIA

The selection of the location of the outfall must satisfy two fundamental criteria. First, the outfall location must result in constituent concentrations that meet the ASG's water quality standards of 0.20 mg/l TN and 0.03 mg/l TP at the edge of a reasonably sized mixing zone. Second, the submarine portion of the pipeline must be routed to minimize the potential for damage from ships' anchors.

WATER QUALITY MODELING

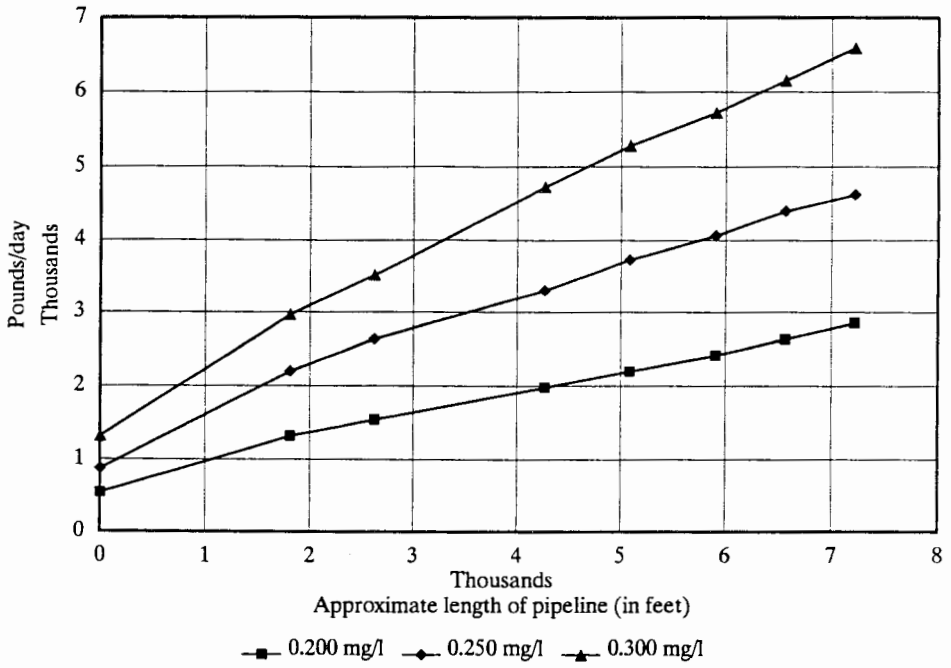
To estimate the extent to which outfall alternatives could meet ASG water quality standards, CH2M HILL performed extensive computer modeling studies to determine the steady-state, or long-term average, impact of cannery discharge at various locations in the harbor. The modeling results are a function of the physical configuration of the harbor (depth and size at various points), influence of the harbor transport processes, and nutrient loadings from both canneries.

Water quality modeling was done for scenarios that included both canneries discharging at the same point in the harbor and for discharges at widely separated locations in the harbor. The results of the modeling studies show that wastewater discharge somewhere between the middle harbor and the outer harbor will meet the ASG's water quality standards through either a joint outfall or adjacent separate outfalls for each cannery. These results, combined with the cost and feasibility studies described below, strongly suggest that a joint outfall be constructed. The studies indicate that, given the existing water quality standards and the most probable maximum nitrogen loadings of 2,500 pounds per day and maximum TP loadings of 450 pounds per day from the two canneries, the length of the pipeline would be between 6,000 and 7,000 feet (see Figure ES-1). TN rather than TP is the controlling nutrient for meeting the water quality standards.

On the other hand, if the existing water quality standard for TN were to be changed to 0.250 mg/l (if this could be done without affecting existing designated uses), the length of the required pipeline would be in the neighborhood of 4,500 feet. In this case, TP is the controlling nutrient. The approximate locations of the pipeline for the two water quality standards are shown in Figure ES-2.

Initial dilution modeling was conducted for a preliminary diffuser configuration. This model, using existing data on currents and density profiles in the harbor, shows that the discharge would generally be trapped beneath the surface so that impacts on the surrounding reef would be minimized. The currents in the harbor are almost entirely wind driven. On the basis of the prevailing offshore wind patterns, local topography, and existing current data, the overall net transport in the outer harbor is into the harbor in the near-surface layer and out of the harbor in the deeper waters. Thus, the long-term net transport of a submerged plume would be out of the harbor and towards the ocean.

A. Combined TN Loading



B. Combined TP Loading

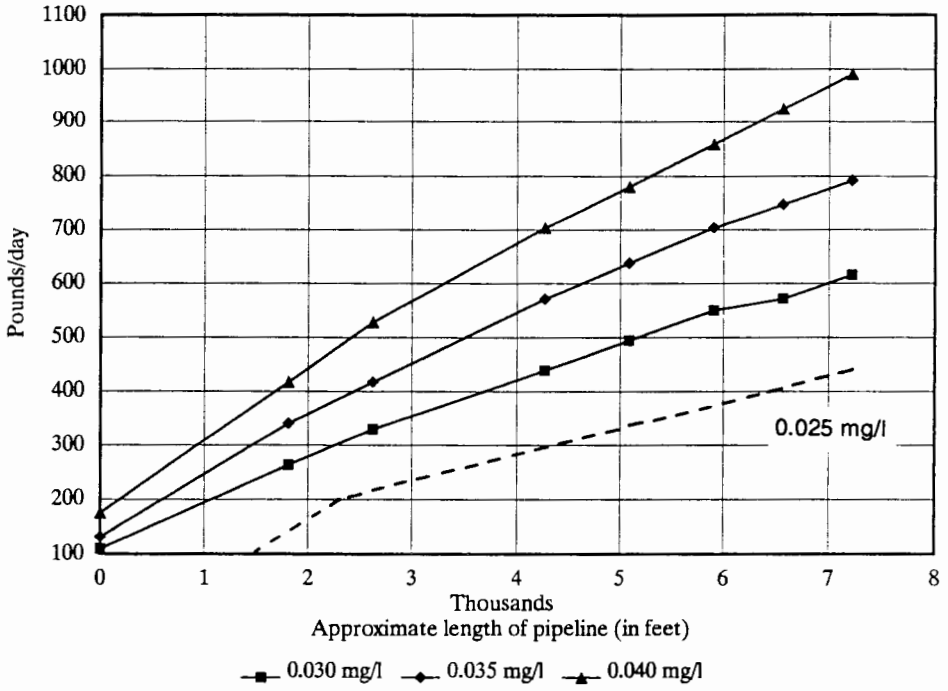


FIGURE ES-1
Approximate Pipeline Length Required for Total Nitrogen (A) and Total Phosphorus (B) Loadings for Both Canneries

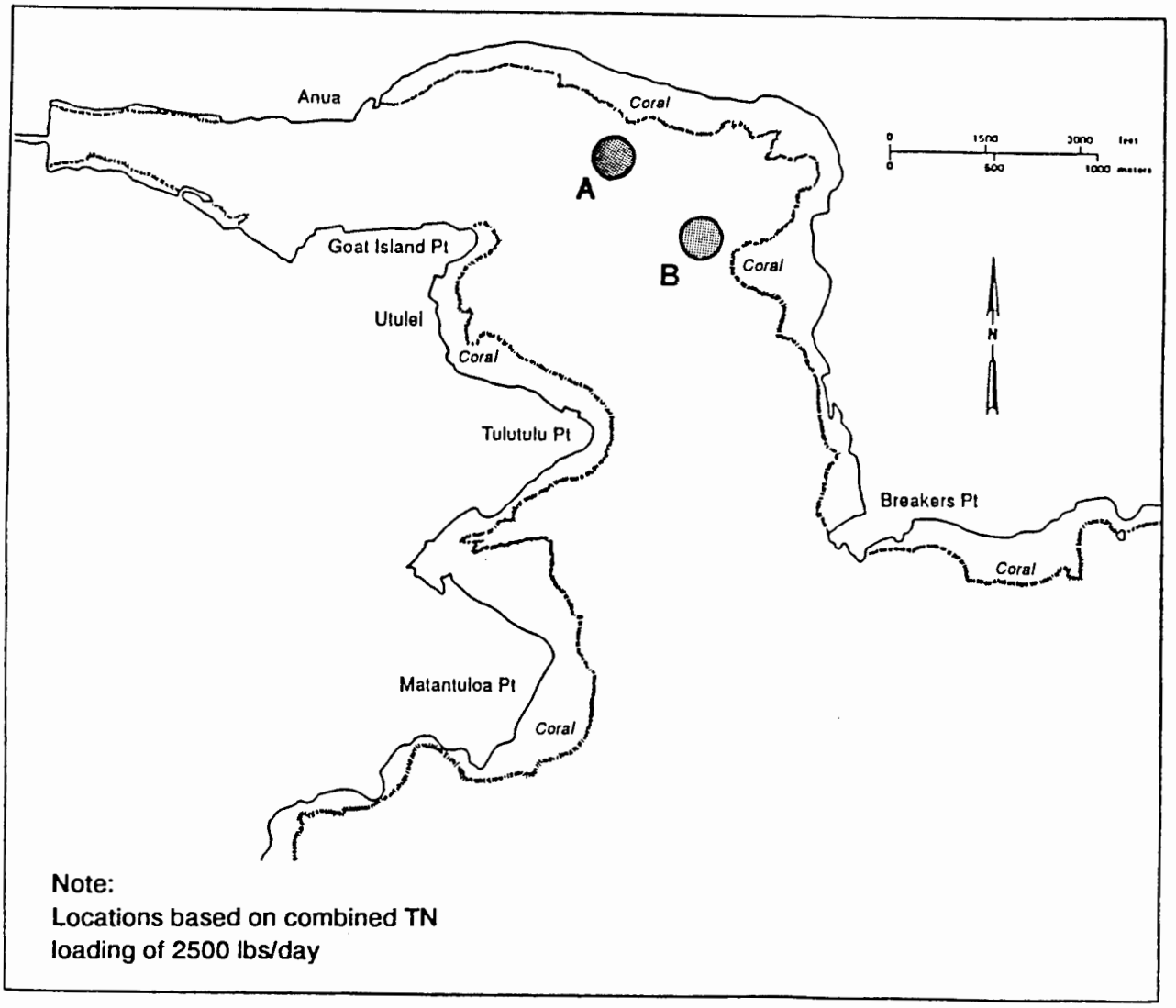


FIGURE ES-2
Approximate Locations of Pipeline Termination Points for TN Standards of 0.250 mg/l (A) and 0.200 mg/l (B)

PIPELINE FEASIBILITY

To investigate the constructibility of a nonburied marine pipeline, CH2M HILL in November 1990 conducted both bathymetric and side scan sonar surveys of the probable pipeline route. Data from these surveys identify the bottom edge of the fringing reef and several rocky areas along the route. The surveys show no apparent areas of anchor scars on the bottom. The results of the surveys indicate that a non-buried pipeline route close to the bottom edge of the reef along the north and east sides of the harbor is feasible.

Preliminary costs of several pipeline scenarios were estimated and strongly suggest that a joint pipeline would be the most cost-effective alternative for both canneries. For a maximum combined flow of 3.2 million gallons per day (mgd), including 2.0 mgd for StarKist and 1.2 mgd for Samoa Packing, a 14-inch pipeline should be considered.

Contacts with the U.S. Army Corps of Engineers in Hawaii and the ASG's environmental coordinator have indicated the extent and nature of the permitting requirements necessary to build an outfall. The requirements do not appear to compromise the feasibility of the pipeline.

CONCLUSIONS

CH2M HILL's conclusions with respect to meeting Pago Pago harbor water quality standards are as follows:

- A single submarine pipeline, to be used by both canneries, made of high density polyethylene (HDPE) should be constructed along the north shore of the harbor and extend towards the outer harbor. The exact length of the pipeline will depend on the outcome of the use attainability analysis now underway and the maximum expected loadings from both canneries.

- Given the existing water quality standard of 0.200 mg/l for TN, a joint pipeline approximately 7,000 feet in length would be needed. The estimated cost is $2.6 million. If the standard were changed to 0.250 mg/l, the pipeline could be shortened to approximately 4,500 feet. The cost of such a pipeline would be $2.2 million (see Table ES-1). These cost estimates may vary from -30 to +50 percent. The cost estimates are in 1990 dollars and do not include escalation. They are feasibility-level cost estimates (-30 to +50 percent) that have been prepared for guidance in project evaluation and implementation from the information available at the time of the estimate. The actual costs of the pipelines will depend on actual labor and material costs, actual site conditions, productivity, competitive market conditions, final project scope, final project schedule, and other variable factors. As a result, the actual costs will vary from

the estimates presented herein. Because of these factors, funding needs must be carefully reviewed prior to making specific financial decisions or establishing final budgets.

- StarKist should continue its efforts to minimize waste loadings through in-plant improvements.

- Detailed engineering design should commence no later than March 1991 in order to meet the March 1992 water quality compliance deadline.

- Permit application preparation and concomitant documentation and agency coordination should commence no later than March 1991.

Table ES-1
PRELIMINARY COST ESTIMATES FOR A
14-INCH DIAMETER JOINT PIPELINE

TN Standard (mg/l)	0.250	0.200
Length of Pipe (ft)	4500	7000
Cost/foot	$360	$280
Construction Cost	$1,620,000	$1,960,000
Diffuser	$32,000	$32,000
Construction Management	$173,000	$212,000
Engineering Design	$158,000	$158,000
Subtotal	$1,983,000	$2,362,000
Contingency (10%)	$198,300	$236,200
Total Estimated Cost	$2,181,300	$2,598,200

Notes:
1. These are feasibility-level cost estimates that may vary by -30 to +50 percent. See text for other cost limitations.
2. For both cases, the TP standard is 0.030 mg/l.

Section 1
INTRODUCTION

PURPOSE

The purpose of this study was to evaluate the environmental and engineering feasibility of various cannery wastewater disposal alternatives for Pago Pago Harbor, and to develop and present a cost/benefit analysis of the disposal alternatives and their engineering and environmental feasibility. As a result of the study, several feasible alternatives have been identified from which a single preferred alternative can be selected to allow initiation of final design and environmental documentation for permitting requirements.

BACKGROUND

The American Samoa Government (ASG) Water Quality Standards require that the waters within Pago Pago Harbor that receive the wastewater discharged from the StarKist and Samoa Packing canneries must not exceed specified contaminant concentration limits. These standards require that median values not exceed 0.2 mg/l for total nitrogen (TN) and 0.03 mg/l for total phosphorus (TP).

The present waste load from the combined discharge of the StarKist and Samoa Packing canneries has been significantly reduced because of the canneries' implementation of high-strength waste segregation and open-ocean disposal of such wastes. The high-strength waste segregation operations began in August 1990. The resulting nutrient loading reduction was estimated to be about 50 to 60 percent of the total presegregation waste loads of TN and 20 to 30 percent of TP.

For the remaining wastes the following disposal alternatives were considered in the feasibility evaluation:

- Alternative 1. Modification of the existing inner harbor outfall. This alternative could include outfall extension into deeper water, addition of a diffuser to enhance initial dilution, or a combination of both of these general improvements.

- Alternative 2. Relocation of the outfall to some point in the outer harbor. This alternative could include a range of depths and outfall locations, an additional diffuser, and a variety of diffuser designs.

- Alternative 3. Relocation of the outfall to the mouth of the harbor or beyond. This alternative also could include a range of depths, and outfall locations, an additional diffuser, and a variety of diffuser designs.

Various approaches were considered for each of these primary alternatives. The regions of the harbor that were defined for the alternatives descriptions are shown in Figure 1-1.

A majority of the background water quality data are reported in the *Baseline Water Quality Study* (M&E Pacific, 1979). The *Wasteload Allocation Study* (Hydro Resources International, 1989) summarizes recent water quality data, precipitation and streamflow data, nutrient loading, and harbor hydraulics. Many of the existing oceanographic data concerning the harbor are summarized in the Oceanographic Studies report done for ASG (CH2M HILL, 1984). The Joint Cannery Study (CH2M HILL, 1987) provides much of the background information needed for the engineering feasibility study.

SCOPE OF REPORT

This report describes the methods used to develop various wastewater disposal alternatives and evaluate their environmental and engineering feasibility. It presents the results of these evaluations and develops costs and schedules for the alternatives. This report is limited to addressing the tasks that were necessary to:

- Provide a review and evaluation of existing data on the physical environment of Pago Pago Harbor

- Describe the methods used for collection and analysis of field data for the geophysical pipeline survey and the water quality sampling

- Present the rationale used and the criteria applied in the water quality and initial dilution modeling

- Provide an analysis of the ability to achieve water quality standards by each of the three action alternatives compared to the no-action alternative (existing discharge following waste segregation)

- Provide costs and schedules for construction of the alternatives, potential environmental documentation potentially required to proceed with an alternative, and the expected performance (benefit) of each alternative relative to the no-action scenario

APPROACH

The study examined the environmental, oceanographic, and engineering aspects of the feasibility evaluation alternatives. The approach used was to review existing data from previous studies and synthesize them with additional information gathered by the modeling and field work conducted during the course of the study. Specific elements of the approach are outlined in more detail below.

WATER QUALITY MODELING

Water quality modeling was performed for two purposes: (1) to predict the improvement in water quality in Pago Pago Harbor that can be expected to result from the high-strength waste segregation and (2) to predict the water quality expected for specific alternative outfall locations and diffuser designs. The information and predictions developed during this study were generated in a manner that would verify, extend, and supplement the work already done by Hydro Resources International (HRI) for the 1989 wasteload allocation study sponsored by ASG.

MIXING ZONE DETERMINATION

A mixing zone determination was necessary to evaluate the size of the mixing zone that will be required under a variety of different alternative outfall locations and diffuser configurations. In general, a "mixing zone" is the volume of water around an outfall where water quality standards for the receiving water will not be realized. The size of a mixing zone will be controlled by initial dilution, subsequent (farfield) dilution, and ambient water quality. Initial dilution depends on the effluent properties, the receiving water properties, and diffuser design. Farfield dilution depends on the currents and turbulence of the receiving water in the vicinity of the discharge. Ambient water quality depends on the background concentrations and the flushing characteristics of the harbor.

SEASONAL VARIABILITY OF OCEAN CURRENTS

One of the receiving water characteristics important in determining initial dilution, farfield dilution, and overall nutrient concentration levels is the current speed and direction. The variations in currents are a result of tidal, wind, and density effects. Currents in Pago Pago Harbor vary on tidal and seasonal time scales. The purpose of this task was to review and evaluate the available data on currents and determine the adequacy of the existing data for the initial dilution and mixing zone analysis. It was recognized that seasonal variability might be an important element in the evaluation.

ENGINEERING EVALUATIONS

The three elements described above are related to water quality. Water quality concerns are the major impetus behind the project. However, a number of other factors

must be considered in evaluating the engineering feasibility of the various possible outfall locations. These factors include constructibility, cost, and permitting. The primary purpose of this task was to account for these factors in making an engineering feasibility assessment. Three specific areas are of concern: geotechnical investigations along the land route of an effluent pipeline, geophysical information along the underwater routes of the outfall and diffuser, and environmental permitting factors under the auspices of territorial and federal agencies. In addition to the above topics, conceptual design, cost estimates, and construction schedules were included in this task.

REPORT ORGANIZATION

This report presents the information required to develop a preferred alternative, a description of the selection process for the preferred approach, and a description of the proposed engineering evaluation as developed. The report is divided into sections that address the following areas:

- Section 2 discusses the physical and environmental data that were required to perform the feasibility evaluation of the waste disposal alternatives.
- Section 3 presents the field data collection and analysis methods used for the geophysical survey and the water quality sampling.
- Section 4 describes the water quality modeling, initial dilution modeling, and determination of the mixing zone geometry.
- Section 5 outlines the engineering evaluation done to assess the feasibility of various pipeline and outfall routes, in addition to environmental permitting requirements.
- Section 6, based on the information presented in the previous sections, presents the evaluation of the alternatives.

The final section of the report provides the references and literature cited. Additional detailed information on the modeling and field data collection is located in the appendixes as background and documentation.

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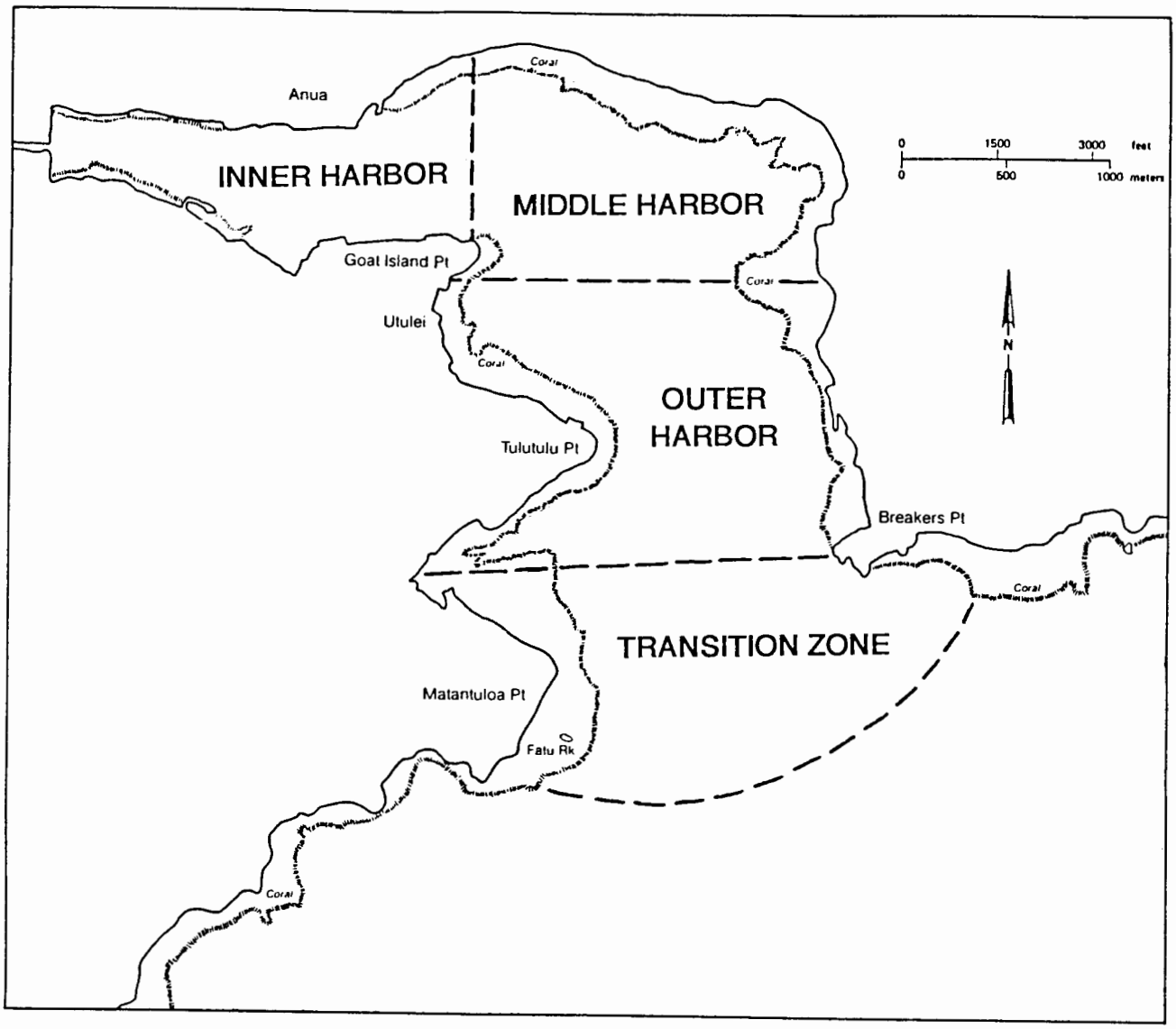

Note: M&E Pacific definition combines outer and middle sections.

FIGURE 1-1
Definition of Regions of Pago Pago Harbor

Section 2
PHYSICAL ENVIRONMENT

An understanding of the physical environment of Pago Pago Harbor is important for this study from two perspectives. First, the physical processes in the harbor, and the forces that control these processes, determine the transport and dispersion of dissolved and suspended constituents in the harbor. Second, the existing loadings, combined with the transport processes, determine the distribution and concentrations of introduced material. The purpose of this section of the report is to provide the information necessary to understand and model the response of the harbor to a range of pollutant loadings introduced at various places in the harbor.

Transport processes are controlled by tidal currents, wind-driven currents, and freshwater flows into the system. In order to assess the relative importance of these factors, brief descriptions are given of the meteorology, hydrology, and tidal characteristics of Pago Pago Harbor. The nature of the transport processes was evaluated on the basis of this information. The result of the evaluation indicated that tidal and freshwater flows are relatively small compared to the wind-driven component of the circulation. Because the wind-driven component is the most variable, random, and complex circulation, a general long-term average description was modeled.

The water quality parameters of interest are the concentrations of TN and TP. These concentrations are controlled by the transport processes, the loadings from various sources, and the natural background levels. A brief description of the recent historical condition of the harbor, the nature of the loadings, and the existing background levels is provided here as a basis for interpreting the model results in the next section of the report.

METEOROLOGY AND HYDROLOGY

The *Wasteload Allocation Study for Pago Pago Harbor, American Samoa* (HRI, 1989) provides a good description of the hydrology and meteorology of Pago Pago Harbor. This reference is used for the following descriptions of the general meteorology and hydrology of Pago Pago Harbor. The reader should refer to this reference for more detail (except for the wind data, which is referenced separately below).

American Samoa is composed of seven islands approximately 2,300 miles southwest of Hawaii, 1,600 miles northeast of New Zealand, and 1,000 miles south of the equator between longitudes 170 and 171°W (Figure 2-1). The total land area of all seven islands is about 76 square miles; Tutuila, the principal island of American Samoa, has an area of about 54 square miles. Tutuila is oriented east and west and has a rugged,

jungle-covered mountain range running from one end of the island to the other. Very little flat land is available on the island. Tutuila is noted for its excellent deepwater harbor, Pago Pago.

RAINFALL

The regional climate of Tutuila Island is tropical, with abundant rain, temperatures ranging between 70 and 90°F, and high humidity. Pago Pago Harbor has about 200 inches of rainfall annually, much of it falling from December to March. However, the local climate of the Pago Pago Harbor area is strongly influenced by Rainmaker Mountain and the associated orographic precipitation effect, so that the harbor area experiences considerably higher precipitation levels than other locations in American Samoa. Consequently, the streamflows in harbor tributaries are high for their watershed size (HRI, 1989).

WINDS

Table 2-1 and Figure 2-2 summarize the monthly wind frequency distribution. These data are from surface weather observations recorded by transient vessels (*U.S. Navy Marine Climatic Atlas of the World*, Volume 5, 1979). The wind statistics were summarized from a 125-year data base (1854 to 1978). The predominant winds are from the east to southeast and from the northeast. The wind patterns are discussed in more detail in the section on current variability, below.

WATERSHED HYDROLOGY

The watershed contributing runoff to the harbor is small relative to the size of the harbor (i.e., 4.9 mi^2 drainage area versus 2.4 mi^2 surface area), so that the volume of streamflow entering the harbor following a rain storm probably is actually less than the volume of direct precipitation onto the harbor (HRI, 1989). The streams tributary to the harbor have small drainages with very steep average channel slopes. Because the precipitation rate is high and exhibits only mild seasonality, the soil remains near a saturated state at most times, so that the streams respond quickly to rainfall. Even though most of the watersheds are heavily vegetated, the runoff coefficients for the harbor subbasins are approximately 30 percent, calculated as annual runoff/annual precipitation. Because groundwater storage is minimal, this suggests that about 70 percent of the rainfall returns to the atmosphere as evaporation. Over open water in the harbor, evaporation is estimated to be about 50 percent of rainfall (HRI, 1989).

OCEANOGRAPHY

Pago Pago Harbor is a deep natural harbor. Reefs of various widths fringe the perimeter of the harbor. Between 1839 and 1927, approximately 23 percent of the reef flat area was filled. Seaward from the reef edge, the depth increases sharply to a relatively flat bottom. Along the centerline of the harbor the bottom slope varies between 1 and 2 percent to a depth of about 200 feet at the harbor mouth (HRI, 1989; from M&E Pacific, 1979).

The volume, or storage capacity, of the harbor is dominated by the outer harbor (Figure 2-3). The distribution of volume is not even, but the harbor narrows, becomes shallower, and contains less volume per unit length as one goes inward from the ocean. This results in restricted circulation and mixing in the inner harbor relative to the outer harbor.

The average surface area of the inner harbor is about 12.6×10^6 square feet, while that of the outer harbor is about 41.4×10^6 square feet. Considering the total volumes, this means that the average depth at mean low water is 71.3 feet for the inner harbor and 100.8 feet for the outer harbor. The overall average depth of Pago Pago Harbor is 94.0 feet (M&E Pacific, 1979).

TIDES

As is common in equatorial locations, the tides at Pago Pago Harbor are nearly sinusoidal and have relatively low amplitudes. Tidal elevations for the harbor can be obtained by applying appropriate corrections to tides that occur at Apia, Western Samoa, which can be found in published tide tables or calculated from tidal harmonic coefficients (HRI, 1989).

According to the NOAA tide tables, the average tidal range for Pago Pago Harbor is 2.5 feet and the tides are semi-diurnal in nature (an average tidal cycle time of 12.4 hours). This means that the outer harbor residence time (volume/daily exchange) when considering tidal exchange only is more than 19.5 days with respect to the transition zone. Similarly, the average inner harbor residence time with respect to the outer harbor is at least 14.8 days, and with respect to the transition zone, 34.3 days (M&E Pacific, 1979). These calculations do not take into account watershed runoff, wind-induced transport, or stratification effects and should be regarded as order-of-magnitude estimates.

CIRCULATION

Previous studies have shown that there is a layered structure of water movement in Pago Pago Harbor (M&E Pacific, 1979; CH2M HILL, 1984). The upper layer moves primarily as a result of wind stress on the surface and, possibly, freshwater flows. The

lower layer responds to the upper layer and the influence of the tide. Exchange at the mouth of the harbor is influenced by the direction and intensity of the nearshore currents, which possibly change seasonally (M&E Pacific, 1979).

M&E Pacific (1979, page V-2) estimates the surface area of the entire harbor as 54 x 10^6 feet^2. The average tidal range is predicted by NOS (1990) to be 2.5 feet. Thus, the average tidal flow into and out of the harbor is 135 x 10^6 feet^3 on each half-tidal cycle (this volume is generally called the mean tidal prism). Figure V-3 in the M&E Pacific Baseline Survey (1979) shows the outer harbor entrance flow area as about 457 x 10^3 feet^2. Figure 1-1 of this feasibility study shows the M&E Pacific definitions of inner and outer harbor and the location of the cross-section at the entrance (between outer harbor and transition area). For a tidal cycle of lunar semi-diurnal period (12.42 hours), the average speed over a half-tidal cycle (6.21 hours) is about 47.6 ft/hr at the outer harbor entrance.

For the inner harbor the same sources estimate the surface area as 12.6 x 10^6 feet^2 and the cross-sectional area at the seaward end of the inner harbor (Figure 1-1) as 291 x 10^6 feet^2. Therefore, the average speed is 17.4 ft/hr.

Maximum tidal flow rates would occur approximately midway between high and low water. For a sinusoidal aproximation of tides, the resulting maximum sectionally averaged flow speeds are 74.8 ft/hr and 27.3 ft/hr for the entrance sections to the inner and outer harbors, respectively. The maximum speeds at a point would be found in the centers of the sections, but would not be expected to be higher than twice the sectionally averaged maximum values.

The tidal flow rates and velocities calculated above are one to two orders of magnitude less than those measured by M&E Pacific (1979) and CH2M HILL (1984). This indicates that the major currents in Pago Pago Harbor are not tidal phenomena.

The maximum freshwater flow into Pago Pago Harbor can be estimated by using the flow duration curves presented in the Wasteload Allocation Study. With station No. 9480 considered typical (pp. 38 and 39, HRI, 1989), the 1-percentile flow is 15 cubic feet per second (cfs) for a drainage area of 0.25 square mile. If this runoff is applied to the entire watershed of 4.9 square miles, the peak flow into the harbor is 294 cfs.

The area of the harbor is about 2.4 square miles, so that direct precipitation consistent with a 30 percent runoff factor would be 294/0.3 times the ratio of the areas (2.4/4.9), or 480 cfs. The sum of the extreme-event freshwater flow plus the extreme-event direct rainfall is 754 cfs. This value represents an order-of-magnitude estimate of the maximum freshwater input into the harbor.

If such a flow were to continue over the time scale of a tidal cycle, it would represent about 17 million cubic feet over a half-tidal cycle, or 12 percent of the tidal prism. It is

unlikely that even for extreme events the freshwater inflows would significantly modify the circulation or current patterns of the harbor for any length of time. For example, if the freshwater were to dilute the upper 30 feet (about the observed size of a surface layer) from 34.5 to 28 parts per thousand, about 4,000 cfs would be involved in an ocean-directed, density-driven surface flow. The cross-sectional area of the mouth of the harbor in the upper 30 feet is about 100,000 square feet (M&E Pacific, 1979, p. V-5). The surface current generated by the extreme event constructed above would be about 0.04 feet/second or 1.2 cm/sec. The median stream discharge (50th percentile) is only about 1/25th of the peak discharge. Clearly, freshwater-runoff-driven flows in the harbor are a minor contribution to the overall circulation based on the current speeds measured in other studies.

CURRENT VARIABILITY

The currents, and therefore the general circulation pattern, in Pago Pago Harbor are not predominantly tidal or freshwater inflow driven. The currents that can be generated by these forces are much smaller than observed currents. The only other agent available as a forcing function is the wind. The conclusion is that the currents in the Pago Pago Harbor are predominantly wind driven. This has a number of implications on circulation, transport, and the dispersion of introduced pollutants, including:

- Existing meter and drogue data indicate that the currents are highly variable in direction and magnitude. There is no regular pattern other than long-term averages, associated with long-term average wind conditions.

- The currents are not easily predictable either quantitatively or statistically. The number of field data required to characterize the details of the currents would require a large number of stations, with meters at different depths at each station, occupied over a long period of time. A number of wind stations would need to be simultaneously occupied. Such a data collection effort is neither practical nor feasible.

- Without the data described above, a wind-driven model of the harbor would be difficult to calibrate and verify. The use of a model with existing data, although providing some information, could not definitively describe the details of the harbor circulation.

Because of the nature of the circulation in the harbor and the data available, the following approach was taken to account for current variability in the harbor:

- No new current data were collected because the effort and cost to add meaningful amounts of data to the existing data base would be unreasonably large.

- The available offshore wind data were acquired (Table 2-1 and Figure 2-2), and a description of the overall (long-term average) nature of the currents in the harbor was developed from an understanding of wind-driven circulation.

- The available data from current meters and drogue releases (Table 2-2 and Figures 2-4a and 2-4b) were inspected and the effect of local topographic effects was incorporated to refine the description of long-term average current patterns.

- Short-term variability of current speed and direction was accounted for by developing an appropriate dispersion (diffusion) coefficient based on long-term averages of TN and TP concentrations and the model described in Section 4.

Examination of the offshore wind data shows that the predominant direction of the wind is from the southeast and east. Because of the topography of the harbor and nearshore area, and on the basis of experience with wind-driven circulation in other areas, the predominant wind-driven currents are expected to be as described in Figure 2-5.

Examination of available current and drogue release data, particularly when some simultaneous wind data are also available, allows some refinement and additional detail. Because of the general shape of the coastline and the nearshore topography, a large eddy, in the long-term net pattern, appears to exist at the east side of the outer harbor and harbor entrance (Figure 2-5). This results in outward surface and deeper flows in this area, on a long-term basis.

TRANSPORT AND DISPERSION

Once wastewater is discharged into the ocean or a harbor, it is transported and dispersed by currents and turbulence. The currents are influenced by the general circulation pattern and by local winds, tides, watershed runoff, coastline morphology, and submarine topography. Turbulence, and thus effective diffusion and dilution, is influenced by the same factors. Precise prediction of wastefield transport and dispersion can require extensive data acquisition and complicated numerical or physical modeling procedures. A good idea of general circulation patterns in Pago Pago Harbor was obtained from current meter and drogue data as described above.

Probably the most critical criterion for outfall location in Pago Pago Harbor area is meeting water quality standards within the harbor itself. This can be accomplished by discharging at a location outside the harbor to reduce the chance of transport back into the harbor, or at a location in the harbor that flushes rapidly into the open ocean. The distant-location alternative is appropriate for sludge and high-strength waste disposal

but, as documented in following sections of this report, is expensive and is not necessary for making the remaining discharge meet harbor water quality criteria. An alternative approach is to select a location within the harbor that has appropriate flushing characteristics. A wastewater discharge plume along the northeast side of the harbor would be in a location with a net outward transport. However, surface drogue studies have shown that winds could transport floating material into the harbor from these locations. Wastewater discharged at these locations should therefore be free of floatables, and the plume should be kept submerged if possible.

Although discharge in an area of net outward transport is desirable, the highly variable nature of the currents in Pago Pago Harbor will result in the distribution of pollutants throughout the harbor regardless of the discharge point. The prediction of concentrations requires the specification of a turbulent diffusion coefficient. Horizontal dye dispersion measurements were made by M&E Pacific (1979) on three occasions in the inner harbor and once in the outer harbor. The horizontal dispersion coefficient was calculated from the definition developed by Brooks (1960), on the basis of Fick's Law.

The variation inherent in this type of measurement is evident in Figure 2-6. The inner harbor dispersion coefficient magnitude and relationship to scale is typical for a semi-confined water body in that the overall rate of increase with scale is slow and the smaller scale values are somewhat higher than has been theoretically calculated for open ocean conditions with no boundary effects. The few data points obtained for the outer harbor are insufficient to define the effect of scale on the dispersion coefficient. Figure 2-6 shows that the water column mixes as deep as about 100 feet very rapidly. This information on the dispersion coefficients in Pago Pago Harbor is useful in making dispersion calculations after initial dilution for wastewater discharges. However, these data are not appropriate for the calculation of long-term averages or larger scales (i.e., the entire harbor). Turbulent diffusion coefficients for larger temporal and spatial scales were developed by using existing water quality data (see Section 4).

WATER QUALITY AND SEDIMENT CHARACTERISTICS

This section provides brief descriptions of water, sediment, and effluent characteristics. Other sources are referenced that have more detailed descriptions of the historical trends of these parameters. Some of this information is summarized in Appendix A for convenience. The material presented below provides background about recent data and specific points for comparison and use in later sections of this report.

WATER QUALITY

The primary constituents of concern are TN and TP. HRI (1989) developed a detailed description of the temporal and spatial (longitudinal and vertical) trends for these parameters up to 1988. In August of 1990 the canneries began high-strength waste segregation and disposal of these wastes at sea. To provide a basis for evaluating the

effects of this action, the TN and TP data available for the period 1987 through August 1990 were described in terms of mean, range, and standard deviation. These summaries are presented in Tables 2-3 and 2-4. Figure 2-7 shows the locations of these historial ASG sampling stations. Complete listings of the data are provided in Appendix A.

After high-strength waste segregation was begun, one set of water quality samples was collected by CH2M HILL in Pago Pago Harbor to document the present receiving water nutrient concentrations and harbor sediment conditions and to provide supporting information for the feasibility study. Additional data have also been collected by ASG.

The ASG water quality standards for nutrients in Pago Pago Harbor are the basis of comparison in this study. The ASG water quality standards for effluent discharges (as applied at the boundary of a mixing zone) are 0.200 mg/l for TN and 0.030 mg/l for TP.

The purpose of the water quality sampling performed in this feasibility study was to provide additional TN and TP values in Pago Pago Harbor following the canneries' implementation of high-strength waste segregation. On November 1, 1990, 35 water samples were collected at various depths at seven historical ASG sampling stations. One sample was taken from the surface at the Utulei outfall. The seven ASG sampling stations are located outside the harbor (Station 5), in the outer harbor (Station 6), in the middle harbor (Stations 9 and 10), and in the inner harbor (Stations 11, 12, and 13). Figure 2-7 shows the locations of the sites sampled on November 1.

The water quality sampling in Pago Pago Harbor was conducted in accordance with the procedures specified in the field protocol for water quality sampling (Appendix B). An additional sample was collected at the surface wastefield for the Utulei outfall (sanitary discharge), which was not initially specified in the field protocol.

The results of the TN and TP analyses are presented in Table 2-5. Nutrient values are highest at the inner harbor stations and in the surface waters. Comparisons of these data with the 1987 through 1990 presegregation data are presented in Table 2-6.

As expected, there appears to be a general decrease in TN and TP concentrations. Figures 2-8a and 2-8b illustrate this decrease by comparing depth profiles of TN and TP at the sampling stations. The ASG data obtained after the initiation of high-strength waste segregation are also shown in Table 2-6.

The background concentrations are important when evaluating or modeling the effects of various loadings. The background condition is defined as the concentration that would be found in the absence of any loadings. In the case considered here, this is the typical nearshore open coastline (outside the harbor) value. The best data sources are the Baseline Water Quality Survey data (M&E Pacific 1979) summarized in Table 2-7,

and the minimum values measured in the transition zone (Station 5) given in Tables 2-3 and 2-4. Values used in this study for background are 0.120 mg/l for TN and 0.0125 mg/l for TP.

SEDIMENT CHARACTERISTICS

The seabed or benthic environmental impacts of an ocean outfall wastewater discharge result from the settling of the wastewater's suspended solids around an outfall diffuser site. The potential effects include near-bottom dissolved oxygen depletion, sediment biochemical oxygen demand and volatile solids loadings, and sedimentation of the suspended solids on immobile organisms and fringing reef areas (CH2M HILL, 1984). Available information about the quality of the sediments that make up the benthic environment are summarized in this section to provide a background for the sediment sampling described in the following section.

The harbor is generally fringed by shallow reefs, actively growing at least in the outer harbor. Abrasion of these reefs by waves and other forces generates the bulk of the coral sand and rubble generally found throughout the harbor. In the inner harbor, sedimentary conditions are influenced by freshwater inflow, which supplies quantities of fine terrigenous material. Flocculation and sedimentation of this material in combination with coral debris produce the calcareous mud found in much of the inner harbor. Early investigations of the bottom sediment indicate that brown volcanic mud comprises 67 percent of sample weight at the head of the harbor but only 6 percent of the sample weight at the harbor mouth (Mayer, 1924; from ASCRI, 1980).

When terrigenous material is combined with sanitary and industrial wastes, a localized area of fine eutrophic black mud occurs (URS, 1974). This anoxic black mud is particularly notable near the tuna canneries and Pago Pago Park. The thickness of anoxic black silt near the canneries varies from 1 to 5 feet (0.3 to 1.5 m). Black anaerobic sediment averages 23 inches (60 cm) deep in the inlet between the StarKist cannery and the drydock facility. Across the harbor, gray sediment averages 7 inches (16 cm) deep off Fagatogo. In general, this surface layer is underlain by a mixture of dense gray mud, silty sand, gravel, rock, and broken coral fragments extending at least 50 to 60 feet below the harbor bottom (ASCRI, 1980).

EFFLUENT LOADING

The water quality of the harbor, as measured by TN and TP, is predominantly driven by the effluent loadings of the canneries. Other water quality parameters, such as salinity, are only influenced in a minor way by the cannery discharges. HRI (1989) has presented a detailed summary of available information on effluent loadings by the canneries, the Utulei sewage treatment plant, and other point and nonpoint sources. The HRI description of the effluent loadings from the canneries is presented in Appendix A.

Two points have not been addressed by previous studies. These are the general variability (short term) of the effluent loadings, and the impact of high-strength waste segregation on TN and TP loadings. These points are discussed below.

SHORT-TERM VARIABILITY

Data from two periods, December 18 to 22, 1989, and January 8 to 12, 1990, are available that provide time series of TP and TN concentrations as well as effluent flow rates every 2 hours. There is considerable variability both in time and effluent flow rate. The loadings used to determine water quality impacts on the harbor should be composites or averages in order to account for the short-term fluctuations. Plots of TN, TP, and flow rate are provided in Appendix A.

FUTURE TN AND TP LOADINGS

The outfall location will depend on the loadings after high-strength waste segregation. The StarKist loadings for TN and TP measured since the initiation of high-strength waste segregation are shown in Figure 2-9. This figure shows the results of twice-weekly composite samples for August through December 1990. These values can be compared to the historical levels given in Appendix A. The maximum TN loading observed since high-strength waste segregation was started is under 2,000 pounds per day, and the 90 percentile level is about 1,700 pounds per day. The maximum TP loading is just over 300 pounds per day, with a 90 percentile level at about 250 pounds per day.

- does this take into account: ① SP effluent loadings? ② Future cannery production?

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Table 2–1
PERCENT FREQUENCY OF WINDS FROM
EACH DIRECTION BY MONTH

WIND DIRECTION	MONTH												TOTAL
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
NORTH	14	17	9	4	5	2	2	–	3	4	5	12	7
NORTHEAST	18	17	15	7	10	9	5	6	9	8	10	19	11
EAST	24	21	31	31	34	41	38	40	33	44	29	29	33
SOUTHEAST	13	12	13	32	39	35	44	43	48	33	33	20	31
SOUTH	7	5	3	8	7	5	3	5	6	4	6	5	5
SOUTHWEST	5	4	1	1	–	–	2	1	1	–	2	3	2
WEST	4	5	8	5	1	–	1	–	–	–	2	3	3
NORTHWEST	9	13	12	6	2	2	–	–	–	1	4	6	5
CALM	3	2	4	4	3	1	2	1	2	2	3	2	3

Note:
– denotes winds < 0.5 % frequency, but > 0 %

(Source: *U.S. Navy Marine Climatic Atlas of the World,* Volume 5, October 1979)

Table 2-2
SUMMARY OF AVAILABLE CURRENT DATA
FOR PAGO PAGO HARBOR

STATION NO.	STATION DEPTH (ft)	CURRENT METERS ON ARRAY	CURRENT METER DEPTH (ft)
CH2M HILL (1)			
1	150	Mid-depth	60
2	172	Mid-depth	70
3	180	Upper	15
		Mid-depth	60
4	220	Upper	80
		Mid-depth	125
5	200	Upper	20
		Mid-depth	65
6	114	Upper	15
		Mid-depth	60
7	138	Upper	15
		Mid-depth	60
8	125	Upper	20
		Mid-depth	65
CH2M HILL (2)			
5	N/A	Upper	30
		Mid-depth	70
		Mid-depth	90
		Bottom	130
CH2M HILL (3)			
1	120	N/A	N/A
M&E PACIFIC (4)	75	Mid-depth	30-35

Note:
(1) CH2M HILL current meters deployed for 42 days for the period July 15 through August 25, 1983.
(2) CH2M HILL current meters deployed April 29 through June 10, 1985 at Station 5 (called Stations 85-1 and 85-2)
(3) CH2M HILL current meters deployed October 14 and 15, 1975, over one complete tidal cycle (called site 1)
(4) M&E Pacific current meter deployed for 21 days in February and March 1979 and for 17 days in July 1979.

Table 2-3
SUMMARY OF TOTAL NITROGEN DATA PRIOR TO
HIGH-STRENGTH WASTE SEGREGATION (1987-1990)

STATION	DEPTH (ft)	NUMBER OF OBSERVATIONS	TN CONCENTRATION (mg/l) MEAN	MAXIMUM	MINIMUM	STANDARD DEVIATION
5	3	10	0.256	0.410	0.130	0.096
5	30					
5	60	20	0.226	0.410	0.120	0.093
6	3	14	0.245	0.840	0.122	0.175
6	30	1	0.200	0.200	0.200	
6	60	15	0.183	0.280	0.100	0.047
7	3	14	0.344	0.730	0.140	0.160
7	30	4	0.543	1.560	0.140	0.590
7	60	17	0.200	0.312	0.080	0.070
8	3	15	0.426	1.080	0.120	0.266
8	30	1	0.490	0.490	0.490	
8	60	16	0.237	0.420	0.100	0.099
8A	3	15	0.424	0.978	0.170	0.262
8A	30	2	0.245	0.270	0.220	0.025
8A	60	17	0.249	0.490	0.111	0.109
9	3	15	0.559	1.100	0.180	0.294
9	30	2	0.235	0.330	0.140	0.095
9	60	6	0.311	1.020	0.093	0.230
9A	3	15	0.565	1.120	0.200	0.268
9A	30	2	0.280	0.300	0.260	0.020
9A	60	17	0.299	0.800	0.050	0.176
10	3	15	0.390	0.880	0.180	0.210
10	30	2	0.270	0.320	0.220	0.050
10	60	17	0.268	0.630	0.120	0.147
11	3	15	0.811	1.630	0.220	3.358
11	30	2	0.980	1.170	0.790	0.190
11	60	17	0.436	1.050	0.133	0.306
11A	3	14	1.071	1.800	0.366	0.407
11A	30	3	1.283	1.880	0.910	0.426
11A	60	17	0.557	1.300	0.127	0.344
12	3	14	0.838	1.240	0.296	0.280
12	30	2	0.555	0.600	0.510	0.045
12	60	17	0.475	1.060	0.155	0.279
13	3	17	1.720	17.200	0.410	3.877
13	30	17	0.711	1.280	0.319	0.284

Table 2–4
SUMMARY OF TOTAL PHOSPHORUS DATA PRIOR TO
HIGH–STRENGTH WASTE SEGREGATION (1987–1990)

STATION	DEPTH (ft)	NUMBER OF OBSERVATIONS	TP CONCENTRATION (mg/l) MEAN	MAXIMUM	MINIMUM	STANDARD DEVIATION
5	3	10	0.022	0.051	0.009	0.012
5	30					
5	60	20	0.020	0.053	0.004	0.012
6	3	14	0.023	0.071	0.002	0.016
6	30	1	0.019	0.019	0.019	
6	60	15	0.019	0.033	0.005	0.007
7	3	14	0.028	0.062	0.012	0.014
7	30	3	0.073	0.160	0.018	0.062
7	60	17	0.020	0.034	0.006	0.008
8	3	15	0.035	0.081	0.013	0.021
8	30	1	0.045	0.045	0.045	
8	60	16	0.023	0.046	0.004	0.010
8A	3	15	0.036	0.084	0.013	0.021
8A	30	2	0.040	0.053	0.027	0.013
8A	60	17	0.021	0.043	0.004	0.010
9	3	15	0.056	0.110	0.018	0.028
9	30	2	0.029	0.033	0.025	0.004
9	60	6	0.031	0.093	0.013	0.019
9A	3	15	0.053	0.141	0.015	0.031
9A	30	2	0.030	0.031	0.029	0.001
9A	60	17	0.029	0.102	0.010	0.020
10	3	15	0.030	0.067	0.001	0.015
10	30	2	0.038	0.046	0.030	0.008
10	60	17	0.022	0.040	0.001	0.009
11	3	15	0.081	0.259	0.035	3.511
11	30	2	0.068	0.108	0.027	0.040
11	60	17	0.039	0.110	0.014	0.026
11A	3	14	0.119	0.250	0.054	0.056
11A	30	3	0.124	0.143	0.113	0.013
11A	60	17	0.054	0.176	0.006	0.042
12	3	14	0.096	0.174	0.038	0.037
12	30	2	0.063	0.076	0.050	0.013
12	60	17	0.054	0.119	0.014	0.033
13	3	17	0.364	4.560	0.046	1.050
13	30	17	0.095	0.199	0.038	0.052

Table 2-5
WATER QUALITY PROFILE DATA
FOR PAGO PAGO HARBOR
SAMPLED 11/1/90

STATION	DEPTH ft (m)	TN (mg/l)	TP (mg/l)
OUTER HARBOR			
5-Surface	S	0.128	0.017
5-Surface/Dup	S	0.144	0.016
5-Mid	82 (25)	0.099	0.014
5-Bottom	164 (50)	0.116	0.017
6-Surface	S	0.192	0.027
6-Mid-Upper	13 (4)	0.125	0.013
6-Mid-Mid	33 (10)	0.116	0.007
6-Mid-Lower	98 (30)	0.106	0.012
6-Bottom	213 (65)	0.109	0.020
Utulei Outfall-Surface	S	0.264	0.031
MIDDLE HARBOR			
9-Surface	S	0.209	0.030
9-Mid-Upper	13 (4)	0.126	0.025
9-Mid-Lower	66 (20)	0.108	0.016
9-Mid-Lower/Dup	66 (20)	0.111	0.013
9-Bottom	157 (48)	0.203	0.029
10-Surface	S	0.248	0.025
10-Mid-Upper	13 (4)	0.223	0.043
10-Mid-Lower	66 (20)	0.124	0.004
10-Mid-Lower/Dup	66 (20)	0.123	0.005
10-Bottom	197 (60)	0.168	0.014
INNER HARBOR			
11-Surface	S	0.308	0.050
11-Mid-Upper	13 (4)	0.357	0.046
11-Mid-Upper/Dup	13 (4)	0.346	0.044
11-Mid-Mid	33 (10)	0.121	0.003
11-Mid-Lower	66 (20)	0.105	0.002
11-Bottom	164 (50)	0.209	0.026
12-Surface	S	0.509	0.066
12-Surface-Dup	S	0.421	0.063
12-Mid-Upper	13 (4)	0.365	0.047
12-Mid-Upper/Dup	13 (4)	0.351	0.057
12-Mid-Lower	33 (10)	0.155	0.021
12-Bottom	131 (40)	0.209	0.028
13-Surface	S	0.371	0.061
13-Surface/Dup	S	0.350	0.060
13-Mid-Depth	13 (4)	0.424	0.064
13-Bottom	66 (20)	0.236	0.037

Note:
Surface samples (S) collected at least 30 cm below and not more than 1 meter beneath surface. Bottom samples (B) collected within 2 meters of the bottom.

Table 2-6
COMPARISON OF PRE- AND POST-
SEGREGATION WATER QUALITY

STATION NO.	DEPTH (ft)	TOTAL NITROGEN (mg/l)					TOTAL PHOSPHORUS (mg/l)				
		HISTORICAL MEAN (1),(4)	CH2M HILL DATA (2)	% DIFF	RECENT ASG DATA (3)	% DIFF	HISTORICAL MEAN (1),(4)	CH2M HILL DATA (2)	% DIFF	RECENT ASG DATA (3)	% DIFF
5	3	0.256	0.136	47	0.140	45	0.022	0.017	23	0.019	14
6	3	0.245	0.192	22	0.350	-43	0.023	0.027	-17	0.043	-87
	30	0.200	0.116	42	na	na	0.019	0.007	63	na	na
9	3	0.559	0.209	63	0.200	64	0.056	0.030	46	0.017	70
	60	0.311	0.110	65	0.145	53	0.031	0.015	52	0.019	39
10	3	0.390	0.248	36	0.140	64	0.030	0.025	17	0.021	30
	60	0.268	0.124	54	0.125	53	0.022	0.005	77	0.028	-27
11	3	0.811	0.308	62	0.205	75	0.081	0.050	38	0.031	62
	30	0.980	0.121	88	na	na	0.068	0.003	96	na	na
	60	0.436	0.105	76	0.320	27	0.039	0.002	95	0.027	31
12	3	0.838	0.465	45	0.335	60	0.096	0.065	32	0.053	45
	30	0.555	0.155	72	na	na	0.063	0.021	67	na	na
13	3	1.720	0.361	79	0.505	71	0.364	0.061	83	0.126	65

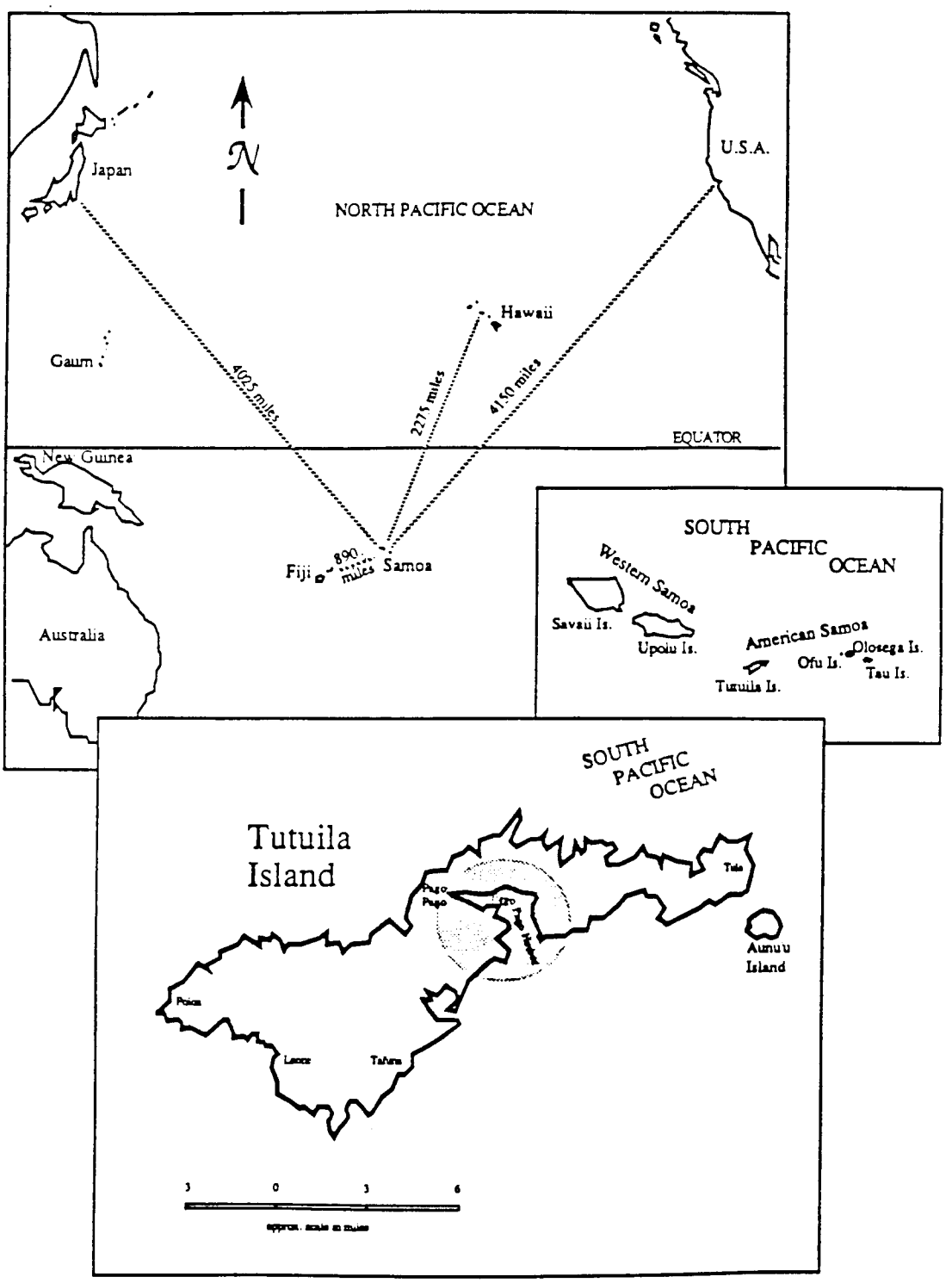
Note:
(1) See Table 2-3.
(2) See Table 2-5 (November 1, 1990); duplicate samples were averaged.
(3) Average of September and October 1990 ASG water quality data.
(4) See Table 2-4.

Table 2-7

OCEAN BACKGROUND CONCENTRATIONS OF
TOTAL NITROGEN AND TOTAL PHOSPHORUS

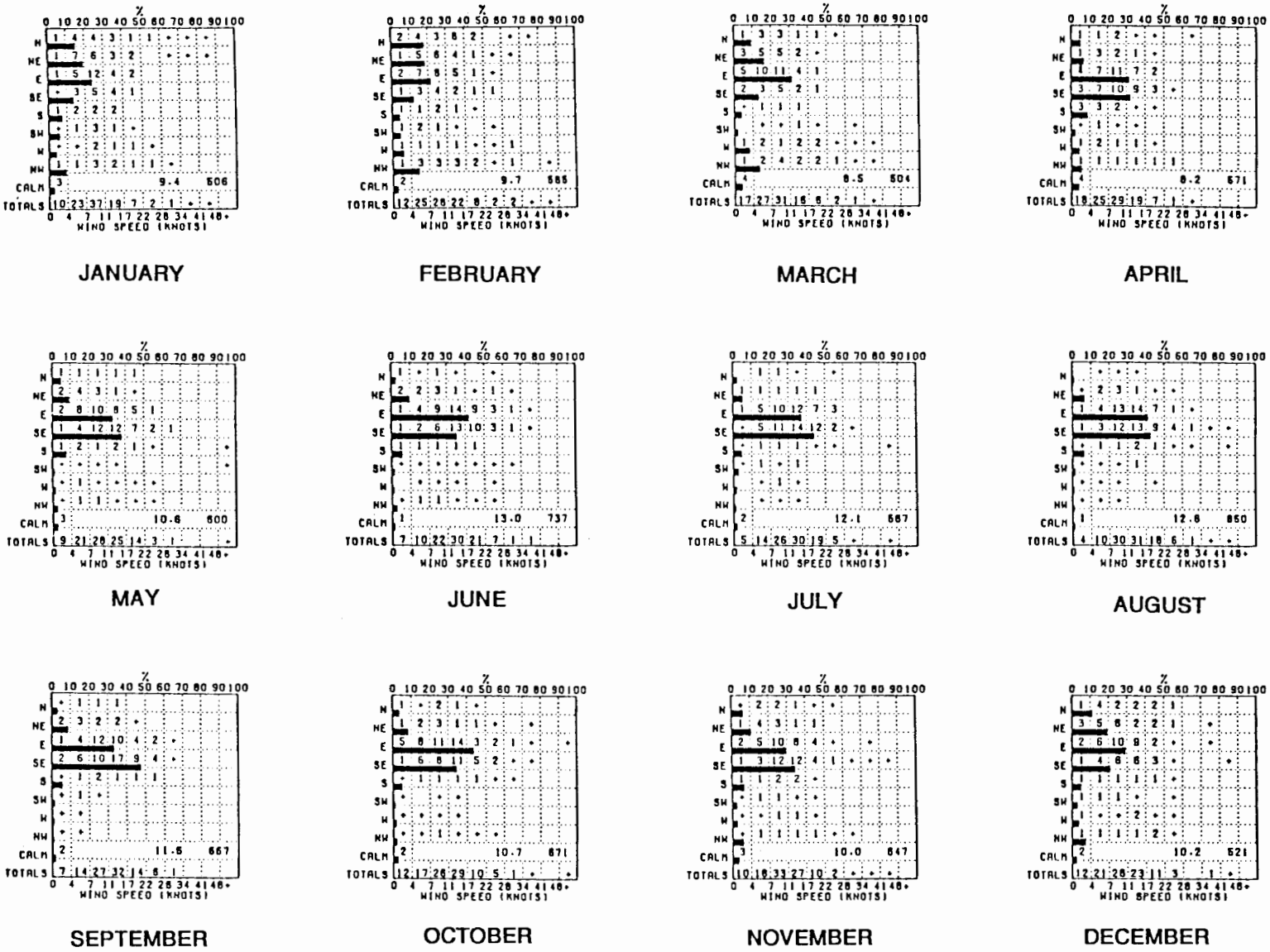
LOCATION	TOTAL KJELDAHL NITROGEN				NITRATE + NITRITE				TOTAL PHOSPHORUS			
	NUMBER OF OBSERVATIONS	MEAN (mg/l)	STD DEV. (mg/l)	MEDIAN (mg/l)	NUMBER OF OBSERVATIONS	MEAN (mg/l)	STD DEV. (mg/l)	MEDIAN (mg/l)	NUMBER OF OBSERVATIONS	MEAN (mg/l)	STD DEV. (mg/l)	MEDIAN (mg/l)
Ocean Stations												
Surface	17	0.103	0.052	0.087	18	0.018	0.020	0.014	17	0.013	0.010	0.012
60 ft	18	0.106	0.032	0.103	18	0.016	0.017	0.011	17	0.011	0.006	0.010
Open Coastal-Nearshore												
Surface	9	0.101	0.021	0.107	12	0.047	0.033	0.039	12	0.012	0.008	0.007
60 ft	9	0.095	0.031	0.100	12	0.036	0.033	0.027	12	0.007	0.003	0.006
Embayment												
Surface	6	0.072	0.009	0.075	6	0.024	0.068	0.026	6	0.022	0.017	0.016
60 ft	6	0.120	0.043	0.105	6	0.016	0.012	0.015	6	0.014	0.009	0.016

Source: M & E Pacific, 1979



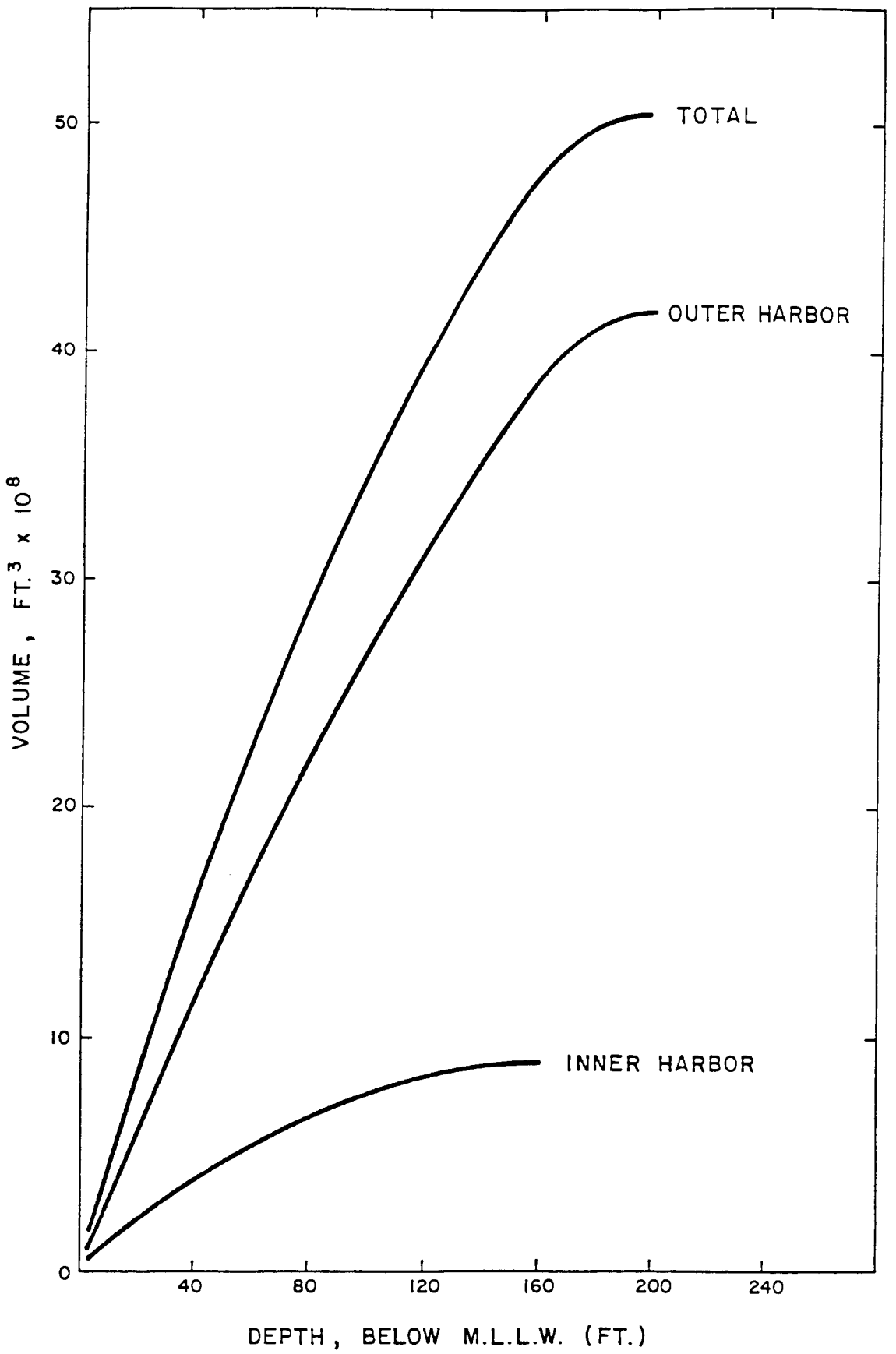
Note: from HRI, 1989.

FIGURE 2–1
Location of Study Area



Note: from U.S. Navy, 1979.

FIGURE 2–2
Offshore Wind Speed and Direction Frequency



Note: from M&E Pacific, 1979.

FIGURE 2-3
Volume Distribution of Pago Pago Harbor

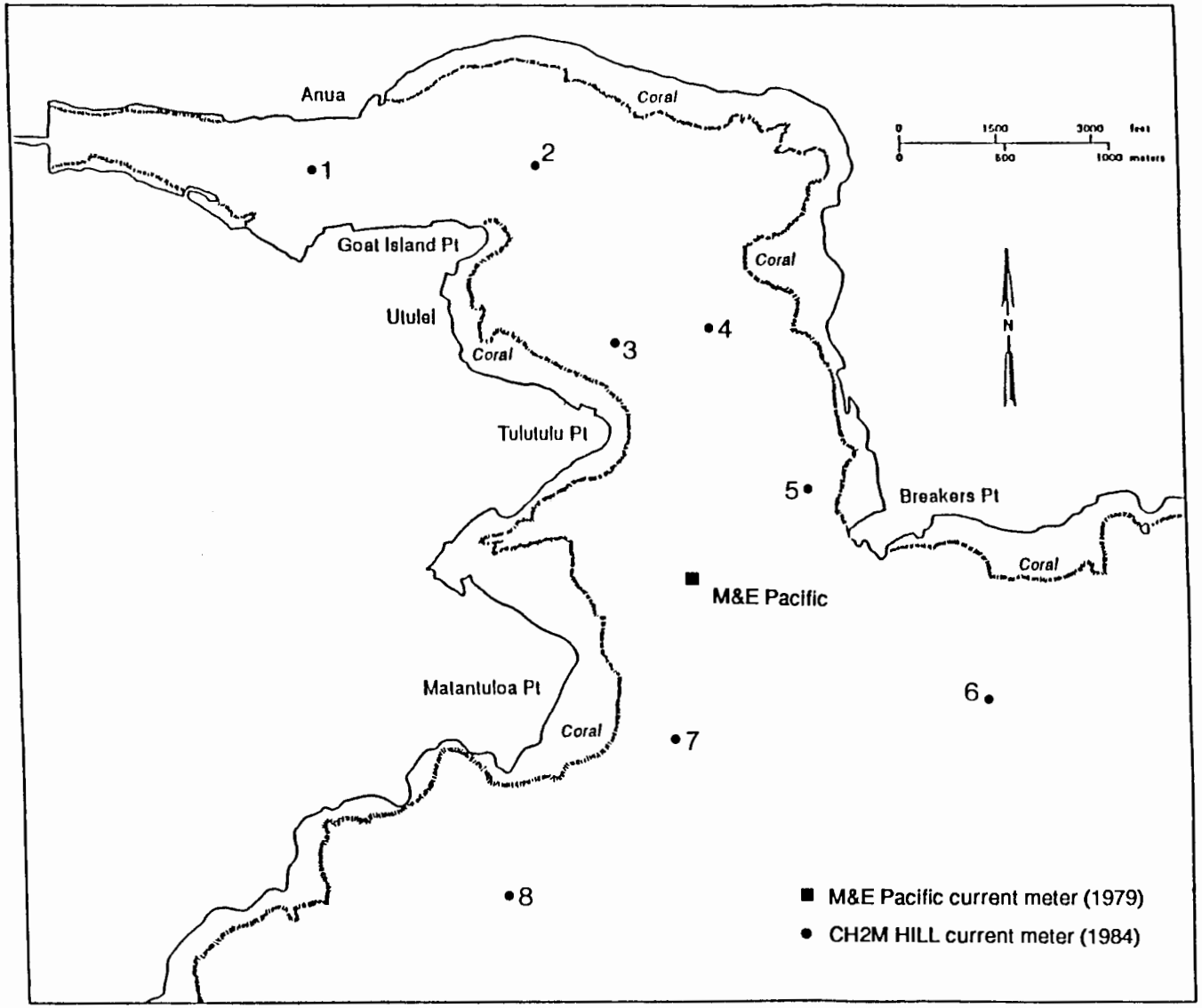


FIGURE 2–4a
Location of Current Meter Stations

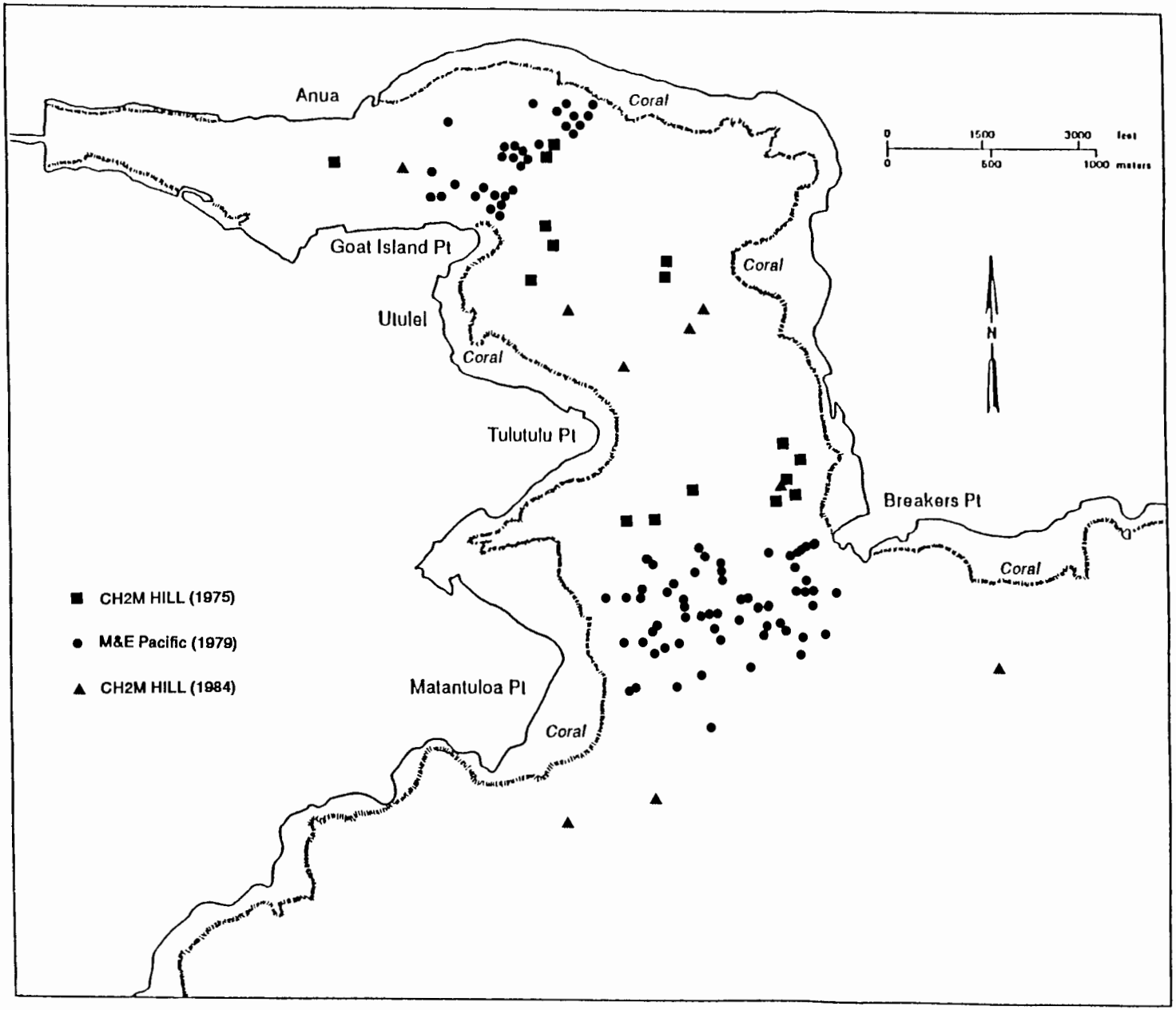


FIGURE 2-4b
Drogue Release Points

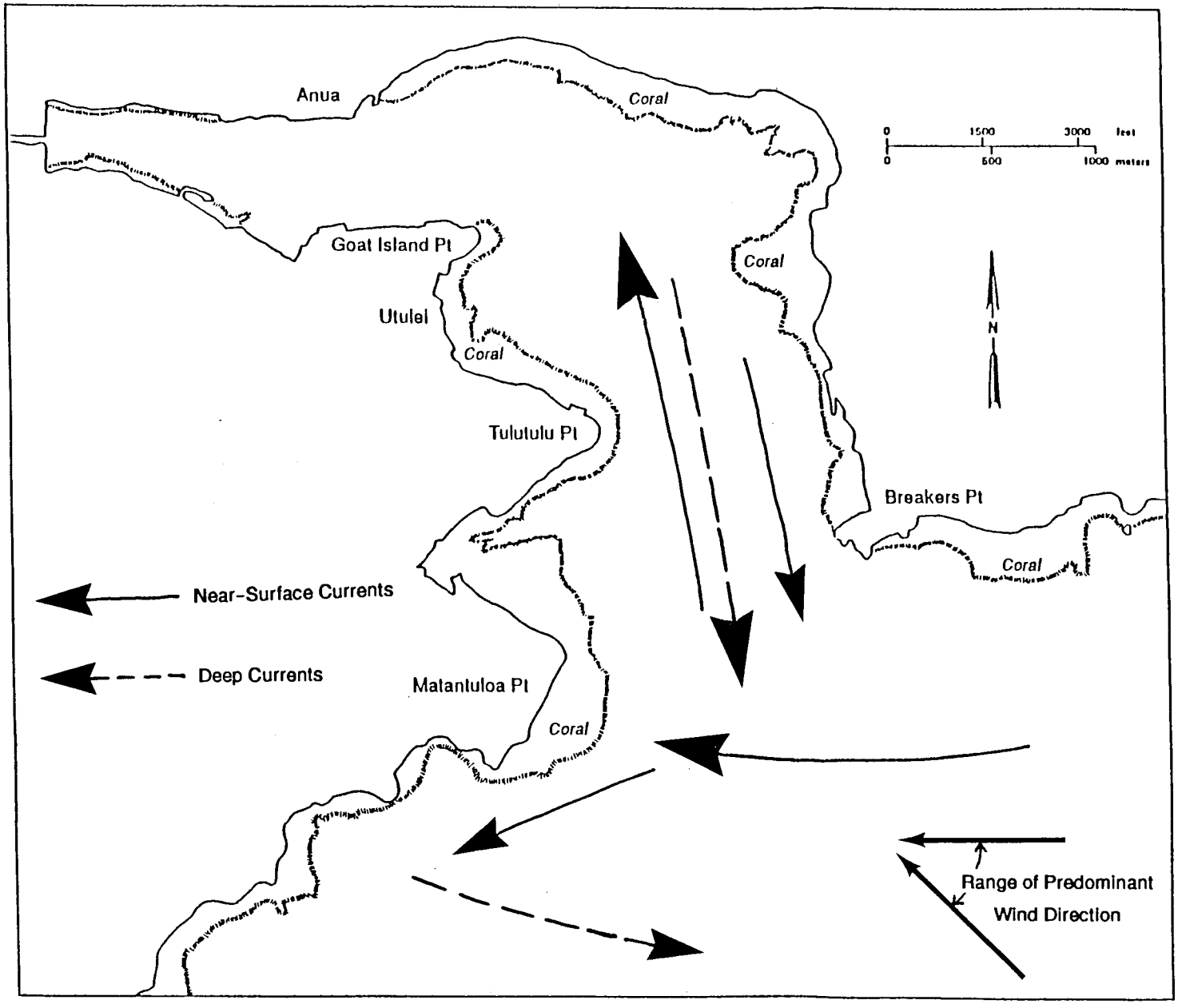
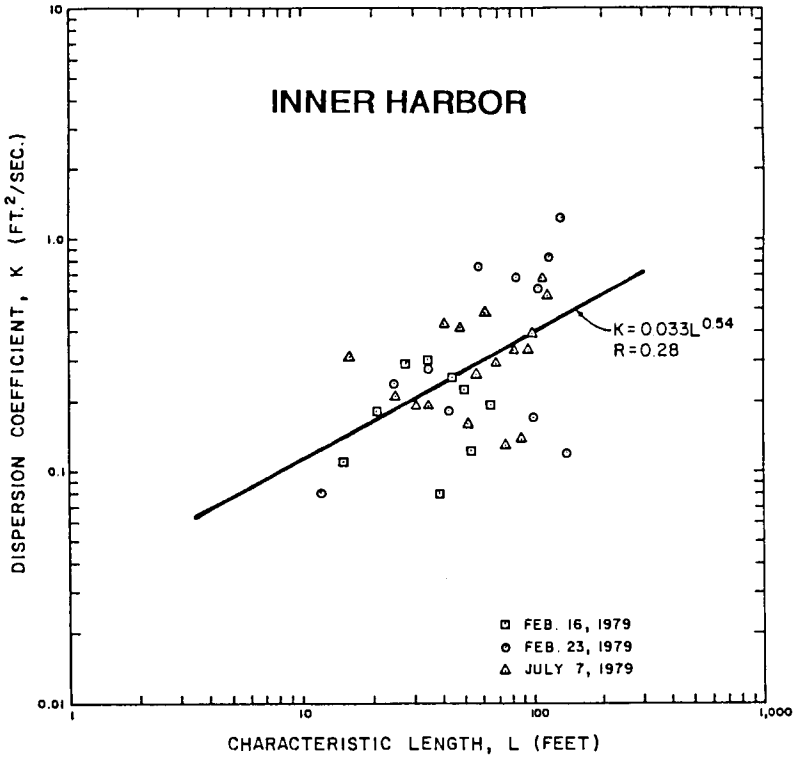
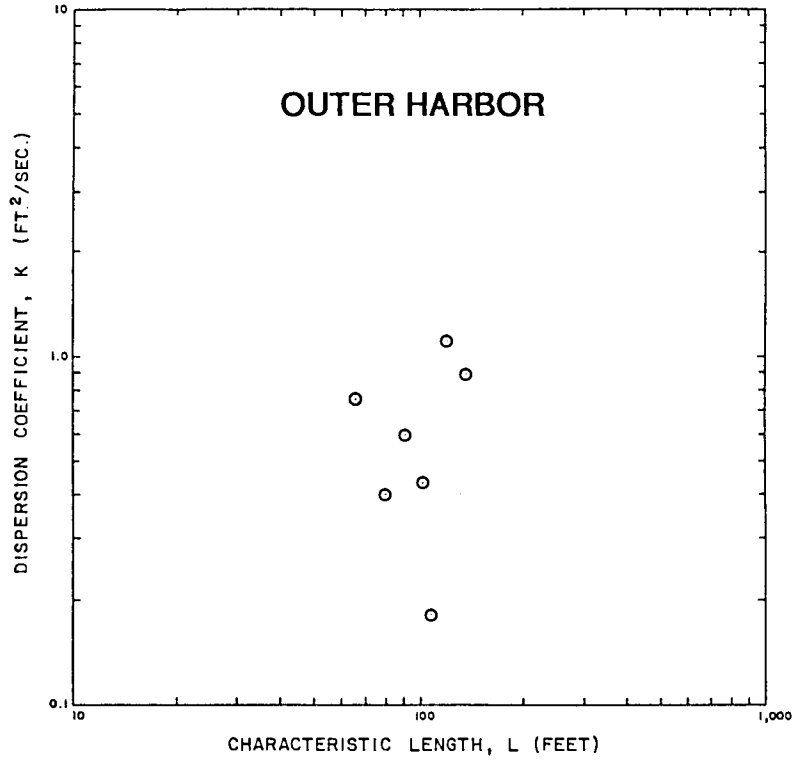


FIGURE 2-5
Inferred Long-Term
Circulation Pattern





Note: from M&E Pacific, 1979.

FIGURE 2-6
Measured Dispersion Coefficients

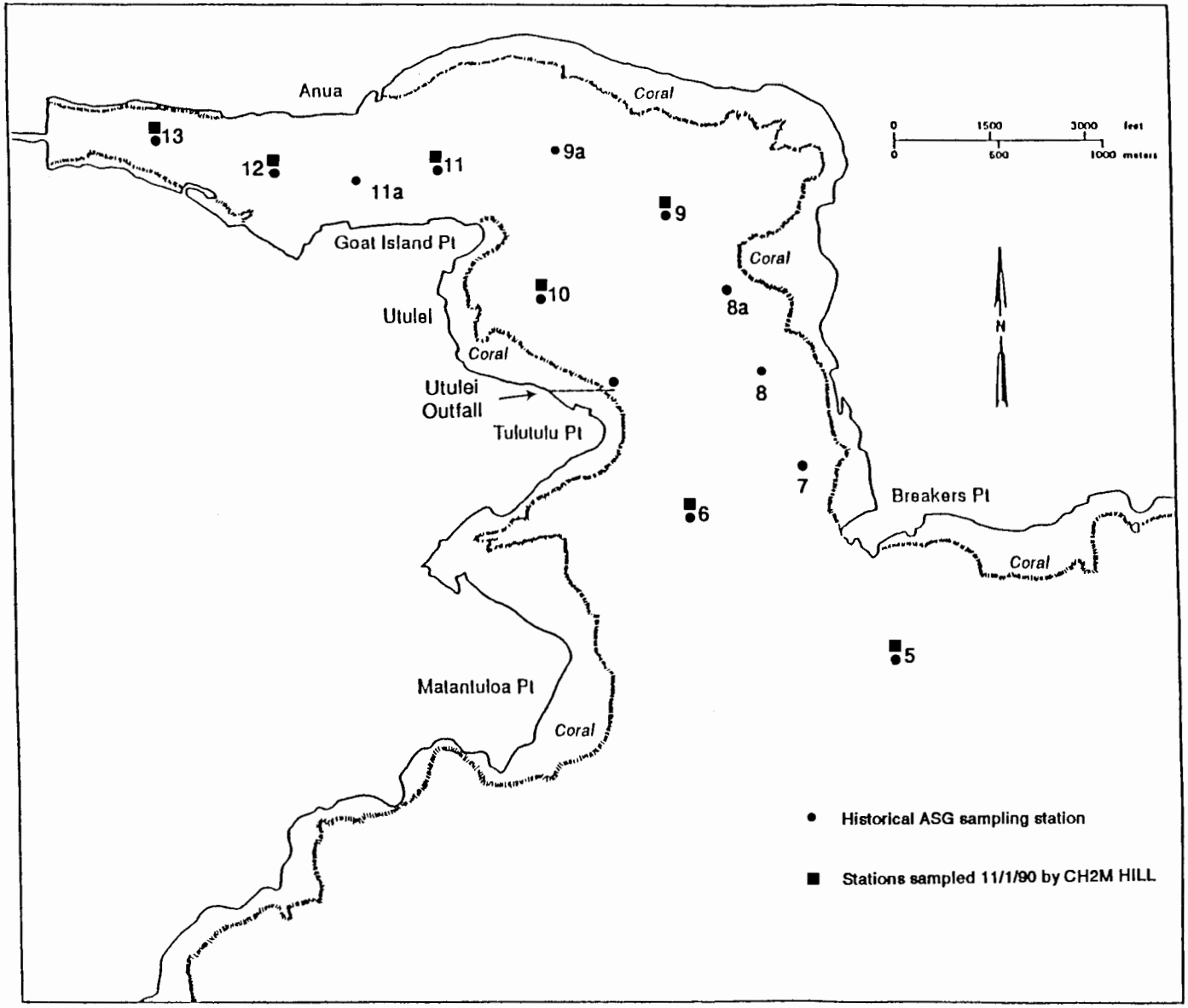
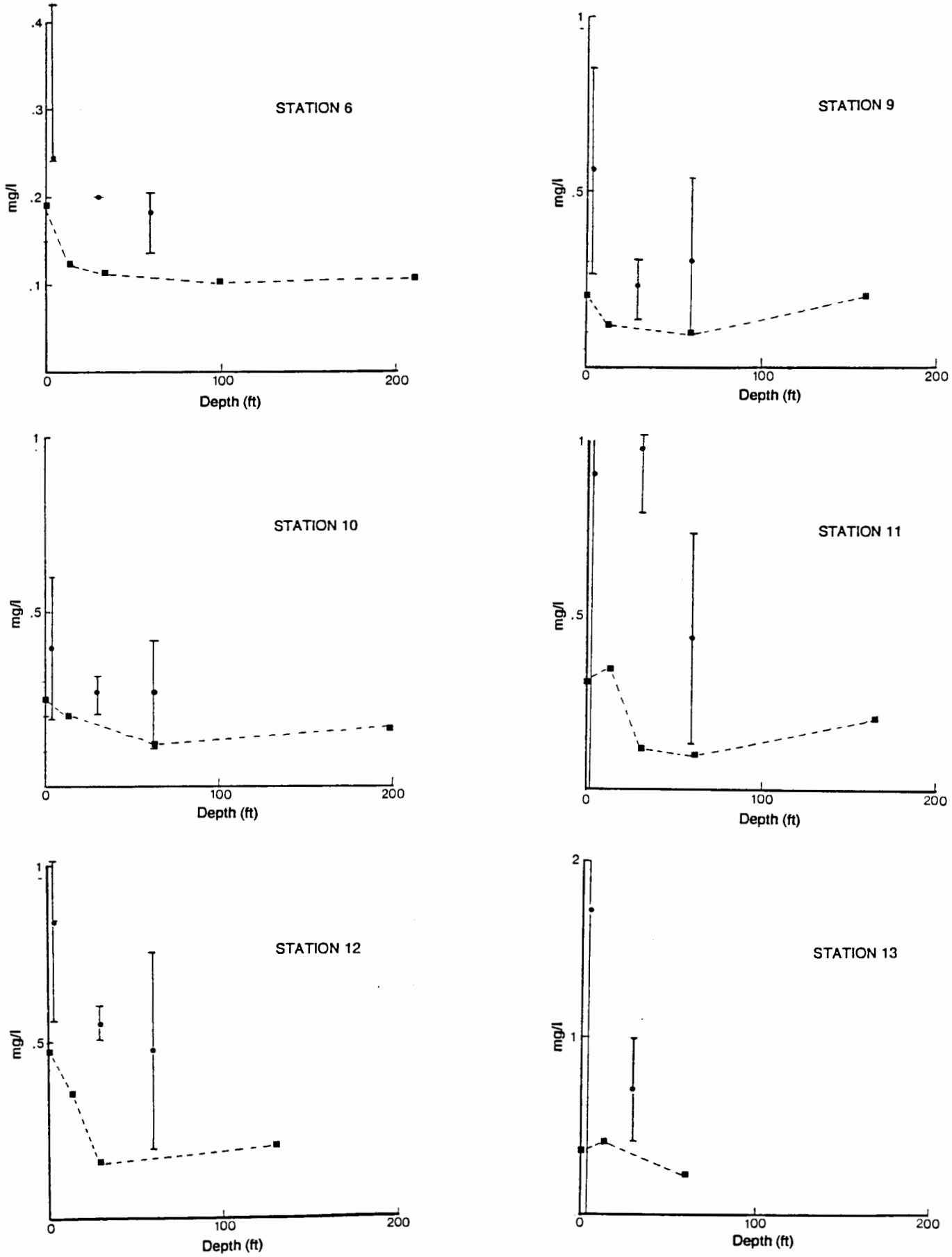
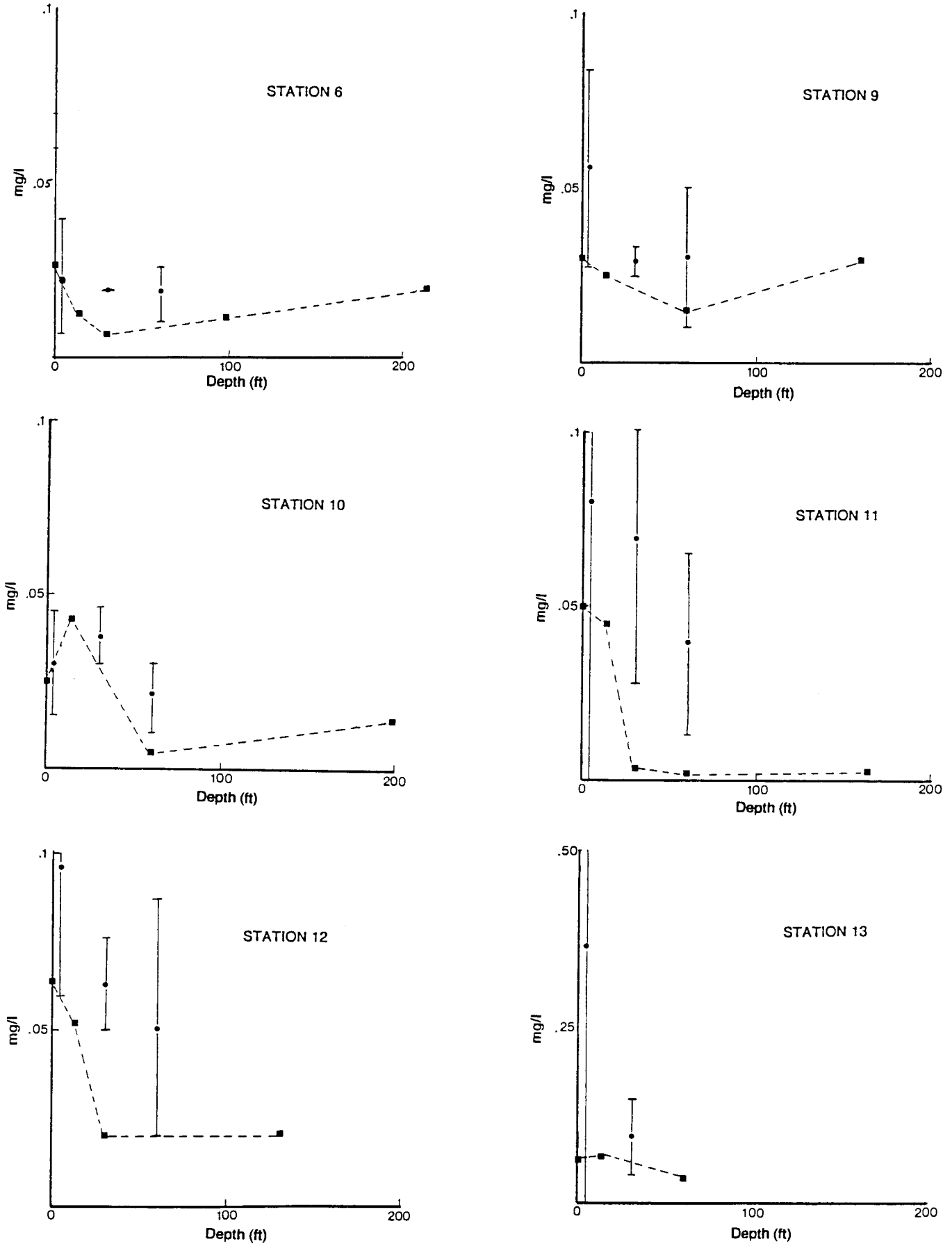


FIGURE 2–7
Location of Water Quality
Sampling Stations



• 1987 – 1990 DATA
■ 1990 CH2M HILL DATA

FIGURE 2-8a
Comparison of Pre- and Post-Segregation TN Concentrations



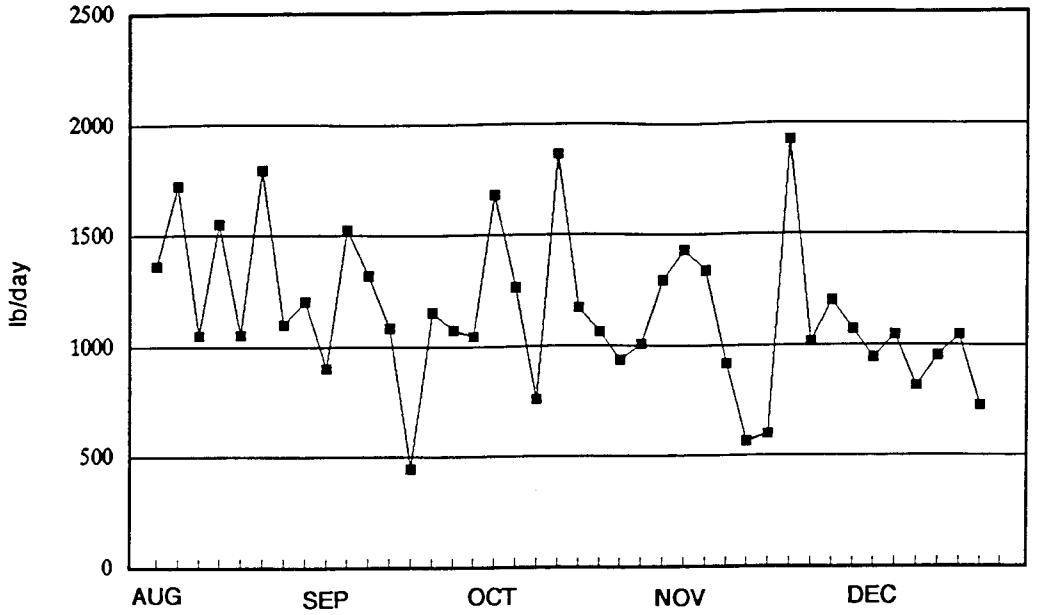
• 1987 – 1990 DATA (pre–segregation)

■ 1990 CH2M HILL DATA (post–segregation)

FIGURE 2–8b

Comparison of Pre– and Post–Segregation TP Concentrations

A. Total Nitrogen Effluent Loadings



B. Total Phosphorus Effluent Loadings

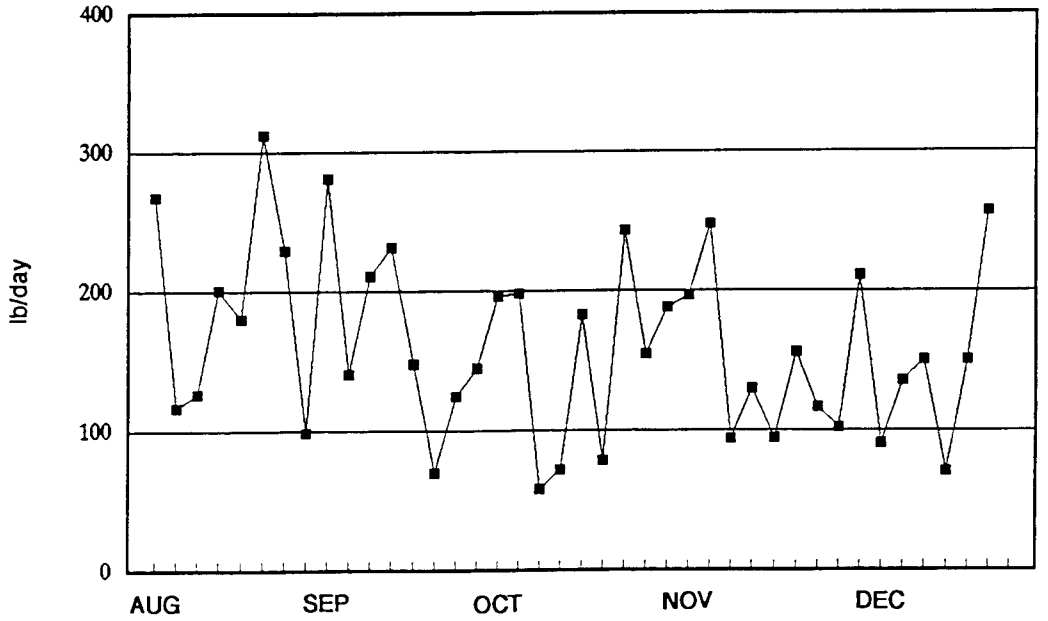


FIGURE 2-9
Post-Segregation Starkist Effluent Loadings of TN and TP , August to December 1990

Section 3
GEOPHYSICAL FIELD DATA COLLECTION AND ANALYSIS

The geophysical survey was done to assist in evaluating the engineering feasibility of a marine outfall pipeline in Pago Pago Harbor. The land outfall pipeline option is discussed in more detail in Section 5, Engineering Feasibility Studies.

The survey was accomplished by collecting bathymetric and side scan sonar data and was conducted by a geophysical subcontractor, Williamson and Associates, under the direction of CH2M HILL personnel. The engineering feasibility analysis relies on the bathymetric and side scan sonar maps that were generated from the survey data. The approximate area of Pago Pago Harbor that was surveyed is shown in Figure 3-1.

The main objectives of the geophysical survey were:

- Refine and supplement existing bathymetric data in the survey area under investigation
- Map the surficial seafloor features in the survey area to determine the most feasible outfall route and the overall feasibility of a marine pipeline route

The optimum marine pipeline outfall route will be one that is relatively flat and stable and avoids underwater obstacles, areas of anchor drag, areas of intense sediment transport, and rock and coral outcrops.

GEOPHYSICAL FIELD PROCEDURES

The survey consisted of two standard methods for gathering geophysical data: precision echo sounding (bathymetry) and side scan sonar. The manufacturers and model numbers of the equipment used for the survey are given in Appendix B. A brief description of each type of equipment and how it was used during the survey is provided in Appendix B.

Bathymetric and side scan sonar data were obtained on separate transect lines on November 1 and 2, 1990. The survey grid consisted of about 50 dip lines (transect lines oriented perpendicular to the depth contours) spaced at about 100-foot intervals for the bathymetric transects. The survey began at a position adjacent to the canneries at Trading Point (near Anua) and as near to the shore as possible. The survey progressed east from this area and followed the northern and eastern shorelines of the harbor south to Breakers Point (Figure 3-1). The survey was generally confined (as

much as possible) between the 10-fathom and the 30-fathom depth contours (60 and 180 feet, respectively). This restricted the survey area to water depths deep enough for the outfall, yet located a distance from the reef that would not put the survey boat at risk. The potential outfall diffuser sites were included in the survey area off Tafagamanu Point and south and east of Breakers Point. This includes the land pipeline option as well as the marine pipeline option.

The transect lines were kept a minimum of about 65 feet away from the coral reef for three reasons: (1) this distance avoided damage to the survey vessel, (2) the steep dropoff seaward of the reef would act as an acoustic reflector and could adversely affect the quality of the bathymetric and side scan data; and (3) the pipeline should avoid the steep slope of the coral reef and be placed instead on the relatively flat harbor floor in front of the reef. Enough transects were made to provide adequate coverage of the survey area.

BATHYMETRY

The National Ocean Survey (NOS) was contacted to determine the availability of existing bathymetric data. Smooth sheets (maps with individual soundings taken during surveys) were available for the offshore region, but no reliable data were available for Pago Pago Harbor. Experience with installing current meters indicated that the existing navigation chart could be misleading. Therefore, a bathymetric survey of the potential pipeline route was necessary.

The goals of the bathymetric portion of the geophysical survey were to produce a bathymetric map of the seafloor along the pipeline route by using precision echo sounding equipment. Navigational control during the survey was obtained with a range-azimuth laser tracking system that was placed on a U.S. Coast Guard daymark (Front Range) located on the north side of the harbor near Leloaloa. The bathymetric data were obtained along dip lines oriented in an approximate zigzag pattern starting near the canneries at Trading Point out to Breakers Point. The trackline plot showing the location of the bathymetric transects is shown in Appendix B. Further details on the bathymetry are given in Appendix B.

NAVIGATION

Because navigation is an integral part of acquiring precise bathymetric data, a brief description of the navigation system used for the survey is presented here.

Horizontal control during the survey was provided by using a range-azimuth laser positioning system (Lasertrak) that can provide accuracies up to 30 cm (horizontal) and 0.01 degree (vertical). The Lasertrak was positioned on a U.S. Coast Guard daymark (Front Range), which is a surveyed control point. This location allowed continuous tracking of the survey vessel without having to move survey locations.

Backsights at Goat Island and Breakers Points were periodically checked from this survey location.

Information on the vessel's position (range and angle from the established baseline) was collected continuously by the Lasertrak unit and was downloaded onto a portable microcomputer for post-cruise editing and plotting. Data files containing the navigational data were backed up and checked for completeness at least twice during each survey day. An example of navigation data for both bathymetric and side scan sonar transects is given in Figure 3-2. The navigation data were correlated with the geophysical data by clocks that were synchronized between the geophysical survey equipment and the shore-based navigation equipment. A fiducial (fix) mark was manually placed on all bathymetric and side scan sonar records on board the survey vessel at 15-second intervals.

PRECISION ECHO SOUNDER

This equipment transmits and receives a high frequency (100 kHz) acoustic signal from a transducer fixed onto a vertical support that is attached to the hull of the survey vessel. This signal is reflected from the sea floor and provides detailed information on the water depth along the survey vessel's line of travel. These data were used to produce a bathymetric chart of the survey area after they were corrected manually for water level variations. Because the tidal range in Pago Pago Harbor is minimal, vertical control was obtained from published NOAA tide tables that give tidal times and ranges for the time the survey was conducted.

DESCRIPTION OF SURVEY RESULTS

As would be expected, the escarpment or reef front is extremely steep. On several occasions the bow of the survey vessel was against the reef, and the echo sounder transducer, which was located midships, indicated a depth of 80 feet. The outline of the reef is extremely complex, with numerous small indentations and promontories. It would be nearly impossible to map these variations, even with a very detailed bathymetric survey. The contour maps produced from the bathymetric survey (provided in Appendix B) are highly interpretive in the shallow water areas because of the limited data coverage for such a complex region. Seaward from the base of the reef, which is at a depth of approximately 160 feet, the seafloor has a gradual slope out to a depth of 200 feet, at which point it appears to be flat. The bathymetric data in this area are considered very reliable.

SIDE SCAN SONAR

The goals of the side scan sonar data collection were to use a precision side scansonar system to produce a map of surficial seafloor conditions and any obstacles. Side scan sonar data were obtained with both 50-kHz (low resolution) and 100-kHz (high

resolution) transducers along transects starting near the canneries at Trading Point out to Breakers Point at the entrance of Pago Pago Harbor. Two transects for both types of sonar transducers were run approximately parallel to the fringing coral reef. The trackline plot showing the location of the side scan sonar transects is given in Appendix B.

SONAR EQUIPMENT AND DEPLOYMENT

Both 50- and 100-kHz transducers (towfishes) were cable-mounted and towed below the water surfce along the potential outfall pipeline route. This equipment provided a reflected sonar image (sonogram) of an approximately 400-meter-wide seabed area behind the survey vessel (Figure 3-3). The side scan sonogram was plotted on recording paper and correlated with the navigation data. The information gathered by the side scan sonar is summarized in Figure 3-4. Sonograms are provided in Appendix B.

Depending on the relief of the seafloor, the sediment grain size, and the biological features, various amounts of reflected or backscattered energy will be received by the side scan sonar transducer. This reflected energy will appear on the sonogram as varying shades of uniform intensity (continuous fields of sands, or organic muds), coherent patterns (sand waves), sharp outlines (rocks), and zones of no reflection (acoustic shadows behind large objects that project above the seafloor, i.e. rocks). These patterns can be identified on the sonograms, making it possible to map the surficial characteristic of the seafloor over a large area.

SIDE SCAN SURVEY RESULTS

The side scan sonar data clearly show the reef front (see Figure 3-4 and Appendix B) as a dark continuous line on the left side of the sonogram. This feature was not as continuous on the return traverse, because the vessel was much farther offshore and the side scan sonar was set for a maximum range of 600 feet to each side.

A number of discrete targets that appear to be boulders and large rocks can be identified on the sonograms. These features are shown in Figure 3-4 and described in Appendix B. Nearly all of the features identified as rocks produced an acoustic shadow. Two targets, however, do not. This suggests that these rather extensive patchy areas might be zones of organic-rich sediments containing biogenic gas, or possibly coral heads with low relief.

Most of the area on the sonograms has a very continuous uniform pattern, which is characteristic of fine- to medium-grain sediments. Although the lateral extent of these sediments, as well as the distribution of rocks and other materials, can be mapped from the side scan sonar data, the thickness of these sediments is unknown.

SUMMARY OF GEOPHYSICAL SURVEY RESULTS

The conclusions from the bathymetric and side scan sonar surveys are:

- The near-shore bathymetry along the reef escarpment is extremely complex and cannot be easily mapped with standard bathymetric survey procedures.

- Seaward from the base of the reef, at approximately 160 feet, the seafloor slopes gently to 200 feet, and at this depth it appears to be fairly flat.

- Several large rocks, with 40 to 80 feet of relief, were identified seaward from the reef front on the side scan sonar data. Some of these features are not shown on the present charts of the area and were not identified on the bathymetric survey.

- Two rather large patchy zones that have very high amplitude returns (dark reflections on the sonograms) appear to have very little relief above the surrounding seafloor. It is possible that these are areas of organic muds if they are not low-relief coral heads.

- In general, the seafloor appears to be covered with fine- to medium-grain sediments throughout the survey area. The thickness of these sediments could be quite variable, particularly in the areas of the rock outcrops.

sea7809/004.51

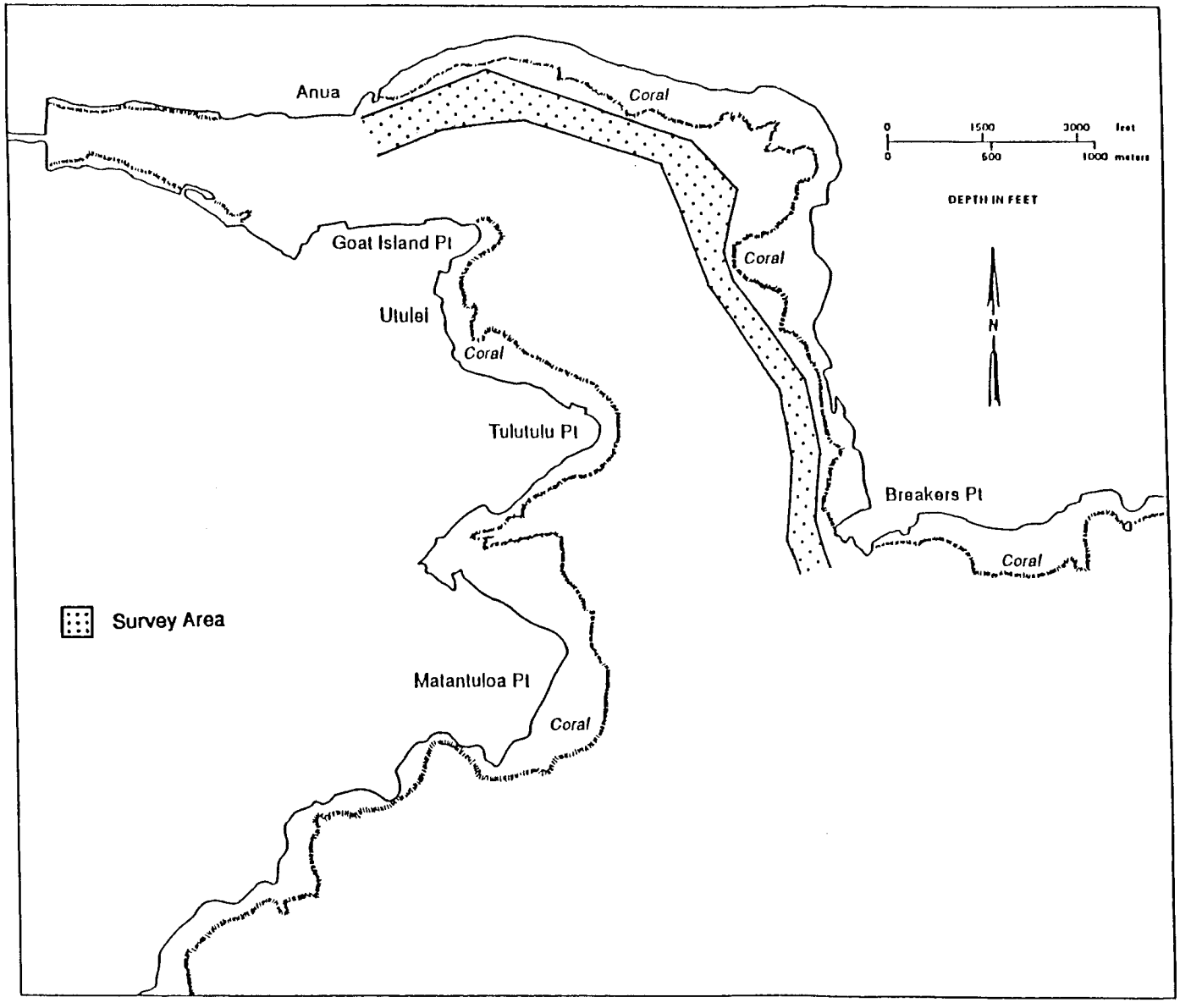


FIGURE 3–1
Location of Geophysical Survey Area

Data log file on 11-02-1990 at 09:12:08 for point# 1 at location
Northing: 309253 Easting: 261749

For STARKIST
Job Number:PDX30702
Location:PP HARBOR

Northing	Easting	Time	range	bearing	angle
|-----Boat Location-----|			Lasertrack Information		
3906.41	1879.19	09:13:21	1321.3	25.69	-.14
4020.48	1934.92	09:13:22	1360	25.7	-.22
4015.14	1932.36	09:13:23	1358.2	25.7	-.27
4011.03	1929.52	09:13:24	1356.7	25.69	-.3
4007.31	1925.15	09:13:25	1355.1	25.66	-.29
4002.00	1922.59	09:13:26	1353.3	25.66	-.27
3998.24	1919.07	09:13:26	1351.8	25.64	-.25
3993.54	1915.96	09:13:28	1350.1	25.63	-.25
3989.51	1911.45	09:13:28	1348.4	25.6	-.26
3984.85	1907.51	09:13:29	1346.6	25.58	-.26
3980.16	1904.41	09:13:30	1344.9	25.57	-.24
3975.76	1901.45	09:13:31	1343.3	25.56	-.25
3971.02	1899.19	09:13:32	1341.7	25.56	-.24
3966.61	1897.08	09:13:33	1340.2	25.56	-.13
3961.87	1894.81	09:13:34	1338.6	25.56	-.14
3959.77	1887.02	09:13:36	1337	25.48	-.14
3955.45	1881.57	09:13:36	1335.1	25.44	-.19
3950.71	1879.32	09:13:37	1333.5	25.44	-.19
3946.95	1875.00	09:13:38	1331.9	25.41	-.19
3941.91	1872.60	09:13:39	1330.2	25.41	-.2
3937.47	1870.49	09:13:40	1328.7	25.41	-.21
3932.73	1868.24	09:13:41	1327.1	25.41	-.18
3930.57	1860.49	09:13:42	1325.5	25.33	-.25
3925.89	1856.60	09:13:44	1323.7	25.31	-.24
3921.76	1853.81	09:13:44	1322.2	25.3	-.26
3917.31	1851.70	09:13:45	1320.7	25.3	-.26
3912.26	1849.32	09:13:46	1319	25.3	-.27
3907.51	1847.07	09:13:47	1317.4	25.3	-.29
3903.44	1843.48	09:13:48	1315.8	25.28	-.18
3898.04	1842.59	09:13:49	1314.2	25.3	-.22
3893.35	1837.89	09:13:50	1312.3	25.27	-.26
3798.88	1721.65	09:14:08	1271.3	24.38	-.35
3793.84	1714.58	09:14:10	1269	24.32	-.27
3788.16	1709.62	09:14:10	1266.8	24.29	-.26
3782.17	1702.95	09:14:11	1264.3	24.24	-.25
3777.66	1694.58	09:14:12	1262	24.16	-.26
3772.25	1687.41	09:14:13	1259.6	24.1	-.25
3765.96	1684.60	09:14:14	1257.5	24.1	-.24
3761.71	1674.82	09:14:15	1255.1	24	-.22
3755.11	1671.88	09:14:16	1252.9	24	-.23
3751.11	1661.48	09:14:18	1250.5	23.89	-.25
3744.23	1658.43	09:14:18	1248.2	23.89	-.19
3737.91	1654.85	09:14:19	1246	23.88	-.22
3731.31	1651.93	09:14:20	1243.8	23.88	-.21
3725.57	1646.28	09:14:21	1241.5	23.84	-.19
3720.69	1626.30	09:14:25	1237.7	23.61	-.29
3092.15	-3747.07	09:28:59	1480.8	309.53	-.2
4442.46	-5377.64	09:29:00	2126.1	309.56	-.18
4447.99	-5382.43	09:29:03	2128.3	309.57	-.18

FIGURE 3–2
Example of Navigation Data Format

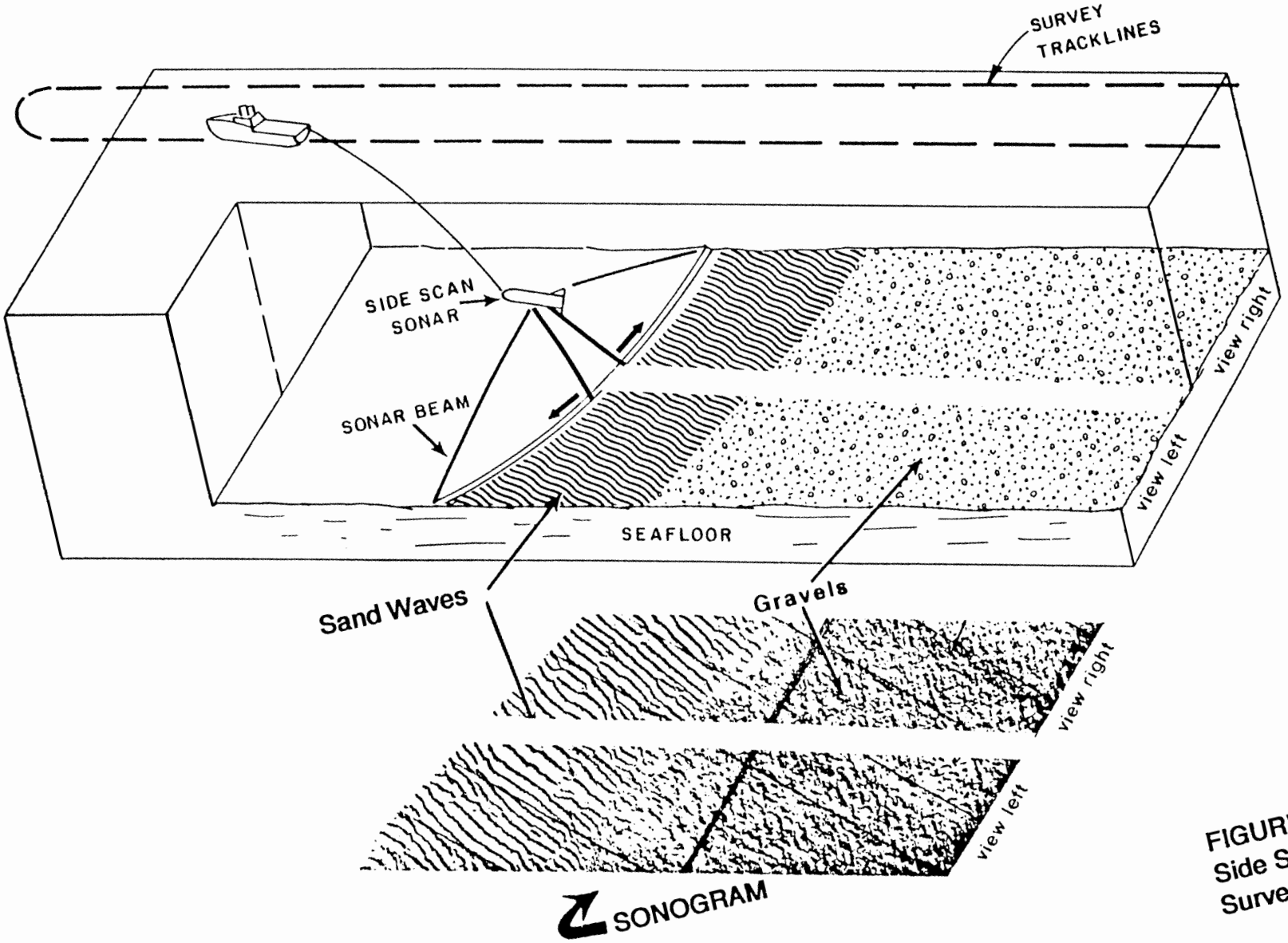


FIGURE 3-3
Side Scan Sonar
Survey Method

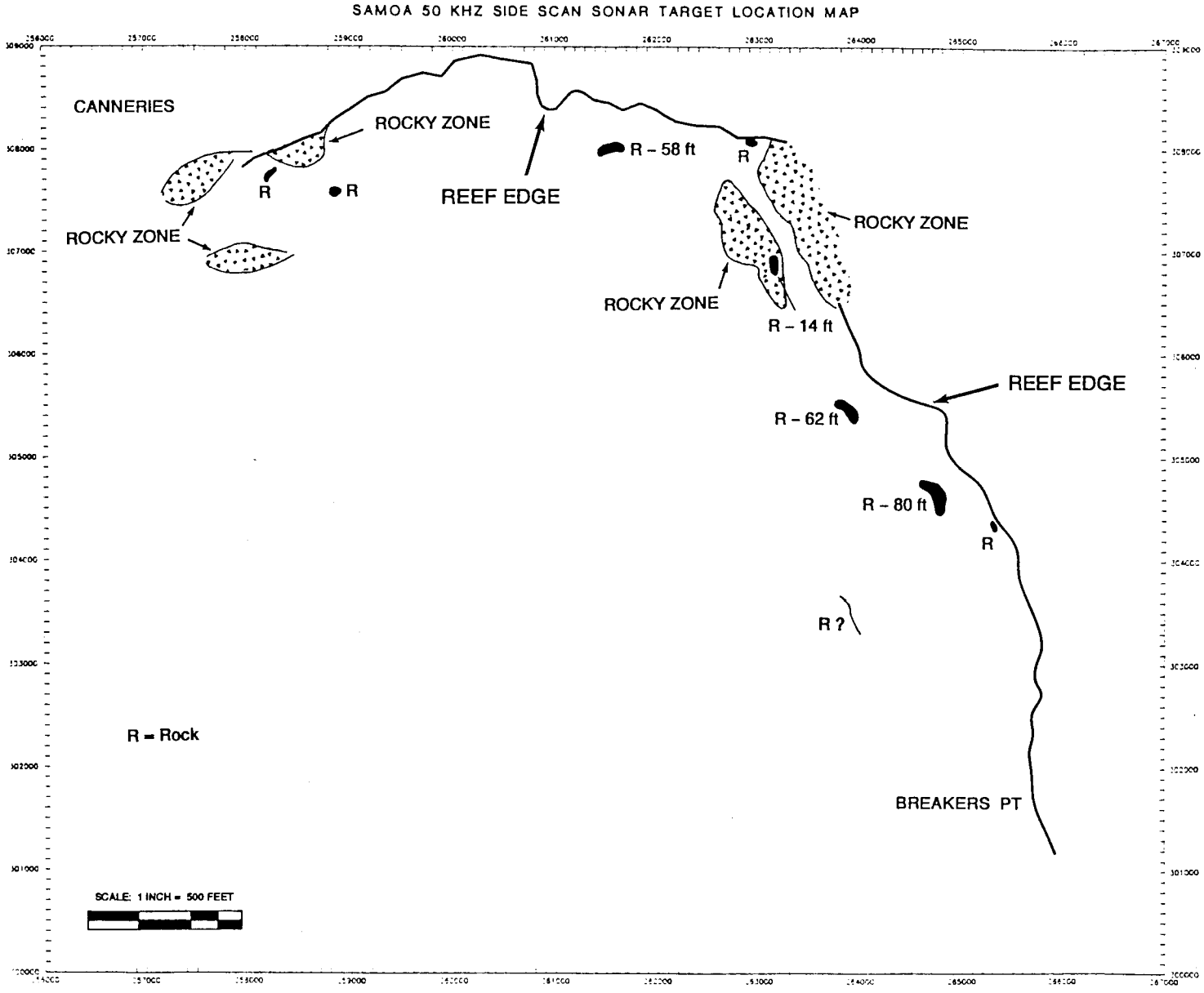


FIGURE 3–4
Summary of Side Scan Sonar Findings

Section 4
WASTEFIELD TRANSPORT MODELING

INTRODUCTION

The focus of the modeling study was the fate of effluent constituents under alternative disposal options. Ambient conditions and means of disposing of the effluent are reported in separate sections of this report. In this section, the wastefield resulting from effluent discharged at alternative locations is analyzed for concentration, size, location, and movement with the use of numerical models. Computer modeling is an efficient means of calculating such parameters under various hypothetical conditions. The conclusions presented in this section are based on model results. The models and their calibration procedure are described below.

PURPOSE OF MODELING

Models are used to predict responses of water column concentrations to variations in effluent loads. To do this, models simulate effects of diffusion and advection of effluent constituents in the harbor in the presence of tides, wind-driven currents, and freshwater inflow. Modeling permits quantitative comparison of water column concentrations under controlled conditions. For example, one may quantitatively compare the effects on concentrations by varying one parameter under otherwise identical conditions.

APPROACH

Three types and scales of physical processes are involved in the distribution and concentration of discharged material in a body of water. Each of these three phenomena were considered and modeled separately:

- The initial dilution process happens quickly as the buoyant jet and plume is released from the outfall pipe or diffuser. Standard EPA-developed models are used to predict the mixing of effluent with receiving water during this process.

- The subsequent (or farfield) dilution process was analyzed by using the method of Brooks (1960). This process is less energetic than initial dilution, but still results in fairly high mixing rates as a small-scale process.

- The large-scale, long-term average concentrations throughout the harbor must be predicted to determine the potential for water quality violations in the harbor. This was done with a wastefield transport model based on the original completely stirred tank reactor (CSTR) approach of HRI (1989). A model consisting of an enhanced version of the HRI model

(PT121) was developed and applied by CH2M HILL for characterizing the concentrations of TN and TP throughout the harbor for a variety of loadings and outfall discharge locations.

The basic approach of the modeling was to use the wastefield transport model to predict the large-scale constituent concentration distributions resulting from discharge at a particular point. The initial dilution model was then used, with known or assumed effluent concentrations, to determine the concentrations of the plume at the end of the initial dilution process.

If the initial dilution is high enough to meet the water quality standards, the plume length and diameter constitutes the mixing zone. The concentration of the plume must be calculated on the basis of the ambient concentration of the surrounding water as predicted by the wastefield transport model. If the initial dilution is not sufficient to meet the water quality standards, the farfield dilution analysis must be done to determine the size of the mixing zone.

SCOPE AND LIMITATIONS

The initial dilution characteristics of the outfall at alternative harbor locations were analyzed. The basis of this analysis is the results of two hydrodynamic models published by EPA, UMERGE and UDKHDEN. The results are preliminary in nature because the siting of the diffuser and the establishment of discharge rates have not been finalized. The results are therefore presented for a range of possible operation and siting scenarios.

Contaminant concentrations throughout the harbor resulting from discharge of the effluent analyzed with PT121, an enhanced version of the model HARBOR, developed by HRI for the ASG in the *Waste Load Allocation Study for Pago Pago Harbor* (HRI, 1989). The mixing zone size and geometry are based on the application of the Brooks (1960) method. This method is the basis of the EPA-published farfield dilution models CDIFF and RDIFF.

INITIAL DILUTION MODELING

This section provides a summary of the preliminary initial dilution modeling results for the outfall. The purpose of the initial dilution modeling was to (1) provide preliminary information on the general characteristics of the diffuser configuration for use in the engineering feasibility evaluation, (2) provide information about the expected initial dilution to assess the ability to meet water quality standards, and (3) determine the initial concentrations of effluent constituents and wastefield plume characteristics for use in the mixing zone analysis.

MODELS USED

The dilution characteristics of the outfall were analyzed by using the EPA guidelines and the hydrodynamic models UMERGE and UDKHDEN developed for multiport diffusers (Muellenhoff et al., 1985). The models were used to evaluate the initial dilution performance for three effluent flow conditions (flow rates and effluent densities) for typical ambient water density profiles. These models calculate the average dilution, plume trajectory, and trapping level for submerged, buoyant plumes from a single port diffuser or a single row of ports on a multiple-port diffuser. The initial dilution and the trapping level of various diffuser configurations were evaluated for a range of depths within the inner and outer areas of Pago Pago Harbor.

UMERGE is a two-dimensional model that analyzes a buoyant discharge by tracing the position of the effluent plume through its trajectory and dilution. The model approximates plume development by using single, one-step integrations over discrete time increments rather than integration over distance. Ambient current direction is assumed to be normal to the axis of the diffuser. UDKHDEN, on the other hand, is a fully three-dimensional model and, as such, is much more sophisticated than UMERGE. It considers variable profiles throughout the zone of flow establishment and uses a fourth-order integration routine along the centerline of the effluent plume to trace its position and dilution over time. Unlike UMERGE, the ambient current direction relative to the diffuser axis can vary between 45 and 135 degrees. For the preliminary initial dilution modeling, however, the current direction relative to the diffuser axis was held constant for both UMERGE and UDKHDEN runs.

RECEIVING WATER PROPERTIES

Two profiles of ambient seawater density were selected from the *Oceanographic Studies in Support of American Samoa Wastewater Facilities Planning--Final Report* (CH2M HILL, 1984) for use in the modeling to represent typical water column stratification in both the inner and outer harbor. The locations of the sampling stations selected are shown in Figure 4-1. The density profiles used in the initial dilution modeling are tabulated in Table 4-1 and are shown in Figure 4-2. Both profiles exhibit weak density stratification throughout the entire water column in both the inner and outer harbor.

The current speed used in the modeling was based on data recorded during current meter deployment in the above-mentioned report. During the oceanographic studies, the inner harbor currents were too low to obtain reliable readings. As a result, zero current was used for the inner harbor profile (the use of zero current in a wind-driven system is a conservative approach). Outer harbor currents are generally much higher and are more dependent on location in the outer harbor and prevailing wind and tidal conditions. Two cases, zero current and 5 cm/sec, were selected for use in the modeling. The 5 cm/sec case appears to be a reasonable lower limit for typical wind-driven currents generally prevailing in the outer harbor.

EFFLUENT CONDITIONS

The effluent density (in grams per cubic centimeter) and salinity (in parts per thousand) were calculated on the basis of conservation of mass (salt) for two representative effluent flow rates supplied by StarKist: (1) 1.4 mgd, of which 1.0 mgd is freshwater and 0.4 mgd is seawater, and (2) 2.2 mgd, of which 1.0 mgd is freshwater and 1.2 mgd is seawater. The density and salinity were calculated for two effluent temperature conditions: present average effluent temperature (90°F), and projected future (attainable) average effluent temperature (85°F). The results of these calculations are:

Flow (mgd)	Salinity (o/oo)	Temperature (°F)	Density (g/cm^3)
1.4	10.20	85	1.0033
1.4	10.19	90	1.0023
2.2	19.33	85	1.0100
2.2	19.31	90	1.0090

The densities and salinities at 85°F were used in the initial dilution modeling runs because they likely represent the future (average) effluent temperature.

SELECTION OF DIFFUSER CONFIGURATION

Standard guidelines for diffuser port configuration as outlined by Fischer, et al. (1979), indicate that the sum of all the port areas should be between one-third and two-thirds of the outfall pipe cross-sectional area. With this guideline in mind, several simple diffuser configurations were selected. For effluent flow rates of 1.4 mgd and 2.2 mgd, the outfall pipe diameter was estimated to be about 12 inches. For a total port area/pipe area ratio of one-half and a calculated maximum allowable port area of 57 square inches for a 12-inch-diameter outfall pipe, the following diffuser configurations were considered for a 60-foot-long diffuser:

No. of Ports	Port Diameter (inches)	Port Spacing (feet)
2	6	60
3	5	30
5	4	15
10	3	7
15	3	4

To determine which of the above port configurations would yield the highest initial dilutions, UMERGE was run with the following parameters:

- Effluent flow rates: 1.4 mgd and 2.2 mgd
- Vertical angle of ports relative to the horizontal: zero degrees
- Port depth: 125 feet (MLLW)
- Ambient current speed and direction: 0 and 5 cm/sec, normal to the diffuser axis
- Average effluent temperature: 85°F
- Effluent salinities of 10.20 o/oo (1.4 mgd) and 19.33 o/oo (2.2 mgd)

Under both flow conditions and at both the inner and the outer harbor locations, the UMERGE results suggest using five 4-inch-diameter ports spaced about 15 feet apart (Figure 4-3). Two additional sets of UMERGE model runs were made for five diffuser ports to check the efficiency of this configuration. In the first set of runs, the port diameter was varied between 3 and 6 inches (1-inch increments) for both flow rates. Dilution was not increased significantly by decreasing the port diameter to five 3-inch ports. Conversely, dilution was not reduced significantly by increasing port diameter (e.g., five 5-inch or five 6-inch ports). Figure 4-4 shows dilution as a function of port diameter.

In the second set of additional runs, the port spacing was varied for five 4-inch ports (thereby increasing the overall diffuser length). Five 4-inch ports, spaced 15 feet apart, at a 125-foot-discharge depth and for a 1.4-mgd flow rate, yield dilutions of about 200:1. The dilution is not increased significantly by increasing the port spacing beyond about 15 feet (Figure 4-4). This appears to be a satisfactory spacing for the preliminary runs for this particular port configuration. However, some additional dilution can be achieved, particularly at higher effluent rates, with increased port spacing. Additional analysis is presented in Appendix D that suggests a port spacing of 25 to 30 feet should be considered for final diffuser design.

The diffuser configuration with five 4-inch-diameter ports spaced 15 feet apart was used for the remainder of the preliminary initial dilution modeling. After selecting the diffuser configuration, the discharge depth was varied to calculate the dilution as a function of depth (all other input parameters, except for current speed, were held constant). Discharge depths were selected from a bathymetric map of the harbor by using minimum and maximum soundings based on the outfall's possible new locations. The depths that were selected are:

Profile	Location	Current Speed (cm/sec)	Discharge Depth (ft)
1	Inner harbor	0	50,100,150
4	Outer harbor	0, 5	100,150,200

One additional depth was added to each density profile to account for the maximum discharge depth for which seawater properties were not measured during the field studies. The temperature, salinity, and density data for the last depth sampled in the profile were extended to the maximum discharge depths of 150 and 200 feet for the inner and outer harbors, respectively.

PREDICTED INITIAL DILUTIONS

Dilution as a function of discharge depth for both the UMERGE and UDKHDEN model runs is shown in Figures 4-5 through 4-7 for inner and outer harbor density profiles. Table 4-2 summarizes the results of these model runs. For the inner harbor profiles, UMERGE and UDKHDEN gave nearly the same results (for both flow rates) and calculated dilutions that range between 100:1 and 200:1 when no ambient current is present (Figure 4-5). In this case, the models predicted similar dilutions and plume trapping levels when the discharge depth is relatively shallow (less than 100 feet).

The outer harbor profile model runs yielded different results in comparison to those using inner harbor profiles, as shown in Figures 4-6 and 4-7. With no current present, the dilution and trapping level predicted by the two models are similar for both of the two flow rates (Table 4-2). However, when a 5-cm/sec current was added to the same model run, UMERGE and UDKHDEN predicted different dilutions and trapping levels (Table 4-2).

The large difference between the predicted dilutions and trapping levels can be explained in terms of the inherent differences between the two models. As a result of its basic assumptions, UDKHDEN is much more sensitive to water column density gradients. This is especially true as the discharge depth increases. Differences that are observed between predicted dilutions and trapping levels between the two models can be attributed mainly to this sensitivity to water column stratification. For this reason, the effluent plumes are trapping much deeper beneath the surface than plumes predicted by the UMERGE model runs. This can be seen for the 150- and 200-foot discharge depths in Figures 4-6 and 4-7. UDKHDEN gives higher dilutions at 150 feet but nearly the same (or lower) dilutions at 200 feet for the lower effluent flow rate.

In physical terms the UDKHDEN results seem reasonable because, as the discharge depth is increased, the effluent plume must rise through a greater volume of (denser)

water before reaching its equilibrium height (water of equal density) and trapping below the surface. Overall, the models predict that for both inner and outer harbor density gradient conditions, at either ambient current speed, the five 4-inch port diffuser configuration will achieve dilutions (in all cases modeled) well above 100:1 for both effluent flow rates. In addition, the plume trapping levels are well beneath the surface, largely because of the density gradient in the water column.

An additional set of model runs for low flow conditions was performed. An effluent flow rate of 1.0 mgd (50 percent seawater) was used. The results were similar to the results presented above for 1.4 mgd. The results of these model runs are provided in Appendix D.

WASTEFIELD TRANSPORT MODELING

PURPOSE OF MODELING

The wastefield transport model is used to predict temporal and spatial responses of water column concentrations to variations in effluent loads. It does this by simulating diffusive and advective transport in a body of water in response to tides, winds, and freshwater input, such as precipitation and runoff. The model itself is actually made up of two smaller models: the first component simulates the hydrodynamics of the system and calculates the flow rates in response to tidal forces and input of freshwater (such as point source discharge, runoff, and rainfall). The second component models water quality by using information based on initial water column concentration, point and nonpoint loading, and data calculated from the hydrodynamics component.

MODEL APPROACH

The approach used to simulate wastefield transport is to model the hydrodynamics of the system by calculating longitudinal flow rates in response to tidal forces and freshwater input. Next, water quality parameters were calculated on a two-dimensional depth-averaged basis by using the hydrodynamic output, loadings, initial concentrations, and diffusion coefficients.

The hydrodynamics portion of the model, which also is used to simulate advective transport, is based on a series of control volumes or computational line cells that represent the harbor. This series of line cells is divided into square cells laterally across the harbor width. Figure 4-8 shows the arrangement of line cells and cells. Advective transport is a combination of tidal nonpoint and point source discharge effects. Two-dimensional diffusive transport (mixing) is used in the model, and the eddy diffusion coefficient is assumed to account for wind and density-driven effects. The model assumes that the water column can be represented as depth averaged.

The resolution of the model is determined by the cell size. Using cells that are about the same length in each direction and are relatively small in comparison to the overall size of the model grid (the harbor) provides the ability to investigate the response of concentration on sufficiently small time and space scales to assist in evaluating alternative outfall locations. This approach works well if the speed at which a hydrodynamic change is propagated through a cell is much smaller than the cell dimension divided by the time step used. The model is described in more detail in Appendix C.

MODEL INPUT CONDITIONS

The model requires four input files: a job control file, a hydrodynamics/geometric data file, a tidal data file, and a water quality/geometric data file. These are described in more detail in Appendix C. The job control file contains the program control variables, variable titles, and all input and output switches and filenames. This file also controls the dimensions of the model grid, the size of each cell, and the length of the time step. If point source loading is being considered, the job control file also controls cell locations, flow rates, and loading rates for each point source. The tidal data file is simply a two-column file containing tidal elevations (above some datum) and their corresponding times, usually given in hours.

Both the hydrodynamics and the water quality components of the model have separate input files, and each is coupled with geometric information. The hydrodynamics input file contains two types of information: cross sectional areas and top widths for each cross section (line cell) of the basin, and the nonpoint source flow rate for runoff into each line cell. The water quality data input file contains information on the characteristics of the water such as the initial concentration, the diffusivity constant, and the decay rate (if one is used). The file also includes data inherent to the cells themselves and their location in the grid: starting and ending cell numbers making up the model grid, average depth in each cell, and the boundary conditions.

MODEL OUTPUT

The model produces three different output files: for output of input data (mirror file), for output of hydrodynamic results, and for output of pollutant concentration results. These files are described in more detail in Appendix C. The primary data output is essentially a plan view diagram showing the model grid as it has been designed, with each individual cell designated by a pollutant concentration (Figure 4-9). Also contained in the output is information on the time step used, such as the day, hour, and time. The water level and the output interval are also provided.

The hydrodynamics and input mirror data files were primarily designed to provide testing while the model was still under development. These are mainly used as a way

to perform validation tests of the routines involved in calculating hydrodynamic and water quality parameters. These output files list quantities (for each line cell) such as flow rate, cross sectional area, and velocity.

INITIAL AND BOUNDARY CONDITION SPECIFICATION

Initial concentrations are input into the model as a means of reducing run time necessary to reach a steady-state condition. These values are input to the model via the water quality specifications input file. In this model the boundary condition at the open end of the basin is used to fix the background concentration of dissolved material in the ocean water. The boundary condition at closed sides of model cells is no transport of material across the solid boundary. This is implicitly done for advection, except at the closed end where it is explicitly stated. For diffusion the condition is explicitly stated for all closed cell boundaries.

MODEL CALIBRATION

The model is designed to allow for a decay rate term that will account for the natural deterioration of a constituent. However, for this term to be implemented in the model, there must be some physical rationale for using such a term. The use of a decay term in the model implies that the information exists on transport pathways and possible sources and sinks of the constituent in the system. For the runs reported here, no decay term was used (this is a conservative approach). This is equivalent to assuming equilibrium of sources and sinks of a constituent that does not undergo chemical or radioactive decay into a different chemical species.

If a constant decay term is not used, calibration of the model is based solely on the dispersion or diffusivity coefficient (K). The value of K may vary depending upon several physical factors, but especially upon circulation and flushing ability of the system. The model allows K to vary along the length of the harbor. During model calibration it was discovered that the use of two values of K--one for the inner harbor and one for the outer harbor--appeared to give the best results.

The method used to calibrate the model is to vary the inner and outer harbor K values until the best agreement with observed concentrations and loadings was achieved. The conditions used were the same as those used in the *Waste Load Allocation Study* (HRI, 1989). These are long-term average values, and thus they result in a model best suited for long-term average predictions. Figure 4-10 shows the agreement between observed and predicted concentrations achieved in the calibrations of the model. More information on calibration and validation is provided in Appendix C.

RESULTS FOR TOTAL NITROGEN CONCENTRATION

Estimates of the total nitrogen concentration in Pago Pago Harbor as predicted by the water quality model are presented in the form of concentration contour plots in Appendix C. These runs were based on calibration, verification, and validation of the model, as outlined previously. To determine whether the water quality standards would be met throughout the harbor, the model was run at a space scale of 200 meters. The contour plots indicate, in lines of equal nitrogen concentration (in milligrams/cubic meter), the predicted equilibrium values and spatial distribution that can be expected under various harbor discharge scenarios: inner, middle, outer and entrance discharge; effluent discharge by one or two sources (canneries); and various cannery loading values, including zero loading.

Information generated by the model for a range of combined cannery nutrient loadings was used to develop a series of plots that incorporate maximum predicted concentration outside of the mixing zone to estimate the maximum allowable cannery loadings for a particular water quality standard. These plots are shown in Figure 4-11 for three representative locations in the harbor. From the line used to describe the relationship between these parameters, a specific combined loading for any particular water quality standard can be calculated. The present standard of 0.200 mg/l is indicated on the plots. The plots indicate the total or combined cannery maximum loading possible at a particular harbor discharge location (inner, middle, or outer) that will result in meeting the proposed water quality standards for Pago Pago Harbor.

The maximum allowable combined cannery loading also was plotted as a function of distance from the entrance of the harbor (as measured along the harbor axis). These plots are shown in Figure 4-12. The plots were made for various possible water quality standards ranging from 0.200 to 0.400 mg/l for total nitrogen. This series of plots shows the spatial variation of maximum loading along the harbor axis from the harbor entrance to the inner harbor that can be discharged under a particular water quality standard. The harbor-mouth-to-discharge-point distances shown in these plots can be converted to pipeline lengths by subtracting them from the distance between the canneries and the harbor mouth (12,500 feet).

RESULTS FOR TOTAL PHOSPHORUS CONCENTRATION

Plots of total phosphorus concentration were developed in the same fashion as for total nitrogen described above. Contour plots are shown in Appendix C. However, there are separate sets of TP concentration plots based on two assumptions about background TP concentrations in the open ocean. In the development of their water quality model, HRI used a background value of 0.0225 mg/l. However, after review of available data, it is believed that a lower value of 0.0125 mg/l is a more realistic and appropriate value. Both of these background values were used for both the concentration contour plots and the plots showing maximum concentration outside the mixing zone as

a function of combined nutrient loading. The maximum predicted concentrations are shown in Figures 4-13 through 4-15. The maximum allowable loadings are shown in Figure 4-16 as a function of location in the harbor and possible water quality standards.

MIXING ZONE GEOMETRY

The wastefield transport model provides an assessment of the average concentrations throughout the harbor over time scales greater than a tidal period and space scales consistent with the cell size (200 meters horizontal dimension). The initial dilution model provides an assessment of the mixing action of the effluent plume with the receiving water. Neither of these models provides precise details on the geometry of a mixing zone. For the purposes of the discussion in this section, we defined a mixing zone as that area outside of which the water quality standards are achieved all, or a specified percentage, of the time.

The enclosed nature of the harbor and concomitant long flushing and residence times, the stochastic nature of the wind-driven circulation, and the extremely difficult water quality standards in terms of available capacity combine to make the definition of a "mixing zone" a somewhat subjective exercise. However, this does not negate the results of the wastefield transport model predictions, which show compliance with the water quality standards at specified loadings on a long-term average basis.

A number of approaches can be used to describe the appropriate mixing zone dimensions. These approaches vary in their spatial and temporal resolution as well as in the physical approach used. The approaches can be broadly classified as volumetric based, initial dilution based, or based on analysis of subsequent (farfield) dilution. Each of these approaches is discussed below.

MIXING ZONE BASED ON INITIAL DILUTION

If a mixing zone is to be based on initial dilution only, the receiving water must have a sufficiently low concentration of the constituent of concern that the concentration of the plume, at the end of the initial dilution process, meets the water quality standards. In an enclosed system like Pago Pago Harbor, the receiving water concentration (steady state or long term average) is elevated above the background concentration. Background concentration is defined here as the concentration that would be found if there were no release of the constituent; in this case, the nearshore ocean background concentrations described in Section 2. The steady-state concentration is defined as the concentration in an area of the harbor that results from the long-term release of the constituent.

The required initial dilution (S) to meet a particular water quality standard concentration at the end of the initial dilution process (Cs) depends on the effluent concentration

(Ce) and the ambient (steady state) concentration (Ca). The relationship between these variables is:

$$S\ (Ca - Cs) = (Ca - Ce).$$

Thus, the standard can never be met if the ambient concentration equals the water quality standard and only initial dilution is accounted for in the mixing zone definition.

The closer the values of the standard and the ambient concentrations, the more difficult it is to meet the standards, that is, the higher the initial dilution must be to meet the water quality standard. For example, if the ambient TN concentration is the ocean background (the outfall is beyond the harbor entrance) of 0.12 mg/l and the water quality standard is 0.200 mg/l, the required initial dilution to meet the standard, except within the effluent plume, is expressed as:

$$S = (Ce - 0.120)/0.080$$

As an example, typical post-segregation effluent concentrations for the StarKist effluent are expected to be in the range of 90 to 100 mg/l. This means that initial dilutions on the order of 1,250 are required, which are probably much higher than can practically be obtained. Moving the discharge into the harbor where the ambient concentrations are higher leads to even higher, and unattainable, initial dilution requirements. A mixing zone based solely on initial dilution is not feasible for the present water quality standards.

MIXING ZONE BASED ON VOLUMETRIC ANALYSIS

The transport model provides an assessment of the size of the mixing zone, based on a description of long-term average concentrations. The resolution of the model is a cell 200 meters square (656 feet square). In addition, the model is a depth-averaged, completely stirred model. The fine-scale details of the effluent plume and the nearfield concentrations are neither square nor constant with depth or horizontal dimension. However, the model does give a good indication of the strength of the concentration gradient that can exist for the dispersion coefficient applicable for the model cell size.

The plots shown in Figures 4-11 through 4-16 are based on the following criteria:

- In the inner harbor the concentration is above the plotted value (maximum concentration or water quality standard) in two model cells. That is, the long-term average, depth-averaged mixing zone is 200 by 400 meters.

- In the outer harbor the concentration is above the plotted maximum or water quality standard concentration in one model cell. The long-term average mixing zone is 200 by 200 meters.

- In the middle harbor the model was originally run with discharge to two cells, but examination of the results indicated that the mixing zone is more like the outer harbor case. The long-term average mixing zone for the middle harbor is estimated to be intermediate between those of the inner and outer harbors (1.5 cells).

For the middle and outer harbors the nominal depth of the diffuser is about 150 feet and the minimum initial dilution expected from the initial dilution modeling is over 150:1. For an effluent concentration of TN of 100 mg/l, the dilution at the end of the initial dilution process is 0.87 mg/l, based on an ambient concentration of 0.200 mg/l. The volume of water in 1.5 model cells is about 100 times that involved in the initial dilution process, and the concentration after initial dilution is approximately 4 times the average predicted for the 1.5 model cells. The overall volumetric requirements for a mixing zone predicted by the wastefield transport model appear reasonable.

APPLICATION OF THE FARFIELD DILUTION MODEL

To investigate the geometry of the mixing zone in more detail, the model CDIFF (Yearsley, 1989) was used. This model is based on the Brooks (1960) model, and therefore does not work well under near-zero current conditions, that is, the advective transport term should be at least as large as the diffusive term. The model, if a constant diffusion coefficient is selected, calculates a diffusivity of 0.58 square feet/second. Reference to Figure 2-6 indicates that this is a reasonable value for Pago Pago Harbor on the basis of the dispersion experiments of M&E Pacific (1979). The nearfield concentration gradient of the effluent discharge, combined with the diffusivity, indicates that the model should not be used for currents less than about 0.05 cm/sec. This condition simulates the zero-current-speed situation (diffusive and advective fluxes are about the same size near the origin).

For the model and the concentration gradient near the middle harbor discharge point predicted by the wastefield transport model (the long-term average concentrations), the dilution predicted by CDIFF will reduce the effluent plume concentration from 0.87 (following initial dilution) to 0.20 within 1,300 feet of the discharge point. This calculation is based on no vertical mixing of the plume and therefore is very conservative. It also is the centerline dilution and thus the highest value in the plume.

RESULTS OF MIXING ZONE ANALYSIS

A most conservative estimate of mixing zone size, based on the above models and analyses, would be:

- For average long-term conditions, a mixing zone of 450 feet in radius appears reasonable for the middle harbor; the size would increase towards the inner harbor and decrease towards the outer harbor.

- For maximum values, a mixing zone of 1,300 feet in radius (centered on the outfall diffuser) appears sufficient for the middle harbor; its size would likewise decrease as one moved toward the ocean and increase toward the inner harbor.

For the above maximum values, the mixing zone is defined such that at any one time the concentration would be above the water quality standard at the boundary only over about 1/4 of the mixing zone area. Within most (over 75 percent) of such a designated mixing zone, at any given time, the water quality standards would be met. Thus the actual size, at any time, of the zone of water quality exceedance is quite small. However, because the currents are constantly changing direction and speed, the "effective" mixing zone would be moving in response to these currents. The developments presented above were constructed to be a worst case scenario.

DISCUSSION OF MODEL RESULTS

The alternative locations of the outfall were evaluated in terms of diffuser performance (initial dilution), whole harbor water quality criteria (wastefield transport), and mixing zone size (farfield dilution) by using accepted modeling techniques. Although the study was principally aimed at the StarKist effluent discharge, it was recognized that water quality would need to be met in terms of combined cannery loadings. Therefore, most of the analyses were done based on "adjacent" or joint discharges.

In the case of the wastefield transport model, some separate discharge location scenarios were run (see Appendix C). In the case of the initial dilution models, only the StarKist discharge was simulated, but the addition of Samoa Packing discharge will change the results only slightly (number of ports required, somewhat less dense effluent) and will not change the general conclusions of the study. For the mixing zone analysis the results will also be nearly the same in terms of the worst case scenario.

sea7809/005.51

Table 4-1
DENSITY PROFILES USED FOR
INNER AND OUTER HARBOR

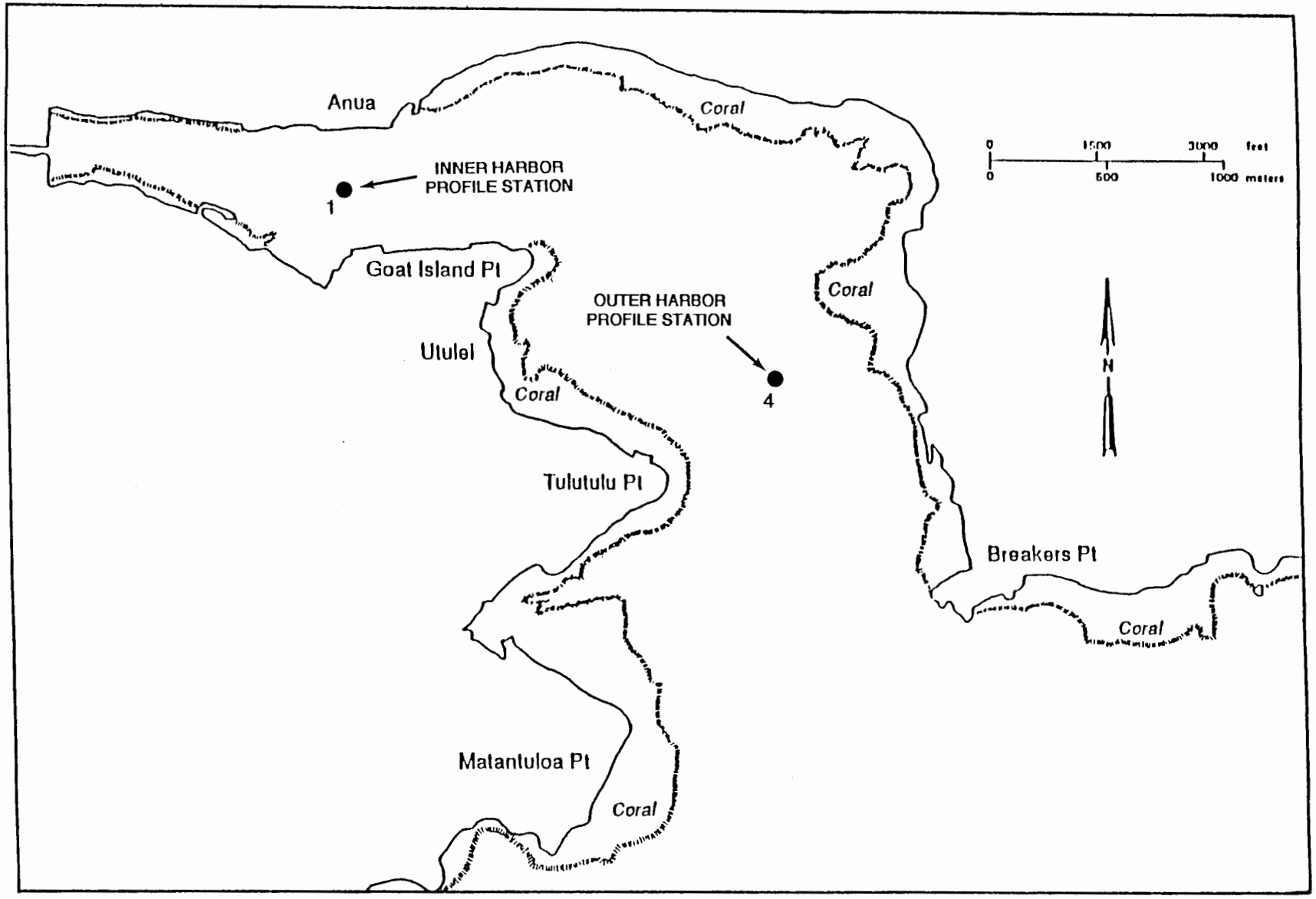
DENSITY PROFILE LOCATION	DEPTH ft (m)	TEMPERATURE (C)	SALINITY (o/oo)	DENSITY (sigma-t)
Inner Harbor	3 (0)	27.5	35.0	22.6
	10 (3)	27.4	35.5	22.9
	20 (6)	27.4	35.5	22.9
	30 (9)	27.4	35.5	22.9
	39 (12)	27.3	35.6	23.0
	49 (15)	27.3	35.7	23.0
	59 (18)	27.3	35.8	23.1
	69 (21)	27.2	35.8	23.2
	79 (24)	27.2	35.8	23.2
	89 (27)	27.1	35.8	23.3
	98 (30)	27.1	35.8	23.3
	108 (33)	27.1	35.9	23.3
	118 (36)	27.1	35.9	23.3
	151 (46)	27.1	36.0	23.5
Outer Harbor	3 (0)	27.3	35.5	23.0
	10 (3)	27.3	35.5	23.0
	20 (6)	27.2	35.6	23.1
	30 (9)	27.2	35.6	23.1
	39 (12)	27.2	35.7	23.1
	49 (15)	27.2	35.8	23.2
	59 (18)	27.2	35.8	23.2
	69 (21)	27.2	35.8	23.2
	79 (24)	27.2	35.9	23.3
	89 (27)	27.2	35.9	23.3
	98 (30)	27.2	35.9	23.3
	108 (33)	27.2	35.9	23.3
	118 (36)	27.2	35.9	23.3
	128 (39)	27.2	35.9	23.3
	200 (61)	27.2	36.0	23.4

Note:
Shaded data were added for model runs; all other data are from reported values (CH2M HILL, 1984).

Table 4-2
DILUTION AND TRAPPING LEVEL FOR FIVE 4-INCH-
DIAMETER PORTS FOR VARIOUS DISCHARGE DEPTHS

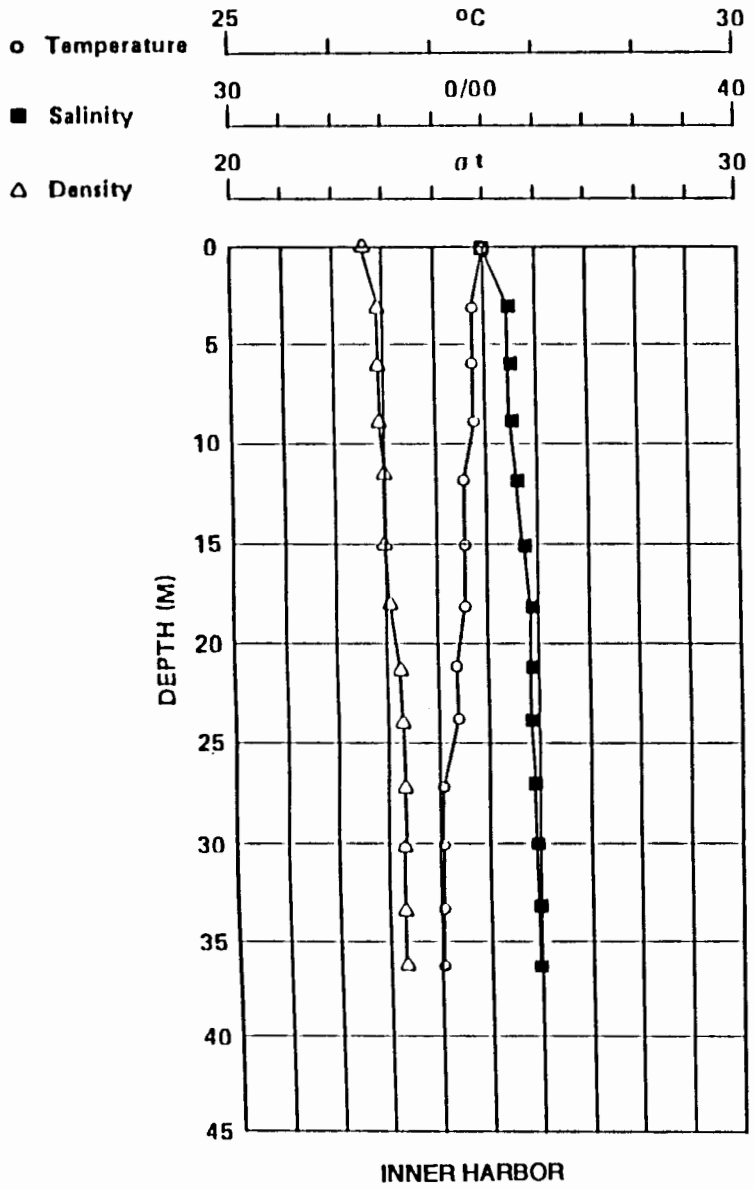
DENSITY PROFILE LOCATION	FLOW (mgd)	CURRENT SPEED (cm/sec)	DISCHARGE DEPTH ft (m)	UMERGE		UDKHDEN	
				DILUTION	TRAP LEVEL ft (m)	DILUTION	TRAP LEVEL ft (m)
Inner Harbor	1.4	0	50 (15.2)	125	6.9 (2.1)	134	7.9 (2.4)
	1.4	0	100 (30.5)	173	45.6 (13.9)	172	46.9 (14.3)
	1.4	0	150 (45.7)	218	79.4 (24.2)	209	80.7 (24.6)
	2.2	0	50 (15.2)	101	7.9 (2.4)	97	8.5 (2.6)
	2.2	0	100 (30.5)	125	48.9 (14.9)	120	49.5 (15.1)
	2.2	0	150 (45.7)	148	85.6 (26.1)	139	86.3 (26.3)
Outer Harbor	1.4	0	100 (30.5)	196	38.4 (11.7)	189	39.7 (12.1)
	1.4	0	150 (45.7)	271	68.2 (20.8)	295	50.5 (15.4)
	1.4	0	200 (61.0)	384	74.2 (22.6)	340	74.8 (22.8)
	1.4	5	100 (30.5)	382	45.6 (13.9)	345	69.9 (21.3)
	1.4	5	150 (45.7)	531	73.5 (22.4)	859	76.1 (23.2)
	1.4	5	200 (61.0)	1072	78.1 (23.8)	676	141.7 (43.2)
	2.2	0	100 (30.5)	140	40.7 (12.4)	133	41.3 (12.6)
	2.2	0	150 (45.7)	191	69.2 (21.1)	202	49.5 (15.1)
	2.2	0	200 (61.0)	260	74.8 (22.8)	226	75.1 (22.9)
	2.2	5	100 (30.5)	280	46.9 (14.3)	242	70.5 (21.5)
	2.2	5	150 (45.7)	371	74.2 (22.6)	576	76.1 (23.2)
	2.2	5	200 (61.0)	379	128.3 (39.1)	440	144.4 (44.0)

Note:
Dilution is the average initial dilution of plume; trapping level is given as depth below surface.



Note: from CH2M HILL, 1984.

FIGURE 4–1
Receiving Water Density
Profile Station Locations



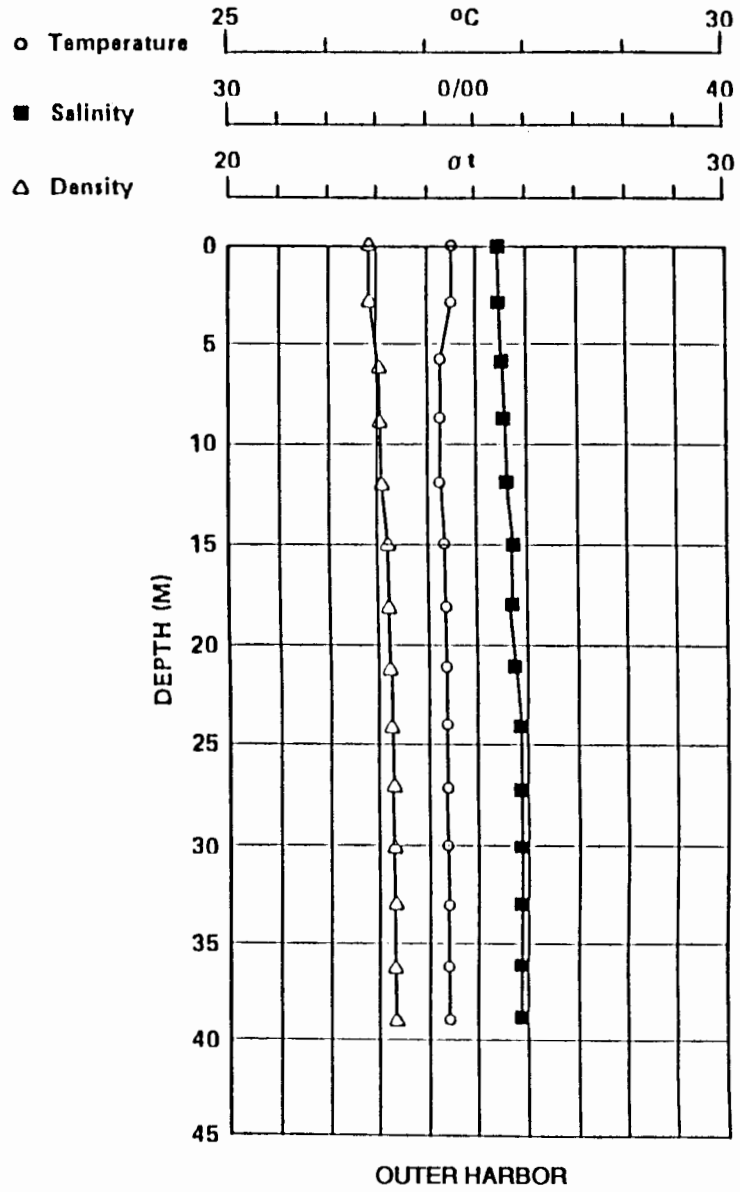
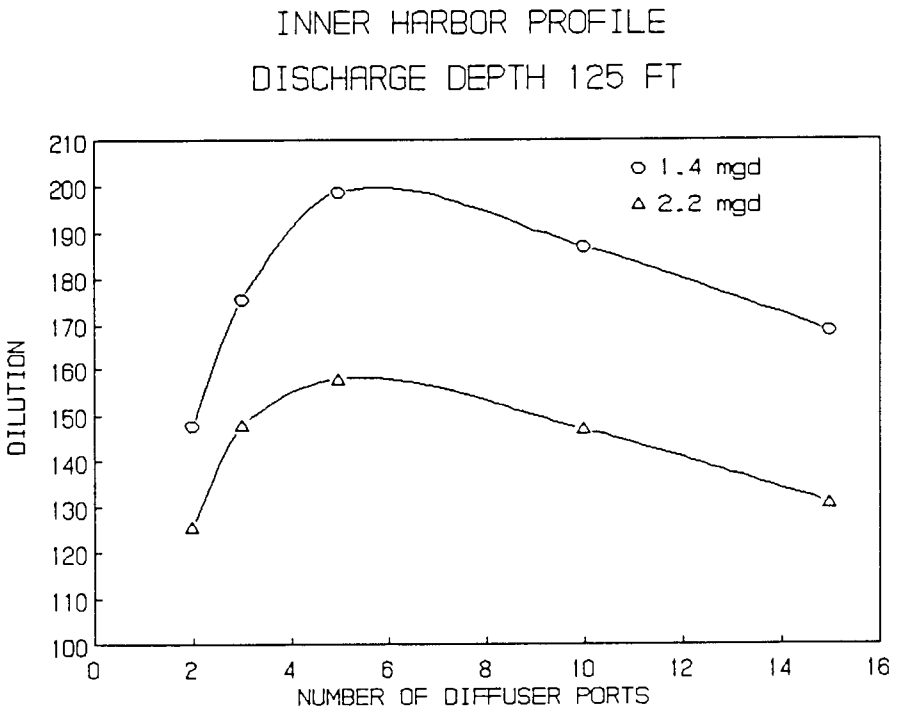


FIGURE 4–2
Inner and Outer Harbor Density Profiles Used in Initial Dilution Modeling



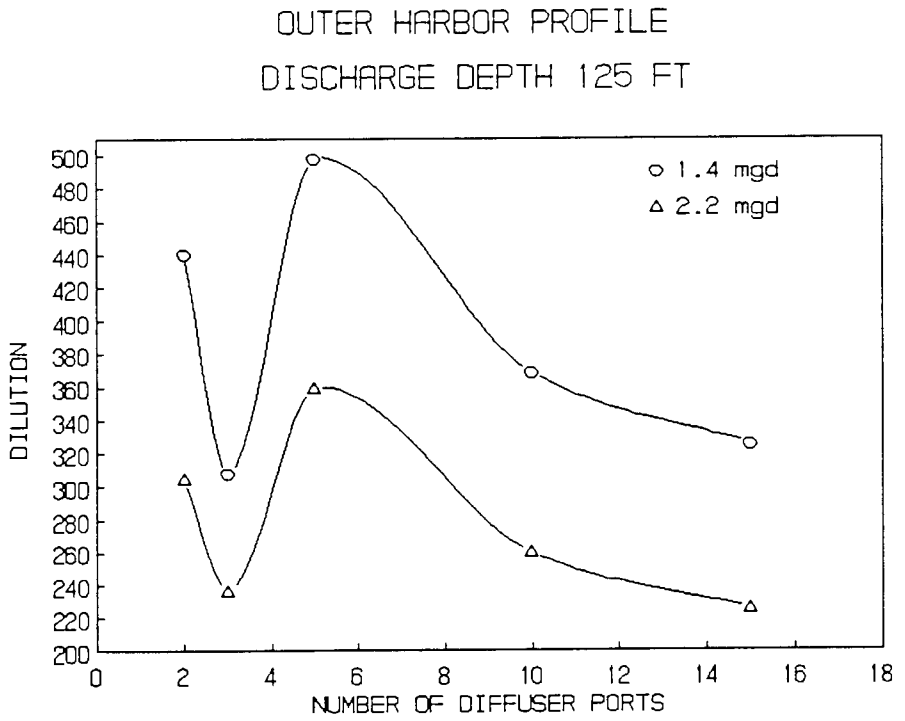
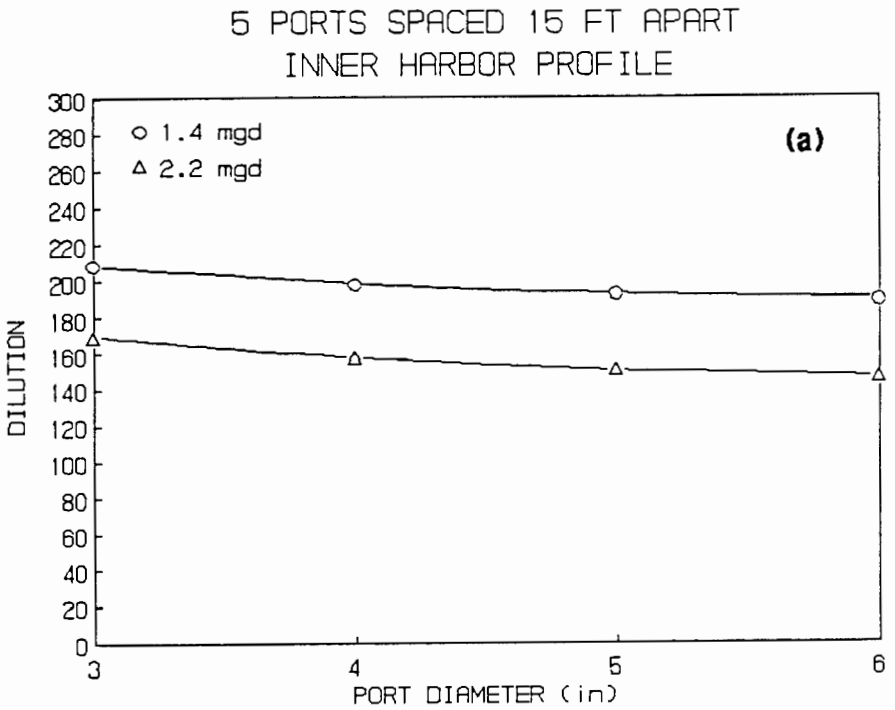


FIGURE 4-3
Diffuser Configuration Selection Results



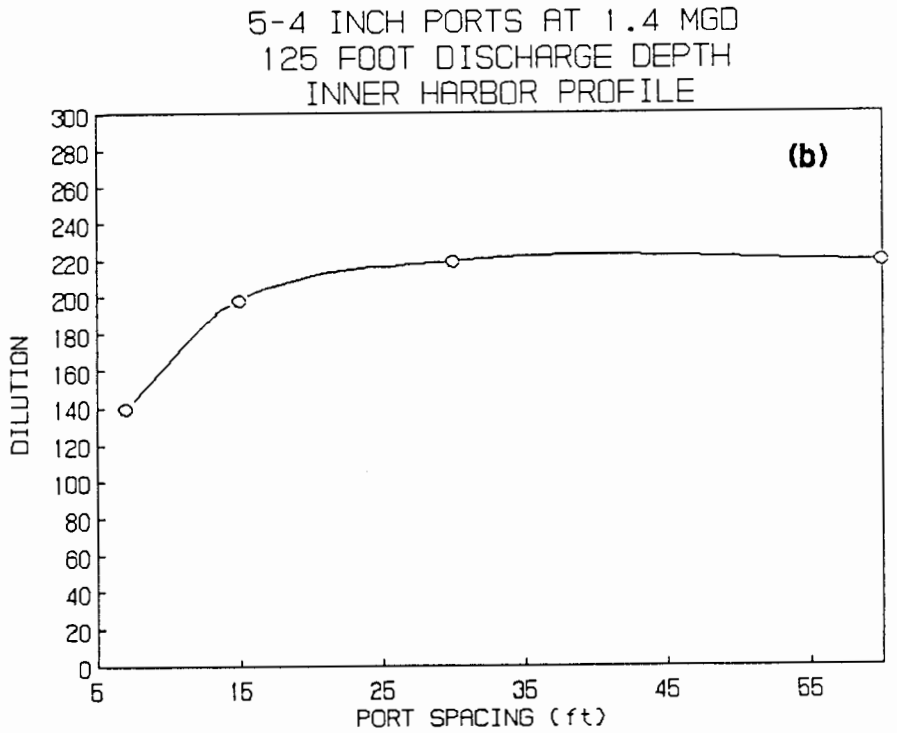
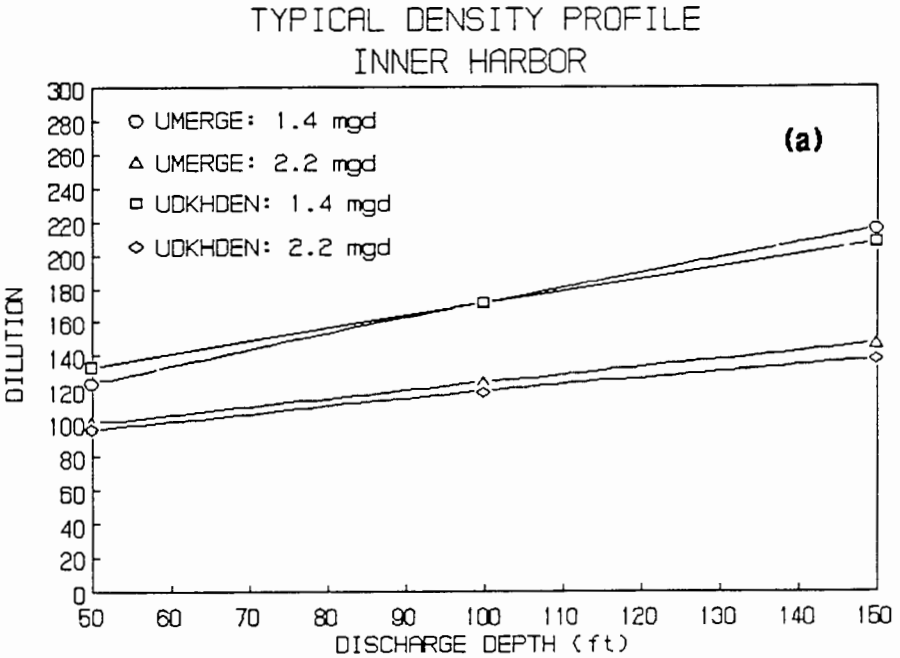


FIGURE 4–4
Effects of (a) Port Diameter and (b) Port Spacing on Initial Dilution



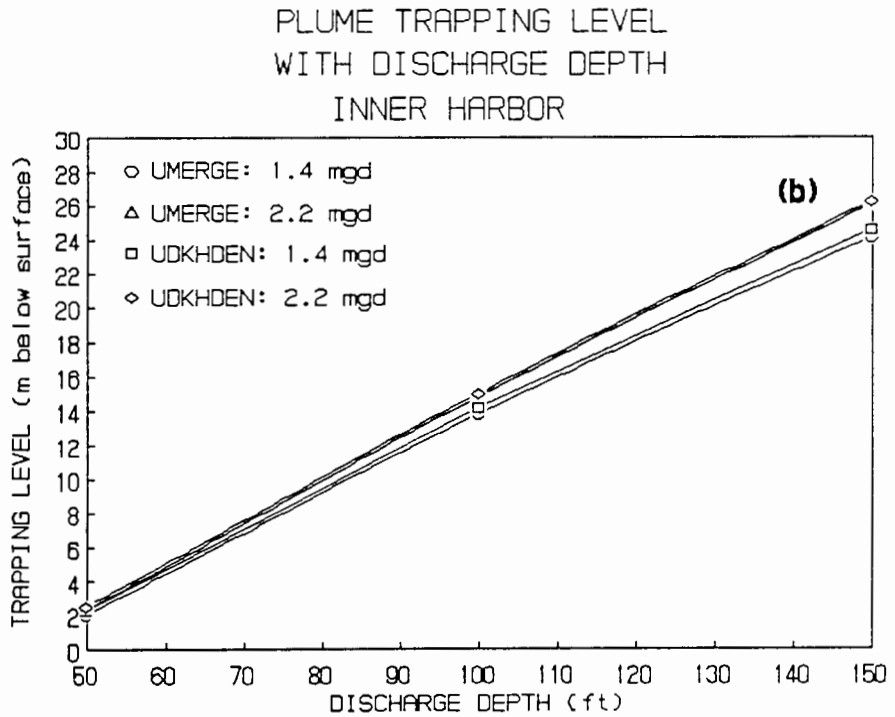
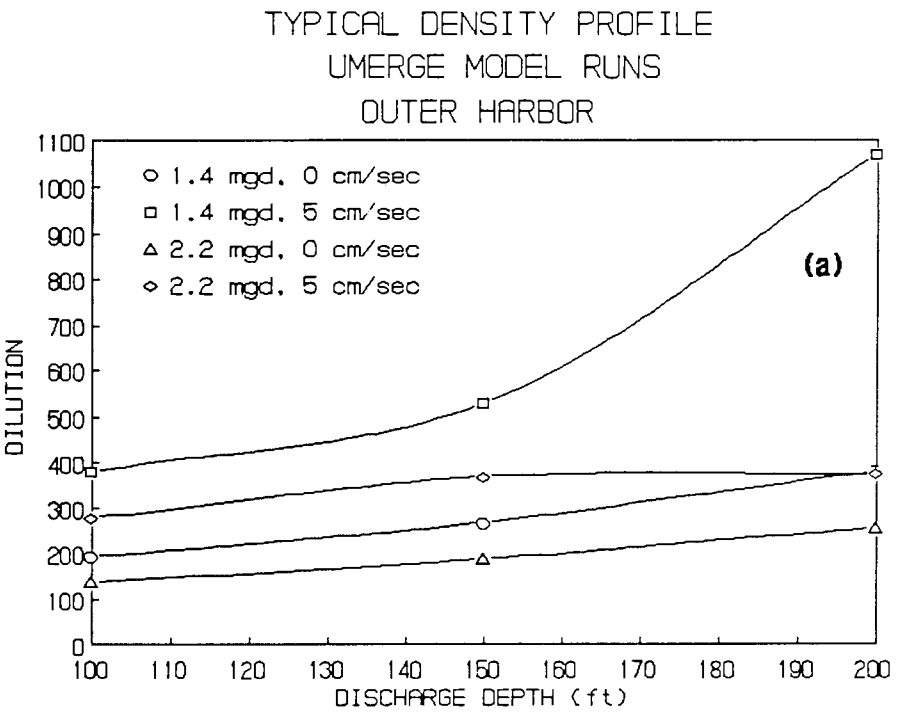


FIGURE 4–5
Predicted (a) Initial Dilution and (b) Trapping Level for Inner Harbor Conditions Using UMERGE and UDKHDEN



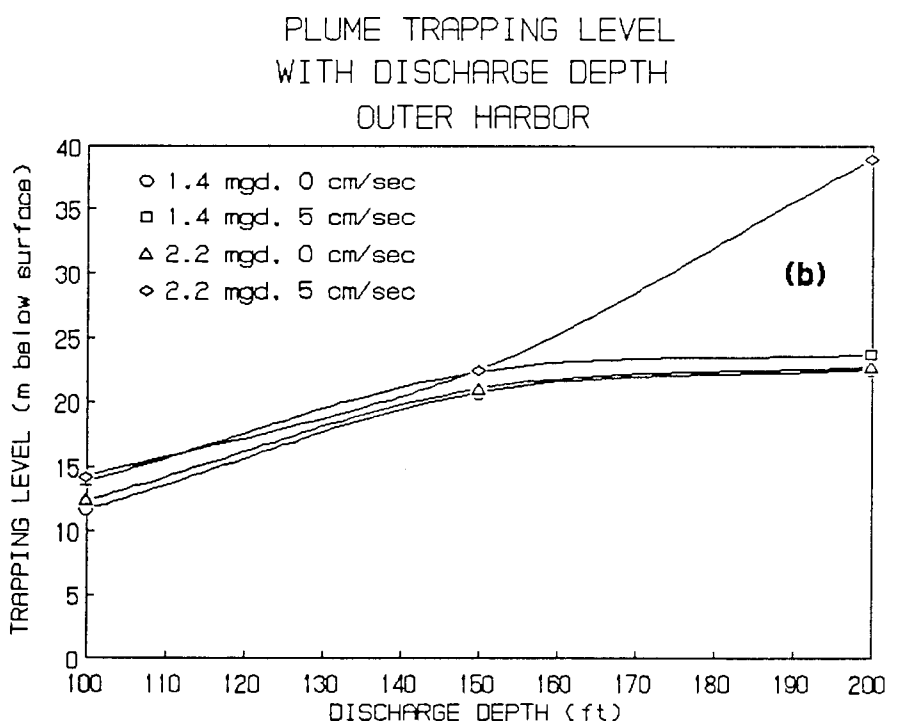
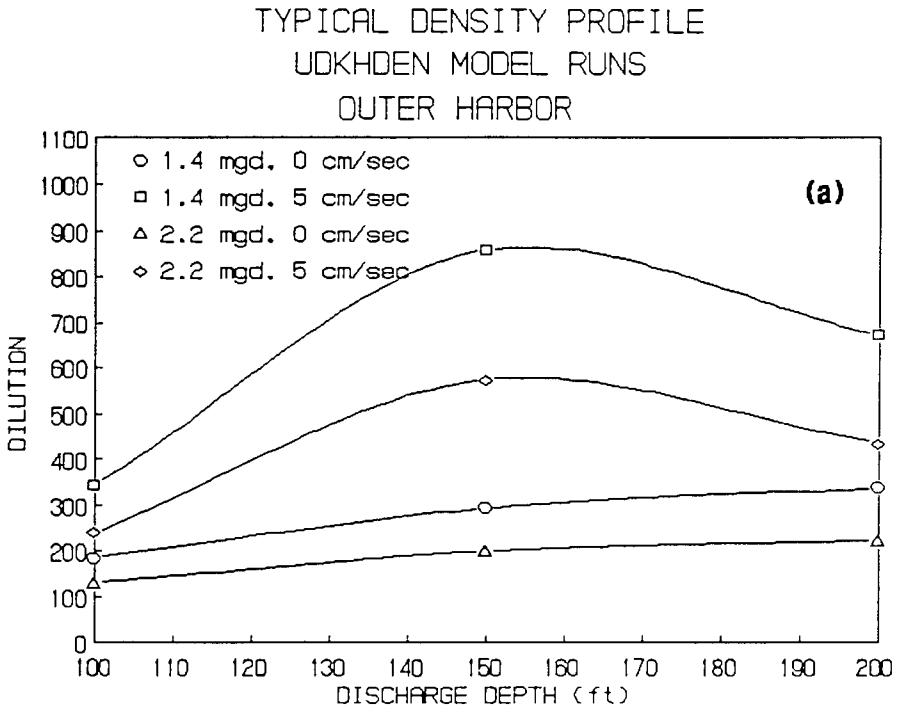


FIGURE 4-6
Predicted (a) Initial Dilution and (b) Trapping Level for Outer Harbor Conditions Using UMERGE



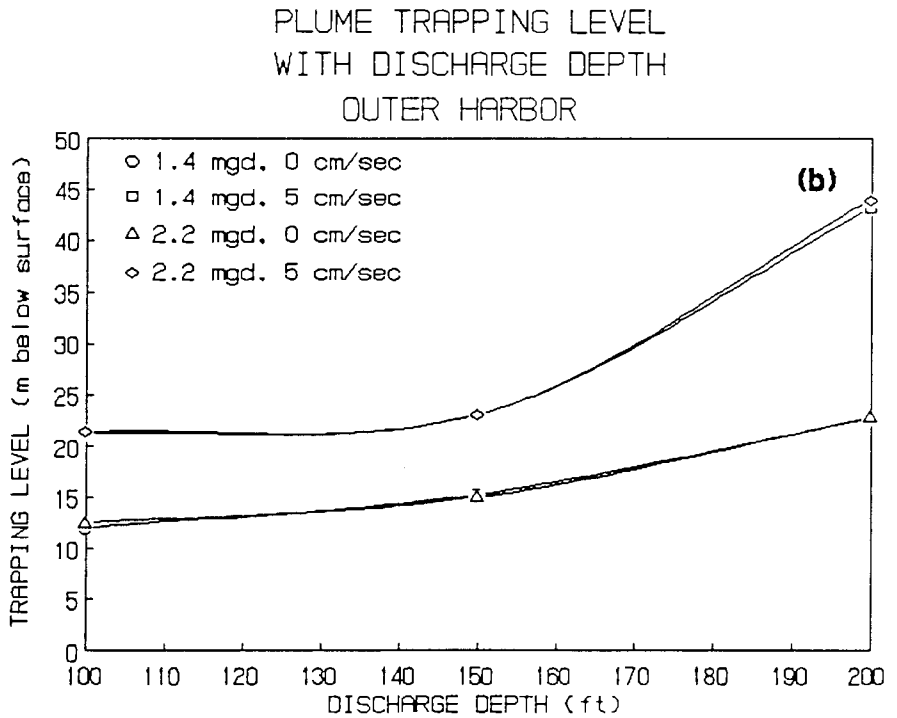


FIGURE 4-7
Predicted (a) Initial Dilution and (b) Trapping Level for Outer Harbor Conditions Using UDKHDEN

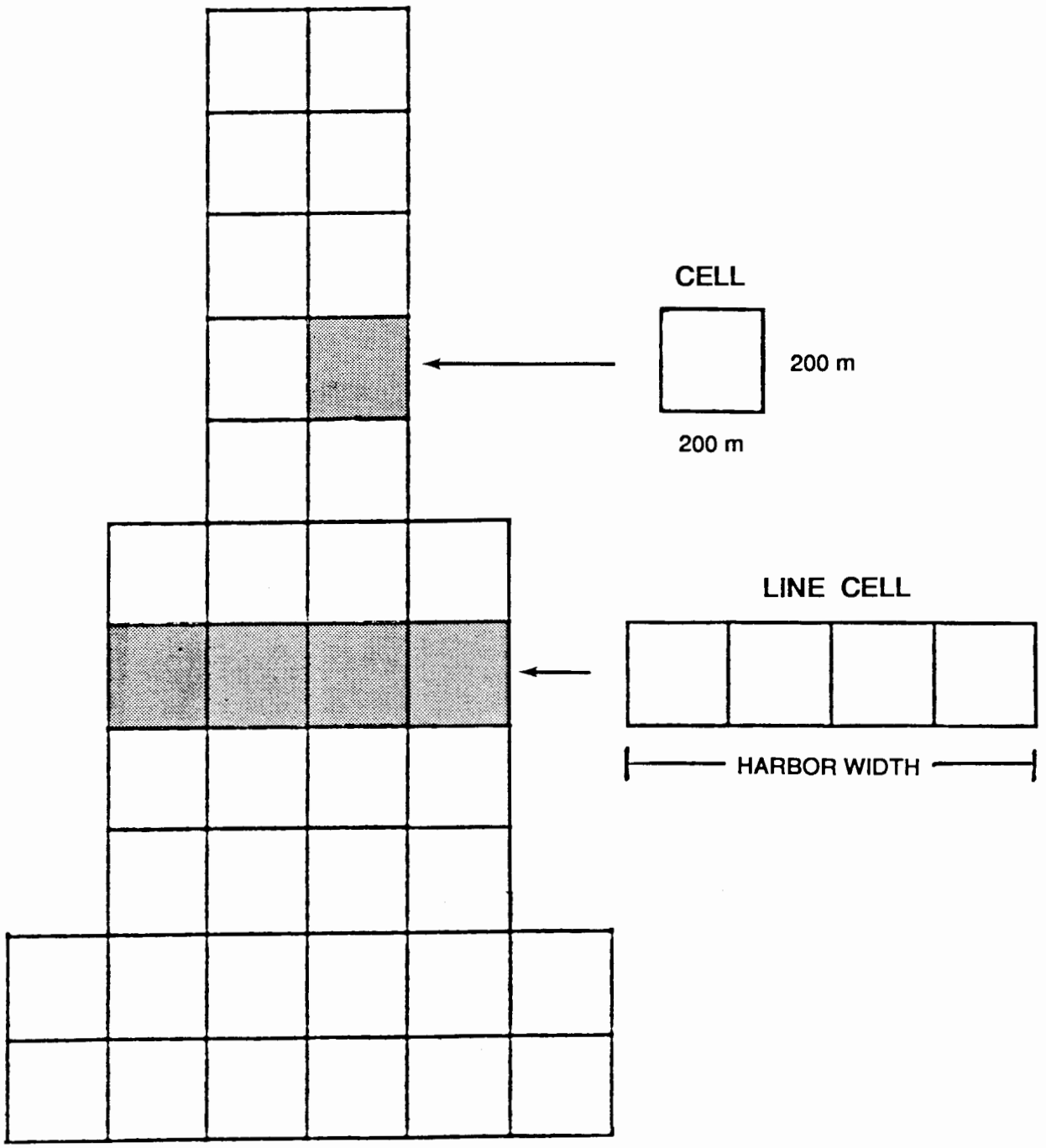


FIGURE 4–8
Definition of Model
Line Cells and Cells

SIMULATIONS RUN FOR TOTAL NITROGEN
TOTAL LOADING OF 500 kg/day
INNER HARBOR OUTFALL LOCATION

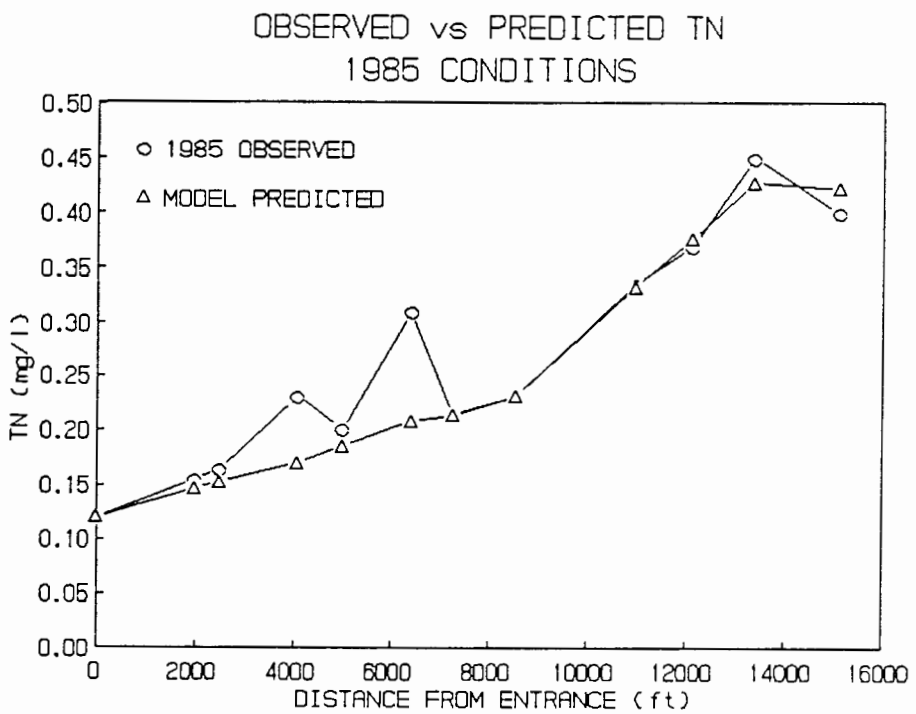
DISSOLVED CONSTITUENT TRANSPORT SIMULATION FOR PAGO PAGO HARBOR
Preliminary Model Run-Total Nitrogen-Loading of 500 kg/day - Inner Harbor
No Decay Term, Diffusivity Split at 6000 and 26000 m^2 per hour

Day: 0
Hour: 0
Time (hrs): 0.00
Water Level (m): -0.01
Output Interval: 480

Table of Concentrations in mg/m^3

J/I	0	1	2	3	4	5	6	7	8	9	10	11
27												
26						120	120					
25						120	120					
24						120	120					
23						120	120					
22					120	120	120	120				
21					120	120	120	120				
20					120	120	120	120				
19					120	120	120	120				
18					120	120	120	120				
17					120	120	120	120				
16				120	120	120	120	120	120			
15				120	120	120	120	120	120			
14			120	120	120	120	120	120	120	120		
13			120	120	120	120	120	120	120	120		
12		120	120	120	120	120	120	120	120	120	120	
11		120	120	120	120	120	120	120	120	120	120	
10			120	120	120	120	120	120	120	120		
9			120	120	120	120	120	120	120	120		
8				120	120	120	120	120	120			
7				120	120	120	120	120	120			
6			120	120	120	120	120	120	120	120		
5			120	120	120	120	120	120	120	120		
4		120	120	120	120	120	120	120	120	120	120	
3		120	120	120	120	120	120	120	120	120	120	
2		120	120	120	120	120	120	120	120	120	120	
1		120	120	120	120	120	120	120	120	120	120	
0	120	120	120	120	120	120	120	120	120	120	120	120

FIGURE 4–9
Example of Model Output



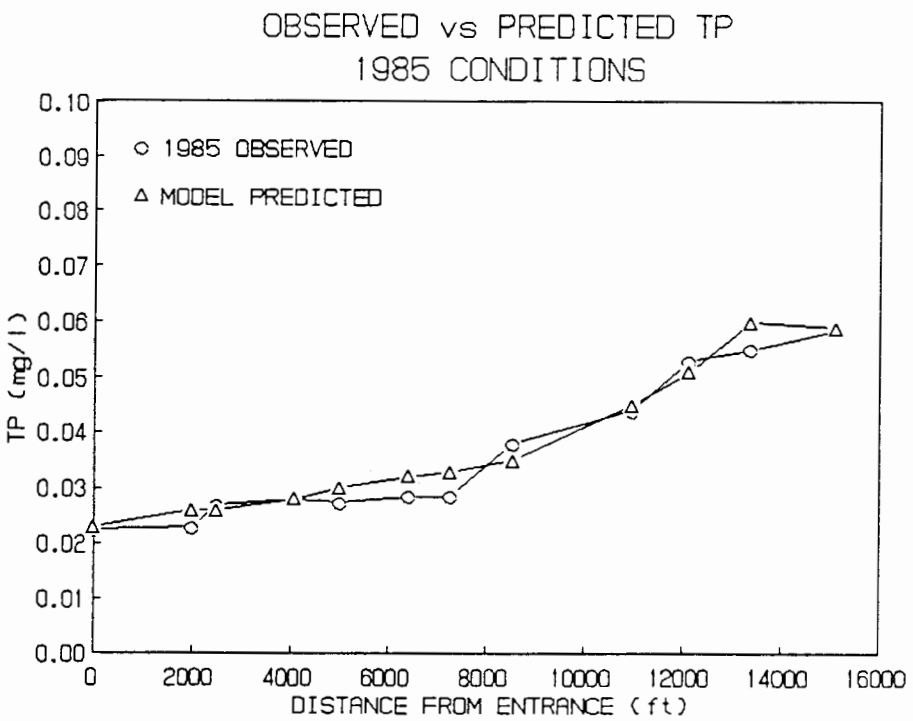


FIGURE 4–10
Calibration Results for Wasteload Transport Model

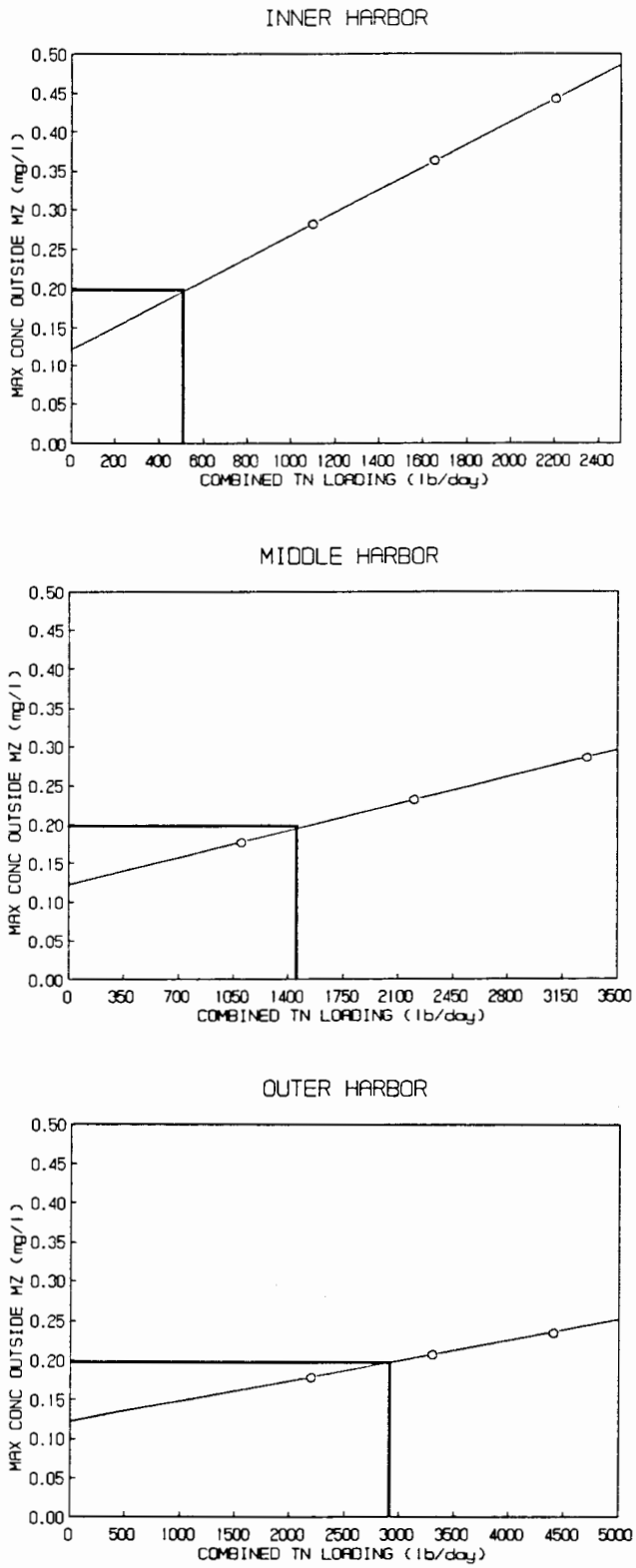


FIGURE 4-11
Relationship of TN Concentration and Loading

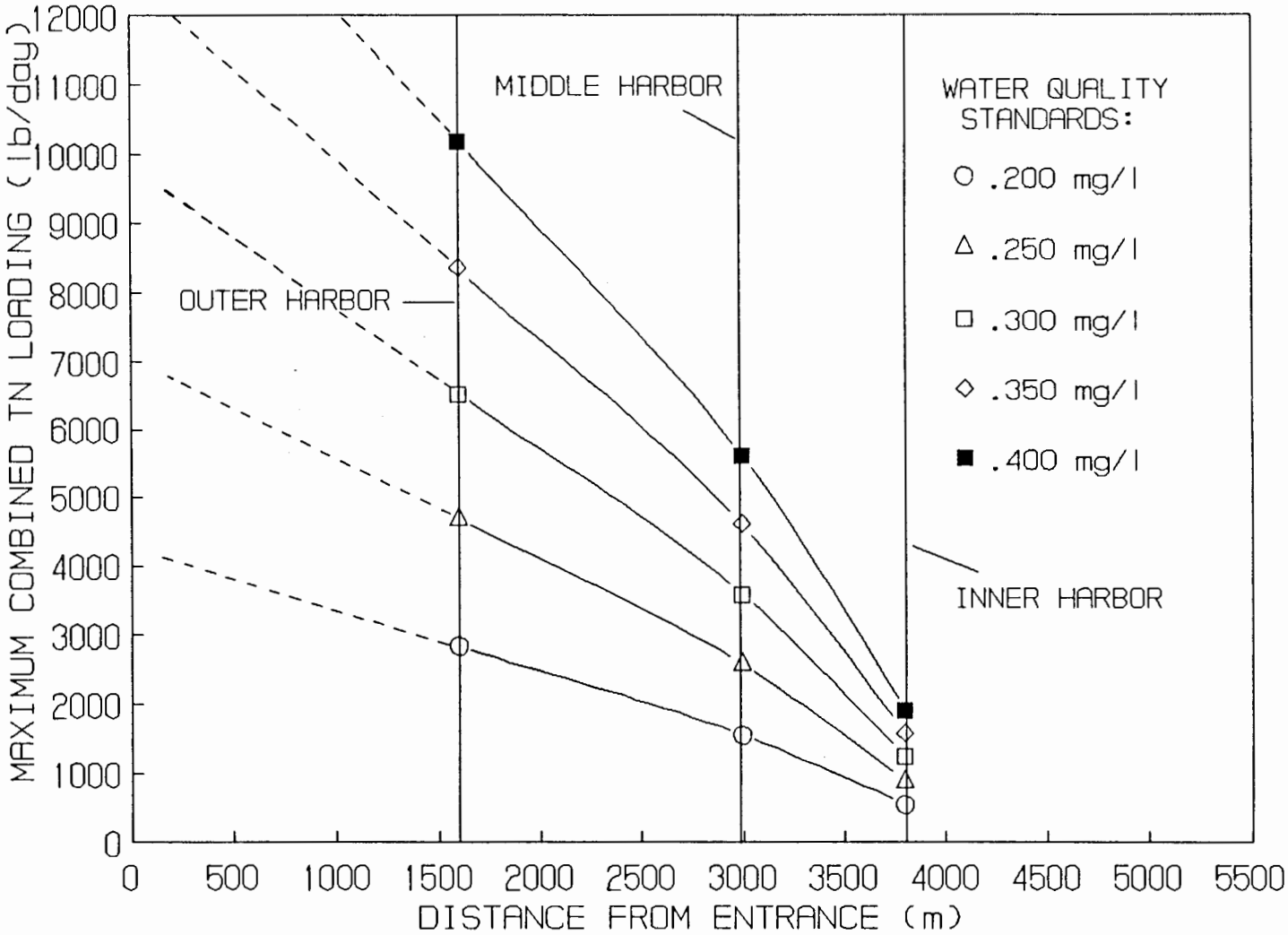
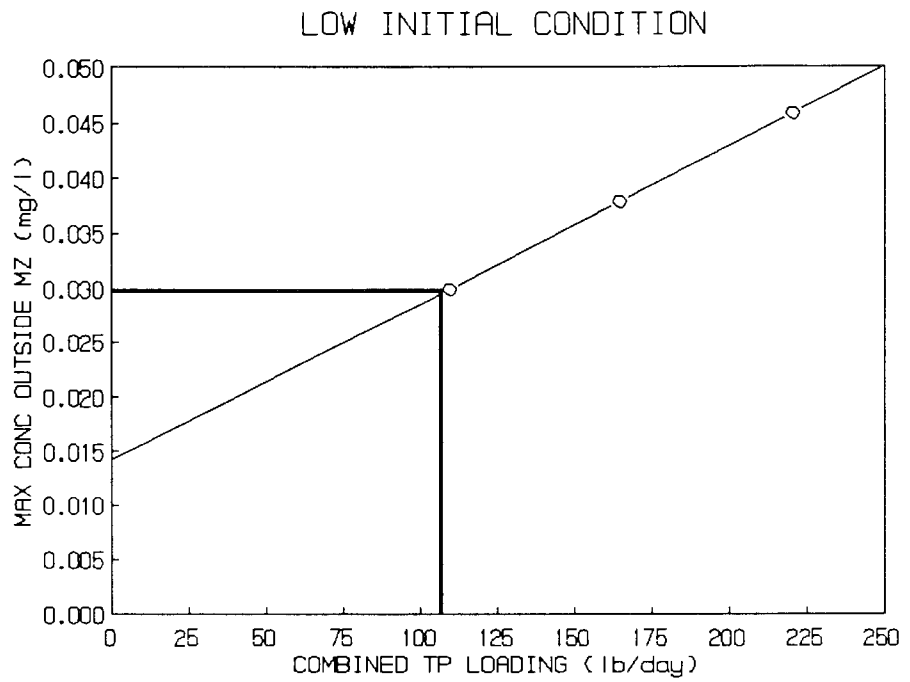


FIGURE 4–12
Maximum TN Loading Versus Distance from Harbor Entrance



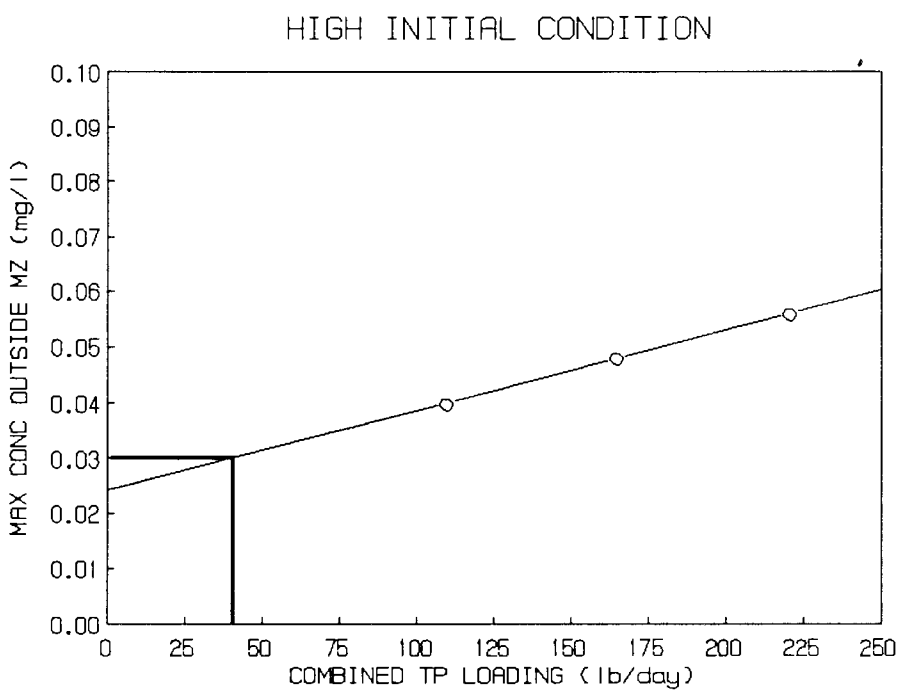
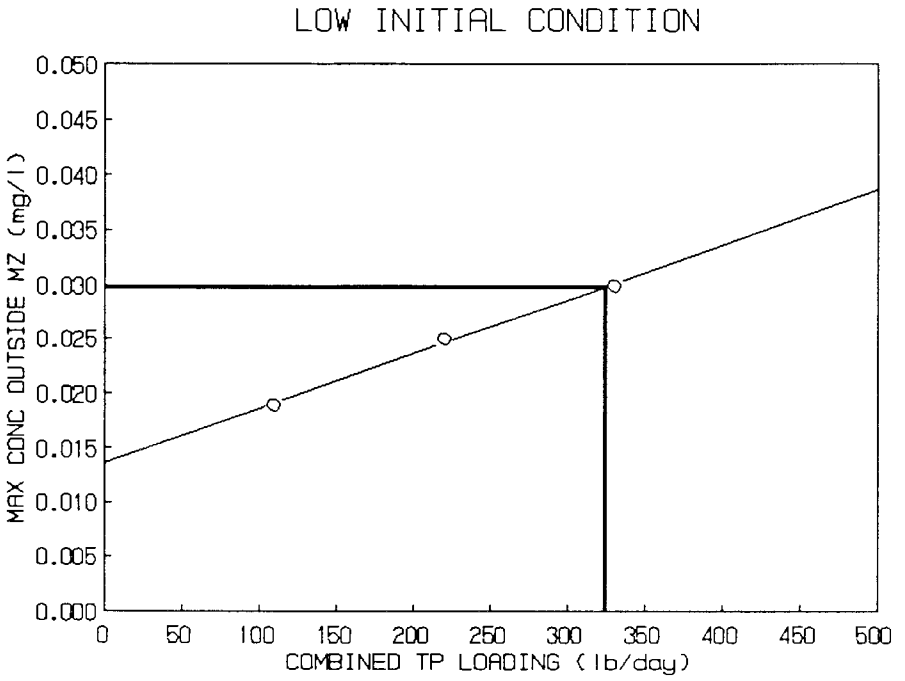


FIGURE 4–13
Maximum Predicted TP Concentrations for Inner Harbor Discharge



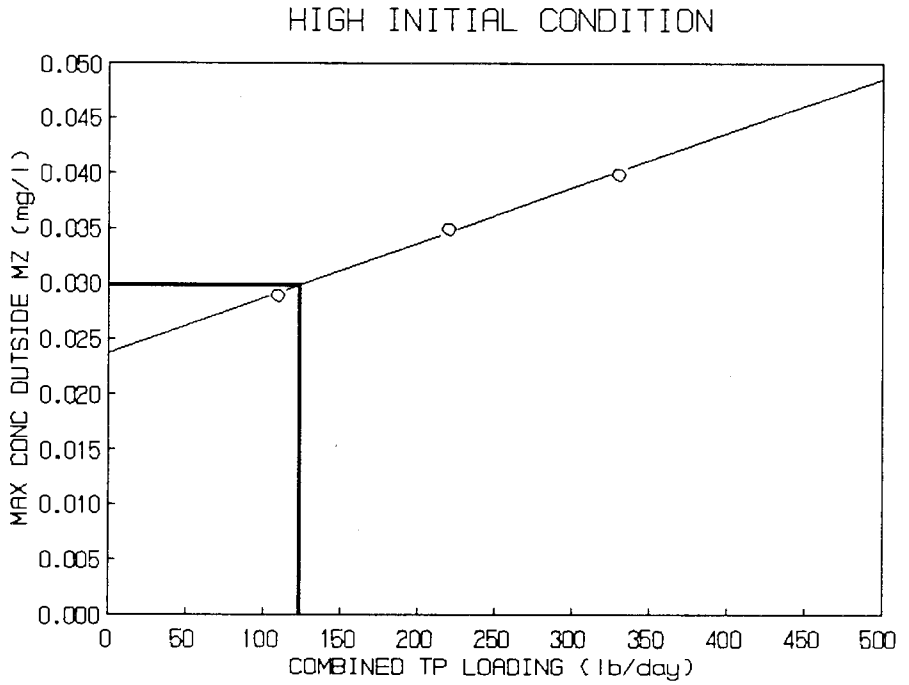
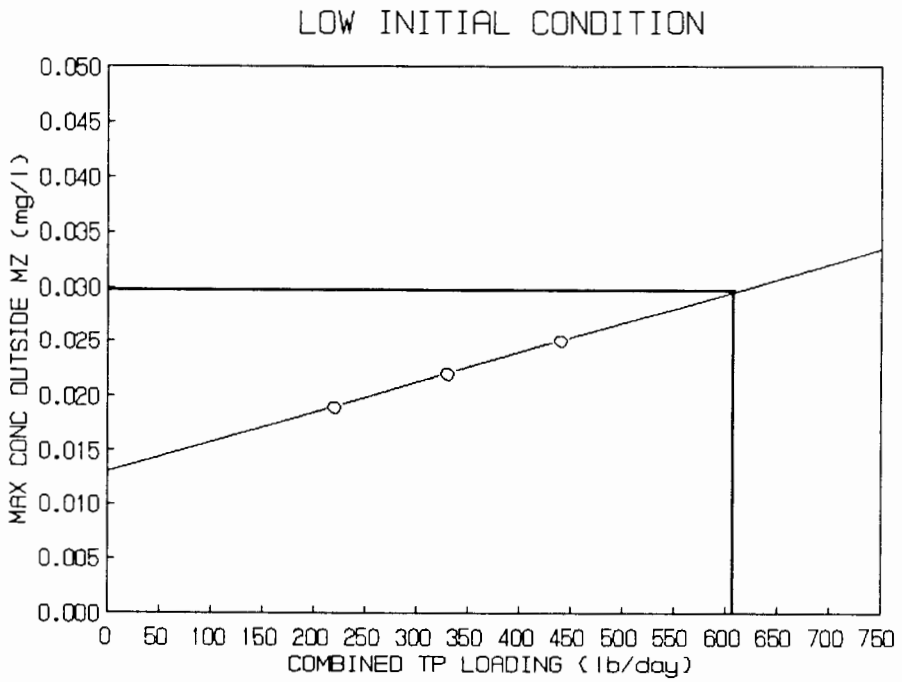


FIGURE 4–14
Maximum Predicted TP Concentrations for Middle Harbor Discharge



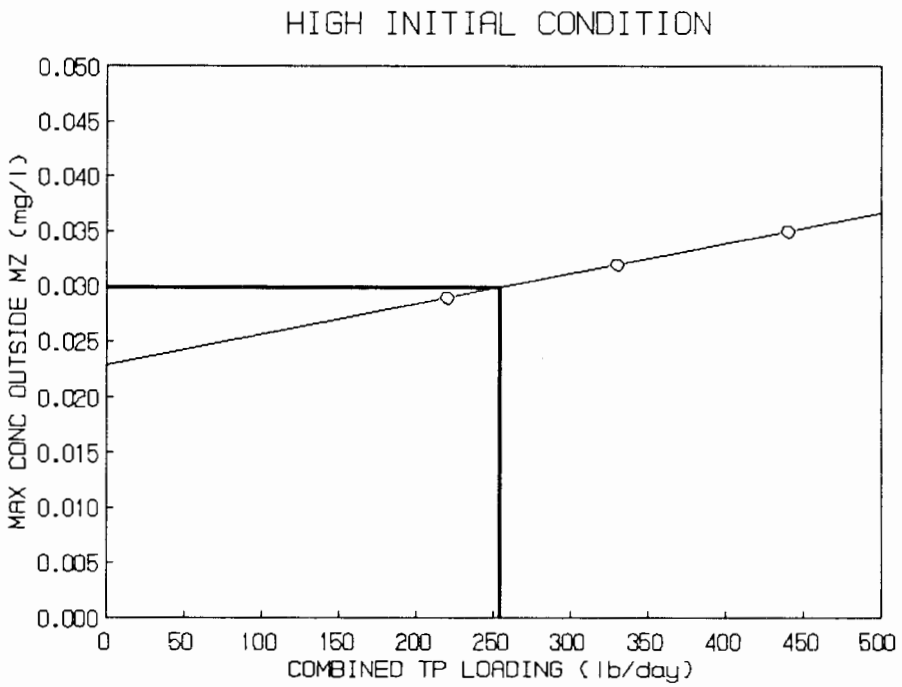
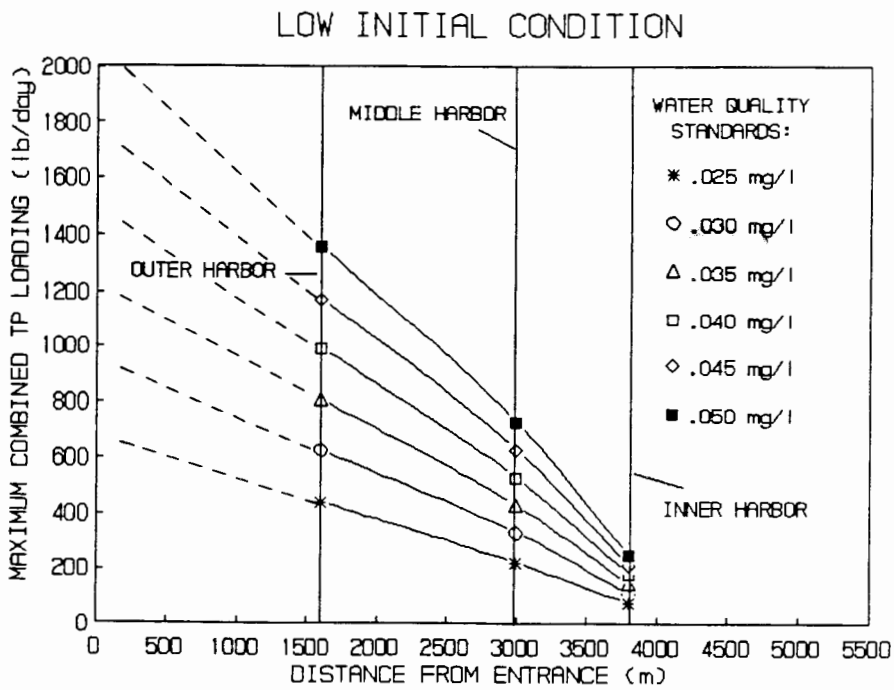


FIGURE 4–15
Maximum Predicted TP Concentrations for Outer Harbor Discharge



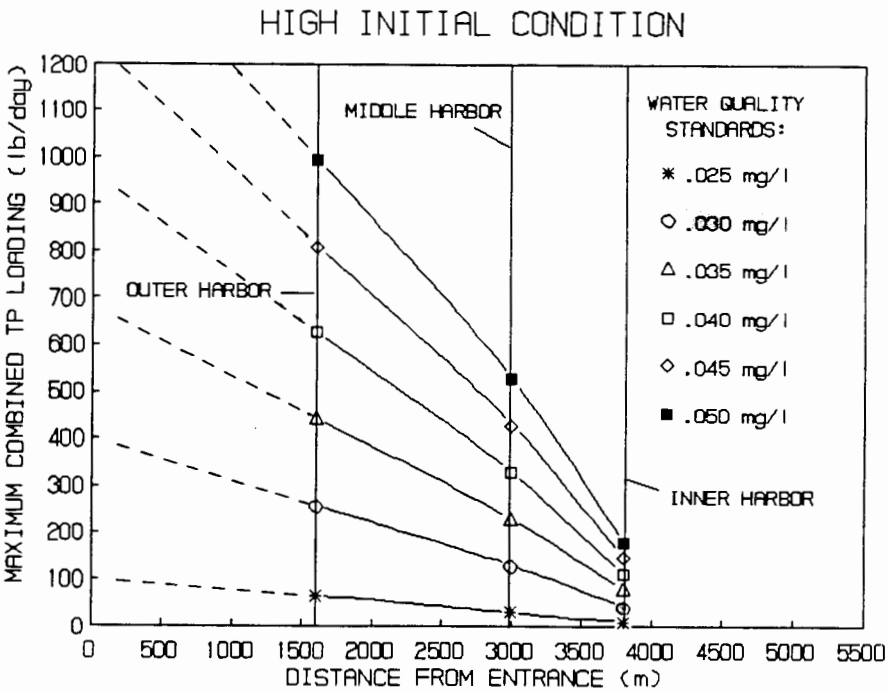


FIGURE 4–16
Maximum TP Loading Versus Distance from Harbor Entrance

Section 5
ENGINEERING FEASIBILITY STUDIES

INTRODUCTION

The results of the wastefield transport modeling provided the basis for locating the cannery effluent discharge point within Pago Pago Harbor. This section examines engineering details of possible routes for a pipeline from the cannery to the discharge location and discusses pertinent design and construction aspects of pipelines and the diffuser. Cost estimates are presented and documented at a level that permits decisions regarding construction and choices between alternative pipeline routes.

Two alternatives are examined for their design and installation details: a land pipeline route and a marine pipeline route. For each, the length and type of pipe, construction difficulties, and time and cost of construction are analyzed. The diffuser would be identical for both alternatives. The marine pipeline route analysis is based on an unburied pipeline. The pipeline would be held on the bottom or suspended from concrete anchors. The land route analysis is based on a pipeline buried along the road from the StarKist plant toward Breakers Point. Either of these routes could accommodate a joint outfall carrying the discharge from both canneries.

LAND PIPELINE

The land pipeline route alternative consists of pipe trenched into the ground from the StarKist cannery along the road bordering the northern and eastern edges of the harbor to the point where it crosses the shoreline perpendicularly and extends across the harbor bottom to the depth and location specified by the results of the transport modeling and the geophysical survey.

ROUTE

The route is restricted to the road right-of-way that follows the northern and eastern edge of the harbor, as shown in Figure 5-1. The pipe in this alternative is trenched into the road in the lane closest to the harbor. The underground portion of the route begins at the cannery gate, as marked in Figure 5-1. Near the terminal point of the pipeline, the route turns in to the harbor and follows a submerged path to a depth of 130 to 170 feet, as shown in Figure 5-2.

Along much of the route, the distance between the edge of pavement and the shoulder of the cross-section profile is as narrow as a few feet. Property owners would probably object if pipeline burial or temporary placement of excavation material is made on the

landward side of the road. Therefore, the route should be confined to the eastbound lane of this two-lane road.

MATERIAL

The pipeline materials that were considered are ductile iron (DI), polyvinylchloride (PVC), and high-density polyethylene (HDPE). The DI pipe could be desirable because it would have lower maintenance costs at the shallow depth required. Only a thin layer of fill between the pipe and pavement is possible over most of the culvert crossings along the route, requiring the pipe to resist stresses applied by vehicles. However, representative costs for DI, PVC, and HDPE were developed and are provided in Appendix A.

CONSTRUCTION

The method of construction is relatively simple for this alternative, thereby widening the field of potential bidders. The equipment required for construction is a backhoe, a loader, a dozer, dump trucks, and an asphalt batcher and layer, all of which are available on the island. Crews are available, but backhoe operators having skill levels beyond that found on the island might be required because of the risk of damaging other utilities buried under the pavement. Wires are overhead, and utility lines run beneath the road. Fire hydrants are located on either side of the road, indicating that the fire main crosses the road under the pavement and trenching in one lane would certainly encounter it. The road crosses at least 16 culverts between the plant location and Breakers Point. On the route south of Leasi Point, the distance between top of road and top of culvert at most culvert crossings is as little as 1 foot. Such a shallow depth of burial as 1 foot would require the pipe to be routed over the culvert and adjacent to the pavement and not under it, much the same as seen in Figure 5-3.

Protection of this road from erosion by waves must be assured. Effects of wave-induced erosion were noticed on the harbor side of the road (some culverts are undercut), and shore protection work is underway. The shore protection is engineered (placed riprap is being installed over geotextile), but review of the riprap size in relation to the possible wave forces is warranted. Assuming that the land route would entail burial in one lane of the road, construction would be disruptive to traffic. The road is the only route from Pago Pago to Breakers Point and beyond and is heavily traveled by buses and cars during shift changes at StarKist and Samoa Packing.

More space would be needed for contractor work area and staging area with the land route than with the submerged route. Available space is limited. A flat area at Trading Point is a potential space for a contractor. The main docks are busy, but facilities for offloading barges appear adequate.

The design life of the outfall pipeline with respect to the expected remaining life of utilities over or adjacent to the pipeline must be considered. Replacement and repair of other utilities might interrupt service of the outfall pipeline or place it at risk of damage.

SCHEDULE AND COSTS

The construction schedule is illustrated in Figure 5-4a, beginning after materials have been procured. The total estimated time to complete the project via the land route is 26 to 29 weeks. Unit costs of materials and installation for the land route are itemized in Appendix E. The cost estimates are based on 1990 prices adjusted for conditions and mobilization in American Samoa.

In addition to unit costs, two land route scenarios are estimated in Appendix E to provide an idea of the range of costs:

- Least Cost Scenario--Ship and install 6-inch PVC pipe and 6-inch HPDE outfall to Tafagamanu Point. This is a distance of 14,000 feet at an estimated cost of $2,200,000, not including design or construction management.

- Most Cost Scenario--Tug and barge, and install 18-inch DI pipeline and outfall to Breakers Point. This is a distance of 16,000 feet at an estimated cost of $4,200,000, not including design or construction management.

The cost estimates could increase, depending on fuel and raw material costs, more than normally expected in 1991. Other cost assumptions and limitations are discussed in Appendix E.

Shorter land routes were not considered because of the width of the reef along most of the route. Permitting would probably be more difficult if large areas of coral reef were involved. However, the unit prices given in Appendix E can be used to generate cost estimates for any desired route or length of pipeline. Design and construction management costs were not estimated for the land route, but would be higher than those estimated below for the marine route.

MARINE PIPELINE

The marine pipeline would enter the harbor at the StarKist wharf at the location where the present pipeline extends from the wharf face, angles downward, and enters the harbor. The pipeline would connect with a new line, also to be installed as part of the present project, leading from the process water flume. The marine pipeline, as described for cost estimating, would be made of HDPE and held in place with concrete

weights along a route near the base of the reef at the northern and eastern sides of the harbor toward the entrance.

ROUTE

The route of the pipeline was determined with the aid of maps generated by the geophysical exploration and sidescan sonar images. Figure 5-5 shows a generalized description of the pipeline route. After entering the harbor at the wharf face, the pipeline would traverse the steep side of the harbor generally normal to the depth contours to a depth of about 120 feet and a distance from the wharf of 750 feet. At that point the route turns east for about 4,000 feet before turning south.

The geophysical survey showed that the harbor bottom along the potential route is covered with sand and loose rock. Close to the cannery, organic matter might cover the bottom to a thickness of several feet. Any occasional large rocks in the route would have to be avoided while laying pipe. The side of the reef at some locations is very steep, nearly vertical. During geophysical data collection on October 31 and November 1, 1990, it was observed that a refrigerator ship was anchored close to the survey control point. This location apparently is frequently used for anchorage. It is also known that some fishing boats have lost steerage in this reach and have grounded on the reef. It can be assumed that those boats would drop (and drag) anchor in this area. Near Tafagamanu Point, a pipeline would cross under a liquefied natural gas unloading zone. The Blue Flame Gas Company receives product by way of a flexible pipeline connected to ships that are anchored stern-first to the shoreline.

MATERIAL

The pipe will be HDPE with a pressure rating determined by the standard dimension ratio (SDR) of 11. The material has several ideal characteristics for marine installation. It is resistant to corrosion and abrasion, yet it is flexible. Several marine contractors who typically do outfall work in this part of the Pacific Ocean are experienced with handling HDPE pipe.

CONSTRUCTION

Laying the marine pipeline would require operation from barges, reducing the need for a shoreside staging area. Assembly of the pipeline would be done in stages. The pipe is manufactured in 40-foot lengths. The contractor first could weld pipes to make up 160-foot-long sections, which could be loaded onto a barge for shipment to Pago Pago. At Pago Pago, these sections could be welded into 320-foot-long sections and stored floating in a location in the harbor. Prior to placing pipe along the route, the 320-foot sections could have concrete weights installed on them and could be welded to make up 960-foot sections and towed to the location for connection and sinking into position. The pipe, weights, and welding machine can be moved to the site by barge, precluding the need for handling and storing material on land.

SCHEDULE AND COSTS

The construction schedule is illustrated in Figure 5-4b, beginning after materials have been procured. The total time to complete the project via the marine route is 18 to 20 weeks.

Unit costs of materials and installation for the marine route are itemized in Appendix E. The costs of materials and installation depend on length and pipe size (Figure 5-6). The cost estimates are based on 1990 prices adjusted for conditions and mobilization in American Samoa. Costs for design are estimated at approximately $158,000. Costs for construction management are estimated at $173,000 to $212,000, depending on construction time, which depends partly on pipeline length.

DIFFUSER

The recommended diffuser configuration is based on modeling results using the published EPA guidance and hydrodynamic models UMERGE and UDKHDEN. The diffuser design provides maximum feasible initial dilution at desired locations in the harbor and is configured to maintain a plume trapped below the surface. The preliminary design indicates the following approximate configuration:

- Diffuser pipe diameter — 12 inches
- Number of ports — Five
- Port diameter — 4 inches
- Port spacing — 25 feet
- Port discharge angle — Horizontal (0 degree)

The conceptual configuration of the proposed diffuser section is shown in Figure 5-7. This diffuser configuration is recommended as a starting point. The port diameters and recommended number of ports might be modified as necessary to meet effluent and head loss requirements, depending on the design flows selected and whether separate or joint cannery outfalls are selected.

MATERIAL

The diffuser will be fabricated from HDPE. The diffuser is assumed to be fabricated in Hawaii and barged to Pago Pago with other pipeline construction material for the marine pipeline. For the land route, it would be fabricated at a west coast United States location.

CONSTRUCTION

The diffuser will consist of three 40-foot lengths, fused together, with ports bored through the pipe wall. A removable end gate structure or blind flange will be installed at the diffuser terminus. The diffuser will be flanged and bolted at the connection with the pipeline. It will be weighted and sunk into position by the same method used for installing the pipeline.

COSTS

Materials and installation costs for the diffuser are itemized in Appendix E. The total estimated cost for materials and installation depends on pipe size and is $21,000 to $36,000. Cost estimates are based on 1990 prices adjusted for conditions and mobilization in American Samoa.

COMBINED OUTFALL FOR STARKIST AND SAMOA PACKING

If the two canneries construct separate outfalls, approximately 6-inch-diameter and 12-inch-diameter pipes would be required. Instead, the combined flows could be discharged through a single 14-inch pipeline with about the same available head. As can be seen in Appendix E, the single 14-inch outfall is more economical than two outfalls of 6-inch and 12-inch diameter.

ENVIRONMENTAL PERMITTING

Pipeline construction in Pago Pago Harbor will require both local and federal permits. Information on permit requirements has been obtained from the American Samoa Environmental protection Agency (ASEPA), American Samoa Coastal Management Program (ASCMP), and the U.S. Army Corps of Engineers (USACE). This information is summarized below.

Local Requirements:

Permit:	Mixing zone approval
Agency:	Environmental Quality Commission
Reference:	Water Quality Standards 24.0207 (a) (1)-(4)

Permit:	Water Quality Certification
Agency:	Environmental Quality Commission
Reference:	Water Quality Standards

Permit: Land use permit
Agency: ASCMP
Reference: Application form CZM 201

Permit: Coastal Zone Consistency Certification
Agency: ASCMP
Reference: Environmental Impact Assessment

Federal Requirements

Permit: Construction in navigable waters
Agency: USACE
Reference: Department of the Army Eng Form 4345 (see Appendix F)

Permit: Archaeological site
Agency: ASG Historic Preservation Officer
Reference: Section 106 National Historic Preservation Act

Preparing an environmental impact assessment (EIA) is the mechanism to transmit required information to ASG for its decision on mixing zone and land use permits. Specific subjects to be addressed in the EIA are listed in the letter dated December 27, 1990, from Leli Peau (Appendix F). In addition to preparing an EIA, the steps remaining for completing the local permitting process are:

- Possibly conduct public hearing
- Consultant and representative of StarKist attend Project Notification and Review System (PNRS) review conference
- Submit land use application (Appendix F) with verification of land ownership, site plan, and vicinity map

ANALYSIS OF FEASIBILITY STUDY RESULTS

From an engineering (design and construction) point of view, both the land route and the nonburied marine route are feasible. The cost of the land route is higher under realistic assumptions about materials. Scheduling will be critical to finish the pipeline by March 1992, and the marine route has a shorter schedule time for construction and possibly for design. The marine route also might be more flexible in terms of location of the outfall termination. The marine route might be easier to permit, particularly in the case of shorter pipeline scenarios. The relative advantages and disadvantages of each approach are discussed in Section 6.

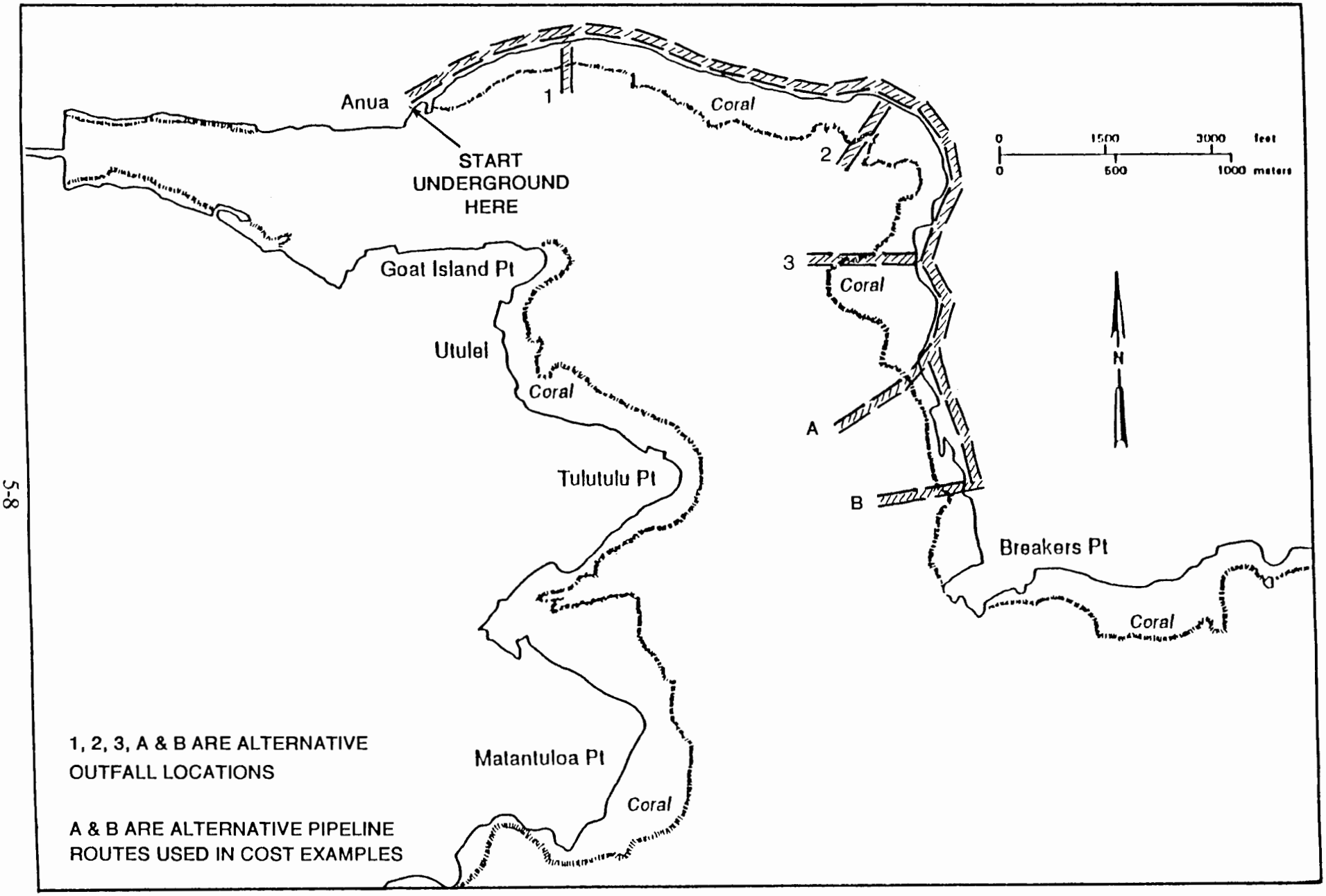


FIGURE 5–1
Land Pipeline Route
Alternatives Considered

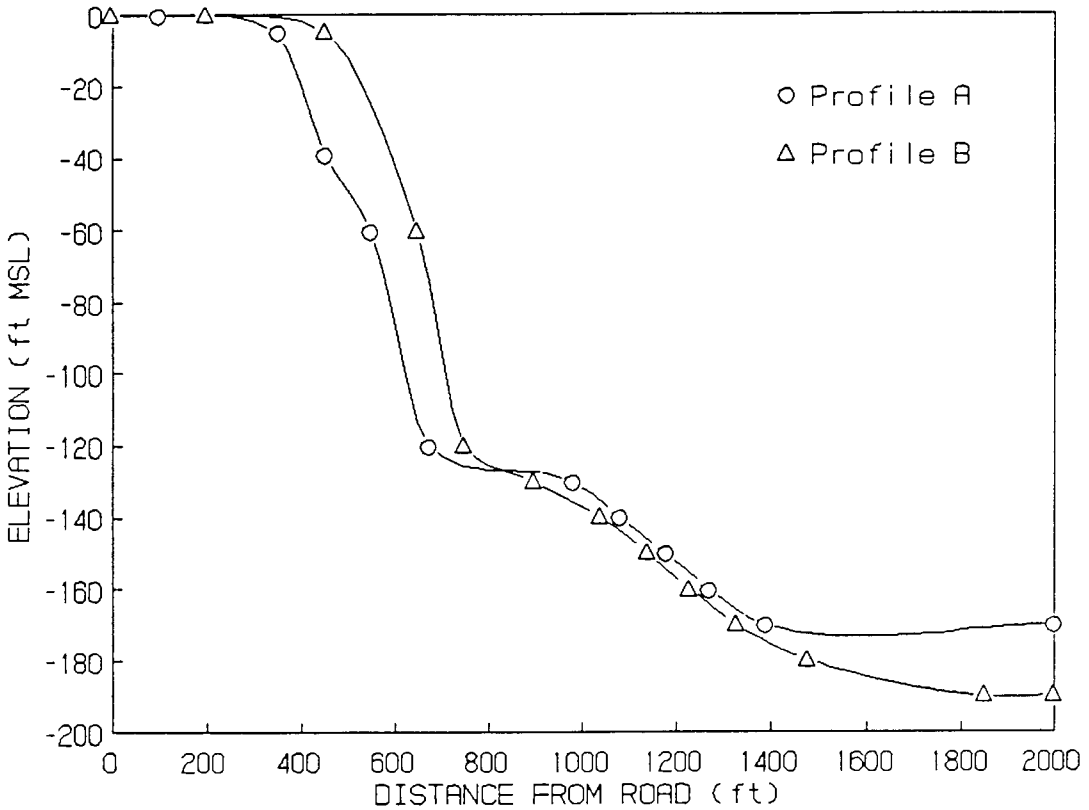


FIGURE 5-2
Representative Profiles at Outfall Location for Land Pipeline Route

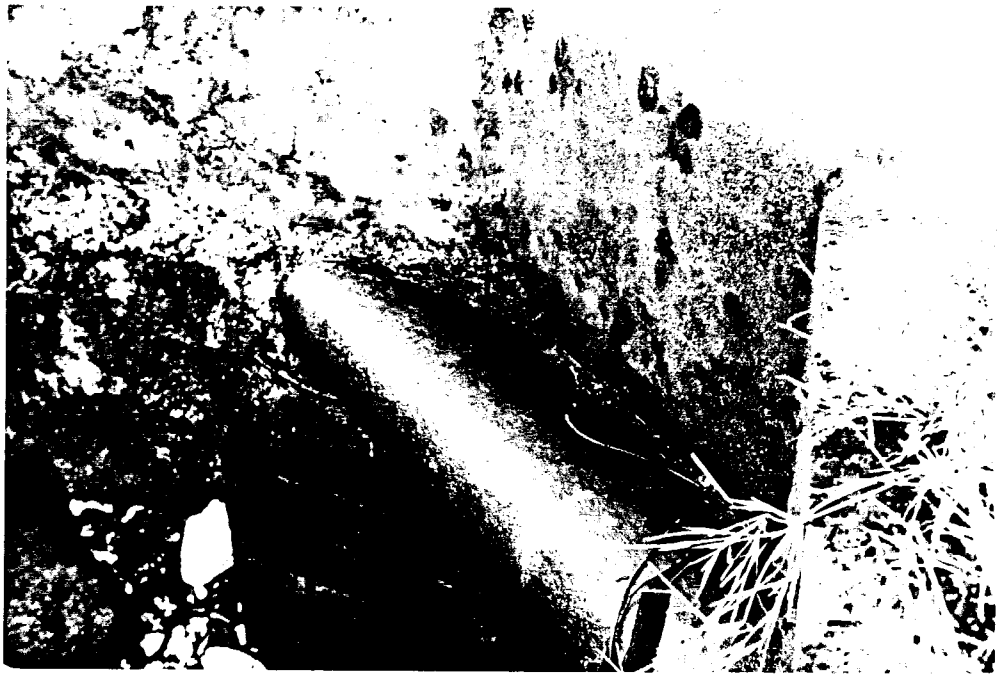


FIGURE 5–3
Possible Land Pipeline
Culvert Passover Approach

A. Land Route

TASK	NUMBER OF DAYS TO COMPLETE
Ship Materials to Samoa	30
Unload	2
Construct	135–150
Barge in Outfall	20
Unload	2
Connect, Weight, & Sink	20
Construct Pump	
Test Pump Station	5
Resurface Road	

B. Marine Route

TASK	NUMBER OF DAYS TO COMPLETE
Fabricate 120' Sections	42–49
Loadout Barge for Samoa	5
Barge is Underway	20
Unload	4
Install Pipeline	42–54
Construct Pump Station	
Test Pump Station	5

FIGURE 5–4
Estimated Pipeline Construction Schedules

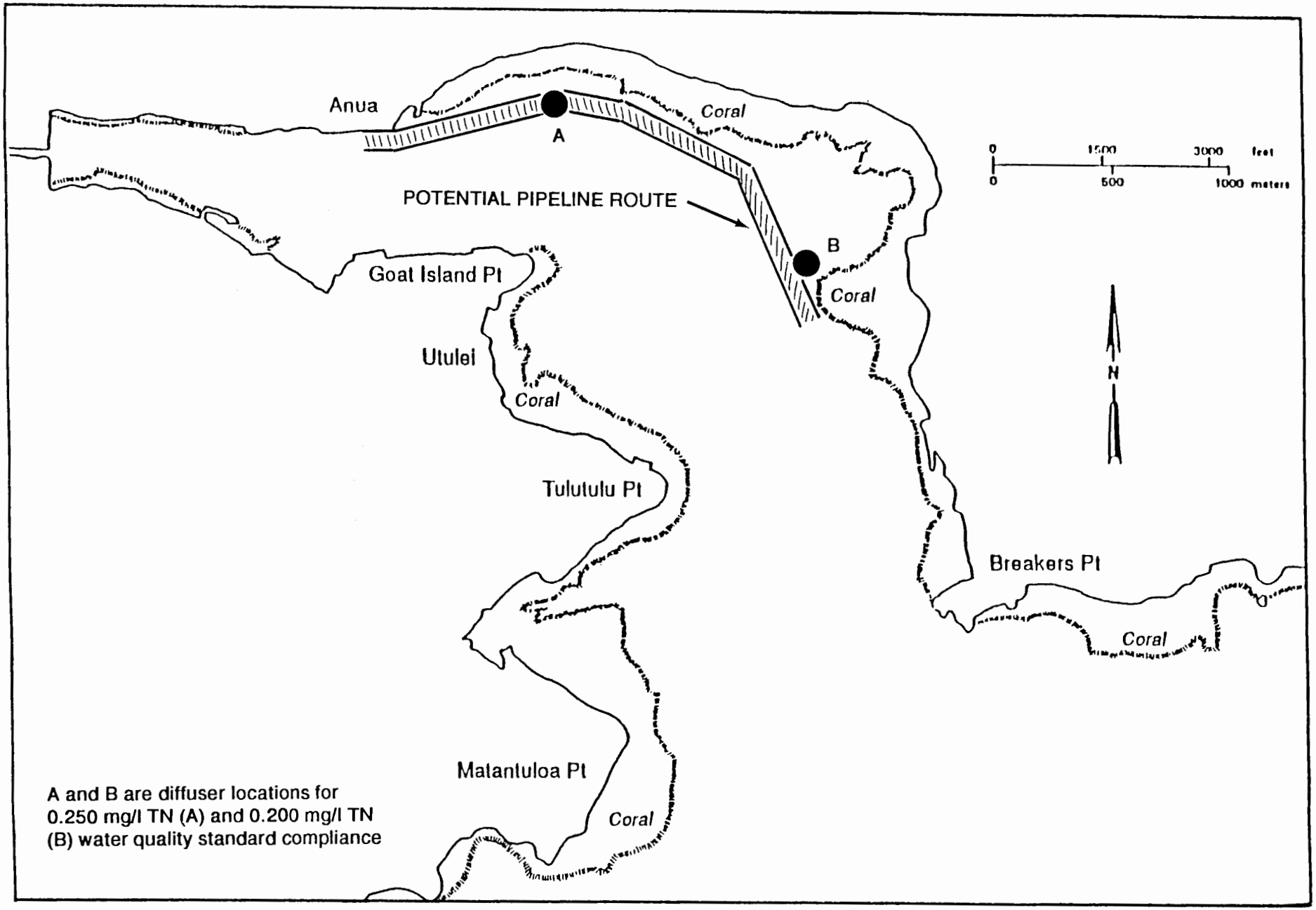
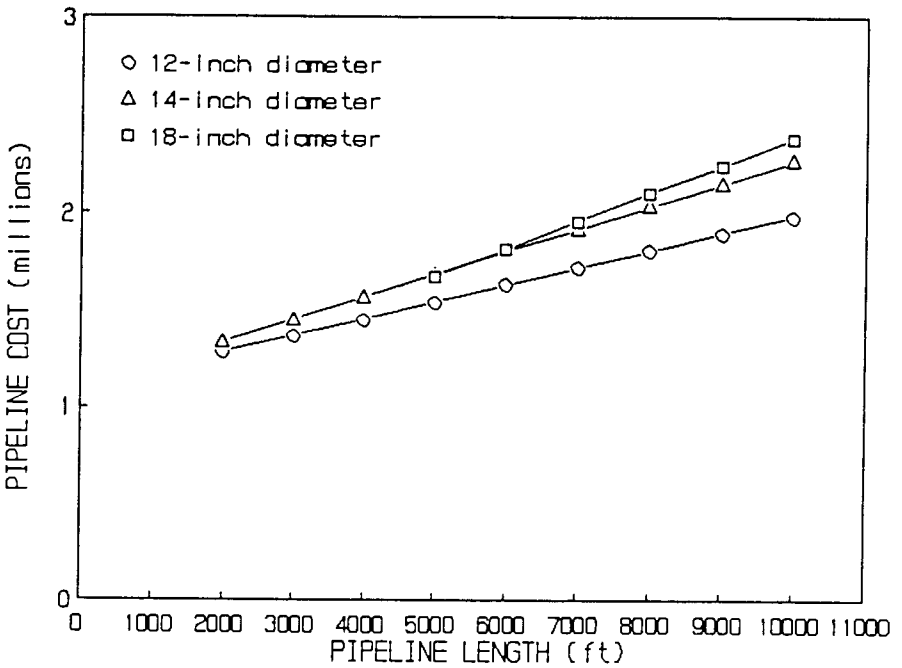


FIGURE 5–5
Potential Marine
Pipeline Route



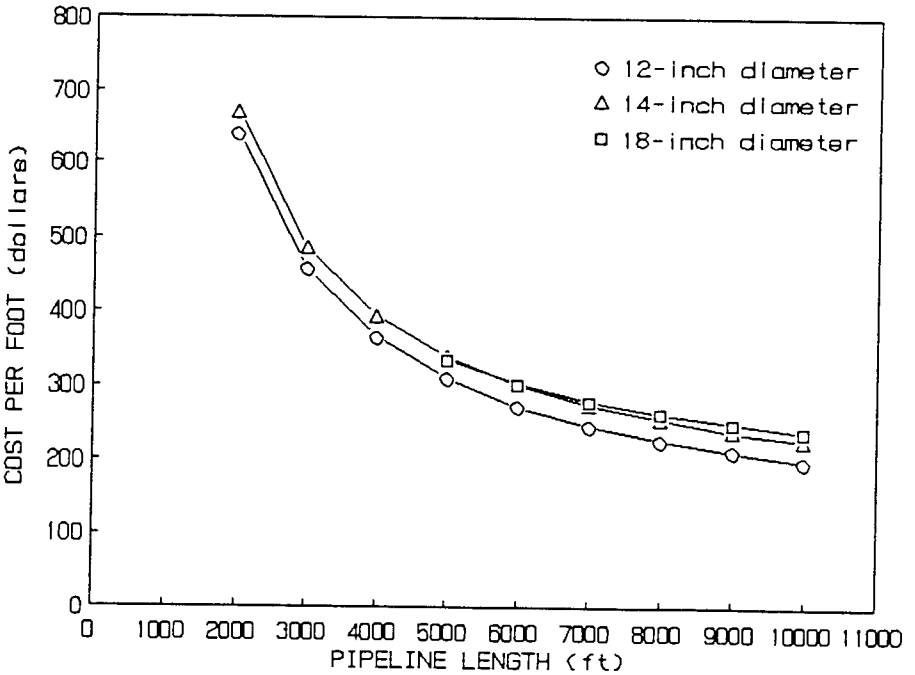


FIGURE 5-6
Estimated Costs for Marine Pipeline

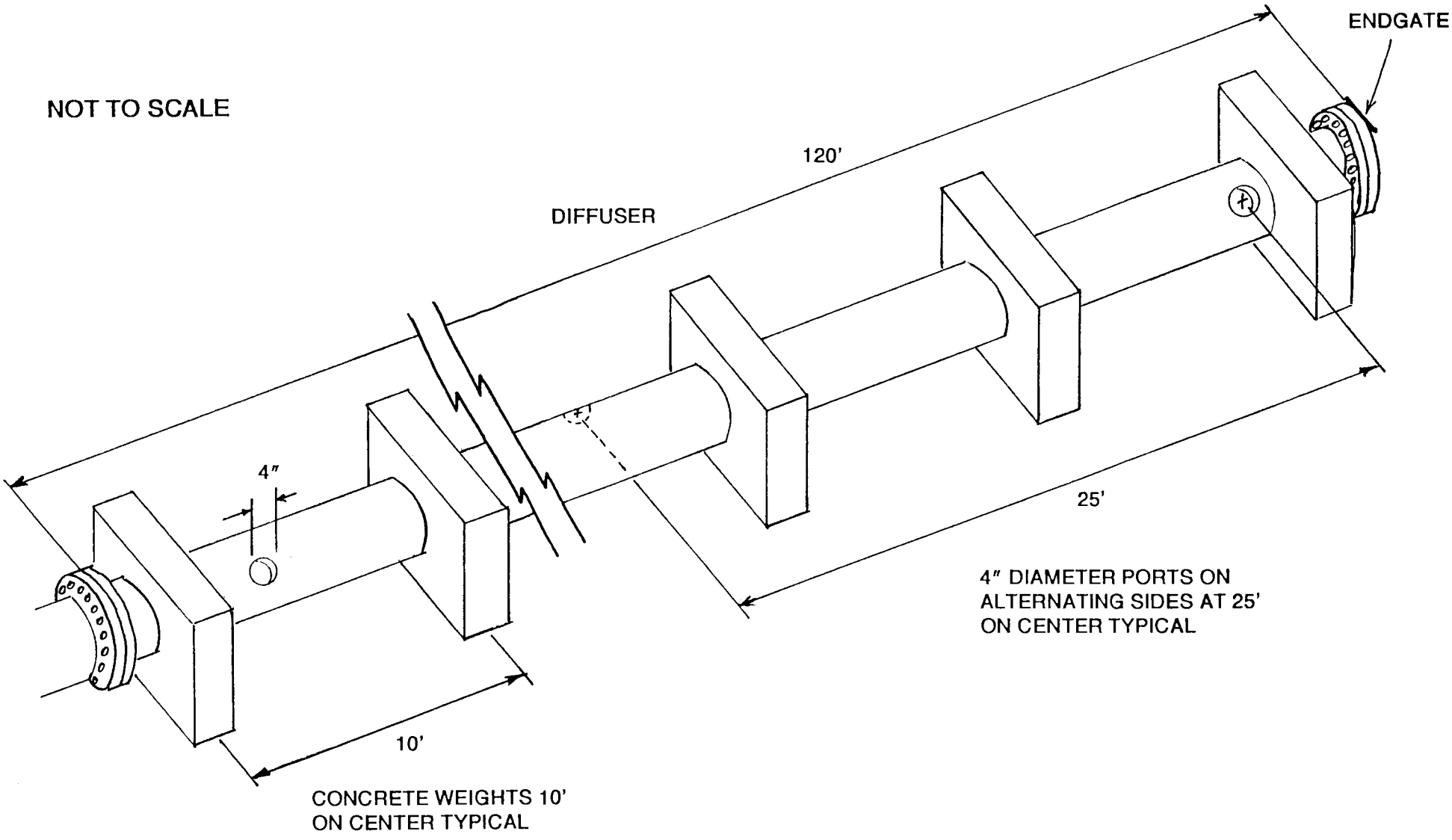


FIGURE 5-7
CONCEPTUAL DIFFUSER
CONFIGURATION

Section 6
EVALUATION OF ALTERNATIVES

Two main classes of alternatives have been evaluated for cannery wastewater disposal: alternative disposal locations, and alternative routes for conveying the wastewater to the disposal location. The evaluation of these alternatives is based on the field surveys and modeling results discussed in the previous sections. All of the wastewater disposal methods considered involve transport by pipeline to a marine diffuser, and all are based on continued barging of high-strength waste for ocean dumping. In addition, several other approaches to wastewater handling that were developed in other studies are briefly discussed in this section.

Two principal pipeline alternatives were considered: a land route and a marine (underwater) route. These are discussed in the Evaluation of Pipeline Route section, below.

The alternative disposal locations are all in the marine environment. Three general disposal locations were considered: the inner harbor, the outer (middle and outer areas) harbor, and at or beyond the harbor entrance (see Figure 1-1). All the alternatives assumed that the outfall would terminate in a diffuser to enhance initial mixing of the effluent. The inner harbor alternative would be a modification of the existing outfall, possibly involving replacement or extension and diffuser retrofitting of the existing outfall. The evaluation of the disposal location alternatives was the principal task of this study. This evaluation is presented in the Outfall Termination section, below.

The feasibility study primarily addressed wastewater disposal alternatives, and it did not specifically address wastewater treatment alternatives. It is recognized that additional wastewater treatment or waste minimization practices, which would reduce TN and TP loads, could affect the disposal alternatives in terms of outfall diffuser location in the harbor. However, it is unlikely that additional wastewater treatment alternatives can be feasibly implemented. Some waste minimization practices might be possible. The practice of high-strength waste segregation significantly expands the possible range of locations of any in-harbor wastewater disposal alternatives.

EVALUATION OF PIPELINE ROUTE

For the analyses done in Section 5 and in this section, only a marine pipeline placed on or above the bottom (not buried) was considered. The advantages of a buried marine pipeline could be obtained more economically by the land pipeline. In addition, because of the depth of the marine pipeline (more than 100 feet deep along most of the route) and the nature of the bottom (possible coral/rocky outcrops and thin sediments in many locations), the construction costs of a buried marine pipeline are significantly higher than those of a buried land pipeline. The buried marine pipeline would also be less accessible for maintenance.

The advantages and disadvantages of the land and marine pipeline routes are summarized in Table 6-1 and discussed below.

COMPARISON OF PIPELINE ROUTE ADVANTAGES

- Costs--The construction costs of the marine pipeline are estimated to be less than the land route for all potential locations of the outfall diffuser. The difference in costs are significant (see Section 5 and Appendix E).

- Construction Schedule--The estimated construction schedule for the marine pipeline is shorter than for the land route. The schedule for the marine pipeline also appears to be more flexible because much of the initial work (pipe welding) will be done on land prior to shipping. This would result in a much shorter period of construction in American Samoa (see Section 5).

- Potential Disruptions--The possibility of disruptions to construction will be less for the marine pipeline than for the land route. The primary potential delays associated with the marine route would be from the effects of severe weather on floating plant. These effects should be minimized, however, by the protected configuration of the harbor.

  Unexpected delays due to encountering unknown utilities under the road, or the occurrence of other unplanned events should be anticipated for the land route construction. The estimated construction schedules for the two routes (Section 5) do not include contingencies. The schedule contingency for the land route construction should be higher than for the marine route because, once construction is underway, there are more potential sources of schedule delays. The disruptions to other activities by the construction of the pipeline are also higher for the land route. Traffic, access, and potential utility line disruptions can be expected and must be planned for.

- Permitting--It is anticipated that permitting would be more complex for the land route pipeline. This pipeline is potentially more disruptive to the daily activities of the population, and local residents would be more aware of construction-related activities. The outfall portion of the land route would cross undisturbed fringing coral and nearshore habitats. Noise, air quality, traffic, and other environmental elements would be more affected by the land pipeline construction than the marine route.

- Outfall Options--Possible outfall locations and diffuser sites are more limited if a land route is used. The locations where the land pipe can be connected to a marine outfall would depend on property ownership,

environmentally sensitive area considerations, other waterfront activities, and the suitability of the terrain for an outfall.

- Related Costs and Impacts--There is a higher potential for increased costs for the land route. For example, mitigation measures might be required for construction activity impacts such as traffic disruptions during pipeline construction or habitat disturbance at the outfall location. Such costs have not been included in the construction cost estimates. The land pipeline might require the additional construction of shoreline erosion protection to prevent damage to the pipeline. Costs for shoreline protection have not been included in the construction cost estimates. The design of the land pipeline would require consideration of both land and marine elements and can be expected to be costlier. Although there could be, and probably are, some as yet unidentified related costs associated with the marine route, it appears that there is a much higher potential for such costs for the land pipeline route.

- Damage Potential--The potential for damage to the pipeline is probably no higher for the marine route than for the land route. However, this category is considered a net disadvantage for the marine route because of difficulty of repair. If repair costs are included as a factor of damage potential, the overall advantage is with the land route in this category. The main source of damage to a marine pipeline would be from anchors from large vessels. Some measures can be taken to minimize this possibility, and these are discussed briefly below. There is also some damage potential to the land route (for example, during excavation to repair or replace utility lines or road surface).

- Maintenance and Repair--This is the single category that appears to present a distinct disadvantage for the marine pipeline. The pipeline will typically be in more than 100 feet of water and will be difficult and relatively expensive to repair if damaged.

REDUCTION OF MARINE ROUTE DISADVANTAGES

Measures can be taken to minimize the damage and repair disadvantage of the unburied marine pipeline. These include:

- Using the detailed bathymetric and side scan sonar data that have been acquired along the pipeline route in order to (1) place the pipeline as close to the bottom edge of the reef as possible and (2) identify any obvious hazards to the pipeline, such as areas of intense anchor drag scars on the bottom, rocky areas, or steep slopes.

- Arrange for the U.S. Coast Guard to indicate the location of the pipeline in its publications and charts and, if possible, secure a restricted anchorage area to protect the pipeline.

- Have the pipeline route included on NOAA navigation charts.

- Include the development and design of repair procedures as an integral part of the initial pipeline design.

- Include preparation of an operation and maintenance manual as part of the design.

OUTFALL TERMINATION

Regardless of whether the pipeline route is primarily land or marine, as described above, the outfall termination method and location must be determined. The discussion below addresses these issues on the basis of the information presented in the preceding sections of this report.

TERMINATION METHOD

The methods of termination considered primarily involved use of a diffuser. It is unlikely that a "single port" or open pipeline termination would be acceptable to the permitting agencies. The evaluation was based on the requirement of a multiport diffuser to provide the best possible initial dilution characteristics. The size of the mixing zone can be minimized by taking advantage of the initial dilution processes associated with a multiport diffuser configuration. The diffuser configuration, however, must be selected with respect to some practical considerations, which could result in a system that does not achieve the maximum possible initial dilution. These considerations are described below.

The principal physical constraints identified for the diffuser design concern the need to prevent port blockage and the desirability of keeping the plume submerged. The discussions on initial dilution presented in Section 4, Appendix D, and in this section are based on the assumption of discharge of StarKist effluent alone. If a joint pipeline is eventually selected, the effluent discharge rates, pipeline diameter, and other parameters will change. However, the general evaluation and conclusions will not change, although some details (for example, the number of ports in the diffuser) will need to be adjusted.

The diffuser port size should be designed to avoid the possibility of blockage and thus minimize the potential for maintenance operations, discharge bypass of the outfall, and disruption to plant operations. The diffuser should be designed with an easily operated end gate structure to facilitate cleaning if blockage does occur. The results of the

modeling indicate a reduction in diffuser performance with large port sizes, but spacing the ports far enough apart to avoid early plume merging can partially offset this factor. This approach results in a somewhat longer diffuser section, but the marginal cost is small compared to the overall cost of the pipeline.

The minimum port size that should be considered is 4 inches in diameter. At this size the port spacing should be about 25 feet, and approximately five ports will suffice for the range assumed for the StarKist effluent discharge rate. If the two cannery discharges are combined, the number of ports and length of diffuser will probably need to be adjusted. The number of ports should also be selected in consideration of potential future increases in effluent rates.

The suggestion of a minimum 4-inch port diameter is based on experience and preliminary modeling and needs to be carefully considered during final design. The ports should be large enough to avoid the potential of blocking even if initial dilution performance suffers somewhat. The potential for blocking is strongly influenced by the material that might, even occasionally, be carried in the effluent stream. The material in the effluent stream is affected in large part by the training and expertise of plant personnel who are in the position of introducing material into the waste stream, the effectiveness of any pretreatment or screening operations, and the nature of the effluent constituents (for example, is there a potential for aggregation as the effluent is carried along the pipeline).

DIFFUSER DEPTH AND LOCATION

The evaluation of diffuser location is based on the ability to meet water quality standards throughout the harbor and the costs of constructing and maintaining the outfall diffuser. Differences in maintenance costs depend primarily on the issues of damage potential and repairability, as discussed above. The information required for an evaluation of construction costs was presented in Section 5.

Cost

In general, particularly for the marine pipeline, the pipeline construction cost can be considered in three parts: a fixed mobilization cost; an incremented mechanical system cost for pumps, the terminal diffuser, and other single-unit items that depend on flow rate and overall pipeline length; and a per-foot cost that would change only when the pipe length reaches a point at which the pipe diameter must increase to avoid excessive pressures or head losses.

Mobilization costs would vary little for any outfall termination point within the harbor. For a short inner harbor pipeline, the mobilization costs would be nearly the same as for any other location in the harbor. For outfall locations outside the harbor, it is likely that mobilization costs could be significantly higher than for inside the harbor because of more difficult construction conditions (for example, depths, wave climate, and

distance from staging area). However, for the case of outfall extension beyond the harbor mouth, the mobilization costs become a relatively small part of the total cost.

Incremental costs for pumps, the diffuser, connecting to the existing system, and similar items would vary for outfall terminations in general areas of the harbor (inner, outer, entrance areas). Linear costs (per foot) would also vary with general locations.

The cost evaluation first considers differences in general location; differences within a general location then become a fixed plus per-foot cost. The inner harbor discharge location appears not feasible, as described below for reasons other than cost. The harbor entrance and beyond location does not appear to have any advantage from a water quality perspective and would be significantly costlier than an outer harbor alternative. Therefore, as described below, the evaluation of cost becomes primarily an evaluation of pipeline length within the middle and outer harbor areas.

Water Quality

The location of the outfall/diffuser termination was the primary concern of much of this study, particularly the wastefield transport modeling. The most striking feature of Pago Pago Harbor in terms of physical transport processes is the apparent differences in the inner and outer portions of the harbor. The differences include geometry (volume of water), diffusion and dispersion rates, and flushing characteristics. These differences are discussed below for the three areas considered for wastewater disposal:

- Inner Harbor--The continuation of disposal within the inner harbor, even after the institution of high-strength waste segregation, does not appear feasible under the present water quality standards. The loadings of TN and TP would have to be decreased to a point that does not appear possible. Sufficiently increased wastewater treatment to achieve such loadings is expensive, is technically complex to operate and maintain, requires significant additional land area, requires shipment of supplies or chemicals on a continuing basis, and might require significant increased electrical power consumption.

- Harbor Entrance and Beyond--The transport model used was not constructed to investigate the transport processes outside the harbor. Discharge outside the harbor is not required to meet ASG water quality standards. Therefore, the cost of constructing, calibrating, and running a nearshore coastal transport model was not warranted. However, results based on modeled effluent release points within the harbor indicate that the closer to the harbor entrance the diffuser is placed, the higher the TN and TP loadings can be and still satisfy water quality standards. Extrapolation of model results for locations within the harbor indicates that a discharge at or beyond the harbor entrance would result in meeting water quality standards within the harbor even in the absence of

high-strength waste segregation, although a mixing zone would still be required in order to meet water quality criteria in the discharge area.

- Outer Harbor--The results of the modeling indicate that the inner portion of the outer harbor (referred to as the middle harbor location in the modeling descriptions, Section 4) would be suitable and sufficient for wastewater disposal under estimated present levels of TN and TP loadings with the current level of high-strength waste segregation. The closer to the mouth of the harbor the discharge is located, the higher the loading can be and still meet water quality standards throughout the harbor. The selection of the discharge location depends on the selection of the appropriate maximum or "design" loading. As discussed in an earlier section of the report, the TN loading generally controls the outfall discharge location.

MIDDLE TO OUTER HARBOR LOCATION EVALUATION

The wastefield transport modeling was done on a long-term average basis for the reasons given in the modeling description (Section 5). Because of the nature of the physical processes in Pago Pago Harbor, it is not feasible to address short-term fluctuations in loadings and the response of harbor concentrations to such fluctuations. Therefore, the appropriate location of the outfall must be based on the modeled long-term responses of harbor concentrations to average loadings. However, the appropriate location must also be selected to avoid violations of water quality standards in the receiving waters.

Because of the limitations on the predictability of the harbor processes and the need to meet water quality standards, a conservative approach should be used to select the outfall diffuser location. The existing NPDES permit requirements recognize the variability in loadings (effluent concentrations) and the implicit effect on receiving water quality. The permit conditions allow effluent concentrations to exceed the average permitted conditions 10 percent of the time. Although the permit requirements address effluent concentrations, it is not unreasonable to apply the same philosophy to a future permitted mixing zone and associated TN and TP loadings. Therefore, one approach would be to place the outfall in a location where water quality conditions would be met on a long-term average basis at a loading that is not exceeded 90 percent of the time based on the wastefield transport model results. This would be a conservative approach in that predicted water column TN and TP would be less than the water quality standards most of the time.

The selection of a location for the outfall becomes one of setting the appropriate loading, then using of the plots of maximum loading against location in the harbor (Section 5). Because high-strength waste segregation has been in place only a limited amount of time, there is limited information for developing a loading criterion such as the 10-percentile criterion suggested above. However, a 10 percentile level can be

determined for the data collected on effluent loadings prior to high-strength waste segregation. The pre-segregation relationship can then be applied to the expected future loadings by using the relationships between loading and production rates and the information available on the expected reduction due to high-strength segregation. Additional data for post-segregation loadings will become available as final design and permitting for the outfall are carried out and can be used to refine initial estimates of the design loadings.

The selection of a "design loading" by using the method above, a similar approach, or even by setting an arbitrary upper limit, should include any anticipated future increase in loading. This design loading can then be used with the relationships developed in Section 5 to determine the appropriate location in the harbor. It must be realized that regardless of how the design loading is obtained, maintaining loadings at or below that level becomes the means of achieving water quality standards.

A mixing zone will be required. The volume of the mixing zone can be determined from the wastefield transport modeling. The geometry of the mixing zone is more complex and, in fact, will vary with meteorological and oceanographic conditions. With the mixing zone defined as the area within which water quality standards are not met, the horizontal linear dimension of the mixing zone was limited to 200 meters or less in the middle and outer harbor regions during the wastefield transport modeling. The best way to limit the size of the mixing zone is to maximize the initial dilution characteristics of the plume.

OTHER APPROACHES

Alternatives to wastewater discharge in the middle-to-outer harbor include ocean dumping, advanced wastewater treatment, and waste minimization. These approaches were not explicitly considered in this study. However, such practices could affect the outfall location required to meet water quality standards. The implications of these approaches on the outfall location are reviewed briefly below.

Large-scale ocean dumping in place of an outfall for the entire waste stream is neither economically nor technically feasible. The segregation of high-strength wastes and the subsequent barging of those wastes to sea are already being done. This results in significant reductions in TN and TP loads to the Pago Pago Harbor and decreases the length of outfall pipeline necessary to meet water quality standards outside a reasonable mixing zone.

Potential types of additional wastewater treatment were investigated in the *Joint Cannery Study* (CH2M HILL, 1987). The types of treatment described in the 1987 report were reviewed. The possibility of any recent advances or new technologies was investigated. The potential use of ultrafiltration (reverse osmosis technology) was considered.

Operational problems with high-technology systems, unavailability of sufficient land area, logistical problems of maintenance and supply, and electrical power requirements are serious problems for the initiation of advanced wastewater treatment in American Samoa. The conclusion was, as in 1987, that advanced wastewater treatment would be difficult to accomplish in American Samoa. The combination of high-strength waste segregation, ocean disposal of dissolved air flotation (DAF) sludge and high-strength waste (cooker juice and press liquor), and an extended outfall is the best approach. Any waste minimization steps that can be taken to reduce TN and TP loadings should be instituted.

CONCLUSIONS

The conclusions of this study fall into four categories: pipeline considerations, diffuser location, other approaches, and schedule.

PIPELINE CONSIDERATIONS

A submarine pipeline (nonburied) appears to have a preponderance of advantages over a land route pipeline. This appears to be the best alternative, provided that the measures described above to minimize the damage potential to such a pipeline are taken. Considerations of cost, permitting, and environmental protection all indicate that a single pipeline serving both StarKist and Samoa Packing is the best approach. Considerations of cost, schedule deadlines, and ease of construction in American Samoa indicate that an unburied, anchored or suspended, high-density polyethylene pipeline should be employed.

The actual costs of the pipeline construction depend on the pipe length and diameter. The length of the pipeline depends on the loadings anticipated and the water quality standards that must be met. The results of the use attainability analysis currently being conducted could affect the compliance standards and thus have an effect on the pipeline length. The pipeline diameter will depend on the length and the effluent flow rates the pipe will carry. Two independent pipelines, although each would be smaller than a joint pipeline, would cost significantly more than a single joint pipeline. The construction costs of a joint pipeline are estimated to be in the range of $1,400,000 to $2,100,000 for a 14-inch HDPE marine pipeline between 2,500 and 8,000 feet long (see Figures 5-6, 4-12, and 4-16). These costs are feasibility-level estimates (-30 to +50 percent variability) and are based on 1990 prices; 1991 prices should be assumed to increase by approximately 10 percent for planning purposes. The costs do not include construction management or engineering design.

DIFFUSER LOCATION

The exact length of the pipeline and the location of the end of the outfall depend on loadings anticipated and water quality standards. For the present water quality

standards and estimates of TN loadings for both canneries, it appears that a location in the middle or outer harbor is required. For example, a maximum combined TN loading of 2,500 pounds per day would require a pipeline approximately 6,000 to 7,000 feet long.

OTHER APPROACHES

The recommended approach is to continue high-strength waste segregation and construct an outfall of sufficient length to meet water quality standards under maximum expected loading conditions. No wastewater treatment methods in addition to present operations are recommended. However, efforts directed at minimizing waste loadings through in-plant improvements and operational procedures should be continued.

SCHEDULE

Preliminary estimates are that the construction of a marine pipeline will take approximately 4 to 5 months after material procurement. The target date for operation is March 1992. Therefore, it is essential that design and permitting be started as soon as possible after a decision is made to proceed with an outfall. The construction schedule for a land route pipeline is longer than for the marine route and would present an even more difficult design and permitting schedule.

It is recommended that final design begin no later than March 1991. It might be prudent to determine the amount and size of material required and begin procurement of long-lead-time items as the final design progresses.

It is also recommended that permitting and environmental documentation begin in March 1991. Permit applications should be filed as soon as possible. When possible, incomplete applications should be filed with a statement that required information, such as final design drawings, will be provided as available. This procedure has the advantage of beginning the formal permitting processes as early as possible to identify any difficulties or additional requirements.

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Table 6–1
COMPARISON OF PIPELINE ROUTES

CRITERION	LAND PIPELINE	MARINE PIPELINE
Cost	Higher	Lower
Schedule		
Length	Longer	Shorter
Flexibility	Fixed	Flexible
Disruption Potential		
To Construction	Higher	Lower
By Construction	Higher	Lower
Damage Potential	Lower (1)	Higher (1)
Maintenance & Repair	Easier	More Difficult
	Lower Costs	Higher Costs
Permitting	More Problems	Fewer Problems
Location Options	Fewer Options	More Options
Potential Environmental Impacts	Higher	Lower

(1) Refer to text section titled Reduction of Marine Route Disadvantages.

Section 7
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EVALUATING OCEAN DUMPING AS A SOLUTION TO SEAFOOD WASTE DISPOSAL

FINAL REPORT

to the

NATIONAL MARINE FISHERIES SERVICE

300 SOUTH FERRY STREET ROOM 2016

TERMINAL ISLAND, CA. 90731

AGREEMENT NO. NA-85-00002

by

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1. EXECUTIVE SUMMARY

a. Description of Project

(1). The project was undertaken to facilitate the evaluation of ocean dumping of nontoxic fish processing wastes by developing a cost effective and technically acceptable method for monitoring the fate and effects of dumping such materials in the marine environment.

(2). The basic approach taken was that the degradation of representative dissolved air flotation (DAF) wastes could effectively be measured in laboratory tank tests and could confirm field results obtained in previous investigations. Those results suggested the feasibility of using ammonia-N as a parameter to monitor the fate of the wastes in the ocean. Tank tests were not intended to reproduce field conditions precisely, but rather to control or reduce problems encountered in field tests such as dispersion, dilution and the difficulty of remaining in the center of the waste plume while monitoring. Field research consisted of completing two benthic surveys of the ocean dump site off Los Angeles to update surveys done previously in 1982.

b. Findings

(1). Ammonia-N analysis was shown to be a simple, rapid and effective means for monitoring the degradation of the waste material, confirming results of previous field tests. Ammonia-N in the wastes, which is detectable for 4-8 hrs in the field, may persist longer in tanks where dispersion and dilution are not possible. Ammonia-N measurements in tank tests showed a consistent pattern of relatively uniform levels for much as 8-12 hrs, decreasing rapidly thereafter as the wastes were degraded.

Laboratory results gave statistically significant correlations of ammonia-N with five-day biochemical oxygen demand (BOD_5), confirming correlations found in prior field tests.

Other parameters such as nitrate, nitrite, silicate and phosphate did not provide significant correlations with BOD_5 or ammonia-N.

Ammonia-N thus can be used in monitoring to protect the environment by determining that the wastes do not persist, creating a buildup to unacceptable levels.

There were no clear indications of duirnal differences in degradation rates; further research is needed on this aspect.

The breakdown of ammonia-N apparently is a function of aerobic microheterotrophs, since water filtration removed phytoplankton, and ammonia-N persisted in the tanks when the sludge mixture was deprived of dissolved oxygen.

Growth of Mussels suspended in 0.1% sludge mixed with ambient seawater for 46 days was statisticlly significant. Delutions at or above 0.5% were lethal to most of the mussels.

Microtox toxicity tests using bioluminiscent marine bacteria confirmed optimal biostimulatory effects at the 0.125% to 0.25% range. The dilution measured in the immediate wake of the discharging vessel is 0.1%. Thus, raped dispersion and diffusion might negate the nutrient value of the floating waste plume.

(2). The Environmental Protection Agency did not cooperate in giving a research permit and has delayed issuing a provisional permit to Star-Kist Foods since 1982 for ocean dumping of sludge off Los Angeles. This prevented further field testing of monitoring techniques when Star-Kist Foods discontinued dumping bail water and thaw water as uneconomical if sludge could not also be dumped. Star-Kist stopped processing anchovy for meal and oil and closed their largest processing plant. Most tuna processing has been restricted to American Samoa and Puerto Rico because

the United States refused to sign international agreements to manage the highly migratory species. As a consequence U.S. tuna fishermen were denied access to tropical Eastern Pacific coastal waters.

c. Benefits

The EPA now is requesting that monitoring studies be undertaken concurrently by processors in Puerto Rico, American Samoa and Los Angeles for proposed issuance of ocean dumping permits. Based on our research, ammonia-N measurement will be included, along with dissolved oxygen, temperature, salinity and pH, for tracking plumes. An extensive biological and oceanographic monitoring program has also been proposed. Processors find the expanded scope of work proposed by EPA to be excessive and expensive, more in keeping with those required for major publicly owned treatment plants (POTWs) which have outfalls discharging millions of gallons of effluent per day. The processors have not agreed to the scope as yet, since ocean dumping must be cost effective or more plants may close.

11. INTRODUCTION

Waste management is one of the major problems associated with any domestic fishery program, and solutions are crucial to development. In some instances new marketable products may be developed from wastes, but ultimately there are substances which must be disposed of, preferably in the most economical and environmentally safe manner.

Fish processing plants, ranging from large, year-round tuna processors to small seasonal packers, were under great pressure for more than a decade to adopt advanced and expensive waste management practices. The mandate for dissolved air flotation treatment (DAF) for the tuna industry was enforced in the mid-1970s, and efforts were made to have DAF applied to the entire fishing industry regardless of size or location as the best available technology (BAT). Ultimately, best conventional technology (BCT), usually screening, was adopted for all but the tuna industry, which was already equipped with DAF systems, although in some cases State water quality agencies have attempted to impose more stringent requirements such as DAF on the other processors (Soule and Oguri, 1984).

The DAF process produces a semi-solid, odoriferous sludge which has required disposal in landfill, as well as liquid wastes which must be disposed of in some localities via publicly owned treatment plants (POTWs) or piped directly into receiving waters in others.

In 1979 Congress passed legislation for ocean dumping of untreated fish wastes in federal waters, but the legislative intent was considered by EPA to apply only to fish or shellfish gutted or headed on shipboard. Recently the EPA has reconsidered the exemption as potentially applicable to DAF-treated plant wastes, subject to designation of ocean dumping sites.

Public Law 92-532, the Marine Protection, Research and Sanctuaries Act, also known as the Ocean Dumping Act, provides for the issuance of

permits for disposal of wastes in the ocean by dumping at designated sites. Evaluation of the fate and effects of the wastes and calculation of the dispersion of wastes in the receiving waters must be considered and documented in applying for permits. If a permit is issued, a monitoring program is required to determine whether adverse effects will result from ocean dumping and whether corrective measures can be developed.

Fish processing wastes in American Samoa, Puerto Rico and Los Angeles are treated by DAF. The liquids separated from the sludge and other untreated liquids are released as effluents piped to the ocean in the islands of American Samoa and Puerto Rico, whereas in Los Angeles liquids are sewered to the City of Los Angeles Terminal Island treatment plant for secondary waste treatment.

Sludge from the Los Angeles operations was trucked to a La Puente landfill site some 60 mi distant, and recently sludge has been trucked to a farm near Bakersfield, about 150 miles away. For several years Star-Kist Foods dumped bail (vessel hold) water and thaw water off Los Angeles, which did not require a permit. When the permit to dump sludge was not forthcoming, they discontinued the operation as uneconomical.

In Puerto Rico, the environmental agency is pressing for cessation of landfill disposal as a public nuisance. In American Samoa, there is little available land and a dearth of soil to cover the semisolid sludge in the available landfill. A crisis arose when a child chasing a dog drowned in the morass, as did an adult who tried to rescue them. Public demand forced the EPA to issue an ocean dumping permit, which expired in 1983, and the EPA has stalled on the renewal application ever since. Ocean dumping continued there, however, since a permit is considered to be in effect until a new one is issued or formally denied.

It is difficult to interpret EPA's reluctance to issue a permit to dump non-toxic fish wastes while a dump site has been approved for the oil industry off Los Angeles during the period of delay for the fish processors, and dumping of dredged material continues. The original excuse from EPA was fear of the domino effect of granting any ocean dumping permits, which no longer holds true if oil wastes have now been permitted.

The southern California commercial sport fishery association and recreational sports fishery association have supported the ocean dumping of sludge in unusual agreement with the processors because they view it as the addition of valuable nutrients to local waters. Hence this research project received endorsement from all factions in the original proposal.

Anchovy and mackerel fishermen have carried sludge in their bait tanks or use it as chum on occasion to demonstrate their evaluation of sludge. In extensive observations using SONAR, it was noted that the forage fish off Los Angeles were attracted to the waste dumping vessel and followed it until the waste began being discharged, after which they followed the material as portions of the waste sank toward the bottom. There may be some enrichment for benthic invertebrates as well. These species are likely to seek food as well as protection from predation in turbid waters, so the waste plume is of some value to the ecostystem. The ecological role in American Samoa probably differs. Waters off American Samoa reach 600 fms within a mile of the volcanic islands so there are few shoaling waters and few forage fish. Species observed offshore near the dumpsite there, such as young tuna, are unaccustomed to turbid waters and tend to avoid the dump vessel slick as well as inshore runoff plumes or muddy shoals. The tropical species noted, as well as sharks, do not seem to feed on particulates and are not attracted to them. Because the waters are so deep, the role of the waste in those waters would differ. Instead

of providing nutrients, the wastes probably contribute little to the ecosystem, but neither could they be considered harmful as they disperse.

III. PURPOSE

a. Ocean dumping could provide a solution to at least some of the problems of fish waste disposal for a number of regional fisheries, provided that the potential benefits and impacts can be documented and weighed to the satisfaction of regulatory agencies. Prior research by the principal investigators under funding by the NOAA - Office of Marine Pollution Assessment program and the tuna processing industry produced some positive tentative conclusions which needed to be further documented (Soule and Oguri, 1982; 1983a,b; 1984; Soule, Oguri and Soule, 1983). The previous investigations showed that only minor transitory adverse impacts occurred in the marine environment in tropical American Samoa and temperate Los Angeles. Turbidity, ammonia-N concentration and five-day biochemical oxygen demand (BOD_5) were the parameters measured that were affected. A slight, very transitory sag in dissolved oxygen was detected in the plume, and a slick was visible for several hours in some cases.

Data analysis indicated that BOD_5 and ammonia-N, as determined by specific ion electrode, were apparently equivalent parameters for monitoring purposes. The BOD_5 technique, which measures the amount of oxygen required for the degradation of carbonaceous and some nitrogenous material in wastes, requires calculations of dilutions, extensive preparations, special glassware, a large incubator capacity and five days to obtain results, whereas ammonia analysis with a specific ion electrode is considerably easier and more rapid to perform and can in some cases be done at sea.

Results from the field studies showed positive correlations between

BOD_5, suggesting that ammonia-N might thus be useful to trace the persistence of waste plumes in receiving waters. Ammonia-N, as a normal product of marine animal excretion and of bacterial proteolytic activity, is usually present in seawater only in micro concentrations. The concentrations of ammonia-N in ocean waters are reported to range from 0.35 to 3.5 ug-at/L (Sverdrup et al., 1946). Mean values for coastal waters off Los Angeles ranged from 0.70 ug-at/L in the spring of 1978 to 1.9 ug-at/L in the winter (Soule and Oguri, 1980). Values near the sewage treatment plant in Los Angeles Harbor averaged from 6.2 ug-at/L in winter to a peak of 44.8 ug-at/L in the summer of 1978 during a plant malfunction. Ambient levels at control sites off American Samoa were slightly higher than those off Los Angeles, ranging from 1.6 to 4.9 ug-at/L (Soule and Oguri, 1983a). Since ammonia-N is a preferred source of nitrogen for phytoplankton, uptake by phytoplankton would reduce ambient levels during the spring in temperate waters with high standing crops of phytoplankton. The usually low standing crop of phytoplankton in clear tropical waters such as those off American Samoa may result in somewhat higher ambient levels of ammonia-N in coastal waters (Soule and Oguri, 1984).

The role of bacterial populations in the metabolism of nitrogenous wastes in the marine environment has not been as well documented and quantified as that of phytoplankton. However the microheterotrophic component of the nanoplankton (bacteria, yeasts, fungi and protistans) is known to increase exponentially during sudden influxes of nutrients (Sullivan et al., 1978; Soule and Oguri, 1979). The importance of the chemosynthetic primary producers and microheterotrophs in the detrital food web has only been recognized relatively recently (Fenchel, 1970; Fenchel and Jorgensen, 1977; Jannasch, 1979; Jannasch and Wirsen, 1979;

Soule and Soule, 1981). Fish processing wastes are already heavily colonized with microheterotrophs when dumped and marine waters off Los Angeles support extensive populations. Ammonia-N production from proteolytic activity, followed by degradation of ammonia-N by microheterotrophs and plankton should provide a good relative indicator of the organic content of the wastes and when they have been assimilated into the ecosystem.

b. The project goal was to provide for a more cost effective and environmentally safe disposal of fish processing wastes so that fisheries development is not inhibited by problems arising for waste management practices and costs. The objectives are as follows:

1). to explore the development of a more efficient and cost effective method of assessing the effects of discharging fish processing wastes to the marine environment, and;

2). to establish the role of those wastes in the ecosystem once they are discharged.

The research should serve to expedite the granting of ocean dumping permits for fish processing wastes as a generic category. This should result in direct savings to the industry, and to the consumer, as well as enhancing forage fisheries.

IV. APPROACH

a. The research as originally proposed included both field and laboratory efforts. Field studies included monitoring waste plumes containing sludge and updating the benthic baseline data after several years of dumping liquid waste. Laboratory efforts were to include tank tests of the degradation of ammonia-N, nitrate and nitrite, and bioassay-growth stimulation experiments.

Because local dumping ceased, plume monitoring could not be done;

hence the data base for sludge dumping consists of that obtained in American Samoa (Soule and Oguri, 1983a) and the data base off Los Angeles consists of monitoring various liquid waste dumps (Soule and Oguri, 1982). The two benthic surveys were carried out as planned.

Laboratory efforts were expanded in refocusing the scope of work, permitting much more extensive testing than would otherwise have been possible. Methods and results will be discussed below in sections for each of these laboratory efforts. Tests consisted of the following:

(1). Ammonia-N as a parameter for monitoring the degradation of wastes. Outdoor tank tests were conducted which permitted the elimination of dispersion and dilution, as well as reduction of diffusion from the degradation process. (Some in-situ container tests were also attempted but it was impossible to supply the waste mixture with adequate oxygen and these were discontinued);

(2). Mussel toxicity - biostimulation experiments;

(3). "Microtox" bioluminescence toxicity tests.

(4). Field sampling consisted of two benthic surveys.

1). AMMONIA-N AS A PARAMETER FOR MONITORING THE DEGRADATION OF WASTES

Introduction

In our NOAA-OMPA report (Soule and Oguri, 1984) we discussed the results of pilot tests on the degradation of ammonia-N in a large 200 gal plastic tank. The initial intent of these tests was to establish the persistence of ammonia-N from the wastes in the marine environment under conditions of zero dispersion and dilution and without the problem of locating the center of the dispersing plume. In the present studies, repetition of the general procedures used for those tests offered an

opportunity to verify results of earlier tests and compare results with actual field data. It also appeared that there might be a relationship of ammonia-N degradation to day-night changes in irradiation since the changes appear to be due to microbial activities. It is known that microbial metabolism is inhibited by sunlight. The changes in other nutrient parameters could also be investigated, as they coincided in time and space with the changes in the concentration of ammonia-N.

In earlier tests (Soule and Oguri, 1984) about 500 grams of freshly collected sludge from the DAF system operated by the Star-Kist Foods facility at Terminal Island, California, were added to about 400 liters of filtered sea water in a black tank about 1.5 meters in diameter. The fish being processed at that time was tuna.

Results of those tests showed that the ammonia-N concentrations remained essentially stable for about 5 to 6 hrs after the start of the experiment and then dropped fairly sharply to levels approaching background. The period of initial stability at high values coincided in part with daylight hours.

In one of the previous experiments nitrate and nitrite concentrations showed a pattern similar to that of the ammonia-N concentrations with the initial levels dropping sharply after several hours of relative stability. However in that case the drop took place about 8 to 10 hrs after the start of the experiment as compared to the 6 to 8 hr interval for the reduction in ammonia-N concentrations. Although sampling was continued until 1100 hrs the following day no further significant change was noted in the concentration of any of the measured parameters.

Procedures

In the earlier tests, and in the present series of tests discussed

below, a sample of the waste from the Star-Kist canneries dissolved air flotation system (DAF) was added to seawater filtered through a cartridge filter of 10 um nominal porosity into a large cylindrical tank. The mixture was aerated and continuous stirring was maintained. To keep the material in suspension the mixture was pumped from the bottom of the tank near the center and the pumped material discharged at the surface of the tank in a tangential direction. The tank was held within another larger tank filled with cooled or flow-through fresh water to simulate approximately ambient temperature control. These tests were conducted outdoors in an area shielded from direct exposure to sources of artificial illumination. The inner test tank was covered with a sheet of clear plastic to permit exposure to ambient light and to prevent contamination by dust.

Periodic observations for the duration of each experiment were made of temperature, dissolved oxygen and pH using a Martek Instrument Mark V water quality analyzer. At the same time, samples were drawn for ammonia-N analysis, which was performed using the Orion model 95-10 or 95-12 ammonia-N electrode. Samples were also taken for analysis of other parameters selected for investigation during particular experiments in this series. These included analyses of the nutrient salts nitrate, nitrite, phosphate and silicate. Analyses were performed with a Technicon AutoAnalyzer. Kjeldahl nitrogen analyses were performed once using standard laboratory procedures. Biochemical oxygen demand (BOD_5) determinations were made using a procedure modified for use with seawater samples. In general the temperatures showed little diurnal variation, approximately $\pm 3^{o}C$.

The series of tests presented opportunities to alter procedures in order to examine changes in degradation according to changed conditions. Each set of tests is presented separately, with results and discussions.

Experiment AA3

The experiments designated AA3 were started at approximately 1100 hrs and used essentially the same setup as the earlier tests, although in the present tests, 450 grams of the sludge was added to about 375 liters of seawater. The cannery had stopped processing tuna and closed one of the two plants in the area by this time. The fish being processed consisted largely of mackerel used for both human consumption and for pet food. The wastes produced had a significantly higher oil content than those produced in the processing of tuna.

Analyses planned for these experiments included tests for silicate, phosphate and Kjeldahl nitrogen in addition to the ammonia-N, nitrate and nitrite determinations done previously. These experiments were atypical of the previous tests in this series since filtering of AutoAnalyzer Samples prior to analysis was instituted at about 1900 hrs, 8 hrs after the start of this test, to prevent clogging of the AutoAnalyzer tubing.

Ammonia-N levels (Figure 1) dropped almost immediately from the initial high levels to moderate levels of about 50 to 70 ug-at/L of NH4-N and remained at these levels until about 0230 hrs on the following day when they fell to levels about 20 ug-at/L. They rose slightly after sunrise. It was not necessary to filter the samples prior to ammonia-N analysis since the specific ion electrode used was not affected by particulate matter.

Nitrate and nitrite, considered to be among the nutrient salts utilized by phytoplankton, rose sharply in concentration upon the addition of the waste and appeared to stabilize at levels of about 100 ug-at/L for several hours (Figure 2). The extent to which filtration affected the measurements is not fully clear but the nitrate plus nitrite, phosphate and

silicate data (Figures 2 and 3) show marked changes in concentrations after filtration was started at 2130 hrs. After the start of filtration, there was a sharp drop followed by an increase in concentration, possibly due to break-up of particulate matter on the filter. Values then started decreasing within a few hours and reached levels below the background concentrations in the diluting water. A similar change in concentration at the end of the experimental period also appeared in the data for phosphate although the post-filtration rise was not pronounced in silicate.

Kjeldahl nitrogen data (Figure 4) showed no discernible pattern in values as a function of the time of sampling. Kjeldahl-N measures total organic-N and would include ammonia-N but not nitrate and nitrite. The Kjeldahl-N levels in mg/L mask the ammonia-N signal in ug-at/L. The variability of the Kjeldahl-N values and the lack of any consistent trend led to the decision to discontinue analysis of that parameter.

Dissolved oxygen (DO) in the test tank generally dropped to about three mg/L during the period of decrease in concentration of the nutrient salts. It increased slightly in the early daylight hours at which time the ammonia-N concentrations also showed a slight increase, suggesting the presence of autotrophs. Figure 5 illustrates a typical DO curve. The pH values in the test tank, shown in the same figure, decreased throughout the period of the experiment but did not go below pH seven.

In earlier field observations (Soule and Oguri, 1983a) the data showed minor and transitory changes of less than 0.5 mg/L in dissolved oxygen and 0.25 of a pH unit in the immediate wake of the dump vessel. This suggests that dispersion and mixing of the waste field in well oxygenated receiving waters are important factors in ameliorating the oxygen demand of the wastes.

Experiment AA4

Experiment series AA4 utilized the same tank configuration with 500 grams of the waste being added to about 400 liters of filtered sea water in the test tank. However, this experiment was started at 1500 hours to investigate the possible influence of insolation as a factor on the changes noted in ammonia-N concentrations.

The ammonia-N data showed that in unfiltered samples there was a slight initial drop in concentration followed at 2030 hrs by a very high value (Figure 6). There was then a return to the previous levels and little further change until 2400 hrs, 9 hrs after the start, when a sharp drop to background levels was noted. Adequate samples were left from these analyses to permit filtration of the samples and reanalysis. Data for the filtered samples, shown in the same figure, resulted in a smoothing of the curve without materially affecting the other values, suggesting that the extraordinarily high value was due to the presence in the aliquot of non-randomly distributed particulate matter containing a high concentration of ammonia-N.

An anomalously high value similar to that for ammonia-N noted above also appeared in the data for nitrate and nitrite (Figure 7) and to a lesser extent in the silicate and phosphate data (Figure 8). The pattern of changes in concentration for nitrate, nitrite and phosphate otherwise appeared to echo the pattern noted for ammonia-N. The silicate data, however, showed a very slight rise throughout the period of the experiment.

The dissolved oxygen and pH in experiment AA4 (Figure 9) are mostly similar to those noted for experiments AA3. The pH showed a slight drop immediately upon addition of the waste sample and then a gradual decrease throughout the period of the experiment, but did not drop below pH 7. The dissolved oxygen values also showed an initial drop which was followed by

relatively little further change until 2030 hrs when a significant downward trend occurred. This coincided with the time at which the ammonia-N concentrations started their sharp decline. The experiment was terminated before a daylight rise might have occurred.

Experiment AA5

Experiment series AA5 was designed to investigate the relationship of five-day Biochemical Oxygen Demand (BOD_5) to the fate of the ammonia-N. In field tests of a dispersing cannery waste field off American Samoa (Soule and Oguri, 1983) BOD_5 was found to correlate significantly with ammonia-N concentrations. The configuration of these experiments was essentially the same as in experiments AA4, with a mixture of 500 grams of waste being diluted into 400 liters of 10 um-filtered seawater. The experiment started at 1500 hrs and the last samples were taken at 0330 hrs the following day, 12.5 hrs later. BOD_5 samples were processed to determine if these data for a laboratory experiment would show a relationship to the ammonia-N concentrations similar to that found in earlier field studies. No nutrient analyses were done for these experiments.

Ammonia-N concentrations, shown in Figure 10, were similar to those found in the previous experiments and showed a similar trend. High initial values were followed by a slow decrease for about 8 hrs. At about midnight, 9 hrs after the start, values dropped sharply, approaching the background levels in the diluent; they did not show further change.

Typical (BOD_5) data are presented in Figure 11. They followed the same pattern of changes that were observed in the ammonia-N concentrations but the drop in values with time was less pronounced. Although the change in the BOD_5 curve does not seem large it coincided in time with changes in ammonia-N and the correlation is statistically significant (see p. 18;

Figures 19, 20).

Typical dissolved oxygen and pH values observed in these experiments are presented in Figure 12. These show the same general pattern seen in the previous tests of this series. The pH initially decreased slightly, followed by a gradual reduction with time but never fell below a value of pH seven. The dissolved oxygen in this experiment did not show the initial drop upon addition of the waste but was otherwise similar to the pattern found in previous experiments of this series.

Experiment AA6

The experiments designated AA6 in this series of tests and all subsequent ones utilized a deeper experimental tank, which permitted the use of over 1000 liters of the experimental mixture. The tank is gray which is felt to approximate more nearly the color of local seawater. The lighter color also would effectively reduce any heat build-up due to insolation during the period of the experiment. The outer tank was also increased in size to raise the level of cooling water around the experimental tank.

These experiments were designed to investigate the effect of higher waste loading in the experimental tank than we had previously used. About 2000 grams of waste were added to 1000 liters of filtered seawater, an increase in concentration by a factor of about 1.6 over that which had been used in the other experiments of this series. The starting time was set at 0800 hrs and the last samples and observations were to be taken at 0700 hrs the following day.

The ammonia-N values found were considerably higher than in previous experiments due to the higher concentration of waste used (Figure 13). The initial observation after the addition of the waste showed a concentration of about 167 ug-at/L of NH4-N. This rose by 1200 hrs to over 230 ug-at/L

and then fluctuated between about 190 and 210 ug-at/L until 0300 hrs. The subsequent ammonia-N values rose to about 220 ug-at/L at 0500 hrs. They remained at about this level until 0700 hrs, the end of the period of observation.

Among the nutrient salts, nitrate plus nitrite showed a trend similar to that for ammonia-N (Figure 14). An initial increase in concentration corresponding in time with the rise in ammonia-N was followed within a few hours by a decrease to levels slightly above those found in the diluting seawater. No further major changes were noted. Silicate concentrations followed the same pattern with an initial increase followed by a rapid drop to the levels found in the diluting seawater with no essential change in values thereafter.

Both dissolved oxygen and pH displayed the slight initial decrease noted previously upon addition of the waste (Figure 15). The subsequent pH values showed the small, gradual decrease found in the previous experiments, never falling below a value of pH 7. Dissolved oxygen dropped rapidly in concentration and, despite increasing the aeration to stem the depletion, fell to values close to 0.0 ppm within twelve hours of the start of the experiment.

The reduction in silicate, nitrate and nitrite while ammonia-N remained at high levels as the oxygen fell is of interest since it had been felt that ammonia-N was more ephemeral in seawater than the other parameters. No explanation for this is apparent from inspection of the data. It is also of interest that the pH did not go below 7 although the oxygen was apparently completely depleted. Past observations had indicated that anoxic conditions were accompanied by an acidic pH.

The relative persistence of the ammonia-N at high levels throughout

this experiment, without the decline in concentration that occurred after several hours in previous experiments, is probably related to the depletion of dissolved oxygen. This has never been observed in any of the the studies of ocean disposal of cannery wastes or in any of the previous tank tests during the course of these investigations. In field observations of disposal off American Samoa a minor reduction in dissolved oxygen of less than 0.5 ppm was observed in the immediate wake of the discharging ship but this was transitory in nature (Soule and Oguri, 1983a). The oxygen sag in the expanding and diluting waste plume throughout the periods of monitoring also showed a maximum reduction in dissolved oxygen of less than 10%. The persistence of ammonia-N under anoxic conditions suggests that the micro-heterotrophs involved are aerobic forms.

Determination of biochemical oxygen demand was attempted. However, the oxygen demand of the mixture was underestimated and the dilutions of the samples selected were inadequate to reflect this. Consequently the oxygen in the BOD bottles of diluted sample was too depleted during the five-day incubation period to produce useable results.

Experiment AA7

Experiment series AA7 utilized the larger tanks as in experiments AA6. However, only 500 grams of the cannery waste were used, diluted into 1000 liters of filtered seawater. Aeration in the experimental tank was approximately doubled over that which had been in effect previously.

The control observations and sampling of the diluting water was done at 0755 hrs and the waste was added to the experimental tank at 0800 hrs. The first samples and observations after the addition of the waste were taken at 0830 hrs and the last at 1300 hrs the following day. In addition to the standard observations of temperature, dissolved oxygen and pH,

samples were also taken for ammonia-N analysis and BOD_5 determination. No nutrient samples were taken.

The ammonia-N concentrations increased about five-fold upon the addition of the waste and remained at high levels until about 1300 hrs, 8 hrs after starting. This was followed by a decrease similar to that noted in the previous experiments (Figure 16). Within twelve hours after the start, concentrations had reached an asymptotic low, somewhat below that recorded for the background level in the diluting water prior to the addition of waste, where they stayed for the remainder of the experiment.

The BOD_5 measurements showed an initial high value of 235 mg/L immediately after the addition of the waste (Figure 17). This dropped to about one third of the initial value and stayed at that level until 1830 hrs, the time at which the ammonia-N concentrations started to decrease. The values then started a decline that was less precipitous than the one noted for the ammonia-N and leveled out at values of less than 50 mg/L at about 0230 hrs the next day. The BOD_5 at the end was two to three times that in the diluting seawater prior to the addition of the waste. The initial high value may have been due to an inordinate amount of particulate matter in the BOD_5 sample collected for this sampling period.

Dissolved oxygen and pH are shown in Figure 18. The pH of the mixture differed somewhat from the pattern of an overall uniform decrease with time that was observed in previous tests. The pH showed a slight decrease upon addition of the waste and then exhibited a peak of 8.1 at 1430 hrs, the time when the ammonia-N started to decrease. It reached a minimum of 7.5 at 2030 and 2230 hrs, sagged again, and rose to a second peak of 7.9 at 0630 hrs the following day, corresponding roughly with the appearance of daylight. The pH then gently decreased throughout the period of the test. The variations in values were slight and did not go below pH 7.

Dissolved oxygen started at a higher concentration than in previous tests, due to the increased aeration. It rose slightly after the waste was added and then decreased, reaching a minimum of 4.9 mg/L at 2030 hrs, the time when the ammonia-N concentrations apparently reached their asymptotic low. The oxygen levels then started to rise after ammonia-N metabolism declined, reaching levels somewhat lower than they were at the start within about six hours.

Statistical Relationship of BOD_5 and Ammonia-N

Previously we discussed the relationship between BOD_5 and ammonia-N data obtained from samples collected from in and near a dispersing tuna processing waste field in the sea off American Samoa (Soule and Oguri, 1983a). Significant correlations were found between the two parameters for the samples collected on each of three trips to that area. This suggested the hypothesis that data on ammonia-N concentrations, being easier and quicker to measure, could serve as an effective and timely tracer of the dispersing waste field and estimator of the ambient quantity of the waste material present at the sampling point.

This series of laboratory tank tests offered the opportunity to carry out studies on the coincidence of the decay curves for BOD_5 and ammonia-N under conditions eliminating the effects of dispersion and dilution. Tests AA5, AA6 and AA7 included sampling for both BOD_5 and ammonia-N, collected synchronously for analysis throughout the sampling period. The ammonia-N samples were analyzed within five hours of collection and the samples for BOD_5 determination were stored no longer than five and a half hours before dilution and incubation.

Statistical analysis of the data from the AA5 test samples yielded a significant correlation of 0.66 ($n = 14$) between BOD_5 and ammonia-N and a

regression coefficient of 0.19 (Figure 19). The correlation, although significant, is lower than the correlations derived from the samples collected during the field studies in American Samoa which ranged from 0.70 (n = 9) to 0.91 (n = 72). The regression coeffient, which ranged from 0.37 to 0.60 in the field studies, is substantially lower in the AA5 tests.

The BOD_5 in the control sample, indicated in the lower left corner of Figure 19, is considerably lower than the other BOD_5 values in this experiment, including the last samples collected, possibly reflecting the presence of more slowly degrading, non-nitrogenous BOD_5 in the added cannery waste. Deletion of this point from the statistical treatment resulted in increasing the correlation to a highly significant 0.83 (n = 13). However, with this data treatment, the regression coefficient dropped to 0.08 (Figure 20).

Statistical treatment of the BOD_5 and ammonia-N data from AA7 yielded a significant correlation of 0.71 (n = 16) between the two parameters and a regression coefficient of 2.88 (Figure 21). Deletion of the control sample from the statistical treatment (Figure 22) changed the correlation to 0.70 (n = 15) and the regression coefficient to 2.76, a relatively insignificant change.

The 30 minute BOD_5 sample (Figure 17) had an unusually high BOD without an accompanying high ammonia-N, possibly reflecting the presence in the BOD_5 subsample of non-randomly distributed particulate matter with a relatively low ammonia-N concentration. Deletion of that sample from the statistical analysis increased the correlation to a highly significant 0.88 (n = 15) with a regression coefficient of 1.90 (Figure 23). Further deletion of the control sample from the data treatment (Figure 24) increased the correlation to a highly significant 0.94 (n = 14) with a

regression coefficient of 1.79.

The regression coefficients calculated between BOD_5 and ammonia-N varied significantly for each of the monitoring and experimental episodes reported here and in our earlier report. The regression coefficients found in the data for the samples collected off American Samoa, where only tuna was being processed, were 0.37, 0.60 and 0.66. In our tank experiments using DAF sludge from the processing of a varied mix of products, regression coefficients ranged from 0.08 to 2.75. However there was internal consistency in the data for each of the occurrences, as indicated by the correlations for the separate data sets. This probably reflects variations in what the cannery was processing, the status of the cannery DAF treatment facility and the concentration of the wastes being produced.

The AA6 experiments were designed to test the effects of overloading the system beyond the greater than 1:1,000 dilution found in the immediate wake of a ship discharging waste under operational conditions. As expected, there was rapid depletion in the tank tests of the available dissolved oxygen. The dissolved oxygen in all BOD_5 dilutions was reduced almost to zero by the end of the standard five day incubation period, producing data that exceeded the 30% to 70% oxygen depletion range within which values could be meaningfully calculated.

Conclusions

The coincidence of the curves for decline in dissolved oxygen and for ammonia-N suggest that the principal oxygen demand imposed by the waste is due to the degradation of ammonia-N by aerobic microheterotrophs. The recovery of dissolved oxygen suggests that the metabolic oxygen demand had been satisfied. This is consistent with the data reported for AA6 in which the ammonia-N was not depleted when the dissolved oxygen was exhausted, as

shown in Figures 13 and 15.

The data from these experiments indicate that good statistical agreement may be expected between ammonia-N concentration and BOD_5 in each batch of waste because the ammonia-N degradation is apparently the major oxygen demanding constituent during the first ten to twelve hours after the introduction of wastes into the marine environment. Other constituents imposing oxygen demands in the mixture apparently varied in quantity and composition, as shown by the variations in regression. These apparently degraded more slowly, as shown by the failure of the BOD_5 values to reach asymptotic levels, although the ammonia-N levels did so during the term of these experiments.

Significant correlation was found between BOD_5 and ammonia-N in these tests which improved to highly significant upon deletion of anomalous values from the data set. This supports the hypothesis advanced after inspection of the field data from American Samoa that there is a more than adequate relationship between BOD_5 and ammonia-N concentrations in cannery waste fields to permit use of the more timely and readily obtainable ammonia-N values as a means of tracing a waste field in the marine environment and quantifying the rate of dispersion and dilution.

These experiments tend to confirm the utility of ammonia-N concentrations as a means of tracing the plume of a cannery waste field in the marine environment. The concentrations appeared to be reasonably uniform for eight to ten hours after the waste was added when aerobic conditions prevailed. If the concentration of waste was such that anaerobic conditions prevailed, the persistence of high concentrations of ammonia-N would be enhanced.

A minor oxygen sag was detected in the immediate wake of a ship discharging cannery waste off American Samoa and in the plume resulting

from the discharge (Soule and Oguri, 1983a). This was transitory and the reduction in dissolved oxygen never exceeded 10%. The ocean dumping of the cannery wastes, under the regimen observed, resulted in theoretical dilutions of the wastes that exceeded 1:1,000 in the immediate zone of dilution of the discharging vessel. This apparently imposes a loading on the receiving waters that is well within their assimilation capacity.

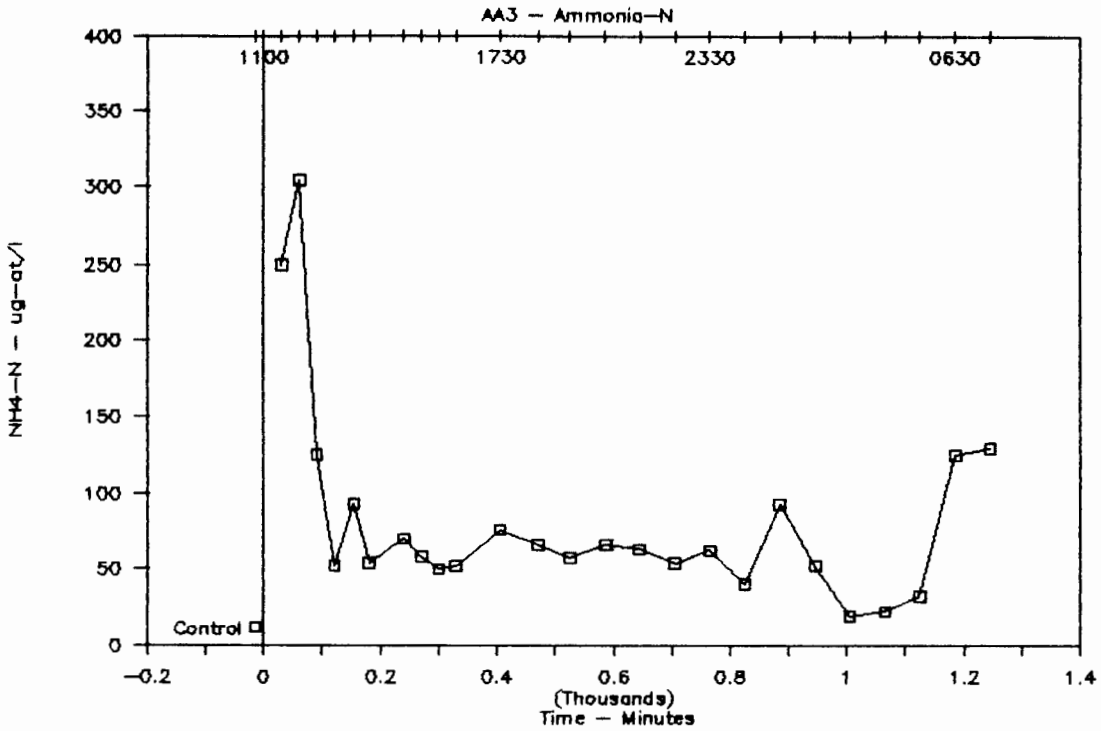

Figure 1. Ammonia-N measurements by electrode in tank tests AA3 on degradation of DAF sludge. Vertical line indicates addition of sludge. Control is tank sample prior to addition of sludge. Top line indicates real time; bottom line is lapsed time.

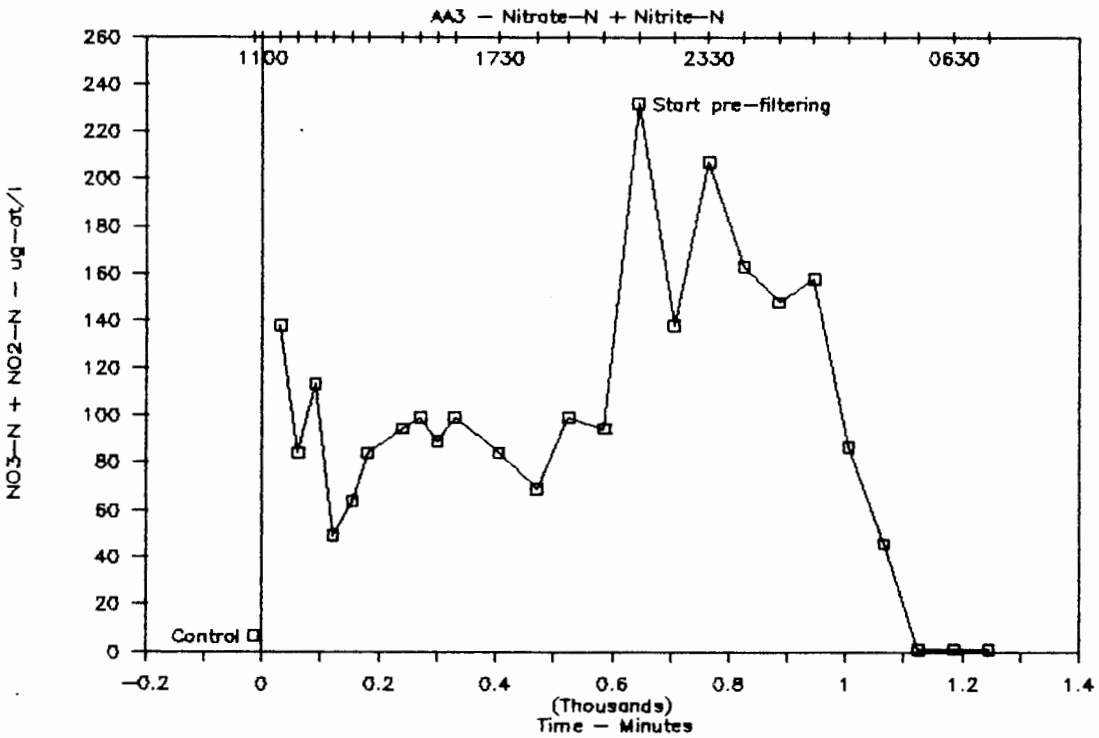

Figure 2. Nitrate-N plus nitrite-N determined by AutoAnalyzer in tank tests AA3.

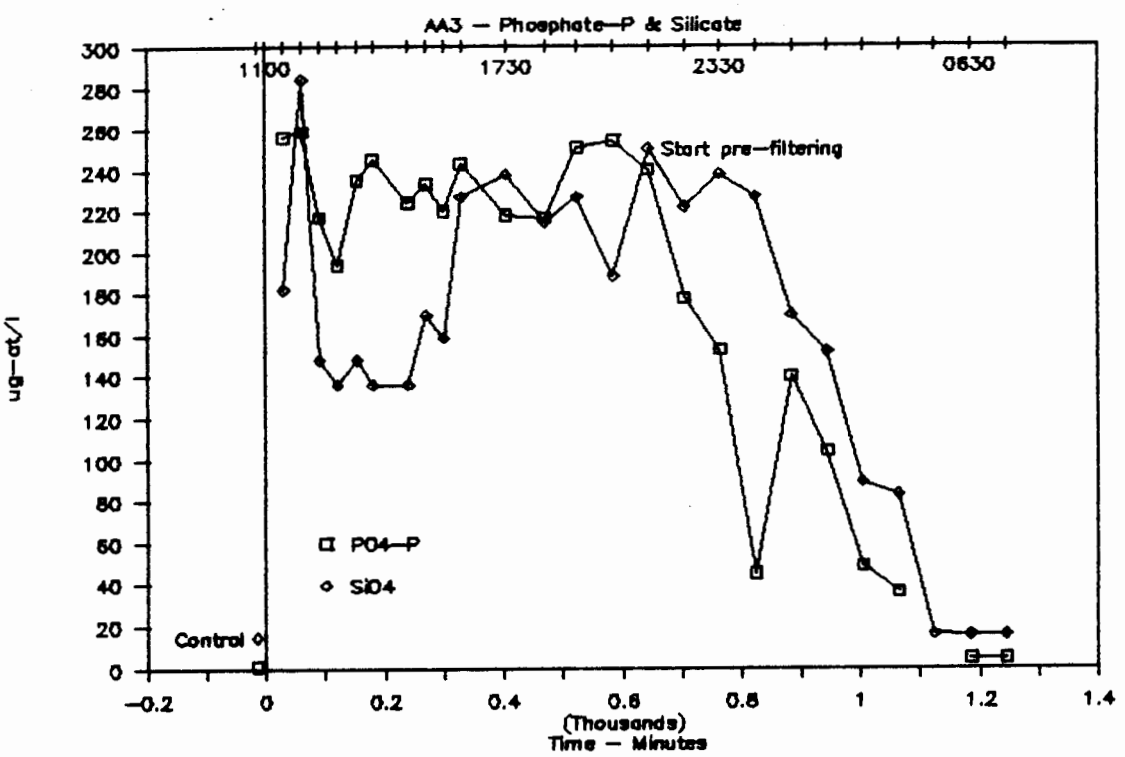

Figure 3. Phosphate-P and silicate measured by AutoAnalyzer in tank tests AA3 on degradation of DAF sludge. Vertical line indicates addition of sludge. Control is tank sample prior to addition of sludge. Top line indicates real time; bottom line is lapsed time.

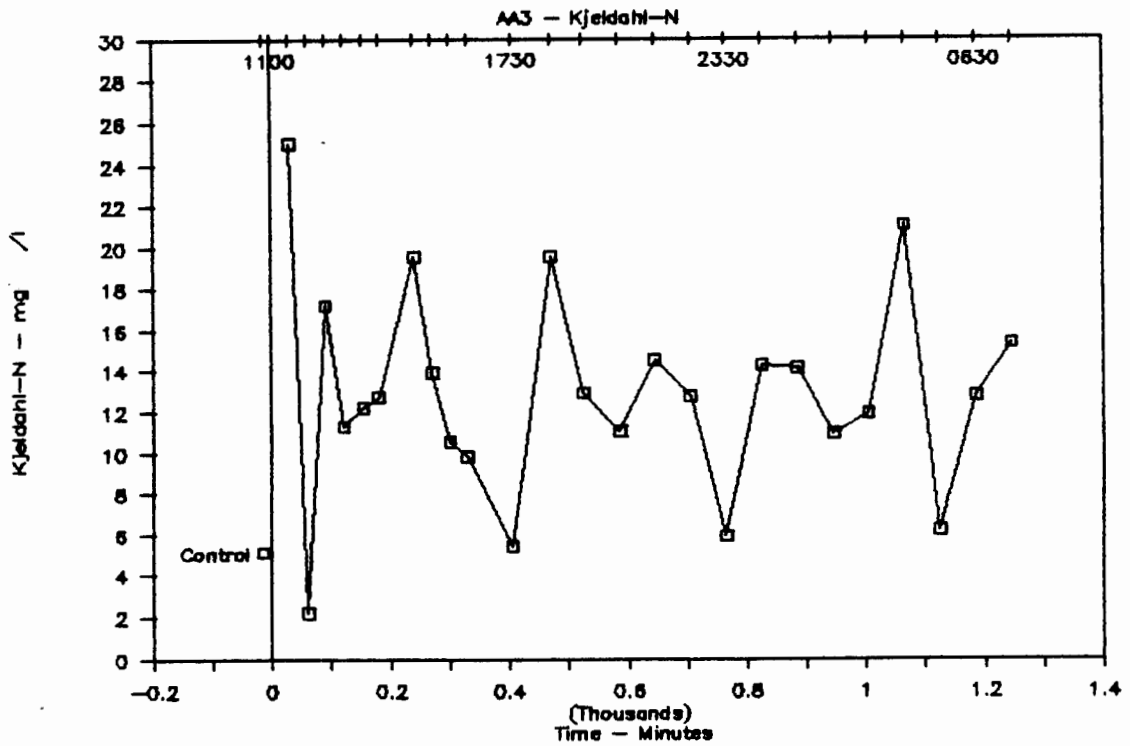

Figure 4. Kjeldahl-N measurements of organic-N in mg/L. Erratic pattern may have been due to particulates.

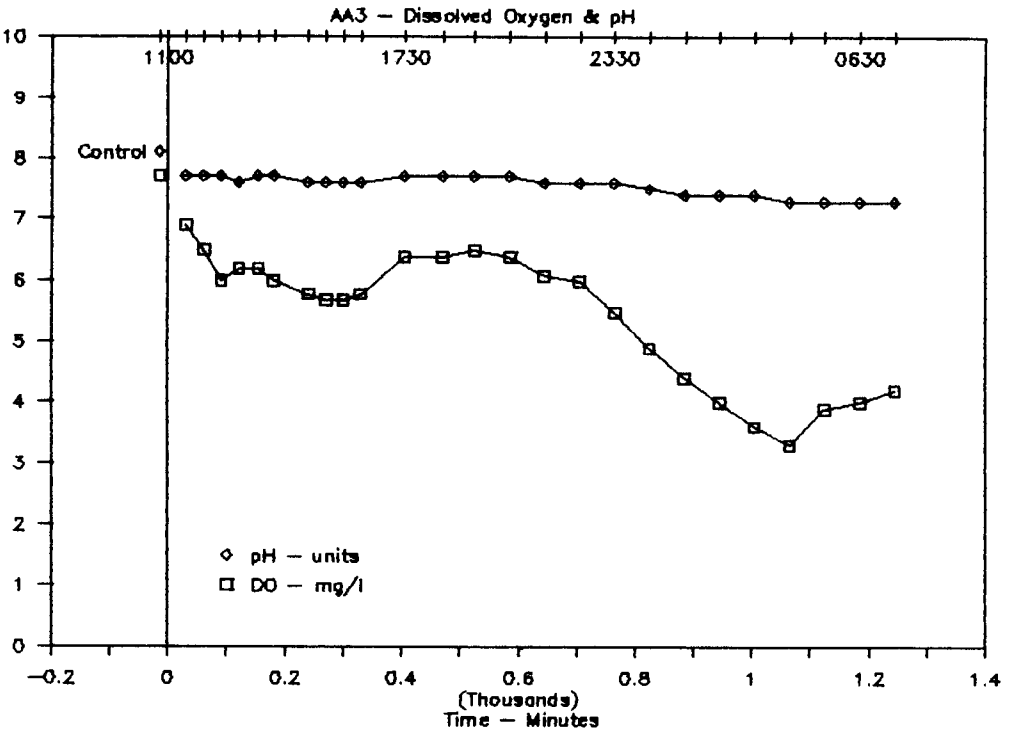

Figure 5. Dissolved oxygen and pH during tank tests AA3. Decline in dissolved oxygen apparently did not reach inhibitory levels.

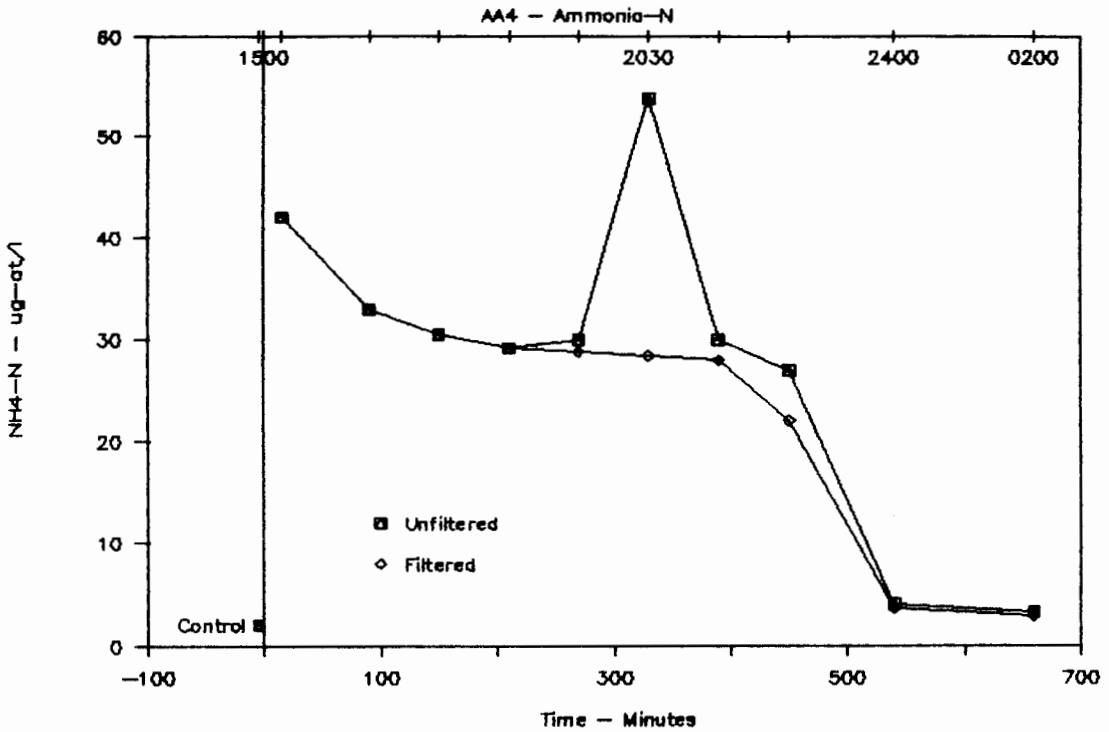

Figure 6. Ammonia-N measurements by electrode in tank tests AA4 on degradation of DAF sludge, with filtered and unfiltered samples. Vertical line indicates addition of sludge. Control is tank sample prior to addition of sludge. Top line indicates real time.

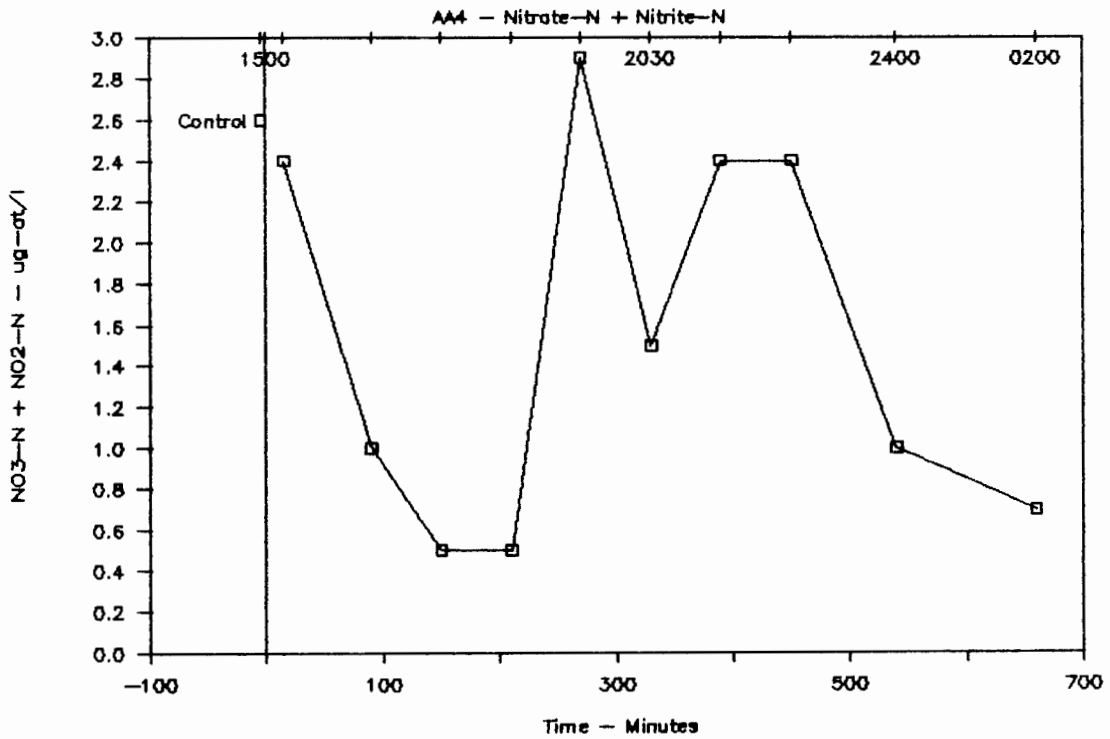

Figure 7. Nitrate-N plus nitrite-N determined by AutoAnalyzer in tank tests AA4.

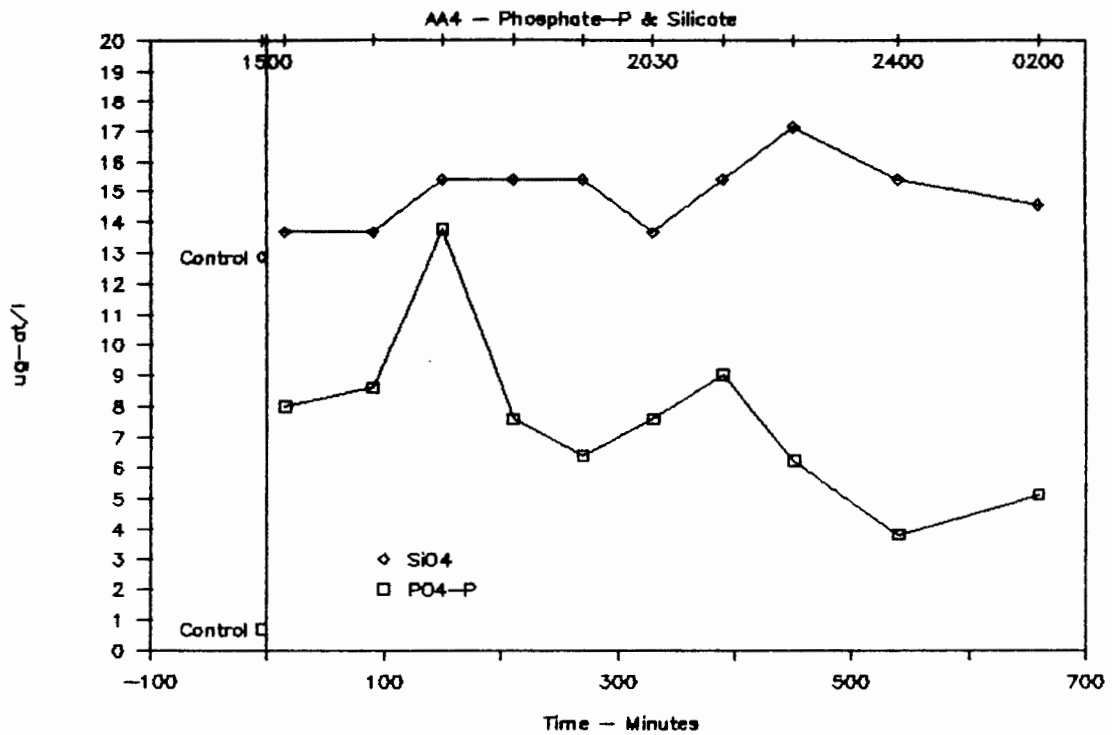

Figure 8. Phosphate-P and silicate measured by AutoAnalyzer in tank tests AA4 on degradation of DAF sludge. Vertical line indicates addition of sludge. Control is tank sample prior to addition of sludge. Top line indicates real time; bottom line is lapsed time.

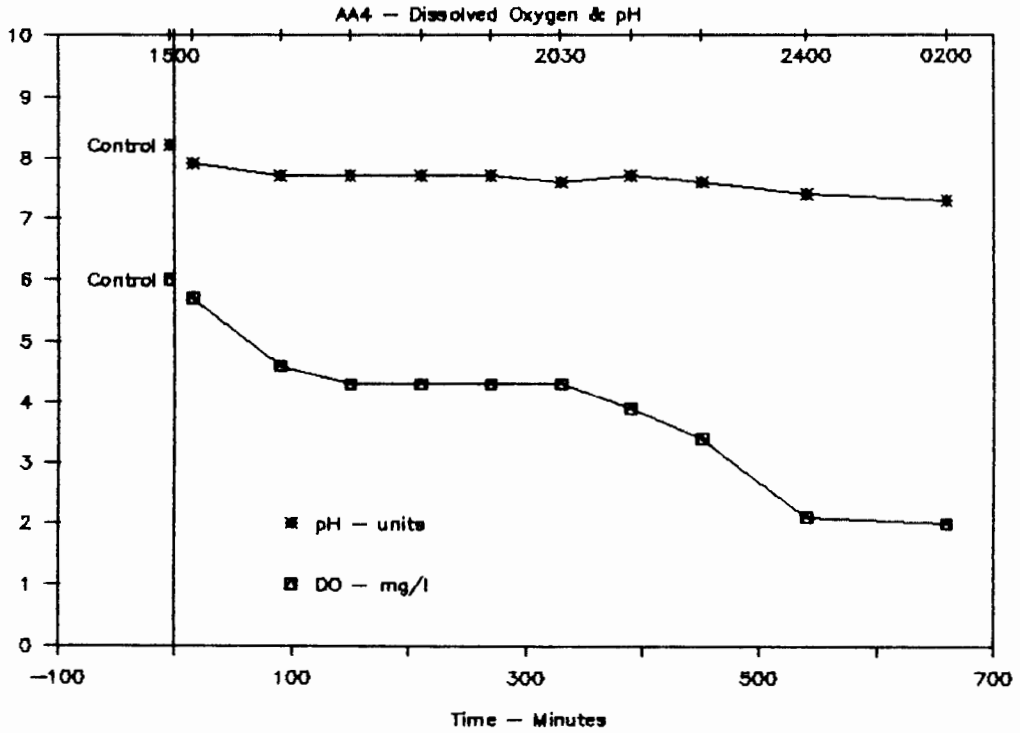

Figure 9. Dissolved oxygen and pH during tank tests AA4. Decline in dissolved oxygen coincided with decline in ammonia-N (Figure 6).

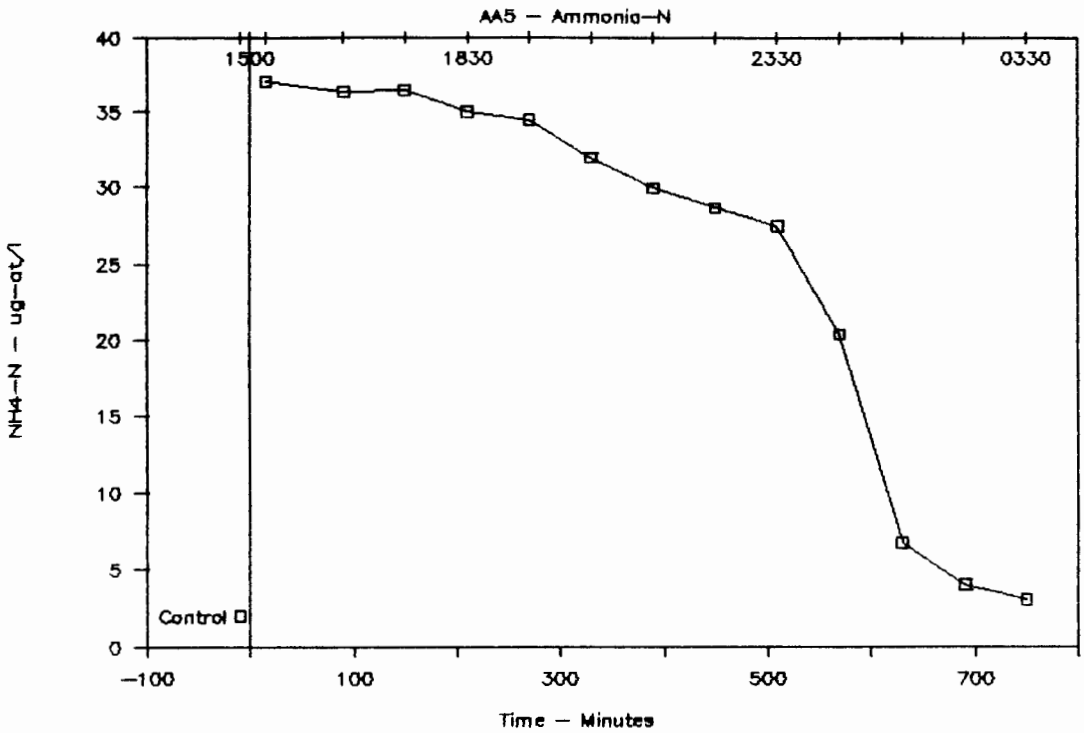

Figure 10. Ammonia-N measurements by electrode in tank tests AA5 on degradation of DAF sludge. Vertical line indicates the addition of sludge. Control is tank sample prior to addition of sludge. Top line is real time; bottom line is lapsed time.

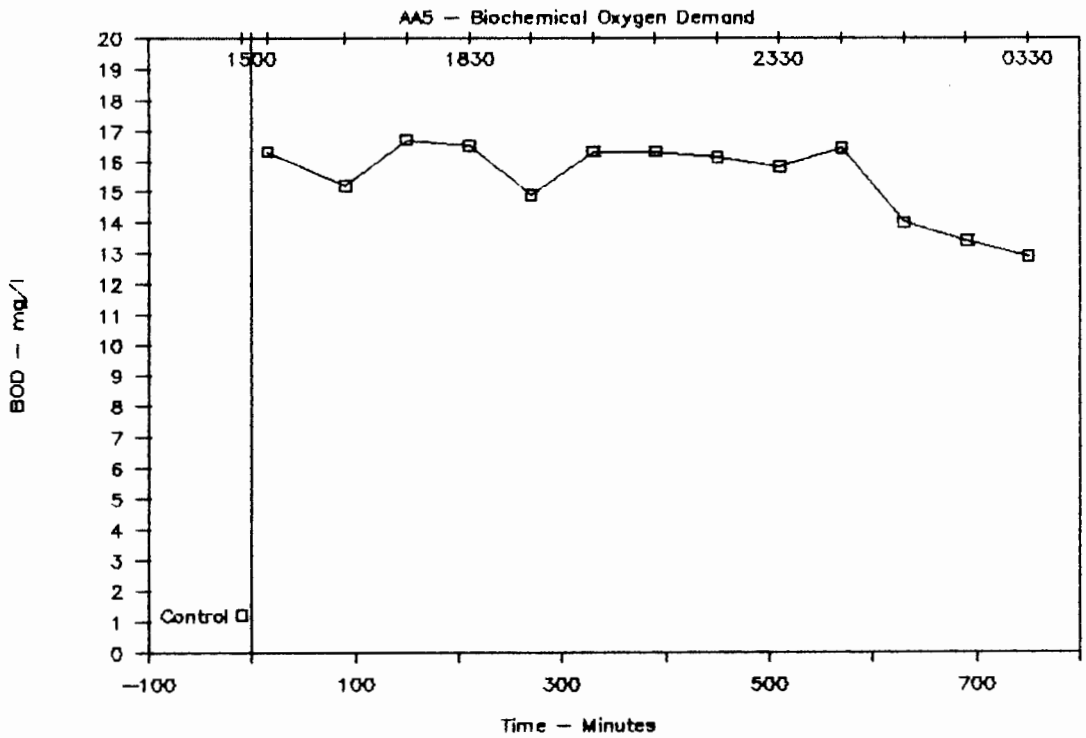

Figure 11. Five day Biochemical Oxygen Demand (BOD_5). Correlation with ammonia-N is statistically significant even though decrease in BOD_5 is small (see also Figures 16, 17, 19, 20).

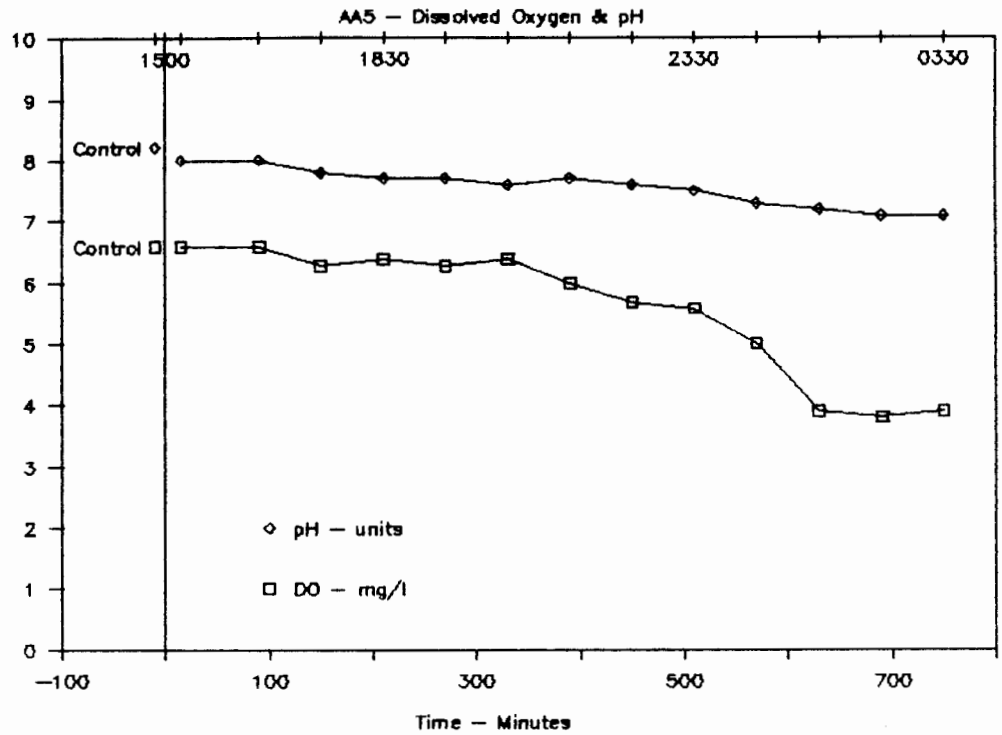

Figure 12. Dissolved oxygen and pH in tank tests AA5 of degradation of DAF sludge. Vertical line indicates addition of sludge. Decline in dissolved oxygen is not sufficient to stress the system.

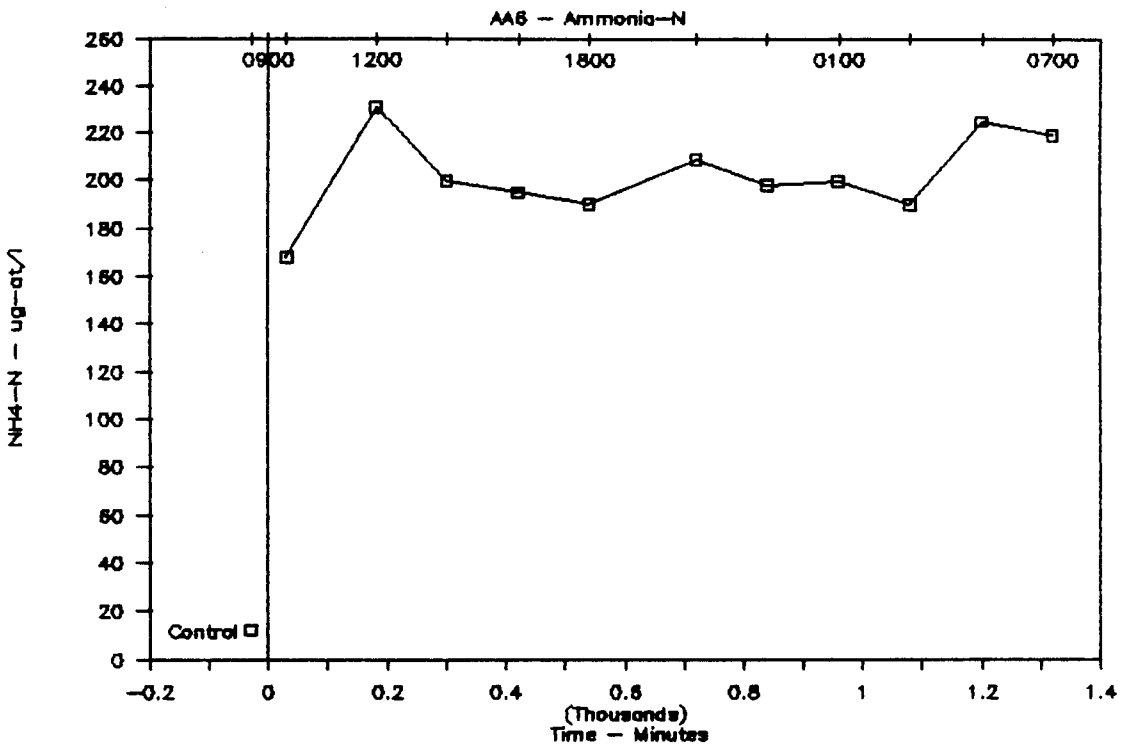

Figure 13. Ammonia-N measurements by electrode in tank tests AA6 on degradation of DAF sludge. When test tank was depleted of dissolved oxygen, depletion of ammonia-N did not occur, suggesting aerobic microheterotrophic activity.

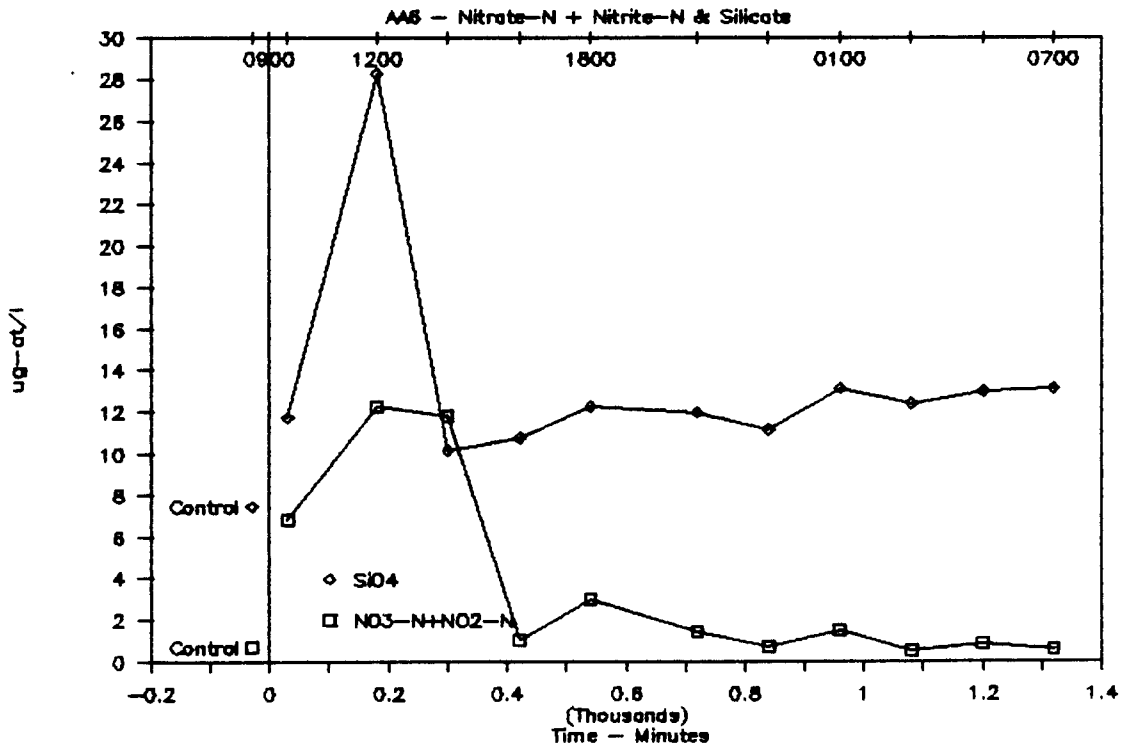

Figure 14. Nitrate-N plus nitrite-N and silicate in tank tests AA6. Initial rise in parameters paralleled initial rise in ammonia-N, above.

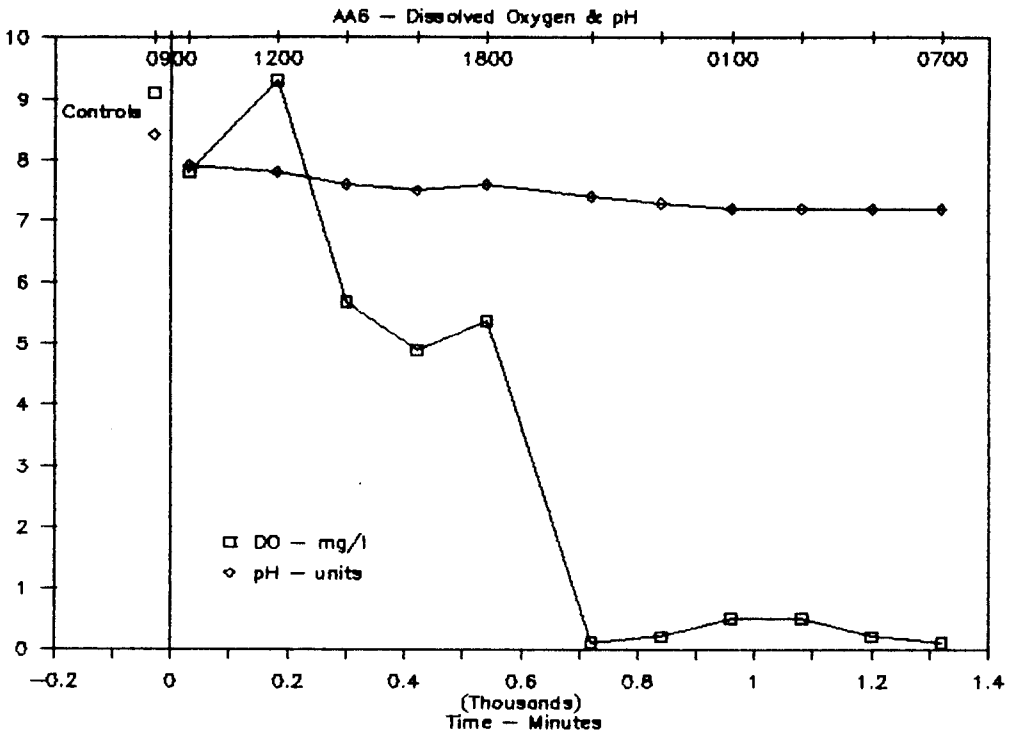

Figure 15. Dissolved oxygen and pH in tank tests AA6 of degradation of DAF sludge. Tests increased loading to stress the system, resulting in hypoxia and production of sulfide; ammonia-N (Figure 13) did not decline as is usual under aerobic conditions. The pH showed little change. Vertical line indicates the start of the tests; controls are samples from the test tank prior to addition of sludge.

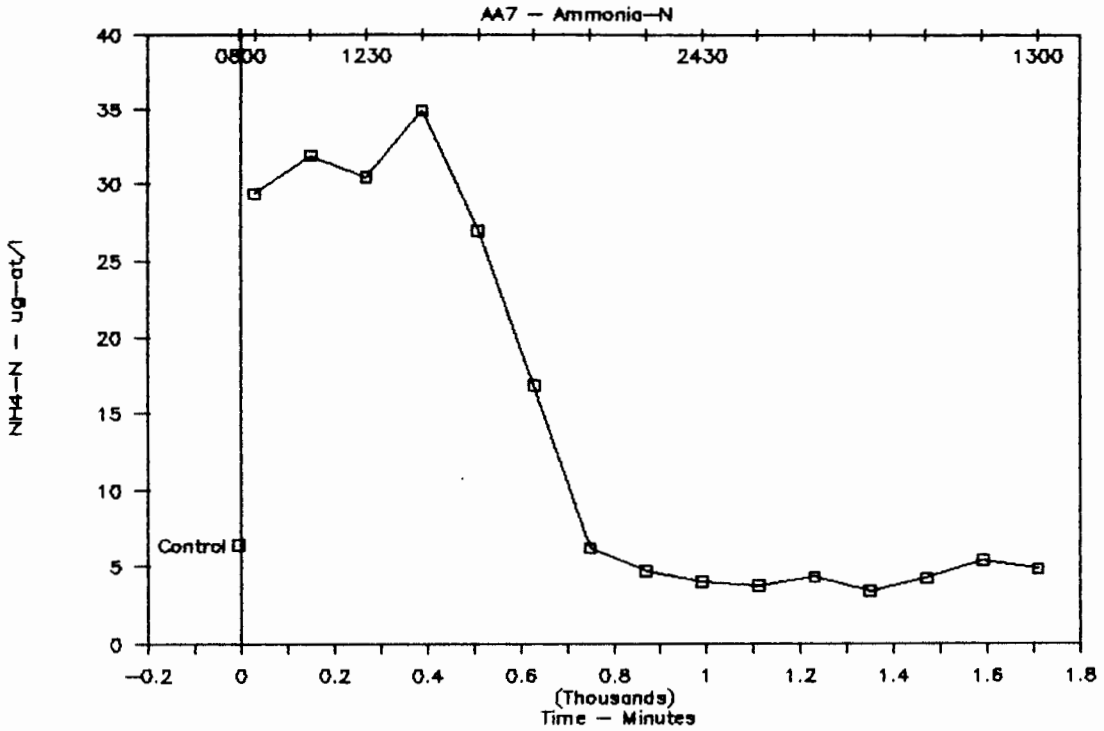

Figure 16. Ammonia-N measurements in tank tests AA7 of degradation of DAF sludge. Levels were relatively low, but rose over first 6 hrs and declined to control level about 12 hrs from start.

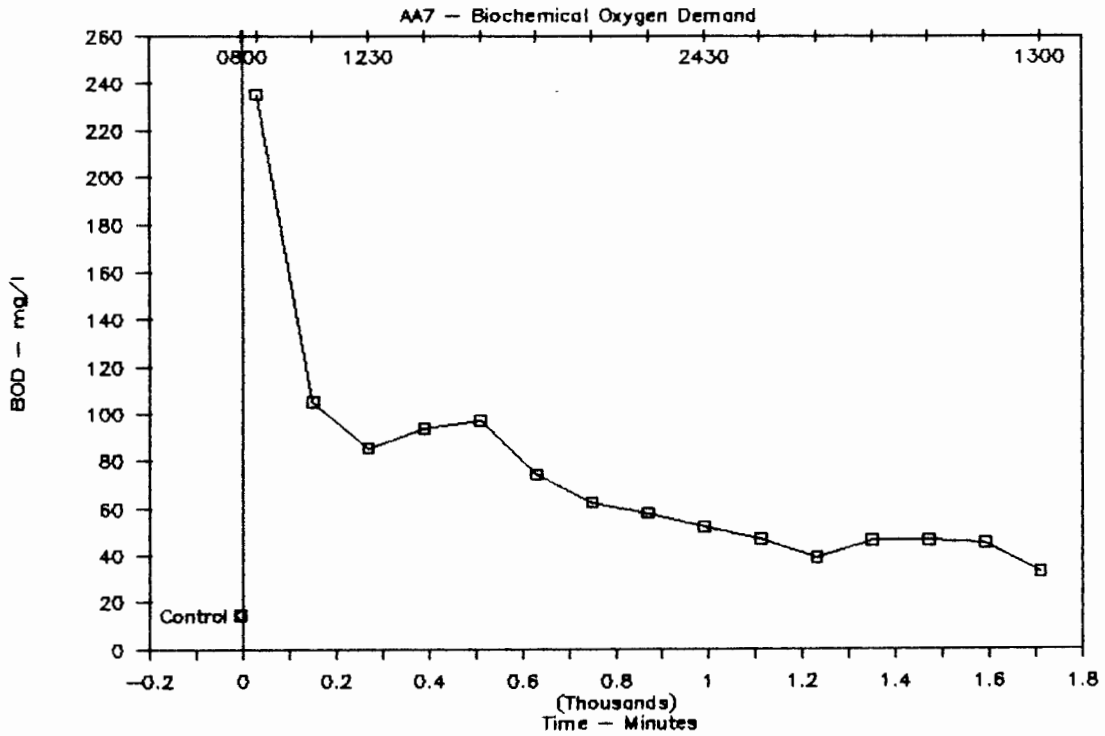

Figure 17. Five day biochemical oxygen demand (BOD_5) in tank tests AA7. Except for first data point, trend follows that of ammonia-N, above; relationship is statistically significant.

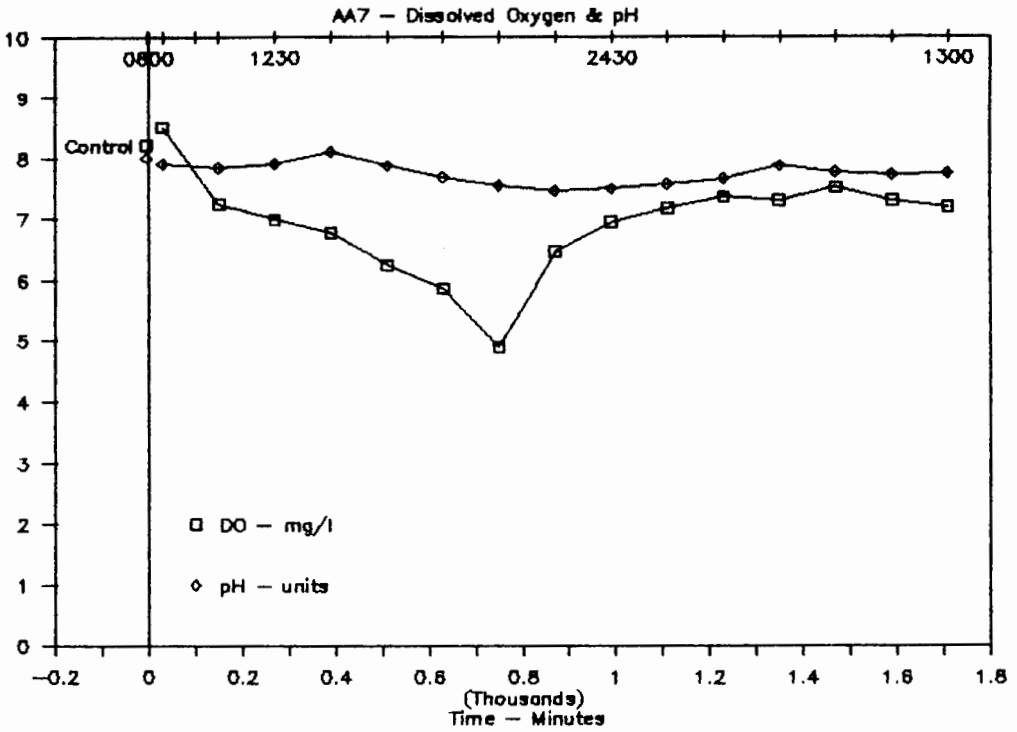

Figure 18. Dissolved oxygen and pH in tank tests AA7 of degradation of DAF sludge. Aeration was increased in these tests to compensate for downward trend and prevent hypoxia. The pH remained relatively stable, with minor declines and peaks. Vertical line indicates the addition of sludge at the start of tests; control is sample from tank prior to addition of sludge.

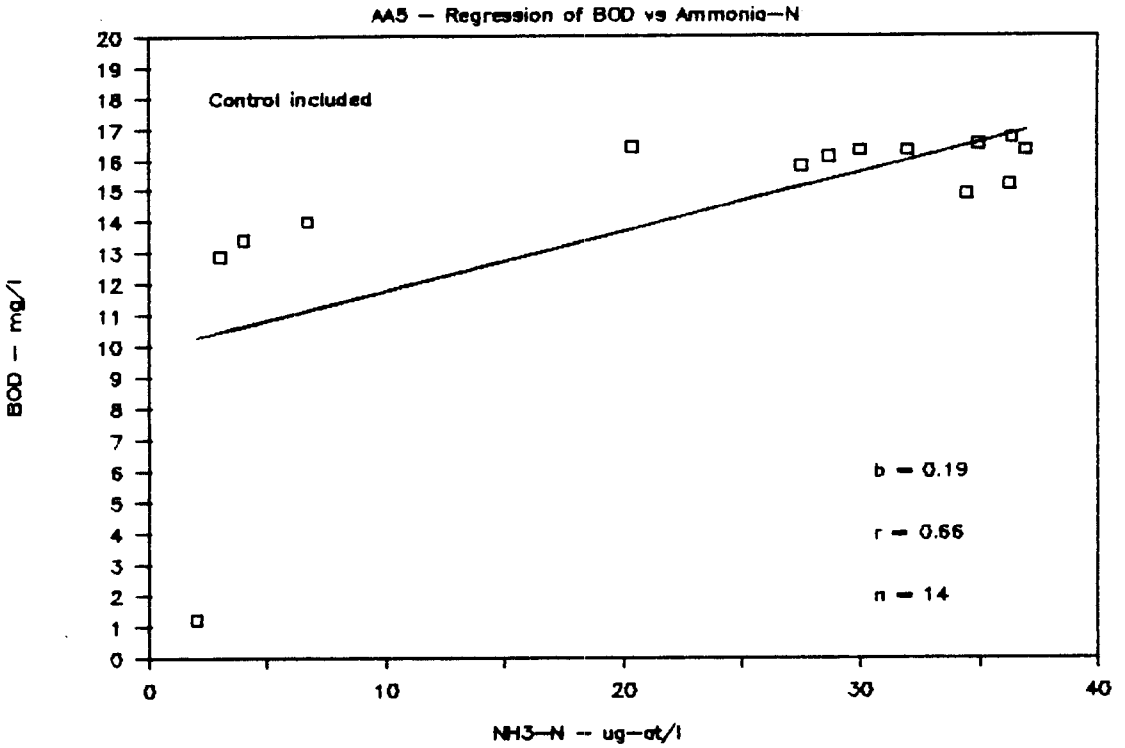

Figure 19. Statistical analysis of test AA5 data on BOD_5 and ammonia-N yielded significant correlation of 0.66 (N=14) and regression coefficient of 0.19. Correlations from field studies in American Samoa ranged from 0.70 (N=9) to 0.91 (N=72) with regression coefficients of 0.37 to 0.60.

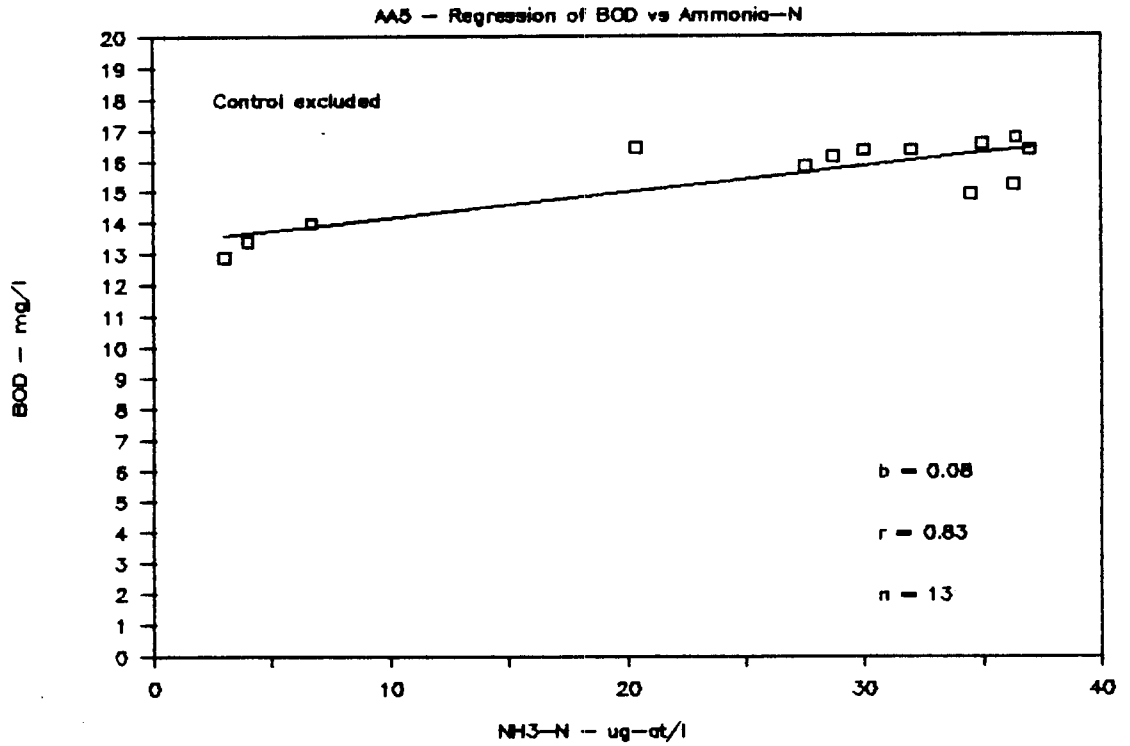

Figure 20. If low control BOD_5 value is dropped from test AA5 data analysis, correlation is increased to highly significant at 0.83 (N=13) but regression coefficient is reduced to 0.08.

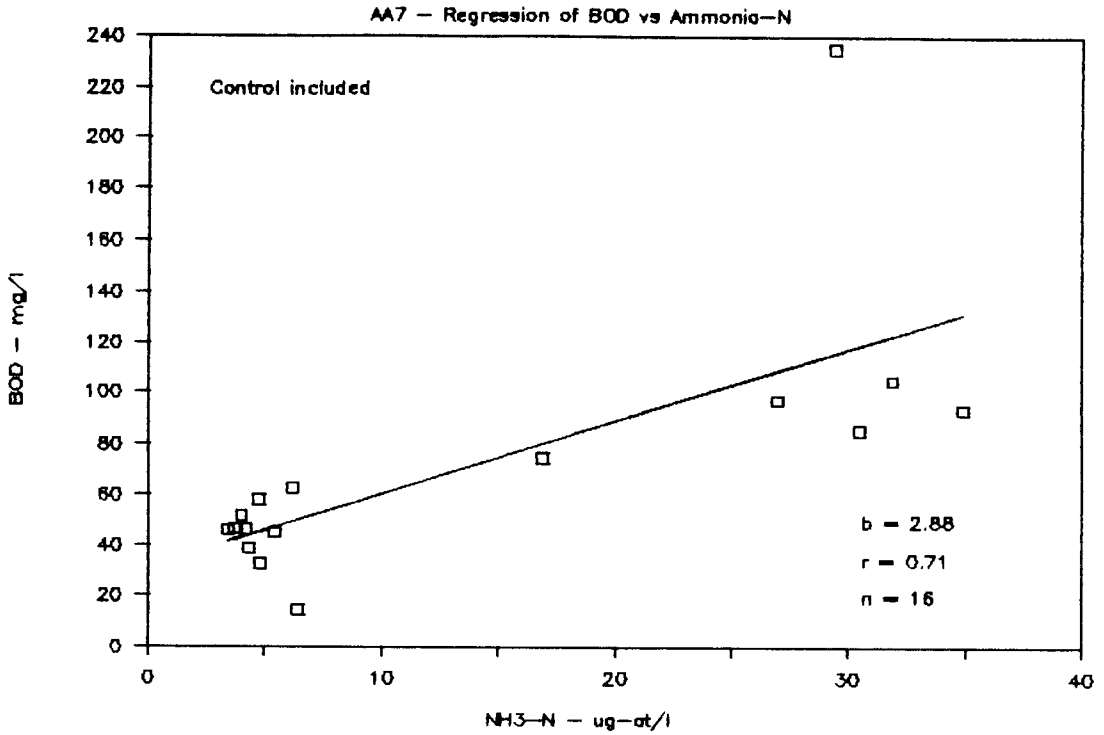

Figure 21. Statistical analysis of test AA7 data on BOD_5 and ammonia-N yielded significant correlation of 0.71 (N=16) and regression coefficient of 2.88.

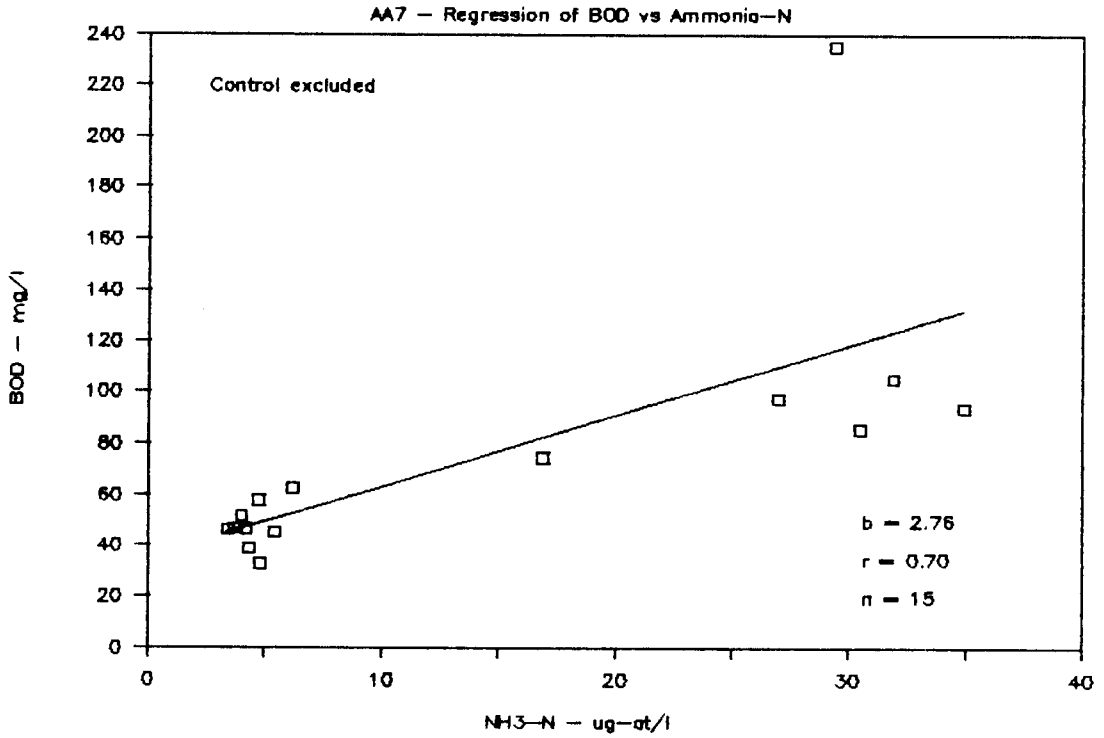

Figure 22. Deletion of control from test AA7 data produced minor changes: a significant correlation of 0.70 (N=15) and regression coefficient of 2.76.

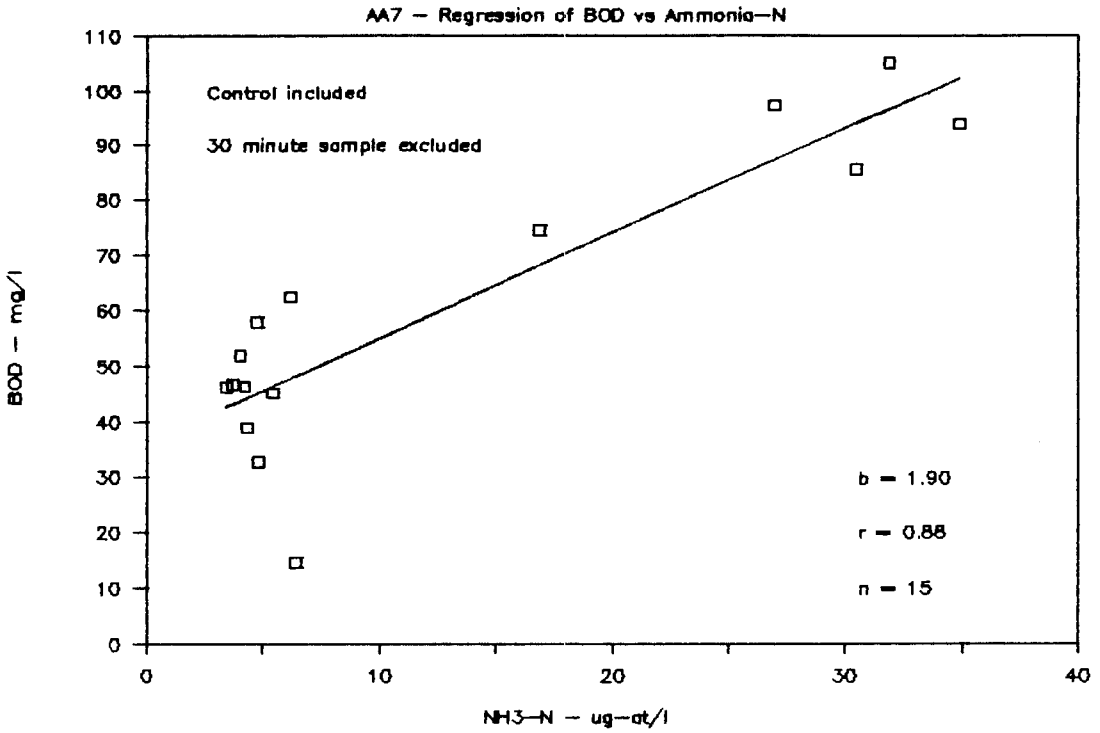

Figure 23. Test AA7 data analyzed with the low control value included but the anomalous 30 min BOD_5 value excluded. Correlation is highly significant at 0.88 (N=15) with regression coefficient of 1.90.

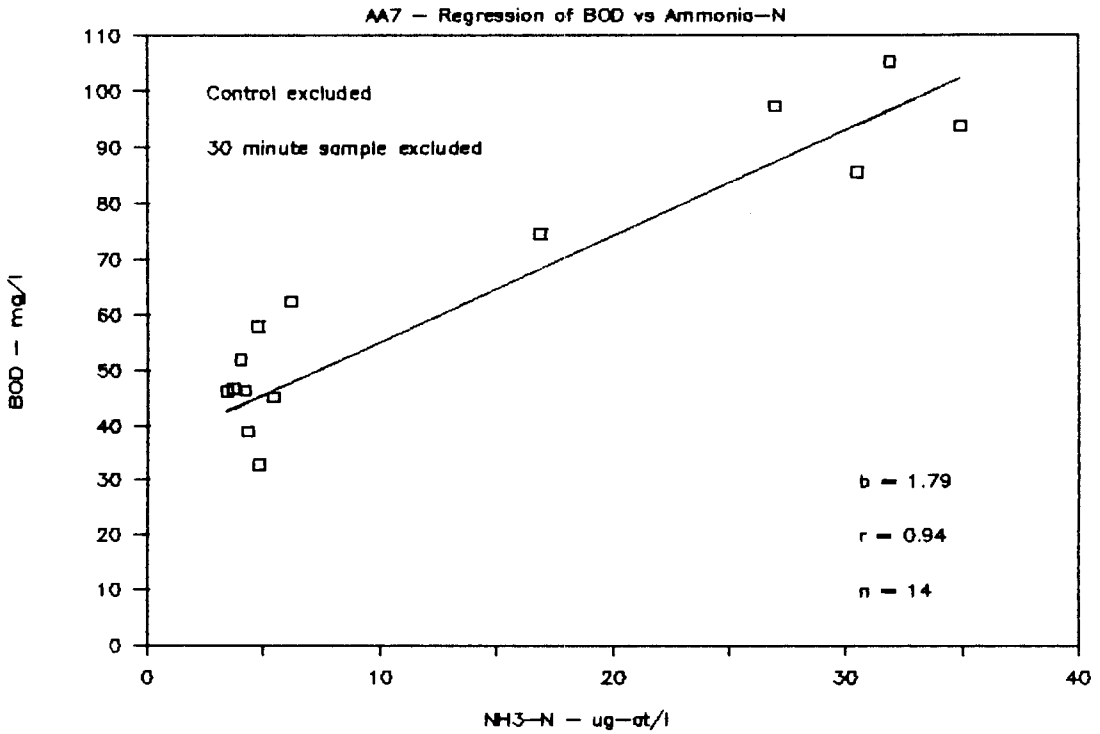

Figure 24. Test AA7 data analyzed with both low control value and anomalous 30 min BOD_5 value excluded. Correlation is highly significant, increased to 0.94 (N=14) with regression coefficient of 1.79.

2). TOXICITY-BIOSTIMULATION EXPERIMENTS ON MUSSELS

Introduction

The potential for toxicity, biostimulation and/or bioaccumulation from fish processing wastes has been investigated in a series of bioassay tests by Soule and Oguri (1979, 1983b and unpublished, 1978, 1979, 1980). These included tests using various combinations of fish processing wastes alone and in combination with secondary treated urban wastes. Liquid wastes in the stream prior to DAF treatment, post-DAF treated liquid and the semi-solid DAF sludge have been tested in 96-hour acute toxicity tests as well as longer term tests of up to 20 days.

In the 1979 studies a variety of animals were used, including the copepod *Acartia tonsa*, the polychaete worm *Neanthes arenaceodentata*, the California killifish *Fundulus parvipinnis*, larvae of the northern anchovy *Engraulis mordax*, the bay mussel *Mytilus edulis*, and the sand crab *Emerita analoga*, as well as the phytoplankton *Skeletonema* sp., *Nitschia* sp., and *Scrippsiella trochoidea*. In the 1982 investigations *Mytilus edulis* and *Fundulus parvipinnus* were used. In the 1983 report, concentrations lethal to 50 percent of the test organisms (LC_{50}) were calculated for American Samoa sludge using *Acartia* sp., *Acanthomysis sculpta* and *Fundulus*.

At concentrations simulating those of the post-DAF treated fish waste effluent stream as it is received by the treatment plant, and those of the secondary effluent released into the harbor, there was no pattern of either toxicity or bioaccumulation of trace metals or total chlorinated hydrocarbons (Soule and Oguri, 1983). There was a biostimulatory effect on phytoplankton, especially at the 1.0% level of secondary effluent. Similarly, mussels exposed to 1.0% concentration showed significant increases in weight as compared with controls. Experiments in which dried or

wet DAF sludge was fed to anchovies showed that the material supported growth triple that of controls.

Because there have been changes in the types of polymers and coagulants used in the DAF process in the past several years it was deemed advisable to retest a representative species for the NOAA investigations in 1983-84. Therefore the effects of long term (74 day) exposure to the semi-solid DAF sludge were tested on *Mytilus edulis* (Soule and Oguri, 1984).

In the 1983-84 experiments, mussels were collected from pier pilings in the vicinity of the USC Fish Harbor Marine Laboratory, Los Angeles. Mussles were cleaned by scraping debris from shells, measured and weighed on a triple-beam balance. Randomly selected mussels, in groups of seven, were placed in each of four experimental tanks and three control tanks. Each of the experimental tanks were filled with 30 liters of a mixture of 0.1% sludge in sea water. The sludge was collected from the dissolved air flotation (DAF) treatment tanks at Star-Kist Foods, Inc. Tuna was being processed at that time. On a weekly basis the tanks were exchanged for freshly cleaned ones containing a mixture of freshly collected sludge at the same concentration. The control tanks were supplied with flow through seawater from the laboratory system. Aeration was maintained in all tanks for the duration of the experiment.

Only one control and one test mussel died during the 74 day experiment, which provided information on non-toxic concentrations but did not provide significant growth. Results indicated that long term growth of the ubiquitous bay mussel, *Mytilus edulis*, was apparently enhanced by exposure to low levels of sludge. There was a small increase in average weight of the mussels exposed to 0.1% sludge, which was changed weekly, as compared to control mussels held in flowing sea water. However, the difference noted was not statistically significant, whether the data were considered

on the basis of the weight change of all individuals (Figure 25) or on the basis of average weight change of the mussels in each experimental tank versus that in each control tank (Figure 26). The 74 day experiment was terminated when mold appeared in the experimental tanks. It is not known what effect the mold had on the results of the experiment.

Procedures

In the present investigations, experiments were conducted for 46 days in February and March 1986 to verify the earlier findings and to test the effect of DAF sludge primarily produced from the processing of mackerel but also including other pet food products. The sludge from tuna processing has a lower oil content than does the mackerel sludge.

In the 1986 study, the mussels were collected from pier pilings in Marina del Rey. Instead of being placed on the bottom of the tanks, mussels were suspended in net bags in groups of ten. Two bags containing a total of 20 mussels were placed in each tank. Filtered seawater was used to make 1.0%, 0.5%, and 0.1%, sludge mixtures and controls. The water was changed twice weekly and freshly collected sludge was added, at which time the dead were removed. Three replicates were used for each dilution. Initial and final weights were taken with an electronic top-loading balance (Sartorius, Model 1409B). This greatly speeded the weighing of the mussels and improved the precision of measurements. Samples were taken for ammonia-N analysis and measurements made of temperature, dissolved oxygen and pH prior to and after each change of solution.

Results and Discussion

Survival in the tanks containing 1.0% and 0.5% sludge concentrations was poor, with only five of the 60 mussels in the three 1.0% tanks and seven in the 0.5% tanks surviving for the 46 days of the test. In the 0.1%

and in the control tanks 59 of the 60 mussels held at each of the conditions survived.

Death of the mussels at the higher concentrations might be attributed to the lack of dissolved oxygen caused by the high oxygen demand of the sludge, although measurements of dissolved oxygen usually showed adequate levels. Prior to changing the solutions it was noted that sulfides had formed in those tanks. In the freshly mixed 1.0% and 0.5% solutions, significant reductions in dissolved oxygen were observed within one to two hours after preparing the mixtures, indicating that the oxygen demand was great. This was apparently satisfied prior to the next change three to four days later since oxygen concentrations at the time of the next change of mixture were usually above 2 ppm. Increased aeration in the tanks failed to completely alleviate the condition and the mussels continued dying in the tanks at the higher concentrations.

The few survivors at the 1.0% and 0.5% concentrations lost weight and the mussels at 0.1% gained weight in comparison to the controls (Figure 25). If the data treatment of the 0.1% test considers the individual mussels, the changes in weight observed were not significant. However, if the data are treated according to the average weight change of all the mussels in each bag exposed to the 0.1% sludge concentration and in the control tanks, there is a significant difference in the weight change between the two groups. This difference is further enhanced if the comparison is made using the average weight change of all the mussels in each of the three replicate tanks for each of the treatments (Figure 26). Analyses of the 1983-84 data are shown in Figures 27 and 28. If mussels per tank are combined, the data are statistically significant (Figure 28). The increased amount of oil in mackerel DAF sludge as compared with tuna DAF

sludge might account for the non-statistically significant growth at 0.1% in earlier tests and statistically significant growth in present tests.

Conclusions

The data indicate that the cannery waste, at appropriate dilution, can serve as a substrate for these organisms. At higher concentrations the oxygen demand of the sludge and the presence of sulfide adversely affected water quality and stressed the organisms. The positive test growth effects would probably be eliminated in the field since the wastes would be discharged in an environment where dilution, diffusion and dispersion would rapidly dissipate the nutrients.

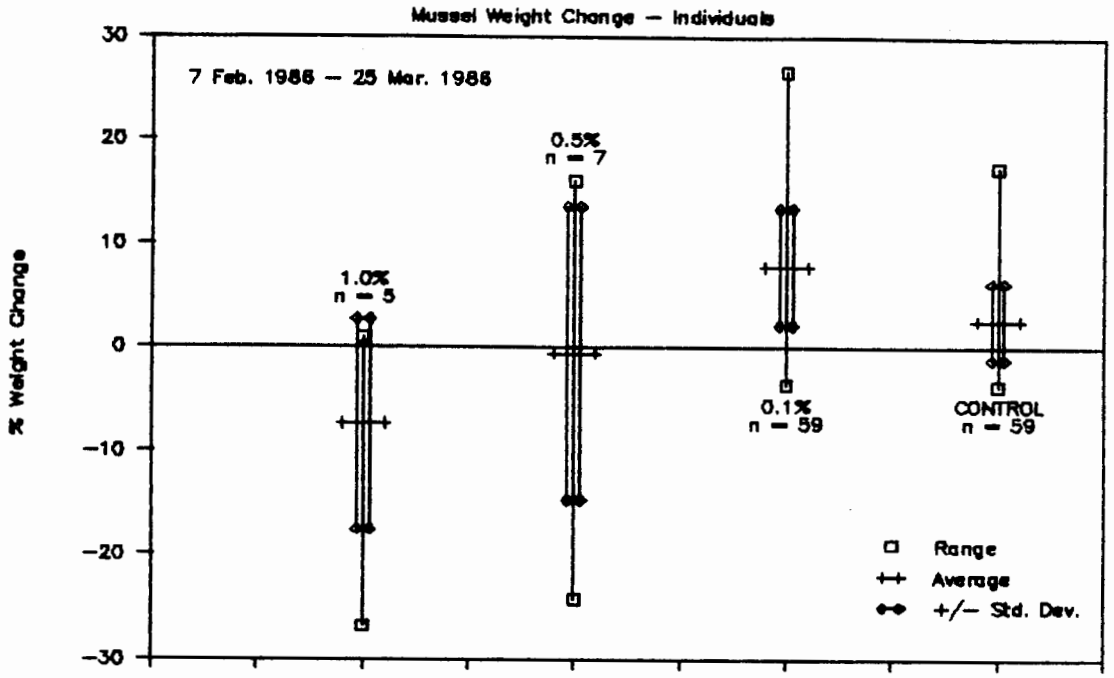

Figure 25. Mussel growth stimulation test, 7 Feb. 1986 to 25 Mar. 1986 using 1.0%, 0.5% and 0.1% mackerel DAF sludge. If individual weights are analyzed, there is no significant difference.

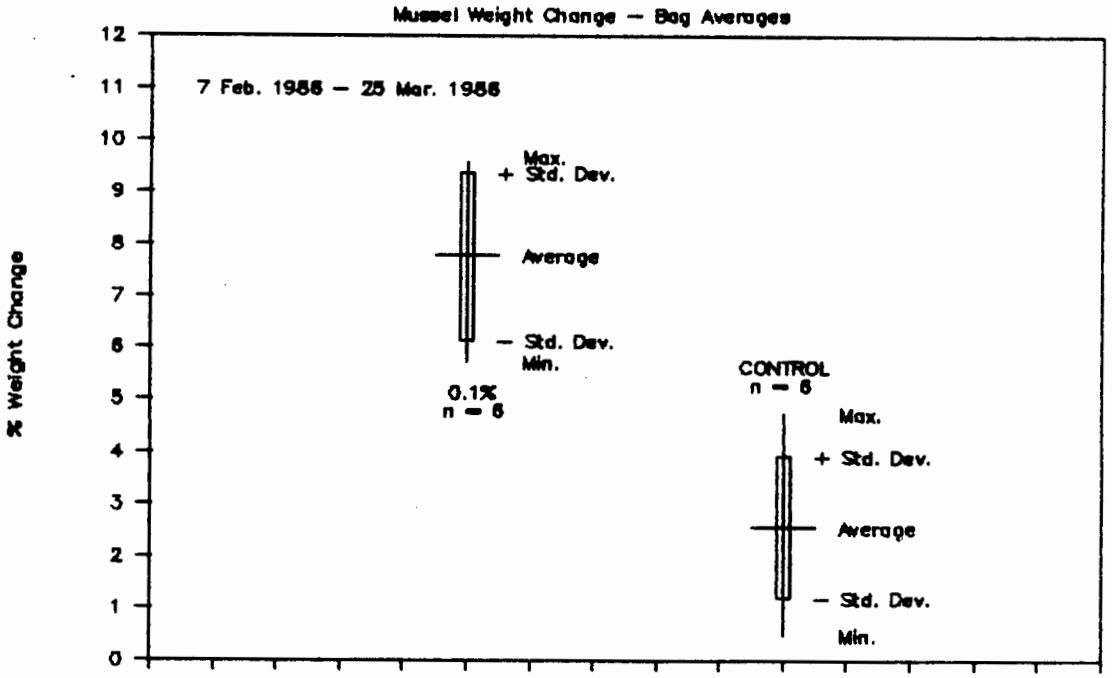

Figure 26. Mussel growth stimulation in 1986 test, 0.1% mackerel DAF sludge. If data on weights of mussels per bag are analyzed, difference is statistically significant.

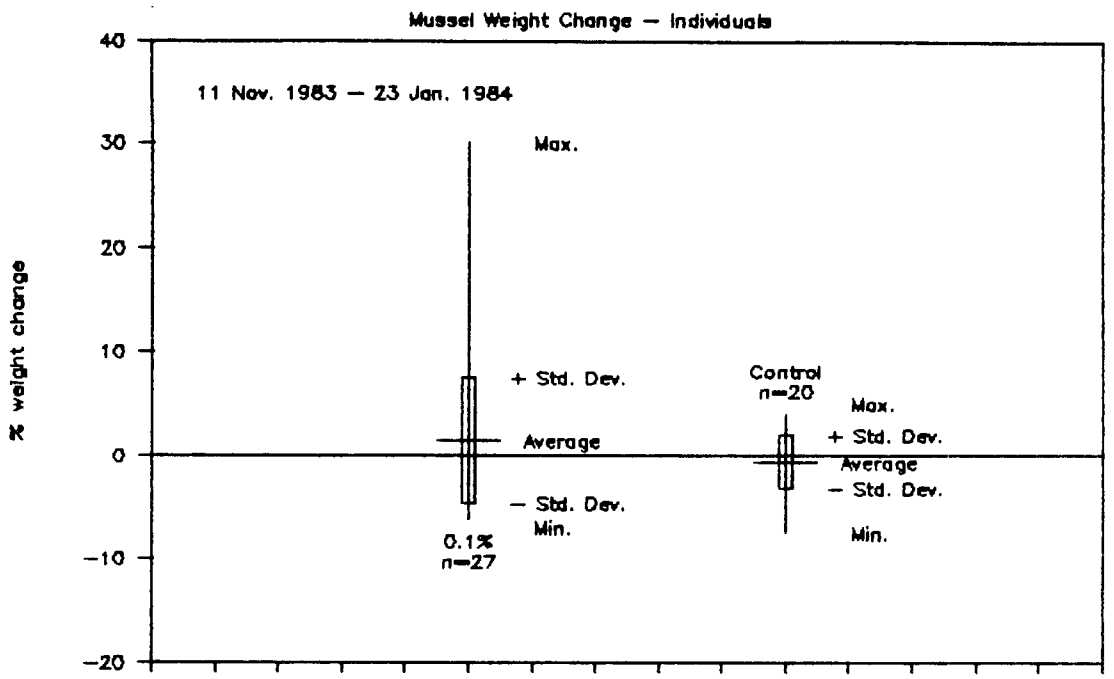

Figure 27. Mussel growth stimulation test, 1 Nov. 1983 to 23 Jan. 1984 using 0.1% tuna waste DAF sludge. If individual weights are analyzed, there is no significant difference.

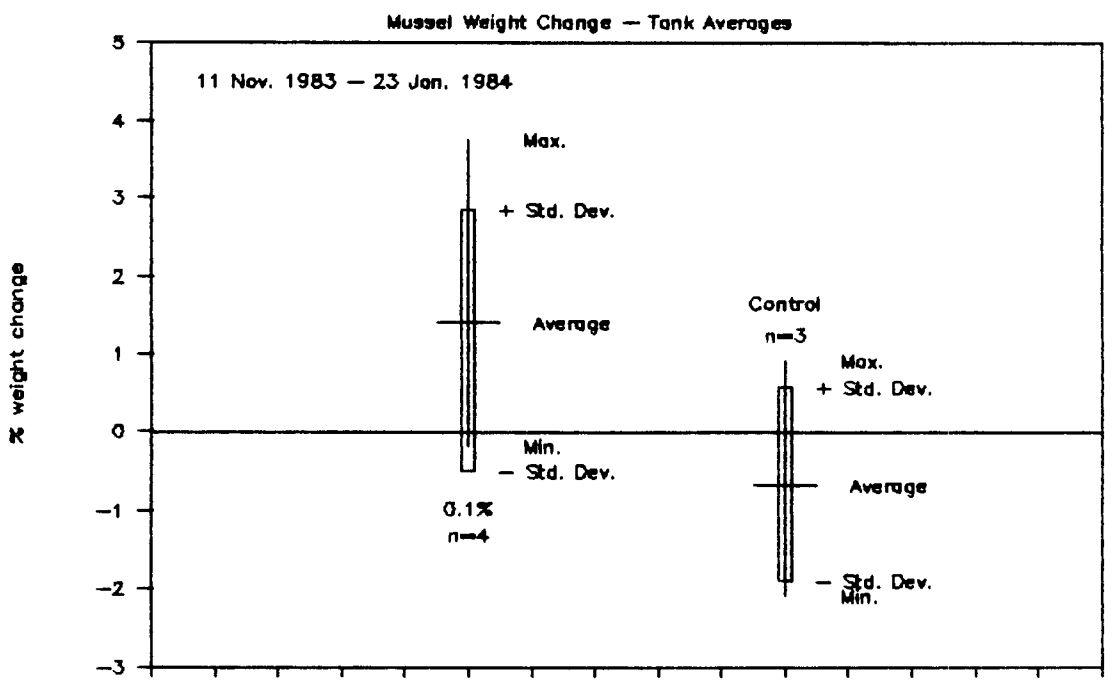

Figure 28. Mussel growth stimulation in 1983-84 test; data analysis is based on average weights by tank. Difference is not statistically significant.

3). "MICROTOX" BIOLUMINESCENCE TOXICITY TESTS

Introduction

During the past year the opportunity arose to conduct some trials of a new, rapid method of bioassay testing, the Microtox Toxicity Analyzer System, manufactured by the Microbics Corp. of Carlsbad, CA. This system utilizes as the test organism a stock culture of *Photobacterium phosphoreum*, a non-pathogenic luminescent marine bacterium.

Procedures

The bacteria are supplied in a lyophilized state and are reconstituted prior to use. The bacteria, the reagent blank, a standard diluent and the appropriately diluted solutions to be tested in small cuvettes are allowed to equilibrate in temperature controlled wells in the instrument. For the determinations a measured quantity of the reconstituted bacteria is mixed with the diluted test solutions and the luminescence read by the photometer. The test readings are compared to the standardized reading obtained with the reagent blank consisting of the standard diluent with an added aliquot of the reconstituted bacterial suspension. Light production is apparently affected by any substances that disturb the normal metabolic processes of the organisms. Based on demonstrations using a standard toxicant, the luminescence produced is proportional to the concentration of the toxicant.

It takes approximately 15 minutes for the reconstituted bacteria to stabilize. The luminescence of the bacteria in the test samples can then be read, yielding the data within a few minutes. Since light production under test conditions decreases with time, it was found that readings of the test solutions should be completed within half an hour to avoid the noisy signal entailed with operating the photometer at high sensitivity.

Four test series were conducted using the Microtox system. Each series is discussed separately in the following paragraphs.

Experiment I

The first test used a 0.1% concentration of sludge in filtered seawater. The sludge had been obtained from the dissolved air flotation system at the Star-Kist Foods facility located on Terminal Island, CA. The mixture was three days old and had been used in the long-term bioassays of mussel growth discussed elsewhere in this report. At the time of the Microtox test the mixture in the tank was due to be changed. A 50% dilution of the sludge mixture with the standard Microtox diluent, resulting in a final dilution of the sludge to 0.05%, was used as the test solution. This test was run about two hours after the bacteria had been reconstituted requiring use of the high sensitivity setting of the instrument.

Results. The readings reflected the noisy signal but nevertheless yielded reasonable data. With the reagent blank set to 70 on the recorder scale, the sample gave a reading of approximately 92, an apparent enhancement of 31%. This indicates that, rather than inhibition of luminescence of the organisms, there was some biostimulation stemming from exposure to the waste mixture at the 0.05% dilution.

Experiment II

The second series of tests used a stock solution of 5% sludge in filtered sea water. Samples for measurement were prepared from the stock by 50% serial dilutiions of an aliquot of the stock mixture with the Microtox diluent to produce samples with concentrations of 2.5%, 1.25%, 0.625% and 0.3125%. These were read immediately and gave corrected readings indicating that light production had been reduced to 53%, 51%, 72% and 65%, respectively. Replicate samples at the same dilution had been

prepared from the stock solution and these were read after 30 minutes. The corrected readings had changed to respective values of 78%, 84%, 91% and 92%. The data are summarized in the following text table:

Microtox test of serially diluted 5% cannery waste. Calibration values and readings are scale units on the recorder.

	Immediate			+ 30 minutes		
% Waste	Calibration	Reading	% Change	Calibration	Reading	% Change
0	80	78	- 2	90	91	1
0.3125	80	52	-35	84	76	- 9
0.625	74	53	-28	85	77	- 9
1.25	75	39	-48	84	71	-15
2.5	71	38	-46	91	71	-22

Results. Although these data show an overall reduction in light production by the test organisms they suggest that a lag phase in response was in progress between the two sets of measurements. The data do not indicate whether this had reached completion at the time of the second set of readings, but the data from the earlier test suggests that it had not. The lowest concentration of waste used in this test, 0.3125%, was higher by a factor of 6 than that used in the previous test, 0.05%, and may have exceeded the range in which enhancement would occur.

Experiment III

The third test series used a stock solution of 1% sludge which was serially diluted with the Microtox diluent to give concentrations of 0.5%, 0.25%. 0.125% and 0.0625%. These concentrations cover the range of 0.5%, at which there was mortality in mussels in the bioassays discussed elsewhere in this report, and 0.1%, the concentration at which there was apparent growth enhancement. In this test a single series of serial dilutions was made and repetitive readings were taken at short intervals of about 2 to 3 minutes to detect any short term changes in the effect of the

waste on the organisms. The data are summarized in the following text table:

Microtox test of serially diluted 1% cannery waste. The values listed are the percent change between the cuvettes prior to the addition of the sample and after the addition. These values were corrected for the change in the readings of the 0% concentration. Each set of observations was separated by two to three minutes.

Observation No.	1	2	3	4	5	6	7	8
% Waste								
0.0625	- 2	- 2	- 4	- 5	- 6	- 9	- 9	-10
0.125	-10	+ 6	+ 4	+ 4	+ 5	+ 5	+ 6	+ 5
0.25	+ 4	+10	+10	+10	+10	+10	+11	+11
0.5	+ 1	+ 4	+ 4	+ 4	+ 3	+ 2	+ 3	+ 2

Results. The results of this test suggest that an optimal concentration was in the range of 0.25% to 0.1% waste. At these concentrations there was apparent enhancement of luminescence of the test organisms. There appeared to be a short term lag phase before enhancement appeared at the two higher concentrations and a longer one in the lowest concentration. At 0.125% concentration, however the initial lag phase was more pronounced. The lag phase could not be more fully explored due to instrument availability.

Experiment IV

The forth test series utilized the same concentration of stock and sample solutions as the previous test. The 1% stock solution of the waste was serially diluted to 0.5%, 0.25%, 0.125% and 0.0625%. However, the stock solution was aerated for several hours prior to the test to determine whether this would affect the lag phase mentioned above. This also represented more exactly the conditions of exposure of the mussels in the long term bioassays. The intervals between repetitive readings were lengthened to 15 or 30 minutes to extend the period of observation. As in the precee-

ding test, A single series of dilutions were used. The data are summarized in the following text table:

Microtox test of serially diluted 1% cannery waste. The data are the change in percent luminescence in the cuvettes after addition of the waste sample corrected for the change noted in the 0% sample.

Time - Minutes	0	+15	+3	+45	+60	+90
0.0625	- 4	- 2	- 3	- 6	- 6	+18
0.125	- 1	- 6	- 5	-12	- 8	+17
0.25	-10	- 9	-13	-25	-20	+ 6
0.5	-14	-15	-29	-41	-37	-34

Results. The indications of a lag phase of at least one hour can be seen in these data. Although the 31% enhancement found in the first test series was not present, lower percents of enhancement (17% and 18% at concentrations of 0.125% and 0.0625% respectively) were present in these tests at dilutions below 0.25%. The optimal concentration consistent with the data from these tests appears to be 0.125%, although there was some indication that at higher concentrations a longer lag phase may lead to some level of enhancement.

Conclusions

The Microtox system, loaned to us for these experiments, provided results that were surprisingly consistent with bioassay results. An optimal concentration of 0.125% DAF sludge caused microbial biostimulation using the Microtox method. The growth stimulation at 0.1% found in traditional bioassays was statistically significant for the total number of organisms but not for individuals, suggesting that a slightly higher level would be more effective. The temporary lag phases which varied with concentration suggest that stimulation and inhibition are related over a

fairly narrow range. The dilutions involved simulate exactly the observed concentrations of waste in waters in the immediate wake of the discharging vessel (Soule and Oguri, 1983a).

FIELD INVESTIGATIONS: BENTHIC SURVEYS

Introduction

Benthic fauna, the organisms living in or on the benthos, are valuable indicators of environmental quality, because they tend to form more stable populations than pelagic or planktonic species. Fish or zooplankton may change with the tide, time of day, season or variation in coastal water masses.

Although there have been many benthic surveys in southern California, the area selected as the dumpsite for fish processing wastes had not been sampled previous to preparation of the application by Star-Kist Foods for a permit to dump sludge. In April 1982 seven stations were selected (Figure 29) to obtain a baseline for the area. As in the water quality monitoring, several control stations were established; one to the northwest (CW) and one to the southeast (CE) of the dumpsite, because of expected differences in the currents. Location CW is subject to periodic upwelling whereas CE is apparently little affected by it. Another control, Station J_1, lies to the south in deeper water at the top of a steep slope. It was selected because there is an extensive fish survey record there, made by the Occidental College *Vantuna* Group, and also because the area could serve as a secondary waste dumpsite if the main site proved unsuitable for any reason.

Benthic samples were taken with a Reinecke box corer from the USC R.V. *Sea Watch* on 14 April 1982. The box corer takes a sample one-sixteenth meter^2 of surface area, with a maximum penetration of up to 61 cm. The box corer brings up a sediment sample with the surface untouched by metal or plastic, so that live animals are still moving. Subsamples were taken for analysis of grain size and heavy metals aluminum, cadmium and mercury as specified by EPA. Results are given in Table 1 (Soule and Oguri, 1982).

The sediment characteristics were similar for Stations 1 through 6, being composed primarily of from 27 to 37% silt and 57 to 70% fine sand. Station 7, to the northeast at the top of a slope, consisted primarily of fine and medium sand, with some coarse sand and gravel and little silt (Table 1A). This could influence the compositon of the benthic fauna.

The level of aluminum was highest at Station 2 and lowest at Station 7; levels at the dumpsite were higher than those at southeast control station but similar to those at the northwest control site (Table 1B). Although sludge contains aluminum, sludge had not been dumped at the dumpsite as yet

Cadmium levels were similar to levels found in outer Los Angeles Harbor in 1978 (Soule and Oguri, 1980) but they were nearly an order of magnitude lower than levels found by Chen and Lu (1974) in the Southern California Bight. However, cadmium levels were 2 to 4 times lower in the outer harbor in 1978 than in 1972-1973 (Soule and Oguri, 1976), indicating a general reduction.

Mercury was lowest at Stations 2 and 7. Both stations are at the top of slopes and since some metals complex with finer sediments and move down into deeper waters this may account for lower levels. Levels were similar to those in the outer Los Angeles Harbor in 1978 (Soule and Oguri, 1980), which in turn were an order of magnitude or more lower than those found in the outer harbor in 1972-73 (Soule and Oguri, 1976).

Procedures

Benthic sampling was performed on 12 April 1985 and 25 October 1985 in the present program, using the Reinecke box corer from the R.V. Sea Watch. Box corer muds are dropped into a plastic bin, where the top 23 cm of the core is removed and washed through a 0.5 mm screen. Specimens are

bottled and preserved in 10% formaldehyde in seawater for transport to the sorting laboratories. There specimens are transferred to 70% ethanol and sorted to major taxonomic groups for identification to species level, as feasible. Calculations of populations per meter ^{2} are made by multiplying by a factor of 16. The field logs and a complete listing of the species and occurrences is presented in Appendix A.

In calculating species diversity and evenness, animals identified to higher taxonomic level are counted as single species even though this may cause the number of species to be underestimated because more than one species may be included in an unidentified taxon. However, to omit those not identified to species level would increase that error considerably. Two indices of diversity were used, the Gleason (Margolef) and the Shannon-Wiener, formulated as follows:

Gleason's Index

$$D = \frac{S-1}{\log_e N}$$

where: D = diversity of sample
S = number of species
N = number of individuals
Log_e = the natural log

Shannon-Wiener Index

$$H' = -\Sigma \frac{n_j}{N} \log_e \frac{n_j}{N}$$

where: H' = diversity index
$-\Sigma$ = the negative sum
n_j = the number of individuals in the $_j$th species
$\log_e$ = the natural log

Evenness in the sampled community is calculated as follows:

$$J' = \frac{H'}{\log_e N}$$

Results and Discussion

There was a general trend that was apparent in the April 1982 data of high numbers of species and individuals at the Control West (CW) Station 1 site (Figure 29), decreasing toward the Control East (CE) Station 3 site, with low numbers also at the south site J_1 (Station 2). The lowest number of individuals was found at Station 5 (Figure 30), but there was little difference in numbers between that station and Stations 4, 3 and 2. The lowest number of taxa in 1982 (Figure 31) was at Station 2, followed by Stations 7 and 5. It should be noted that the April 1982 survey was during the El Niño period of warm waters throughout the Bight.

The April 1985 data are compared with April 1982 data in Figures 30 and 31. Strong increases in taxa were found at the CW site (Station 1) and at Stations 5 and 3 along with a decline at Station 7. The numbers of individuals in April 1985 also increased strongly at Station 1, along with increases at Stations 5, 3 and 2. Conversely, there were decreases in both individuals and taxa at Station 7.

In October 1985 the number of individuals had decreased greatly as compared with either April 1982 or April 1985. Figure 32 indicates, by the large change in scale, that there was a 40% reduction in total numbers. The exception was at Station 7, where counts more than doubled. The number of taxa in October 1985 decreased (Figure 33) at Stations 1, 2 and 5 but increased at Stations 3, 6 and 7 as compared with April 1985. Peaks in the number of individuals can easily represent a sudden reproductive bloom of a single species, whereas peaks in both species and numbers may indicate a change in conditions which opens an area for recolonization or new colonization. The drop in numbers of individuals in October probably represents a seasonal decrease.

The data on number of taxa and individuals are as follows:

NUMBER OF TAXA

Date/Station	1	2	3	4	5	6	7
April 1982	106	73	84	94	81	100	79
April 1985	134	96	108	78	101	84	51
Oct. 1985	118	78	123	78	91	105	108

NUMBER OF INDIVIDUALS/M^2

Date/Station	1	2	3	4	5	6	7
April 1982	14080	6016	5680	5632	4928	7808	7632
April 1985	19872	7632	12305	6096	17988	7408	4084
Oct. 1985	7617	4560	7329	2977	5699	7137	10016

Evenness and species diversity calculations on the three data sets provide some interesting comparisons. In Figure 34 for April 1982, the differences for evenness are small. The Shannon-Wiener species diversity index (Figure 35) also is quite uniform, with all values above 3.6 except at Station 2, where it was 3.29. The results compare well with the H'_{max} values, diversity indices of hypothetical communities having the same number of species and individuals as the observed community. The Gleason index showed more variation, with Stations 1, 6, and 4 being high, Stations 5 and 3 intermediate, and Stations 7 and 2 being low.

In April 1985, the evenness index was much less stable (Figure 36), primarily because of deviations at Station 5. There, numbers were increased radically due to a bloom of a cumacean *Leptostylis* sp. A. The Shannon-Wiener species diversity index (Figure 37) was not as uniform as it was in 1982 due to the same phenomenon at Station 5, and a drop in both species and numbers of individuals at Station 7. This created more deviation from

the H'_{max} values. The Gleason index showed more variation, with the Station 7 value falling well below the line of the other data points.

The October 1985 evenness index returned to the smoother curve of the April 1985 period (Figure 38). The Shannon-Wiener index also produced values with little variation, which followed the H'_{max} values closely Figure 39). The Gleason index displayed larger differences, with high values at Stations 1, 7 and 3, and low values at Stations 4 and 2. The Shannon-Wiener index appears to characterize the area more generally, whereas the Gleason index points up the differences between the stations more graphically since it is more affected by numbers of individuals.

The percent change between April 1982 and April 1985 benthic data is diagrammed in Figure 40. The zero horizontal line indicates the transition from percent decreases to percent increases, while the verical line indicates the center of the dumpsite. The peak at Station 5 again shows the dominance of the single species.

The values for the various indices can be compared as follows:

EVENNESS (J_1)

Date/Station	1	2	3	4	5	6	7
April 1982	0.80	0.77	0.86	0.87	0.89	0.85	0.84
April 1985	0.80	0.86	0.79	0.84	0.65	0.76	0.77
Oct. 1985	0.86	0.87	0.90	0.89	0.86	0.84	0.83

SHANNON-WIENER SPECIES DIVERSITY INDEX

Date/Station	1	2	3	4	5	6	7
April 1982	3.71	3.29	3.83	3.93.	3.91	3.90	3.69
April 1985	3.93	3.94	3.69	3.66	3.02	3.54	3.00
Oct. 1985	4.12	3.79	4.33	3.88	3.88	3.92	4.80

The Shannon-Wiener values are quite consistent with those found in the 60-meter survey by the Southern California Coastal Water Research Project (Word and Mearns, 1978).

Placing the species in descending order of numbers for the entire sampling station area illustrates the dominance of one species of cumacean, *Leptostylis* sp. A, at one station in the April 1985 data (Table 2). Other dominant species are more evenly distributed throughout the stations. That species did not appear in the April 1982 data, or in the October 1985 data. The second ranked species, a polychaete *Spiophanes missionensis*, in April 1985 became the dominant species in October 1985 (Table 3). Since some polychaete species are in reproduction year around, and have short reproductive times, they may have a competitive advantage over other species. Seasonality was probably a factor in the difference between the rankings of other species in April and October, as few of the same species remained in the top 30 or in the same position.

Conclusions

Although dumping of ball and brine water stopped in October 1984, it is very doubtful that any changes in the benthic populations could be associated with dumping or cessation of dumping. The nutrient content of the ball and brine waters is low and no additives such as those in DAF sludge were included. Upwelling returned in the San Pedro Valley marine canyon with the disappearance of the El Niño warm water conditions in October 1984.

There is no evidence that the period of dumping ball water and brine water between 1981 and 1984 produced any negative or positive effect on the benthic fauna. The three surveys probably represent the range of natural variation for the area, and provide a good baseline for future studies when the appropriate permits are issued.

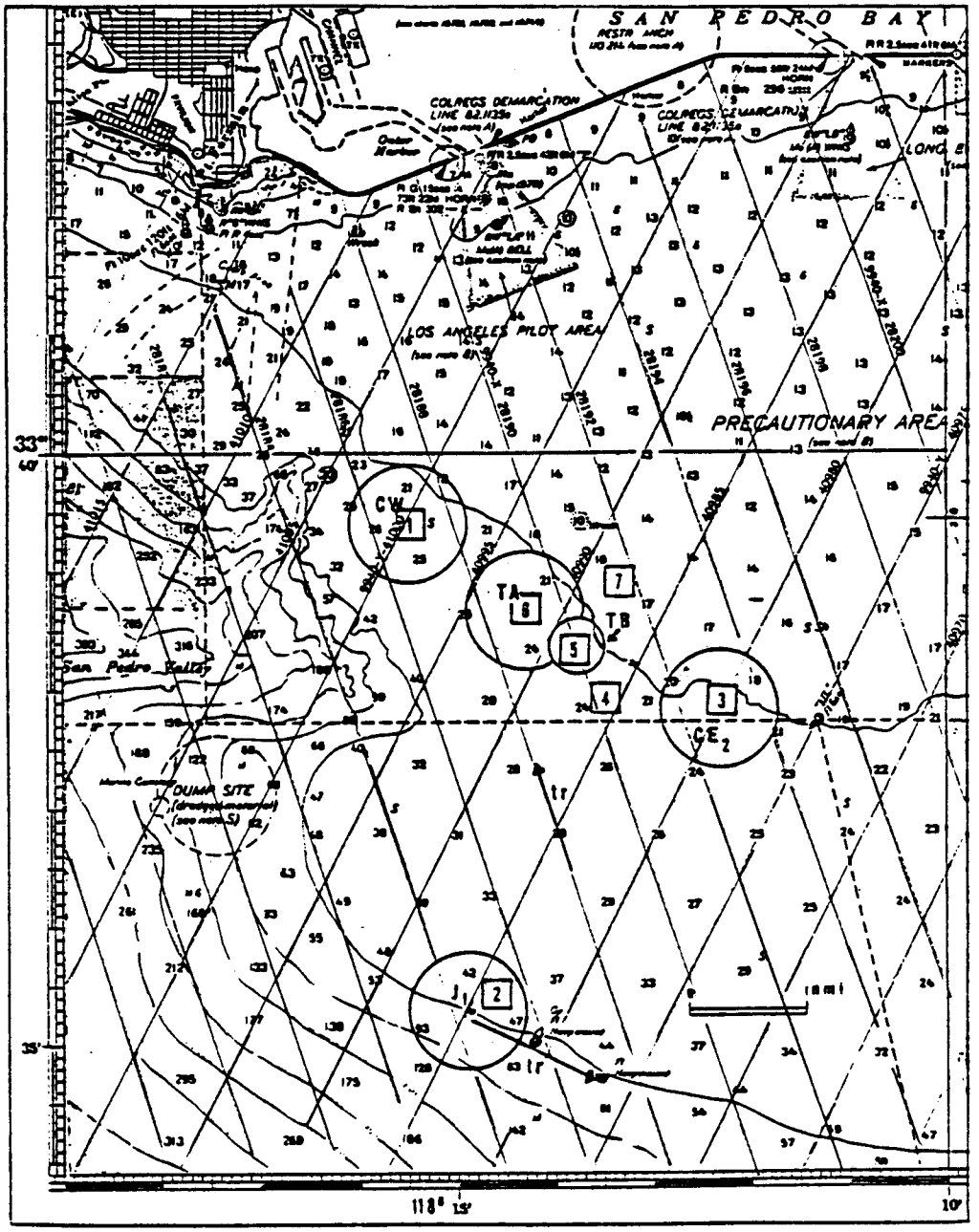

Figure 29. Fish Waste Disposal Site off Los Angeles. Control West (CW), Control East (CE) and Control J_1. Primary Test Site (TA), is center of dump circle, Secondary Test Site (TB) is starting point of counterclockwise dumping path. Boxes are Benthic Stations. Depths in fms.

Table 1A. Grain Size Distribution in Samples of Bottom Sediment at Stations in the Proposed Dumpsite Area. Percent, and Size in mm. tr=trace. Collected 14 April 1982.

Benthic Station Designation	Clay %	Silt %	Sand			Gravel %
			Fine	Medium	Coarse	
	< 0.005	0.005-0.075	0.075-0.45	0.45-2.75	2.75-4.75	<4.75
1. CW 25 fms	2	28	70	---	---	---
2. J1 50 fms	3	35	62	---	---	---
3. CE2 20 fms	5	27	57	9	1	1
4. CE1 25 fms	3	31	58	3	2	3
5. TB 23 fms	3	37	58	1	1	tr
6. TA 24 fms	2	32	63	1	2	---
7. NETA 15 fms	---	2	33	41	8	16

Table 1B Metals Analysis of Bottom Sediment Samples from Stations in the Proposed Dumpsite Area. Collected 14 April 1982 (in ppm, wet wt).

Sample	% Solids	Aluminum, mg/kg		Cadmium, mg/kg		Mercury, mg/kg	
		as is	dry	as is	dry	as is	dry
Sample #1	67.9	3,700	5,150	0.39	0.57	0.073	0.110
Sample J1 #2	70.3	4,800	6,830	0.26	0.37	0.037	0.053
Sample 3 of #3	68.7	1,700	2,470	1.00	1.46	0.049	0.071
Sample 2 of #4	63.8	3,800	5,960	0.40	0.63	0.087	0.140
Sample 1 of #5	73.9	4,300	5,820	0.60	0.81	0.143	0.190
Sample #6	68.1	3,300	4,840	0.43	0.63	0.058	0.085
Sample #7	83.9	940	1,120	0.30	0.36	0.049	0.058

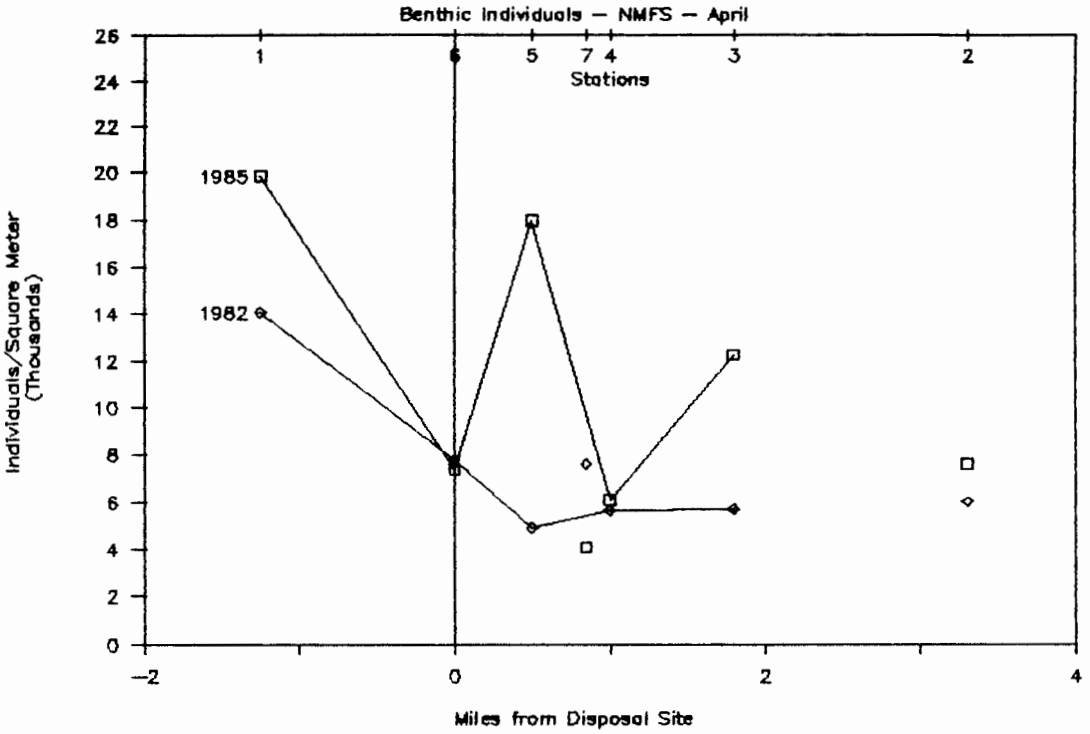

Figure 30. Number of Benthic Individuals in April 1982 and April 1985 compared. Vertical line indicates dumpsite center. Stations are in linear plot by distance from dumpsite center, from northwest to southeast except for Station 7 (northeast) and Station 2 (south). 1985 peak at Station 5 is due to one species.

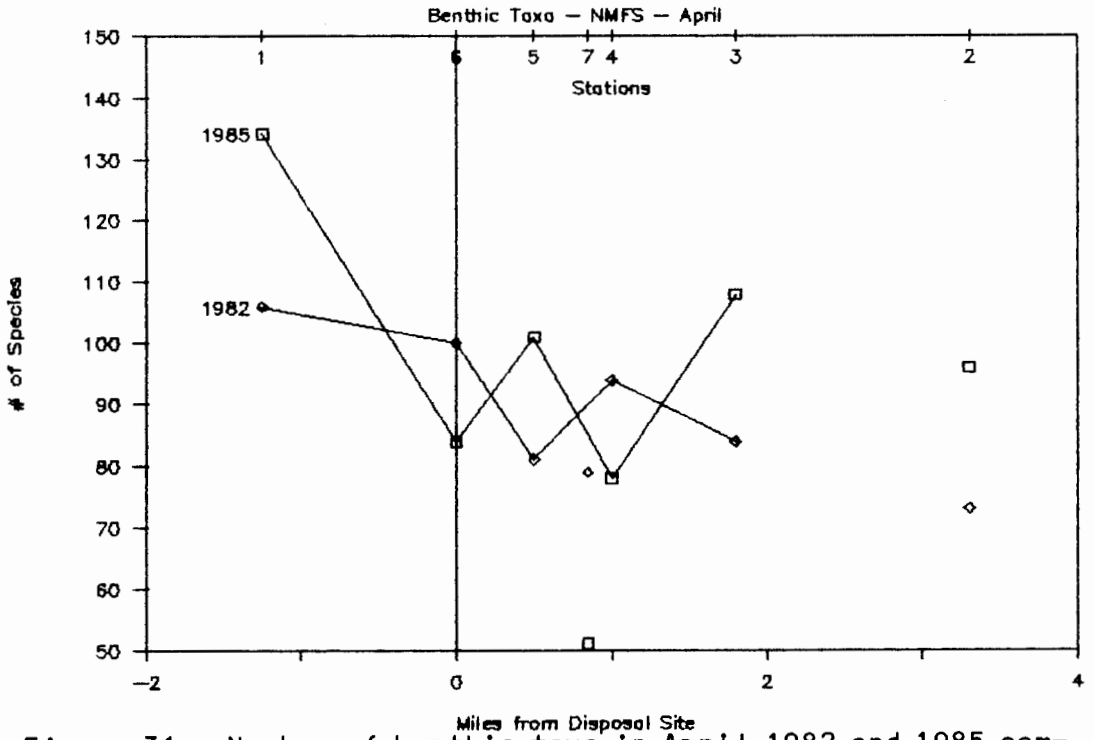

Figure 31. Number of benthic taxa in April 1982 and 1985 compared; note drop at Station 7.

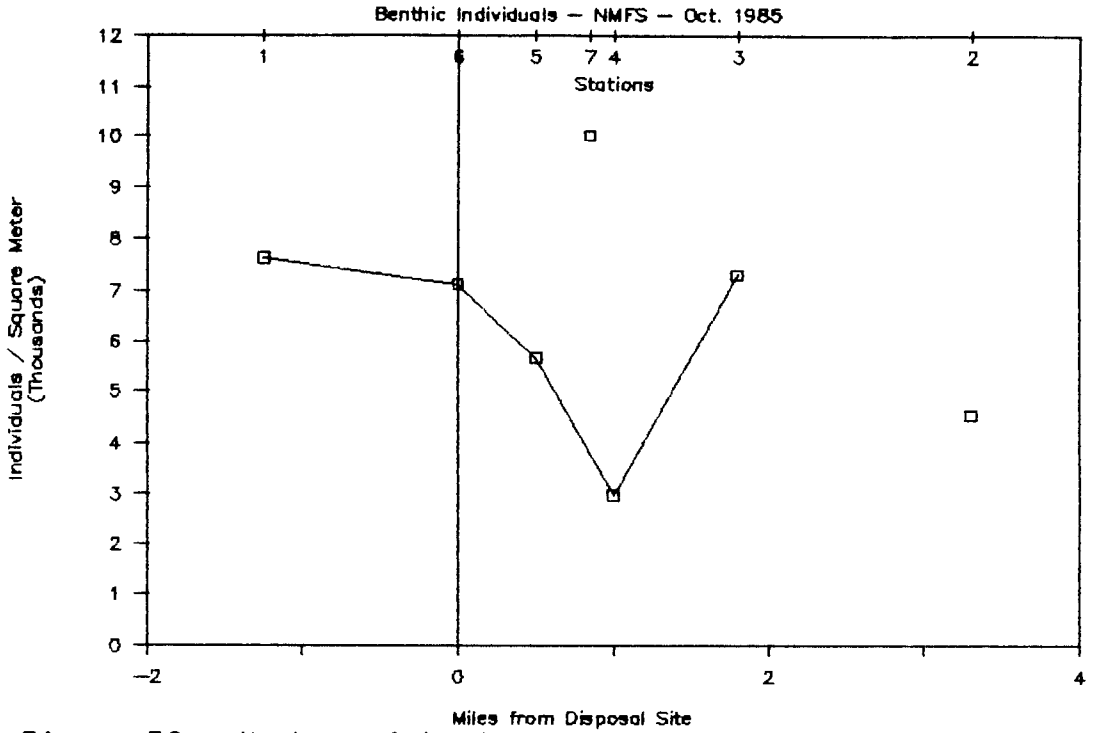

Figure 32. Number of benthic individuals in October 1985. Vertical line indicates center of dumpsite. Stations are in linear plot according to distance from dumpsite center, from northwest to southeast, except for Station 7 to the northeast and Station 2 to the south.

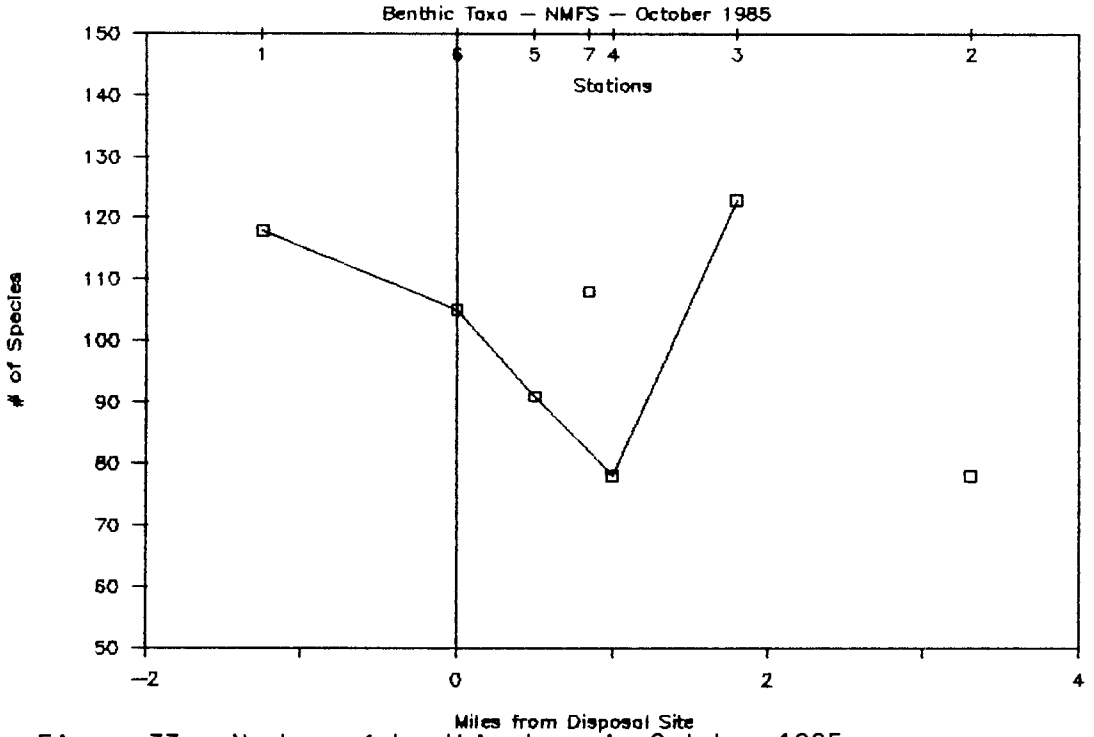

Figure 33. Number of benthic taxa in October 1985.

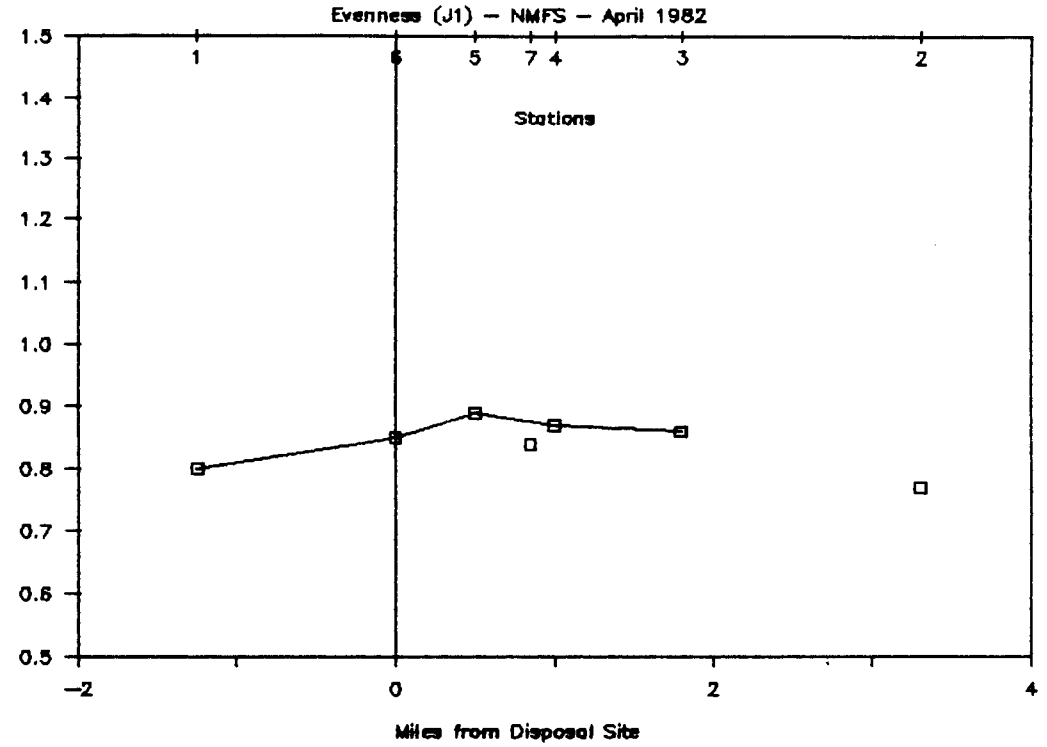

Figure 34. Evenness in April 1982. Vertical line indicates center of dumpsite. Stations are in linear plot from northwest to the southeast except for Station 7 to the northeast and Station 2 to the south.

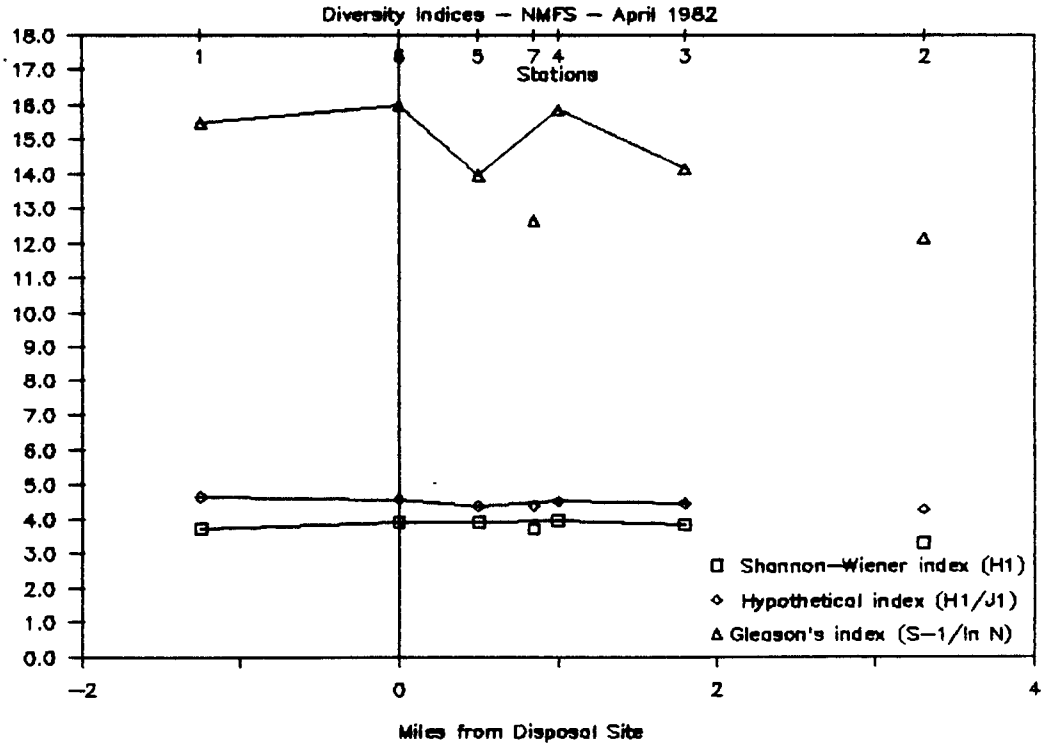

Figure 35. Diversity indices for April 1982. Shannon-Wiener index compared to H'_{max} shows uniformity of area; Gleason index shows variations between stations.

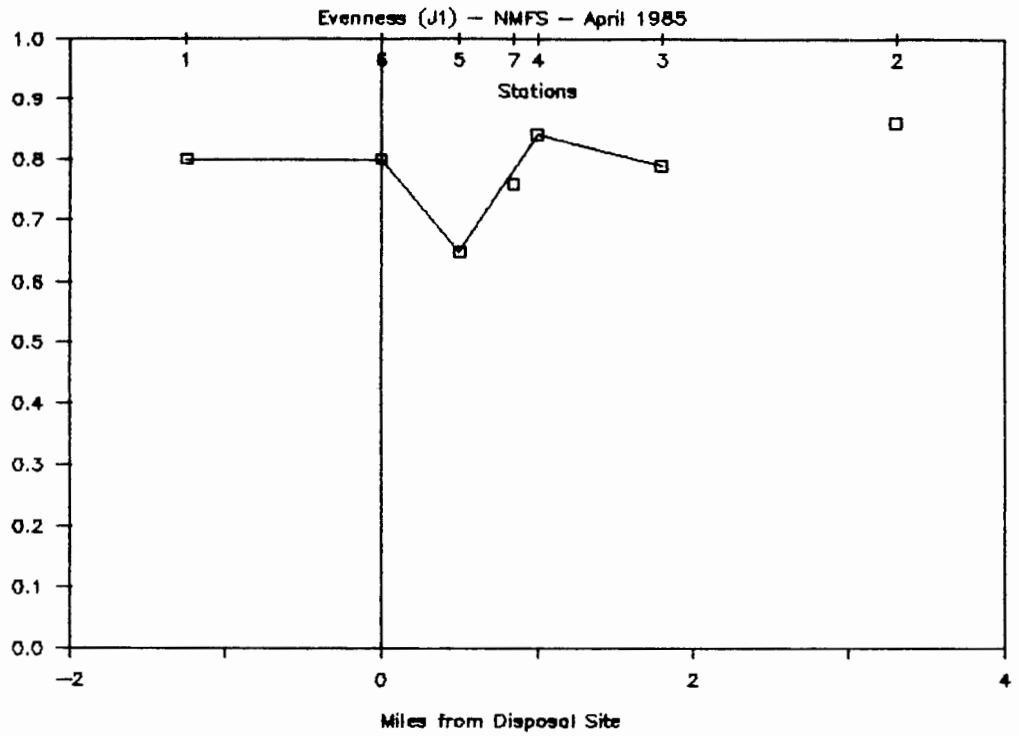

Figure 36. Evenness in April 1985. Peak at Station 5 in number of individuals (Figure 30) resulted in drop in evenness. Vertical line indicates dumpsite center. Stations are in linear plot from northwest to southeast except for Station 7 (northeast) and Station 2 (south).

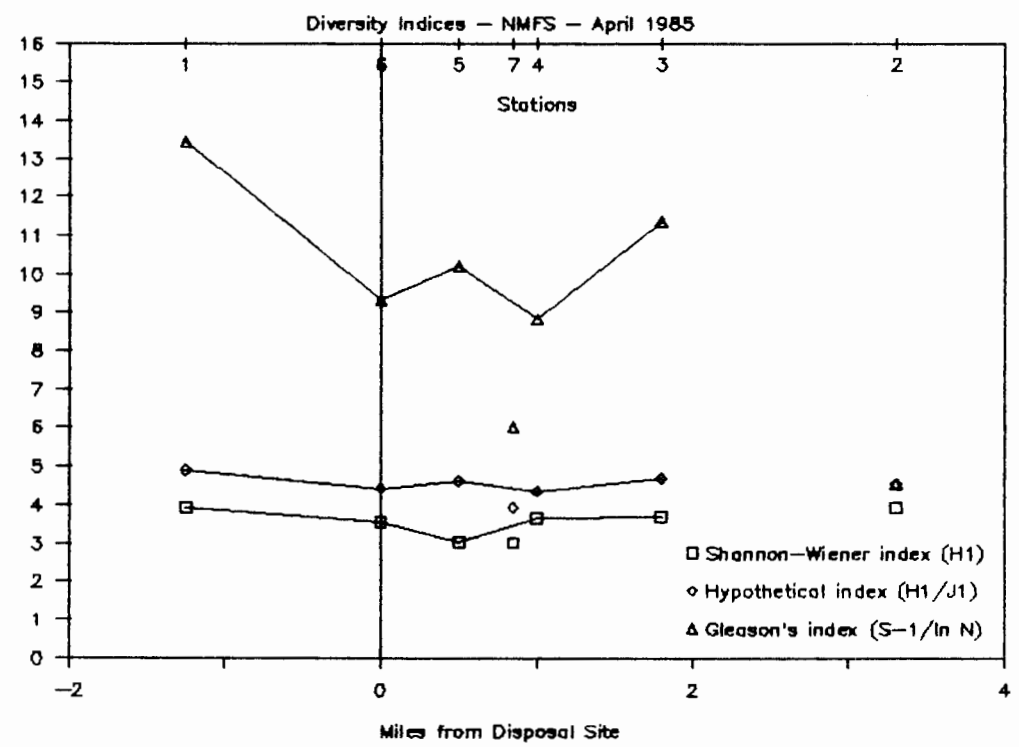

Figure 37. Diversity indices for April 1985. Shannon-Wiener index shows slight deviation for Station 5; Gleason index shows variations between stations.

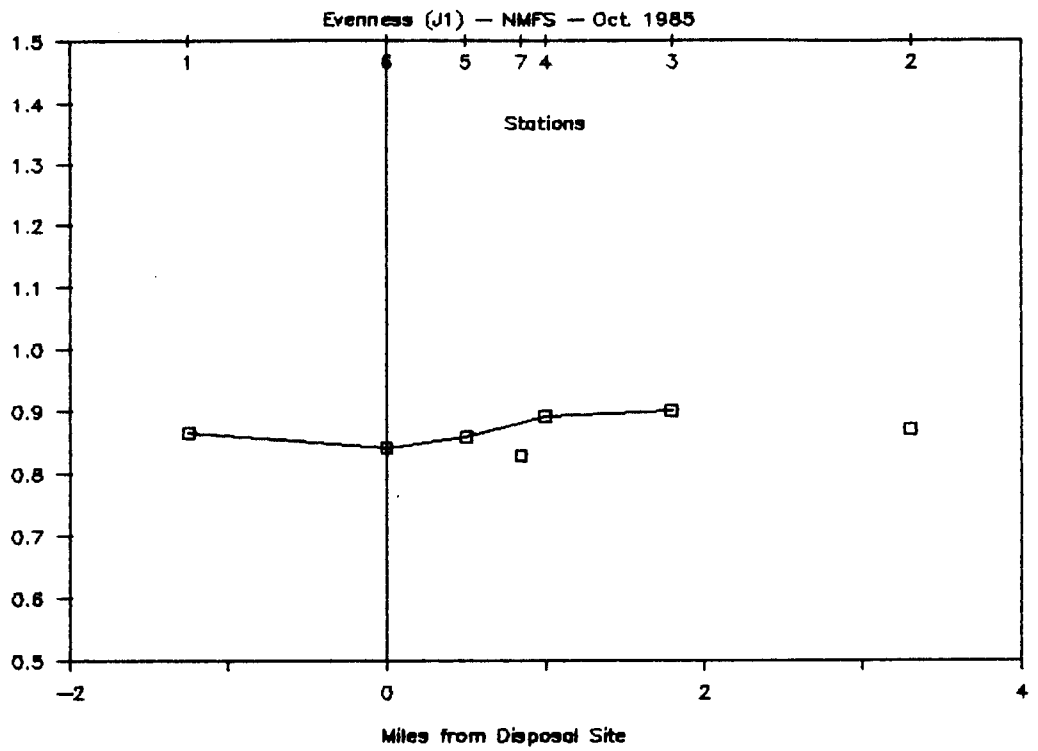

Figure 38. Evenness in October 1985. Vertical line indicates dumpsite center. Stations are in linear plot from northwest to southeast except for Station 7 (northeast) and Station 2 (south).

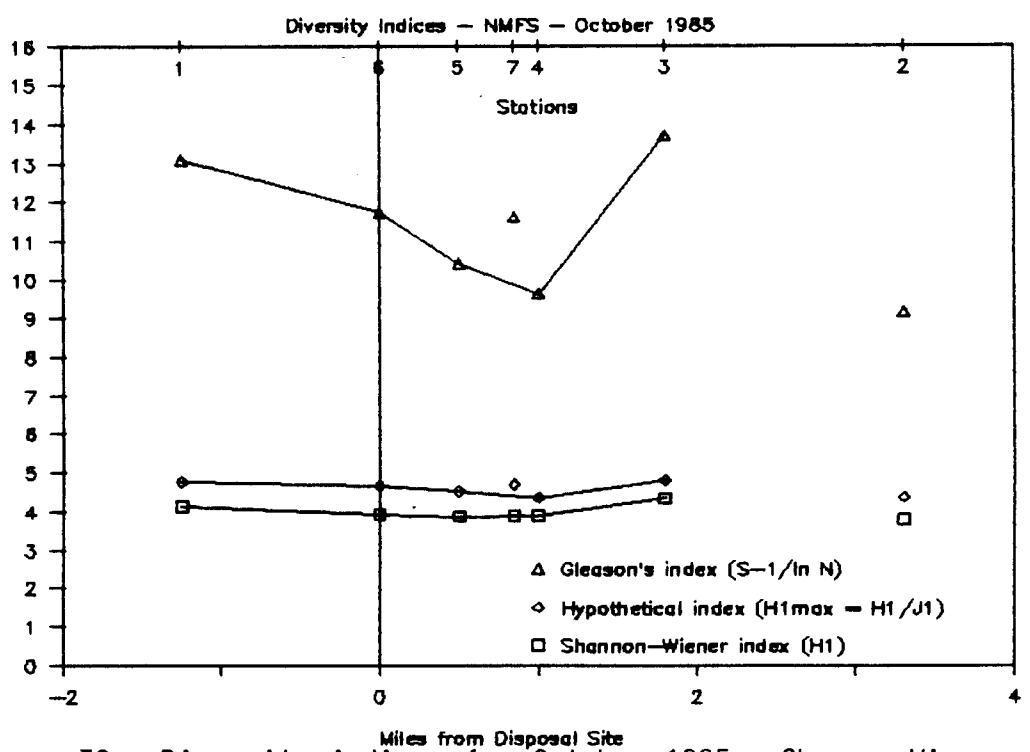

Figure 39. Diversity indices for October 1985. Shannon-Wiener index shows uniformity of area as compared to H'_{max}; Gleason index shows variations between stations.

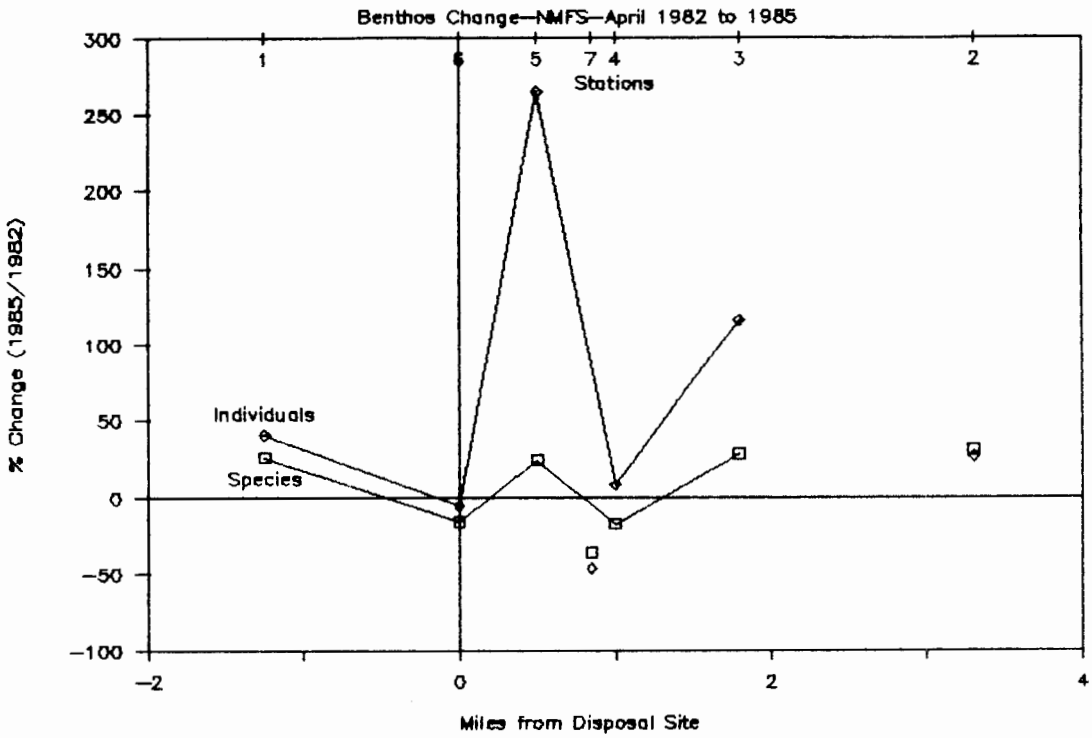

Figure 40. Percent difference between number of benthic individuals and species in April 1982 and April 1985. Vertical line is dumpsite center; stations are in linear plot from northwest to southeast except for Station 7 (northeast) and Station 2 (south). Horizontal zero line indicates difference between negative change (decrease) and positive change (increase) in 1985. Principal deviation is in the large numbers of one species found at Station 5.

Table 2. Benthic Invertebrates - NMFS - 12 April 1985

Stations	1	2	3	4	5	6	7	TOTAL
Leptostylis sp. A	128	32	384		6416	16	16	6992
Spiophanes missionensis	2976	752	432	560	1120	1040		6880
Euchone incolor	656	64	864	880	1344	1200		5008
Acmira catherinae	1760	256	272	64	400	384		3136
Caprella sp. E	608		1536	416	368	48		2976
Caprellidea, unid.	272	208	1152	320	848	48	32	2880
Cumella sp. B	704		784	128				1616
Glottidia albida	576		192	112	480	80		1440
Fabrisabella sp. A	192	144	288	256	496			1376
Myriochele sp. M	784	16	80	32	128	320		1360
Marphysa disjuncta			16	48	1024	256		1344
Mediomastus ambiseta	432	320	80	48	144	240		1264
Amphideutopus oculatus	336		736	32	128			1232
Phoronis sp.	560	48		288	144	96		1136
Aricidea wassi	880		144	32	32	32		1120
Nemertea, unid.	320		224	112	128	80	160	1024
Prionospio sp. A	160	448	48		144	64		864
Sipunculida, unid.				16	16	32	800	864
Leptochelia dubia	176	304	64	16	64	96	32	752
Sthenelanella uniformis	160	48	48	144	192	160		752
Ophiuroconis bispinosa		80	560	48	32	32		752
Phyllochaetopterus prolifica	144			128	128	320		720
Chone ecaudata	208		48	144	112	208		720
Photis sp.	144		208		240	112		704
Nephtys cornuta franciscana	224	96	80	80	80	128		688
Spiochaetopterus costarum	320	16	64	80	128	16	48	672
Amphiodia urtica	176		80	80	272	48		656
Harpactiocoidea, unid.					16		624	640
Foxiphalus similis	176	32	288		96	16		608
Eudorella pacifica	96	432		32		16		576

Table 3. Benthic Invertebrates - NMFS - 25 October 1985

Stations	1	2	3	4	5	6	7	TOTAL
Spiophanes missionensis	1056	528	352	224	448	720	32	3360
Fabrisabella sp. A	192	96	192	272	240	400	304	1696
Spiophanes bombyx	288	48	272	32		368	336	1344
Golfingia sp.					272	16	960	1248
Caecum crebicinctum					240		960	1200
Spiochaetopterus costarum	160	32	192	128	256	224	48	1040
Phyllochaetopterus prolifica	224		208	64	48	448	32	1024
Amphiodia urtica	80	64	112	192	176	224	128	976
Apoprionospio pygmaea	112	112	384	64	32	192	64	960
Lumbrineris sp.	48	16	48		16		704	832
Glottidia albida	288		16	112		400		816
Sthenelanella uniformis	144	64	96	80	96	256	32	768
Acmira catherinae	288	32	112	64		256		752
Nemertea, unid.	80	32	96	128	160	128	96	720
Lysippe labiata	80	16	240	64	112	32	144	688
Oligochaeta, unid.			48				640	688
Ampelisca pugetica	144		272	16	192	16		640
Prionospio sp. A	144	352	48	48	16	16		624
Parvilucina tenuisculpta	192	96	176	16	16	48	16	560
Calyptraea fastigiata	16		16		16	16	464	528
Notoproctus pacificus					464			464
Pentactinia californica					288	32	144	464
Nematoda, unid.		16	32		224	16	176	464
Ampelisca hancocki	32	208	32			176		448
Phoronis sp.	48		64	64	16	224	16	432
Euchone incolor	64	32	96	16		160	32	400
Foxiphalus obtusidens	96	48	176	16	48			384
Nephtys cornuta franciscana	112		80		16	160		368
Tubulanus polymorphus	16		64	16	96	112	64	368

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b. Project Management

The project has been managed and conducted by the University of Southern California under the direction of Dr. Dorothy F. Soule, Principal Investigator and Mikihiko Oguri, Co-Principal Investigator. Star-Kist Foods contributed personnel time, materials and consultation. Kjeldahl nitrogen analysis was performed by Associated Laboratories, Inc. of Orange, CA.

V. FINDINGS

a. Accomplishments and Findings.

Laboratory tests were conducted on the degradation of DAF sludge from fish processing to determine the feasibility of ocean dumping of the wastes. The laboratory experiments were divided into several approaches which are detailed in the previous section, as follows:

1). Ammonia-N as a parameter for monitoring degradation of wastes;

2). Toxicity - growth biostimulation effects on mussels;

3). Microtox bioluminescence toxicity tests.

Field research consisted of the following:

4). Two benthic surveys of the dumpsite off Los Angeles.

The following findings summarize those presented in detail in the preceeding sections:

1). Laboratory results confirmed that ammonia-N analysis provides a relatively simple, rapid, and inexpensive method for tracking the degradation and distribution of wastes in the disposal plume;

2). Laboratory results gave statistically significant correlations of ammonia-N with five - day biochemical oxygen demand (BOD_5), a parameter useful in quantifying the oxidative nutrient and chemical content of

wastes which react to deplete the ambient medium of dissolved oxygen;

3). The correlation coefficients between ammonia-N and BOD_5 approached those from field samples taken in American Samoa;

4). Other parameters tested such as nitrate, nitrite, silicate and phosphate did not correlate with BOD_5 or ammonia-N;

5). No diurnal effects could be clearly identified; this aspect requires further field and laboratory investigation;

6). Microheterotrophs active in the degradation of ammonia-N are apparently aerobic, since that activity stopped in wastes when oxygen supply was purposely depleted;

7). Growth was statistically significant in mussels suspended in 0.1% sludge mixed in ambient seawater during long term bioassay tests when data for groups of mussels were analyzed. Dilutions at or above 0.5% were lethal to most of the mussels, perhaps due to appearance of sulfide;

8). Microtox toxicity tests using bioluminescent bacteria confirmed an optimal biostimulatory effect at 0.125% to 0.25%. The dilution in the immediate wake of the discharging vessel is 0.1%. Rapid dilution, dispersion and diffusion at the surface may negate the nutrient value of the floating waste plume;

9). Benthic surveys were made in April and October 1985 at the stations sampled off Los Angeles in April 1982. Comparisons indicate that there were no discernible effects from the ocean dumping of bail water and brine water which took place between 1981 and 1984;

10). Benthic species diversity indices indicated that the area is remarkably uniform, with minor variations between stations;

11. There appears to be a trend toward a decline in numbers of species and individuals from the northwest, where upwelling sometimes occurs, toward the southeast;

b. The project accomplished more than it set out to do, but with the scope of work changed from that originally outlined. As discussed with the project monitor, the EPA refused to issue a research permit or a sludge dumping permit for Star-Kist Foods. Star-Kist ceased dumping waste waters because it was not economically feasible unless sludge could also be dumped. Therefore the project expanded the laboratory efforts in the absence of field monitoring. The data base for field monitoring is limited to those for sludge dumping off American Samoa and liquid waste waters off Los Angeles, both performed by the present investigators.

Results from laboratory experiments are remarkably consistent with field results, and added benefits included recognizing the aerobic requirements for the microheterotrophs active in the degradation of ammonia-N.

The fishing industry is already using the results of this research in negotiating with EPA for permits in Puerto Rico, Los Angles and American Samoa. The difference in cost estimates was documented in Soule and Oguri (1984), but will have to be revised when the EPA makes a decision on the scope of the monitoring program. Discussions are underway at the present time, as indicated elsewhere in this report. The general feasibility is indicated by the fact that the industry has pursued permits since 1979, when the ocean dumping exemption was approved by Congress. The analysis of ammonia-N has now been included in the monitoring scope by both EPA and the processors.

VI. APPLICATION

The processors who use DAF as the Best Practicable Treatment (BAT) have requested copies of this report so that it can be incorporated into the EPA decision making process immediately. The investment in ammonia-N

analysis is very small when coupled with the other monitoring requirements of EPA permits. The Microtox equipment is expensive as a research tool unless some requirement for routine bioassay of wastes is instituted. The procedure has been accepted by EPA in certain other applications. If the EPA requires bioassays from processors and accepts the method, it would be far more economical than bioassays of mussels or other test organisms as a routine procedure.

VII. PROJECT EVALUATION

a. Benefits Derived

As has been described above, if waste dumping permits are approved for the major processors who are required to use DAF treatment of sludge, a major problem will be solved. Not only is it cost effective, but it would solve the mounting problem of the refusal of landfills to accept the sludge. The safety of some landfill operations was demonstrated in American Samoa by the deaths of a child and his dog as well as the adult who tried to rescue them from drowning in the sludge landfill.

b. Probable Impacts of the Project

As detailed above, results of this project, coupled with results of previous investigations by the present investigators, could result in the issuance of ocean dumping permits for fish processing wastes including sludge. This would solve a major problem for present processsors as well as those hoping to undertake new development of fish products.

NOTE:

All sections concerned with financial affairs have been reported under separate cover by the University of Southern California.

APPENDIX A

Benthic Field Log

Benthic Species per Square Meter

CRUISE: NMFS85 Date: 12 April 1985 Type: Benthic/Sediment

VESSEL & PERSONNEL:

Soule, D., P.I., USC	R.V. Sea Watch
Oguri, M. USC	Gregson, S., Skipper
Williams, S. USC	Beaton, T.
Ljubenkov, J.	Kelly, J.
Bester, R.	Hankins, C.

STATION LOCATIONS, OBSERVATIONS AND SAMPLING PARAMETERS:

	LORAN C	Latitude/Longitude
CW1	41000x28186.5	33°39.18'x118°15.57'
J1	40985x28184	33°35.27'x118°14.91'
CE	40980.5x28190	33°37.84'x118°12.35'
	40986x28190.2	33°38.90'x118°13.38'
TB	40989x28190	33°38.40'x118°13.74'
TA1	40992x28189	33°38.18'x118°14.42'
	40988x28191.5	33°37.83'x118°13.38'

SAMPLING STATIONS:

Station	Time	Bottom Depth	Comments
	Delay in departure due to new cable being installed		
Left dock	1145		
Sampling Started			
1A	1218	142	Very foggy.
B	1245		Lost power coming up,
B	0103		Second grab.
C	0110		Empty
2A	0148	266	Very sandy and silty.
B	0157	269	
C	0212	269	Lost grab contents.
	0221		Second grab.

SAMPLING STATIONS: Date: 12 April 1985

Station	Time	Bottom Depth	Comments
3A	0249	124	Grab empty.
	0256		Second grab, empty.
	0304		Third grab successfull.
	Divide numbers by 3 - all three grabs combined.		
4A	0324	140	
5A	0338	142	
6A	0351	142	
7A	0405	112	Empty.
	0413	112	Empty.
	0414		Grab stuck, making third
	0422		drop, divide by 2.
			Coarse red sand.

CRUISE: NMFS85 Date: 25 October 1985 Type: Benthic/Sediment

VESSEL & PERSONNEL:

Soule, D., P.I., USC	R.V. Sea Watch
Oguri, M. USC	Benson, Marty - Skipper
Williams, S. USC	Campagne, R.
Ljubenkov, J.	Callaghan, M.
Bester, R.	Campagne, R
	Jennings, V

STATION LOCATIONS, OBSERVATIONS AND SAMPLING PARAMETERS:

	LORAN C	Latitude/Longitude
CW1	41000x28186.5	33°39.18'x118°15.57'
J1	40985x28184	33°35.27'x118°14.91'
CE	40980.5x28190	33°37.84'x118°12.35'
	40986x28190.2	33°38.90'x118°13.38'
TB	40989x28190	33°38.40'x118°13.74'
TA1	40992x28189	33°38.18'x118°14.42'
	40988x28191.5	33°37.83'x118°13.38'

SAMPLING STATIONS:

Station	Time	Bottom Depths	Comments
Left dock	0904		High fog, sun coming out,
Sampling Started			
1A	0119	146	Mud with shell fragments.
2A-1	0956	286	Fog has lifted, beautiful clear day. Very little in first grab, will try again.
2A-2	1020	270	Second grab, still not much. Composite with first grab.

Several dolphin off in distance

SAMPLING STATIONS: Date: 25 October 1985

Station	Time	Bottom Depth	Comments
3A-1	1054	130	Poor grab, will try for second one.
3A-2	1133	130	Shell fragments. Composite with first grab.
3B-1	0148	128	Empty, making second drop.
3B-2	0204	128	Mostly mud, some debris.
4A	2247	143	Two bottles of shell debris.
5A	1202	130	Very hard black mud chunks. Filled 3 jars.
6A	1225	143	Shell debris and black mud. Filled 3 jars.
7A	1250	113	Very coarse sand. Filled 4 jars.

Benthic Invertebrates 12 April 1985

Stations	1A	2A	3A	4A	5A	6A	7A
ANNELIDA							
OLIGOCHAETA							
Oligochaeta, unid.							160
Tubificidae							
Peloscolex gabriellae							
POLYCHAETA							
Acrocirridae							
Acrocirrus sp.							16
Ampharetidae							
Amage scutata		96	16				
Ampharete labrops				48	16	16	
Amphicteis scaphobranchiata			32	16	16		
Amphisamytha bioculata	48						
Anobothrus gracilis	16	32					
Asabellides lineata		80	16	32	48	16	
Lysippe labiata	112	16	16	16	48	48	
Melinna oculata	80				32	16	
Samytha californiensis					16	16	
Amphinomidae							
Chloeia pinnata	64	112	64	16		16	
Pareurythoe sp. juv.							256
Arabellidae							
Arabellidae, unid. juv.							
Arabella sp.							
Notocirrus californiensis			16				
Drilonereis falcata							
Drilonereis mexicana		48					
Capitellidae							
Capitella capitata	32	16	16				
Decamastus gracilis		16					
Mediomastus acutus							
Mediomastus ambiseta (= M. californiensis, = Capitita ambiseta)	432	320	80	48	144	240	
Notomastus magnus							
Notomastus tenuis							

Benthic Invertebrates 12 April 1985

Stations	1A	2A	3A	4A	5A	6A	7A
Notomastus sp.		16					
Chaetopteridae							
Phyllochaetopterus prolifica	144			128	128	320	
Spiochaetopterus costarum	320	16	64	80	128	16	48
Chrysopetalidae							
Chrysopetalum occidentale							
Paleanotus bellis							
Cirratulidae							
Cirratulidae, unid.							
Caulleriella alata							
Caulleriella bioculata							
Caulleriella hamata							
Caulleriella sp., juv.							
Chaetozone armata							16
Chaetozone corona	16						
Chaetozone setosa	16	16					
Chaetozone nr setosa (= Chaetozone setosa)	16	16					16
Chaetozone sp.							
Cirratulus cirratus							
Cirriformia luxuriosa							
Cirriformia spirabrancha							
Cirriformia sp., juv.							
Tharyx nr. tesselata		16					
Tharyx spp.	352	48			80	32	
Cossuridae							
Cossura candida							
Cossura pygodactylata							
Ctenodrilidae							
Ctenodrilus serratus							
Dorvilleidae							
Dorvilleidae, unid.							
Ophryotrocha puerilis							
Protodorvillea gracilis							128
Schistomeringos longicornis							16
Eunicidae							
Marphysa belli oculata							

Benthic Invertebrates 12 April 1985

Stations	1A	2A	3A	4A	5A	6A	7A
Marphysa disjuncta			16	48	1024	256	
Marphysa sp.	16						
Flabelligeridae							
Flabelligeridae, unid.							
Pherusa capulata							
Pherusa neopapillata				16	16	32	
Pherusa papillata			64				
Pherusa sp., juv.	32				16		
Piromis sp. A				16	16		
Glyceridae							
Glycera americana							
Glycera capitata	16	32			16		
Glycera convoluta							
Gylcera rouxii							
Glycera sp., juv.			16				
Goniadidae							
Goniadidae, unid. juv.							
Glycinde armigera							
Goniada brunnea	48	32		32	32		
Goniada littorea							
Goniada sp., juv.							
Hesionidae							
Hesionidae, unid.							
Gyptis brunnea							
Heteropodarke heteromorpha							16
Microphthalmus sp.							80
Micropodarke dubia	48						16
Ophiodromus pugettensis							
Podarkeopsis glabra (= Gyptis brevipalpa)	32		16		32		
Heterospionidae							
Heterospio catalinensis	16						
Lumbrineridae							
Lumbrineridae, unid.							
Lumbrinerides platypygos							48
Lumbrineris californiensis	16						

Benthic Invertebrates 12 April 1985

Stations	1A	2A	3A	4A	5A	6A	7A
Lumbrineris ? crassidentata							
Lumbrineris cruzensis		16					
Lumbrineris erecta							
Lumbrineris lagunae							
Lumbrineris limicola							
Lumbrineris ? tetraura							
Lumbrineris sp.	96		16	48	26	80	32
Magelonidae							
Magelona berkeleyi	32						
Magelona pacifica							
Magelona pitelkai							
Magelona sacculata							
Maldanidae							
Maldanidae, unid.	16	48			64		
Asychis disparidentata							
Asychis sp.							
Axiothella sp.							
Euclymeninae sp. C	64		32	112	32	16	
Euclymeninae sp D (sp. C&D formerly Axiothella rubrocincta)	80						
Maldane sarsi	32						
Petalopractus neoborealis					32		
Praxillella pacifica (= affinis pacifica)	112	96	64	32		48	
Praxillella sp.							
Praxillura maculata					16	32	
Nephtyidae							
Nephtyidae, unid. juv.							
Nephtys caecoides	80	80	16	16	16	32	16
Nephtys californiensis							
Nephtys cornuta franciscana	224	96	80	80	80	128	
Nephtys ferruginea			16			16	
Nereididae (= Nereidae)							
Nereididae, unid. juv.							
Gymnonereis crosslandi americana		16					
Neanthes acuminata (= Neanthes arenaceodentata)							

Benthic Invertebrates 12 April 1985

Stations	1A	2A	3A	4A	5A
Nereis latescens					
Nereis procera	112				32
Nereis sp., juv.					
? Perinereis monterea					
Platynereis bicanaliculata			16	16	
Onuphidae					
Onuphidae, unid. juv.	64	112	64		58
Diopatra ornata			16		
Diopatra splendidissima					
Diopatra sp., juv.					
Diopatra tridentata	48				
Mooreonuphis nebulosa (= Onuphis nebulosa)	240		32		32
Onuphis elegans (= Nothria elegans)					
Onuphis iridescens (= Nothria iridescens)					
Onuphis multiannulata			16		
Rhamphobrachium longisetosum	16				
Opheliidae					
Armandia bioculata					
Ophelina acuminata			16		
Polyophthalmus pictus					
Orbiniidae, unid.	16				
Leitoscoloplos elongatus (= Haploscoloplos elongatus)		32			16
Naineris dentritica					
Scoloplos nr. armiger		48			
Scoloplos acmeceps					
Oweniidae					
Myriochele gracilis		16			
Myriochele nr. heeri		16			16
Myriochele sp. M	784	16	80	32	128
Owenia collaris					

Benthic Invertebrates 12 April 1985

Stations	1A	2A	3A	4A	5A	6A	7A
Paraonidae							
Acmira catherinae (= Acesta catherinae)	1760	256	272	64	400	384	
Acmira horikoshii (= Acesta horikoshii)							
Acmira simplex		16					
Acmira sp.							16
Allia antennata	96	48		16		48	
Allia ramosa	128	16		32		48	
Aricidea wassi	880		144	32	32	32	
Levinsenia oculata (= Tauberia oculata; = Paraonis gracillis oculata)	16	112	16				
Paraonella platybranchia (= Paraonides platybranchia)	16						
Pectinariidae							
Pectinaria californiensis (= P. c. newportensis)	32	96	32	16		16	
Phyllodocidae							
Phyllodocidae, unid.	16		16				
Eteone californica							
Eteone dilatae							
Eteone sp.							
Eulalia ? myriacyclum							
Eulalia quadrioculata (= Eulalia aviculiseta)							
Eulalia sp., juv.							
Eumida bifoliata							
Eumida sanquinea							
? Genetyllis castanea							
Hesionura coineaui difficilis							384
Phyllodoce hartmanae	16		16		16	16	
Phyllodoce (Anaitides) papillosa	80		48	32	32		
Phyllodoce sp.							
Phyllodoce (Anaitides) sp., juv.							
Pterocirrus sp.							

Benthic Invertebrates 12 April 1985

Stations	1A	2A	3A	4A	5A	6A	7A
Pisionidae							
Pisione sp.							160
Pilargiidae							
Ancistrosyllis hamata							
Pilargis berkeleyi							
Sigambra tentaculata	32				32	32	
Poecilochaetiidae							
Poecilochaetus johnsoni							
Poecilochaetus sp. A		32					
Polynoidae							
Polynoidae, unid.							
Halosydna johnsoni							
Halosydna sp.							
Harmothoe sp.	32				16		
Harmothoe ? crassicirrata						16	
Harmothoe hirsuta							
Harmothoe imbricata							
Harmothoe scriptoria							
Harmothoe sp.				16			
Lepidonotus ? squamatus							
Tenonia priops (= Harmothoe priops)			16				
Subadyte sp.		32					
Sabellariidae							
Sabellaria cementarium							
Sabellidae							
Sabellidae, unid.							
Chone albocincta		32				16	
Chone ecaudata	208		48	144	112	208	
Chone gracilis	32				32	16	
Chone mollis							
Chone veleronis	64		32	16			
Chone sp.							
Demonax medius							
Euchone arenae		48					32
Euchone incolor	656	64	864	880	1344	1200	

Benthic Invertebrates 12 April 1985

Stations	1A	2A	3A	4A	5A	6A	7A
Euchone limnicola							
Fabricia sp.						256	16
Fabrisabella sp. A	192	144	288	256	496		
Jasmineira sp.		16					
Megalomma pigmentum			16				
Myxicola ? infundibulum						16	
? Potamilla sp.							
Scalibregmatidae							
Ascierochellus beringianus				16			
Scalibregma inflatum					16		
Serpulidae							
Serpulidae, unid.							
Hydroides elegans (= Hydroides pacifica)							
Hydroides gracilis (= Eupomatus gracilis)							
Sigalionidae							
Pholoe glabra	16		16		32		
Pholoe minuta							16
Sthenelais verruculosa							
Sthenelanella uniformis	160	48	48	144	192	160	
Sphaerodoridae							
Sphaerodoridae unid. juv.							32
Spionidae							
Spionidae, unid.							
Aonides sp.							64
Apoprionospio pygmaea (= Prionospio pygmaeus)	32				16		
Boccardia sp.							
Boccardia basilaria							
Boccardiella hamata (= Boccardia hamata)							
Caraziella calafia (= "Pseudopolydora sp.")							
Laonice cirrata		16					
Laonice sp., juv.	16						

Benthic Invertebrates 12 April 1985

Stations	1A	2A	3A	4A	5A	6A	7A
Microspio maculata (= Spio maculata; = Nerinides maculata)				16	16		
Microspio pigmentata		16					
Minuspio cirrifera (= Prionospio cirrifera)			16				
Paraprionospio pinnata	64	48	48	16	128		
Polydora bioccipitalis							
Polydora cardalia	304	16	32		48	112	16
Polydora caulleryi (= P. brachycephala)							
Polydora ligni							
Polydora neocardalia				32			
Polydora socialis							
Polydora sp.							
Prionospio heterobranchia (= P. h. newportensis)							
Prionospio sp. A (= Prionospio "steenstrupi"; = P. nr. malmgreni)	160	448	48		144	64	
Prionospio sp.							
Pseudopolydora paucibranchiata							
Rynchospio arenicola							
Rhynchospio sp.							
Scolelepis acuta (= Nerinides acuta)							
Scolelepis sp. A							
Spio ? filicornis							
Spiophanes berkeleyorum		352					
Spiophanes bombyx	160		240	32			16
Spiophanes missionensis	2976	752	432	560	1120	1040	
Spiophanes sp.							16
Streblospio benedicti							
Spirorbidae							
Janua brasiliensis							
Pileolaria pseudomilitaris							

Benthic Invertebrates 12 April 1985

Stations	1A	2A	3A	4A	5A	6A	7A
Syllidae							
Syllidae, unid.							
Autolytus sp.							
Brania sp.							
Ehlersia heterochaeta	16					16	
Ehlersia sp. A	16					48	
Ehlersia sp. B						16	
Eusyllis sp.							16
Exogone gemmifera	16						
Exogone lourei							
Exogone molesta	16						
Exogone verugera							
Exogone sp. A							
Exogone sp.							
Odontosyllis phosphorea							
Sphaerosyllis californiensis		16	16	16		16	32
Sphaerosyllis sp.							
Streptosyllis sp.							16
? Syllis sp.							
Typosyllis ? hyalina							
Typosyllis sp.			16				
Terebellidae							
Terebellidae, unid.							
Amaeana occidentalis		16					
Lanassa gracilis		96		32		16	
Lanice conchilega		48	16	16	32	64	
Loimia medusa	32						
Pista alata					16		
Pista disjuncta (= Pista fasciata)							
Pista nr disjuncta							48
Pista sp. B		48			16		3
Pista sp., juv.							
Polycirrus sp.		16		16	16		
Streblosoma crassibranchia	176		32	16	160	144	

Benthic Invertebrates 12 April 1985

Stations	1A	2A	3A	4A	5A	6A	7A
Trichobranchidae							
Artacamella hancocki	32			16	16		
Terebellides californica		32					
ARTHROPODA							
CRUSTACEA							
CEPHALOCARIDA							
COPEPODA							
CALANOIDA							
Calanoida, unid							
CYCLOPOIDA							
Cyclopoidea, unid.							
Clausidium vancouverense							
HARPACTICOIDA							
Harpactiocoidea, unid.					16		624
OSTRACODA							
Ostracoda, unid.							
Bathyleberis sp.	32	16					
Cylindroleberis sp.							
Euphilomedes carcharodonta	64		48		32	48	
Euphilomedes producta		384					
Philomedes sp.							
Rudiderma rostrata						48	
Rutaderma lomae	112	96	64				
Sarsiella sp.	16	16	32				
Sarsiella sp A			16				
Scleroconcha sp.							
CIRRIPEDIA							
Balanus (Balanus) pacificus							
Balanus trigonus							
Balanus sp.							
Megabalanus tintinnabulum californicus (= Balanus)							
MALACOSTRACA							
DECAPODA							

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Stations	1A	2A	3A	4A	5A	6A	7A
Anomura							
Callianassidae							
Callianassa californiensis							
Callianassa sp.							
Upogebia sp.							
Paguridae							
Pagurus sp.							
Brachyura							
Canceridae							
Cancer anthonyi							
Cancer gracilis							
Cancer sp., juv.							
Grapsidae							
Hemigrapsus oregonensis							
Hemigrapsus sp., juv.							
Majidae							
Majidae megalops, unid.							
Loxorhyncus crispatus							
Pyromaia tuberculata							
Pinnotheridae							
Pinnotheridae, unid.							
Opisthopus transversus							
Pinnixa franciscana							
Pinnixa sp.							
Scleropiax granulata							
Caridea							
Alpheidae							
Alpheidae, unid.							
Alpheus californiensis							
Alpheopsis equidactylus (= Alpheus equidactylus)							
Betaeus ensenadensis							
Betaeus sp. unid.							
Palaemonidae							
Palaemonella holmesi							
LEPTOSTRACA							
Epinebalia sp.							

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Stations	1A	2A	3A	4A	5A	6A	7A
PERACARIDA							
AMPHIPODA							
CAPRLIDEA							
Caprellidae							
Caprellidea, unid.	272	208	1152	320	848	48	32
Caprellidae, unid. B	16						
Caprella californica							
Caprella equilibra							
Caprella sp. E	608		1536	416	368	48	
GAMMARIDEA							
Gammaridea, unid.							
Ampeliscidae							
Ampelisca brevisimulata	144	96	32				
Ampelisca cristata	80						
Ampelisca hancocki	80	80	16	16	32	16	
Ampelisca milleri	64						
Ampelisca pacifica							
Ampelisca pugetica	64		96	48	192	32	
Ampelisca sp.	16						
Byblis veleronis						32	
Amphilochidae							
Gitana calitemplado	176		112	48	160	16	
Argissidae							
Argissa hamatipes							
Bateidae							
Bataca lobata							
Corophiidae							
Amphideutopus oculatus	336		736	32	128		
Corophium acherusicum							
Lembos audbettius				128		112	
Photis brevipes	16		48		32		
Photis sp.	144		208		240	112	
Rudilemboides stenopropodus	128	48	208		80		
Eusiridae							
Rhachotropis oculatus	48		48		48		
Gammaridae							
Metaceradocus occidentalus							16

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Stations	1A	2A	3A	4A	5A	6A	7A
Ischyroceridae							
Ericthonis brasiliensis		96					
Microjassa litotes				96			
Liljeborgiidae							
Listriella diffusa	160		32		16	32	
Listriella goleta							
Lysianassidae							
Orchomene oculata					16		
Oedicerotidae							
Bathymedon sp.			16				
Monoculodes hartmanae			144				
Monoculodes sp.							
Synchelidium shoemakeri	32	16	64		16		
Westwoodilla caecula	32	32	16				
Phoxocephalidae							
Foxiphalus obtusidens	16					32	16
Foxiphalus similis	176	32	288		96	16	
Heterophoxus oculatus	32			32	112	16	
Rhepoxynius bicuspidatus							
Rhepoxynius daboius		48					
Rhepoxynius epistomus							
Rhepoxynius stenodes	32		64				
Pleustidae							
Parapleustes pugettensis		32					
Pleusymtes subglaber (= Sympleustes subglabor)	48	16	48		16	32	
Podoceridae							
Podocerus cristatus							
Stenothoidae							
Metopa dawsoni	112		48	112	112		
Synopiidae bigarria							
Syrrhoites bigarra (= Syrrhoites bigarra)							16
CUMACEA							
Cumacea, unid.							

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Stations	1A	2A	3A	4A	5A	6A	7A
Campylaspis rubromaculata							
Campylaspis sp.							
Campylaspis sp. B	16		128	48			16
Campylaspis sp. E					32		
Cumella sp.		16					
Cumella sp. A		32			320	128	16
Cumella sp. B	704		784	128			
Cumella vulgaris	96			32			
Cyclaspis nubilla			208	48	80		16
Cyclaspis sp. A		32		128			
Diastylis sp.							
Diastylis sp. A		176					
Diastylopsis tenuis							
Eudorella pacifica	96	432		32		16	
Hemilamprops californica		16				48	
Leptostylis sp. A	128	32	384		6416	16	16
Leucon subnasica	16	16	32	48			
Oxyurostylus pacifica							
ISOPODA							
Isopoda, unid.							
Cyathura sp.							
Edotea sp.							
Edotea sublittoralis							
Gnathia crenulatifrons		32	16				
Gnathia sp.	16	80			32		
Jaeropis dubia				16			48
Limnoria sp.							
Munna sp.							
Munna ubiguita	16	128	64	96	112	48	16
Neastacilla californica	32			96			
Silophasma geminatum	32	48	16				
Synidotea magnifica	48		16				
MYSIDACEA							
Mysidacea, unid.							

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Stations	1A	2A	3A	4A	5A	6A	7A
TANAIDACEA							
Tanaidacea, unid.							
Anatanais normani							
Leptochelia dubia	176	304	64	16	64	96	32
Leptochelia sp.		144	32		16		
INSECTA							
Chironomidae, larvae							
Paraclunio alaskensis, larvae							
CHELICERATA							
PYCNOGONIDA							
Pycnogonida, unid.					16		
Pycnogonida, unid. B	48		32				
Anoplodactylus erectus							
Callipallene californiensis							
Pallenidae, unid.							
Tantystylum intermedium							
ASCHELMINTHES							
Nematoda, unid.			64			16	304
BRACHIOPODA							
Glottidia albida	576		192	112	480	80	
BRYOZOA (= ECTOPROCTA)							
Bowerkankia gracilis							
Bugula neritina							
Celleporaria brunnea							
Cryptosula pallasiana							
Membranipora tuberculata							
Schizoporella unicornis							
Scrupocellaria diegensis							
Tubulipora tuba							
Watersipora arcuata							
Zoobotryon verticillatum							

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Stations	1A	2A	3A	4A	5A	6A	7A
CHORDATA							
UROCHORDATA							
Ascidiacea, unid.			1				64
CEPHALOCARDATA							
Branchiostoma californiense							32
CNIDERIA (= COELENTERATA)							
ANTHOZOA							
Anthozoa, unid.			32				
ALCYONARIA							
Alcyonaria, unid.			16				
ACTINIARIA							
Actiniaria, unid.							
Diadumenidae							
Diadumene sp.							
Edwardsiidae							
Edwardsiidae, unid.							
Edwardsia californica							
Edwardsia sp.							
Edwardsia sp. A		16					
Edwardsia sp., juv.							
Isoedwardsia sp. A	48	48					
Haloclividae							
Mesacmaea sp. A							
PENNATULACEA							
Stylatula elongata							
Acanthoptilum gracile							
CERIANTHARIA							
Ceriantharia, unid.							
HYDROZOA							
HYDROIDA							
Hydrozoa, unid.				32	16		
Aglaophenia diversidentata							
Aglaophenia nr. pluma							
Aglaophenia sp.							
Corymorpha aurata (= Euphysa sp. A)							
Obelia sp.							

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Stations	1A	2A	3A	4A	5A	6A	7A
ECHINODERMATA							
ASTEROIDEA							
Astropecten verrilli	32						
ECHINOIDEA							
Echinoidea, unid. juv.		32					
Lytechinus sp.			16		16		
Strongylocentrotus purpuratus							
HOLOTHUROIDEA							
Cucumaria sp.	16						
Holothuroidea, unid.							
Leptosynapta sp.		32		16			
OPHIUROIDEA							
Ophiuroidea, unid. juv.					48		
Amphichondrius granulosus					64		
Amphiuridae, unid.			16				
Amphiodia urtica	176		80	80	272	48	
Ophiuroconis bispinosa		80	560	48	32	32	
ECHIURA							
Echiura, unid.							16
Listriolobus unid.			16				
Listriolobus pelodes	32		16		16		
Urechis caupo							
HEMICHORDATA							
Enteropneusta, unid.							
Enteropneusta	32						
Pterobranchia	256						
NEMERTEA							
Nemertea, unid.	320		224	112	128	80	160
Cerebratulus californiensis				16	16		
Euplectonema burgeri							
Lineus bilineatus							
Micrura alaskensis							
Paranemertes sp. A							
Tubulanus cingulatus	96		16	32	16		

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Stations	1A	2A	3A	4A	5A	6A	7A
Tubulanua nothus	16						
Tubulanus pellucidus					80		
Tubulanus polymorphus			32	32		32	
PHORONIDA							
Phoronis pallida							
Phoronis sp.	560	48		288	144	96	
Phoronopsis sp.			128				
PLATYHELMINTHES							
Polycladia, unid.		16			16		
SIPUNCULIDA							
Sipunculida, unid.				16	16	32	800
MOLLUSCA							
GASTROPODA							
Gastropoda, unid. juv.							
PROSOBRANCHIA							
MESOGASTROPODA							
Caecidae							
Caecum crebicinctum							64
Caecum sp.							
Fartulum sp.							
Micranellium sp.							
Calypteridae							
Calyptraeidae, unid.			208		48		
Crepidula onyx							
Crepidula dorsata (= Crepepatella lingulata)							
Crepidula preforans							
Crepidula sp., juv.	80						
Eulimidae							
Eulima sp.	96						
Lamellariidae							
Marseniopsis sharonae (= Lamellaria sharonae)							
Neverita recluziana							
Sinum sp.							

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Stations	1A	2A	3A	4A	5A	6A	7A
Vitrinellidae							
Vitrinella oldroydi							
NEOGASTROPODA							
Columbellidae							
Alia carinata (= Mitrella carinata)							
Mitrella sp., juv.							
Muricidae							
Ocenebra sp. juv.			16				
Pteropurpura festiva							
Nassariidae							
Nassarius mendicus							
Nassarius perpinguis							
Nassarius sp.							
Olividae							
Olivella baetica							
Turridae							
Kurtziella plumbea							
OPHISTHOBRANCHIA							
CEPHALASPIDEA							
Cephalaspidea, unid.							
Acteonidae							
Rictaxis punctocaelatus							
Aglajidae							
Aglaja sp.							
Atyidae							
Haminoea vesicula							
Haminoea sp. juv.			32	16		32	
Bullidae							
Bulla gouldiana							
Philinidae							
Woodbridgea sp.							
Retusidae							
Sulcoretusa sp.							
Volvulella panamica							

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Stations	1A	2A	3A	4A	5A	6A	7A
Scaphandridae							
Cylincha diegensis							
Cylichnella culcitella (= Acteocina culcitella)							
Cylichnella harpa (= Acteocina harpa)							
Cylichnella inculta (= Acteocina inculta)							
NUDIBRANCHIA							
Nudibranchia, unid.							
Acanthodoris sp.							
Cuthona sp. (= Trinchesia sp.)							
EUTHYNEURA							
PYRAMIDELLIDA							
Pyramidellidae							
Odostomia sp.							
Turbonilla sp.							
PELECYPODA							
Pelecypoda, unid. juv.							
Cardiidae							
Laevicardium substriatum	16	48	16	48		16	
Cooperellidae							
Cooperella subdiaphana							
Cultellidae							
Ensis myrae							
Siliqua lucida							
Donacidae							
Donax gouldii							
Erycinidae							
Lasaea subviridis							
Hiatellidae							
Hiatella arctica							
Kelliidae							
Kellia laperousi							

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Stations	1A	2A	3A	4A	5A	6A	7A
Leptonidae							
Platomysia meroeum (= Lepton meroeum)							
Lucinidae							
Parvilucina approximata	64					32	
Parvilucina tenuisculpta (= Parvilucina sp.)							
Lucina nuttalli							
Lyonsiidae							
Lyonsia californica							
Mactridae							
Mactridae, juv.							
Mactra californica							
Mactra sp.							
Spisula catilliformis							
Spisula sp.							
Tresus nuttalli							
Montacutidae							
Mysella grippi							
Mysella pedroana							
Mysella sp.							
Neaeromga sp. (= Orobitella sp.)							
Myidae							
Cryptomya californica							
Mytilidae							
Mytilidae, juv.							
Amygdalum sp.							
Modiolus sp.							
Musculus senhousei	16				48		
Mytilus edulis							
Nuculanidae							
Nuculana sp.							
Ostreidae							
Ostrea lurida							

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Stations	1A	2A	3A	4A	5A	6A	7A
Pectinidae							
Leptopecten latiauratus							
Petricolidae							
Petricola tellimyalis							
Petricola sp.							
Semelidae							
Cumingia californica							
Theora lubrica							
Solecurtidae							
Tagelus subteres							
Solenidae							
Solen rosaceus							
Solen sicarius							
Solen sp. juv.							
Tellinidae	16					16	
Leporimetis obesa							
Macoma acolasta							
Macoma cariottensis							
Macoma nasuta							
Macoma yoldiformis	112	176				32	
Macoma sp., juv.							
Tellina carpenteri	64	32	112	48	48	32	
Tellina modesta							
Tellina sp., juv.							
Thraciidae							
Thracia curta							
Thyasiridae							
Axinopsida serricata							
Thyasira flexuosa							
Veneridae							
Chione ? undatella							
Chione sp. juv.	512					32	1
Compsomyax subdiaphana							
Protothaca staminea							
Protothaca sp., juv.							

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Stations	1A	2A	3A	4A	5A	6A	7A
Saxidomus nuttalli							
Saxidomus sp., juv.							
POLYPLACOPHORA							
Polyplacophora, unid.							
SCAPHOPODA							
Cadulus fusiformis							

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Stations	1A	2A	3B	4A	5A	6A	7A
ANNELIDA							
OLIGOCHAETA							
Oligochaeta, unid.			48				640
Tubificidae							
Peloscolex gabriellae							
POLYCHAETA							
Acrocirridae							
Acrocirrus sp.							16
Ampharetidae		16					
Amage anops				16			
Amage scutata		32					
Ampharete acutifrons						16	
Ampharete labrops						16	16
Amphicteis scaphobranchiata		32		16			
Amphisamytha bioculata	16					16	
Anobothrus gracilis		48	16				
Asabellides lineata	64		48	32			80
Lysippe labiata	80	16	240	64	112	32	144
Lysippe sp. B		288					
Melinna oculata	16		160	16	32	64	
Samytha californiensis							
Amphinomidae							
Chloeia pinnata		16					
Pareurythoe californica							16
Pareurythoe sp. juv							
Arabellidae							
Arabellidae, unid. juv.							
Arabella sp.							
Drilonereis falcata	48		32			16	
Drilonereis mexicana				16			
Notocirrus californiensis	16	16				16	
Capitellidae							
Capitella capitata							
Decamastus gracilis		16					

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Stations	1A	2A	3B	4A	5A	6A	
Mediomastus acutus					16	16	
Mediomastus ambiseta	64	32	48	16			32
(= M. californiensis,		32					
= Capitita ambiseta)							
Notomastus magnus							
Notomastus tenuis							
Notomastus sp.							16
Chaetopteridae							
Chaetopteridus sp.					16		144
Phyllochaetopterus prolifica	224		208	64	48	448	32
Spiochaetopterus costarum	160	32	192	128	256	224	48
Chrysopetalidae							
Chrysopetalum occidentale							
Paleanotus bellis							
Cirratulidae							
Cirratulidae, unid.							
Caulleriella alata							
Caulleriella bioculata							
Caulleriella gracilis					16		
Caulleriella hamata							
Caulleriella sp., juv.							
Chaetozone armata			80				144
Chaetozone corona							
Chaetozone setosa			16				
Chaetozone nr setosa							
(= Chaetozone setosa)							
Chaetozone spinosa			64				112
Chaetozone sp.							
Cirratulus cirratus				16			
Cirriformia luxuriosa							
Cirriformia spirabrancha							
Cirriformia sp., juv.							
Tharyx nr. tesselata							
Tharyx spp.	32	16	16	16	16		80
Cossuridae							

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Stations	1A	2A	3B	4A	5A	6A	7A
Cossura candida	16						
Cossura pygodactylata							
Ctenodrilidae							
Ctenodrilus serratus							
Dorvilleidae							
Dorvilleidae, unid.							
Ophryotrocha puerilis							
Protodorvillea gracilis							16
Protodorvillea sp.							32
Schistomeringos longicornis							
Eunicidae							
Eunice americana	16		16			16	
Marphysa belli oculata			16	48		64	
Marphysa disjuncta							
Marphysa sp.							
Flabelligeridae							
Flabelligeridae, unid.							
Pherusa capulata							
Pherusa neopapillata					32		
Pherusa papillata	16		16			16	32
Pherusa sp., juv.							
Piromis sp. A				16	112		
Glyceridae							
Glycera americana			16		16		
Glycera capitata		48	16	48		32	
Glycera convoluta							
Gylcera rouxii							
Glycera sp., juv.							
Goniadidae							
Goniadidae, unid. juv.							
Glycinde armigera							
Goniada aciculata					16		
Goniada brunnea		32	48		32	16	48
Goniada littorea							
Goniada sp., juv.							

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Stations	1A	2A	3B	4A	5A	6A	7A
Hesionidae							
Hesionidae, unid.							
Gyptis brunnea							
Heteropodarke heteromorpha							32
Microphthalmus sp.							
Micropodarke dubia							
Ophiodromus pugettensis							48
Podarkeopsis glabra (= Gyptis brevipalpa)	16						
Heterospionidae							
Heterospio catalinensis							
Lumbrineridae							
Lumbrineridae, unid.							
Lumbrinerides platypygos							80
Lumbrineris californiensis				48		32	
Lumbrineris ? crassidentata							
Lumbrineris cruzensis							
Lumbrineris erecta							
Lumbrineris lagunae							
Lumbrineris limicola							
Lumbrineris ? tetraura							
Lumbrineris sp.	48	16	48		16		704
Magelonidae							
Magelona berkeleyi	16	16					
Magelona pacifica							
Magelona pitelkai							
Magelona sacculata							
Maldanidae							
Maldanidae, unid.	48			32	32	16	
Asychis disparidentata							
Asychis sp.							
Axiothella sp.							
Clymenura gracilis		32					
Euclymeninae sp. C	32		16	48			32
Euclymeninae sp D (sp. C&D formerly Axiothella rubrocincta)		32					

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Stations	1A	2A	3B	4A	5A	6A	7A
Isocirrus longiceps						16	
Maldane sarsi		16	16	16		32	
Notoproctus pacificus					464		
Petaiopractus neoborealis							
Praxillella pacifica (= affinis pacifica)	48		144	16			
Praxillella sp.							
Praxillura maculata			48				
Nephtyidae							
Nephtyidae, unid. juv.							
Nephtys caecoides	32	80		16		32	
Nephtys californiensis							
Nephtys cornuta franciscana	112		80		16	160	
Nephtys ferruginea	16	48					
Nereididae (= Nereidae)							
Nereididae, unid. juv.							
Gymnonereis crossiandi americana							
Neanthes acuminata (= Neanthes arenaceodentata)							
Nereis latescens							32
Nereis procera	32		16			48	16
Nereis sp., juv.							
? Perinereis monterea							
Platynereis bicanaliculata				16			
Onuphidae							
Onuphidae, unid. juv.	32						
Diopatra ornata							
Diopatra splendidissima							
Diopatra sp., juv.	32						
Diopatra tridentata			96	16	64	32	16
Hyalinoecia juvenalis	16						
Mooreonuphis nebulosa (= Onuphis nebulosa)	16		64				
Onuphis elegans (= Nothria elegans)							

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Stations	1A	2A	3B	4A	5A	6A	7A
Onuphis geophilliformis (= Nothria geophilliformis)		16	48	16		16	
Onuphis iridescens (= Nothria iridescens)	32		16				
Onuphis multiannulata							
Rhamphobrachium longisetosum	32						
Sarsonuphis parva (= Onuphis pava)		112					
Ophelliidae							
Armandia bioculata							
Ophelina acuminata						16	
Polyophthalmus pictus							
Orbiniidae							
Orbiniidae, unid.							
Leitoscoloplos elongatus (= Haploscoloplos elongatus)		48			16		
Naineris dentritica							
Scoloplos nr. armiger			16				
Scoloplos acmeceps							
Scoloplos sp.	16						
Oweniidae							
Myriochele gracilis		48					
Myriochele nr. heeri							
Myriochele nr. pygidialis		16					
Myriochele sp. M	80	16	16			16	
Owenia collaris							32
Paraonidae							
Acmira catherinae (= Acesta catherinae)	288	32	112	64		256	
Acmira horikoshii (= Acesta horikoshii)							
Acmira simplex							
Acmira sp.							
Allia antennata	128	80	48	16		48	
Allia nolani							64

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Stations	1A	2A	3B	4A	5A	6A	7A
Allia ramosa							
Allia sp.				80			
Aricidea wassi	128		48	16	16	64	
Levinsenia oculata		16					
(= Tauberia oculata;							
= Paraonis gracillis oculata)							
Paraonella platybranchia							
(= Paraonides platybranchia)							
Pectinariidae							
Pectinaria californiensis	16	16		16	32		
(= P. c. newportensis)							
Pholoidae							
Pholoides aspera					16		
Phyllodocidae							
Phyllodocidae, unid.							
Eteone californica							
Eteone dilatae							
Eteone sp.							
Eulalia bilineata			16				
Eulalia ? myriacyclum							
Eulalia quadrioculata							
(= Eulalia aviculiseta)							
Eulalia sp., juv.		16					
Eumida bifoliata							
Eumida sanquinea			16				
? Genetyllis castanea							
Hesionura coineaui difficilis							48
Phyllodoce hartmanae		16			16		
Phyllodoce (Anaitides) groenlandic	32						
Phyllodoce (Anaitides) papillosa							
Phyllodoce sp.							16
Phyllodoce (Anaitides) sp., juv.							
Pterocirrus sp.							
Pisionidae							
Pisione sp.							

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Stations	1A	2A	3B	4A	5A	6A	7A
Pilargiidae							
Ancistrosyllis hamata							
Parandalia ocularis					16		
Pilargis berkeleyi							
Sigambra tentaculata							
Poecilochaetiidae							
Poecilochaetus johnsoni							
Poecilochaetus sp. A							
Polynoidae							
Polynoidae, unid.							
Halosydna johnsoni							
Halosydna sp.							
Harmothoe ? crassicirrata							
Harmothoe hirsuta							
Harmothoe imbricata							
Harmothoe scriptoria							
Harmothoe sp.					32		16
Lepidonotus ? squamatus							
Tenonia priops (= Harmothoe priops)							
Subadyte sp.							
Sabellariidae							
Sabellaria cementarium	16						
Sabellidae							
Sabellidae, unid.							
Chone albocincta	32	48	48	16	16	16	
Chone ecaudata	80		144	32		96	
Chone gracilis							
Chone mollis							
Chone veleronis	16		16	32		16	
Chone sp.							
Demonax medius					16		
Euchone arenae		16					144
Euchone incolor	64	32	96	16		160	32
Euchone limnicola							

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Stations	1A	2A	3B	4A	5A	6A	7A
Fabricia sp.			128		16	48	
Fabrisabella sp. A	192	96	192	272	240	400	304
Fabrisabella sp. B			16				
Jasmineira sp.							
Megalomma pigmentum							
Megalomma roulei					16		
Myxicola ? infundibulum							
? Potamilla sp.							
Scalibregmatidae							
Asclerocheilus beringianus							
Scalibregma inflatum			16		16		128
Serpulidae							
Serpulidae, unid.							
Hydroides elegans (= Hydroides pacifica)							
Hydroides gracilis (= Eupomatus gracilis)							
Sigalionidae							
Pholoe glabra	16		16		16		
Pholoe minuta					16		112
Sthenelais fusca						16	
Sthenelais verruculosa							
Sthenelanella uniformis	144	64	96	80	96	256	32
Sphaerodoridae							
Sphaerodoridae unid. juv.							
Sphaerodoropsis biserialis							48
Spionidae							
Spionidae, unid.							
Aonides sp.							
Apoprionospio pygmaea (= Prionospio pygmaeus)	112	112	384	64	32	192	64
Boccardia sp.							
Boccardia basilaria						32	
Boccardiella hamata (= Boccardia hamata)							

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Stations	1A	2A	3B	4A	5A	6A	7A
Caraziella calafia (= "Pseudopolydora sp.")							
Laonice cirrata			16				
Laonice sp., juv.							
Microspio maculata (= Spio maculata; = Nerinides maculata)							
Microspio microcera			16				32
Microspio pigmentata	16	96				16	
Minuspio cirrifera (= Prionospio cirrifera)		16		16			32
Paraprionospio pinnata	32	16	32	16		64	
Polydora bioccipitalis							
Polydora cardalia	48		16	16			16
Polydora caulleryi (= P. brachycephala)							
Polydora ligni							
Polydora neocardalia							
Polydora socialis							
Polydora sp.							
Prionospio heterobranchia (= P. h. newportensis)							
Prionospio sp. A (= Prionospio "steenstrupi"; = P. nr. malmgreni)	144	352	48	48	16	16	
Prionospio sp.							
Pseudopolydora paucibranchiata							
Rynchospio arenicola							
Rhynchospio sp.							
Scolelepis acuta (= Nerinides acuta)							
Scolelepis sp. A							
Spio ? filicornis							
Spiophanes berkeleyorum		352				16	
Spiophanes bombyx	288	48	272	32		368	336

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Stations	1A	2A	3B	4A	5A	6A	7A
Spiophanes missionensis	1056	528	352	224	448	720	32
Spiophanes sp.							
Streblospio benedicti							
Spirorbidae							
Janua brasiliensis							
Pileolaria pseudomilitaris							
Sternaspidae							
Sternaspis fossor		16					
Syllidae							
Syllidae, unid.							
Autolytus sp.							
Brania sp.							
Ehlersia heterochaeta	16		32				
Ehlersia sp. A			16				
Ehlersia sp. B							
Eusyllis sp.							
Exogone gemmifera							
Exogone lourei							32
Exogone molesta							
Exogone verugera							
Exogone sp. A							
Exogone sp.							
Odontosyllis phosphorea					32		
Pionosyllis uraga							80
Sphaerosyllis californiensis			16				64
Sphaerosyllis sp.							
Streptosyllis sp.							
Syllis reishi							48
? Syllis sp.							
Typosyllis alternata							112
Typosyllis ? hyalina							
Typosyllis sp.							
Terebellidae							
Terebellidae, unid. juv.	16		16				
Amaeana occidentalis		16					

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Stations	1A	2A	3B	4A	5A	6A	7A
Lanassa gracilis							
Lanice conchilega	32		48	112		80	
Loimia medusa							
Pista alata			32				
Pista brevibranchiata					48	16	272
Pista disjuncta (= Pista fasciata)							
Pista nr. disjuncta		16				16	
Pista sp. B		32	32	16			208
Pista sp., juv.							
Polycirrus sp.							16
Streblosoma crassibranchia	48			16		64	
Streblosoma sp B	16		32	16		48	
Trichobranchidae							
Artacamella hancocki			32		16	16	
Terebellides californica			32				
ARTHROPODA							
CRUSTACEA							
CEPHALOCARIDA							
COPEPODA							
CALANOIDEA							
Calanoida, unid	16						
CYCLOPOIDEA							
Cyclopoidea, unid.							
Clausidium vancouverense							
HARPACTICOIDEA							
Harpactocoidea, unid.			32			16	32
OSTRACODA							
Ostracoda, unid.							
Bathyleberis sp.	16						
Cylindroleberis sp.							
Euphilomedes carcharodonta	128		32		128	16	
Euphilomedes producta		16					
Philomedes sp.	128						
Rudiderma rostrata							

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Stations	1A	2A	3B	4A	5A	6A	7A
Rutaderma lomae	32			16			
Sarsiella sp.							
Sarsiella sp A					32		
Scleroconcha sp.							
CIRRIPEDIA							
Balanus (Balanus) pacificus							
Balanus trigonus							
Balanus sp.							
Megabalanus tintinnabulum californicus (= Balanus)							
Scalpellum californicum			16				
DECAPODA							
Decapoda -- larval							16
Anomura	16					16	16
Callianassidae							
Callianassa californiensis							
Callianassa sp.	16						
Upogebia sp.							
Paguridae							
Pagurus californicus			16				
Pagurus sp.							
Brachyura	16				16		64
Cancéridae							
Cancer anthonyi							
Cancer gracilis							
Cancer sp., juv.							16
Grapsidae							
Hemigrapsus oregonensis							
Hemigrapsus sp., juv.							
Majidae							
Majidae megalops, unid.							
Loxorhyncus crispatus							
Podochela sp.			32		48		16
Pyromaia tuberculata							

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Stations	1A	2A	3B	4A	5A	6A	7A
Pinnotheridae							
Pinnotheridae, unid.							
Opisthopus transversus							
Pinnixa franciscana							
Pinnixa sp.							
Scleroplax granulata							
Caridea							
Alpheidae							
Alpheidae, unid.							
Alpheus californiensis							
Alpheopsis equidactylus (= Alpheus equidactylus)							
Betaeus ensenadensis							
Betaeus sp. unid.							
Crangon resima						16	32
Palaemonidae							
Palaemonella holmesi							
LEPTOSTRACA							
Epineballa sp.							
PERACARIDA							
AMPHIPODA							
CAPRELLIDEA							
Caprellidae							
Caprellidea, unid.	16		192		32		64
Caprellidae, unid. B							
Caprella californica							
Caprella equilibra							
Caprella sp. E							
GAMMARIDEA							
Gammaridea, unid.						16	
Ampeliscidae							
Ampelisca agassizi			64				
Ampelisca brevisimulata	16	96	64		16	16	
Ampelisca careyi	96		64		16	32	
Ampelisca cristata	64		16				

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Stations	1A	2A	3B	4A	5A	6A	7A
Ampelisca hancocki	32	208	32			176	
Ampelisca milleri			16	32		16	
Ampelisca pacifica							
Ampelisca pugetica	144		272	16	192	16	
Ampelisca sp.	32				32	16	
Byblis veleronis		32					
Aoroides sp.			96				
Amphilochidae							
Gitana calitemplodo			16			32	32
Argissidae							
Argissa hamatipes							
Bateidae							
Betaea lobata		32		16			
Corophiidae							
Amphideutopus oculatus	64		112		48	32	
Corophium acherusicum							
Gammaropsis thompsoni			176				
Lembos audbettius					16		
Megamphopus mamolus				32			16
Photis brevipes					16		
Photis californicas				16			
Photis sp.	48		32	48	96	48	16
Rudilemboides stenopropodus					48	64	
Eusiridae							
Rhachotropis oculatus					48	16	32
Gammaridae							
Elasmopus sp.		64					
Metacoradocus occidentalus							
Ischyroceridae							
Ericthonis brasiliensis							
Microjassa litotes							
Liljeborgiidae							
Listriella diffusa	16		16				
Listriella goleta							

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Stations	1A	2A	3B	4A	5A	6A	7A
Lysianassidae							
Orchomene index		48					
Orchomene oculata	16		16				
Uristes dawsoni							16
Melphidippidae							
Melphisana bola	16		32				
Oedicorotidae							
Bathymedon sp.							
Monoculoides hartmanae					80	32	64
Monoculoides norvegica	32						
Monoculoides sp.							
Synchelidium shoemakeri	32	16				16	
Westwoodilla caecula	64		64		16	16	
Phoxocephalidae							
Foxiphalus obtusidens	96	48	176	16	48		
Foxiphalus similis			80				
Heterophoxus oculatus	192			16		96	
Metaphoxus freguens	32	64				16	
Rhepoxynius bicuspidatus							
Rhepoxynius daboius							
Rhepoxynius epistomus			16				
Rhepoxynius stenodes		16				32	
Pleustidae							
Parapleustes pugettensis							
Pleusymtes subglaber (= Sympleustes subglaber)	48		16			32	
Podoceridae							
Podocerus cristatus							
Stenothoidae							
Metopa dawsoni							
Synopiidae							
Garrosyrrhoe bigarra (= Syrrholtes bigarra)							176
CUMACEA							
Cumacea, unid.							

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Stations	1A	2A	3B	4A	5A	6A	7A
Campylaspis rubromaculata						16	
Campylaspis sp.							
Campylaspis sp. B							
Campylaspis sp. E					16		128
Cumella sp.							
Cumella sp. A		32		16			
Cumella sp. B							
Cumella vulgaris							
Cyclaspis nubilla							
Cyclaspis sp. A							
Diastylis californica	16					16	
Diastylis sp.	16						
Diastylis sp. A							
Diastylopsis tenuis							
Eudorella pacifica	144	80	16			64	
Hemilamprops californica							
Leptocuma forsmani	144			16		80	32
Leptostylis sp. A							
Leucon subnasica	16		64			32	
Oxyurostylus pacifica							
Procampylaspis sp A	16		16	16	48	32	48
ISOPODA							
Isopoda, unid.							
Cyathura sp.							
Eurydice caudata				16			272
Edotea sublittoralis							
Edotea sp.							
Gnathia crenulatifrons		16	32		16	80	
Gnathia sp.							
Jaeropis dubia				16			16
Limnoria sp.							
Munna ubiguita							
Munna sp.							
Neastacilla californica				16		16	
Silophasma geminatum	96				16	16	
Synidotea magnifica	16			16			

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Stations	1A	2A	3B	4A	5A	6A	7A
MYSIDACEA							
Mysidacea, unid.	32		16			16	
TANAIDACEA							
Tanaidacea, unid.							
Anatanais normani							
Leptochelia dubia	48	96	32		64	80	48
Leptochelia sp.							
Leptognathia sp. D		48					
Leptognathia sp. E		64					
Leptognathia sp.	32	32	16	16		16	
INSECTA							
Chironomidae, larvae							
Paraclunio alaskensis, larvae							
CHELICERATA							
PYCNOGONIDA							
Pycnogonida, unid.							
Pycnogonida, unid. B							
Anoplodactylus erectus							
Callipallene californiensis							
Pallenidae, unid.							
Tantystylum intermedium							
ASCHELMINTHES							
Nematoda, unid.		16	32		224	16	176
BRACHIOPODA							
Glottidia albida	288		16	112		400	
BRYOZOA (= ECTOPROCTA) Numbers in families (F= fragments)							
Antropora tincta							F
Barentsia discreta			1			1	
Bowerbankia gracilis							
Bugula neritina							
Cellaria mandibulata			F				F
Celleporaria brunnea							
Costazia costazi	1					F	
Crisia occidentalis						F	
Crisia serrulata			F				

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Stations	1A	2A	3B	4A	5A	6A	7A
Cryptosula pallasiana							
Diaperoecia californica			F				F
Discoporella umbellata				1	3		
Hippomonavella longirostrata							F
Lagenipora puctulata			F				
Membranipora tuberculata							
Phidolopora pacifica			F				
Reginella mucronata							F
Rhynchozoon rostratum							F
Scrupocellaria bertholetti							F
Schizoporella errata							F
Schizoporella unicornis							
Scrupocellaria diegensis							
Tubulipora tuba							
Watersipora arcuata							
Zoobotryon verticillatum							
CHORDATA							
UROCHORDATA							
ASCIDIACEA							
Ascidiacea, unid.	16		16				16
CEPHALOCORDATA							
Branchiostoma californiense							16
CNIDERIA (= COELENTERATA)							
ANTHOZOA							
Anthozoa, unid.			48				48
ALCYONARIA							
Alcyonaria, unid.							
ACTINIARIA							
Actinaria, unid.							
Diadumenidae							
Diadumene sp.							
Edwardsiidae							
Edwardsiidae, unid.	32						
Edwardsia californica							
Edwardsia sp.							

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Stations	1A	2A	3B	4A	5A	6A	7A
Edwardsia sp. A	16						
Edwardsia sp., juv.							
Isoedwardsia sp. A		32		32	16	16	
Pentactinia californica					288	32	144
Halocl ividae							
Mesacmaea sp. A							
PENNATULACEA							
Stylatula elongata							
Acanthoptilum gracile							16
CERIANTHARIA							
Ceriantharia, unid.					96		
HYDROZOA							
HYDROIDA							
Hydrozoa, unid.							
Aglaophenia diversidentata							
Aglaophenia nr. pluma							
Aglaophenia sp.							
Corymorpha aurata (= Euphysa sp. A)							
Obelia sp.							
ECHINODERMATA							
ASTEROIDEA							
Astropecten verrilli						16	
ECHINOIDEA							
Echinoidea, unid. juv.							
Lovenia cordiformis					16		
Lytechinus sp.			32	16	32		256
Strongylocentrotus purpuratus							
HOLOTHUROIDEA							
Chiridota sp.							16
Cucumaria sp.							
Havelockia benti							16
Holothuroidea, unid.							
Leptosynapta sp.							
Pentamera populifera		32					

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Stations	1A	2A	3B	4A	5A	6A	7A
Pentamera pseudopopulifera			32	16	16		
Pentamora sp. A			16				32
OPHIUROIDEA							
Ophiuroidea, unid. juv.	48				64		32
Amphichondrius granulosus				16			
Amphiura arcystata					96		
Amphiuridae, unid.							
Amphiodia urtica	80	64	112	192	176	224	128
Ophiuroconis bispinosa	80		64		80	48	
ECHIURA							
Echiura, unid.							
Listriolobus unid.							
Listriolobus pelodes					16		
Urechis caupo							
HEMICHORDATA							
Enteropneusta, unid.							
Enteropneusta							
Pterobranchia							
NEMERTEA							
Nemertea, unid.	80	32	96	128	160	128	96
Amphiporus sp.	16						
Cerebratulus californiensis			16	16			32
Euplectonema burgeri							
Lineus bilineatus	16					16	
Micrura alaskensis							
Paranemertes sp. A							
Tubulanus cingulatus			16				
Tubulanua nothus			32				
Tubulanus pellucidus							
Tubulanus polymorphus	16		64	16	96	112	64
PHORONIDA							
Phoronis pallida							
Phoronis sp.	48		64	64	16	224	16
Phoronopsis sp.							

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Stations	1A	2A	3B	4A	5A	6A	7A
PLATHYELMINTHES							
Polycladia, unid.			48				48
SIPUNCULIDA							
Sipunculida, unid.					64		
Golfingia sp.					272	16	960
MOLLUSCA							
GASTROPODA							
Gastropoda, unid. juv.							
PROSOBRANCHIA							
ARCHAEOGASTROPODA							
Phasianellidae							
Tricolia ? substriata							48
MESOGASTROPODA							
Caecidae							
Caecum crebicinctum					240		960
Caecum sp.							
Fartulum sp.							
Micranellium sp.							
Calypteridae							
Calyptraea fastigiata	16		16		16	16	464
Calyptraeidae, unid.							
Crepidula onyx							
Crepidula dorsata (= Crepepatella lingulata)							
Crepidula preforans							
Crepidula sp., juv.	32					16	16
Eulimidae							
Eulima almo	16						
Eulima sp.							
Lamellariidae							
Marseniopsis sharonae (= Lamellaria sharonae)							
Naticidae							
Neverita recluziana				16			
Sinum sp.							

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Stations	1A	2A	3B	4A	5A	6A	7A
Vitrinellidae							
Vitrinella oldroydi							
NEOGASTROPODA							
Columbellidae							
Alia carinata (= Mitrella carinata)							
Mitrella sp., juv.							
Muricidae							
Murex santarosanus							16
Ocenebra sp. juv.							
Pteropurpura festiva							
Nassariidae							
Nassarius mendicus							
Nassarius perpinguis							
Nassarius sp.							
Olividae							
Olivella baetica							16
Turridae							
Kurtziella beta		16					
Kurtziella plumbea							
OPHISTHOBRANCHIA							
CEPHALASPIDEA							
Cephalaspidea, unid.							
Acteonidae							
Rictaxis punctocaelatus							
Aglajidae							
Aglaja ocelligera					16		
Aglaja sp.							
Atyidae							
Haminoea vesicula							
Heminoea sp. juv.							
Bullidae							
Bulla gouldiana							
Philinidae							
Woodbridgea sp.							

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Stations	1A	2A	3B	4A	5A	6A	7A
Retusidae							
Sulcoretusa sp.							
Volvulella panamica							
Scaphandridae							
Cylincha diegensis							
Cylichnella culcitella (= Acteocina culcitella)							
Cylichnella harpa (= Acteocina harpa)							
Cylichnella inculta (= Acteocina inculta)							
NUDIBRANCHIA							
Nudibranchia, unid.							
Acanthodoris sp.							
Cuthona sp. (= Trinchesia sp.)							
EUTHYNEURA							
PYRAMIDELLIDA							
Pyramidellidae							
Odostomia sp.							16
Turbonilla sp.							16
PELECYPODA							
Pelecypoda, unid. juv.							
Cardiidae							
Laevicardium substriatum							
Trachycardium quadragenarium	16						
Nemacardium centifilosum				16	16		
Cooperellidae							
Cooperella subdiaphana							
Cultellidae							
Ensis myrae							
Siliqua lucida							

Benthic Invertebrates 25 October 1985

Stations	1A	2A	3B	4A	5A	6A	7A
Donacidae							
Donax gouldii							
Erycinidae							
Lasaea subviridis							
Hiatellidae							
Hiatella arctica							
Kelliidae							
Kellia laperousi							
Leptonidae							
Platomysia meroeum (= Lepton meroeum)							
Limidae							
Lima hemphilli					16		
Lucinidae							
Lucina nuttalli							
Lucinoma annulata	16						
Parvilucina approximata							
Parvilucina tenuisculpta (= Parvilucina sp.)	192	96	176	16	16	48	16
Lyonsiidae							
Lyonsia californica				16	16	16	64
Mactridae							
Mactridae, juv.							
Mactra californica							
Mactra sp.							
Spisula catilliformis							
Spisula sp.							16
Tresus nuttalli							16
Montacutidae							
Mysella grippi							
Mysella pedroana							
Mysella sp.							
Neaeromga sp. (= Orobitella sp.)							

Benthic Invertebrates 25 October 1985

Stations	1A	2A	3B	4A	5A	6A	7A
Myidae							
Cryptomya californica							
Mytilidae							
Mytilidae, juv.	16					16	
Amygdalum sp.							
Crenella decussata				16	16		
Modiolus sp.					16		48
Musculus senhousei							
Mytilus edulis							
Nuculanidae							
Nuculana sp.							
Ostreidae							
Ostrea lurida							
Pectinidae							
Leptopecten latiauratus							
Petricolidae							
Petricola tellimyalis							
Petricola sp.							
Semelidae							
Cumingia californica							
Theora lubrica							
Semele sp.							16
Solecurtidae							
Tagelus subteres							
Solemyidae							
Solemya sp.	16		16				
Solenidae							
Solen rosaceus							
Solen sicarius							
Solen sp. juv.							
Tellinidae							
Leporimetis obesa							
Macoma acolasta							

Benthic Invertebrates 25 October 1985

Stations	1A	2A	3B	4A	5A	6A	7A
Macoma carlottensis							
Macoma nasuta							
Macoma yoldiformis							
Macoma sp., juv.							
Tellina carpenteri	128		80			64	
Tellina modesta	16						
Tellina sp., juv.							
Thraciidae							
Thracia curta							
Thyasiridae							
Axinopsida serricata		48			16		
Thyasira flexuosa			16				
Ungulinidae							
? Diplodonta sp.							64
Veneridae			48				16
Chione ? undatella							
Chione sp. juv.							
Compsomyax subdiaphana	16						
Protothaca staminea							
Protothaca sp., juv.							
Saxidomus nuttalli							
Saxidomus sp., juv.							
Transennella tantilla			16				
POLYPLACOPHORA							
Lepedozona sp.							16
Polyplacophora, unid.							
SCAPHOPODA							
Cadulus fusiformis							
Cadulus guadrifissatus		16					
PORIFERA							
Porifera, unid			16				

FINAL REPORT
APPENDIXES

ENGINEERING AND ENVIRONMENTAL FEASIBILITY EVALUATION OF WASTE DISPOSAL ALTERNATIVES

StarKist Samoa, Inc.

CH2M HILL

March 1991

PREFACE

This Engineering and Environmental Feasibility Evaluation of Waste Disposal Alternatives was prepared by CH2M HILL for StarKist Samoa, Inc. The report is presented in two separately bound volumes: a Final Report, and Final Report Appendixes. These Appendixes contain supporting technical information for the Final Report. The Final Report consists of an Executive Summary and Sections 1 through 7.

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APPENDIX A

WATER QUALITY DATA

A-1 American Samoa Government Water Quality Data For Pago Pago Harbor 1987 to 1990, Total Nitrogen and Total Phosphorus

A-2 Historical Water Quality Trends

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A-4 Historical Effluent Characteristics

A-5 Field Protocol For Water Quality Sampling

APPENDIX A-1

American Samoa Government Water Quality Data For Pago Pago Harbor 1987 to 1990, Total Nitrogen and Total Phosphorus

Table A1-1
WATER QUALITY DATA FOR STATION 5
1987-1990

M	D	YR	STN	DEPTH (ft)	TN (mg/l)	TP (mg/l)	CHL a (ug/l)	TURBID (NTU)	S DEPTH (ft)	TEMP (C)	DO (mg/l)
8	24	1989	5							22.0	8.0
12	21	1989	5							22.0	5.2
3	29	1990	5							22.0	4.5
4	30	1990	5							21.0	3.4
5	11	1990	5							21.5	5.5
8	16	1990	5								
1	30	1987	5	3							
3	26	1987	5	3	0.326	0.019	3.250				
6	0	1987	5	3	0.156	0.017	0.585				
8	2	1987	5	3	0.314	0.036	8.100				
3	0	1988	5	3	0.163	0.012	4.830				
11	21	1988	5	3							
12	29	1988	5	3							
4	27	1989	5	3							
7	25	1989	5	3							
7	27	1989	5	3							
8	2	1989	5	3	0.130	0.015	0.040				
10	31	1989	5	3	0.200	0.009	0.790				
12	0	1989	5	3	0.410	0.021	2.680				
3	0	1990	5	3	0.390	0.051	3.840				
4	0	1990	5	3	0.280	0.020					
5	0	1990	5	3	0.190	0.020	0.210				
8	0	1990	5	3							
# OF OBS AT DEPTH					10	10	9				
MEAN					0.256	0.022	2.703				
MAXIMUM					0.410	0.051	8.100				
MINIMUM					0.130	0.009	0.040				
STANDARD DEVIATION					0.096	0.012	2.510				
1	30	1987	5	30							
3	26	1987	5	30							
6	0	1987	5	30							
8	2	1987	5	30							
3	0	1988	5	30							
11	21	1988	5	30							
12	29	1988	5	30							
4	27	1989	5	30							
7	25	1989	5	30							
7	27	1989	5	30							
8	2	1989	5	30				0.4	65		
10	31	1989	5	30							
12	0	1989	5	30				0.3	36		
3	0	1990	5	30				10.0	35		
4	0	1990	5	30				0.5	25		
5	0	1990	5	30				0.2	36		
# OF OBS AT DEPTH								5	10		
MEAN								2.3	21		
MAXIMUM								10.0	65		
MINIMUM								0.2	25		
STANDARD DEVIATION								3.9	13		
1	30	1987	5	60							
3	26	1987	5	60	0.129	0.008	0.140				
6	0	1987	5	60	0.120	0.014	0.406				
8	2	1987	5	60	0.171	0.021	3.100				
3	0	1988	5	60	0.130	0.013	0.527				
11	21	1988	5	60							
12	29	1988	5	60							
4	27	1989	5	60							
7	27	1989	5	60							
7	25	1989	5	60							
8	2	1989	5	60	0.180	0.018	0.050	0.9	65		
10	31	1989	5	60	0.150	0.004	0.260				
12	0	1989	5	60	0.320	0.016	0.230	0.2	36		
3	0	1990	5	60	0.360	0.053	5.280	9.6	35		
4	0	1990	5	60	0.230	0.020		0.3	25		
5	0	1990	5	60	0.170	0.020	0.140	0.4	36		
8	0	1990	5	60							
# OF OBS AT DEPTH					20	20	18	10	10		
MEAN					0.226	0.020	1.914	2.3	39		

Table A1-1
WATER QUALITY DATA FOR STATION 5
1987-1990

M D YR STN DEPTH (ft)	TN (mg/l)	TP (mg/l)	CHL a (ug/l)	TURBID (NTU)	S DEPTH (ft)	TEMP (C)	DO (mg/l)
MAXIMUM	0.410	0.053	8.100	10.0	65		
MINIMUM	0.120	0.004	0.040	0.2	25		
STANDARD DEVIATION	0.093	0.012	2.292	3.8	13		
TOTAL OBSERVATIONS	20	20	18	10	10	5	5
MEAN	0.226	0.020	1.914	2.3	39	21.7	5.3
MAXIMUM	0.410	0.053	8.100	10.0	65	22.0	8.0
MINIMUM	0.120	0.004	0.040	0.2	25	21.0	3.4
STANDARD DEVIATION	0.093	0.012	2.292	3.8	13	0.4	1.5

Table A1-2
WATER QUALITY DATA FOR STATION 6
1987-1990

M	D	YR	STN	DEPTH (ft)	TN (mg/l)	TP (mg/l)	CHL a (ug/l)	TURBID (NTU)	S DEPTH (ft)	TEMP (C)	DO (mg/l)
8	24	1989	6							22.0	9.00
12	21	1989	6							22.0	5.40
3	29	1990	6							22.0	4.50
4	30	1990	6							21.0	3.60
5	11	1990	6							21.2	4.50
8	16	1990	6							20.0	5.00
1	30	1987	6	3	0.159	0.017	0.534				
3	26	1987	6	3	0.122	0.002	0.562				
6	0	1987	6	3	0.172	0.015	0.344				
8	2	1987	6	3	0.312	0.030	5.200				
3	0	1988	6	3	0.143	0.009	0.848				
11	21	1988	6	3	0.209	0.018					
12	29	1988	6	3							
4	27	1989	6	3	0.230	0.016	0.750				
7	25	1989	6	3							
7	27	1989	6	3							
8	2	1989	6	3	0.160	0.021	0.200				
10	31	1989	6	3	0.160	0.013	0.520				
12	0	1989	6	3	0.220	0.031	8.370				
3	0	1990	6	3	0.840	0.071	1.550				
4	0	1990	6	3	0.330	0.030					
5	0	1990	6	3	0.160	0.020	0.360				
8	0	1990	6	3	0.210	0.027					
# OF OBS AT DEPTH					14	14	11				
MEAN					0.245	0.023	1.749				
MAXIMUM					0.840	0.071	8.370				
MINIMUM					0.122	0.002	0.200				
STANDARD DEVIATION					0.175	0.016	2.492				
1	30	1987	6	30							
3	26	1987	6	30							
6	0	1987	6	30							
8	2	1987	6	30							
3	0	1988	6	30							
11	21	1988	6	30			0.630				
12	29	1988	6	30							
4	27	1989	6	30							
7	25	1989	6	30	0.200	0.019	1.300				
7	27	1989	6	30							
8	2	1989	6	30				1.2	65		
10	31	1989	6	30							
12	0	1989	6	30				2.6	43		
3	0	1990	6	30				9.8	40		
4	0	1990	6	30				0.4	29		
5	0	1990	6	30				0.4	32		
8	0	1990	6	30				0.3	22		
# OF OBS AT DEPTH					1	1	2	6	6		
MEAN					0.200	0.019	0.965	2.5	39		
MAXIMUM					0.200	0.019	1.300	9.8	65		
MINIMUM					0.200	0.019	0.630	0.3	22		
STANDARD DEVIATION					0.000	0.000	0.335	3.4	14		
1	30	1987	6	60	0.115	0.021	0.437				
3	26	1987	6	60	0.162	0.005	0.205				
6	0	1987	6	60	0.184	0.017	0.286				
8	2	1987	6	60	0.253	0.033	3.900				
3	0	1988	6	60	0.175	0.016	0.981				
11	21	1988	6	60	0.155	0.021	0.960				
12	29	1988	6	60							
4	27	1989	6	60	0.190	0.010					
7	27	1989	6	60							
7	25	1989	6	60	0.160	0.025	1.210				
8	2	1989	6	60	0.200	0.019	0.210	0.7	65		
10	31	1989	6	60	0.180	0.010	0.480				
12	0	1989	6	60	0.230	0.019	0.520	2.2	43		
3	0	1990	6	60	0.280	0.025	1.480	9.5	40		
4	0	1990	6	60	0.220	0.030		0.6	29		
5	0	1990	6	60	0.140	0.020	0.330	0.4	32		
8	0	1990	6	60	0.100	0.012		0.7	22		

Table A1-2
WATER QUALITY DATA FOR STATION 6
1987-1990

M D YR STN DEPTH (ft)	TN (mg/l)	TP (mg/l)	CHL a (ug/l)	TURBID (NTU)	S DEPTH (ft)	TEMP (C)	DO (mg/l)
# OF OBS AT DEPTH	15	15	12	6	6		
MEAN	0.183	0.019	0.917	2.4	39		
MAXIMUM	0.280	0.033	3.900	9.5	65		
MINIMUM	0.100	0.005	0.205	0.4	22		
STANDARD DEVIATION	0.047	0.007	0.985	3.3	14		
TOTAL OBSERVATIONS	30	30	25	12	12	6	6
MEAN	0.212	0.021	1.287	2.4	39	21.4	5.3
MAXIMUM	0.840	0.071	8.370	9.8	65	22.0	9.0
MINIMUM	0.100	0.002	0.200	0.3	22	20.0	3.6
STANDARD DEVIATION	0.128	0.012	1.837	3.3	14	0.7	1.7

Table A1-3
WATER QUALITY DATA FOR STATION 7
1987-1990

M	D	YR	STN	DEPTH (ft)	TN (mg/l)	TP (mg/l)	CHL a (ug/l)	TURBID (NTU)	S DEPTH (ft)	TEMP (C)	DO (mg/l)
8	24	1989	7							22.0	11.0
12	21	1989	7							22.0	5.0
3	29	1990	7							22.0	4.2
4	30	1990	7							21.0	3.8
5	11	1990	7							21.5	5.2
8	16	1990	7							20.0	5.0
1	30	1987	7	3	0.526	0.022	15.700				
3	26	1987	7	3	0.440	0.020	11.100				
6	0	1987	7	3	0.160	0.017	0.643				
8	2	1987	7	3	0.730	0.062	19.200				
3	0	1988	7	3	0.332	0.030	13.500				
11	21	1988	7	3	0.173	0.017					
12	29	1988	7	3							
4	27	1989	7	3	0.460	0.045	3.110				
7	27	1989	7	3							
7	25	1989	7	3							
8	2	1989	7	3	0.140	0.021	0.270				
10	31	1989	7	3	0.140	0.012	0.440				
12	0	1989	7	3	0.280	0.013	5.670				
3	0	1990	7	3	0.390	0.039	5.060				
4	0	1990	7	3	0.370	0.040					
5	0	1990	7	3	0.360	0.030	10.600				
8	0	1990	7	3	0.310	0.024					
# OF OBSERVATIONS					14	14	11				
MEAN					0.344	0.028	7.754				
MAXIMUM					0.730	0.062	19.200				
MINIMUM					0.140	0.012	0.270				
STANDARD DEVIATION					0.160	0.014	6.322				
1	30	1987	7	30							
3	26	1987	7	30							
6	0	1987	7	30							
8	2	1987	7	30							
3	0	1988	7	30							
11	21	1988	7	30	1.560						
12	29	1988	7	30	0.290	0.018	0.680				
4	27	1989	7	30							
7	27	1989	7	30	0.180	0.041	1.040				
7	25	1989	7	30	0.140	0.160	1.140				
8	2	1989	7	30				1.3	65		
10	31	1989	7	30							
12	0	1989	7	30				0.4	50		
3	0	1990	7	30				10.0	36		
4	0	1990	7	30				0.9	39		
5	0	1990	7	30				0.4	20		
8	0	1990	7	30				0.2	33		
# OF OBSERVATIONS					4	3	3	6	6		
MEAN					0.543	0.073	0.953	2.2	41		
MAXIMUM					1.560	0.160	1.140	10.0	65		
MINIMUM					0.140	0.018	0.680	0.2	20		
STANDARD DEVIATION					0.590	0.062	0.198	3.5	14		
1	30	1987	7	60	0.165	0.029	1.460				
3	26	1987	7	60	0.130	0.006	0.086				
6	0	1987	7	60	0.291	0.020	0.378				
8	2	1987	7	60	0.312	0.029	5.600				
3	0	1988	7	60	0.159	0.014	0.903				
11	21	1988	7	60	0.215	0.022	0.760				
12	29	1988	7	60	0.153	0.028	0.300				
4	27	1989	7	60	0.270	0.026	0.550				
7	27	1989	7	60	0.140	0.026	4.840				
7	25	1989	7	60	0.150	0.034	1.350				
8	2	1989	7	60	0.210	0.021	0.400	1.1	65		
10	31	1989	7	60	0.150	0.009	0.450				
12	0	1989	7	60	0.250	0.011	0.290	0.3	50		
3	0	1990	7	60	0.290	0.028	1.580	10.0	36		
4	0	1990	7	60	0.300	0.020		0.5	39		
5	0	1990	7	60	0.140	0.010	0.910	0.3	20		

Table A1-3
WATER QUALITY DATA FOR STATION 7
1987-1990

M	D	YR	STN	DEPTH (ft)	TN (mg/l)	TP (mg/l)	CHL a (ug/l)	TURBID (NTU)	S DEPTH (ft)	TEMP (C)	DO (mg/l)
8	0	1990	7	60	0.080	0.010		0.4	33		
# OF OBSERVATIONS					17	17	15	6	6		
MEAN					0.200	0.020	1.324	2.1	41		
MAXIMUM					0.312	0.034	5.600	10.0	65		
MINIMUM					0.080	0.006	0.086	0.3	20		
STANDARD DEVIATION					0.070	0.008	1.595	3.5	14		
# OF OBSERVATIONS					35	34	29	12	12	6	6
MEAN					0.297	0.028	3.724	2.2	41	16.1	4.3
MAXIMUM					1.560	0.160	19.200	10.0	65	22.0	11.0
MINIMUM					0.080	0.006	0.086	0.2	20	20.0	3.8
STANDARD DEVIATION					0.254	0.026	5.140	3.5	14	0.7	2.4

Table A1-4
WATER QUALITY DATA FOR STATION 8
1987-1990

M	D	YR	STN	DEPTH (ft)	TN (mg/l)	TP (mg/l)	CHL a (ug/l)	TURBID (NTU)	S DEPTH (ft)	TEMP (C)	DO (mg/l)
8	24	1989	8							22.0	10.0
12	21	1989	8							21.0	5.2
3	29	1990	8							22.0	3.5
4	30	1990	8							21.3	3.4
5	11	1990	8							21.3	4.7
8	16	1990	8							19.0	5.3
1	30	1987	8	3	0.786	0.063	10.950				
3	26	1987	8	3	0.638	0.038	19.500				
6	0	1987	8	3	0.178	0.021	0.309				
8	2	1987	8	3	0.724	0.068	12.000				
3	0	1988	8	3	0.482	0.045	27.300				
11	21	1988	8	3							
12	29	1988	8	3	0.222	0.013	1.800				
4	27	1989	8	3	0.480	0.057	3.570				
7	25	1989	8	3	0.140	0.020	1.350				
7	27	1989	8	3							
8	2	1989	8	3	0.190	0.015	0.310				
10	31	1989	8	3	0.330	0.016	2.930				
12	0	1989	8	3	0.320	0.028	5.340				
3	0	1990	8	3	1.080	0.081	2.840				
4	0	1990	8	3	0.320	0.030					
5	0	1990	8	3	0.380	0.020	5.940				
8	0	1990	8	3	0.120	0.016					
# OF OBSERVATIONS					15	15	13				
MEAN					0.426	0.035	7.241				
MAXIMUM					1.080	0.081	27.300				
MINIMUM					0.120	0.013	0.309				
STANDARD DEVIATION					0.266	0.021	7.875				
3	0	1990	8	30				11.0	32		
8	0	1990	8	30				0.2	33		
4	27	1989	8	30							
3	26	1987	8	30							
8	2	1989	8	30				0.6	65		
12	0	1989	8	30				0.6	39		
3	0	1988	8	30							
6	0	1987	8	30							
8	2	1987	8	30							
11	21	1988	8	30			0.770				
7	27	1989	8	30	0.490	0.045	1.000				
12	29	1988	8	30							
5	0	1990	8	30							
10	31	1989	8	30							
4	0	1990	8	30				0.4	29		
7	25	1989	8	30							
1	30	1987	8	30				0.4	32		
# OF OBSERVATIONS					1	1	2	6	6		
MEAN					0.490	0.045	0.885	2.2	38		
MAXIMUM					0.490	0.045	1.000	11.0	65		
MINIMUM					0.490	0.045	0.770	0.2	29		
STANDARD DEVIATION							0.115	3.9	12		
1	30	1987	8	60	0.100	0.021	0.662				
3	26	1987	8	60	0.143	0.004	0.136				
6	0	1987	8	60	0.303	0.027	0.382				
8	2	1987	8	60	0.270	0.033	3.800				
3	0	1988	8	60	0.243	0.023	10.600				
11	21	1988	8	60			1.060				
12	29	1988	8	60	0.109	0.024	0.330				
4	27	1989	8	60	0.270	0.019	0.960				
7	27	1989	8	60	0.220	0.046	1.300				
7	25	1989	8	60	0.180	0.025	1.240				
8	2	1989	8	60	0.200	0.033	0.010	0.7	65		
10	31	1989	8	60	0.340	0.013	1.030				
12	0	1989	8	60	0.420	0.018	2.040	1.2	39		
3	0	1990	8	60	0.410	0.036	1.200	10.7	32		
4	0	1990	8	60	0.310	0.030		0.3	32		
5	0	1990	8	60	0.180	0.010	2.140	0.4	29		

Table A1-4
WATER QUALITY DATA FOR STATION 8
1987-1990

M	D	YR	STN	DEPTH (ft)	TN (mg/l)	TP (mg/l)	CHL a (ug/l)	TURBID (NTU)	S DEPTH (ft)	TEMP (C)	DO (mg/l)
8	0	1990	8	60	0.100	0.012		0.2	33		
# OF OBSERVATIONS					16	16	15	6	6		
MEAN					0.237	0.023	1.793	2.3	38		
MAXIMUM					0.420	0.046	10.600	10.7	65		
MINIMUM					0.100	0.004	0.010	0.2	29		
STANDARD DEVIATION					0.099	0.010	2.527	3.8	12		
# OF OBSERVATIONS					32	32	30	12	12	6	6
MEAN					0.334	0.030	4.093	2.2	38	21.1	5.4
MAXIMUM					1.080	0.081	27.300	11.0	65	22.0	10.0
MINIMUM					0.100	0.004	0.010	0.2	29	19.0	3.4
STANDARD DEVIATION					0.218	0.018	6.140	3.9	12	1.0	2.2

Table A1-5
WATER QUALITY DATA FOR STATION 8A
1987-1990

M	D	YR	STN	DEPTH (ft)	TN (mg/l)	TP (mg/l)	CHL a (ug/l)	TURBID (NTU)	S DEPTH (ft)	TEMP (C)	DO (mg/l)
8	24	1989	8A							22.0	7.0
12	21	1989	8A							21.0	5.0
3	29	1990	8A							22.0	3.5
4	30	1990	8A							21.2	3.8
5	11	1990	8A							21.5	4.4
8	16	1990	8A							20.0	4.7
1	30	1987	8A	3	0.978	0.08	12.260				
3	26	1987	8A	3	0.780	0.046	23.300				
6	0	1987	8A	3	0.170	0.028	0.515				
8	2	1987	8A	3	0.960	0.084	12.900				
3	0	1988	8A	3	0.375	0.040	23.600				
11	21	1988	8A	3	0.180	0.013					
12	29	1988	8A	3	0.274	0.020	2.280				
4	27	1989	8A	3	0.460	0.046	3.160				
7	25	1989	8A	3							
7	27	1989	8A	3							
8	2	1989	8A	3	0.250	0.017	0.100				
10	31	1989	8A	3	0.300	0.017	5.540				
12	0	1989	8A	3	0.220	0.018	4.880				
3	0	1990	8A	3	0.360	0.042	5.730				
4	0	1990	8A	3	0.520	0.040					
5	0	1990	8A	3	0.340	0.030	6.890				
8	0	1990	8A	3	0.190	0.023					
# OF OBSERVATIONS					15	15	12				
MEAN					0.424	0.036	8.430				
MAXIMUM					0.978	0.084	23.600				
MINIMUM					0.170	0.013	0.100				
STANDARD DEVIATION					0.262	0.021	7.714				
1	30	1987	8A	30							
3	26	1987	8A	30							
6	0	1987	8A	30							
8	2	1987	8A	30							
3	0	1988	8A	30							
11	21	1988	8A	30			2.980				
12	29	1988	8A	30							
4	27	1989	8A	30							
7	27	1989	8A	30	0.270	0.053	1.590				
7	25	1989	8A	30	0.220	0.027	2.310				
8	2	1989	8A	30				1.6	65		
10	31	1989	8A	30							
12	0	1989	8A	30				0.4	32		
3	0	1990	8A	30				12.1	30		
4	0	1990	8A	30				0.5	54		
5	0	1990	8A	30				0.4	16		
8	0	1990	8A	30				0.3	32		
# OF OBSERVATIONS					2	2	3	6	6		
MEAN					0.245	0.040	2.293	2.6	38		
MAXIMUM					0.270	0.053	2.980	12.1	65		
MINIMUM					0.220	0.027	1.590	0.3	16		
STANDARD DEVIATION					0.025	0.013	0.568	4.3	16		
1	30	1987	8A	60	0.129	0.022	0.354				
3	26	1987	8A	60	0.151	0.004	0.197				
6	0	1987	8A	60	0.298	0.025	0.494				
8	2	1987	8A	60	0.267	0.033	3.600				
3	0	1988	8A	60	0.151	0.011	0.824				
11	21	1988	8A	60	0.146	0.014	0.590				
12	29	1988	8A	60	0.111	0.022	0.400				
4	27	1989	8A	60	0.220	0.011	0.190				
7	27	1989	8A	60	0.200	0.012	1.440				
7	25	1989	8A	60	0.250	0.027	2.130				
8	2	1989	8A	60	0.270	0.023	0.430	0.8	65		
10	31	1989	8A	60	0.310	0.014	1.020				
12	0	1989	8A	60	0.470	0.020	0.700	0.6	32		
3	0	1990	8A	60	0.360	0.043	3.100	10.0	30		
4	0	1990	8A	60	0.490	0.040		0.4	54		
5	0	1990	8A	60	0.250	0.010	1.940	0.3	16		

Table A1-5
WATER QUALITY DATA FOR STATION 8A
1987-1990

M	D	YR	STN	DEPTH (ft)	TN (mg/l)	TP (mg/l)	CHL a (ug/l)	TURBID (NTU)	S DEPTH (ft)	TEMP (C)	DO (mg/l)
8	0	1990	8A	60	0.160	0.018		0.8	32		
# OF OBSERVATIONS					17	17	15	6	6		
MEAN					0.249	0.021	1.161	2.2	38		
MAXIMUM					0.490	0.043	3.600	10.0	65		
MINIMUM					0.111	0.004	0.190	0.3	16		
STANDARD DEVIATION					0.109	0.010	1.036	3.5	16		
# OF OBSERVATIONS					34	34	30	12	12	6	6
MEAN					0.326	0.029	4.181	2.4	38	21.3	4.7
MAXIMUM					0.978	0.084	23.600	12.1	65	22.0	7.0
MINIMUM					0.111	0.004	0.100	0.3	16	20.0	3.5
STANDARD DEVIATION					0.210	0.018	6.042	3.9	16	0.7	0.7

Table A1-6
WATER QUALITY DATA FOR STATION 9
1987-1990

M	D	YR	STN	DEPTH (ft)	TN (mg/l)	TP (mg/l)	CHL a (ug/l)	TURBID (NTU)	S DEPTH (ft)	TEMP (C)	DO (mg/l)
8	24	1989	9							21.0	3.8
3	29	1990	9							22.0	3.4
4	30	1990	9							21.2	4.0
5	11	1990	9							21.5	4.2
8	16	1990	9							20.0	4.0
1	30	1987	9	3	1.000	0.073	23.600				
3	26	1987	9	3	0.946	0.070	26.400				
6	0	1987	9	3	0.204	0.030	1.300				
8	2	1987	9	3	0.750	0.086	8.100				
3	0	1988	9	3	0.720	0.082	33.200				
11	21	1988	9	3	0.458	0.024					
12	29	1988	9	3	0.194	0.018	1.530				
4	27	1989	9	3	0.520	0.086	3.950				
7	27	1989	9	3							
7	25	1989	9	3							
8	2	1989	9	3	1.100	0.065	1.350				
10	31	1989	9	3	0.250	0.032	5.440				
12	0	1989	9	3	0.340	0.026	1.940	1.6			
3	0	1990	9	3	0.420	0.110	5.440				
4	0	1990	9	3	0.690	0.050					
5	0	1990	9	3	0.610	0.070	11.400				
8	0	1990	9	3	0.180	0.024					
# OF OBS AT DEPTH					15	15	12				
MEAN					0.559	0.056	10.304				
MAXIMUM					1.100	0.110	33.200				
MINIMUM					0.180	0.018	1.300				
STANDARD DEVIATION					0.294	0.028	10.654				
1	30	1987	9	30							
3	26	1987	9	30							
6	0	1987	9	30							
8	2	1987	9	30							
3	0	1988	9	30							
11	21	1988	9	30			0.820				
12	29	1988	9	30							
4	27	1989	9	30							
7	25	1989	9	30	0.140	0.025	2.410				
7	27	1989	9	30	0.330	0.033	2.900				
8	2	1989	9	30				0.9	30		
10	31	1989	9	30							
12	0	1989	9	30							
3	0	1990	9	30				10.0	24		
4	0	1990	9	30				0.8	41		
5	0	1990	9	30				0.4	17		
8	0	1990	9	30				0.2	34		
# OF OBS AT DEPTH					2	2	3	5	5		
MEAN					0.235	0.029	2.043	2.5	29		
MAXIMUM					0.330	0.033	2.900	10.0	41		
MINIMUM					0.140	0.025	0.820	0.2	17		
STANDARD DEVIATION					0.095	0.004	0.888	3.8	8		
1	30	1987	9	60	0.097	0.015	0.257				
3	26	1987	9	60	0.093	0.013	0.257				
6	0	1987	9	60	0.287	0.025	0.579				
8	2	1987	9	60	0.286	0.029	3.700				
3	0	1988	9	60	0.346	0.032	12.300				
11	21	1988	9	60	0.189	0.016	0.820				
12	29	1988	9	60	0.163	0.022	1.030				
4	27	1989	9	60	0.390	0.040	1.210				
7	25	1989	9	60	0.320	0.021	2.650				
7	27	1989	9	60	0.220	0.028	1.300				
8	2	1989	9	60	0.440	0.032	0.650	1.1	30		
10	31	1989	9	60	0.230	0.013	1.480				
12	0	1989	9	60	0.210	0.020	0.950				
3	0	1990	9	60	1.020	0.093	1.130	9.8	24		
4	0	1990	9	60	0.710	0.040		1.2	41		
5	0	1990	9	60	0.120	0.060	4.040	0.3	17		

Table A1-6
WATER QUALITY DATA FOR STATION 9
1987-1990

M	D	YR	STN	DEPTH (ft)	TN (mg/l)	TP (mg/l)	CHL a (ug/l)	TURBID (NTU)	S DEPTH (ft)	TEMP (C)	DO (mg/l)
8	0	1990	9	60	0.160	0.034		0.3	34		
# OF OBS AT DEPTH					6	6	6	6	6		
MEAN					0.311	0.031	2.157	2.5	29		
MAXIMUM					1.020	0.093	12.300	9.8	41		
MINIMUM					0.093	0.013	0.257	0.3	17		
STANDARD DEVIATION					0.230	0.019	2.929	3.6	8		
TOTAL OBSERVATIONS					34	34	30	11	10	5	5
MEAN					0.416	0.042	5.404	2.4	29	21.1	3.9
MAXIMUM					1.100	0.110	33.200	10.0	41	22.0	4.2
MINIMUM					0.093	0.013	0.257	0.2	17	20.0	3.4
STANDARD DEVIATION					0.286	0.026	8.110	3.6	8	0.7	0.3

Table A1-7
WATER QUALITY DATA FOR STATION 9A
1987-1990

M	D	YR	STN	DEPTH (ft)	TN (mg/l)	TP (mg/l)	CHL a (ug/l)	TURBID (NTU)	S DEPTH (ft)	TEMP (C)	DO (mg/l)
8	24	1989	9A							21.0	4.4
12	21	1989	9A							22.0	4.5
3	29	1990	9A							22.0	3.5
4	30	1990	9A							21.2	3.4
5	11	1990	9A							21.5	4.7
8	16	1990	9A							20.0	4.5
1	30	1987	9A	3	0.506	0.042	2.950				
3	26	1987	9A	3	1.120	0.087	24.200				
6	0	1987	9A	3	0.248	0.032	2.730				
8	2	1987	9A	3	1.060	0.141	14.900				
3	0	1988	9A	3	0.814	0.064	24.400				
11	21	1988	9A	3	0.438	0.015					
12	29	1988	9A	3	0.274	0.028	1.580				
4	27	1989	9A	3	0.680	0.081	4.560				
7	25	1989	9A	3							
7	27	1989	9A	3							
8	2	1989	9A	3	0.510	0.041	0.730				
10	31	1989	9A	3	0.410	0.037	9.220				
12	0	1989	9A	3	0.350	0.031	9.510				
3	0	1990	9A	3	0.520	0.057	9.920				
4	0	1990	9A	3	0.750	0.040					
5	0	1990	9A	3	0.590	0.070	12.300				
8	0	1990	9A	3	0.200	0.026					
# OF OBSERVATIONS					15	15	12				
MEAN					0.565	0.053	9.750				
MAXIMUM					1.120	0.141	24.400				
MINIMUM					0.200	0.015	0.730				
STANDARD DEVIATION					0.268	0.031	7.786				
1	30	1987	9A	30							
3	26	1987	9A	30							
6	0	1987	9A	30							
8	2	1987	9A	30							
3	0	1988	9A	30							
11	21	1988	9A	30			0.840				
12	29	1988	9A	30							
4	27	1989	9A	30							
7	27	1989	9A	30	0.300	0.029	2.780				
7	25	1989	9A	30	0.260	0.031	4.910				
8	2	1989	9A	30				0.7	36		
10	31	1989	9A	30							
12	0	1989	9A	30				1.0	41		
3	0	1990	9A	30				12.6	24		
4	0	1990	9A	30				0.6	37		
5	0	1990	9A	30				0.4	10		
8	0	1990	9A	30				0.3	28		
# OF OBSERVATIONS					2	2	3	6	6		
MEAN					0.280	0.030	2.843	2.6	29		
MAXIMUM					0.300	0.031	4.910	12.6	41		
MINIMUM					0.260	0.029	0.840	0.3	10		
STANDARD DEVIATION					0.020	0.001	1.662	4.5	10		
1	30	1987	9A	60	0.111	0.016	0.522				
3	26	1987	9A	60	0.800	0.102	14.900				
6	0	1987	9A	60	0.327	0.026	0.948				
8	2	1987	9A	60	0.206	0.015	1.200				
3	0	1988	9A	60	0.166	0.010	1.190				
11	21	1988	9A	60	0.183	0.015	0.630				
12	29	1988	9A	60	0.151	0.024	0.620				
4	27	1989	9A	60	0.310	0.020	1.720				
7	27	1989	9A	60	0.290	0.027	3.680				
7	25	1989	9A	60	0.260	0.035	5.660				
8	2	1989	9A	60	0.410	0.023	0.330	1.0	36		
10	31	1989	9A	60	0.280	0.021	2.400				
12	0	1989	9A	60	0.370	0.027	6.850	1.2	41		
3	0	1990	9A	60	0.480	0.041	7.640	10.5	24		
4	0	1990	9A	60	0.520	0.040		0.9	37		
5	0	1990	9A	60	0.050	0.030	2.020	0.3	10		

Table A1-7
WATER QUALITY DATA FOR STATION 9A
1987-1990

M	D	YR	STN	DEPTH (ft)	TN (mg/l)	TP (mg/l)	CHL a (ug/l)	TURBID (NTU)	S DEPTH (ft)	TEMP (C)	DO (mg/l)
8	0	1990	9A	60	0.170	0.022		0.2	28		
# OF OBSERVATIONS					17	17	15	6	6		
MEAN					0.299	0.029	3.354	2.4	29		
MAXIMUM					0.800	0.102	14.900	10.5	41		
MINIMUM					0.050	0.010	0.330	0.2	10		
STANDARD DEVIATION					0.176	0.020	3.846	3.7	10		
# OF OBSERVATIONS					34	34	30	12	12	6	6
MEAN					0.415	0.040	5.861	2.5	29	21.3	4.2
MAXIMUM					1.120	0.141	24.400	12.6	41	22.0	4.7
MINIMUM					0.050	0.010	0.330	0.2	10	20.0	3.4
STANDARD DEVIATION					0.255	0.028	6.482	4.1	10	0.7	0.5

Table A1-8
WATER QUALITY DATA FOR STATION 10
1987-1990

M	D	YR	STN	DEPTH (ft)	TN (mg/l)	TP (mg/l)	CHL a (ug/l)	TURBID (NTU)	S DEPTH (ft)	TEMP (C)	DO (mg/l)
8	24	1989	10							22.0	7.0
12	21	1989	10							23.0	4.5
3	29	1990	10							22.0	3.0
4	30	1990	10							20.7	3.6
5	11	1990	10							21.5	4.0
8	16	1990	10							19.0	4.5
1	30	1987	10	3	0.279	0.025	1.540				
3	26	1987	10	3	0.214	0.001	1.870				
6	0	1987	10	3	0.274	0.026	0.584				
8	2	1987	10	3	0.466	0.067	6.500				
3	0	1988	10	3	0.364	0.020	1.410				
11	21	1988	10	3	0.233	0.021					
12	29	1988	10	3	0.242	0.028	0.980				
4	27	1989	10	3	0.220	0.014	0.970				
7	27	1989	10	3							
7	25	1989	10	3							
8	2	1989	10	3	0.720	0.045	0.530				
10	31	1989	10	3	0.240	0.024	4.470				
12	0	1989	10	3	0.650	0.030	6.590				
3	0	1990	10	3	0.880	0.036	1.820				
4	0	1990	10	3	0.580	0.040					
5	0	1990	10	3	0.310	0.040	9.400				
8	0	1990	10	3	0.180	0.032					
# OF OBSERVATIONS					15	15	12				
MEAN					0.390	0.030	3.055				
MAXIMUM					0.880	0.067	9.400				
MINIMUM					0.180	0.001	0.530				
STANDARD DEVIATION					0.210	0.015	2.824				
1	30	1987	10	30							
3	26	1987	10	30							
6	0	1987	10	30							
8	2	1987	10	30							
3	0	1988	10	30							
11	21	1988	10	30			0.660				
12	29	1988	10	30							
4	27	1989	10	30							
7	25	1989	10	30	0.220	0.030	2.220				
7	27	1989	10	30	0.320	0.046	2.280				
8	2	1989	10	30				1.2	65		
10	31	1989	10	30							
12	0	1989	10	30				0.5	31		
3	0	1990	10	30				16.1	14		
4	0	1990	10	30				1.0	18		
5	0	1990	10	30				0.7	12		
8	0	1990	10	30				0.8	15		
# OF OBSERVATIONS					2	2	3	6	6		
MEAN					0.270	0.038	1.720	3.4	26		
MAXIMUM					0.320	0.046	2.280	16.1	65		
MINIMUM					0.220	0.030	0.660	0.5	12		
STANDARD DEVIATION					0.050	0.008	0.750	5.7	19		
1	30	1987	10	60	0.129	0.021	0.586				
3	26	1987	10	60	0.164	0.012	0.445				
6	0	1987	10	60	0.284	0.026	1.200				
8	2	1987	10	60	0.209	0.001	2.100				
3	0	1988	10	60	0.163	0.016	0.886				
11	21	1988	10	60	0.144	0.014	0.880				
12	29	1988	10	60	0.120	0.022	0.740				
4	27	1989	10	60	0.230	0.017	1.500				
7	25	1989	10	60	0.220	0.026	2.200				
7	27	1989	10	60	0.300	0.019	2.330				
8	2	1989	10	60	0.630	0.035	0.630	1.1	65		
10	31	1989	10	60	0.190	0.016	1.240				
12	0	1989	10	60	0.450	0.022	0.750	0.7	31		
3	0	1990	10	60	0.290	0.028	2.280	14.5	14		
4	0	1990	10	60	0.590	0.040		0.9	18		
5	0	1990	10	60	0.260	0.030	1.740	0.5	12		

Table A1-8
WATER QUALITY DATA FOR STATION 10
1987-1990

M	D	YR	STN	DEPTH (ft)	TN (mg/l)	TP (mg/l)	CHL a (ug/l)	TURBID (NTU)	S DEPTH (ft)	TEMP (C)	DO (mg/l)
8	0	1990	10	60	0.180	0.028		0.4	15		
# OF OBSERVATIONS					17	17	15	6	6		
MEAN					0.268	0.022	1.300	3.0	26		
MAXIMUM					0.630	0.040	2.330	14.5	65		
MINIMUM					0.120	0.001	0.445	0.4	12		
STANDARD DEVIATION					0.147	0.009	0.652	5.1	19		
# OF OBSERVATIONS					34	34	30	12	12	6	6
MEAN					0.322	0.026	2.044	3.2	26	21.4	4.4
MAXIMUM					0.880	0.067	9.400	16.1	65	23.0	7.0
MINIMUM					0.120	0.001	0.445	0.4	12	19.0	3.0
STANDARD DEVIATION					0.185	0.013	2.038	5.4	19	1.3	1.3

Table A1-9
WATER QUALITY DATA FOR STATION 11
1987-1990

M	D	YR	STN	DEPTH (ft)	TN (mg/l)	TP (mg/l)	CHL a (ug/l)	TURBID (NTU)	S DEPTH (ft)	TEMP (C)	DO (mg/l)
8	24	1989	11							21.0	5.1
12	21	1989	11							22.0	4.4
3	29	1990	11							21.0	2.7
4	30	1990	11							21.4	2.8
5	11	1990	11							21.5	3.8
8	16	1990	11							20.0	4.2
1	30	1987	11	3	0.888	0.072	6.970				
3	26	1987	11	3	1.050	0.080	17.600				
6	0	1987	11	3	0.498	0.048	5.030				
8	2	1987	11	3	1.630	0.259	15.800				
3	0	1988	11	3	0.742	0.050	16.800				
11	21	1988	11	3	0.362	0.054					
12	29	1988	11	3	0.420	0.038	2.170				
4	27	1989	11	3	1.300	0.125	4.170				
7	25	1989	11	3							
[illegible]	27	1989	11	3							
8	2	1989	11	3	1.400	0.135	2.900				
10	31	1989	11	3	0.600	0.062	11.100				
12	0	1989	11	3	0.880	0.053	14.500				
3	0	1990	11	3	0.630	0.049	11.210				
4	0	1990	11	3	0.940	0.060					
5	0	1990	11	3	0.610	0.100	19.200				
8	0	1990	11	3	0.220	0.035					
# OF OBS AT DEPTH					15	15	12				
MEAN					0.811	0.081	10.621				
MAXIMUM					1.630	0.259	19.200				
MINIMUM					0.220	0.035	2.170				
STANDARD DEVIATION					3.358	3.511	5.490				
1	30	1987	11	30							
3	26	1987	11	30							
6	0	1987	11	30							
8	2	1987	11	30							
3	0	1988	11	30							
11	21	1988	11	30			0.990				
12	29	1988	11	30							
4	27	1989	11	30							
7	25	1989	11	30	0.790	0.108	15.600				
7	27	1989	11	30	1.170	0.027	5.080				
8	2	1989	11	30				1.3	28		
10	31	1989	11	30							
12	0	1989	11	30				1.2	34		
3	0	1990	11	30				18.4	8		
4	0	1990	11	30				0.6	27		
5	0	1990	11	30				0.7	9		
8	0	1990	11	30				0.6	28		
# OF OBS AT DEPTH					2	2	3	6	6		
MEAN					0.980	0.068	7.223	3.8	22		
MAXIMUM					1.170	0.108	15.600	18.4	34		
MINIMUM					0.790	0.027	0.990	0.6	8		
STANDARD DEVIATION					0.190	0.040	6.154	6.5	10		
1	30	1987	11	60	0.179	0.025	1.220				
3	26	1987	11	60	0.133	0.014	0.105				
6	0	1987	11	60	0.272	0.028	0.798				
8	2	1987	11	60	0.694	0.077	6.700				
3	0	1988	11	60	0.218	0.026	9.120				
11	21	1988	11	60	0.177	0.021	1.870				
12	29	1988	11	60	0.148	0.021	0.720				
4	27	1989	11	60	0.400	0.028	0.900				
7	25	1989	11	60	0.860	0.110	14.900				
7	27	1989	11	60	0.240	0.016	2.630				
8	2	1989	11	60	0.560	0.039	0.460	1.2	28		
10	31	1989	11	60	0.300	0.027	2.530				
12	0	1989	11	60	0.730	0.054	8.710	1.3	34		
3	0	1990	11	60	1.010	0.076	5.020	17.6	8		
4	0	1990	11	60	1.050	0.050		1.1	27		
5	0	1990	11	60	0.220	0.020	1.440	0.3	9		

Table A1-9
WATER QUALITY DATA FOR STATION 11
1987-1990

M	D	YR	STN	DEPTH (ft)	TN (mg/l)	TP (mg/l)	CHL a (ug/l)	TURBID (NTU)	S DEPTH (ft)	TEMP (C)	DO (mg/l)
8	0	1990	11	60	0.220	0.027		0.2	28		
# OF OBS AT DEPTH					17	17	15	6	6		
MEAN					0.436	0.039	3.808	3.6	22		
MAXIMUM					1.050	0.110	14.900	17.6	34		
MINIMUM					0.133	0.014	0.105	0.2	8		
STANDARD DEVIATION					0.306	0.026	4.133	6.3	10		
TOTAL OBSERVATIONS					34	34	30	12	12	6	6
MEAN					0.634	0.059	6.875	3.7	22	15.9	2.9
MAXIMUM					1.630	0.259	19.200	18.4	34	22.0	5.1
MINIMUM					0.133	0.014	0.105	0.2	8	20.0	2.7
STANDARD DEVIATION					0.395	0.047	6.055	6.4	10	9.2	1.8

Table A1-10
WATER QUALITY DATA FOR STATION 11A
1987-1990

M	D	YR	STN	DEPTH (ft)	TN (mg/l)	TP (mg/l)	CHL a (ug/l)	TURBID (NTU)	S DEPTH (ft)	TEMP (C)	DO (mg/l)
8	24	1989	11A							21.0	5.0
12	21	1989	11A							22.0	4.2
3	29	1990	11A							21.0	2.5
4	30	1990	11A							21.5	3.8
5	11	1990	11A							21.5	3.8
8	16	1990	11A							20.0	3.5
1	30	1987	11A	3	1.220	0.134	15.260				
3	26	1987	11A	3	1.260	0.116	18.600				
6	0	1987	11A	3	1.330	0.146	9.230				
8	2	1987	11A	3	1.300	0.198	22.100				
3	0	1988	11A	3	0.970	0.070	20.800				
11	21	1988	11A	3							
12	29	1988	11A	3	0.366	0.057	2.260				
4	27	1989	11A	3	1.370	0.125	6.680				
7	27	1989	11A	3							
7	25	1989	11A	3							
8	2	1989	11A	3	1.800	0.173	2.070	1.5	13		
10	31	1989	11A	3	1.010	0.113	13.900				
12	0	1989	11A	3	0.720	0.054	12.100				
3	0	1990	11A	3	0.690	0.055	5.380				
4	0	1990	11A	3	0.750	0.080					
5	0	1990	11A	3	1.670	0.250	15.200				
8	0	1990	11A	3	0.540	0.088					
# OF OBS AT DEPTH					14	14	12	1	1		
MEAN					1.071	0.119	11.965	1.5	13		
MAXIMUM					1.800	0.250	22.100	1.5	13		
MINIMUM					0.366	0.054	2.070	1.5	13		
STANDARD DEVIATION					0.407	0.056	6.588	0.0	0		
1	30	1987	11A	30							
3	26	1987	11A	30							
6	0	1987	11A	30							
8	2	1987	11A	30							
3	0	1988	11A	30							
11	21	1988	11A	30	1.060	0.143					
12	29	1988	11A	30							
4	27	1989	11A	30							
7	27	1989	11A	30	1.880	0.113	14.300				
7	25	1989	11A	30	0.910	0.116	16.700				
8	2	1989	11A	30							
10	31	1989	11A	30							
12	0	1989	11A	30				2.3	26		
3	0	1990	11A	30				20.5	8		
4	0	1990	11A	30				0.9	22		
5	0	1990	11A	30				1.6	6		
8	0	1990	11A	30				0.4	22		
# OF OBS AT DEPTH					3	3	2	5	5		
MEAN					1.283	0.124	15.500	5.1	17		
MAXIMUM					1.880	0.143	16.700	20.5	26		
MINIMUM					0.910	0.113	14.300	0.4	6		
STANDARD DEVIATION					0.426	0.013	1.200	7.7	8		
1	30	1987	11A	60	1.010	0.117	21.350				
3	26	1987	11A	60	0.127	0.008	0.138				
6	0	1987	11A	60	0.491	0.052	2.380				
8	2	1987	11A	60	0.739	0.076	9.300				
3	0	1988	11A	60	0.179	0.006	0.899				
11	21	1988	11A	60	0.221	0.017	1.085				
12	29	1988	11A	60	0.183	0.026	1.700				
4	27	1989	11A	60	0.210	0.019	0.410				
7	27	1989	11A	60	0.530	0.048	5.880				
7	25	1989	11A	60	1.300	0.176	16.100				
8	2	1989	11A	60	0.510	0.027	0.430	0.9	13		
10	31	1989	11A	60	0.550	0.055	8.740				
12	0	1989	11A	60	0.710	0.053	9.170	2.3	26		
3	0	1990	11A	60	1.090	0.087	10.600	18.2	8		
4	0	1990	11A	60	0.890	0.070		1.2	22		
5	0	1990	11A	60	0.270	0.020	1.290	0.4	6		

Table A1-10
WATER QUALITY DATA FOR STATION 11A
1987-1990

M	D	YR	STN	DEPTH (ft)	TN (mg/l)	TP (mg/l)	CHL a (ug/l)	TURBID (NTU)	S DEPTH (ft)	TEMP (C)	DO (mg/l)
8	0	1990	11A	60	0.460	0.067		0.4	22		
# OF OBS AT DEPTH					17	17	15	6	6		
MEAN					0.557	0.054	5.965	3.9	16		
MAXIMUM					1.300	0.176	21.350	18.2	26		
MINIMUM					0.127	0.006	0.138	0.4	6		
STANDARD DEVIATION					0.344	0.042	6.260	6.4	8		
TOTAL OBSERVATIONS					34	34	29	12	12	6	6
MEAN					0.833	0.087	9.105	4.2	16	21.2	3.8
MAXIMUM					1.880	0.250	22.100	20.5	26	22.0	5.0
MINIMUM					0.127	0.006	0.138	0.4	6	20.0	2.5
STANDARD DEVIATION					0.472	0.057	7.045	6.8	8	0.6	0.8

Table A1-11
WATER QUALITY DATA FOR STATION 12
1987-1990

M	D	YR	STN	DEPTH (ft)	TN (mg/l)	TP (mg/l)	CHL a (ug/l)	TURBID (NTU)	S DEPTH (ft)	TEMP (C)	DO (mg/l)
8	24	1989	12							21.0	4.8
12	21	1989	12							22.0	3.0
3	29	1990	12							21.5	2.0
4	30	1990	12							21.8	3.4
	11	1990	12							21.5	2.0
8	16	1990	12							20.0	3.0
1	30	1987	12	3	1.150	0.120	14.100				
3	26	1987	12	3	1.090	0.096	18.800				
6	0	1987	12	3	0.562	0.052					
8	1	1987	12	3	0.620	0.166	20.900				
3	0	1988	12	3	0.898	0.092	33.800				
11	21	1988	12	3	0.296	0.038					
12	29	1988	12	3	0.402	0.063	2.500				
4	27	1989	12	3	1.200	0.107	5.670				
7	25	1989	12	3							
7	27	1989	12	3							
8	2	1989	12	3		0.174	2.340				
10	31	1989	12	3	0.900	0.098	22.700				
12	0	1989	12	3	0.900	0.060	21.300				
3	0	1990	12	3	0.960	0.078	12.200				
4	0	1990	12	3	0.730	0.090					
5	0	1990	12	3	1.240	0.120	22.000				
8	0	1990	12	3	0.790	0.091					
# OF OBS AT DEPTH					14	15	11				
MEAN					0.838	0.096	16.028				
MAXIMUM					1.240	0.174	33.800				
MINIMUM					0.296	0.038	2.340				
STANDARD DEVIATION					0.280	0.037	9.299				
1	30	1987	12	30							
3	26	1987	12	30							
6	0	1987	12	30							
8	2	1987	12	30							
3	0	1988	12	30							
11	21	1988	12	30			1.680				
12	29	1988	12	30							
4	27	1989	12	30							
7	27	1989	12	30	0.510	0.050	57.700				
7	25	1989	12	30	0.600	0.076	48.400				
8	2	1989	12	30				1.8	9		
10	31	1989	12	30							
12	0	1989	12	30				1.3	16		
3	0	1990	12	30				18.8	6		
4	0	1990	12	30				2.4	7		
5	0	1990	12	30				0.8	9		
8	0	1990	12	30				0.7	20		
# OF OBS AT DEPTH					2	2	3	6	6		
MEAN					0.555	0.063	35.927	4.300	11.167		
MAXIMUM					0.600	0.076	57.700	18.800	20.000		
MINIMUM					0.510	0.050	1.680	0.700	6.000		
STANDARD DEVIATION					0.045	0.013	24.512	6.511	5.080		
1	30	1987	12	60	0.266	0.033	0.257				
3	26	1987	12	60	0.158	0.014	0.111				
6	0	1987	12	60	0.273	0.030	1.990				
8	2	1987	12	60	0.563	0.063	11.500				
3	0	1988	12	60	0.198	0.030	1.760				
11	21	1988	12	60	0.157	0.019	2.120				
12	29	1988	12	60	0.155	0.024	2.010				
4	27	1989	12	60	0.350	0.033	0.480				
7	25	1989	12	60	0.610	0.119	36.100				
7	27	1989	12	60	0.720	0.087	14.800				
8	2	1989	12	60	0.890	0.072	0.640	1.1	9		
10	31	1989	12	60	0.310	0.029	8.730				
12	0	1989	12	60	0.660	0.027	1.310	1.3	16		
3	0	1990	12	60	1.060	0.079	11.400	15.5	6		
4	0	1990	12	60	0.750	0.110		3.2	7		
5	0	1990	12	60	0.250	0.050	1.480	0.6	9		

Table A1-11
WATER QUALITY DATA FOR STATION 12
1987-1990

M	D	YR	STN	DEPTH (ft)	TN (mg/l)	TP (mg/l)	CHL a (ug/l)	TURBID (NTU)	S DEPTH (ft)	TEMP (C)	DO (mg/l)
8	0	1990	12	60	0.700	0.094		0.6	20		
# OF OBS AT DEPTH					17	17	15	6	6		
MEAN					0.475	0.054	6.313	3.7	11		
MAXIMUM					1.060	0.119	36.100	15.5	20		
MINIMUM					0.155	0.014	0.111	0.6	6		
STANDARD DEVIATION					0.279	0.033	9.249	5.3	5		
TOTAL OBSERVATIONS					33	34	29	12	12	6	6
MEAN					0.634	0.073	13.061	4.0	11	21.3	3.0
MAXIMUM					1.240	0.174	57.700	18.8	20	22.0	4.8
MINIMUM					0.155	0.014	0.111	0.6	6	20.0	2.0
STANDARD DEVIATION					0.324	0.040	14.839	6.0	5	0.7	0.9

Table A1-12
WATER QUALITY DATA FOR STATION 13
1987-1990

M	D	YR	STN	DEPTH (ft)	TN (mg/l)	TP (mg/l)	CHL a (ug/l)	TURBID (NTU)	S DEPTH (ft)	TEMP (C)	DO (mg/l)
8	24	1989	13							21.0	3.0
12	21	1989	13							23.0	2.2
3	29	1990	13							21.0	3.9
4	30	1990	13							21.8	1.4
5	11	1990	13							21.8	1.5
8	16	1990	13							20.0	2.5
1	30	1987	13	3	1.010	0.110	19.400				
3	26	1987	13	3	0.712	0.081	21.000				
6	0	1987	13	3	0.410	0.046	12.400				
8	2	1987	13	3	1.150	0.180	38.100				
3	0	1988	13	3	0.794	0.090	21.700				
11	21	1988	13	3	17.200	4.560	58.800				
12	29	1988	13	3	0.468	0.080	6.840				
4	27	1989	13	3	1.230	0.113	8.380				
7	25	1989	13	3	0.860	0.152	98.900				
7	27	1989	13	3	0.490	0.088	40.200				
8	2	1989	13	3	0.750	0.095	1.530	0.9	20		
10	31	1989	13	3	0.550	0.081	31.600				
12	0	1989	13	3	0.720	0.058	11.500	1.4	12		
3	0	1990	13	3	0.690	0.105	10.200	24.0	10		
4	0	1990	13	3	0.730	0.140		3.3	4		
5	0	1990	13	3	0.980	0.140	83.900	2.3	4		
8	0	1990	13	3	0.490	0.065		1.7	11		
# OF OBS AT DEPTH					17	17	15	6	6		
MEAN					1.720	0.364	30.963	5.6	10		
MAXIMUM					17.200	4.560	98.900	24.0	20		
MINIMUM					0.410	0.046	1.530	0.9	4		
STANDARD DEVIATION					3.877	1.050	28.001	8.3	5		
1	30	1987	13	30	0.944	0.102	7.560				
3	26	1987	13	30	0.602	0.038	0.827				
6	0	1987	13	30	0.478	0.046	14.200				
8	2	1987	13	30	1.280	0.125	28.200				
3	0	1988	13	30	0.444	0.053	3.620				
11	21	1988	13	30	0.518	0.048	1.780				
12	29	1988	13	30	0.319	0.072	2.720				
4	27	1989	13	30	0.580	0.076	4.580				
7	25	1989	13	30	1.030	0.199	97.200				
7	27	1989	13	30	0.450	0.039	46.400				
8	2	1989	13	30	0.890	0.065	6.310	1.9	20		
10	31	1989	13	30	0.870	0.154	35.600				
12	0	1989	13	30	0.680	0.053	9.260	1.6	12		
3	0	1990	13	30	0.490	0.157	14.100	21.0	10		
4	0	1990	13	30	0.800	0.140		3.2	4		
5	0	1990	13	30	1.260	0.180	17.000	4.3	4		
8	0	1990	13	30	0.460	0.064		1.6	11		
# OF OBS AT DEPTH					17	17	15	6	6		
MEAN					0.711	0.095	19.290	5.6	10		
MAXIMUM					1.280	0.199	97.200	21.0	20		
MINIMUM					0.319	0.038	0.827	1.6	4		
STANDARD DEVIATION					0.284	0.052	24.494	7.0	5		
TOTAL OBSERVATIONS					34	34	30	12	12	6	6
MEAN					1.216	0.229	25.127	5.6	10	21.4	2.4
MAXIMUM					17.200	4.560	98.900	24.0	20	23.0	3.9
MINIMUM					0.319	0.038	0.827	0.9	4	20.0	1.4
STANDARD DEVIATION					2.795	0.755	26.945	7.6	5	0.9	0.9

APPENDIX A-2

Historical Water Quality Trends

APPENDIX A-2: HISTORICAL WATER QUALITY TRENDS

This appendix presents the results of the analysis of available data from previous reports on the water quality of Pago Pago Harbor. The main source of the information in this appendix is the *Wasteload Allocation Study for Pago Pago Harbor, American Samoa* (HRI, 1989).

The water quality of Pago Pago Harbor is influenced by a variety of natural and human activities, including reef filling, dredging, discharge of domestic wastewater, discharge of cannery wastewater, stream transport of eroded material from construction and agricultural activities, stream transport of solid waste and sanitary waste, and direct discharges from vessels. Salinity and temperature profiles in the harbor show slightly higher temperature and slightly lower salinity in the surface layer, which results in a small but persistent density gradient throughout the harbor at a depth of 10 to 30 feet (HRI, 1989; from M&E Pacific, 1979).

Figure A2-1 shows the time trend in TP and TN levels in the surface waters of the inner harbor for the period 1976 through 1987. The figure combines observations from CH2M HILL (1976), from M&E Pacific (1979), and from the American Samoa Environmental Protection Agency (ASEPA) from 1984 through 1987. The figure is limited to surface waters because only surface concentrations were reported in CH2M HILL (1976) from 1974 sampling. In the 1979 and the 1984 through 1987 periods, the station locations are as shown in Figure 2-7 in Section 2 of the main report; however, stations 9a and 11a were not added until 1985. The 1974 stations used for Figure A2-1 are in the same general areas as the later sites. However, 1974 Station 2 is situated much closer to the tuna cannery outfalls than the later Stations 11, 11a, or 12. The concentrations shown are averages of all available observations for each of the years reported.

The dissolved air flotation (DAF) treatment systems that were implemented by the canneries in 1975 appear to have produced a marked decrease in harbor TP and especially TN levels. However by 1987, harbor TP levels at Stations 11A and 12 increased to the 1974 levels, while the 1987 harbor TN levels remained more than 80 percent below the 1974 values.

Figures A2-2 and A2-3 show 1979 through 1987 time trends of TP and TN in inner harbor surface waters and bottom waters and in outer harbor (including Station 5 in the transition zone) surface waters and bottom waters.

The inner harbor surface waters show a clear and progressive trend of increasing TP concentrations over the period 1979 through 1987. The pattern for TN is similar though more irregular. TP concentration increases over the period 1979 through 1987 range from 60 percent to over 150 percent, while TN increases over the same period range from 200 percent to over 400 percent.

The inner harbor bottom waters exhibit no clear trend in TP or TN levels. The anomalously high 1984 TP value shown is reportedly the result of an outlier observation probably because of sample collection error (HRI, 1989). If the suspect value were removed, the 1984 average would drop to 57 μg/l, which would fall between the 1985 and 1986 values.

The outer harbor surface waters reveal no clear trends in either TP or TN levels. However, the 1987 levels for both TP and TN appear to be anomalously high at Stations 8, 8a, and 9. The averages plotted are based on only four observations, made in January, March, June, and August. No single sample datum seems aberrant.

The outer harbor bottom waters show no clear trends in TN concentrations, although Stations 8, 8a, and 9 again appear inconsistently high. The TP levels reveal a modest decline from 1984 through 1987.

Many estuaries or fjords similar to Pago Pago Harbor exhibit substantial vertical structure or stratification with respect to salinity, nutrient levels, and other water quality parameters. By contrast, Pago Pago Harbor displays little vertical structure in nutrient levels although there does exist some salinity structure, especially during the wet season.

Figure A2-4 presents the vertical freshwater profiles based on four salinity profiles taken at each of the nine 1979 sampling stations. The figure shows the results for the two wet-season sampling visits (February 14 and 19, 1979) and for the two dry season sampling visits (July 5 and July 11, 1979). During the 5 days preceding each of these four visits, the cumulative precipitation recorded at Pago Pago Airport was 0.45, 6.34, 0.16, and 0.35 inches, respectively. The precipitation recorded at the Atu'u station within the basin was 0.97 and 9.90 inches preceding the February 14 and 29 sampling visits, respectively. Unfortunately, the Atu'u station record was discontinued on May 31, 1979. The relative freshwater fraction, f(^{o}/oo), was calculated from the observed salinity as described on page 16 of the Wasteload Allocation Study Report (HRI, 1989).

The freshwater fraction values observed during the wet season were consistently higher than the values observed during the dry season at comparable depths. The freshwater fraction shows a substantial increase from February 14 to 19 and from July 5 to 11 because of the increased precipitation during the interval between sampling visits. The halocline occurs at depths of 10 to 20 feet in the wet season and 20 and 40 feet in the dry season. As might be expected, the highest freshwater fractions occurred in the inner harbor and near the Aua subbasin confluence. On the basis of the 1979 data, there appears to be no association between freshwater fraction and TP levels.

Although there is no notable association between f and TP, Figure A2-5 shows that nutrient levels at 60 feet (i.e., the deepest samples collected during the 1984 through 1987 ASEPA program) are consistently lower than at 3 feet for both TP and TN. Specifically, only 20 percent of the 60-foot TP levels were higher than the

corresponding 3-foot values, and only 2 percent of the 60-foot TN levels were substantially higher. Only 8 percent of the 60-foot TP values were substantially (by ≥25 μg/l) higher. All of the elevated 60-foot TP levels were for inner harbor stations or for the station nearest the Aua subbasin confluence.

Some additional information on vertical profiles of nutrient levels can be drawn from the Department of Public Works (DPW) Quarterly Sampling Program results for November 1986 through June 1988. At five harbor sampling stations, DPW collected samples at 3-foot, 68-foot, and 130-foot depths, which were analyzed for TP and TN. Two of these stations were very near the Utulei outfall, and the other three are near the harbor entrance or mouth. There is considerable variation among the profiles. Many 130-foot samples have higher nutrient levels than the 68-foot samples. Overall, no strong vertical profile seems evident.

In addition to the notable time trends and modest vertical variation in harbor TP and TN concentrations, a strong longitudinal or axial trend is apparent. Figures A2-6 and A2-7 display the annual average (depth-averaged) TP and TN levels versus the longitudinal distance in meters from the harbor entrance or mouth to the station location for the available observations at the M&E Pacific (1979) and ASEPA (1985 through 1987) stations. The TP and TN values plotted were determined from the annual averages for TP and TN for each station and sample depth as provided by the ASEPA. The vertical average was calculated as the average of the 3-foot and 60-foot annual average values (HRI, 1989).

There is a clear and consistent pattern apparent in each of the five available longitudinal profiles: TP and TN levels are highest in the inner harbor and decline toward the lowest levels at the harbor entrance. TP concentrations in the inner harbor were from 200 to 400 percent higher than levels at the harbor entrance, and TN concentrations in the inner harbor were from 30 to 400 percent higher than levels at the harbor entrance.

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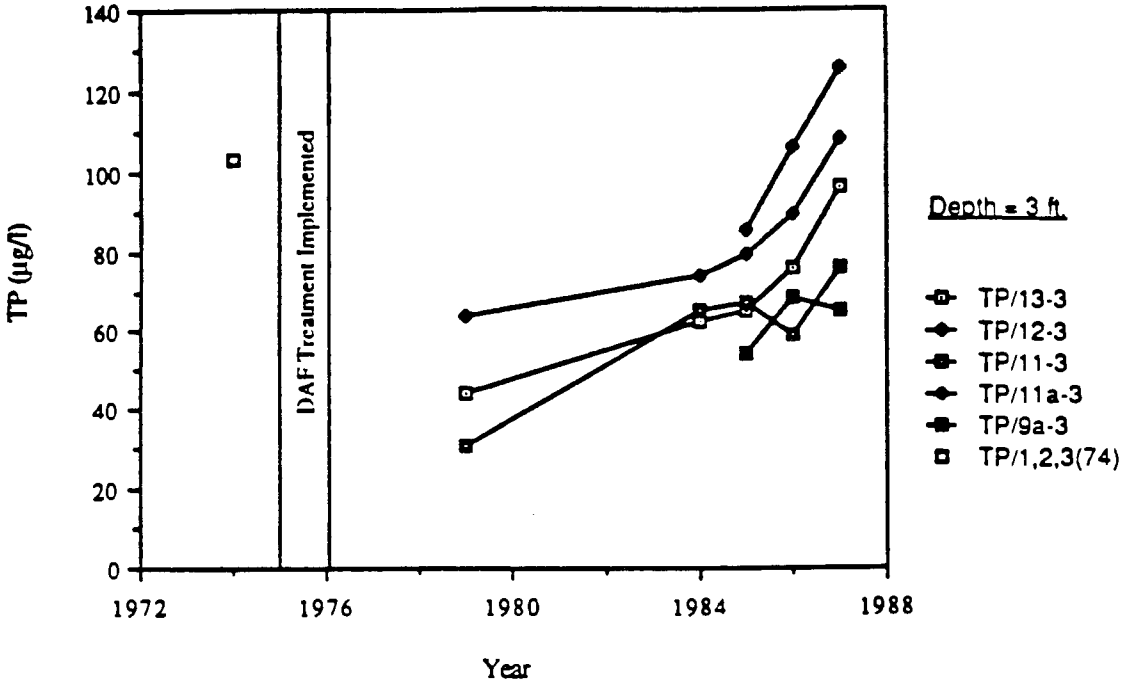


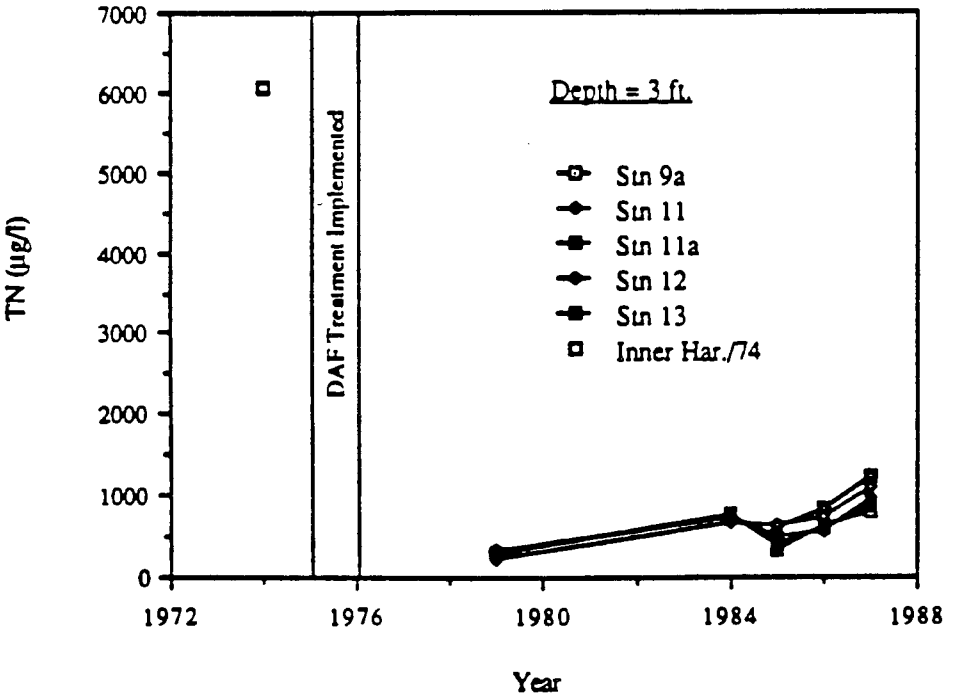


FIGURE A2-1
Long Term Trends in Inner Harbor TP and TN Concentrations (from HRI, 1989)

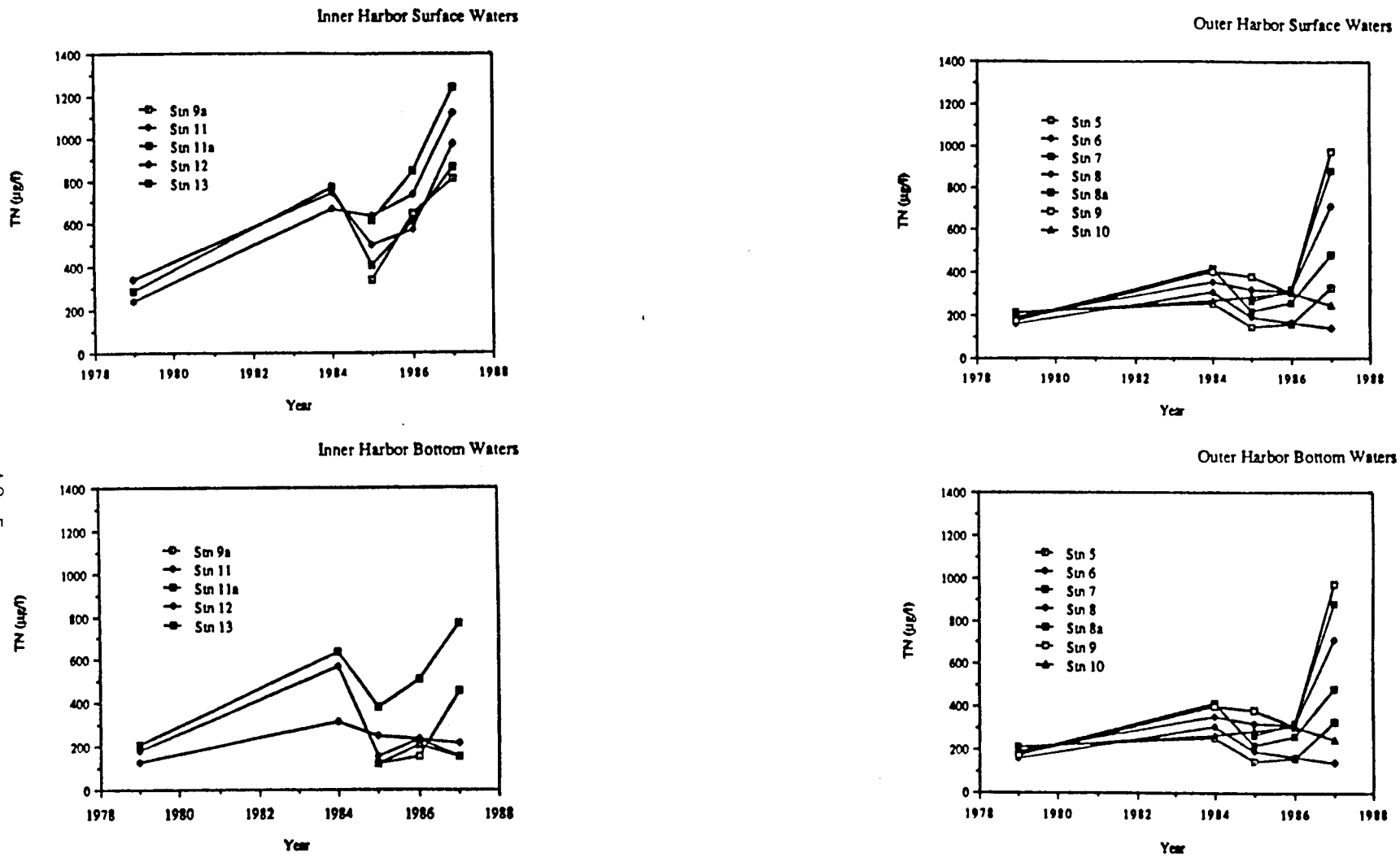


FIGURE A2-2
Trends in TN Concentrations
(from HRI, 1989)

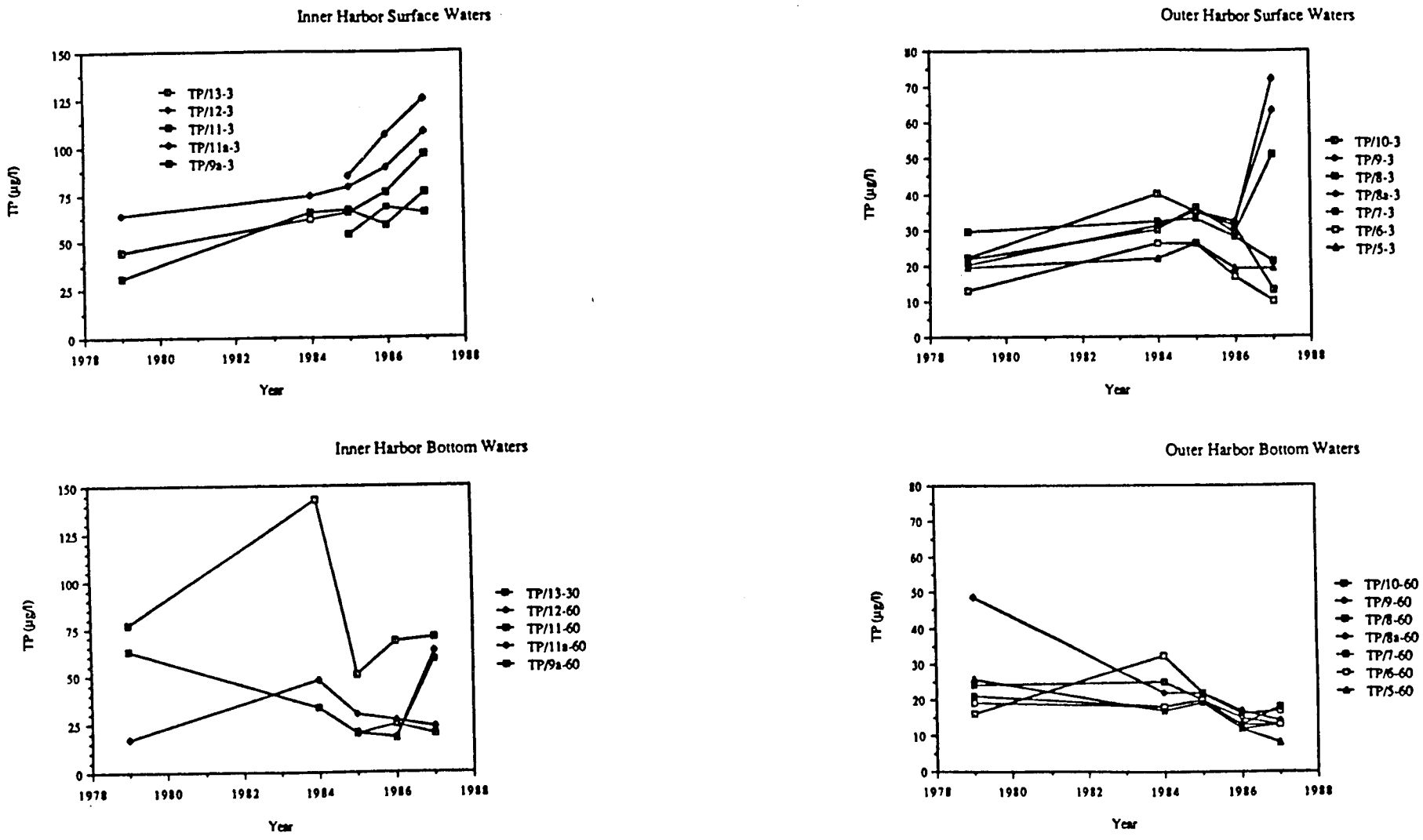


FIGURE A2-3
Trends in TP Concentrations
(from HRI, 1989)

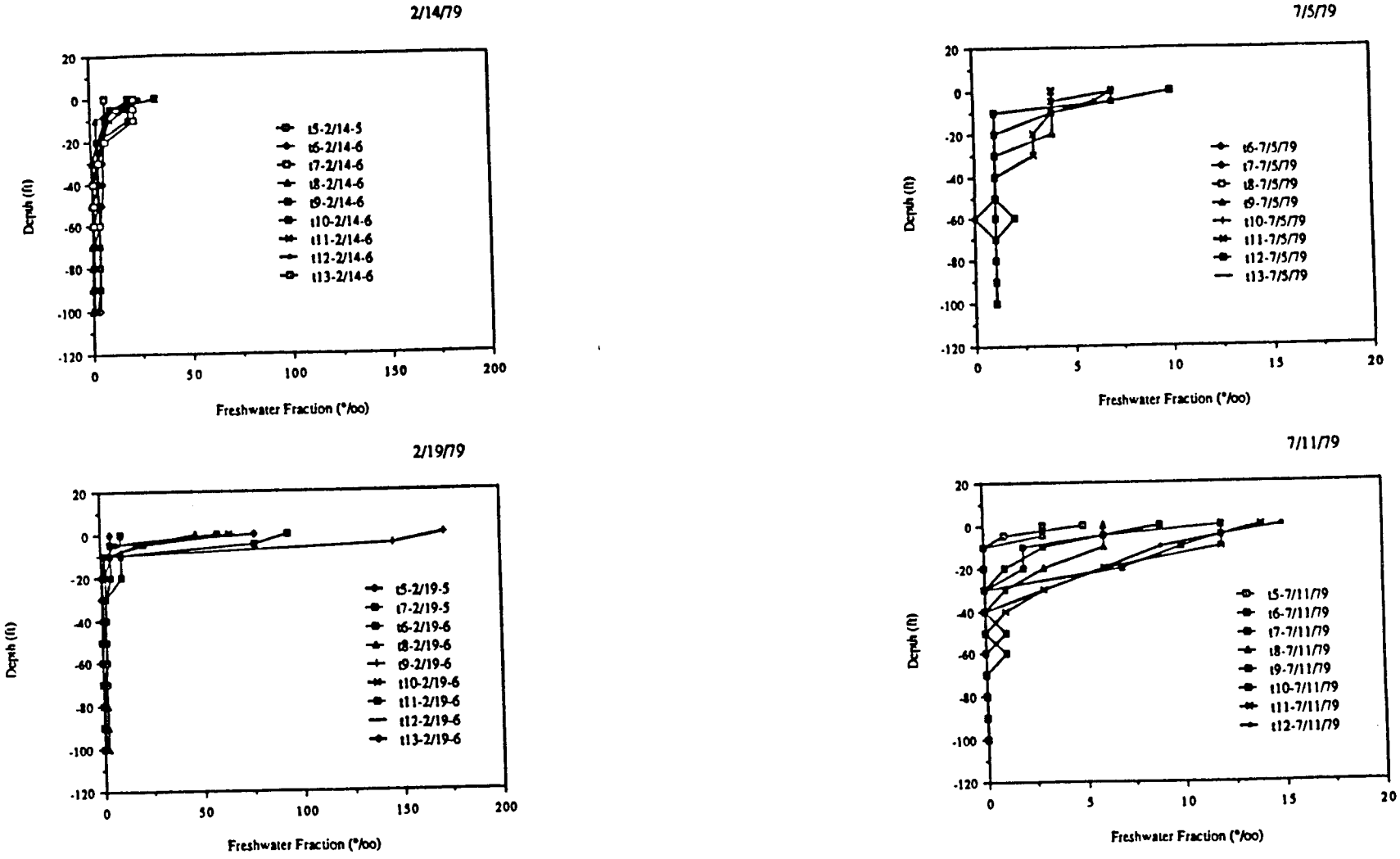
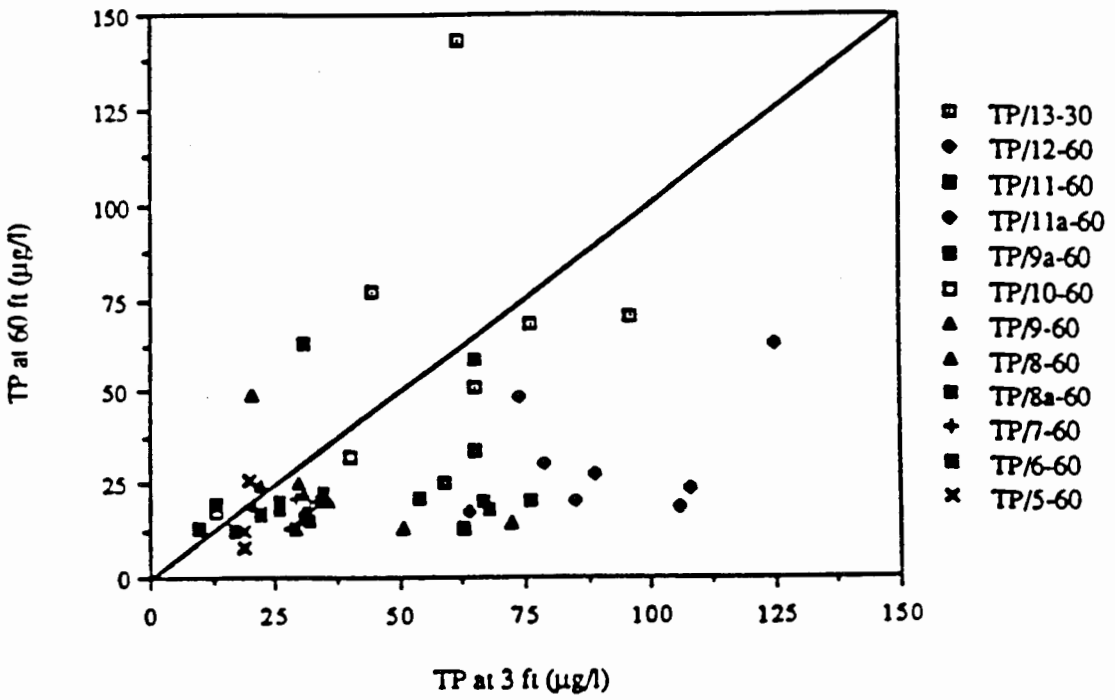


FIGURE A2–4
Vertical Stratification
Based on Relative Fresh
Water Fraction
(from HRI, 1989)



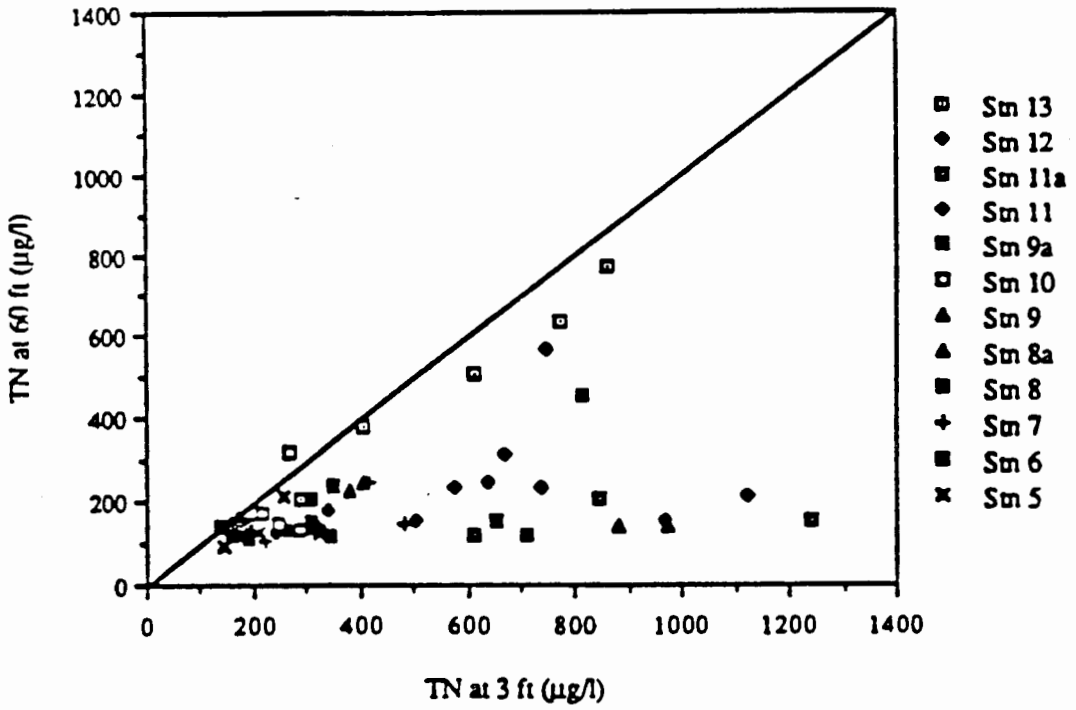


FIGURE A2-5
Vertical Distribution of TN and TP (from HRI, 1989)

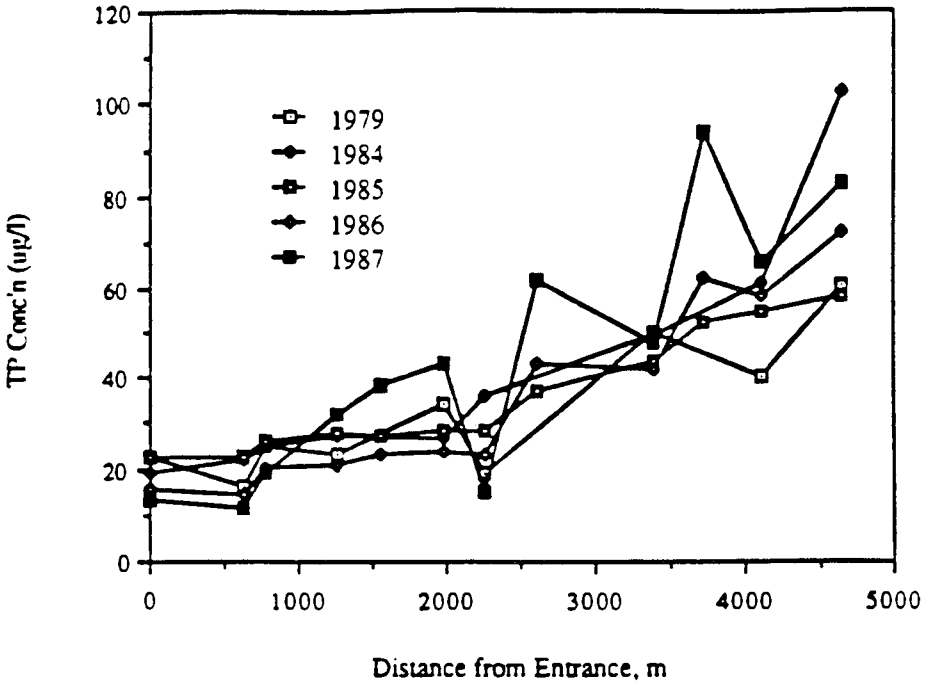


FIGURE A2-6
Annual (Depth-Averaged) Average TP Concentration Along the Harbor (from HRI, 1989)

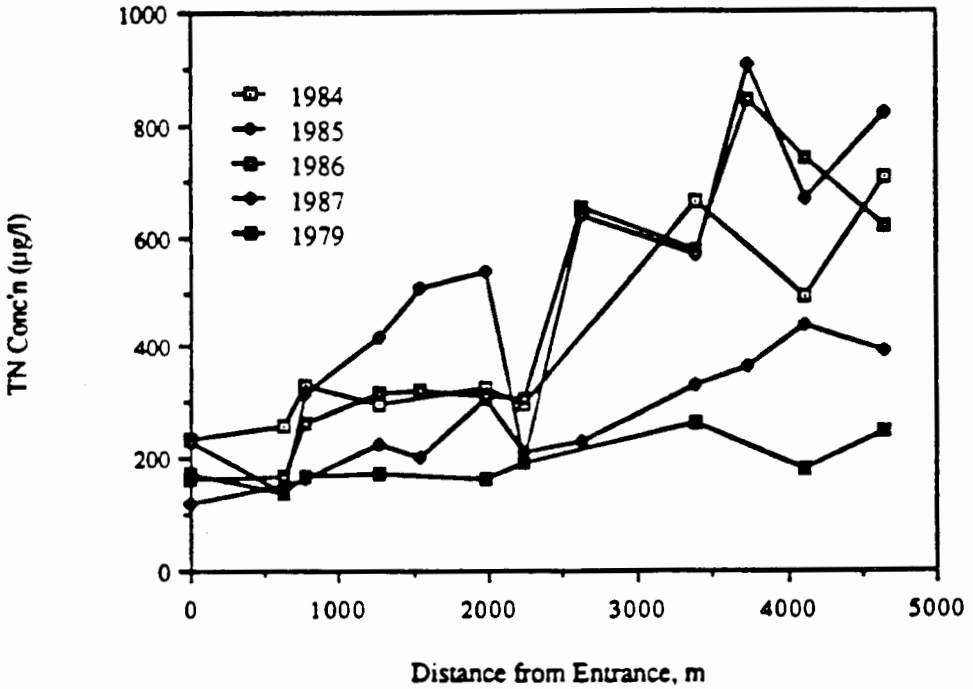


FIGURE A2-7
Annual (Depth-Averaged)
Average TN Concentration
Along the Harbor
(from HRI, 1989)

APPENDIX A-3

Short-Term Effluent Concentration Data

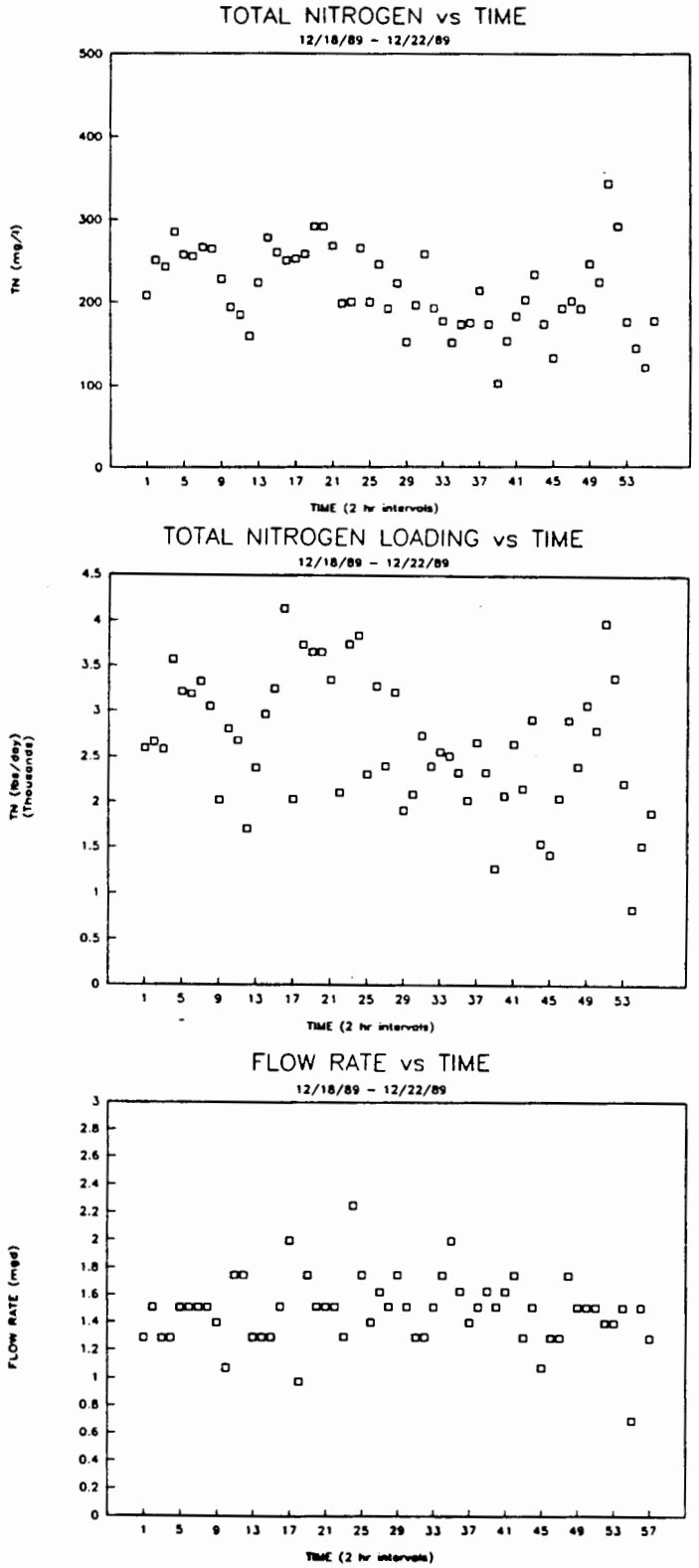


FIGURE A3-1
Short-Term Variability of Effluent Characteristics for TN (12/18/89-12/22/89)

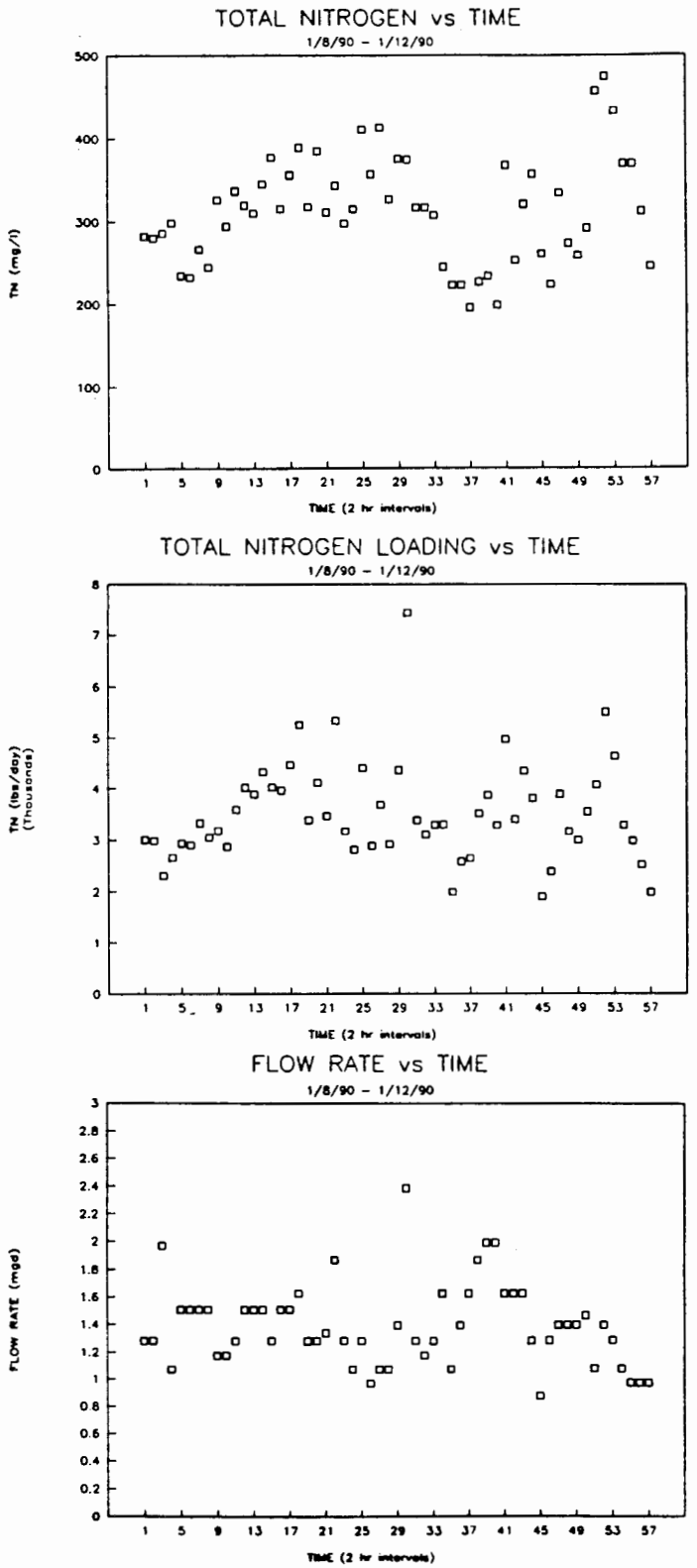


FIGURE A3-2
Short-Term Variability of Effluent Characteristics for TN (1/8/90-1/12/90)

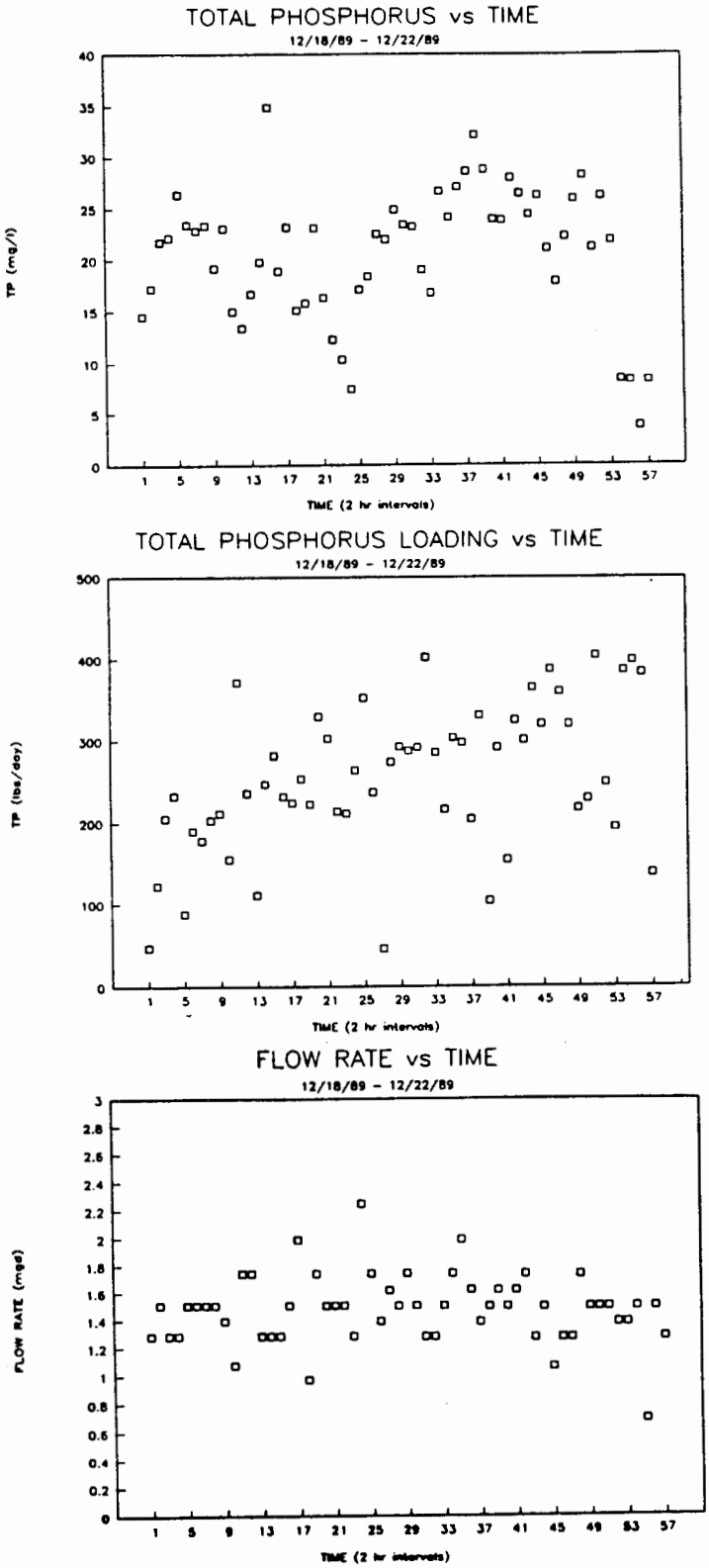


FIGURE A3-3
Short-Term Variability of Effluent Characteristics for TP (12/18/89-12/22/89)

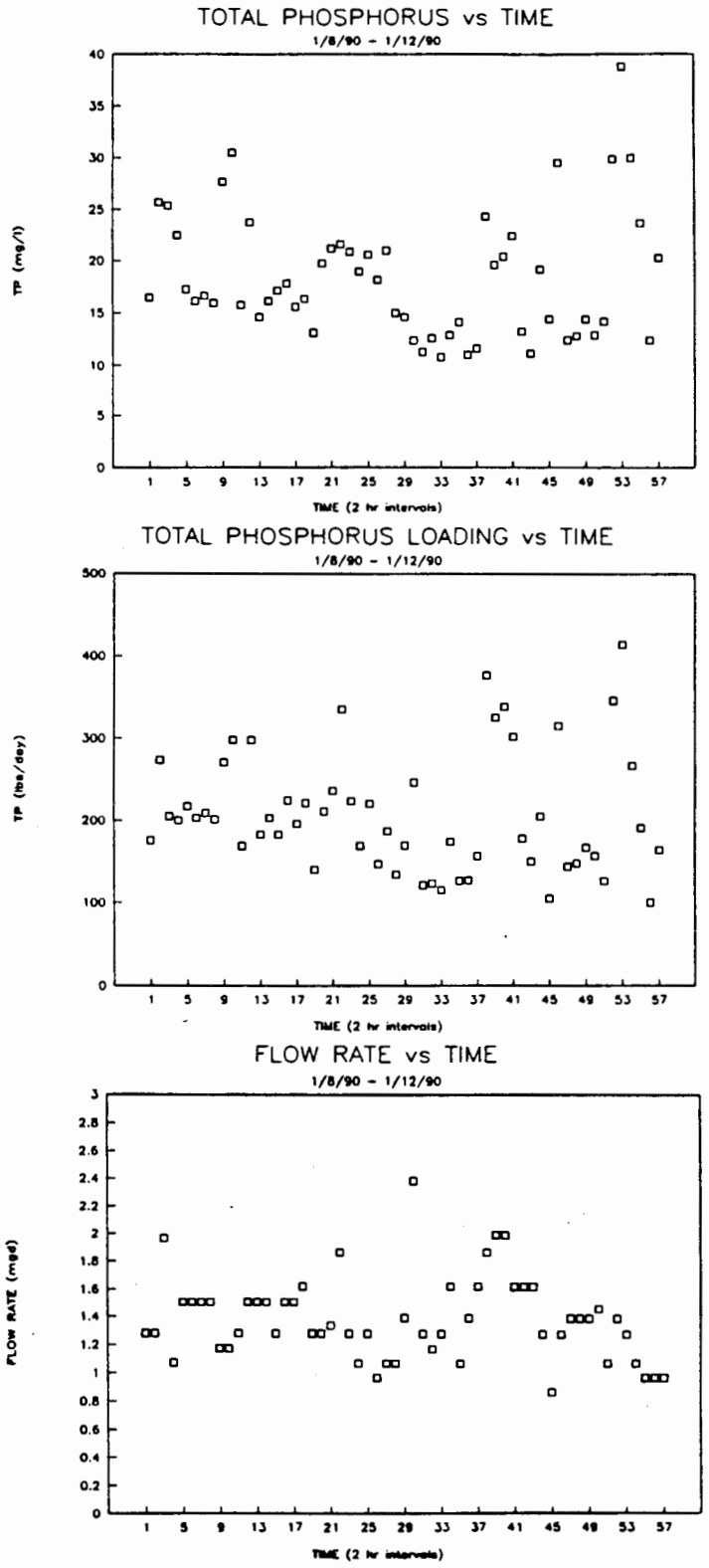
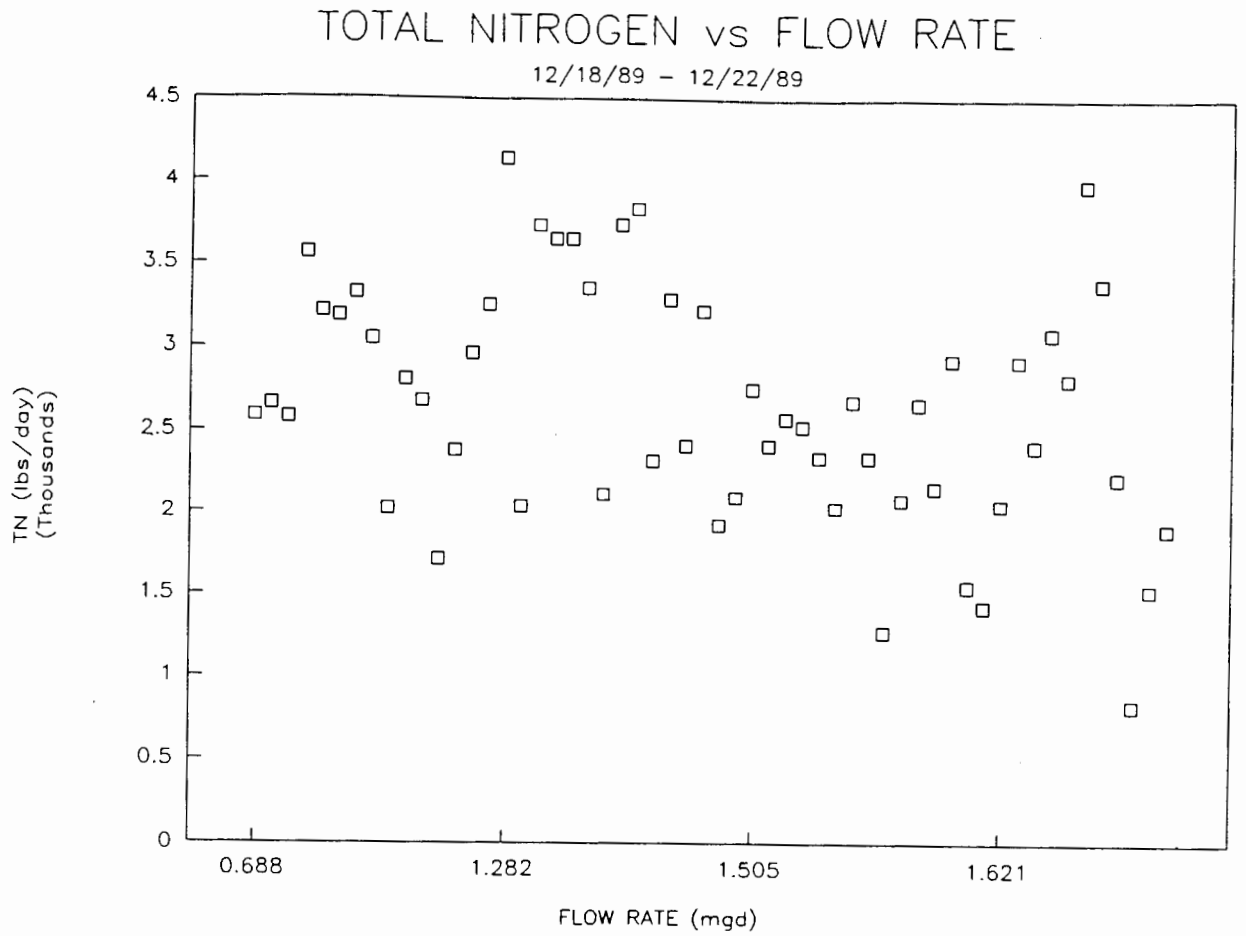


FIGURE A3-4
Short-Term Variability of Effluent Characteristics for TP (1/8/90-1/12/90)



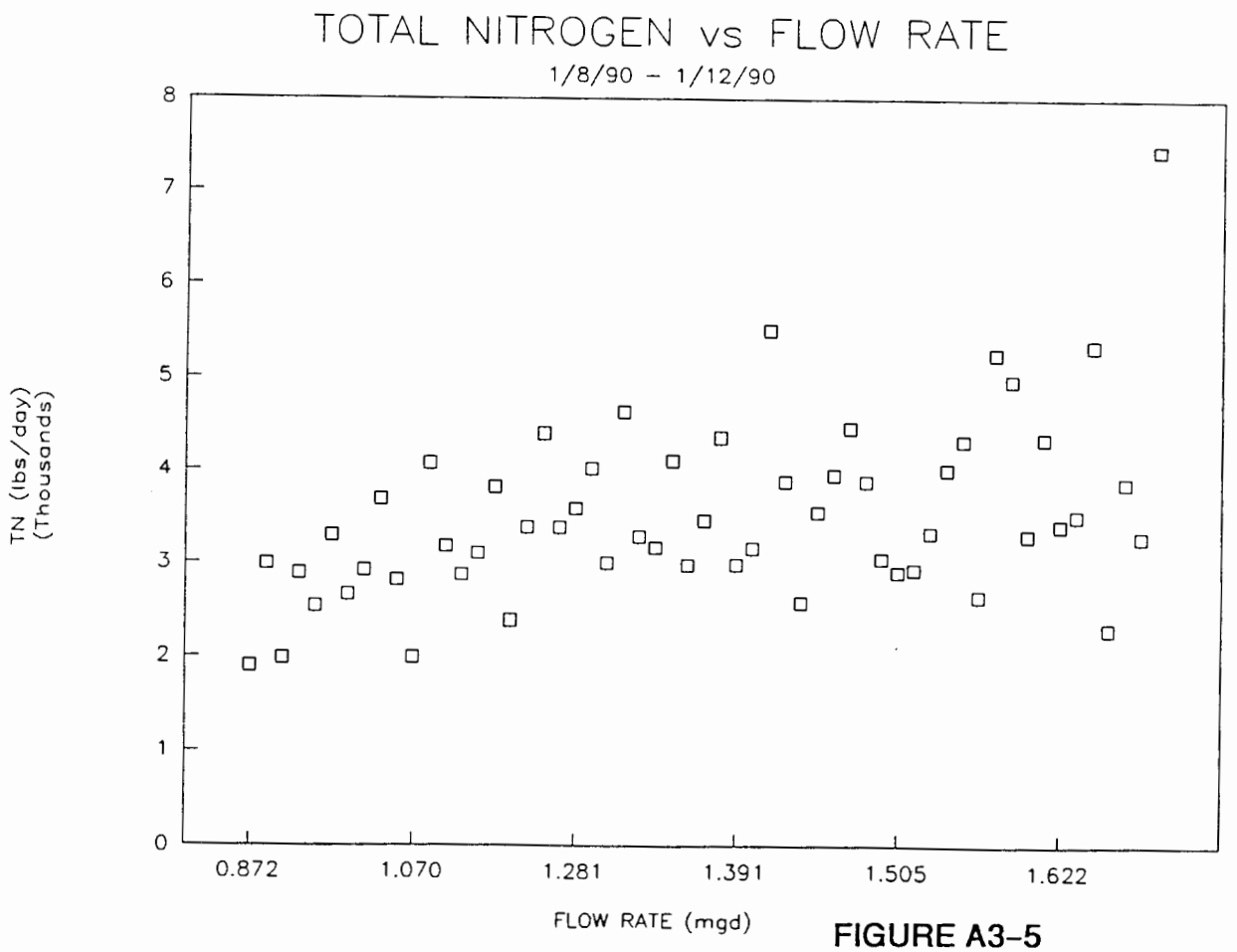
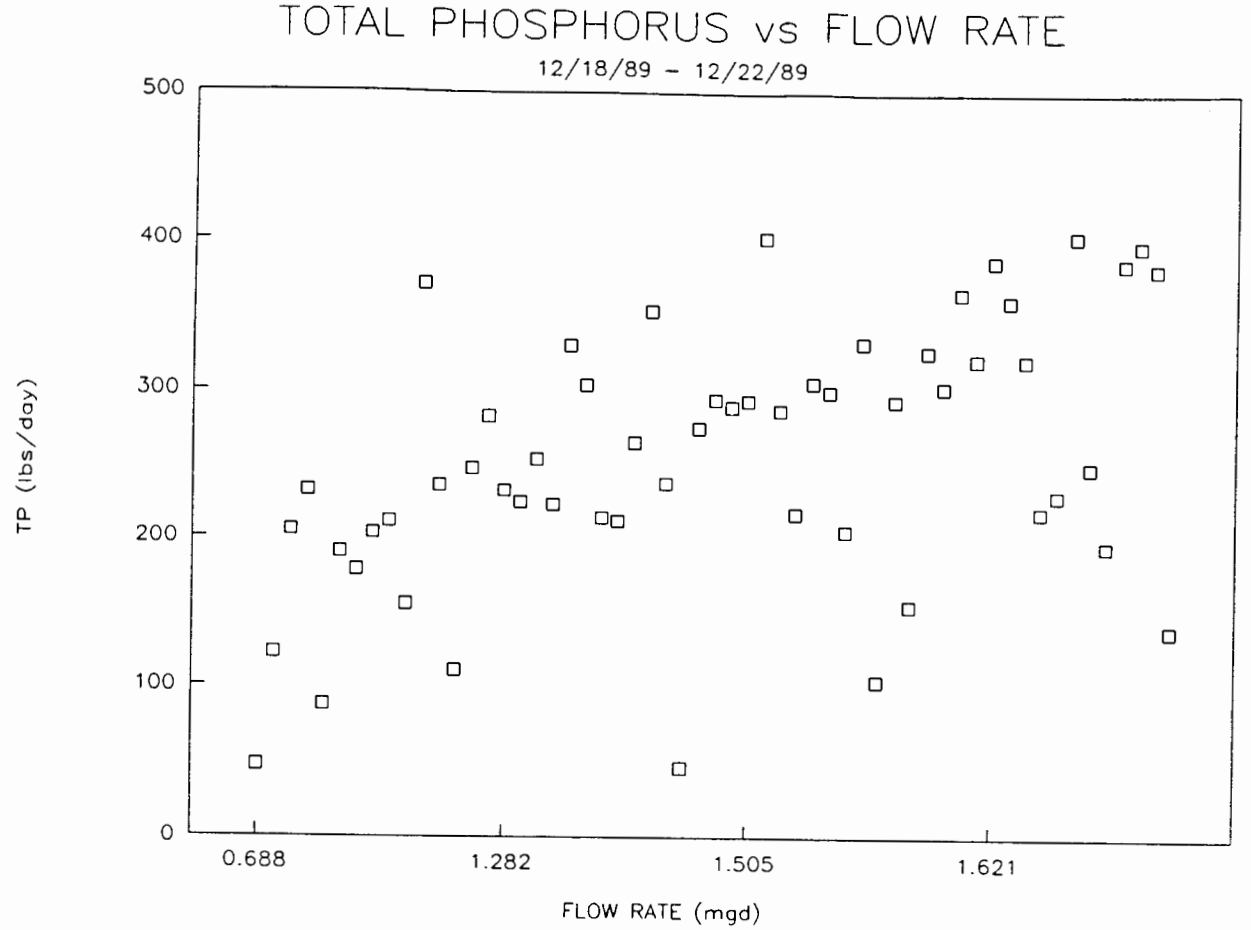


FIGURE A3-5
Short-Term Variability of Loading-Flow Rate Dependence for TN (Dec '89 & Jan '90)



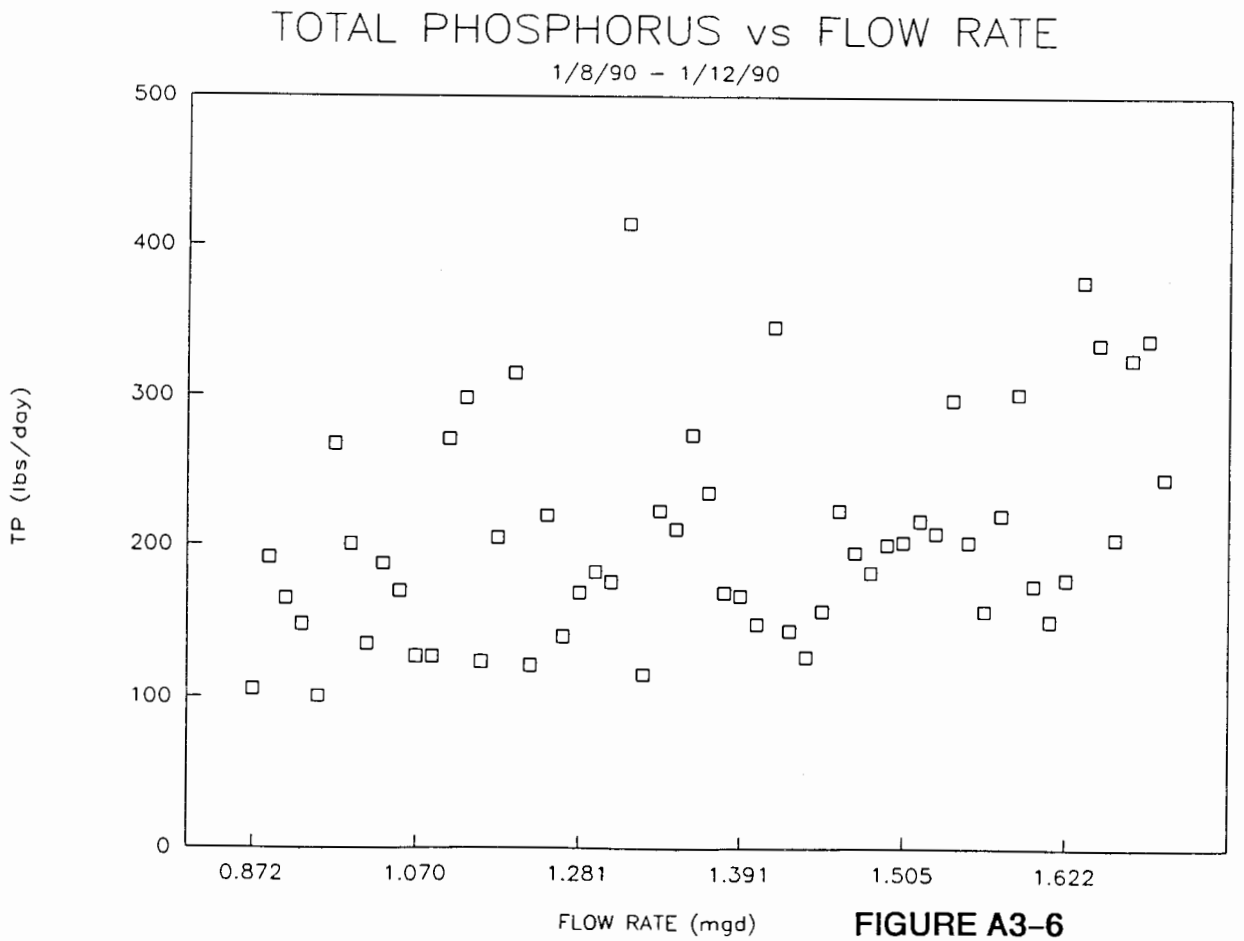


FIGURE A3-6
Short-Term Variability of Loading-Flow Rate Dependence for TP (Dec '89 & Jan '90)

APPENDIX A-4

Historical Effluent Characteristics

APPENDIX A-4: HISTORICAL EFFLUENT CHARACTERISTICS

Most of the previous work has concluded that the Samoa Packing and StarKist tuna canneries are the predominant sources of TP and TN loadings into Pago Pago Harbor (CH2M HILL, 1976; M&E Pacific, 1979; CH2M HILL, 1984). The basis of earlier estimates has been short-term observations of cannery effluent flow rates and TP and TN concentrations. Estimates developed HRI (1989) and discussed below are based on data provided by the Discharge Measurement Reports (DMR) submitted to the ASEPA by Samoa Packing and StarKist for the period December 1984 through June 1988. Some data gaps exist in these reports.

Two distinct sampling methods were used for the DMRs. Prior to April 1987, TP and TN effluent loadings from Samoa Packing were determined from TP and TN concentration measurements made on a single 24-hour composite effluent sample collected once a month during normal cannery operating conditions. Since then, the monthly loading estimates have been based on two 24-hour composite samples collected twice a week during normal cannery operating conditions.

The results of two quality assurance (QA) studies were available that cover TKN and TP analyses by Samoa Packing and StarKist laboratories: Study 7-DMR-QA (July 20, 1987) and Study 8-DMR-QA (July 12, 1988). In both studies, USEPA standards were sent to the laboratories for analysis. The concentration estimates reported by the laboratories as well as the USEPA values are given in Table A4-1. The reported TP values deviate quite substantially from the USEPA values in both directions, although the general tendency seems to be to underestimate the TKN and TP concentrations.

Because the reported cannery loading estimates depend on the TKN and TP concentrations reported by the canneries and because the reported concentrations appear in general to be underestimates of the actual TKN and TP effluent levels, the reported cannery loading estimates may underestimate the actual loadings.

Figure A4-1 displays the time trends in cannery effluent discharge rates, based on the DMR data, for the period December 1984 through June 1988. The monthly average effluent discharge from StarKist appears to have declined from about 1.5 mgd to about 1.1 mgd over this period, while the Samoa Packing monthly average effluent discharge remained approximately constant at 0.45 mgd.

Figure A4-2 shows the time trends in the TP and TN effluent concentrations for each of the canneries. Both TP and TN levels rose substantially in Samoa Packing effluent over the period examined. StarKist effluent TP levels were essentially stable, and TN levels rose modestly. Over the same period, cannery production increased.

All of the reported nutrient loadings in the DMRs are based on effluent concentration measurements taken during normal operating conditions (i.e., tuna are being thawed and processed), even though the fraction of days per month spent in normal operation is highly variable, ranging from 32 to 97 percent. According to cannery officials, the variation is because of scheduled holidays and the availability of tuna (HRI, 1989).

To adjust for the variation in loadings resulting from the month-to-month variation in days of normal operation, the loadings reported in the DMRs were multiplied by the fraction of days of normal operation for the month. Figure A4-3 shows the time trends of adjusted monthly average TP and TN loadings for each of the canneries over the period examined (HRI, 1989).

No attempt was made to use the DMR QA study results to correct or adjust the reported loadings for the HRI study. The reported loadings were used by HRI to develop the water quality model on which the TMDL estimate and the WLAS depend. Because the model calibration to observed water quality conditions in the harbor is conditioned on the cannery loadings assumed, the possible discrepancy between reported and actual loadings was, to some extent, corrected for during the calibration process.

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Table A4-1
QUALITY ASSURANCE STUDY RESULTS
FOR TKN AND TP ANALYSES

DMR-QA STUDY	DATE	WATER QUALITY PARAMETER	USEPA STD (mg/l)	STARKIST		SAMOA PACKING	
				CONC (mg/l)	% DIFF	CONC (mg/l)	% DIFF
#7	7/20/87	TKN	12.80	13.70	-7.03	5.60	56.25
		TP	5.90	1.40	76.27	1.80	69.49
#8	7/12/88	TKN	14.50	12.60	13.10	11.20	22.76
		TP	4.40	2.02	54.09	7.70	-75.00

Source: HRI, 1989

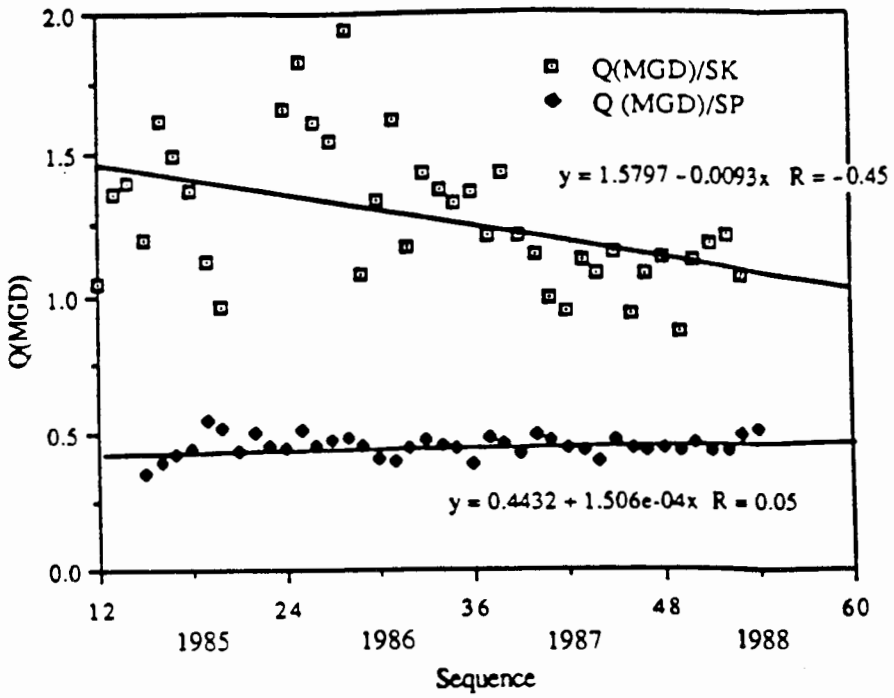
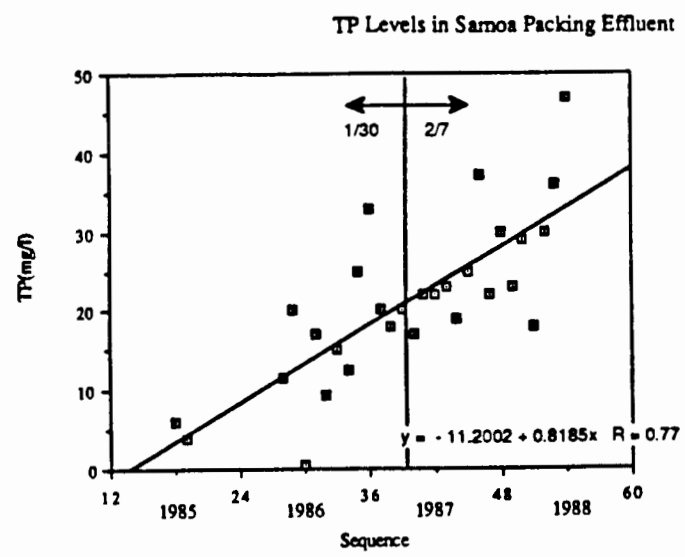
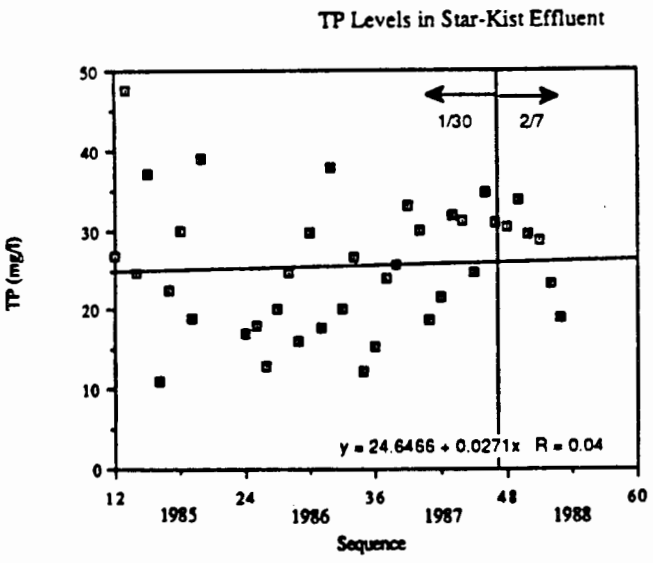
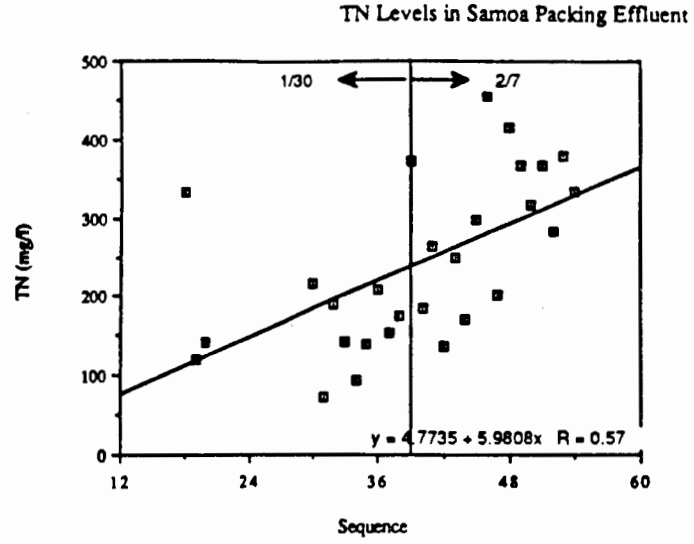


FIGURE A4-1
Time Trends in Effluent Discharge Rates (from HRI, 1989)







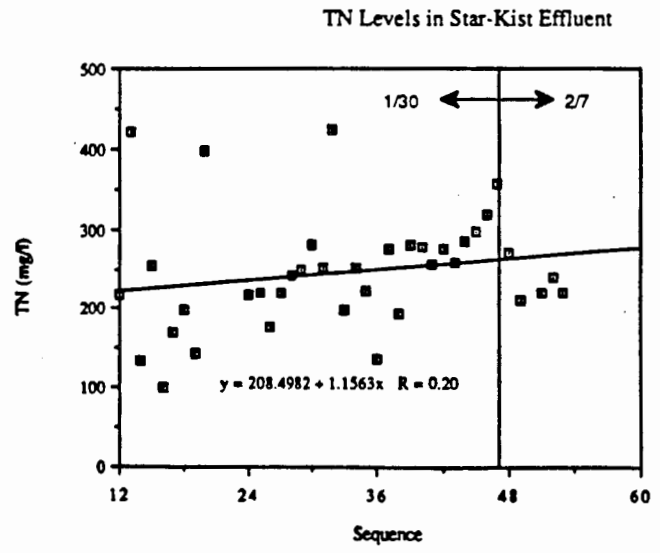
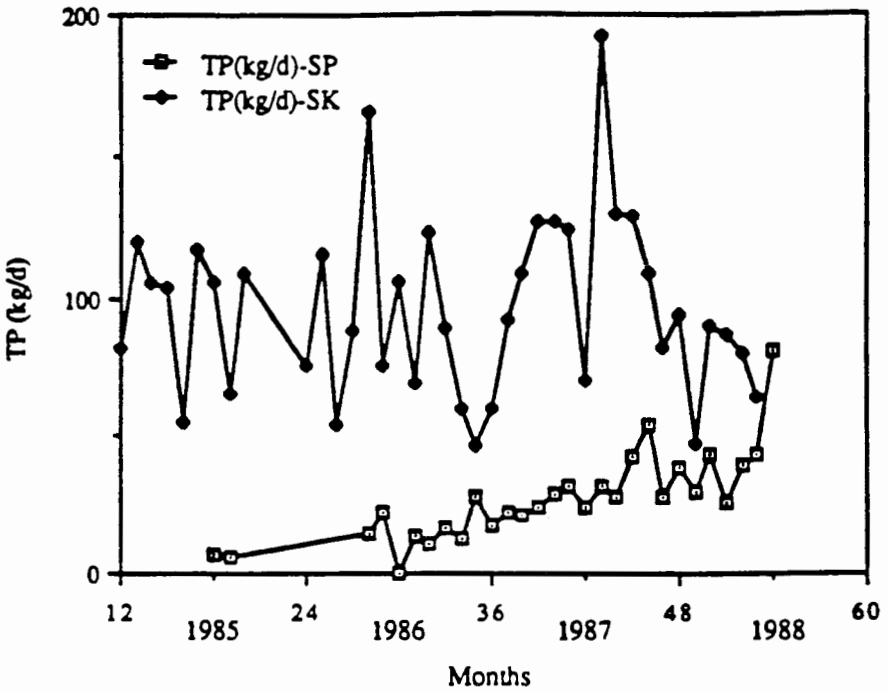


FIGURE A4–2
Trends in TP and TN Loadings
Based on Measured Values
(from HRI, 1989)



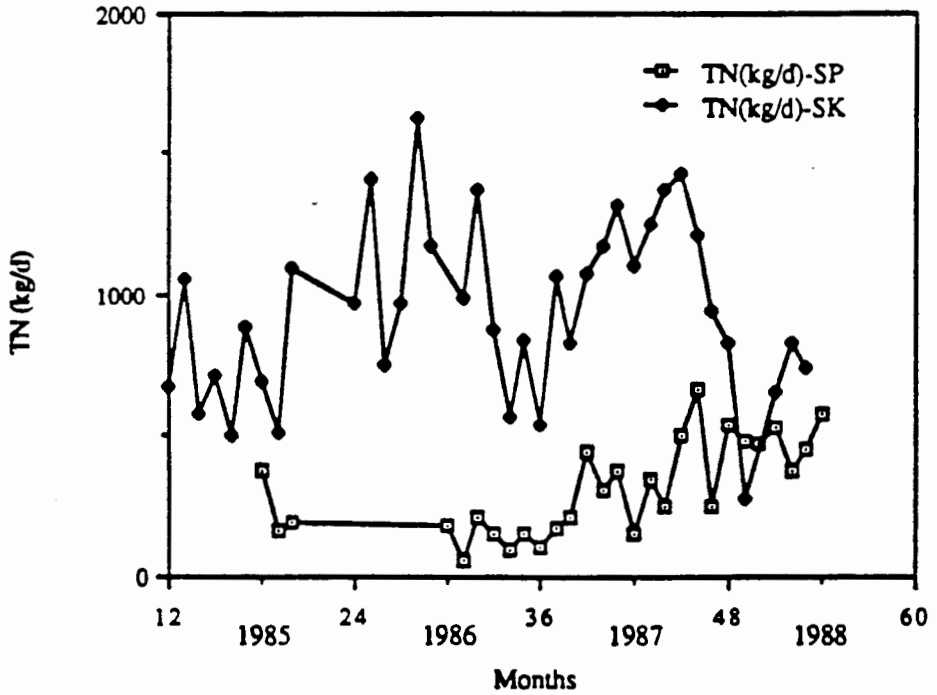


FIGURE A4-3
Trends in TP and TN Loadings Adjusted for Periods of Operation
(from HRI, 1989)

APPENDIX A-5

Field Protocol For Water Quality Sampling

APPENDIX A-5

Field Protocol for Water Quality Sampling: StarKist Samoa Outfall Alternative Feasibility Studies Technical Memorandum

PURPOSE

The purpose of this memorandum is to present a field protocol for the water quality sampling in Pago Pago Harbor to be collected in late October or early November, 1990. This field work is designated Subtask FS2 in the Preliminary Field Operations Plan (Draft Memorandum dated October 1, 1990). The preparation and review of this protocol is a part of the QA/QC for the water quality sampling.

The purpose of the sampling is to help evaluate changes in total nitrogen (TN) and total phosphorous (TP) concentrations in Pago Pago Harbor after the canneries have implemented high strength waste segregation. The water samples will be taken at the same locations in Pago Pago Harbor that have been routinely sampled by ASG to provide a basis for comparison.

SAMPLING LOCATIONS

The sampling stations are those established by M&E Pacific during the Baseline Water Quality Study (1979). Seven sampling station locations (Stations 5, 6, 9, 10, 11, 12, and 13) shown in Figure 1 will be sampled. These stations represent the minimum number of locations that will be sampled, additional locations will be sampled if, during the course of the field work, it appears that expanded sampling would be essential in meeting the objectives of the outfall Alternatives Feasibility Study.

SAMPLING DEPTHS

Up to four water samples will be collected at each station. At every station sampling depths will include both a near surface and a near bottom water sample. The near surface sample will be collected at least 30 cm below the surface and not more than 1 meter below the surface. The near bottom sample will be collected within 2 meters of the bottom but not so close that bottom sediments would be inadvertently included in the sample. One or two mid depth samples will be collected depending on the total depth of the water.

The depths at each station to be sampled have been chosen after reviewing the existing data to account for typically observed vertical structure of the water column. The actual depths sampled will depend upon the water depth at that station and final determinations may be made on station in the field. A total of 28 samples will be collected for analysis of TN and TP as shown in Table 1 below. In addition 7 duplicate samples will be collected of which three will be analyzed for TN, three will be analyzed for

TP, and one will be analyzed for both TN and TP. The duplicates are indicated with a "D" in the sample designator in Table 1. The use of duplicates is a part of the QA/QC for this task.

SCHEDULE AND STAFF

Water samples are scheduled to be collected on November 1, 1990. The scheduled contingency day for the sampling (in the event of weather-related delays or other unforeseen circumstances) is set for November 3. A small, 17 to 25 foot boat with motor will be sufficient for traveling to the sampling stations.

Sample collection will require two CH2M HILL personnel and one deck hand. For planning purposes it is assumed that David Wilson and Tom Coyner will collect the water samples. Overall responsibilities for station location determination, field documentation, and sample custody will be taken by Mr. Wilson. Mr. Coyner will be responsible for equipment mobilization, operation, and demobilization.

SAMPLING PROCEDURES

POSITIONING

Locating the sampling stations will be done using line-of-sight positioning. This method will be sufficient for the level of accuracy needed in sampling the same locations as those by M&E Pacific and ASG (Figure 1). However, if problems are encountered with this method, the range/azimuth laser positioning system being used for the geophysical survey navigation can also be used to locate the sampling site. When located, the sampling station can then be marked with a surface buoy so that sampling can be done at a convenient time.

SAMPLE COLLECTION

Water samples will be collected through a hose attached to a submersible pump. While on station, the pump will be lowered over the side to the desired depth. A pre-measured, marked line (in appropriate depth increments) will be used to lower to hose/pump apparatus to the collection depths.

Travel time for the water through the length of hose (from the pump to the hose end) must be taken into account so that water is collected from the intended depth. The travel time will be calculated knowing the hose diameter, hose length, and pumping rate, all of which are easily measured and checked. At a minimum, the travel time will be multiplied by at least a factor of 5 to ensure that water from the desired depth has entirely flushed the hose before samples are taken.

In the event that the submersible pump malfunctions, water samples will be collected using a Van Dorn or equivalent water sampler (two sampling devices will be taken as backup). These are standard sample collection devices which project staff have used frequently. The same marked line will be used to collect the

sample from the correct depths.

Acid-washed polyethylene sample bottles will be used to collect, store, and transfer the water samples. Bottles will be supplied by AECOS Laboratories. The bottles will be uncapped at the time of sample collection, rinsed thoroughly with the sample water (either from the hose/pump system or a water sampling bottle), and placed in a ice chest which will be maintained at 4 °C or lower until delivered to the lab. A minimum of 125 ml of sample is required for analysis of total nitrogen and total phosphorus.

SAMPLE HANDLING

Sample bottles will be labeled as collected or pre labeled prior to collection. All sample bottle labels will contain the following information: sequential sample number, station number, sample designator, sample water depth, sampling date and time, and any other pertinent information. This information, along with any other pertinent field observations will also be recorded in a field log or notebook at the time of collection.

Samples may be frozen after collection (if facilities are available) or will be kept in an ice bath and then shipped in ice. Holding times of the samples is not a constraint for this study as long as the samples are kept cold or frozen. Samples will be shipped or carried as excess baggage from American Samoa to Honolulu and deliver to AECOS Laboratories. The samples will be analyzed for TN and TP at the laboratory and results transmitted to CH2M HILL project staff in Seattle.

EQUIPMENT REQUIREMENTS

The equipment and supplies required for the collection of the water samples, the source of the equipment, and the backup equipment planned for is listed in Table 2.

Table 1
PLANNED WATER QUALITY SAMPLES

Station		Sample		Constituents
Number	Depth(m)	Designator	Depth(m)	Measured
13	13	13/S	S	TN,TP
		13/SD	S	TN
		13/M	4	TN,TP
		13/B	B	TN,TP
12	31	12/S	S	TN,TP
		12/SD	S	TN
		12/MU	4	TN,TP
		12/MUD	4	TP
		12/ML	10	TN,TP
		12/B	B	TN,TP
11	40	11/S	S	TN,TP
		11/MU	4	TN,TP
		11/MUD	4	TN,TP
		11/MM	10	TN,TP
		11/ML	20	TN,TP
		11/B	B	TN,TP
10	51	10/S	S	TN,TP
		10/MU	4	TN,TP
		10/ML	20	TN,TP
		10/MLD	20	TN
		10/B	B	TN,TP
9	50	9/S	S	TN,TP
		9/MU	4	TN,TP
		9/ML	20	TN,TP
		9/MLD	20	TP
		9/B	B	TN,TP
6	73	6/S	S	TN,TP
		6/MU	4	TN,TP
		6/MM	10	TN,TP
		6/ML	30	TN,TP
		6/B	B	TN,TP
5	40	5/S	S	TN,TP
		5/SD	S	TP
		5/M	20	TN,TP
		5/B	B	TN,TP

Table 2
EQUIPMENT AND SUPPLIES

Item	Number	Source	Backup
Sampling Vessel (with motor/gas)	1	On Location	N/A
Sample Bottles	35	AECOS	5 spares
Pump	1	CH2M HILL	Niskin Type (2)
Hose w/clamps	200'	CH2M HILL	N/A
Marked Line (w/weight)	200'	CH2M HILL	local source
Auto Battery (w/ connectors)	1	On Location	1 spare
Field Log	1	CH2M HILL	duplicate
Ice Chest	1	CH2M HILL	1 spare
Ice or Freezer	-	StarKist	local source
Horizontal Sextant	1	CH2M HILL	Compass
Harbor Chart	1	CH2M HILL	1 spare

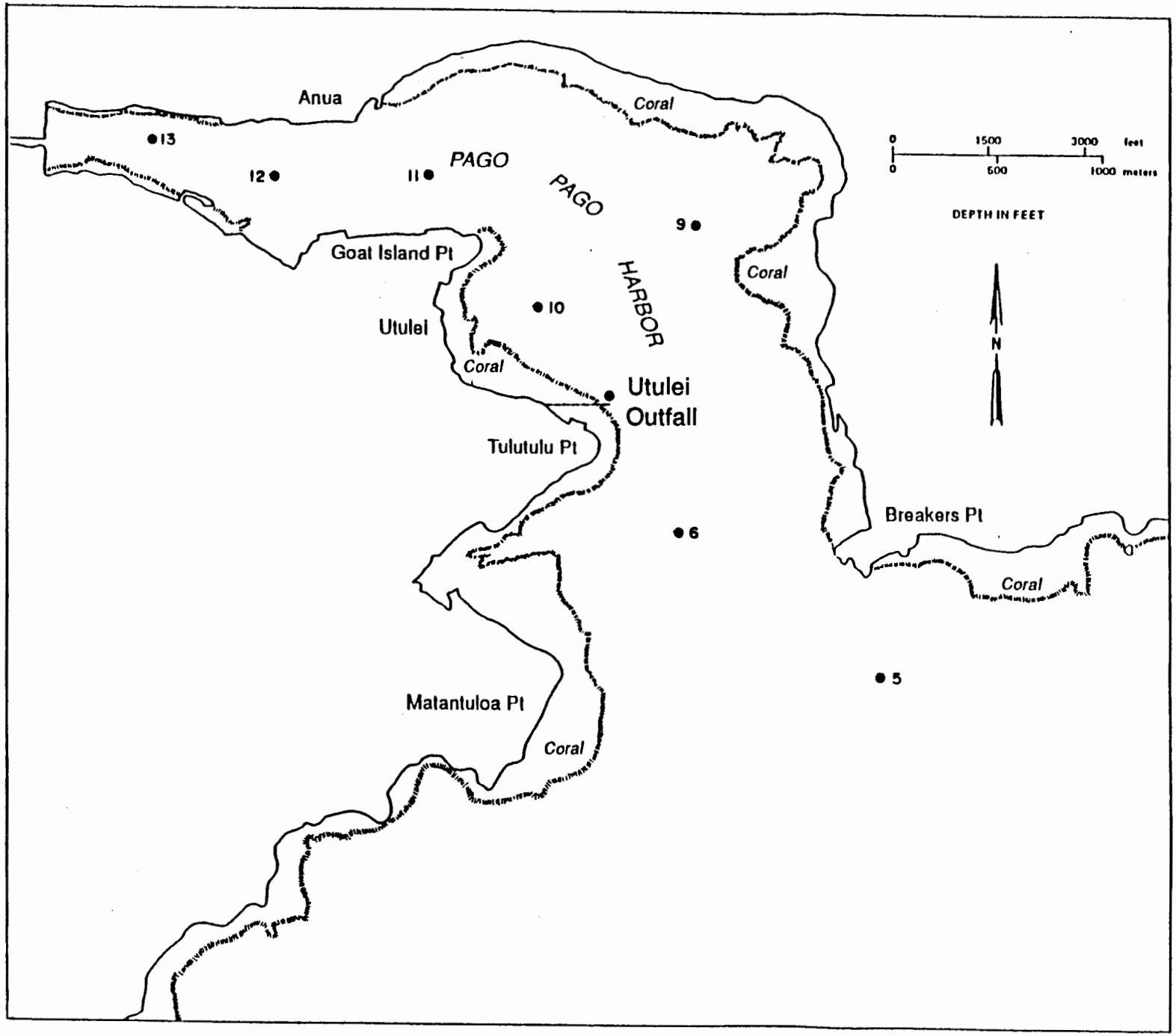


FIGURE 1
Water Quality Sampling Stations

APPENDIX B

GEOPHYSICAL FIELD DATA COLLECTION

B-1 Geophysical Protocol Technical Memorandum

B-2 Bathymetric and Geophysical Results

APPENDIX B-1

GEOPHYSICAL PROTOCOL TECHNICAL MEMORANDUM

APPENDIX B-1

Fieldwork Protocol for Geophysical Survey of Outfall Pipeline Route for Starkist Samoa Engineering Feasibility Evaluation Technical Memorandum

PURPOSE

This draft memorandum presents a protocol of fieldwork operations for the geophysical survey of Pago Pago Harbor. This survey has been designated as Subtask FS1, as outlined in the Preliminary Field Operations Plan (October 1, 1990). The survey will be done to help evaluate the feasibility of a marine outfall pipeline in the harbor. The land outfall pipeline option was discussed briefly in the Engineering And Environmental Feasibility Evaluation of Waste Disposal Alternatives Proposal (May 1990) and in the cost estimate memorandum dated September 14, 1990. The survey will be accomplished by collecting bathymetric and side scan sonar data, and will be conducted by a geophysical subcontractor, Williamson and Associates, under the direction of CH2M HILL. The engineering feasibility analysis will rely upon maps which will be generated from the geophysical survey data. The approximate area of Pago Pago Harbor to be surveyed is shown in Figure 1.

OBJECTIVES

The main objectives of the geophysical survey are:

- To refine and supplement existing bathymetric data in the survey area under investigation
- To map the surficial seafloor features in the survey area to determine the most feasible outfall route

The optimum outfall route will be one which will avoid the following: submarine obstacles, areas of anchor drag, areas of intense sediment transport, and rock and coral outcrops.

APPROACH

The survey will consist of two standard methods for gathering geophysical data: precision echo sounding (bathymetry) and side scan sonar. Manufacturers and model numbers of the equipment to be used are shown in Table 1. A brief description of each type of equipment and how it will be used during the survey is presented below.

- **Navigation:** Horizontal control during the survey will be acquired with a range-azimuth positioning system (Lasertrak) that can provide accuracies up to ± 30 cm (horizontal) and ± 0.01 degree (vertical). The Lasertrak will be positioned on Goat Island Point, a surveyed control point. This location will allow continuous tracking of the survey vessel without moving survey

locations. Pre-selected backsights will be periodically checked from the surveyed control point. Information on the vessel's position (range and angle) will be collected automatically by the Lasertrak unit approximately every 10 to 20 seconds and will be downloaded onto a portable computer. Data files containing the navigational data will be backed up and checked for completeness at least twice during each survey day. Position data will be correlated to the geophysical data by an event generator clock that is synchronized with the geophysical equipment and with the shore-based equipment clock. A fix mark will be automatically or manually placed on all navigation, bathymetric, and side scan sonar records onboard the survey vessel at one minute intervals (for example, every minute on the minute). In the event that the Lasertrak positioning system should malfunction, a backup navigation system will be used (Motorola MiniRanger III, a band-C radar system).

- **Precision Echo Sounder:** This equipment transmits and receives a high frequency (100 kHz) acoustic signal from a transducer attached to a vertical support which is located on the hull of the survey vessel. This signal is reflected from the seafloor and provides detailed information on the water depth along the survey vessel's line of travel. These data will be used to produce a bathymetric chart of the survey area after they have been corrected for tidal elevation. Because the tidal range in Pago Pago Harbor is minimal, water level variations can be monitored using only a tide staff, which will be located in the vicinity of the shore-based positioning equipment. The tide staff will be surveyed into the local datum (MLW). Water levels will be recorded every 15 minutes during the survey by the shore-based survey personnel.

- **Side Scan Sonar:** This equipment will provide a reflected image of an approximately 50-meter wide seabed area. A 100/500 kHz transducer (towfish) will be cable-mounted and towed below the water surface along the potential outfall pipeline route. The side scan sonogram will be plotted on recording paper.

QUALITY ASSURANCE AND QUALITY CONTROL OBJECTIVES

The quality assurance and control objectives for the survey is to collect navigational, bathymetric, and geophysical, data of reliable and acceptable quality. To evaluate the quality of the data, the following operational criteria will be used:

- All geophysical equipment will be calibrated according to the manufacturers' specifications prior to the survey

- All positioning, bathymetric, and geophysical equipment is fully operational

- Maintain accurate vessel positioning (within ± 2 meters accuracy)
- Provide equipment redundancy (backup equipment)
- All equipment will be operated by qualified personnel

FIELD PROCEDURES

The mobilization of equipment (excluding travel time) is expected to be completed in one or two days. However, additional time may be necessary in the event of delays. A contingency day has been factored into the preliminary field activities schedule to account for this possibility.

Mobilization of the geophysical survey equipment will include the following activities:

- Calibration and operational checks of all navigational, bathymetric, and geophysical equipment as well as test field transects to confirm operational status of all equipment
- Installation of the tide staff and surveying into the local datum
- Transport of positioning and geophysical equipment to the surveyed control point and the survey vessel, respectively

The actual survey days (the second and third days) field days will consist of the actual geophysical survey, and will involve the collection of bathymetric and side scan sonar data.

The survey will begin at a position just east of the canneries at Trading Point (near Anua) and as near to the shore as possible. The survey will progress east from this area and will follow the northern and eastern shorelines of the harbor south to Breakers Point (Figure 1). The survey will generally be confined (as much as possible) between the 10-fathom and the 20-fathom depth contours (18 and 36 meters, respectively). This will restrict the survey area to water depths that are deep enough for the outfall to be located, yet are located a safe distance from the reef. The outfall diffuser sites are included in the survey area off of Tafagamanu Point and south and east of Breakers Point. This includes the land pipeline option as well as the marine pipeline option.

Transect lines are to be a minimum of about 50 meters away from the coral reef for three reasons: 1) to avoid damaging the survey vessel, and 2) the steep drop-off seaward of the reef will tend to act as an acoustic reflector and may adversely affect the quality of the bathymetric and side scan data, and 3) the pipeline should avoid the steep slope of the coral reef and be placed instead on the relatively flat harbor floor (away from) in front of the reef.

Several transects will be made to insure that coverage of the survey area is adequate.

SCHEDULE AND PERSONNEL

The field work schedule is listed in Table 2. The dates listed should be considered tentative since delays could occur as a result of inclement weather, delays in shipment of equipment, or other unforeseen events. The responsibilities of personnel (CH2M HILL and Williamson and Associates) are listed in Table 3. Responsibilities of personnel may need to change slightly if Starkist personnel and/or equipment are not available for the survey.

DOCUMENTATION

A field/survey notebook will be maintained by [all] field personnel throughout the geophysical survey. General information and events that occur each day will be recorded in a waterproof (Rite-in-the-Rain) notebook. Each notebook should include, as a minimum, the following information:

- Date and time of arrival and departure from survey location
- Weather observations, sea state
- Names of personnel
- Equipment used during the survey
- Equipment calibration settings, survey control point location(s) and coordinates, and backsight location check
- Any unusual occurrences such as a departure from planned procedures or equipment malfunction

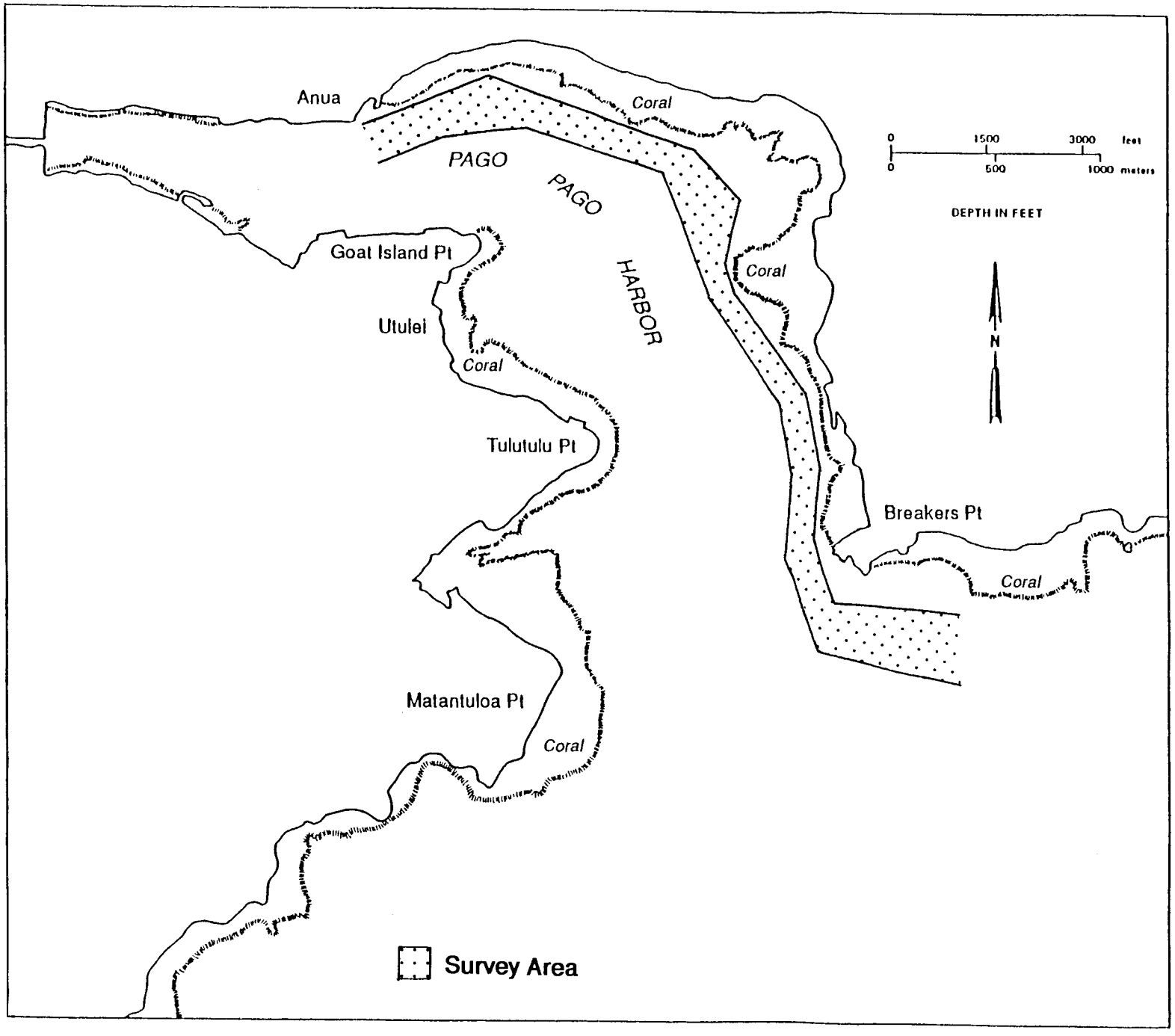


FIGURE 1
Location of Survey Area

TABLE 1
Geophysical Equipment List

SYSTEM	MANUFACTURER	MODEL
Navigation	MDL	Lasertrak L5000
	Motorola (backup)	MiniRanger III
Computer	Compaq (2 units)	SLT/286 Laptop
Fathometer	Raytheon	DE-719
	King (backup)	1350
Side Scan Sonar	Klein	531T
	Wesmar (backup)	100
100 kHZ Towfish	Klein (2 units)	422XS

TABLE 2
Work Schedule

TASK	OPTIMUM DATES	BACKUP DATES
Mobilize Geophysical and Positioning Equipment	October 30,31	
Geophysical Survey	November 1, 2	November 3
Demobilize (Backup Survey Day)	November 3	November 4

TABLE 3
Geophysical Personnel and Responsibilities

STAFF	RESPONSIBILITIES
CH2M HILL	
Brad Paulson	Lasertrak Positioning System (shore)
David Simpson	Geophysical Equipment
David Wilson	Field Backup
Tom Coyner	Field Backup
WILLIAMSON & ASSOCIATES	
Richard Sylwester	Geophysical Equipment
STARKIST	
Vessel Operator	Survey Vessel
Deckhand	Towed Gear, Line Handling

APPENDIX B-2

BATHYMETRIC AND GEOPHYSICAL RESULTS

RESULTS OF A BATHYMETRIC AND SIDE SCAN SONAR SURVEY AT PAGO PAGO, AMERICAN SAMOA

Prepared for:

CH2MHill
Bellevue, Washington

Prepared by:

Williamson and Associates, Inc.
Seattle, Washington

January 1991

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2. Side Scan Sonar Data

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Pocket 2. Plate 2 Bathymetric Contours

Pocket 3. Plate 3 Side Scan Targets

Pocket 4. Plate 4 Side Scan Track Lines

Pocket 5. Plate 5 Bathymetric Track Lines

Pocket 6. Side Scan Sonar Track Line 1, Section 1A

Pocket 7. Side Scan Sonar Track Line 1, Section 1B

Pocket 8. Side Scan Sonar Track Line 1, Section 1C

Pocket 9. Side Scan Sonar Track Line 2, Section 2A

Pocket 10. Side Scan Sonar Track Line 2, Section 2B

Pocket 11. Side Scan Sonar Track Line 2, Section 2C

INTRODUCTION

This report presents the results of a bathymetric and side scan sonar survey, conducted for CH2MHill, at the Star-Kist Tuna Cannery located in Pago Pago, American Samoa. The information from this survey is to be used to assist in the design and location of an offshore discharge pipe from the cannery.

The two geophysical elements of the survey were selected to determine the bathymetry and and the surficial distribution of rocks, muds and sands, on the seafloor.

GEOPHYSICAL SYSTEMS AND FIELD PROCEDURES

The survey consisted of two standard geophysical methods traditionally used in marine geological investigations: precision echo sounding and side scanning sonar. A brief description of the fundamentals of these two methods is presented below.

1. Precision echo sounder: This instrument transmits and receives a high frequency (100kHz), short pulse length acoustic signal that is reflected from the seafloor. These reflected signals provided detailed information on the water depth along the survey tracklines. After editing and correction for tidal fluctuations this data was used to produced the bathymetric chart of the area (Plates 1 and 2).

2. Side scan sonar: The bathymetric system only provide information on the water depth directly beneath the survey vessels trackline. With the side scan sonar, however, information is obtained on the surficial characteristics of the seafloor left and right of the survey trackline (Figure 1). It is a plan view of the seafloor that is similar to an aerial photograph. The swath width used during this study was 400 meters (200 meter left of the trackline and 200 meters right of the trackline).

   Depending on the relief of the seafloor, the sediment grain size, and biological features, various amounts of reflected or backscattered energy will be received by the side scan sonar transducer. This reflected energy will appear on the sonograph as varying shades of uniform intensity (continuous fields of sands, or organic muds), coherent patterns (sand waves), sharp outlines (rocks) and zones of no reflection (acoustic shadows behind large objects that project above the seafloor, i.e. rocks). These patterns can be easily identified on the sonargrams making it possible to map the surficial characteristic of the seafloor over a large area (Plate 3).

   The primary purpose of the side scan sonar data obtained during this survey was to map the reef front or escarpment, locate isolated rock out-

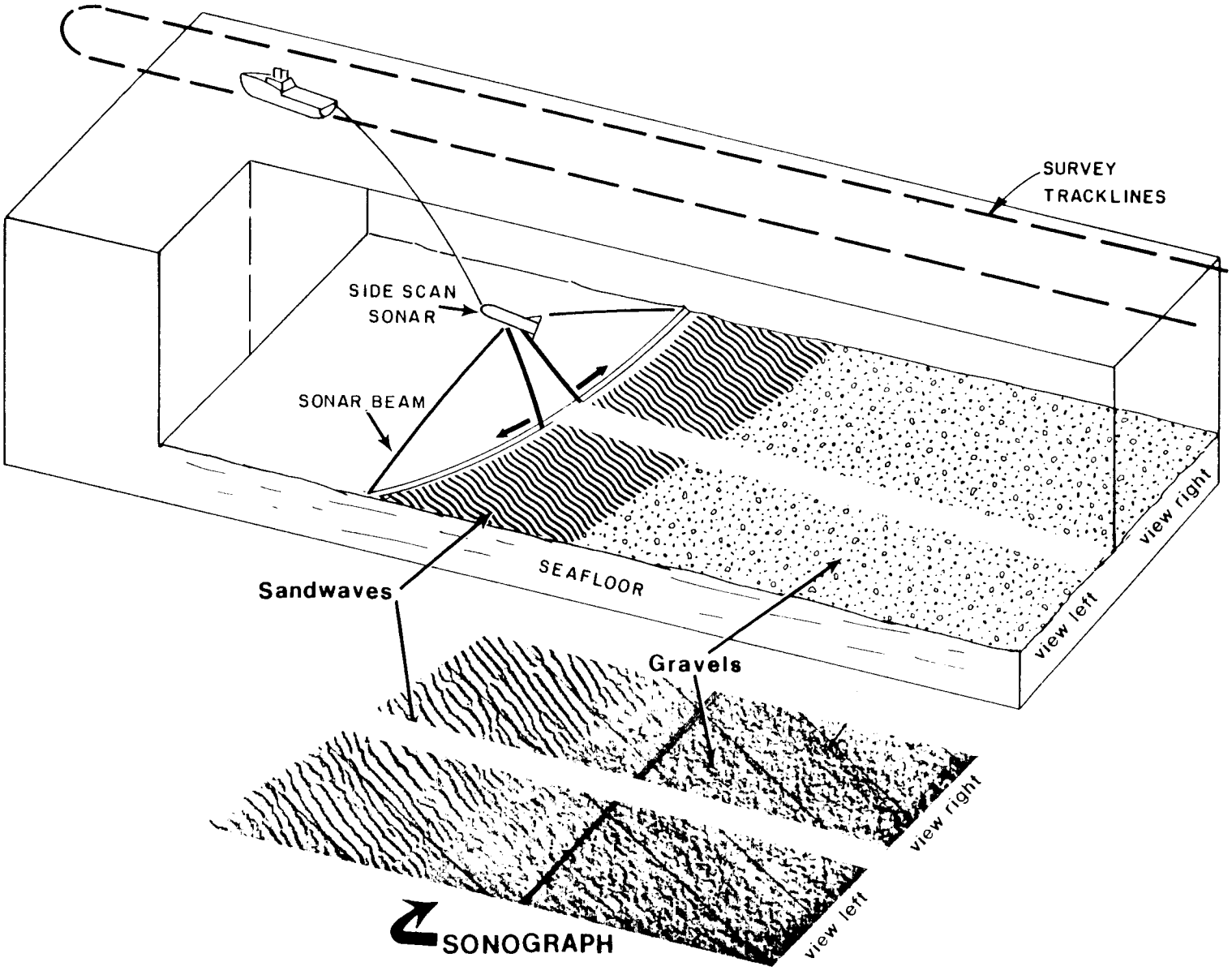

Figure 1. The upper illustration shows a side scan sonar "fish" being towed astern of the research vessel as it surveys along the tracklines. A fan shaped acoustic pulse emitted by the side scan sonar produces an acoustic picture of the sea floor shown in the lower illustration.

crops and provide detailed information on the lateral extent of the unconsolidated sediments.

3. Navigation: Horizontal control during the survey was obtained with a range-azimuth laser system located on a bench mark on the northshore of the harbor. As the survey vessel traversed the area positional information was obtainedevery 20 seconds from the navigation system. These data (range, azimuth, and time) were stored on a portable computer at the shore station as they were being acquired. Onboard the survey vessel the echo sounder and side scan sonar records were marked every 15 seconds using a digital watch that was synchronized with the internal clock in the data acquisition computer. These sets of time marks were used to correlate the geophysical data with the trackline maps during the data analysis phase (Plates 1,2,3,4 and 5).

The primary bathymetric survey transects were run perpendicular to the reef front. The survey vessel traveled shoreward to a depth of 50 to 80 feet which was usually less than 50 feet from the breakers that indicated the top of the reef. The lines extended offshore to a depth of 150 to 200 feet which represented the bottom of the slope that extends from the base of the reef. The side scan sonar lines were run parallel to the reef. The first transect (L-1) ran from the cannery to the breakers and the second transect, which was 200 to 500 feet further offshore, returned to the cannery.

INTERPRETATION AND PRESENTATION OF THE DATA

The following discussion summarize the results of the analysis of the data from the two geophysical systems. The details of these interpretations are presented in Plates 1, 2 and 3 located in the pocket at the end of the report along with copies of sonargrams.

1. Bathymetry-As would be expected the escarpment or reef front is extremely steep. On several occassions the bow of the survey vessel was resting on the reef and the echo sounder transducer, which was located midship, indicated a depth of 80 feet. The outline of the reef is extremely complex with numerous small indentations and promontories. It would probably be nearly impossible to map these variations, even with a very detailed bathymetric survey. The contour maps produced from the bathymetric survey (Plates 1 and 2) are highly interpretive in the shallow water areas due to the limited data coverage for such a complex region. Seaward of the base of the reef, which is approximately at a depth of 160 feet, the seafloor has a very gradual slope out to a depth of 200 feet at which point it appears to be quite flat. The bathymetric data in this area is considered very reliable.

2. Side Scan Sonar-The side scan sonar data clearly shows the reef front (see Line 1, sections 1A, 1B and 1C) as a dark continuous line on the left side of the sonargram. This feature is not as continuous on Line 2, the return traverse, as the vessel is much futher offshore and the side scan sonar is set for a maximum range of 600 feet to each side.

   A number of discrete targets that appear to be boulders and large rocks can be easily identified on the sonargrams. These features are numbered on the sonargrams for the two traverses and these numbers correspond with those shown on Plates 3 and 4, the sonar target map and the trackline map. Nearly all of the features identified as rocks produced an acoustic shadow. Targets 1 and 2, however, do not. This suggests that these rather extensive patchy areas may be zones of organic rich sediments, containing biogenic gas, or possibly coral heads with very low relief.

   Most of the area on the sonargrams show a very continuous uniform pattern which is characteristic of fine to medium grain sediments. Although the lateral extent of these sediments, as well as the distribution of rocks and other materials, can be easily mapped from the side scan sonar data the thickness of these sediments is unknown.

SUMMARY AND CONCLUSIONS

A bathymetric and side scan sonar survey were performed to determine the nature of the seafloor along a corridor for a proposed outfall pipe extending seaward from the Star-Kist cannery in Pago Pago, American Samoa. Some conclusions from this survey are:

* The near shore bathymetry, along the reef escarpment, is extremely complex and cannot be easily mapped using standard bathymetric survey procedures.

* Seaward of the base of the reef, assumed to be at approximately 160 feet, the seafloor slopes gently to 200 feet and at this depth it appears to be fairly flat.

* Several large rocks, with 40 to 80 feet of relief, were identified seaward of the reef front on the side scan sonar data. Some of these features are not shown on the present charts of the area and were not identified on the bathymetric survey.

* Two rather large patchy zones, that have very high amplitude returns (dark reflections on the sonargrams), appear to have very little relief above the

surrounding seafloor. It is possible that these are areas of organic muds if they are not low relief coral heads.

* In general the seafloor appears to be covered with fine to medium grain sediments throughout the survey area. The thickness of these sediments may be quite variable, particulaly in the areas of the rock outcrops. A high resolution subbottom survey would be required to accurately measure the thickness of these sediments.

APPENDIX C

WASTEFIELD TRANSPORT MODEL

C-1 Model Description

C-2 Model Calibration

C-3 Contour Plots

C-4 Model Code

APPENDIX C-1

MODEL DESCRIPTION

Appendix C-1
MODEL DESCRIPTION

PURPOSE AND SCOPE OF MODEL

The transport, dispersion, and concentration of a pollutant discharged into a body of water can be predicted by the application of a series of models that account for the sources, sinks, and transport paths of the substance. Each of the models is used to describe the physical processes involved in pollutant dispersion and transport. The concentration of an introduced substance at a particular place and time can conveniently be considered in four stages or components:

- Background concentration that would exist in the absence of the sources of interest. In the case of Pago Pago Harbor, this is taken as the concentration typically found in the open ocean and nearshore waters around the islands of American Samoa.

- Ambient receiving water concentration that is typical of the harbor and varies throughout the harbor. For the application considered here, the long-term average concentration was modeled. In the immediate neighborhood of point source discharges, the model used for predicting ambient conditions must be supplemented with initial and subsequent dilution models.

- Farfield concentration of the wastefield plume subsequent to the initial dilution processes. This concentration distribution is the result of relatively rapid, small-scale dispersion effects driven by relatively high concentration gradients. The rate of dispersion or change in concentration decreases with distance from the source.

- Concentration at the end of the initial dilution process. Initial dilution is a rapid, intense mixing driven by turbulence generated by jet or buoyancy effects as the effluent is discharged from the outfall or diffuser.

Background concentration values must be determined by measurement, published values, or well-supported assumptions. For this case background concentrations were based on observations published in the available reports. Ambient concentrations would be the same as background for large water bodies with unrestricted circulation and sufficient currents. However, for a confined water body like Pago Pago Harbor, the ambient receiving water concentration will be higher than background values because of limited flushing and high residence times. Concentrations in such a system will increase until the amount leaving is the same as the input rate, for a conservative substance.

It is common practice to include the background concentration as part of the ambient concentration, rather than consider the excess above background. Ambient concentrations are predicted by models of sufficient complexity to adequately represent the circulation and dispersion characteristics of the system. For Pago Pago Harbor, a simplified numerical model (PT121) was used and is described below. This model was developed on the principles described in the Wasteload Allocation Study done by HRI (1989).

Initial dilution is predicted by using EPA-developed models, which are adequately described and documented in the references provided in the text of the report. In addition, the material supplied in Appendix D gives more information on initial dilution modeling for this study. Concentrations resulting from initial dilution predictions based on effluent concentration are generally considered as excess to, or superimposed on, receiving water ambient concentrations. This is a reasonable approach because the physical processes, time scales, and space scales involved in the initial dilution processes are so different from those that are involved in determining the ambient concentrations. The two phenomena can be considered uncoupled.

Farfield or subsequent dilution models are the most difficult to employ. The processes involved in subsequent dilution are physically similar to those modeled in the prediction of ambient receiving water concentrations, wastefield transport models, but at smaller time and space scales. Thus, the wastefield transport model used in this study provides a useful estimate of the subsequent dilution except close to the discharge point. Because of the ability of model PT121 to predict observed concentrations at stations near the existing discharge, the results of the model near the point source discharge are acceptable at a distance of about 1,000 feet at a maximum. Model interpretation were done in a manner such that concentrations did not exceed standards at a distance of 300 to 600 feet from the source and were less than standards at 1,000 feet from the source. Therefore, the analysis of the wastefield transport model predictions was based on providing a zone where water quality standards might be exceeded that was always less than 1,000 feet from the discharge point.

The wastefield transport model is a depth-averaged model that cannot account for the fact that, near the discharge point, the wastefield will exhibit a gradient in concentration with depth and might be a distinct layer. To investigate the expected extent of concentrations at a point (rather than depth averaged) that might exceed a given value, the subsequent dilution model CDIFF was used. This model is described and documented in the EPA publication referenced in the report. The model code is provided in Appendix D-4.

The subsequent dilution model (CDIFF) has features that make it conservative; that is, it provides predictions of dilutions that are probably low (high concentrations). These features include the following:

- The model allows no diffusion in the direction of the current. This results in particularly wide wastefields at low current speeds and physically unrealistic results at very low current speeds.

- The model allows no mixing in the vertical direction and assumes a constant "layer thickness". This results in an overestimate of concentrations, particularly near the source.

- The model, as supplied by EPA, has set values for calculating diffusion coefficients as a function of plume dimension. These values result in a diffusion coefficient, at the start of subsequent dilution, that is about the same as that derived from dye experiments in Pago Pago Harbor. Those experiments were based on visual (photographic) observation rather than concentration measurements. This leads to an underestimate of the eddy diffusion coefficient and means CDIFF is underestimating the dilution factor (overestimating concentration) at least near the beginning of the subsequent dilution process.

- At the end of initial dilution, the concentration of the plume is appropriately described by adding or superimposing it on the ambient concentration. At the end of the subsequent dilution process, the concentration of the plume is the ambient concentration. However, the calculation of subsequent dilution is usually carried out by superimposing the plume concentration on the ambient concentration throughout the entire area considered. This gives conservative (concentration predicted too high) results that are more and more conservative as the distance from the source increases.

The model CDIFF was used to provide a check on the results obtained from the wastefield transport model. CDIFF resulted in a somewhat larger area of possible standard exceedance. However, the model was used in the most conservative fashion described above. In addition, the wastefield transport model was used with the maximum possible loading rather than the average loading. This results in ambient concentrations that are higher than actually expected--another conservative approach.

MODEL CHARACTERISTICS

The initial dilution models (UMERGE, UDKHDEN) and the subsequent dilution model (CDIFF) are fully described and documented in the appropriate references given in the report. The wastefield transport model (PT121) is based on the HARBOR model used for the Wasteload Allocation Study (HRI, 1989). The wasteload allocation study should be referenced for more information on the basic physical principles and model approach. The discussion below primarily addresses the enhancement of the original approach.

PT121 is a quasi-two-dimensional (Q2D) completely stirred tank reactor (CSTR) model. The term Q2D refers to the following model attributes:

- It is a two-dimension horizonal approach that is depth-averaged. There is no variation of any variable with depth. However, the depth does vary throughout the harbor model. It is not a constant-depth model.

- The model is set up in a grid that is laterally symmetric about the longitudinal axis of the model. The longitudinal axis is transformed into a straight line.

- The model grid is set up in two levels. Square cells of constant dimension are used for the calculation of concentrations and transport in both horizontal directions. Rectangular "line cells" are composed of integral numbers of cells in a line perpendicular to the harbor axis. These line cells form the basis for calculating total flow rates in the longitudinal direction and the input of nonpoint source flows and pollutant loading.

- Lateral advective flows are symmetrical about the longitudinal axis, and there is no advection across the longitudinal axis. These flows are calculated on the basis of mass conservation. Longitudinal advective flows are equally divided between individual cells in a line cell, with the provision of no flow through a solid boundary.

- Flow rates are on the basis of changes in volume due to tidal elevation changes. The water surface is considered to change instantaneously throughout the system. Tides are input in tabular form. Thus, longitudinal flows are calculated on the basis of conservation of mass.

- Point source flows and loadings are added to individual cells. Nonpoint source flows and loadings are added to line cells and are equally distributed to cells within the line cell.

- Diffusion coefficients and decay rates can vary along the longitudinal axis of the system but are constant within a line cell. Diffusion is the same in both horizontal directions.

- Diffusive transport is calculated as a Fickian process based on eddy diffusivity. This transport is calculated on a cell-by-cell basis with no transport allowed through a solid boundary.

The term CSTR refers to the following model approach to calculating concentration:

- The total mass of a constituent is calculated from the concentration and cell volume for each cell.

- On the basis of tidal data, the volume of the cell is changed.

- Advective transport is allowed to carry mass to and from adjoining cells on the basis of the concentration, flow rate, length of the time step, and area between the cells. The area is based on the average depth of the two cells and cell width.

- Diffusive transport carries mass between cells on the basis of concentration gradient, area between adjoining cells, and the length of the time step.

- Point source loadings are introduced into appropriate cells. Point source flows are also introduced into individual cells. The mass of constituent and volume of water are based on loadings, flows, and length of the time step.

- Nonpoint source inputs are calculated the same way as point source inputs, but each cell in a line cell has equal inputs.

- The original mass in each cell is allowed to decay on the basis of the specified first order decay constant and the length of the time step.

- Each of the inputs and outputs of mass into each cell is added to the initial mass less the amount of decay, and a new concentration is calculated.

MODEL EXECUTION

The wastefield transport model is run by supplying the required instructions and parameters by means of input files read by the program as it executes. The model is written and compiled in TurboBasic on an IBM-compatible computer operating under MSDOS. The input is in four separate files. The job control file provides input for:

- Input/output file names
- Size of model grid (number of cells)
- Time step length
- Horizontal cell dimension
- Where to start reading from tide data file
- Number of days to do calculations
- Number of point sources considered
- Amount of tidal data to be read
- Input/output control parameters
- Cells where point source loadings are found
- Point source loadings and flows

The hydrodynamics file provides input for cross-sectional area, width, and nonpoint source flows as a function of distance along the harbor (for each line cell).

The tidal data file provides input for tidal elevation as a function of time in tabular format. The water quality/geometry data file provides input for the following parameters and variables:

- Initial concentration as a function of distance along the harbor, and boundary concentration at the open end of the harbor.
- Eddy diffusion coefficient as a function of distance along the harbor.
- Decay rate coefficient as a function of distance along the harbor.
- Nonpoint source loading as a function of distance along the harbor.
- Definition of the cells constituting the side boundaries of the system.
- Depth of each cell at the appropriate tidal elevation.
- Definition of the boundary condition for each of the boundary cells of the system.

Examples of each of the input files are provided in Tables C1-1 through C1-4. Reference should be made to the source code for the model (Appendix C-4) to identify the variables being input.

MODEL OUTPUT

The model results are provided in three optional output files as specified in the job control input file. These files are described below, and example output to a printer is shown. The files consist of a "mirror file" that primarily presents the input, a hydrodynamics file that provides results of the flow calculations, and a water quality output file that provides the results of the transport calculations.

The mirror file provides a listing and tabulations of the input values read and initially manipulated by the program. The primary function of this file is to provide documentation and allow the operation of the program to be checked. The file is generally used for validation runs and is switched off during production runs. The mirror file has four parts:

- A title page that provides a description of the important program and model control parameters (Table C1-5)

- A summary of hydrodynamic and geometric data (Table C1-6)
- A tabulation of the tidal data used by the routine (Table C1-7)
- A tabulation of water quality inputs including initial concentrations, diffusivity and decay coefficients, and loadings (Table C1-8)
- A tabulation of cell depths that are input in feet and converted to meters (Table C1-9).
- A table of boundary conditions (Table C1-10). The significance of the various boundary conditions can be determined by reference to the model code (Appendix C-4).

The hydrodynamics file is also generally used for program validation and is switched off during production runs. This file contains a tabulation for each time step of the change in volume, flow rate, cross-sectional area, and velocity for each line cell or line cell boundary. An example is provided in Table C1-11.

The water quality output file gives a description of the concentration at the end of each time step in each cell. An example of this output is given in the main report (Figure 4-9). The output interval for both the hydrodynamics and water quality output files can be specified if each time step is not desired.

sea7807/026.51

TABLE C1-1

Example of Job Control Input File

```
"JCLPT121"
"BASEHYS"
"TIDETBL"
"BASEWQS"
"dattest "
"hydtest"
"contest "
"DISSOLVED CONSTITUENT TRANSPORT SIMULATION FOR PAGO PAGO HARBOR"
"This is the propgram development and testing output"
"Validation test of pollutant transport routine - continuous release"
11,26
1,200
1,1
3,25
7,0,0,0,0,0,1
```

TABLE C1-2

Example of Hydrodynamics Input File

```
"BASEHYDS"
59100, 1870, 0.0
52300, 1980, 0.0
44600, 2090, 0.0
66500, 1870, 0.0
61000, 1480, 0.0
47400, 1320, 0.0
50000, 1250, 0.0
49400, 1310, 0.0
47600, 1430, 0.0
51000, 1580, 0.0
56400, 1800, 0.0
62000, 2030, 0.0
51800, 1710, 0.0
41300, 1370, 0.0
33300, 1110, 0.0
30400, 1010, 0.0
27400,  900, 0.0
23400,  770, 0.0
19600,  630, 0.0
17600,  650, 0.0
16200,  710, 0.0
10800,  580, 0.0
 5900,  460, 0.0
 3700,  410, 0.0
 1800,  360, 0.0
 1800,  360, 0.0
12, 1.
18, 0
19, 0
```

TABLE C-3

Example of Tidal Data Input File
(First page only)

"TIDETBL with 1413 entries"

-6.77	2.9
-0.60	-.1
5.70	2.3
11.23	.2
17.85	2.9
24.02	-.1
30.32	2.3
35.92	.2
42.47	2.9
48.63	-.1
54.97	2.3
60.55	.2
67.07	2.9
73.27	-.1
79.55	2.3
85.13	.2
91.67	2.8
97.83	.0
104.15	2.3
109.75	.3
116.28	2.7
122.45	.1
128.77	2.3
134.37	.4
140.88	2.6
147.03	.2
153.43	2.2
158.98	.5
165.52	2.5
171.65	.3
178.13	2.2
183.73	.6
190.23	2.4
196.30	.4
202.88	2.2
208.57	.6
215.02	2.2
221.02	.5
227.70	2.2
233.58	.7
239.93	2.1
245.95	.5
252.63	2.2
258.75	.6
264.95	2.0
270.88	.5
277.63	2.3
283.88	.5
290.03	2.0
295.90	.4
302.60	2.5
308.88	.3
315.10	2.1

TABLE C1-4

Example of Water Quality/Geometry Input File

```
"BASEWQS"
0,     0,  4580,  0.000 ,  0.00
1,     0,  4580,  0.000 ,  0.00
2,     0,  4580,  0.000 ,  0.00
3,     0,  4580,  0.000 ,  0.00
4,     0,  4580,  0.000 ,  0.00
5,     0,  4580,  0.000 ,  0.00
6,     0,  4580,  0.000 ,  0.00
7,     0,  4580,  0.000 ,  0.00
8,     0,  4580,  0.000 ,  0.00
9,     0,  4580,  0.000 ,  0.00
10,    0,  4580,  0.000 ,  0.00
11,    0,  4580,  0.000 ,  0.00
12,    0,  4580,  0.000 ,  0.00
13,    0,  4580,  0.000 ,  0.00
14,    0,  4580,  0.000 ,  0.00
15,    0,  4580,  0.000 ,  0.00
16,    0,  4580,  0.000 ,  0.00
17,    0,  4580,  0.000 ,  0.00
18,    0,  4580,  0.000 ,  0.00
19,    0,  4580,  0.000 ,  0.00
20,    0,  4580,  0.000 ,  0.00
21,    0,  4580,  0.000 ,  0.00
22,    0,  4580,  0.000 ,  0.00
23,    0,  4580,  0.000 ,  0.00
24,    0,  4580,  0.000 ,  0.00
25,    0,  4580,  0.000 ,  0.00
26,    0,  4580,  0.000 ,  0.00
12,05,2400
12,06,2400
19,07,0
1,1,10
2,1,10
3,1,10
4,1,10
5,2,9
6,2,9
7,3,8
8,3,8
9,2,9
10,2,9
11,1,10
12,1,10
13,2,9
14,2,9
15,3,8
16,3,8
17,4,7
18,4,7
19,4,7
20,4,7
21,4,7
22,5,6
23,5,6
```

TABLE C1-4

(Continued)

```
24,5,6
25,5,6
00,  10,10,25,40,75,150,175,125,50,40,25,25
01,  10,10,25,40,75,150,175,125,50,40,25,25
02,  5,5,10,20,45,125,200,150,100,50,20,20
03,  5,5,10,20,45,90,125,175,125,75,25,25
04,  10,10,20,20,60,140,200,175,125,40,20,20
05,  10,10,10,20,125,200,225,125,75,25,22.5,22.5
06,  15,15,15,25,130,225,150,90,50,15,15,15
07,  15,15,15,15,125,220,175,110,45,30,30,30
08,  20,20,20,20,125,200,185,100,40,30,30,30
09,  20,20,20,45,140,195,175,70,25,20,20,20
10,  15,15,20,80,130,180,150,75,20,15,12.5,12.5
11,  10,10,20,110,160,190,150,80,45,15,10,10
12,  10,10,30,100,150,190,140,125,60,15,10,10
13,  17.5,17.5,25,75,150,180,160,125,40,10,10,10
14,  10,10,10,45,130,175,150,75,20,10,10,10
15,  20,20,20,30,125,150,130,45,25,17.5,17.5,17.5
16,  25,25,25,25,100,140,130,40,25,25,25,25
17,  72.5,72.5,72.5,72.5,120,130,125,75,50,50,50,50
18,  40,40,40,40,40,120,120,30,30,30,30,30
19,  25,25,25,25,25,100,100,30,30,30,30,30
20,  30,30,30,30,30,90,100,40,40,40,40,40
21,  25,25,25,25,25,80,80,30,30,30,30,30
22,  45,45,45,45,45,65,60,45,45,45,45,45
23,  45,45,45,45,45,45,40,40,40,40,40,40
24,  30,30,30,30,30,30,20,20,20,20,20,20
25,  25,25,25,25,25,25,25,25,25,25,25,25
26,  25,25,25,25,25,25,25,25,25,25,25,25
50
1,1,1,4
2,10,1,5
3,1,2,4
4,10,2,5
5,1,3,4
6,10,3,5
7,1,4,6
8,10,4,7
9,2,5,4
10,9,5,5
11,2,6,6
12,9,6,7
13,3,7,4
14,8,7,5
15,3,8,4
16,8,8,5
17,2,9,1
18,9,9,3
19,2,10,4
20,9,10,5
21,1,11,1
22,10,11,3
23,1,12,6
24,10,12,7
```

TABLE C1-4

(Continued)

25,2,13,4
26,9,13,5
27,2,14,6
28,9,14,7
29,3,15,4
30,8,15,5
31,3,16,6
32,8,16,7
33,4,17,4
34,7,17,5
35,4,18,4
36,7,18,5
37,4,19,4
38,7,19,5
39,4,20,4
40,7,20,5
41,4,21,6
42,7,21,7
43,5,22,4
44,6,22,5
45,5,23,4
46,6,23,5
47,5,24,4
48,6,24,5
49,5,25,6
50,6,25,7

TABLE C1-5

Example of Output Title Page

```
DISSOLVED CONSTITUENT TRANSPORT SIMULATION FOR PAGO PAGO HARBOR
This is the propgram development and testing output
Validation test of hydrodynamics routine

Job Control File is:                JCLPT121
Hydrodynamics/Geometric File is:    BASEHYD
Tidal Data File is:                 TIDETBL
Water Quality/Geometric File is:    BASEWQ
Output File is:                     LPT1:

Model grid is 11 wide and 26 long.

Time Increment in hours             = 1
Length Increment in meters          = 200
Start day in tide table             = 1
End day in tide table               = 7
Number of point source discharges   = 3
Number of tidal extrema used        = 50

I/O control string is: 3 1 1
```

TABLE C1-6

Example of Hydrodynamic/Geometric Output

DISSOLVED CONSTITUENT TRANSPORT SIMULATION FOR PAGO PAGO HARBOR
This is the propgram development and testing output
Validation test of hydrodynamics routine

Node No.	Surface Width (m)	Cross-sectional Area (m^2)	Nonpoint Inflow (m^3/s)	Point source Inflow (mgd)	Total Inflow (m^3/hr)
1	1870	59100	0.000		0.000
2	1980	52300	0.000		0.000
3	2090	44600	0.000		0.000
4	1870	66500	0.000		0.000
5	1480	61000	0.000		0.000
6	1320	47400	0.000		0.000
7	1250	50000	0.000	0.90	141.954
8	1310	49400	0.000		0.000
9	1430	47600	0.000		0.000
10	1580	51000	0.000		0.000
11	1800	56400	0.000		0.000
12	2030	62000	0.000		0.000
13	1710	51800	0.000		0.000
14	1370	41300	0.000		0.000
15	1110	33300	0.000		0.000
16	1010	30400	0.000		0.000
17	900	27400	0.000		0.000
18	770	23400	0.000	0.50	78.863
19	630	19600	0.000	1.00	157.727
20	650	17600	0.000		0.000
21	710	16200	0.000		0.000
22	580	10800	0.000		0.000
23	460	5900	0.000		0.000
24	410	3700	0.000		0.000
25	360	1800	0.000		0.000
26	360	1800	0.000		0.000

TABLE C1-7

Example of Tidal Data Output

DISSOLVED CONSTITUENT TRANSPORT SIMULATION FOR PAGO PAGO HARBOR
This is the propgram development and testing output
Validation test of hydrodynamics routine

Number of Tidal Extrema Used = 50

Time (hrs)	Elevation (ft)	Time (hrs)	Elevation (ft)	Time (hrs)	Elevation (ft)
-6.77	2.90	-0.60	-0.10	5.70	2.30
11.23	0.20	17.85	2.90	24.02	-0.10
30.32	2.30	35.92	0.20	42.47	2.90
48.63	-0.10	54.97	2.30	60.55	0.20
67.07	2.90	73.27	-0.10	79.55	2.30
85.13	0.20	91.67	2.80	97.83	0.00
104.15	2.30	109.75	0.30	116.28	2.70
122.45	0.10	128.77	2.30	134.37	0.40
140.88	2.60	147.03	0.20	153.43	2.20
158.98	0.50	165.52	2.50	171.65	0.30
178.13	2.20	183.73	0.60	190.23	2.40
196.30	0.40	202.88	2.20	208.57	0.60
215.02	2.20	221.02	0.50	227.70	2.20
233.58	0.70	239.93	2.10	245.95	0.50
252.63	2.20	258.75	0.60	264.95	2.00
270.88	0.50	277.63	2.30	283.88	0.50
290.03	2.00	295.90	0.40	0.00	0.00

TABLE C1-8

Example of Water Quality Data Output

DISSOLVED CONSTITUENT TRANSPORT SIMULATION FOR PAGO PAGO HARBOR
This is the propgram development and testing output
Validation test of hydrodynamics routine

Cell Line	Initial Conc (mg/m^3)	Diffusivity Coeff. (m^2/hr)	Decay Rate (1/hr)	Nonpoint Loading (kg/day)	Point Souce Loading (kg/day)
25	120.00	4580	0.0008	0.000	
24	120.00	4580	0.0008	0.000	
23	120.00	4580	0.0008	0.000	
22	120.00	4580	0.0008	0.000	
21	120.00	4580	0.0008	0.000	
20	120.00	4580	0.0008	0.000	
19	120.00	4580	0.0008	0.000	1000 @ I= 7
18	120.00	4580	0.0008	0.000	1000 @ I= 7
17	120.00	4580	0.0008	0.000	
16	120.00	4580	0.0008	0.000	
15	120.00	4580	0.0008	0.000	
14	120.00	4580	0.0008	0.000	
13	120.00	4580	0.0008	0.000	
12	120.00	4580	0.0008	0.000	
11	120.00	4580	0.0008	0.000	
10	120.00	4580	0.0008	0.000	
9	120.00	4580	0.0008	0.000	
8	120.00	4580	0.0008	0.000	
7	120.00	4580	0.0008	0.000	59 @ I= 3
6	120.00	4580	0.0008	0.000	
5	120.00	4580	0.0008	0.000	
4	120.00	4580	0.0008	0.000	
3	120.00	4580	0.0008	0.000	
2	120.00	4580	0.0008	0.000	
1	120.00	4580	0.0008	0.000	

TABLE C1-9

Example of Cell Depths Output

Table of Cell Depths in Meters

J/I	0	1	2	3	4	5	6	7	8	9	10	11
26	7.62	7.62	7.62	7.62	7.62	7.62	7.62	7.62	7.62	7.62	7.62	7.62
25	7.62	7.62	7.62	7.62	7.62	7.62	7.62	7.62	7.62	7.62	7.62	7.62
24	9.14	9.14	9.14	9.14	9.14	9.14	6.10	6.10	6.10	6.10	6.10	6.10
23	13.72	13.72	13.72	13.72	13.72	13.72	12.19	12.19	12.19	12.19	12.19	12.19
22	13.72	13.72	13.72	13.72	13.72	19.81	18.29	13.72	13.72	13.72	13.72	13.72
21	7.62	7.62	7.62	7.62	7.62	24.38	24.38	9.14	9.14	9.14	9.14	9.14
20	9.14	9.14	9.14	9.14	9.14	27.43	30.48	12.19	12.19	12.19	12.19	12.19
19	7.62	7.62	7.62	7.62	7.62	30.48	30.48	9.14	9.14	9.14	9.14	9.14
18	12.19	12.19	12.19	12.19	12.19	36.58	36.58	9.14	9.14	9.14	9.14	9.14
17	22.10	22.10	22.10	22.10	36.58	39.62	38.10	22.86	15.24	15.24	15.24	15.24
16	7.62	7.62	7.62	7.62	30.48	42.67	39.62	12.19	7.62	7.62	7.62	7.62
15	6.10	6.10	6.10	9.14	38.10	45.72	39.62	13.72	7.62	5.33	5.33	5.33
14	3.05	3.05	3.05	13.72	39.62	53.34	45.72	22.86	6.10	3.05	3.05	3.05
13	5.33	5.33	7.62	22.86	45.72	54.86	48.77	38.10	12.19	3.05	3.05	3.05
12	3.05	3.05	9.14	30.48	45.72	57.91	42.67	38.10	18.29	4.57	3.05	3.05
11	3.05	3.05	6.10	33.53	48.77	57.91	45.72	24.38	13.72	4.57	3.05	3.05
10	4.57	4.57	6.10	24.38	39.62	54.86	45.72	22.86	6.10	4.57	3.81	3.81
9	6.10	6.10	6.10	13.72	42.67	59.44	53.34	21.34	7.62	6.10	6.10	6.10
8	6.10	6.10	6.10	6.10	38.10	60.96	56.39	30.48	12.19	9.14	9.14	9.14
7	4.57	4.57	4.57	4.57	38.10	67.06	53.34	33.53	13.72	9.14	9.14	9.14
6	4.57	4.57	4.57	7.62	39.62	68.58	45.72	27.43	15.24	4.57	4.57	4.57
5	3.05	3.05	3.05	6.10	38.10	60.96	68.58	38.10	22.86	7.62	6.86	6.86
4	3.05	3.05	6.10	6.10	18.29	42.67	60.96	53.34	38.10	12.19	6.10	6.10
3	1.52	1.52	3.05	6.10	13.72	27.43	38.10	53.34	38.10	22.86	7.62	7.62
2	1.52	1.52	3.05	6.10	13.72	38.10	60.96	45.72	30.48	15.24	6.10	6.10
1	3.05	3.05	7.62	12.19	22.86	45.72	53.34	38.10	15.24	12.19	7.62	7.62
0	3.05	3.05	7.62	12.19	22.86	45.72	53.34	38.10	15.24	12.19	7.62	7.62

TABLE C1-10

Example of Boundary Conditions Output

Table of Boundary Conditions

I	J	BC	I	J	BC	I	J	BC
1	1	4	10	1	5	1	2	4
10	2	5	1	3	4	10	3	5
1	4	6	10	4	7	2	5	4
9	5	5	2	6	6	9	6	7
3	7	4	8	7	5	3	8	4
8	8	5	2	9	1	9	9	3
2	10	4	9	10	5	1	11	1
10	11	3	1	12	6	10	12	7
2	13	4	9	13	5	2	14	6
9	14	7	3	15	4	8	15	5
3	16	6	8	16	7	4	17	4
7	17	5	4	18	4	7	18	5
4	19	4	7	19	5	4	20	4
7	20	5	4	21	6	7	21	7
5	22	4	6	22	5	5	23	4
6	23	5	5	24	4	6	24	5
5	25	6	6	25	7	0	0	0

(BC is Boundary Condition Designator)

TABLE C-11

Example of Hydrodynamics Calculation Output Summary

DISSOLVED CONSTITUENT TRANSPORT SIMULATION FOR PAGO PAGO HARBOR
This is the propgram development and testing output
Validation test of hydrodynamics routine

Day: 1
Hour: 1
Time (hrs): 1.00
Water Level (m): 0.08
Output Interval: 1

Cell	Change in Volume (m^3)	Flow Rate (m^3/hr)	XSection Area (m^2)	Velocity (m/hr)
26	0	0	1829	0.00
25	6777	6777	1829	3.71
24	8189	14966	3733	4.01
23	9789	24754	5937	4.17
22	12142	36896	10846	3.40
21	12801	49697	16257	3.06
20	12048	61745	17652	3.50
19	13177	74764	19650	3.80
18	15719	90404	23462	3.85
17	17978	108382	27472	3.95
16	19954	128336	30481	4.21
15	23343	151678	33389	4.54
14	28990	180668	41409	4.36
13	35202	215870	51937	4.16
12	36049	251919	62162	4.05
11	31814	283733	56544	5.02
10	28331	312064	51126	6.10
9	25790	337854	47714	7.08
8	24096	361950	49505	7.31
7	24190	385997	50100	7.70
6	26354	412352	47505	8.68
5	31531	443883	61118	7.26
4	37273	481156	66649	7.22
3	38308	519464	44767	11.60
2	36237	555701	52458	10.59
1	17601	573302	59249	9.68

APPENDIX C-2

MODEL CALIBRATION

Appendix C-2
MODEL CALIBRATION

GENERAL PROCEDURE

The objective of the calibration procedure is to develop an acceptable level of confidence in the predictions of the model. The overall calibration procedure, as carried out for this study, consists of three separate steps:

- Model validation. A series of tests to determine that the model code was able to read input correctly, process the input data correctly, and provide physically realistic results.

- Model calibration. Adjustment of the appropriate model parameters until the model predictions of concentration were acceptably close to observed values associated with known input conditions.

- Model verification. Running the models for a different set of known inputs and resulting concentrations than used in the calibration step above to verify that the adjusted model parameters provide acceptable predictions for other situations than those used for the calibration.

MODEL VALIDATION

The model was validated in three stages. First, the source code of the model was carefully inspected and charted, and appropriate parts were individually tested. Next, the model was run and the output files were carefully examined. Particular attention was given to the mirror file and the hydrodynamics output files, and hand calculations were done to check program computations. The final stage involved running the model, using nominal values for parameters such as eddy diffusivity, for various conditions to determine if the model provided physically realistic results. The runs done included:

- Test of volume change component of the transport routine with no advection, diffusion, decay, or source terms. In this case, surface elevations were allowed to vary according to input tidal data.

- Test of volume change and advective components with no diffusion, decay, or source terms. Both tidal elevations and tidal currents calculated for the tidal data were used. Concentrations were calculated on the basis of cell volume and advective transport.

- Test of volume change, advective transport, and diffusive transport calculations without decay or source terms. A nominal diffusivity coefficient of sufficient magnitude to test model operation was used.

- Test of diffusive transport only (flushing of harbor) with no volume change, advective, decay, or source terms. In this case the movement of "ocean" water tagged with a conservative tracer is exchanged with "harbor" water initially without the tracer.

- Test of point source release within harbor without decay or nonpoint source inputs.

No test was done for the decay term because such a term was not used in the model for this study. Nonpoint sources were tested separately during the production runs by simply setting all loadings from the canneries to zero. These sources are so small compared to point sources that they have little effect on the model predictions.

After indicated revisions were made in the model code during the various validation steps ("debugging"), the model provided physically consistent and realistic and computationally correct results for all tests done.

MODEL CALIBRATION

Model calibration was accomplished by selecting a data set that included both known inputs and known responses (concentrations of total nitrogen (TN) and total phosphorus (TP)). The data set used was the 1985 long-term average condition previously developed for the Wasteload Allocation Study done by HRI as referenced in the main report. This data set was used primarily to maintain consistency in the model approach used during the Wasteland Allocation Study. In addition, the data processing necessary to develop a calibration data set had already been done, thus providing a substantial savings in time required to accomplish the modeling.

There were four differences in the calibration of the model between this report and the Wasteload Allocation Study. Differences in the model itself are described in Appendix C-1. These differences were:

- No decay of either TN or TP was considered, as was done in the Wasteload Allocation Study. Rather, it was considered reasonable that the harbor system was in steady state relative to these constituents. There was no information available about the potential sources and sinks of these constituents. The decay rates used by HRI were relatively small. The assumption of no decay is somewhat conservative (leads to overpredictions of TH and TP) on the basis of HRI model results.

- Because TN and TP were both considered conservative constituents (no decay), the model was calibrated by finding the diffusion coefficients that minimized the difference between predicted and observed concentrations of both constituents considered together. HRI's model approach used different diffusion coefficients for each constituent. This study used identical diffusion coefficients for each constituent.

- The Wasteload Allocation Study used a diffusion coefficient (for each constituent) that was constant everywhere in the harbor. During the calibration process used in this study (for both constituents), it was determined that the best fit between observed and predicted concentrations was obtained if different diffusion coefficients were used in the inner and outer harbor. The coefficient in the inner harbor was smaller than that in the outer harbor. Physically, this is interpreted as a distinct difference in the intensity of mixing and transport in the two areas. Available data, such as current meter records, support this interpretation.

- The two diffusion coefficients, for the inner and outer harbor, were selected by minimizing the differences (algebraic difference accounting for sign) between observed and predicted concentrations of TH and TP. The percentage difference at each station was used. Although this does not represent a rigorous statistical approach, there is no doubt that a more involved approach would result in essentially the same answer.

The results of the calibration provided values for inner and other harbor diffusion coefficients that were used throughout the modeling. The differences between predicted and observed values of TH and TP are described in the report (Figure 4-10). This calibration was based on long-term average conditions. The results for the stations closest to the discharge source indicate that the spatial resolution of the model is less than about 1,000 feet.

The implications of this are two-fold: the selection of a 634-foot (200 meter) cell size is appropriate for the system as described by the available data, and the model can be used to evaluate mixing zones at least down to about the 1,000-foot size in linear dimension. This would be a mixing zone based on long-term average conditions.

MODEL VERIFICATION

The model was checked, with the diffusion coefficients developed during calibration, by comparing predicted and observed concentrations for the 1986 and 1987 data sets described in the Wasteload Allocation Study. These data sets were developed from fewer observed data than the 1985 data set used for calibration. The agreement between observed and predicted concentrations was not as good as for the calibration data set, but was acceptable. The differences in the observed and predicted concentrations

appeared to be more dependent on the amount and quality (large range of values for small number of measurements) of the observed data rather than the consistency of the model predictions.

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APPENDIX C-3

CONTOUR PLOTS

APPENDIX C-3

CONTOUR PLOTS

LIST OF FIGURES

TOTAL NITROGEN LOADING AT ONE LOCATION IN PAGO PAGO HARBOR

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Figure C3-3 1000 kg/day Total Nitrogen Inner Harbor Discharge

Figure C3-4 500 kg/day Total Nitrogen Middle Harbor Discharge

Figure C3-5 1000 kg/day Total Nitrogen Middle Harbor Discharge

Figure C3-6 1500 kg/day Total Nitrogen Middle Harbor Discharge

Figure C3-7 1500 kg/day Total Nitrogen Outer Harbor Discharge

Figure C3-8 2000 kg/day Total Nitrogen Outer Harbor Discharge

Figure C3-9 1500 kg/day Total Nitrogen Harbor Entrance Discharge

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Figure C3-11 625 kg/day Total Nitrogen Inner Harbor Discharge
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Figure C3-12 750 kg/day Total Nitrogen Inner Harbor Discharge
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Figure C3-13 750 kg/day Total Nitrogen Middle Harbor Discharge
250 kg/day Total Nitrogen Outer Harbor Discharge

Figure C3-14 1000 kg/day Total Nitrogen Middle Harbor Discharge
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TOTAL NITROGEN LOADING FOR ZERO CANNERY INPUT TO PAGO PAGO HARBOR

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Figure C3-17 50 kg/day Total Phosphorus Inner Harbor Discharge

Figure C3-18 75 kg/day Total Phosphorus Inner Harbor Discharge

Figure C3-19 100 kg/day Total Phosphorus Inner Harbor Discharge

Figure C3-20 50 kg/day Total Phosphorus Middle Harbor Discharge

Figure C3-21 100 kg/day Total Phosphorus Middle Harbor Discharge

Figure C3-22 150 kg/day Total Phosphorus Middle Harbor Discharge

Figure C3-23 150 kg/day Total Phosphorus Outer Harbor Discharge

Figure C3-24 200 kg/day Total Phosphorus Outer Harbor Discharge

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TOTAL PHOSPHORUS LOADING AT TWO LOCATIONS IN PAGO PAGO HARBOR

Figure C3-26 50 kg/day Total Phosphorus Inner Harbor Discharge
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Figure C3-28 75 kg/day Total Phosphorus Inner Harbor Discharge
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Figure C3-29 75 kg/day Total Phosphorus Middle Harbor Discharge
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Figure C3-31 150 kg/day Total Phosphorus Middle Harbor Discharge
25 kg/day Total Phosphorus Outer Harbor Discharge

TOTAL PHOSPHORUS LOADING FOR ZERO CANNERY INPUT TO PAGO PAGO HARBOR

Figure C3-32 0.0 kg/day Total Phosphorus Loading

TOTAL PHOSPHORUS LOADING AT ONE LOCATION IN PAGO PAGO HARBOR WITH HIGH OCEAN BACKGROUND VALUE ASSUMPTION

Figure C3-33 50 kg/day Total Phosphorus Inner Harbor Discharge

Figure C3-34 75 kg/day Total Phosphorus Inner Harbor Discharge

Figure C3-35 100 kg/day Total Phosphorus Inner Harbor Discharge

Figure C3-36 50 kg/day Total Phosphorus Middle Harbor Discharge

Figure C3-37 100 kg/day Total Phosphorus Middle Harbor Discharge

Figure C3-38 150 kg/day Total Phosphorus Middle Harbor Discharge

Figure C3-39 150 kg/day Total Phosphorus Outer Harbor Discharge

Figure C3-40 200 kg/day Total Phosphorus Outer Harbor Discharge

Figure C3-41 150 kg/day Total Phosphorus Harbor Entrance Discharge

TOTAL PHOSPHORUS LOADING AT TWO LOCATIONS IN PAGO PAGO HARBOR WITH HIGH OCEAN BACKGROUND VALUE ASSUMPTION

Figure C3-42 50 kg/day Total Phosphorus Inner Harbor Discharge
25 kg/day Total Phosphorus Outer Harbor Discharge

Figure C3-43 62.5 kg/day Total Phosphorus Inner Harbor Discharge
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Figure C3-44 75 kg/day Total Phosphorus Inner Harbor Discharge
25 kg/day Total Phosphorus Outer Harbor Discharge

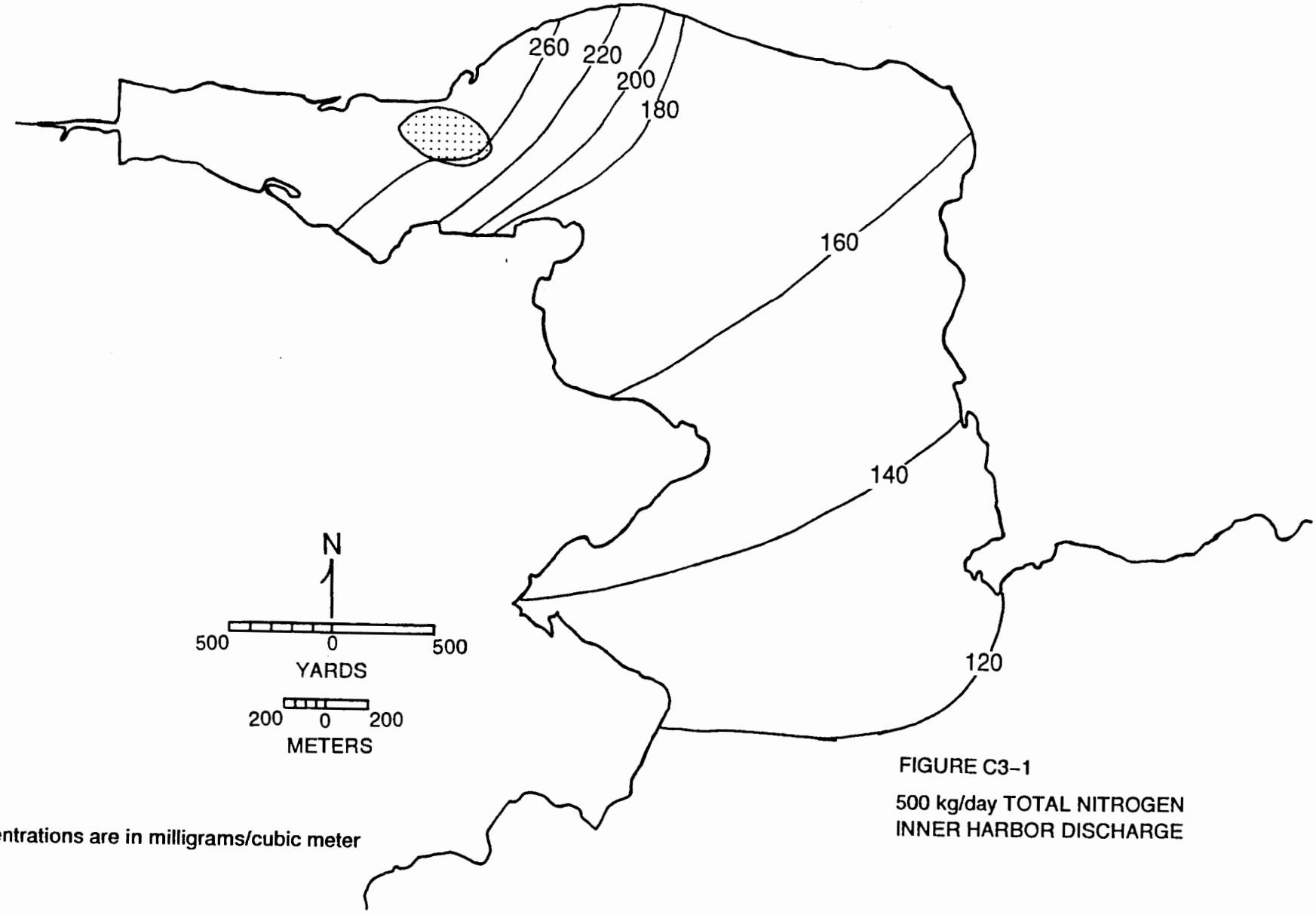
Figure C3-45 75 kg/day Total Phosphorus Middle Harbor Discharge
25 kg/day Total Phosphorus Outer Harbor Discharge

Figure C3-46 100 kg/day Total Phosphorus Middle Harbor Discharge
25 kg/day Total Phosphorus Outer Harbor Discharge

Figure C3-47 150 kg/day Total Phosphorus Middle Harbor Discharge
25 kg/day Total Phosphorus Outer Harbor Discharge

TOTAL PHOSPHORUS LOADING FOR ZERO CANNERY INPUT TO PAGO PAGO HARBOR WITH HIGH OCEAN BACKGROUND VALUE ASSUMPTION

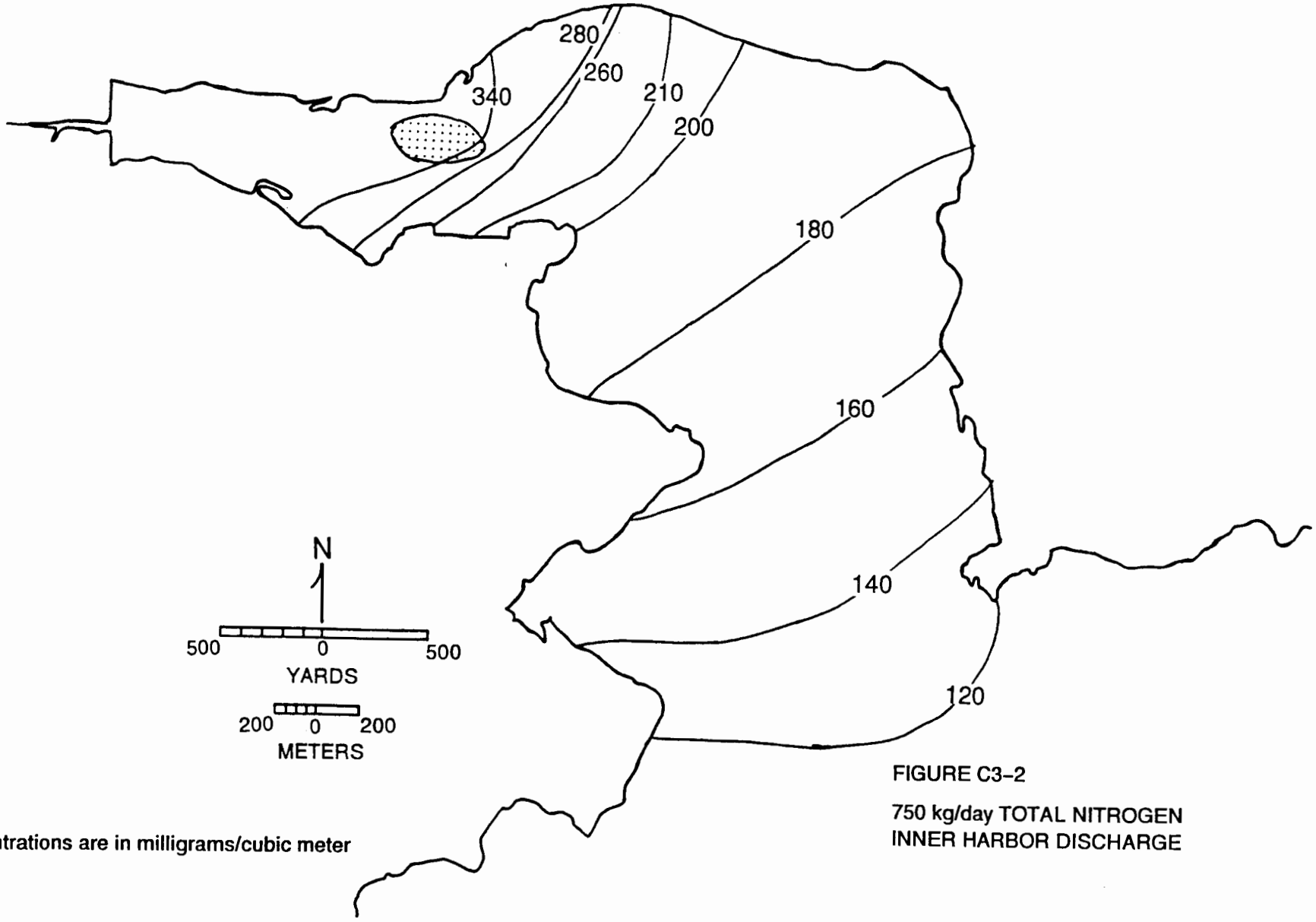
Figure C3-48 0.0 kg/day Total Phosphorus Loading



Concentrations are in milligrams/cubic meter

FIGURE C3-1

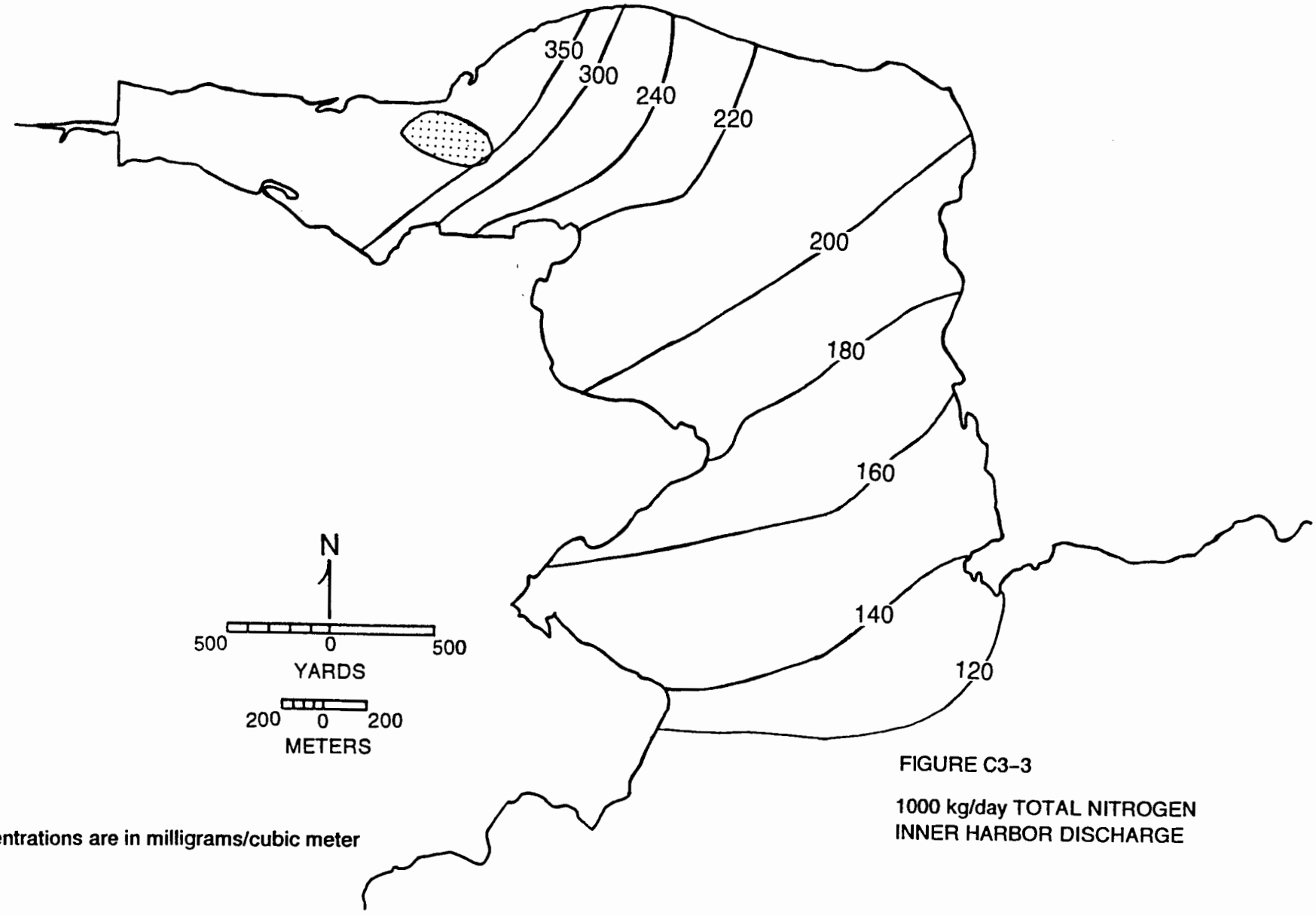
500 kg/day TOTAL NITROGEN
INNER HARBOR DISCHARGE



Concentrations are in milligrams/cubic meter

FIGURE C3-2

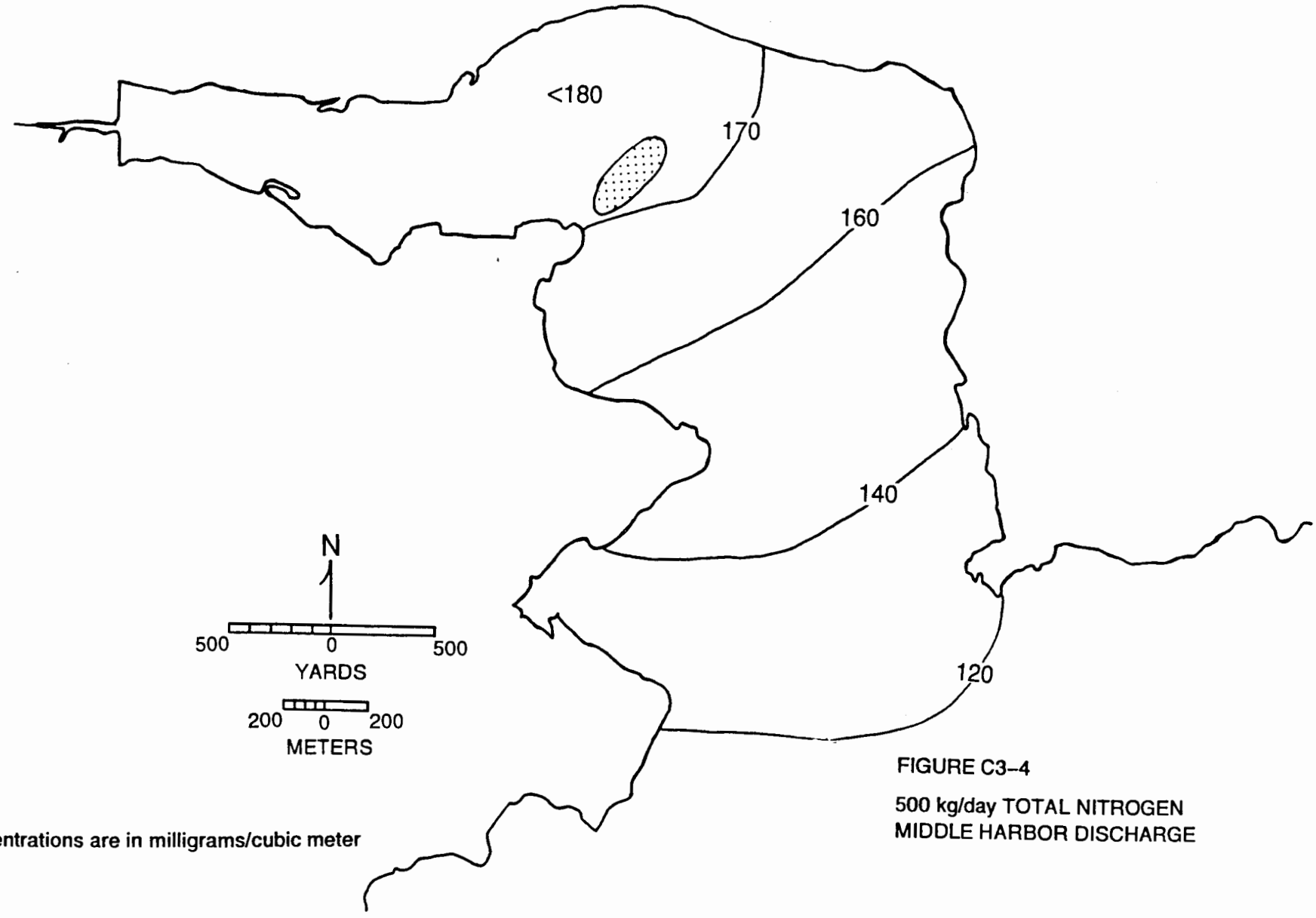
750 kg/day TOTAL NITROGEN
INNER HARBOR DISCHARGE



Concentrations are in milligrams/cubic meter

FIGURE C3-3

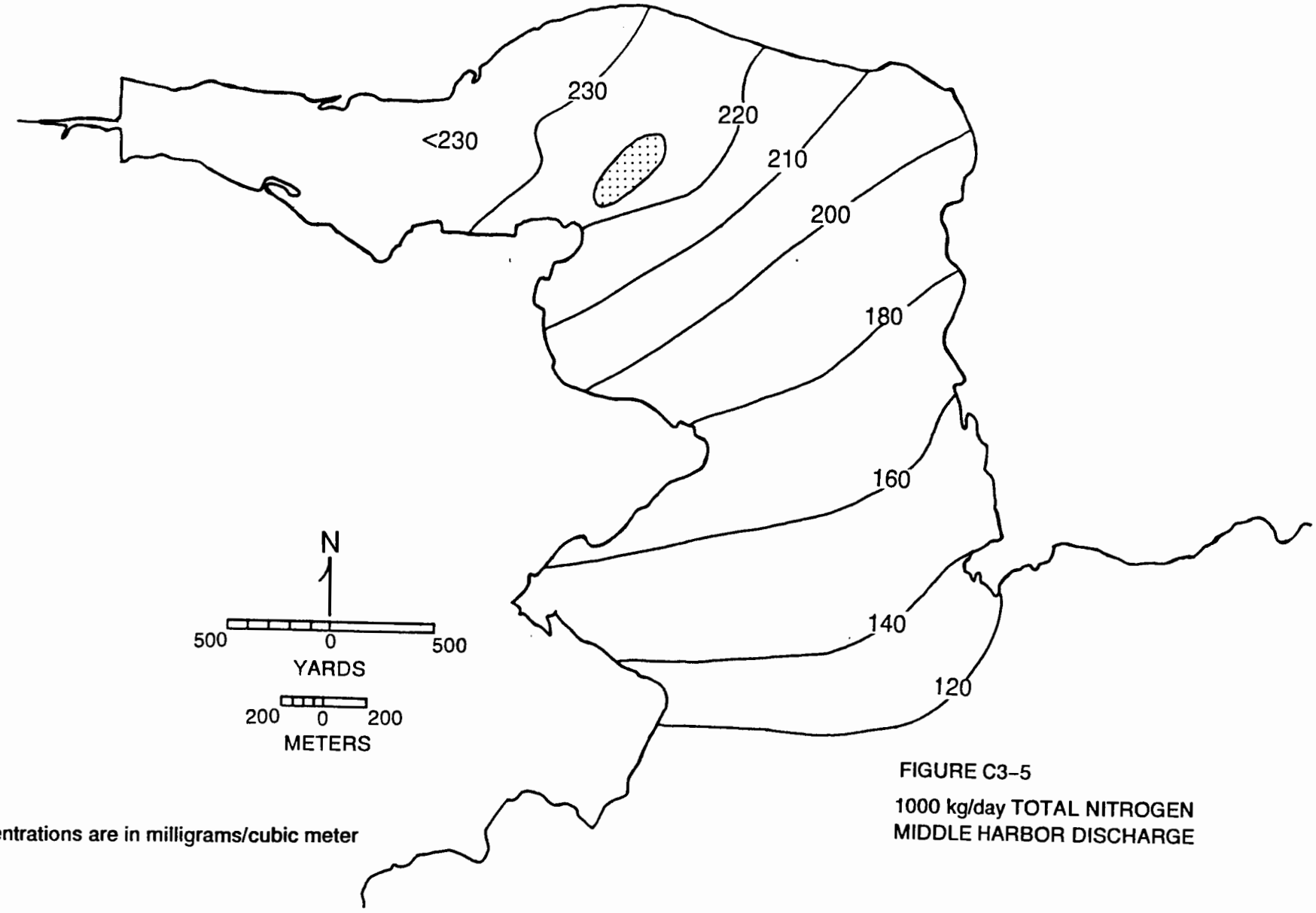
1000 kg/day TOTAL NITROGEN
INNER HARBOR DISCHARGE



Concentrations are in milligrams/cubic meter

FIGURE C3–4

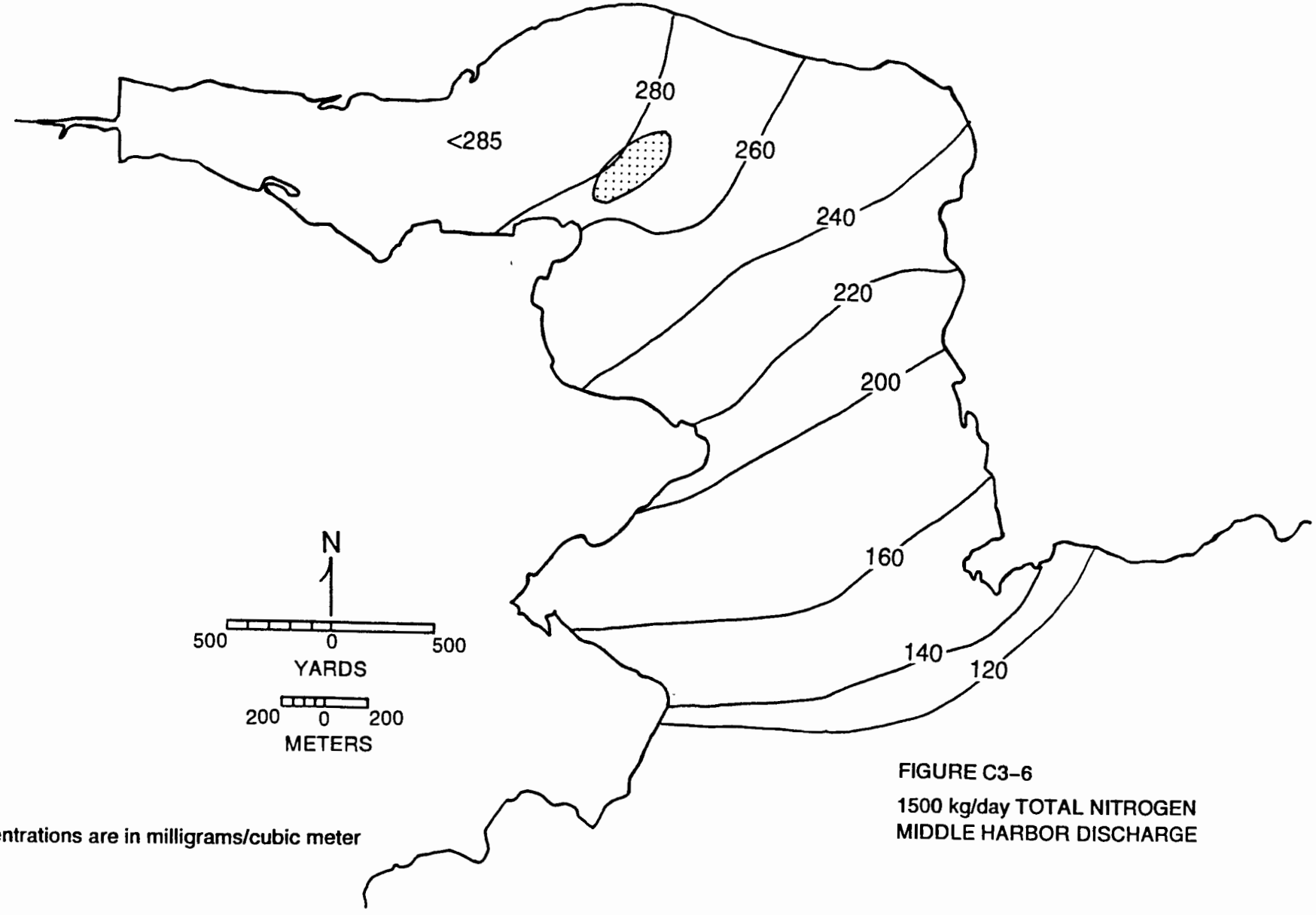
500 kg/day TOTAL NITROGEN
MIDDLE HARBOR DISCHARGE



Concentrations are in milligrams/cubic meter

FIGURE C3-5

1000 kg/day TOTAL NITROGEN
MIDDLE HARBOR DISCHARGE



Concentrations are in milligrams/cubic meter

FIGURE C3-6

1500 kg/day TOTAL NITROGEN
MIDDLE HARBOR DISCHARGE

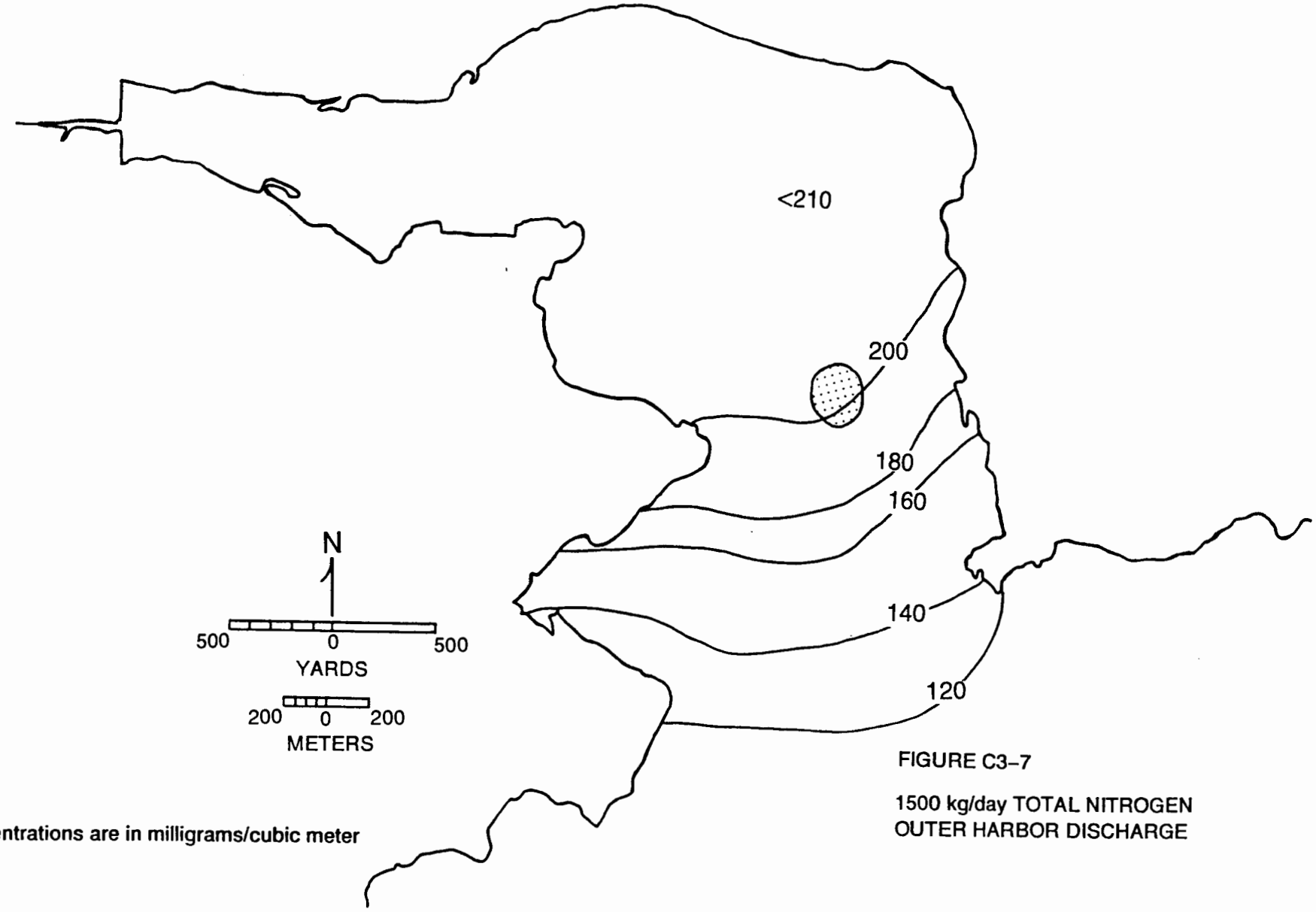
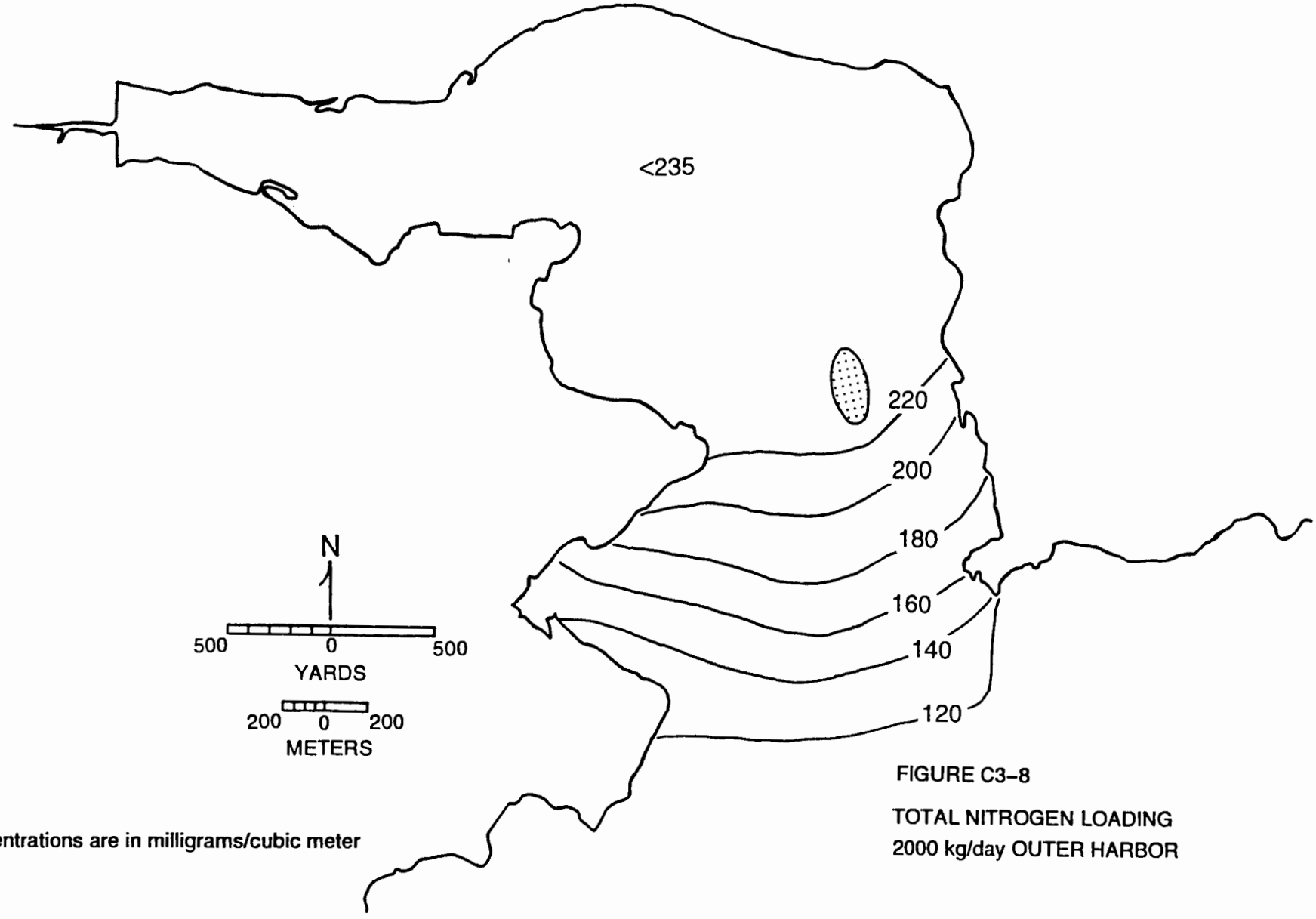


FIGURE C3–7

1500 kg/day TOTAL NITROGEN
OUTER HARBOR DISCHARGE

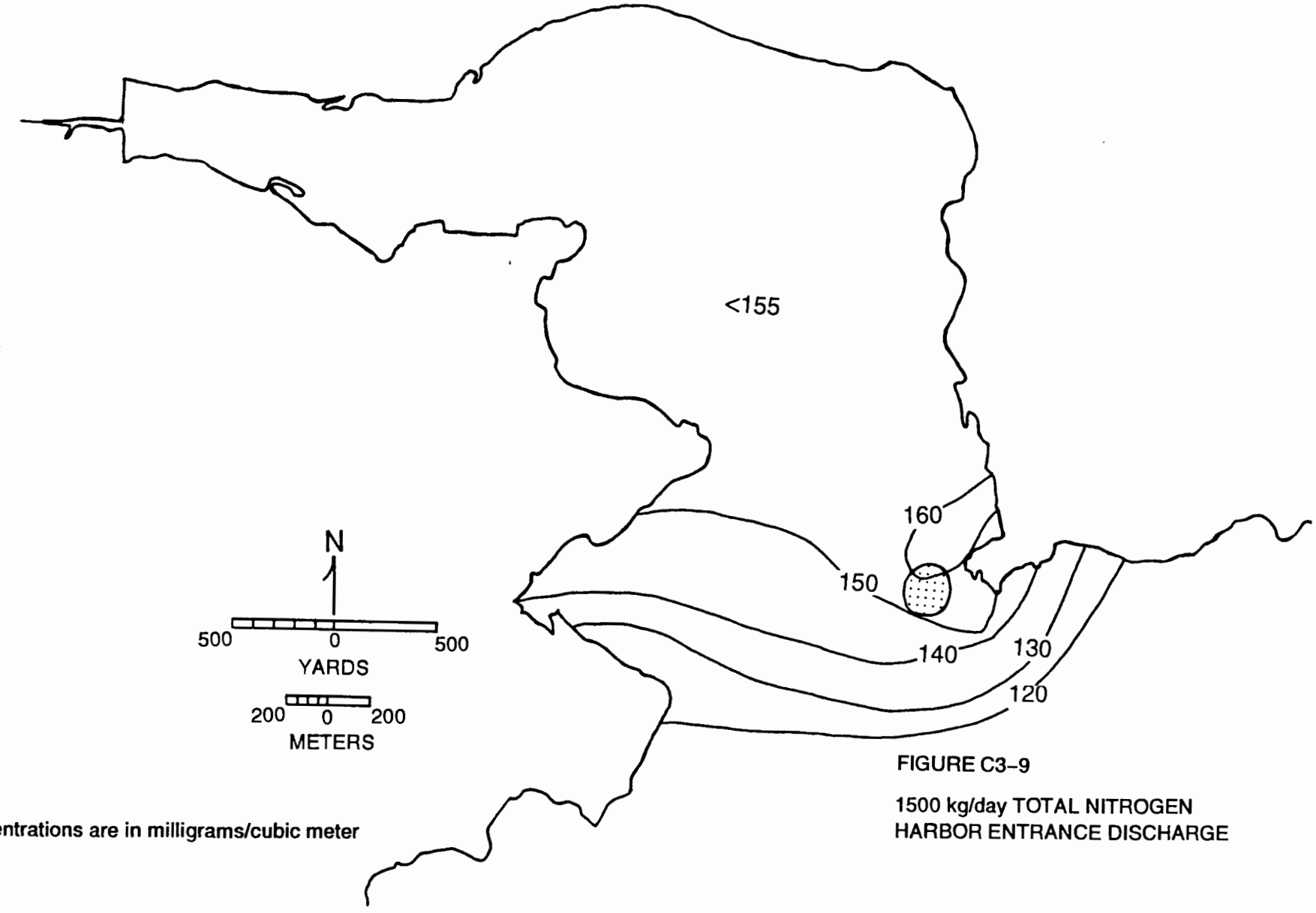
Concentrations are in milligrams/cubic meter



Concentrations are in milligrams/cubic meter

FIGURE C3-8

TOTAL NITROGEN LOADING
2000 kg/day OUTER HARBOR



Concentrations are in milligrams/cubic meter

FIGURE C3-9

1500 kg/day TOTAL NITROGEN
HARBOR ENTRANCE DISCHARGE

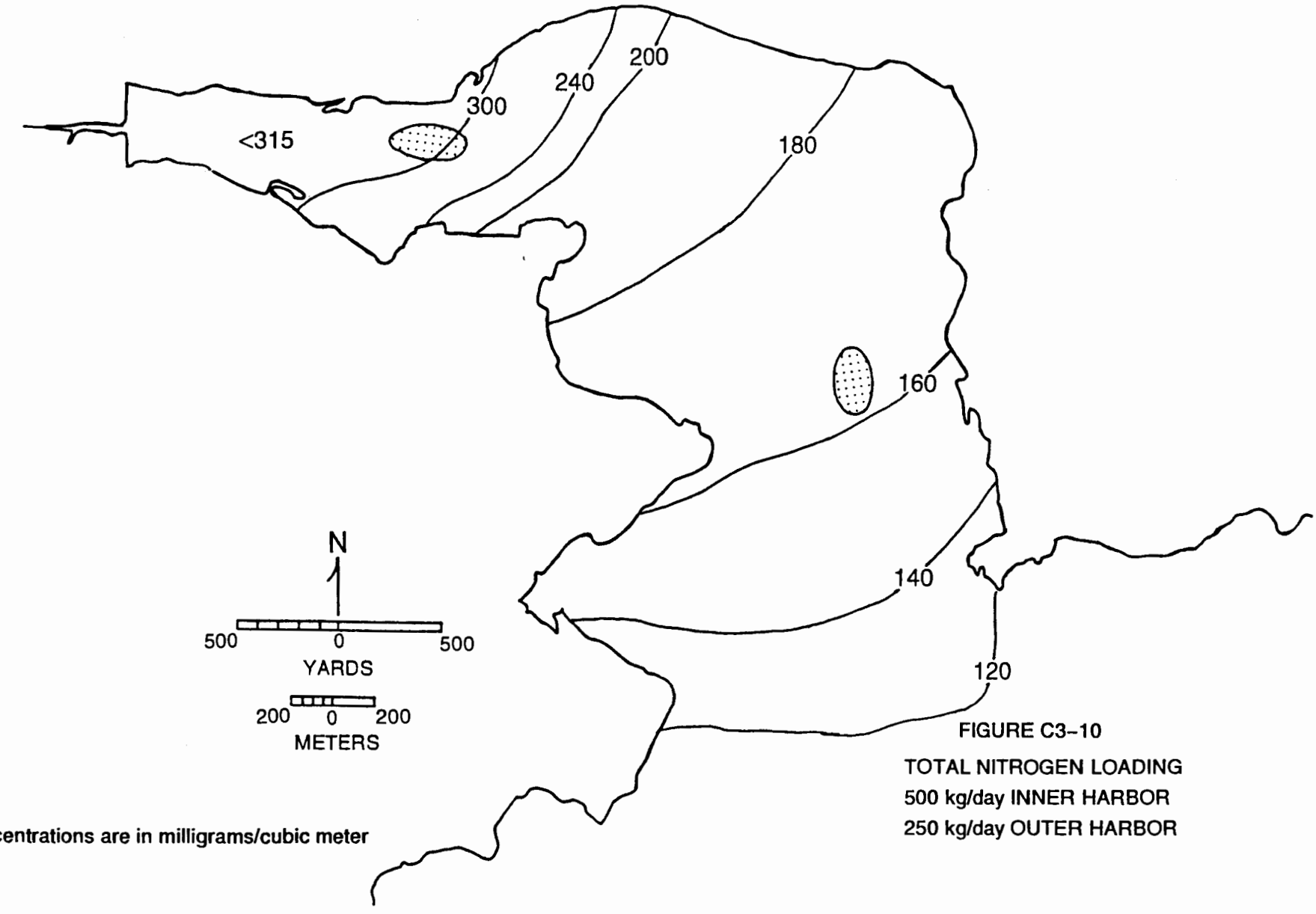
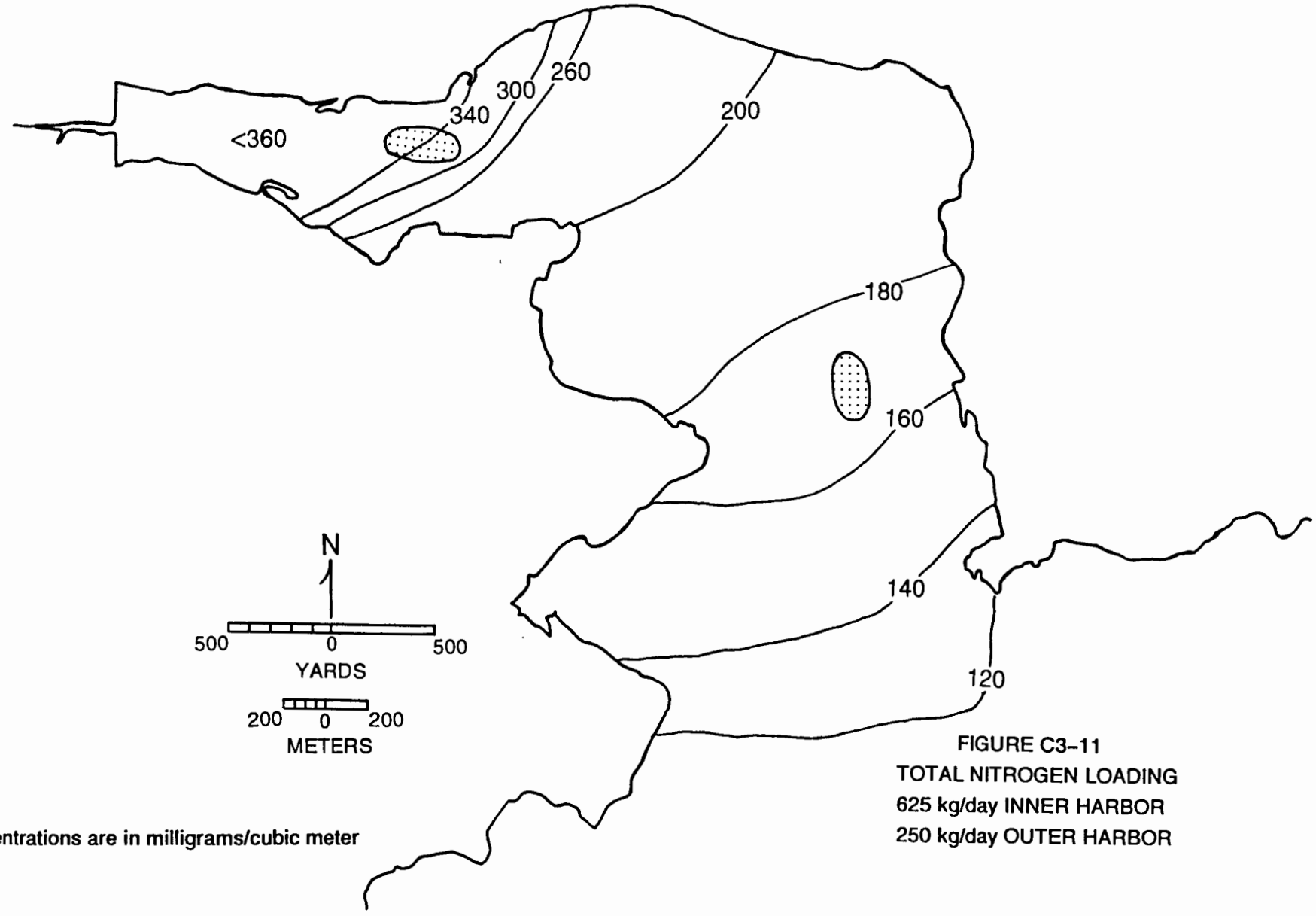


FIGURE C3-10

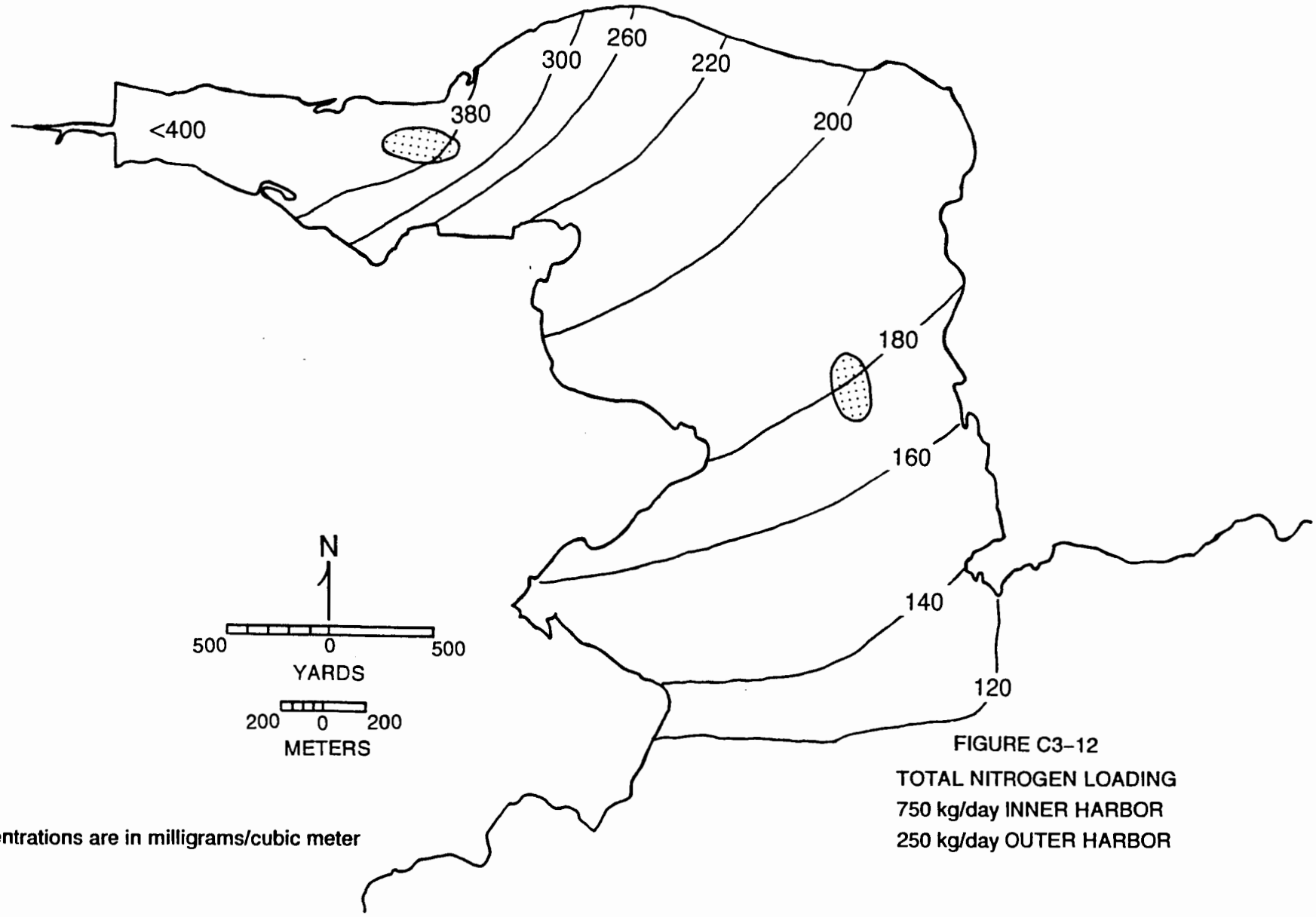
TOTAL NITROGEN LOADING
500 kg/day INNER HARBOR
250 kg/day OUTER HARBOR

Concentrations are in milligrams/cubic meter



Concentrations are in milligrams/cubic meter

FIGURE C3-11
TOTAL NITROGEN LOADING
625 kg/day INNER HARBOR
250 kg/day OUTER HARBOR



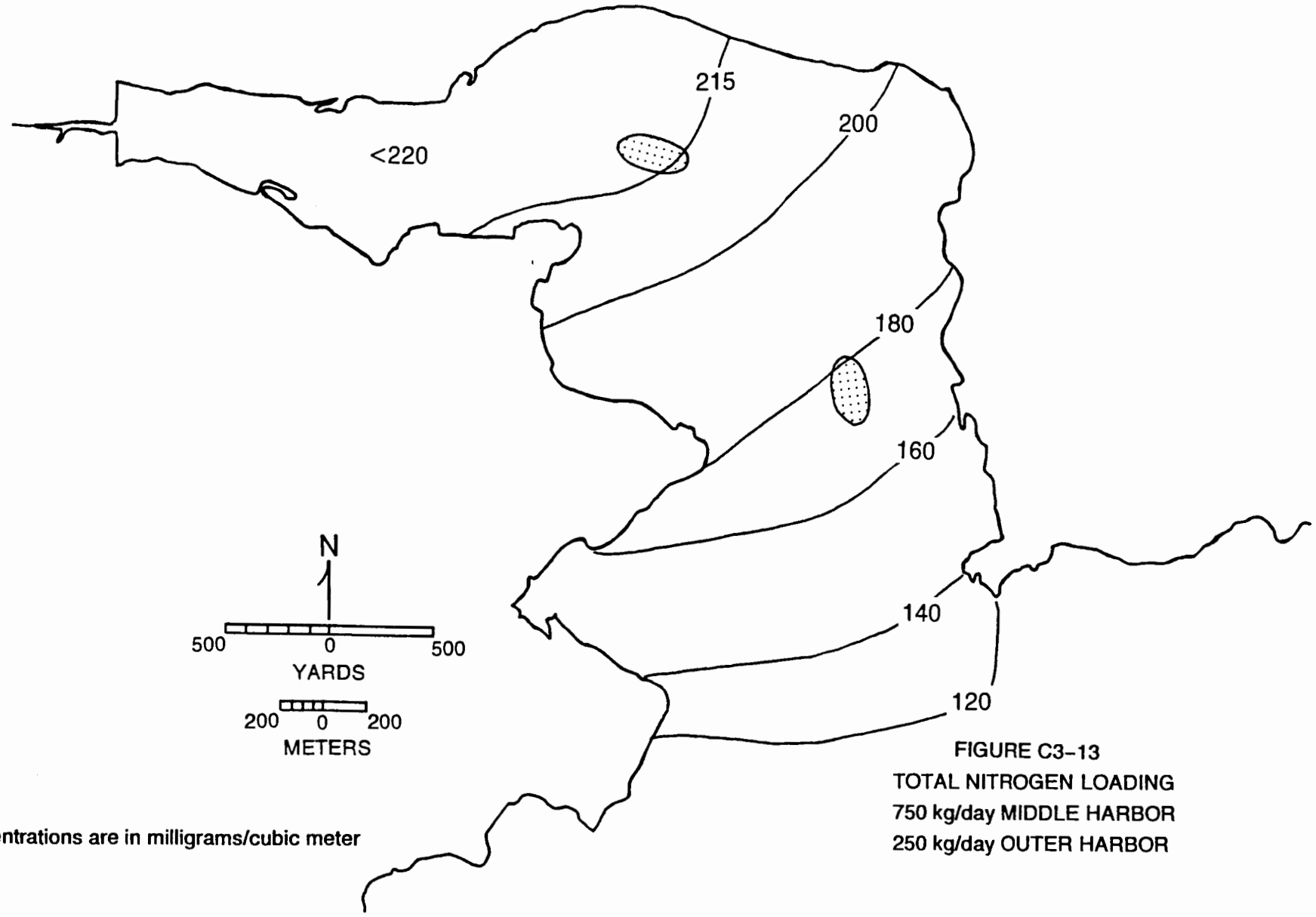
Concentrations are in milligrams/cubic meter

FIGURE C3-12

TOTAL NITROGEN LOADING

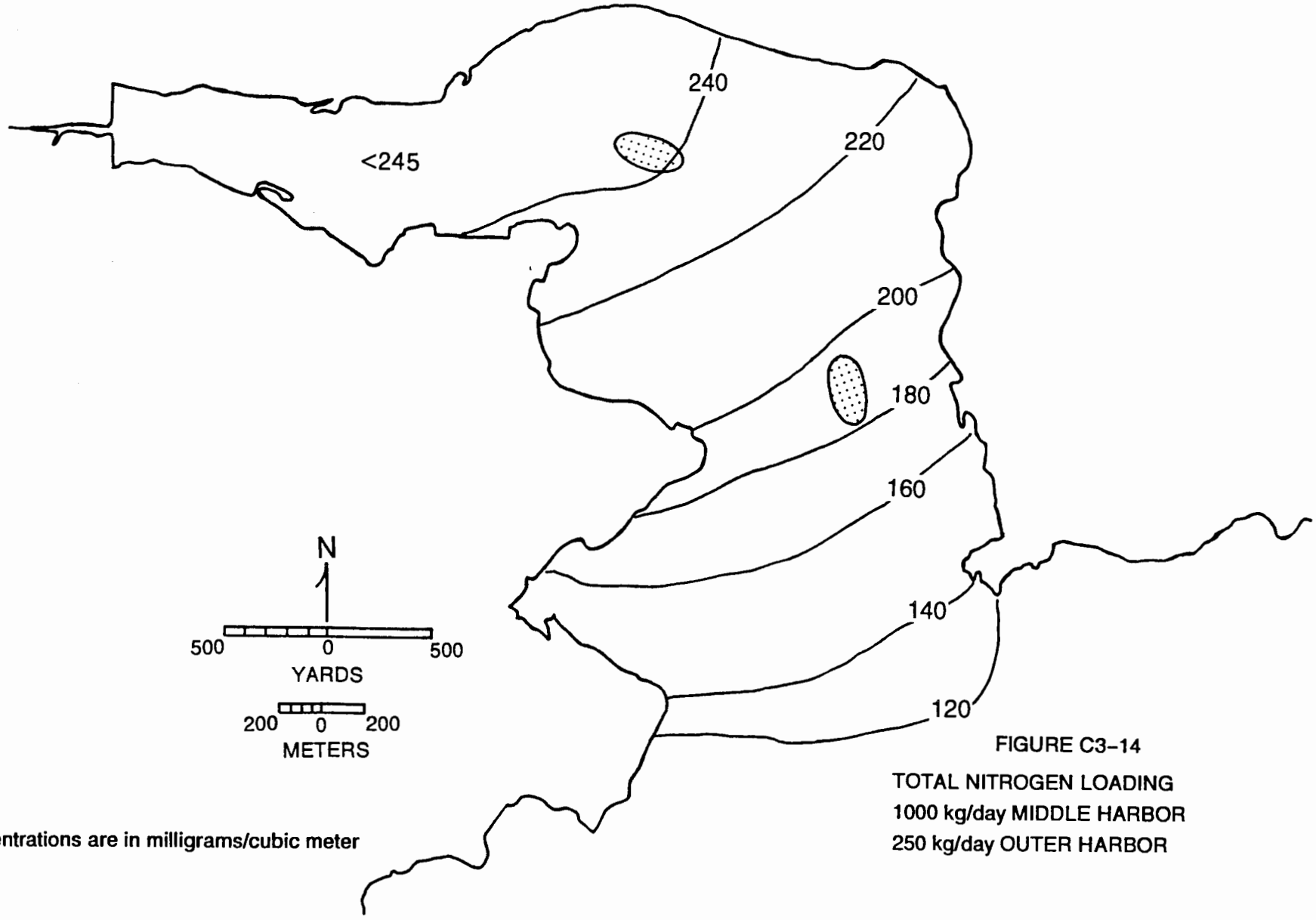
750 kg/day INNER HARBOR

250 kg/day OUTER HARBOR



Concentrations are in milligrams/cubic meter

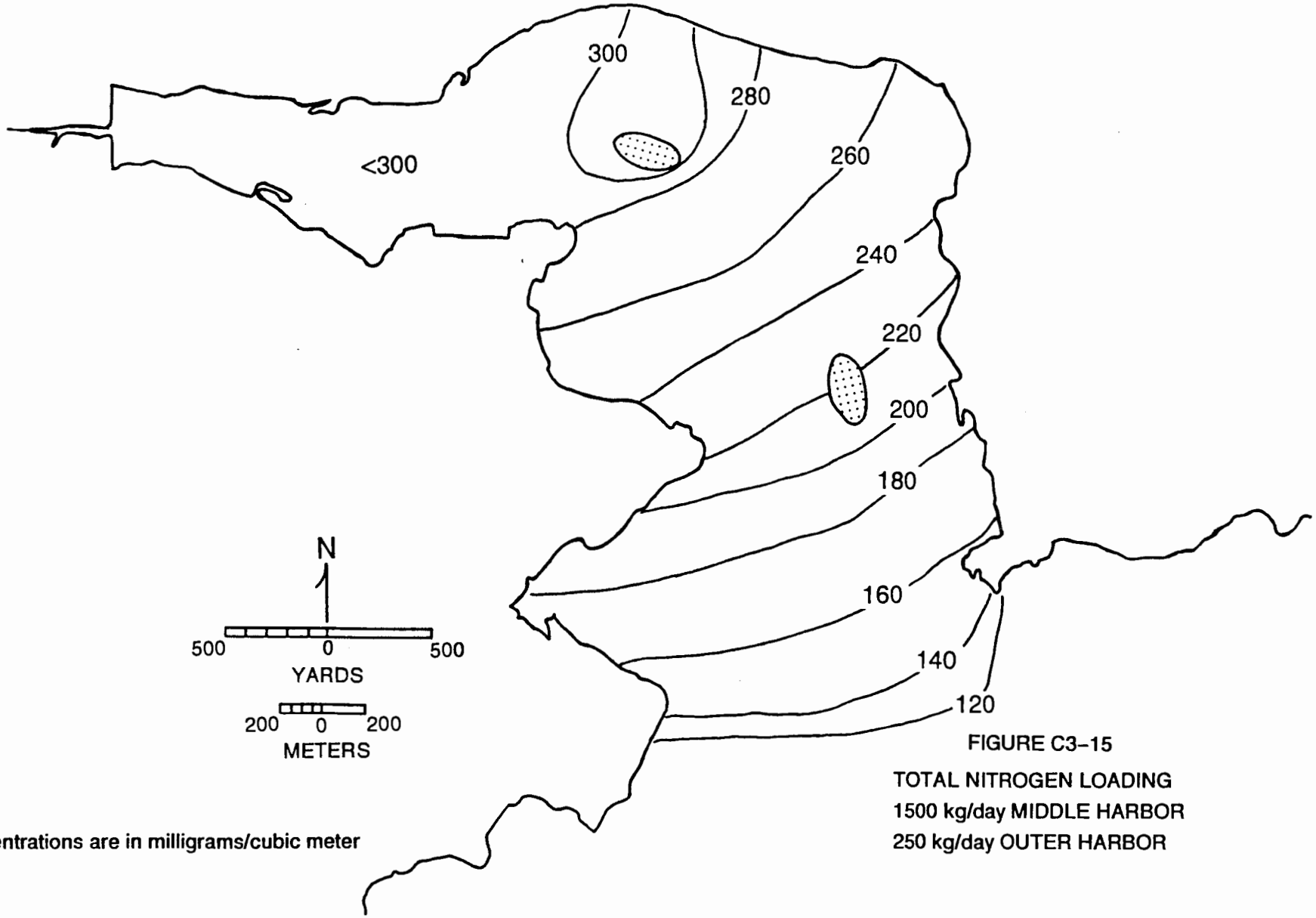
FIGURE C3-13
TOTAL NITROGEN LOADING
750 kg/day MIDDLE HARBOR
250 kg/day OUTER HARBOR



Concentrations are in milligrams/cubic meter

FIGURE C3-14

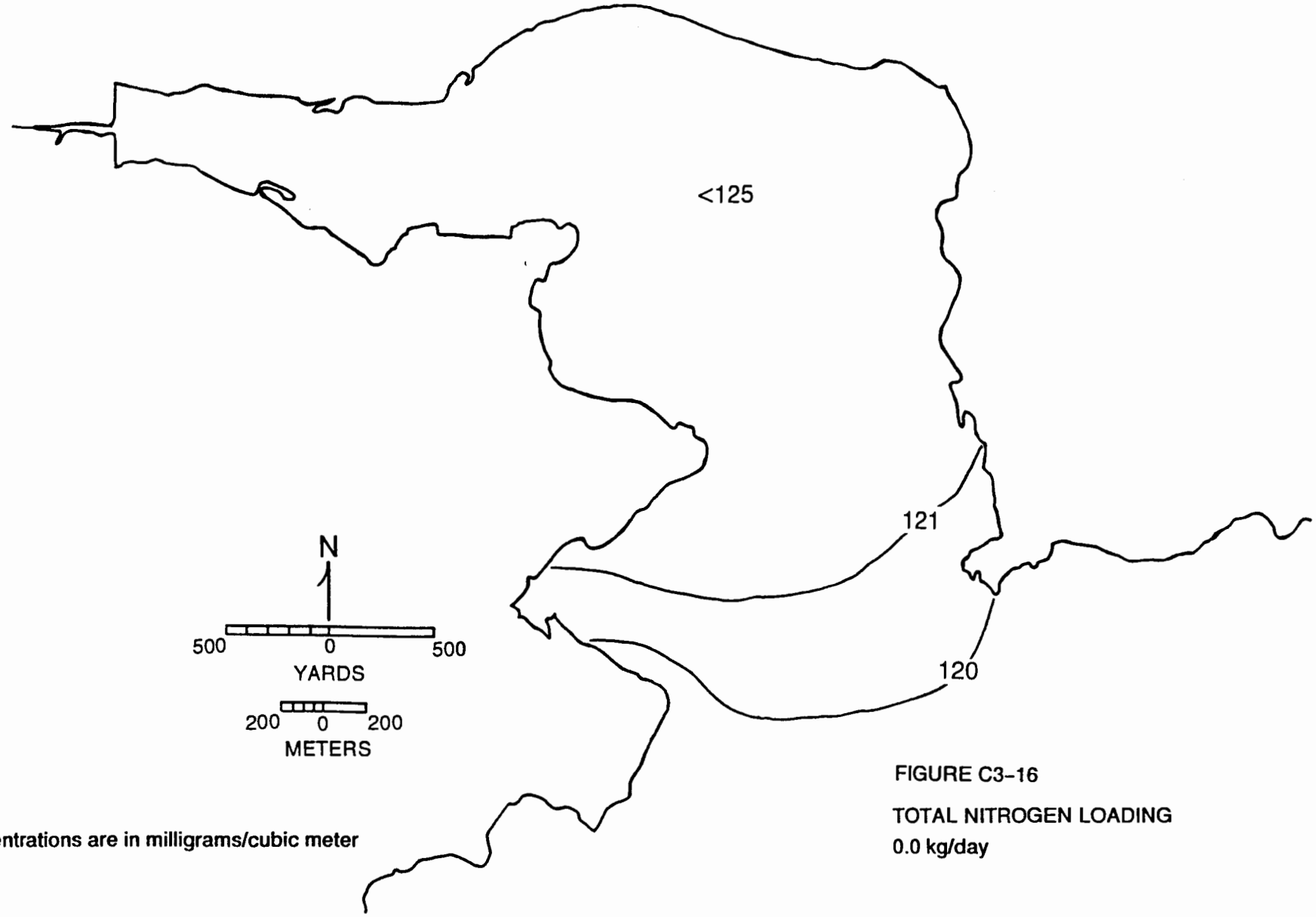
TOTAL NITROGEN LOADING
1000 kg/day MIDDLE HARBOR
250 kg/day OUTER HARBOR



Concentrations are in milligrams/cubic meter

FIGURE C3-15

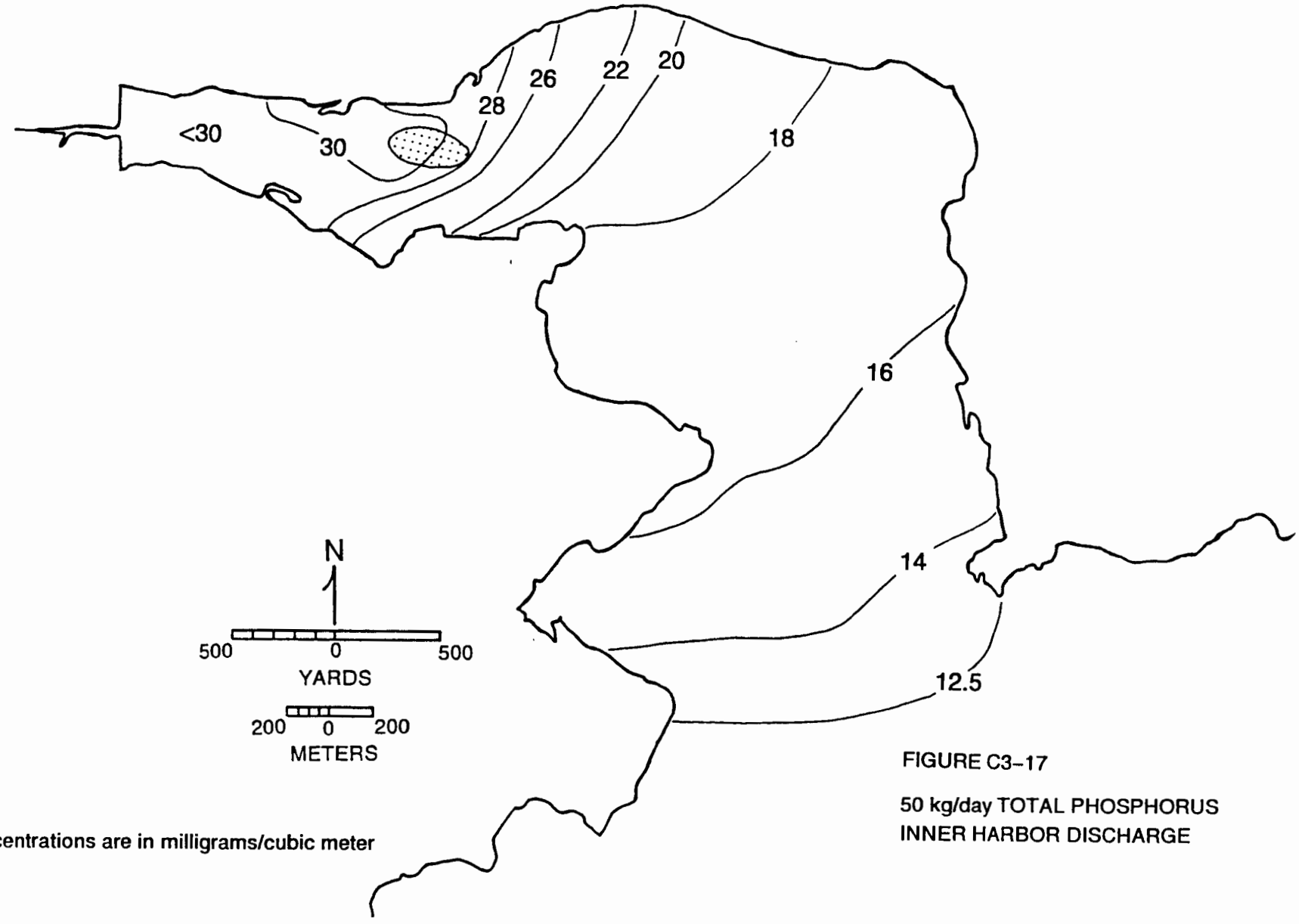
TOTAL NITROGEN LOADING
1500 kg/day MIDDLE HARBOR
250 kg/day OUTER HARBOR



Concentrations are in milligrams/cubic meter

FIGURE C3-16

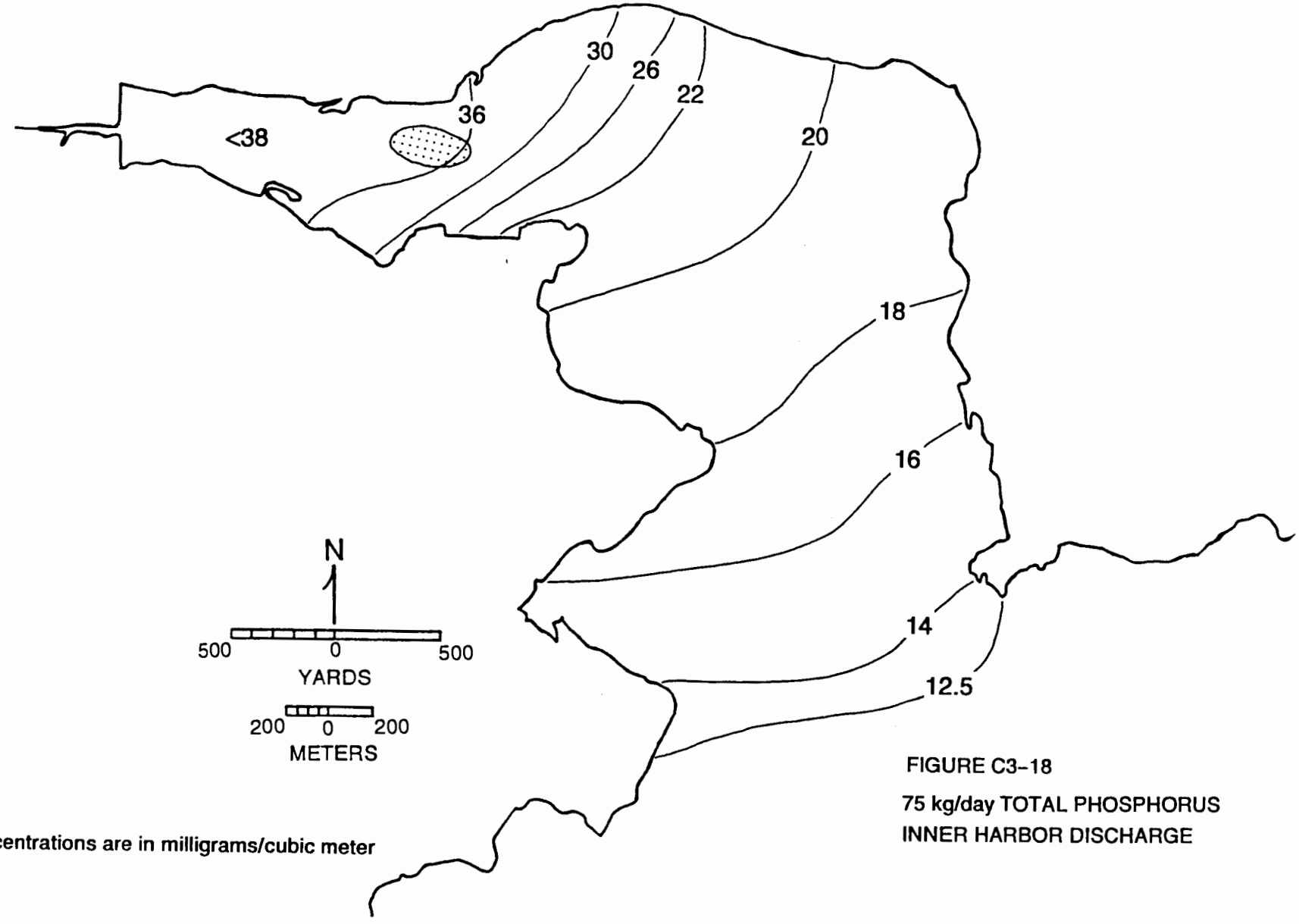
TOTAL NITROGEN LOADING
0.0 kg/day



Concentrations are in milligrams/cubic meter

FIGURE C3-17

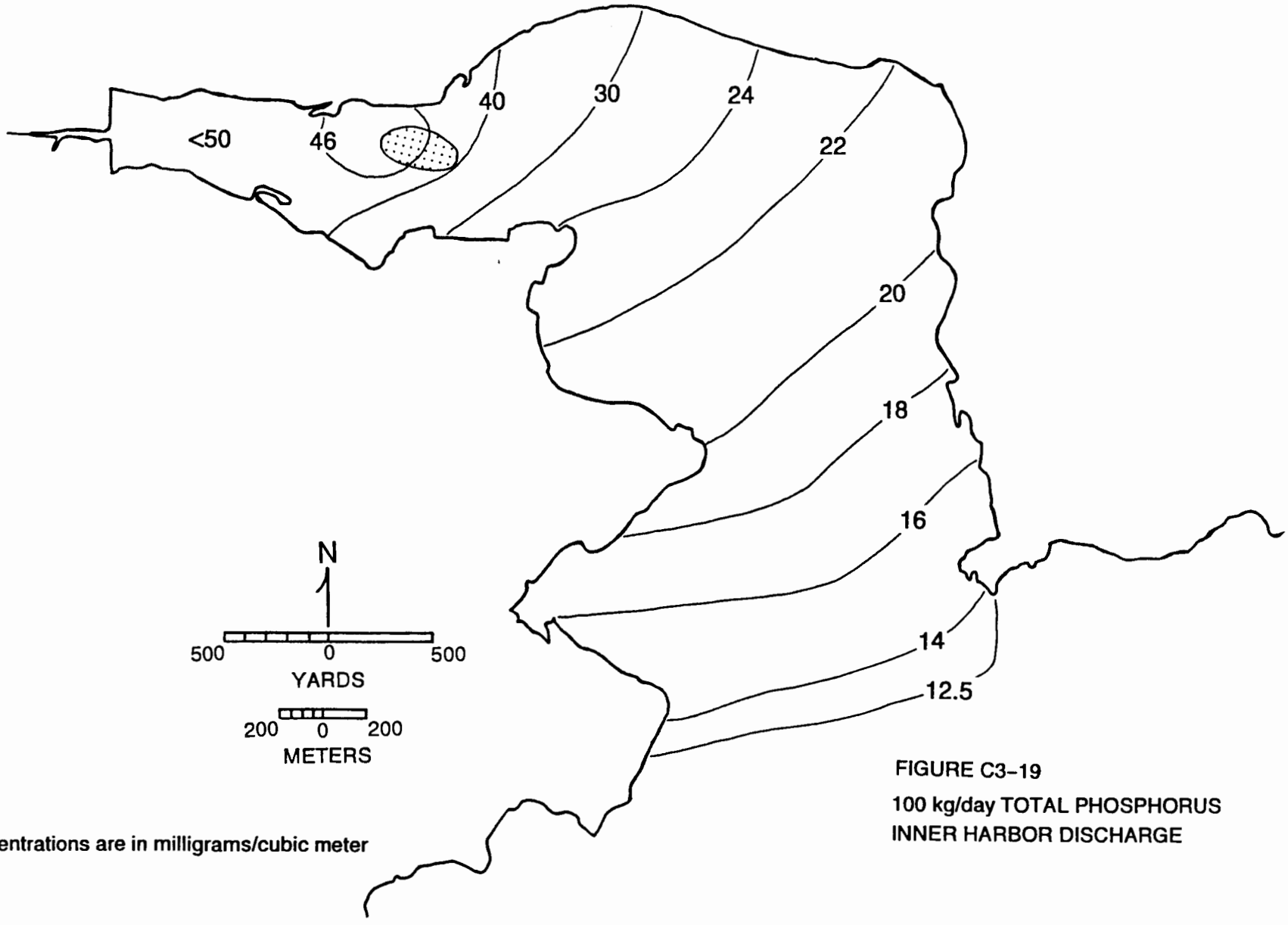
50 kg/day TOTAL PHOSPHORUS
INNER HARBOR DISCHARGE



Concentrations are in milligrams/cubic meter

FIGURE C3-18

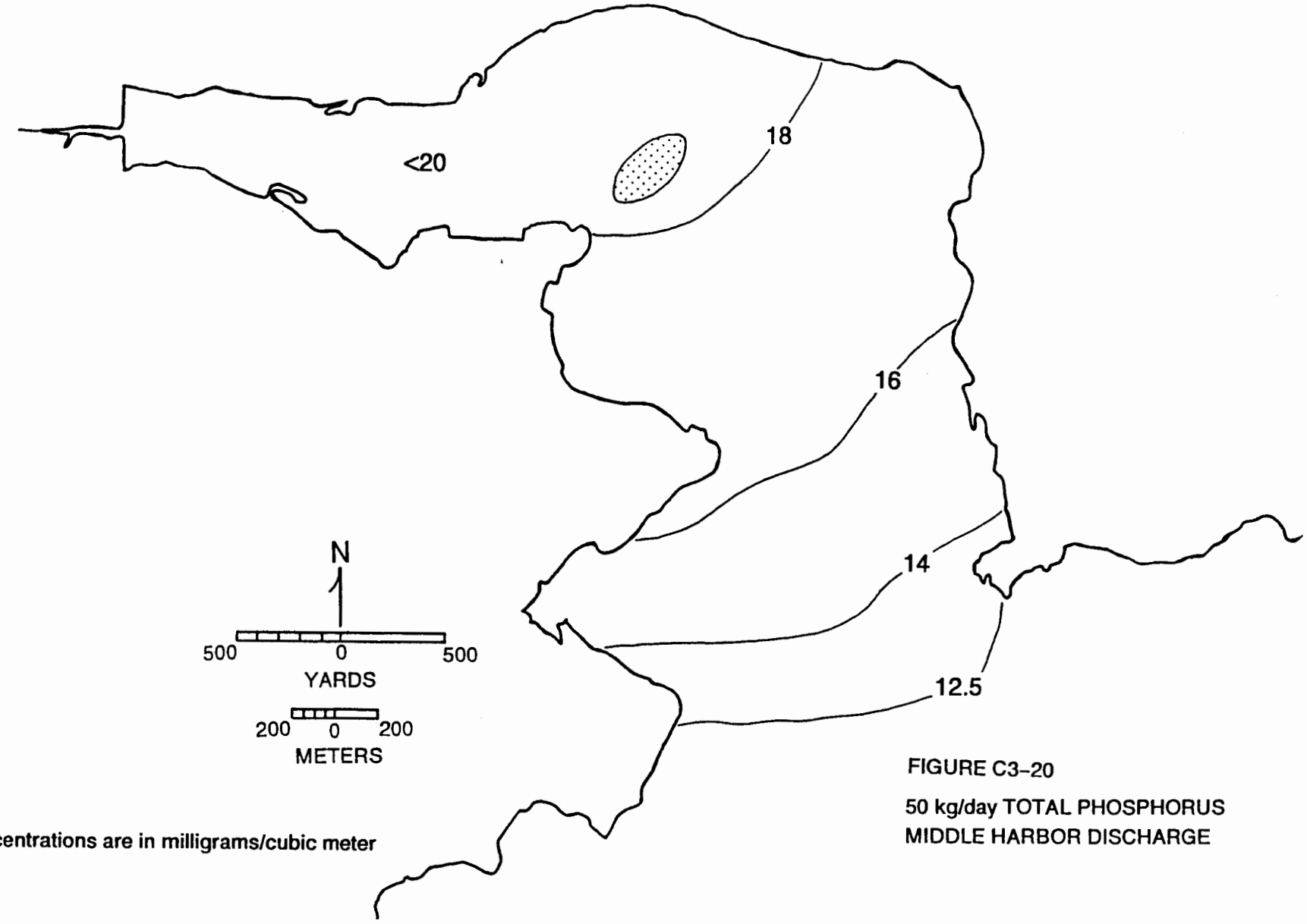
75 kg/day TOTAL PHOSPHORUS
INNER HARBOR DISCHARGE



Concentrations are in milligrams/cubic meter

FIGURE C3-19

100 kg/day TOTAL PHOSPHORUS
INNER HARBOR DISCHARGE



Concentrations are in milligrams/cubic meter

FIGURE C3–20

50 kg/day TOTAL PHOSPHORUS
MIDDLE HARBOR DISCHARGE

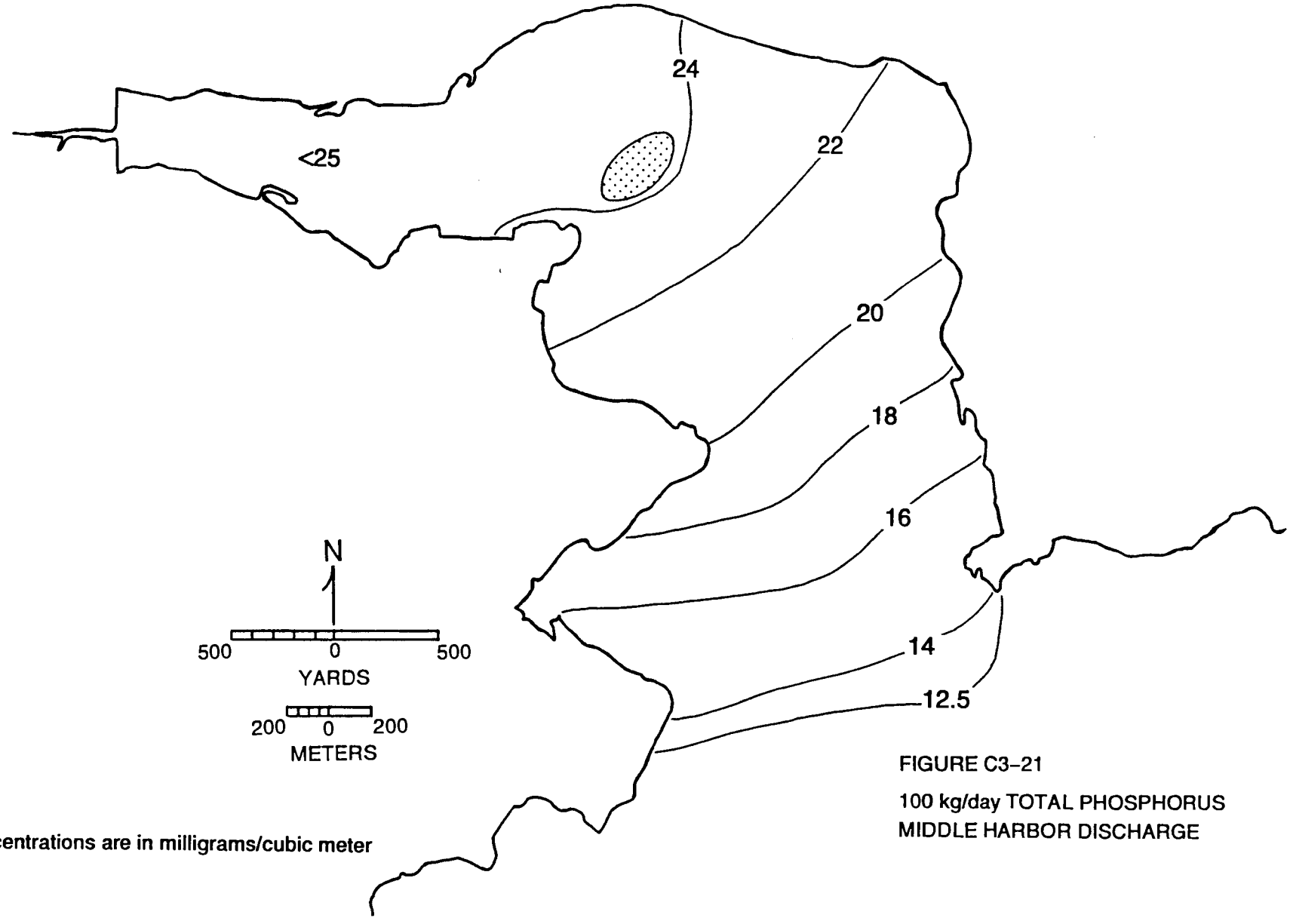
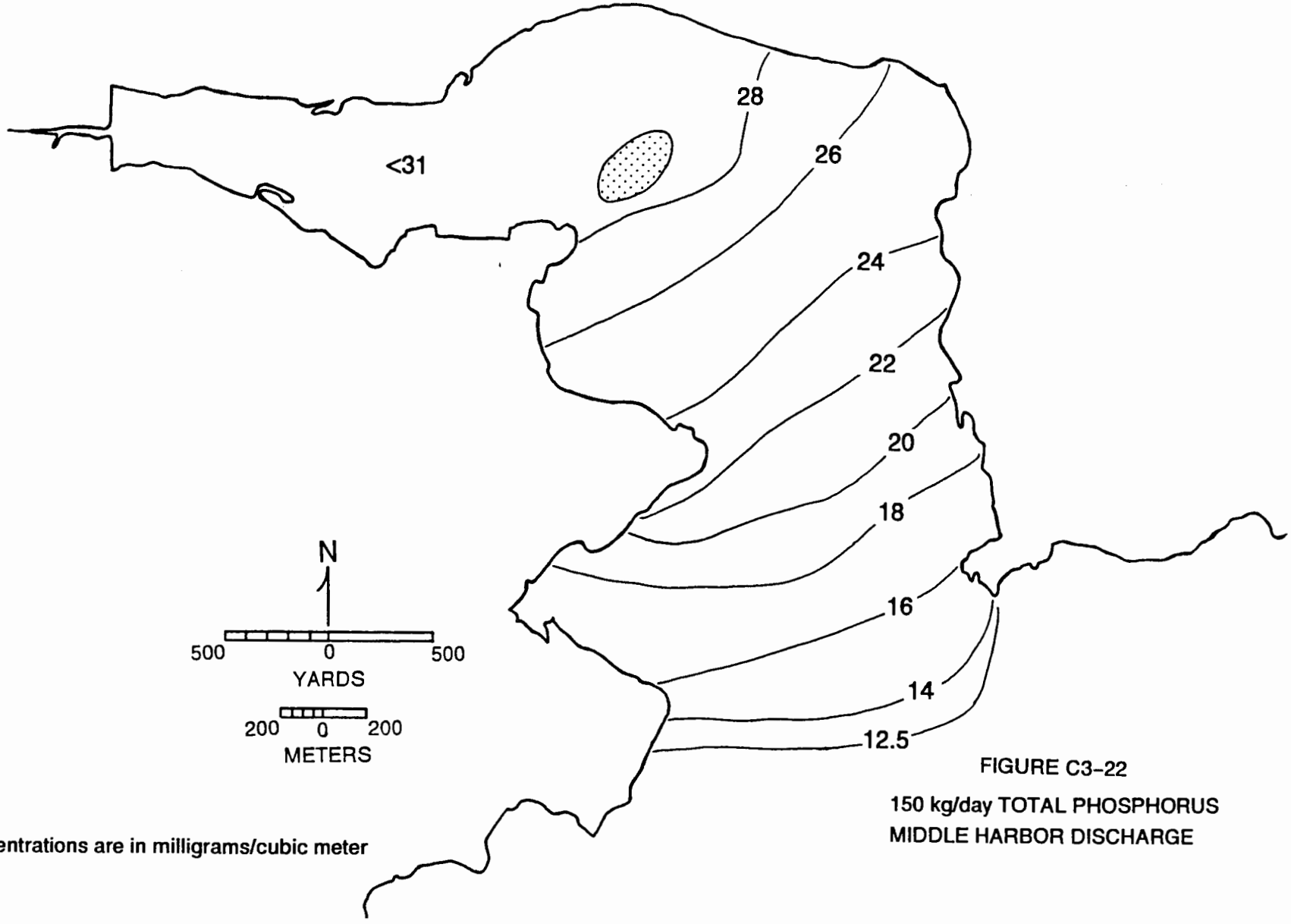


FIGURE C3-21

100 kg/day TOTAL PHOSPHORUS
MIDDLE HARBOR DISCHARGE

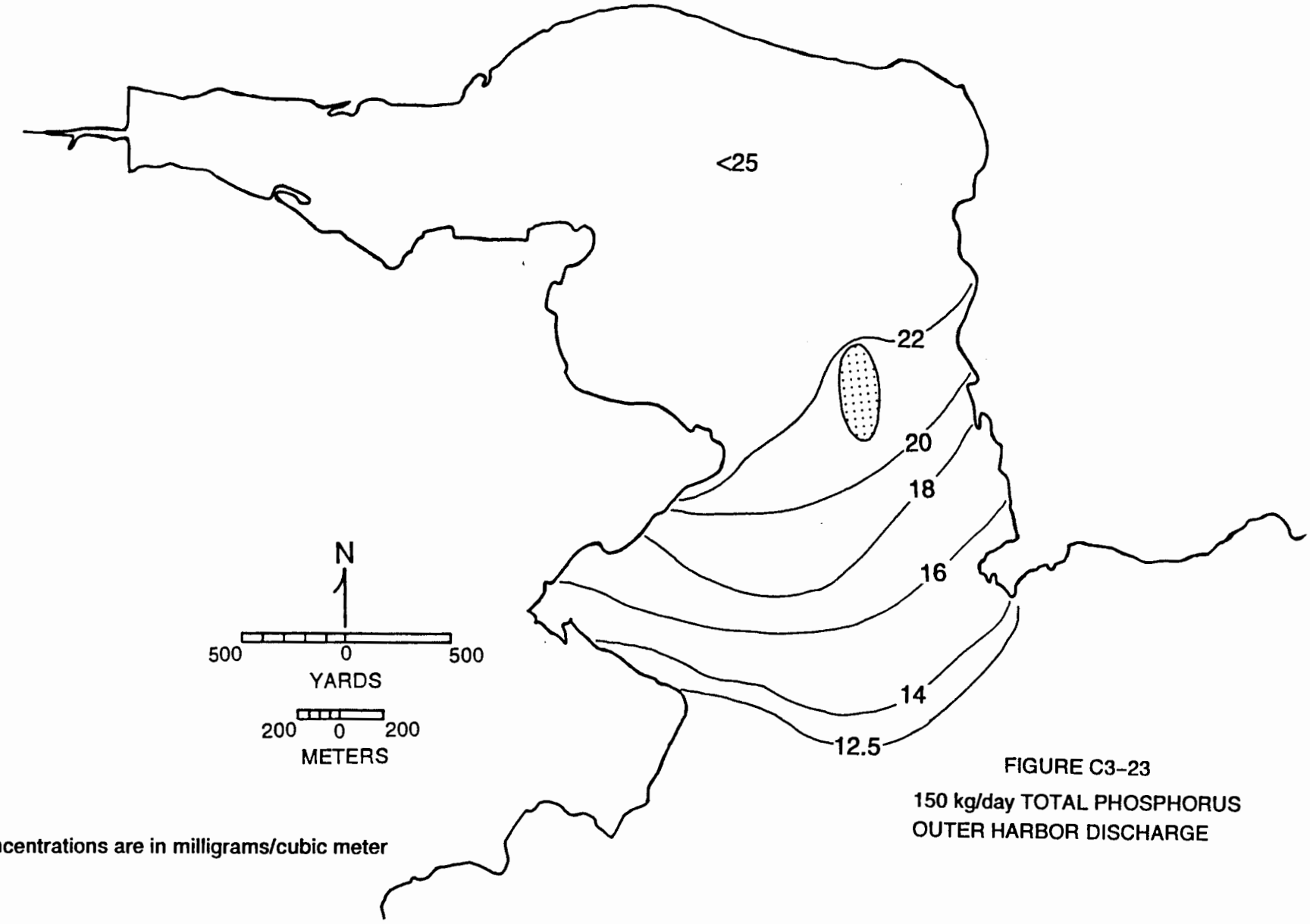
Concentrations are in milligrams/cubic meter



Concentrations are in milligrams/cubic meter

FIGURE C3-22

150 kg/day TOTAL PHOSPHORUS
MIDDLE HARBOR DISCHARGE



Concentrations are in milligrams/cubic meter

FIGURE C3-23

150 kg/day TOTAL PHOSPHORUS
OUTER HARBOR DISCHARGE

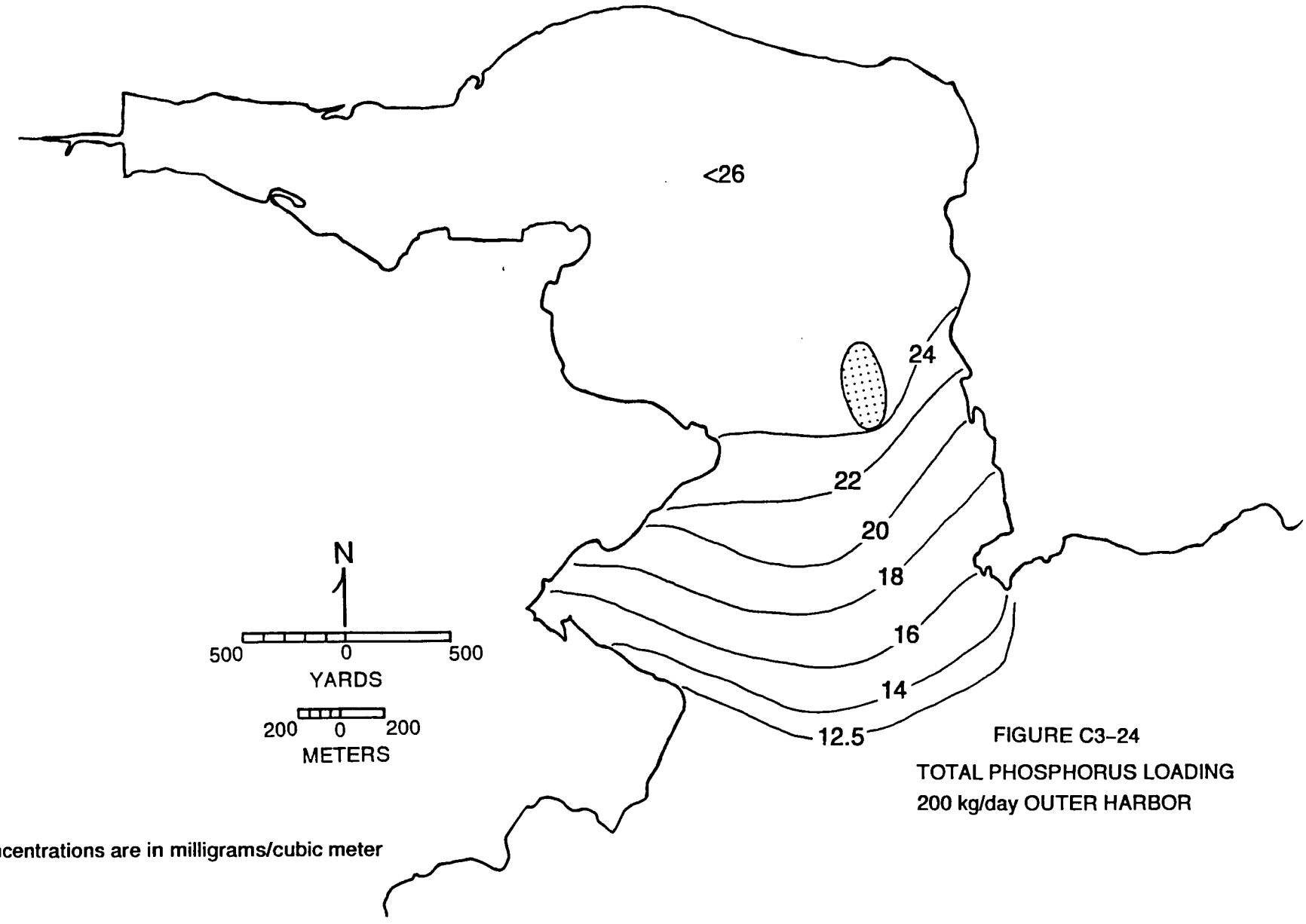
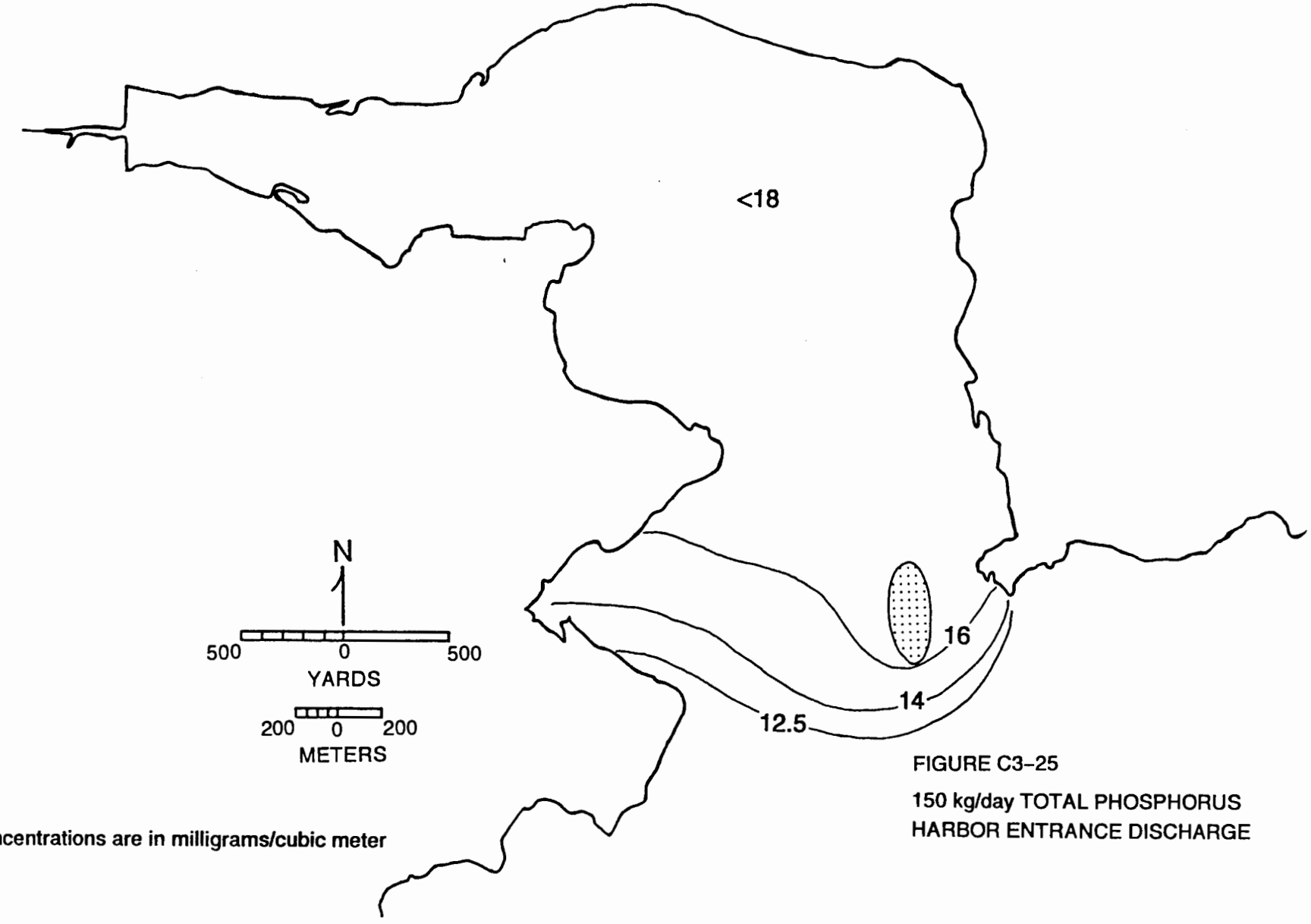


FIGURE C3-24

TOTAL PHOSPHORUS LOADING
200 kg/day OUTER HARBOR

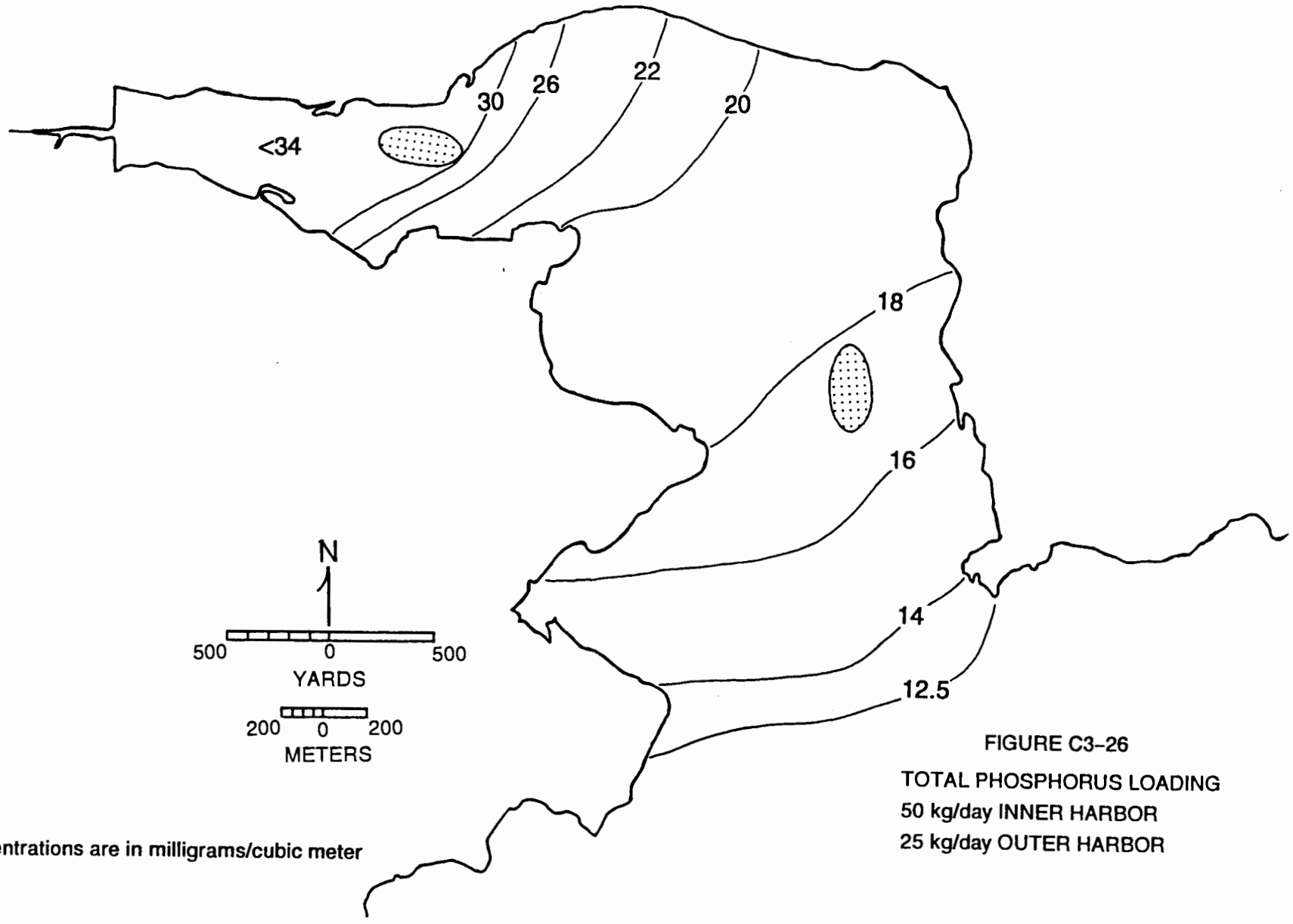
Concentrations are in milligrams/cubic meter



Concentrations are in milligrams/cubic meter

FIGURE C3-25

150 kg/day TOTAL PHOSPHORUS
HARBOR ENTRANCE DISCHARGE



Concentrations are in milligrams/cubic meter

FIGURE C3-26

TOTAL PHOSPHORUS LOADING
50 kg/day INNER HARBOR
25 kg/day OUTER HARBOR

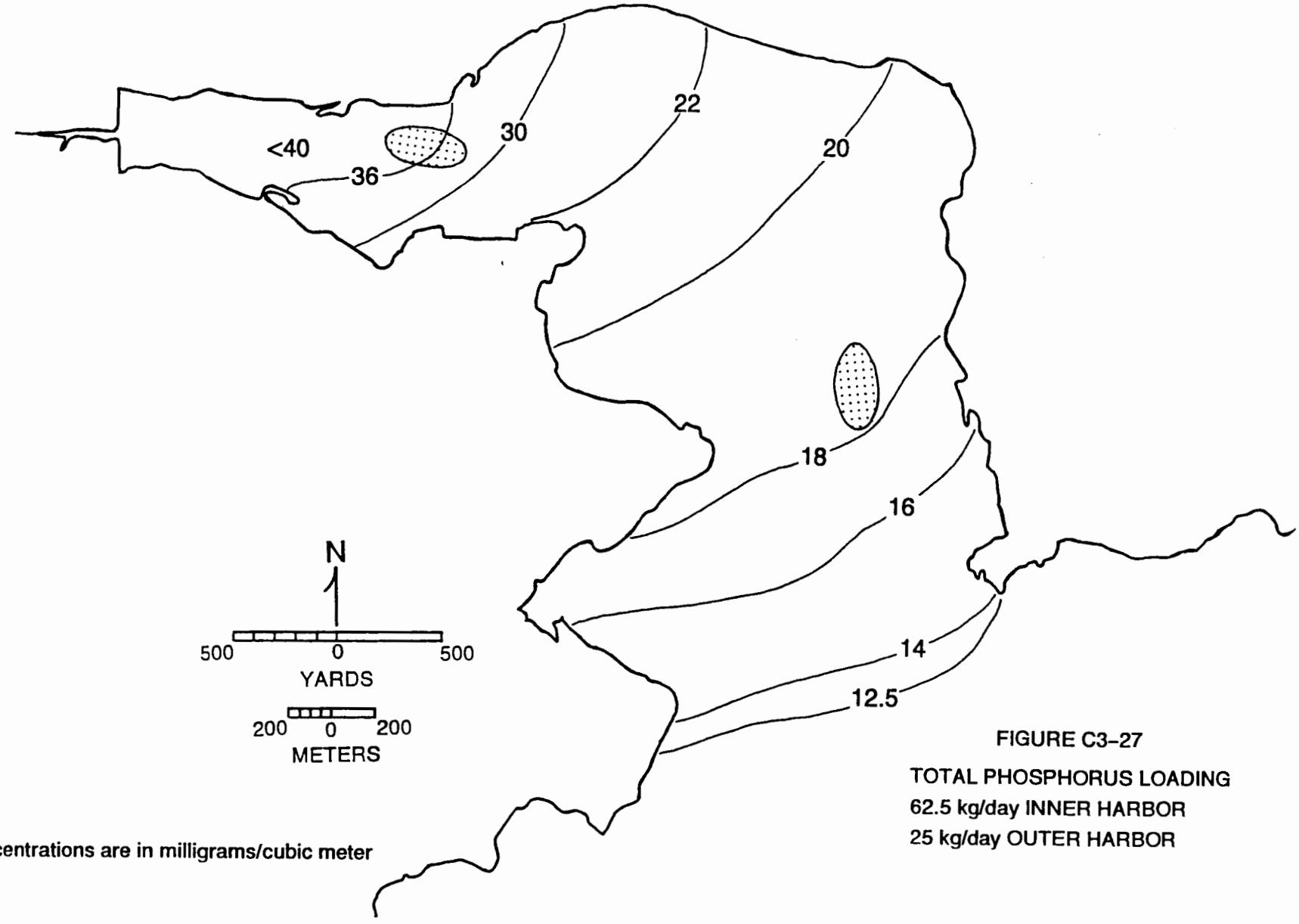


FIGURE C3–27

TOTAL PHOSPHORUS LOADING
62.5 kg/day INNER HARBOR
25 kg/day OUTER HARBOR

Concentrations are in milligrams/cubic meter

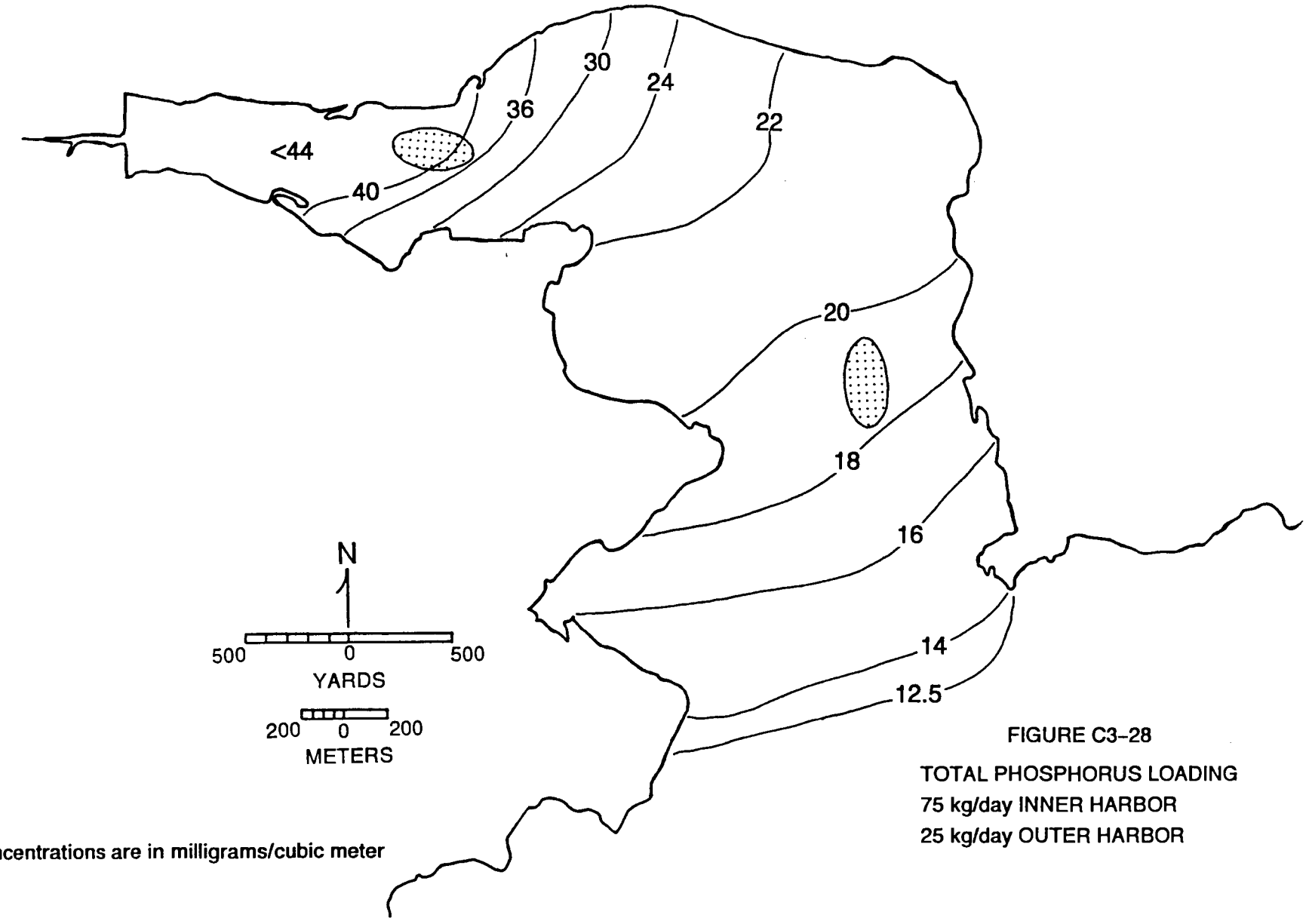
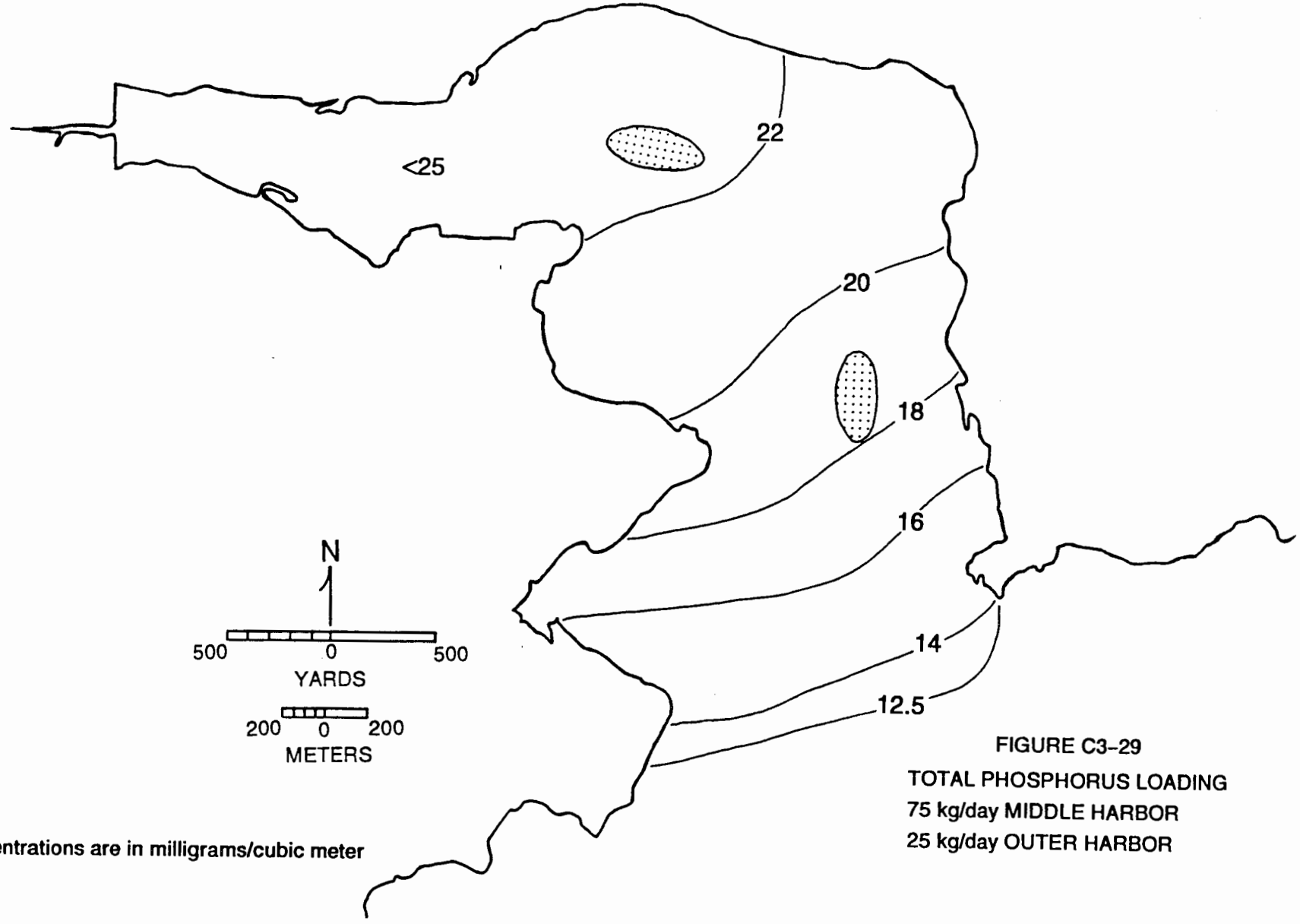


FIGURE C3-28

TOTAL PHOSPHORUS LOADING
75 kg/day INNER HARBOR
25 kg/day OUTER HARBOR

Concentrations are in milligrams/cubic meter



Concentrations are in milligrams/cubic meter

FIGURE C3-29
TOTAL PHOSPHORUS LOADING
75 kg/day MIDDLE HARBOR
25 kg/day OUTER HARBOR

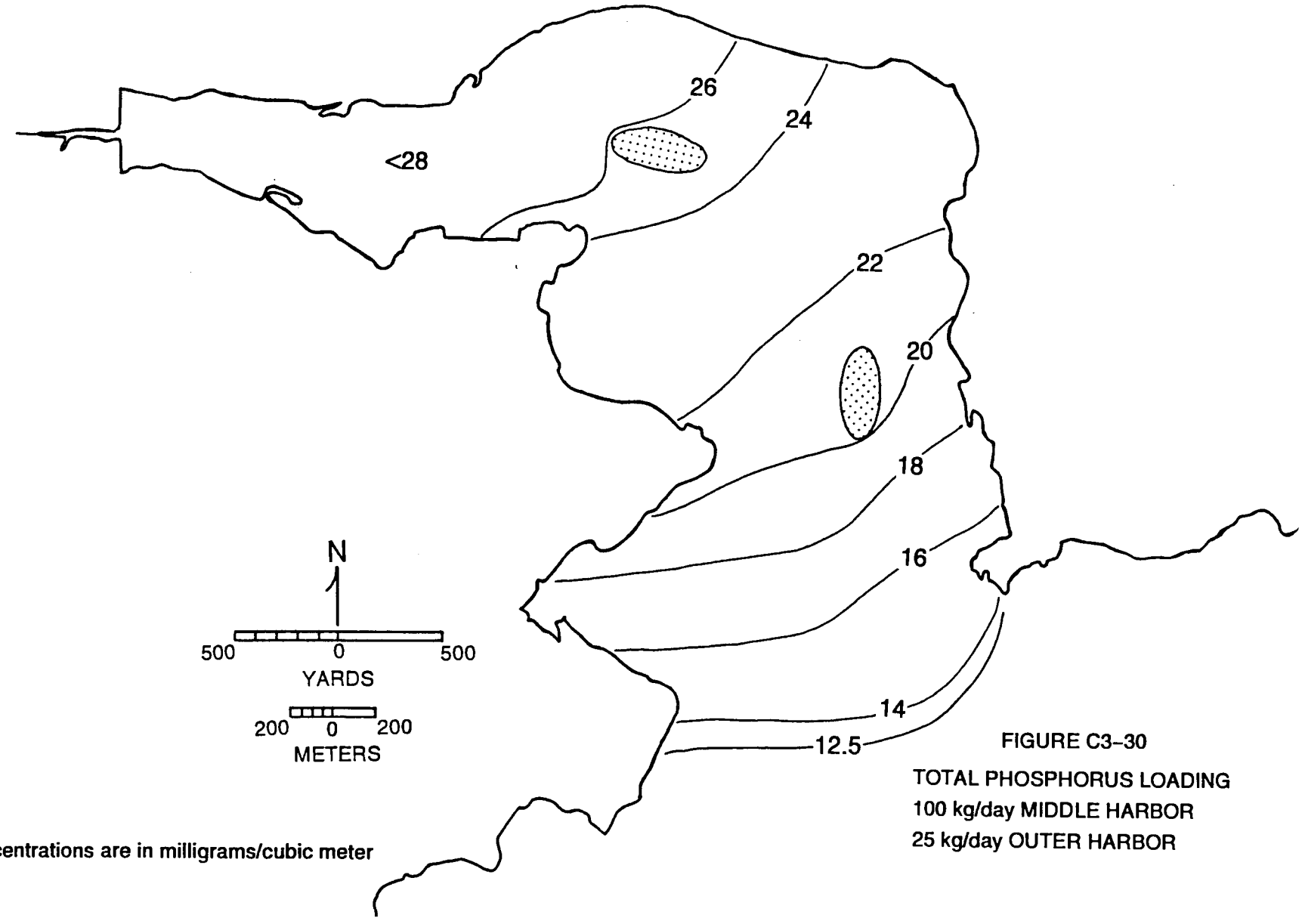
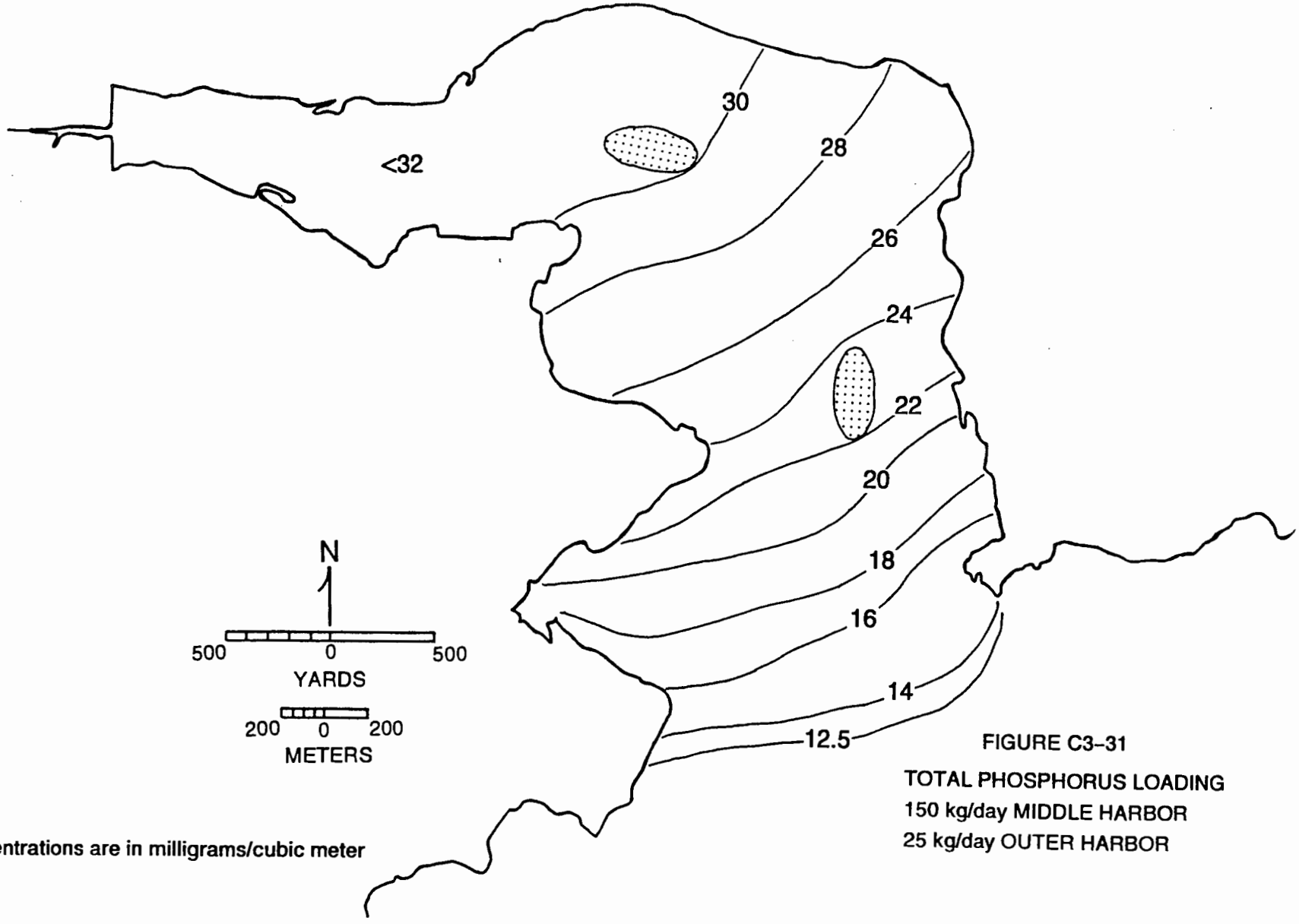


FIGURE C3-30

TOTAL PHOSPHORUS LOADING
100 kg/day MIDDLE HARBOR
25 kg/day OUTER HARBOR

Concentrations are in milligrams/cubic meter



Concentrations are in milligrams/cubic meter

FIGURE C3-31

TOTAL PHOSPHORUS LOADING
150 kg/day MIDDLE HARBOR
25 kg/day OUTER HARBOR

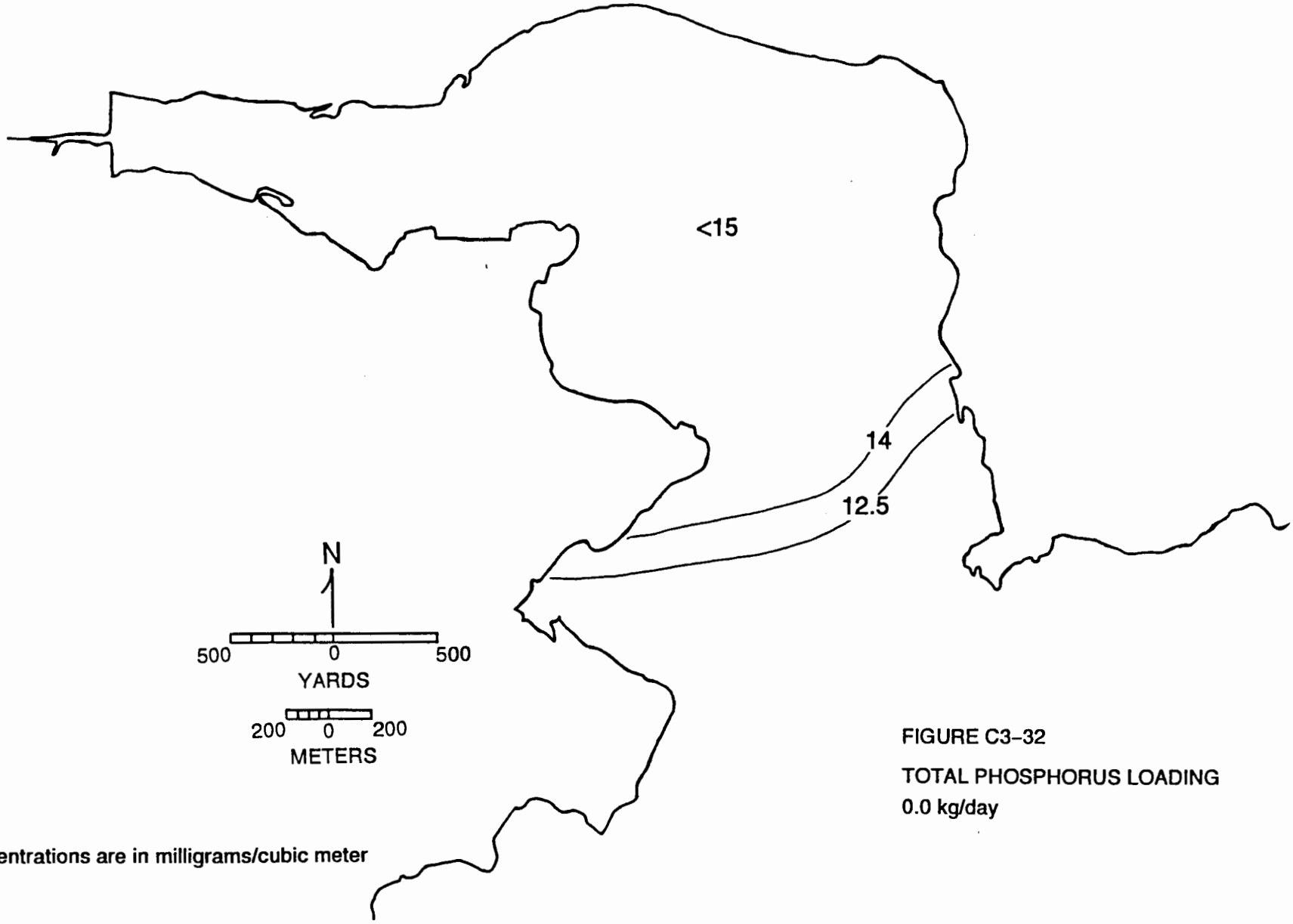
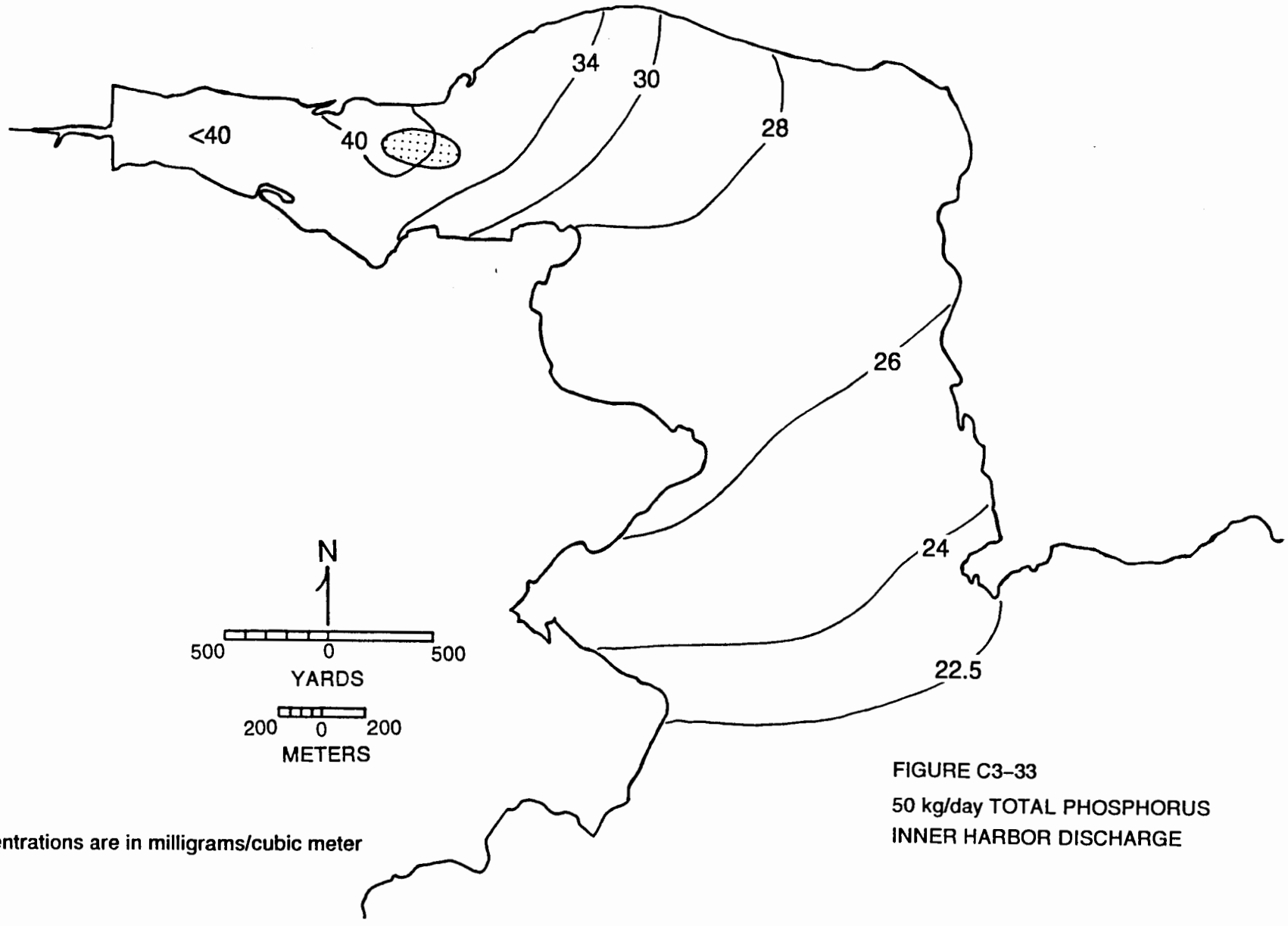


FIGURE C3-32

TOTAL PHOSPHORUS LOADING
0.0 kg/day

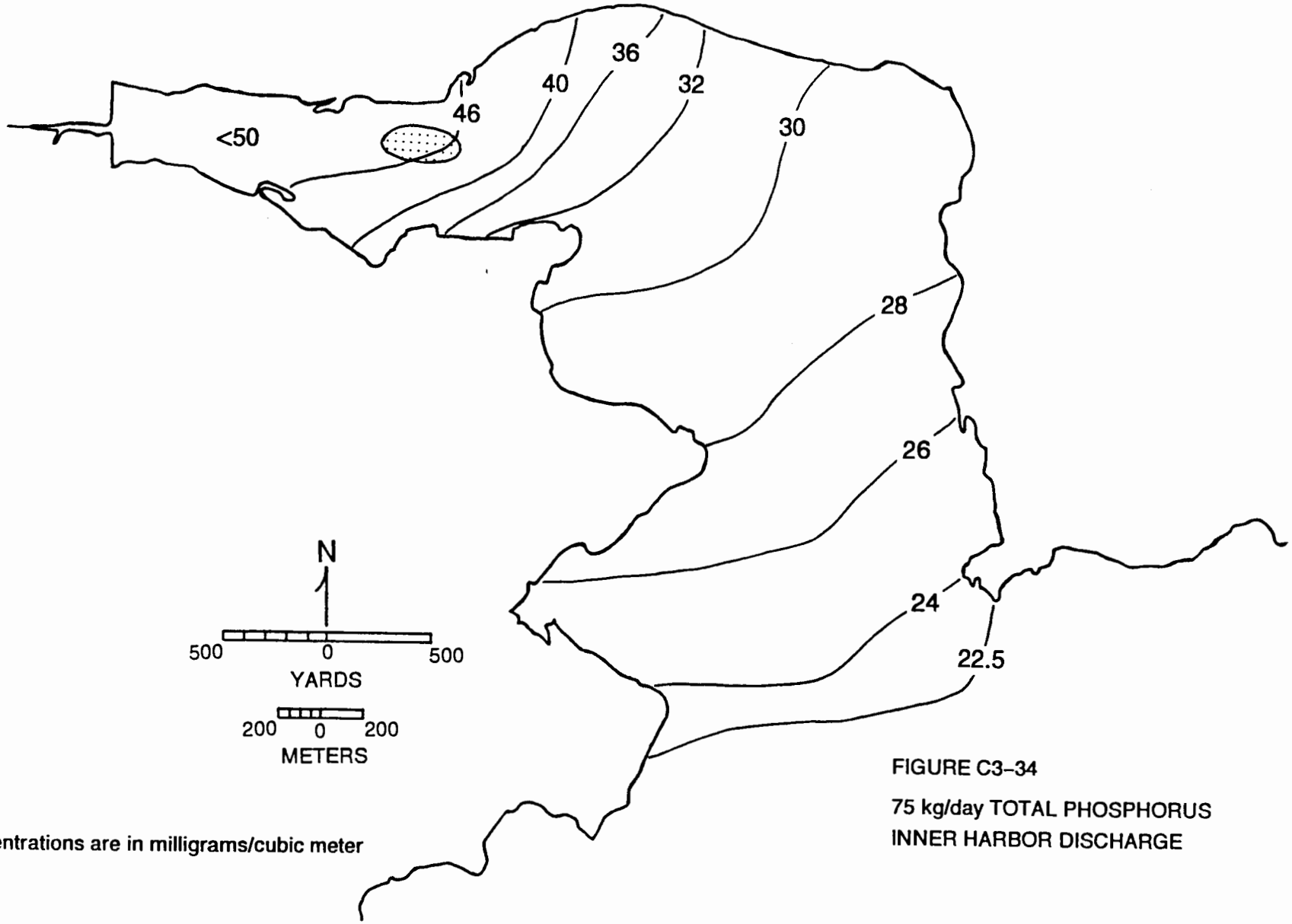
Concentrations are in milligrams/cubic meter



Concentrations are in milligrams/cubic meter

FIGURE C3-33

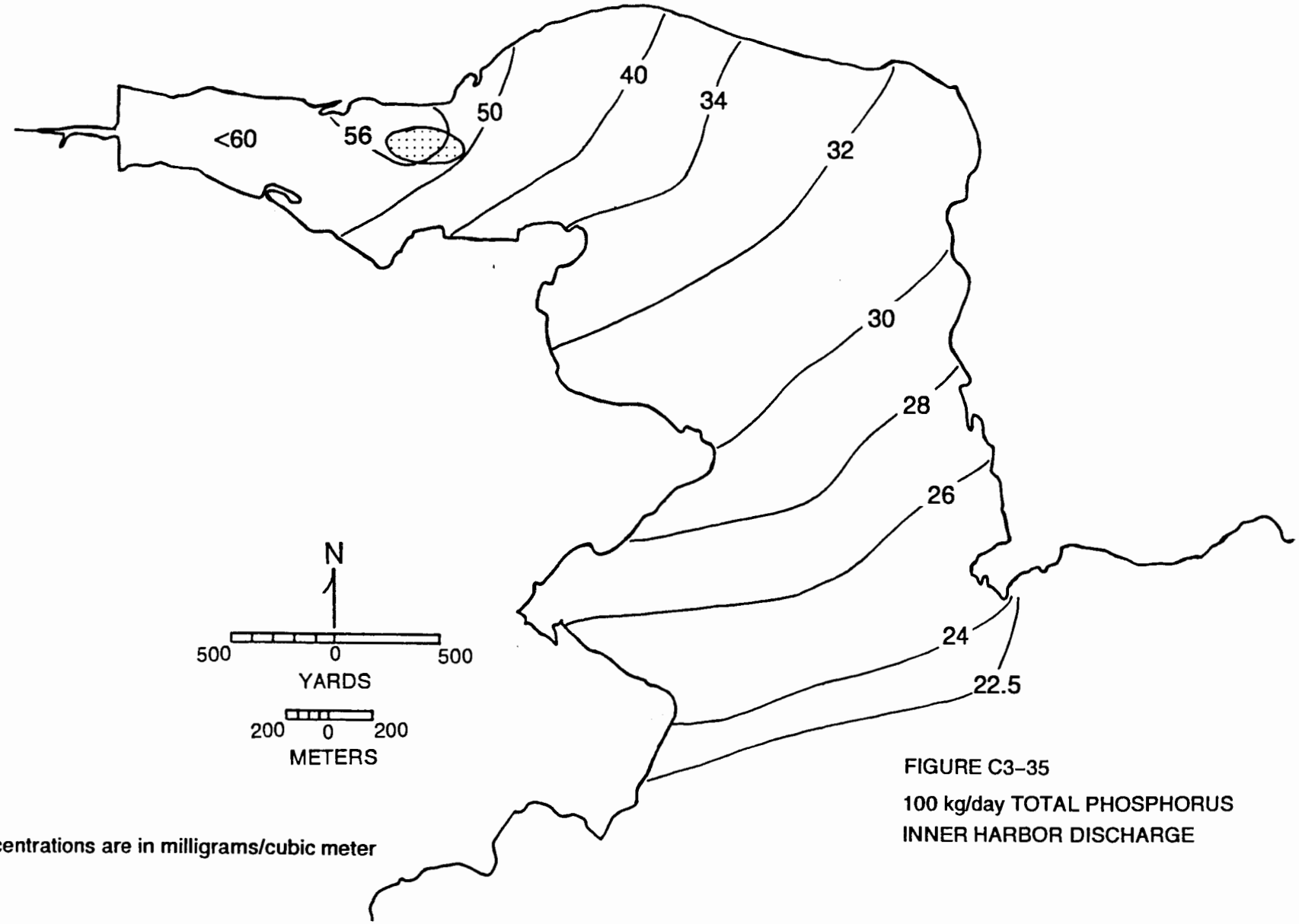
50 kg/day TOTAL PHOSPHORUS
INNER HARBOR DISCHARGE



Concentrations are in milligrams/cubic meter

FIGURE C3–34

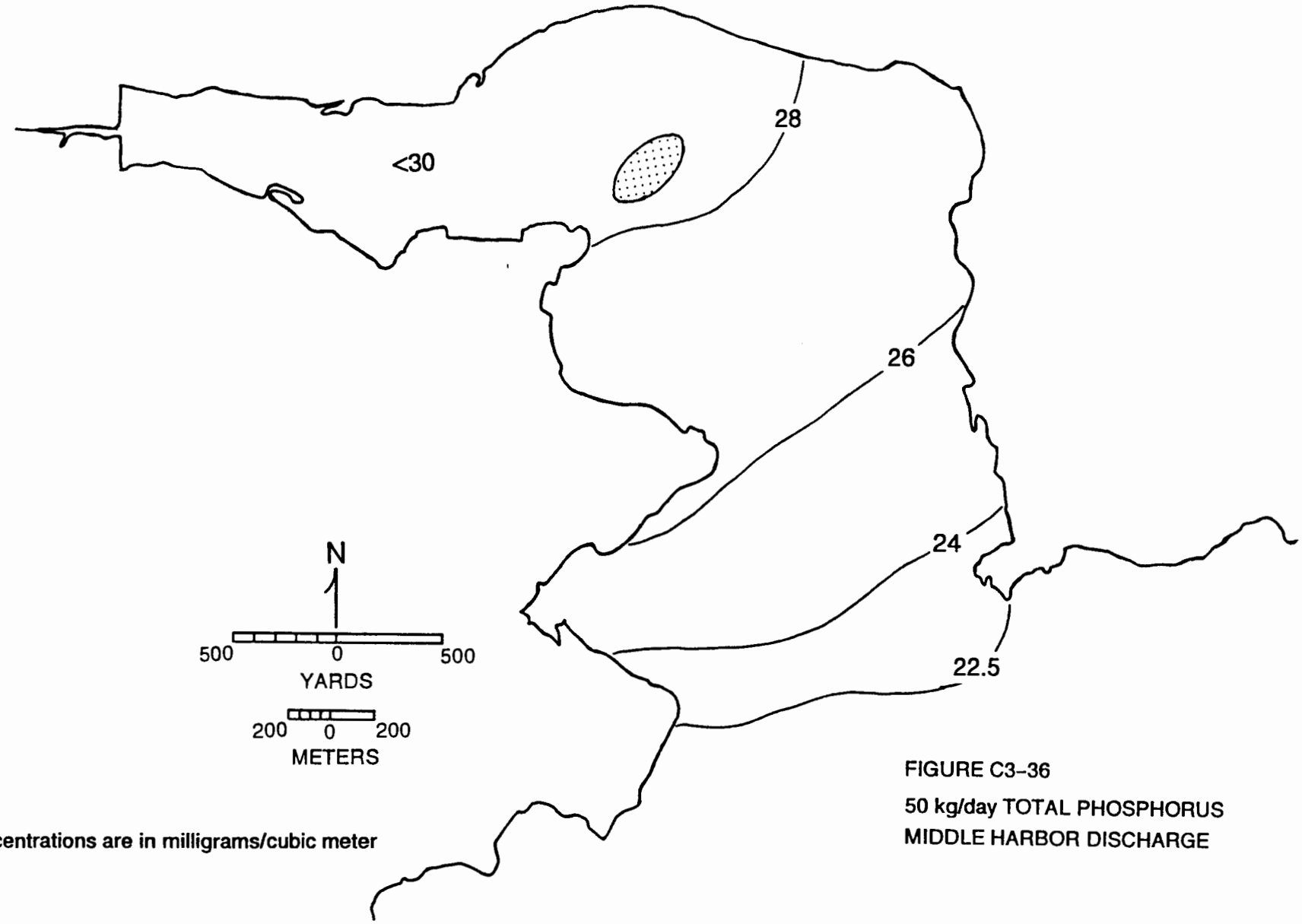
75 kg/day TOTAL PHOSPHORUS
INNER HARBOR DISCHARGE



Concentrations are in milligrams/cubic meter

FIGURE C3–35

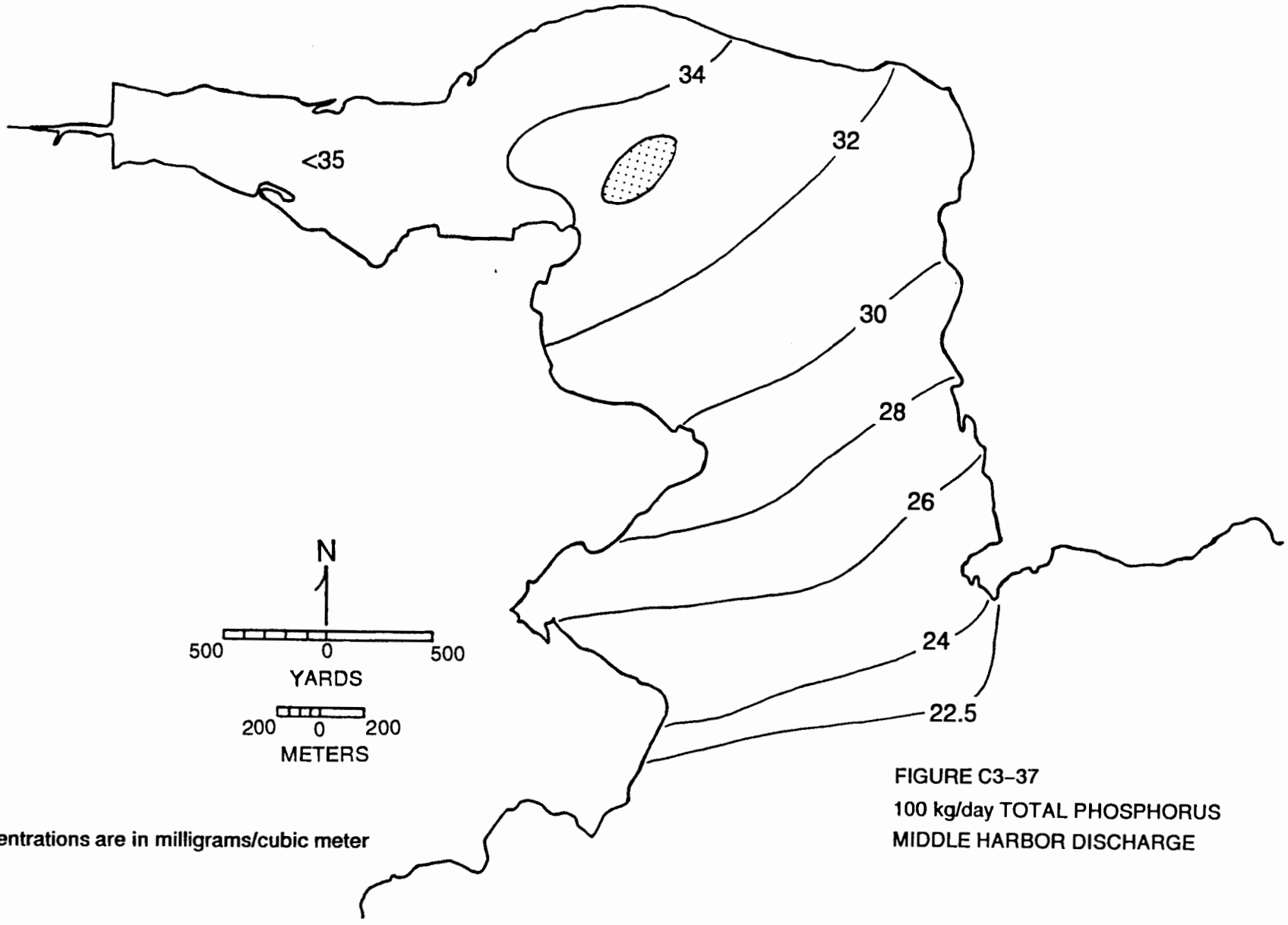
100 kg/day TOTAL PHOSPHORUS
INNER HARBOR DISCHARGE



Concentrations are in milligrams/cubic meter

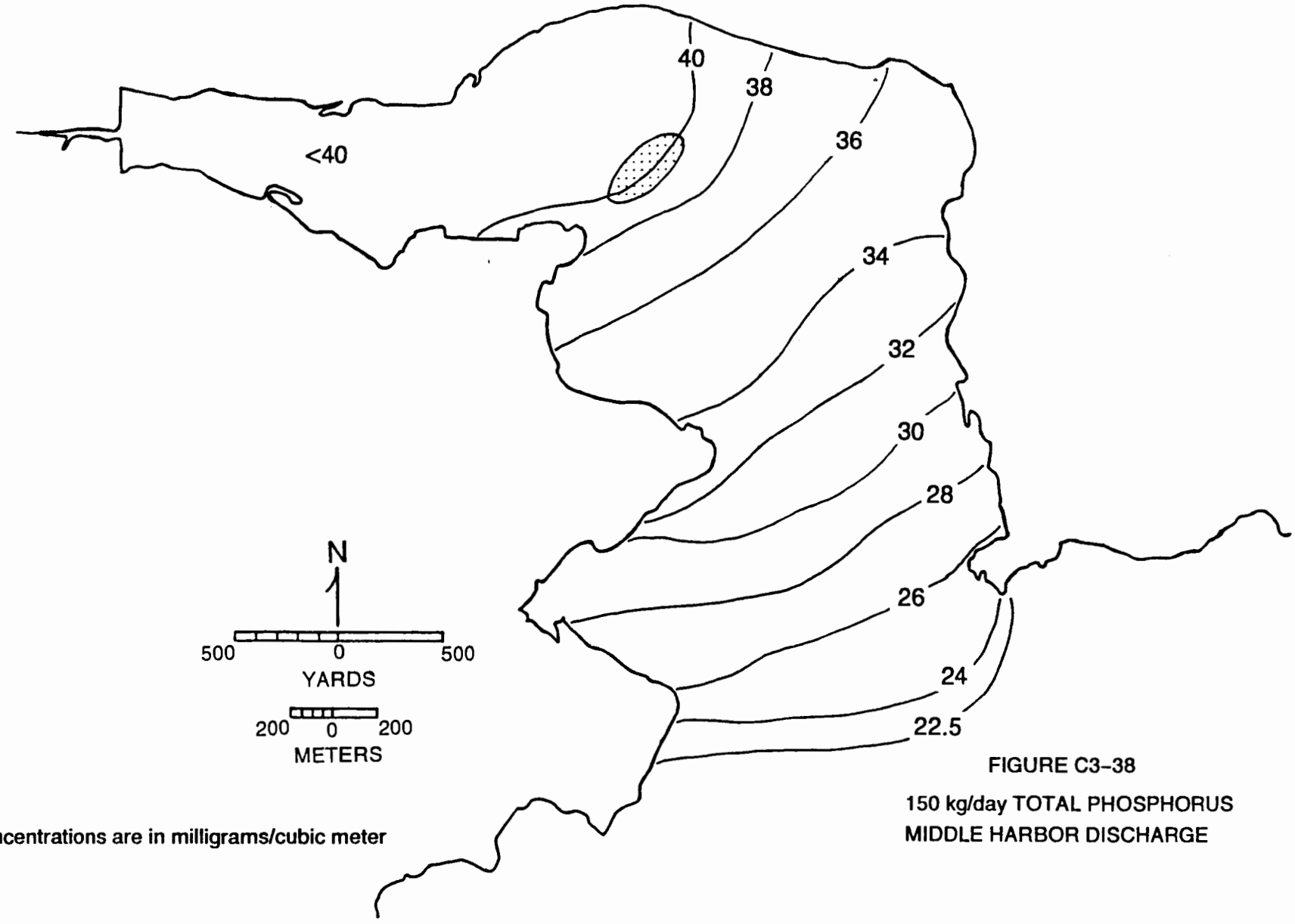
FIGURE C3-36

50 kg/day TOTAL PHOSPHORUS
MIDDLE HARBOR DISCHARGE



Concentrations are in milligrams/cubic meter

FIGURE C3-37
100 kg/day TOTAL PHOSPHORUS
MIDDLE HARBOR DISCHARGE



Concentrations are in milligrams/cubic meter

FIGURE C3-38

150 kg/day TOTAL PHOSPHORUS
MIDDLE HARBOR DISCHARGE

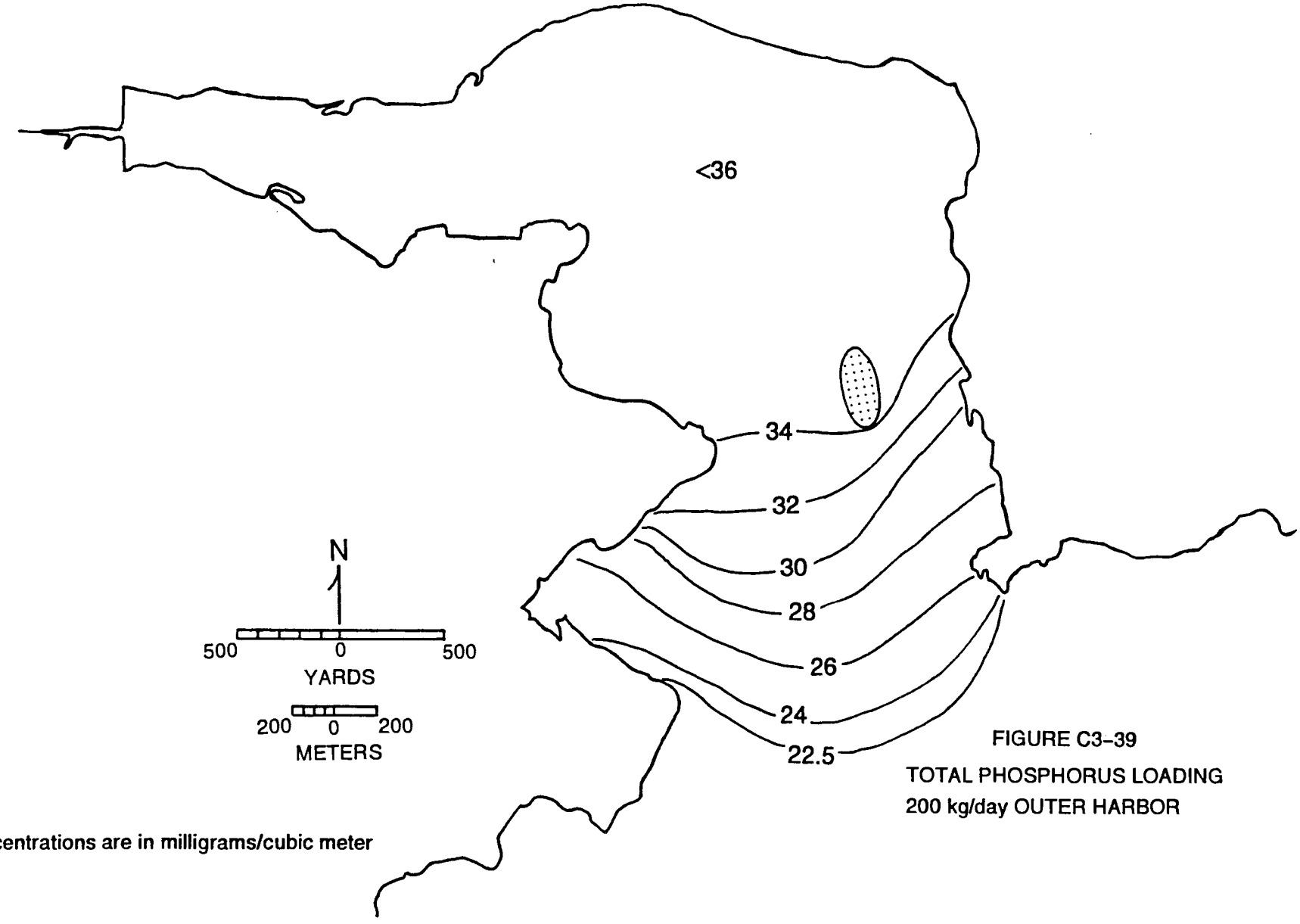
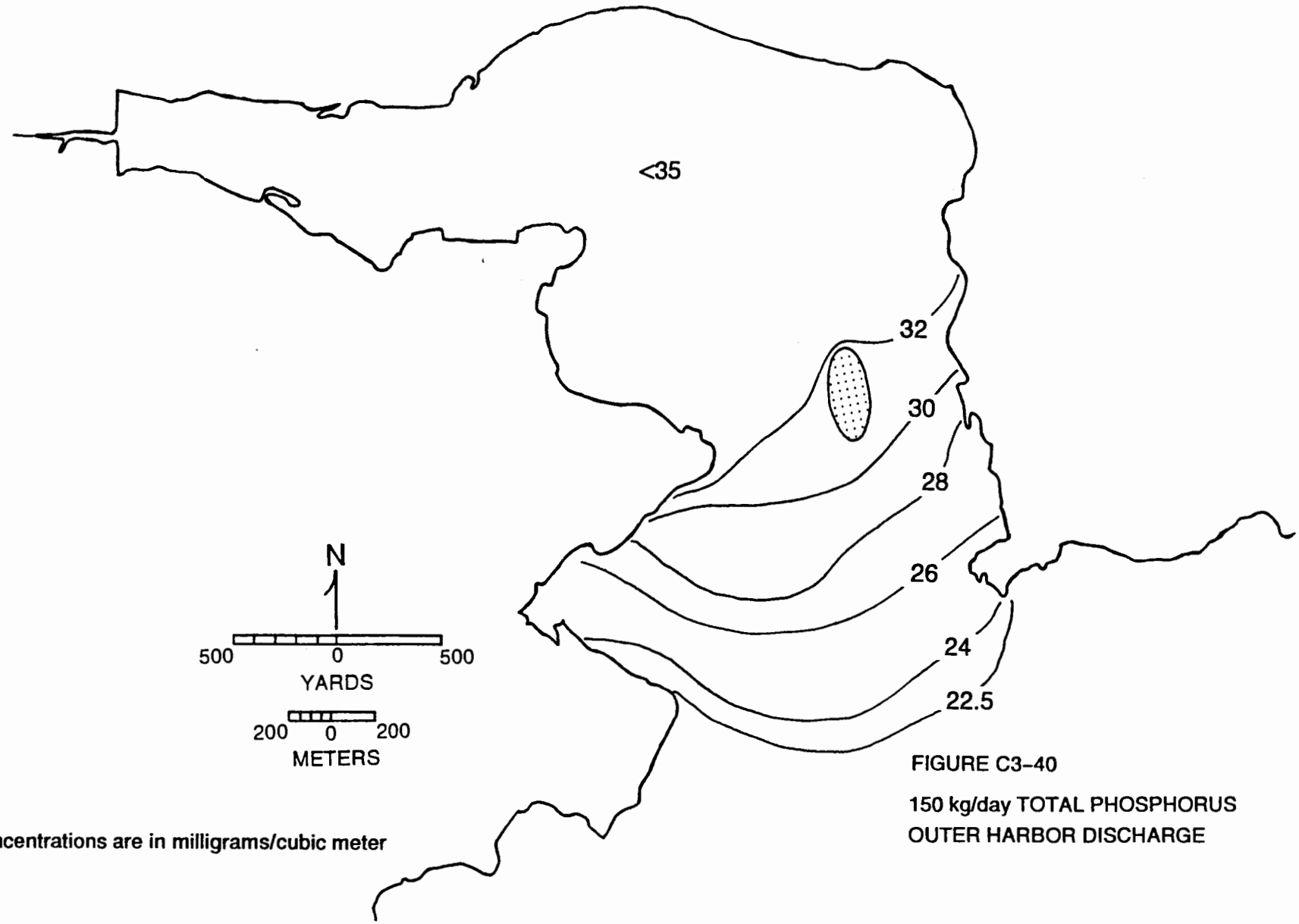


FIGURE C3-39
TOTAL PHOSPHORUS LOADING
200 kg/day OUTER HARBOR

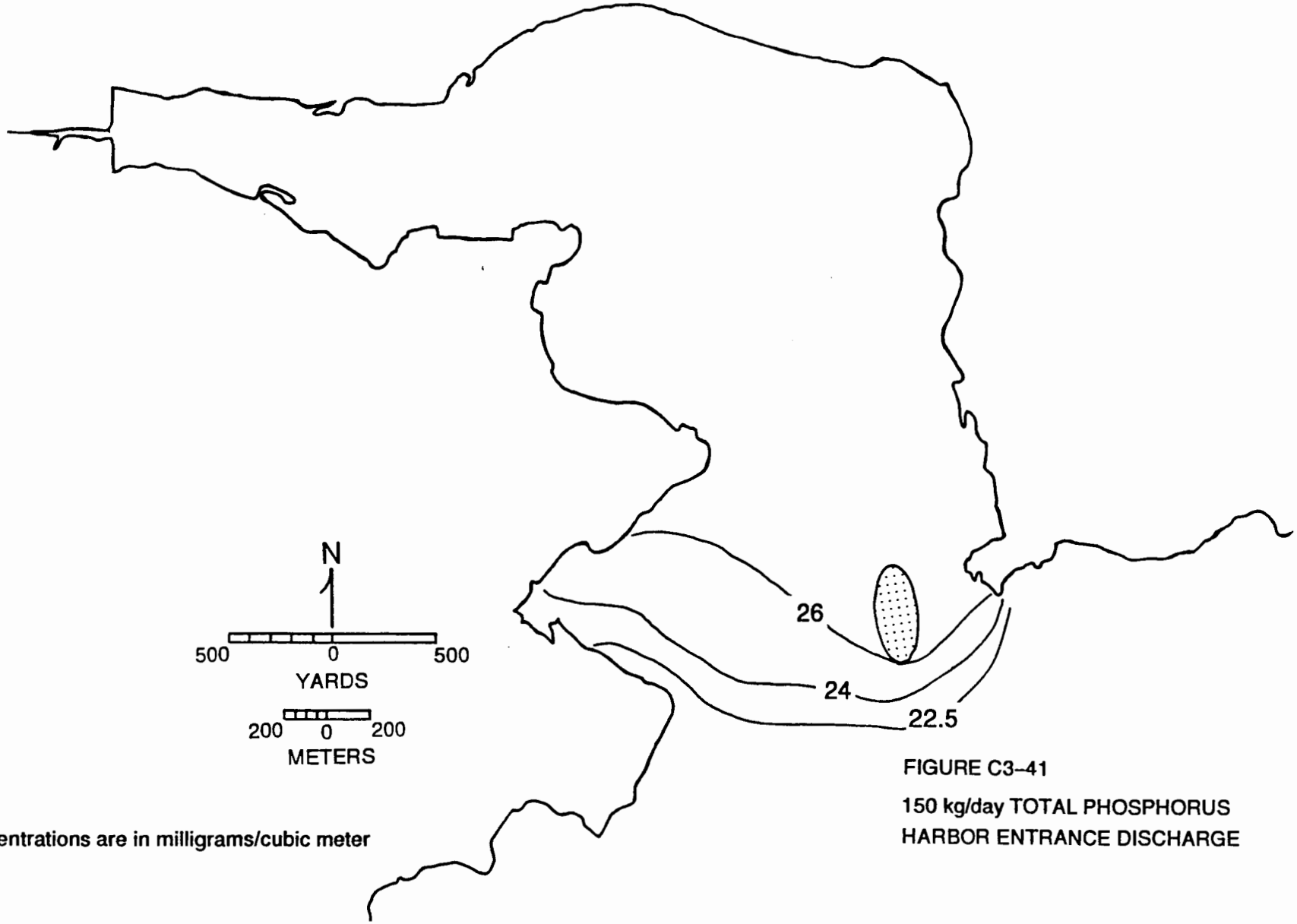
Concentrations are in milligrams/cubic meter



Concentrations are in milligrams/cubic meter

FIGURE C3-40

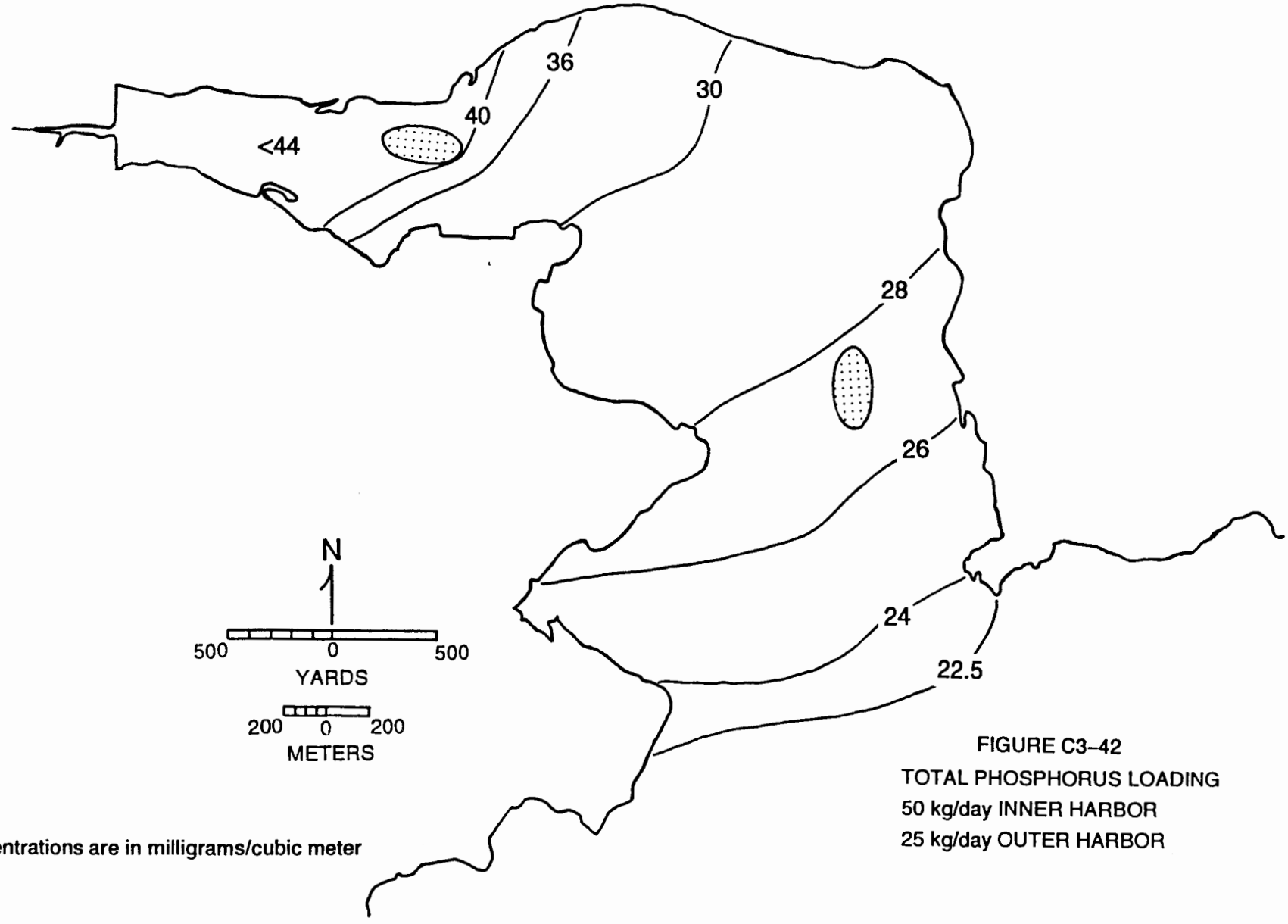
150 kg/day TOTAL PHOSPHORUS
OUTER HARBOR DISCHARGE



Concentrations are in milligrams/cubic meter

FIGURE C3–41

150 kg/day TOTAL PHOSPHORUS
HARBOR ENTRANCE DISCHARGE



Concentrations are in milligrams/cubic meter

FIGURE C3–42
TOTAL PHOSPHORUS LOADING
50 kg/day INNER HARBOR
25 kg/day OUTER HARBOR

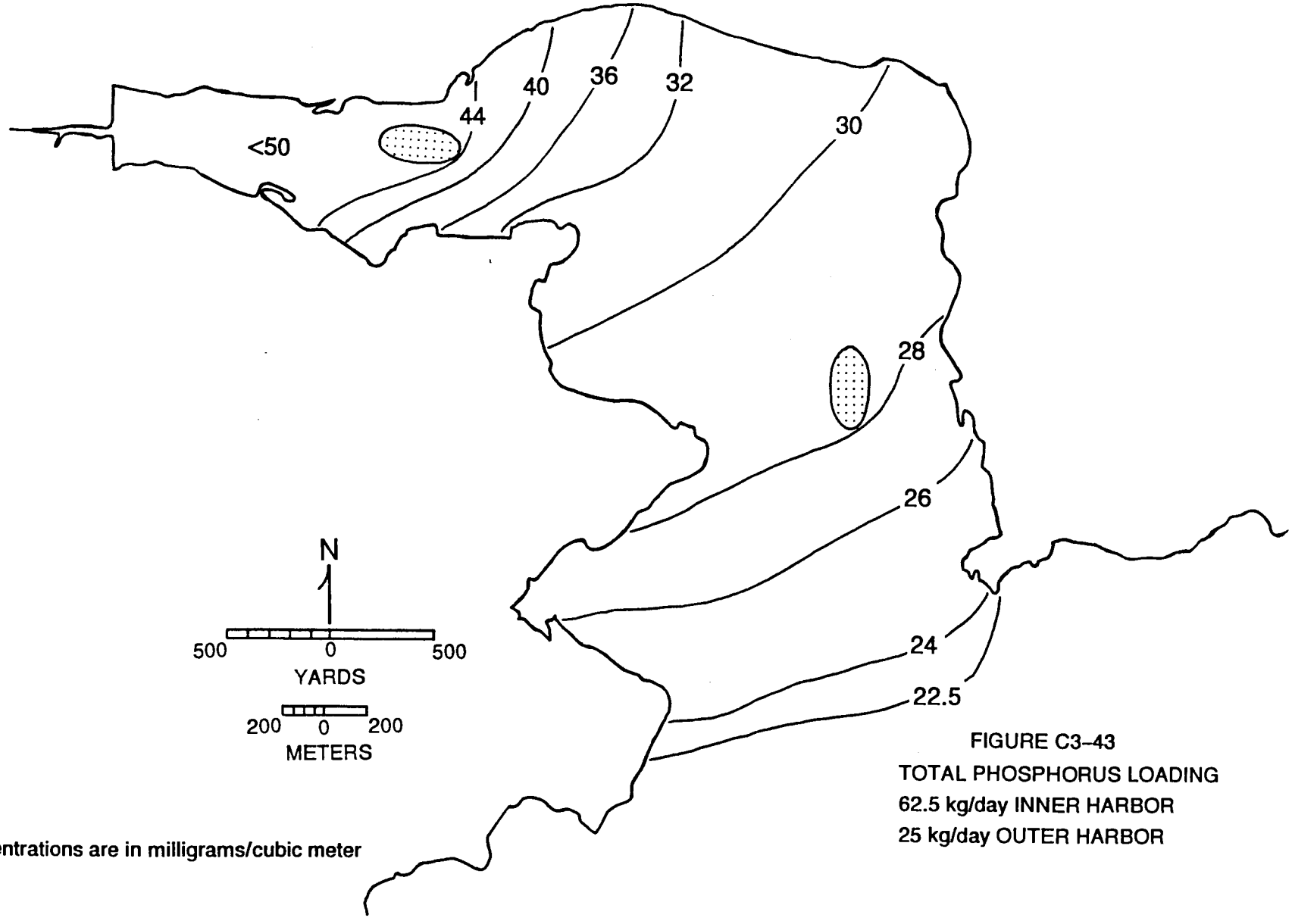
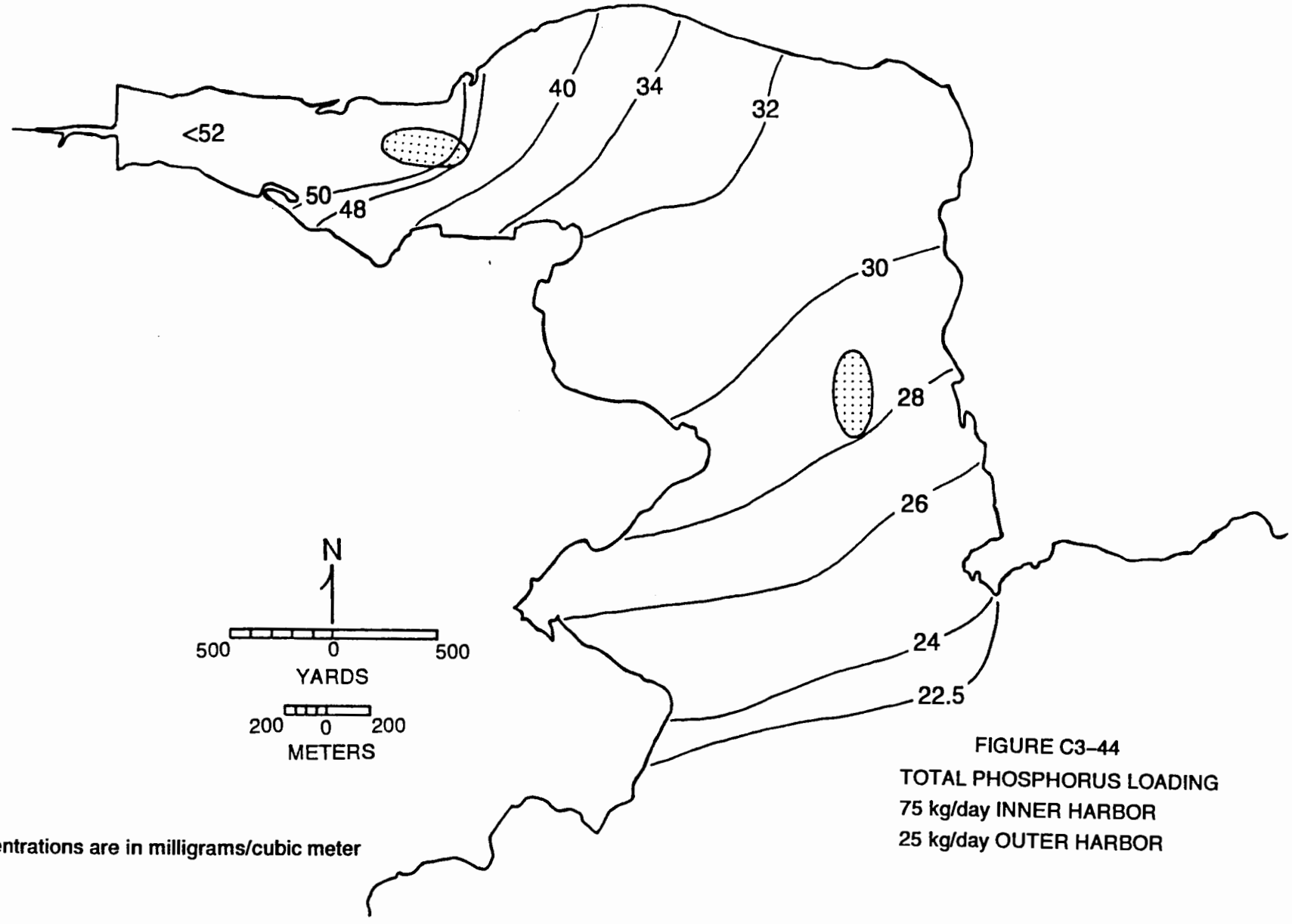


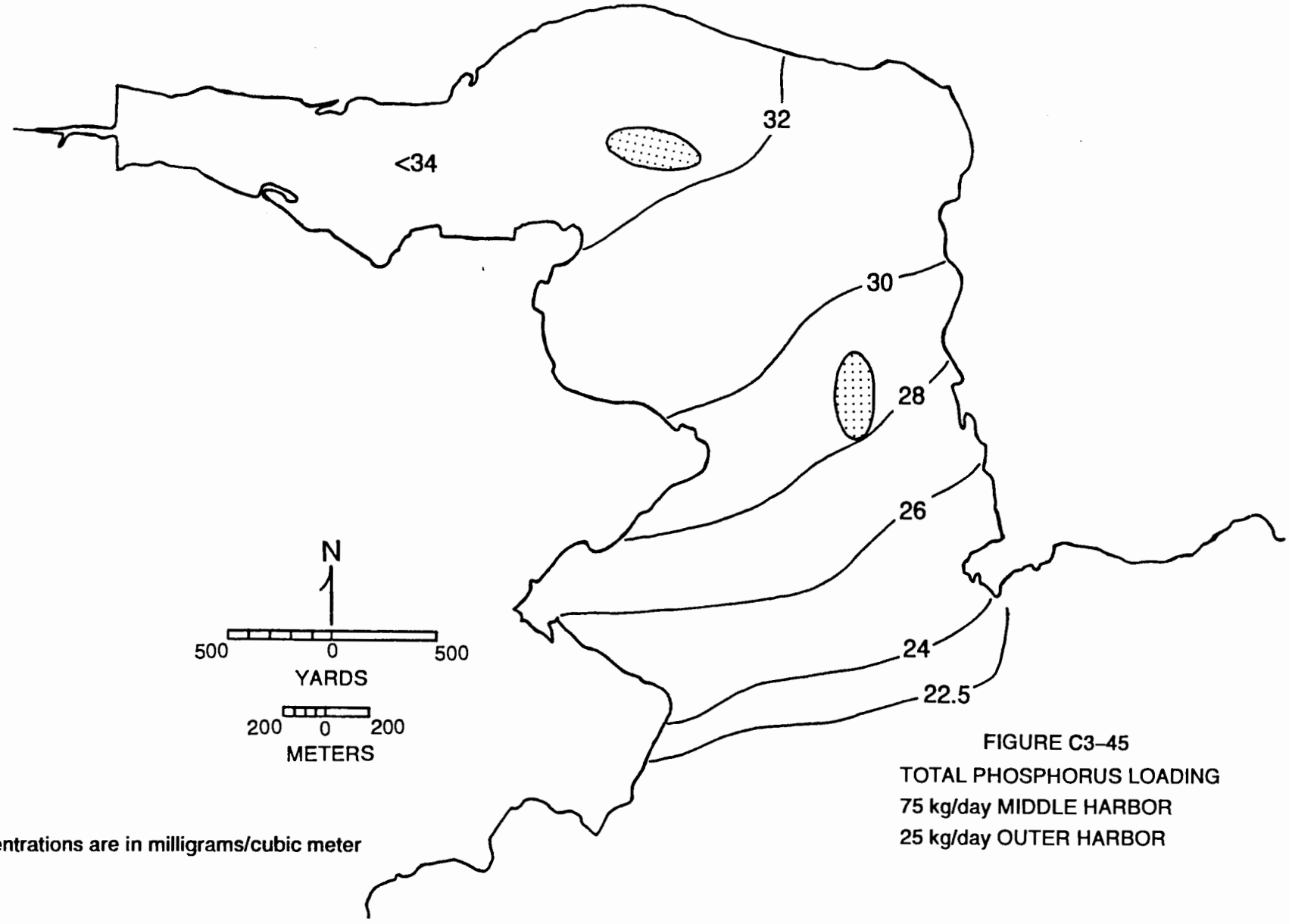
FIGURE C3–43
TOTAL PHOSPHORUS LOADING
62.5 kg/day INNER HARBOR
25 kg/day OUTER HARBOR

Concentrations are in milligrams/cubic meter



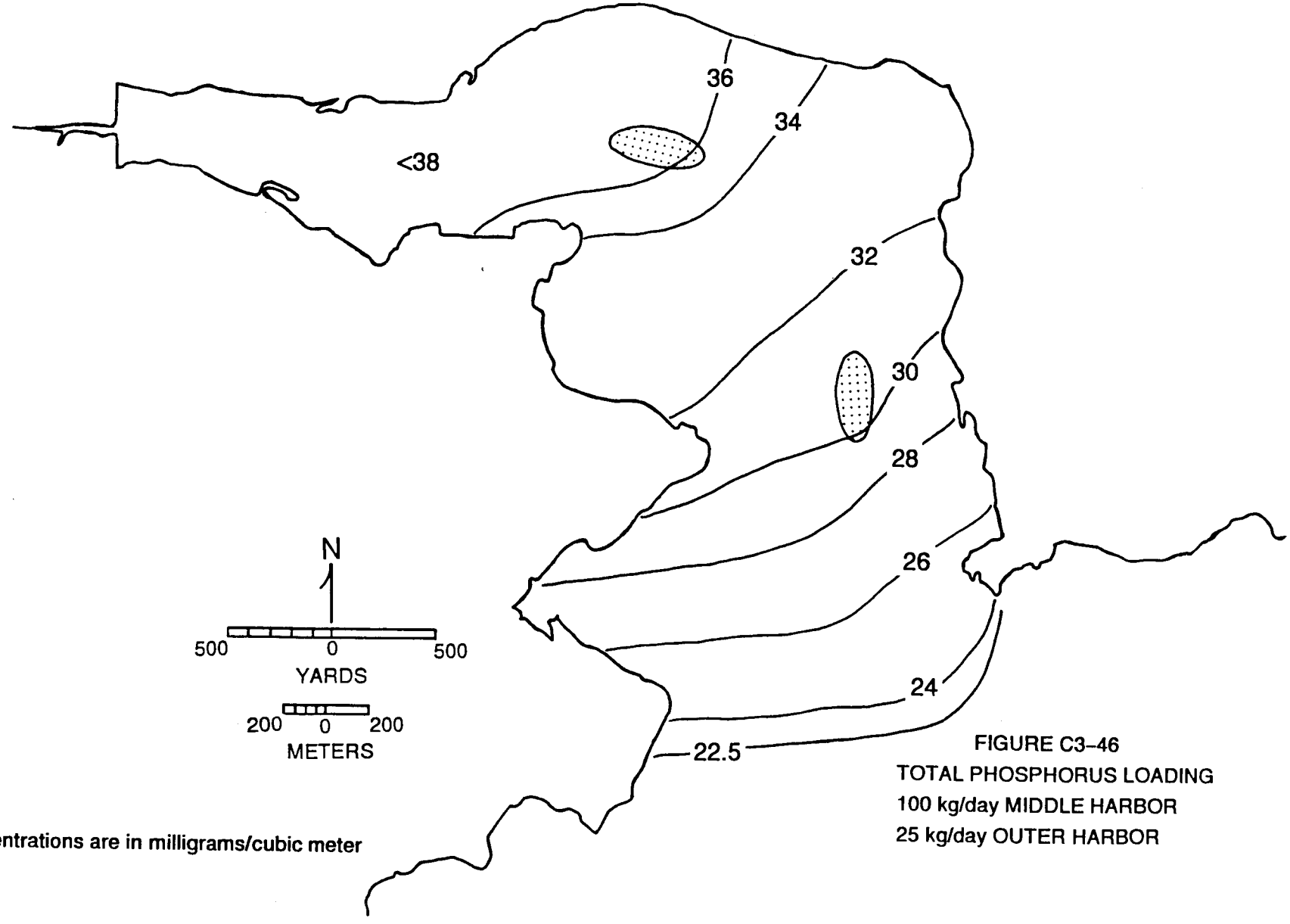
Concentrations are in milligrams/cubic meter

FIGURE C3–44
TOTAL PHOSPHORUS LOADING
75 kg/day INNER HARBOR
25 kg/day OUTER HARBOR



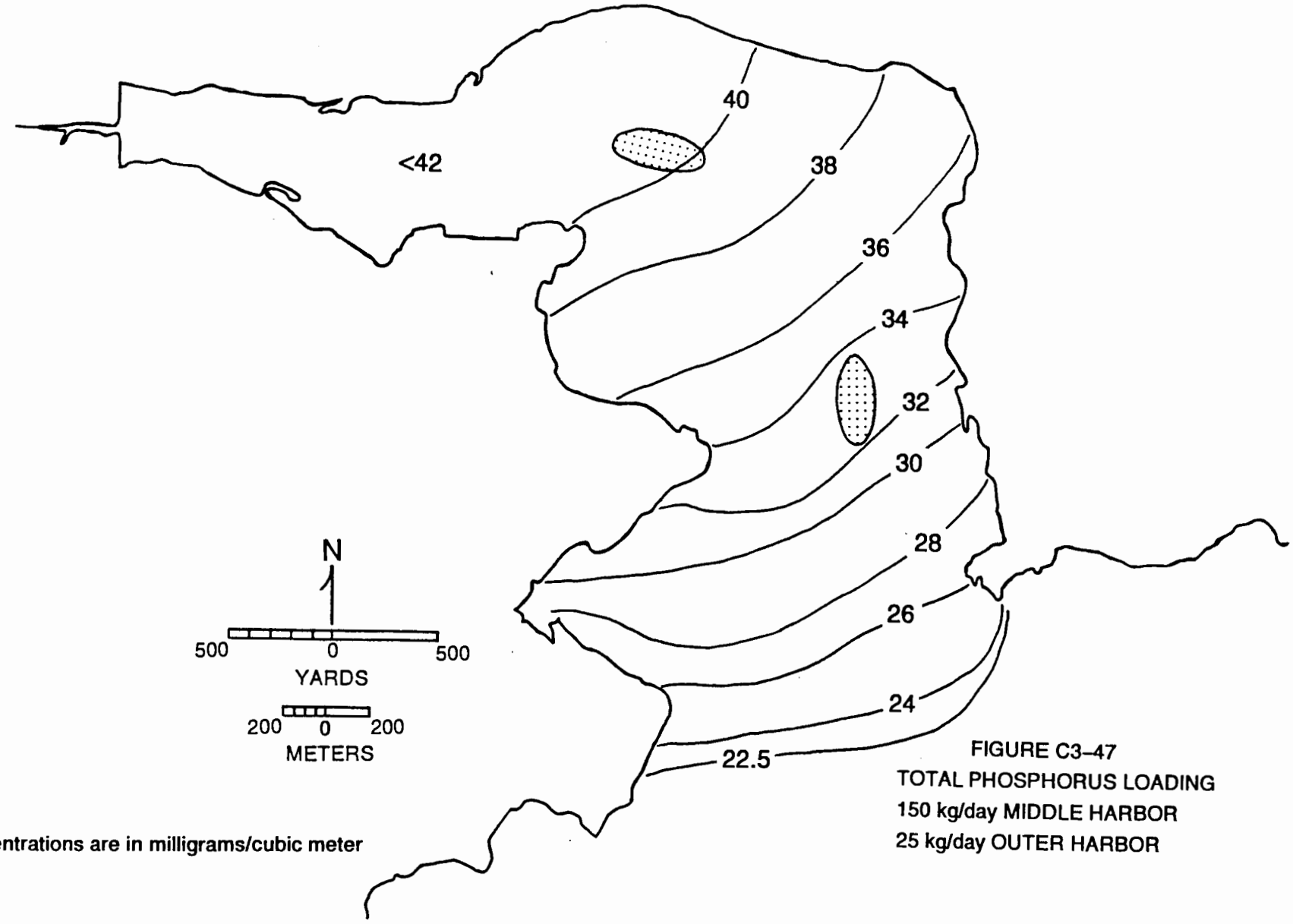
Concentrations are in milligrams/cubic meter

FIGURE C3–45
TOTAL PHOSPHORUS LOADING
75 kg/day MIDDLE HARBOR
25 kg/day OUTER HARBOR



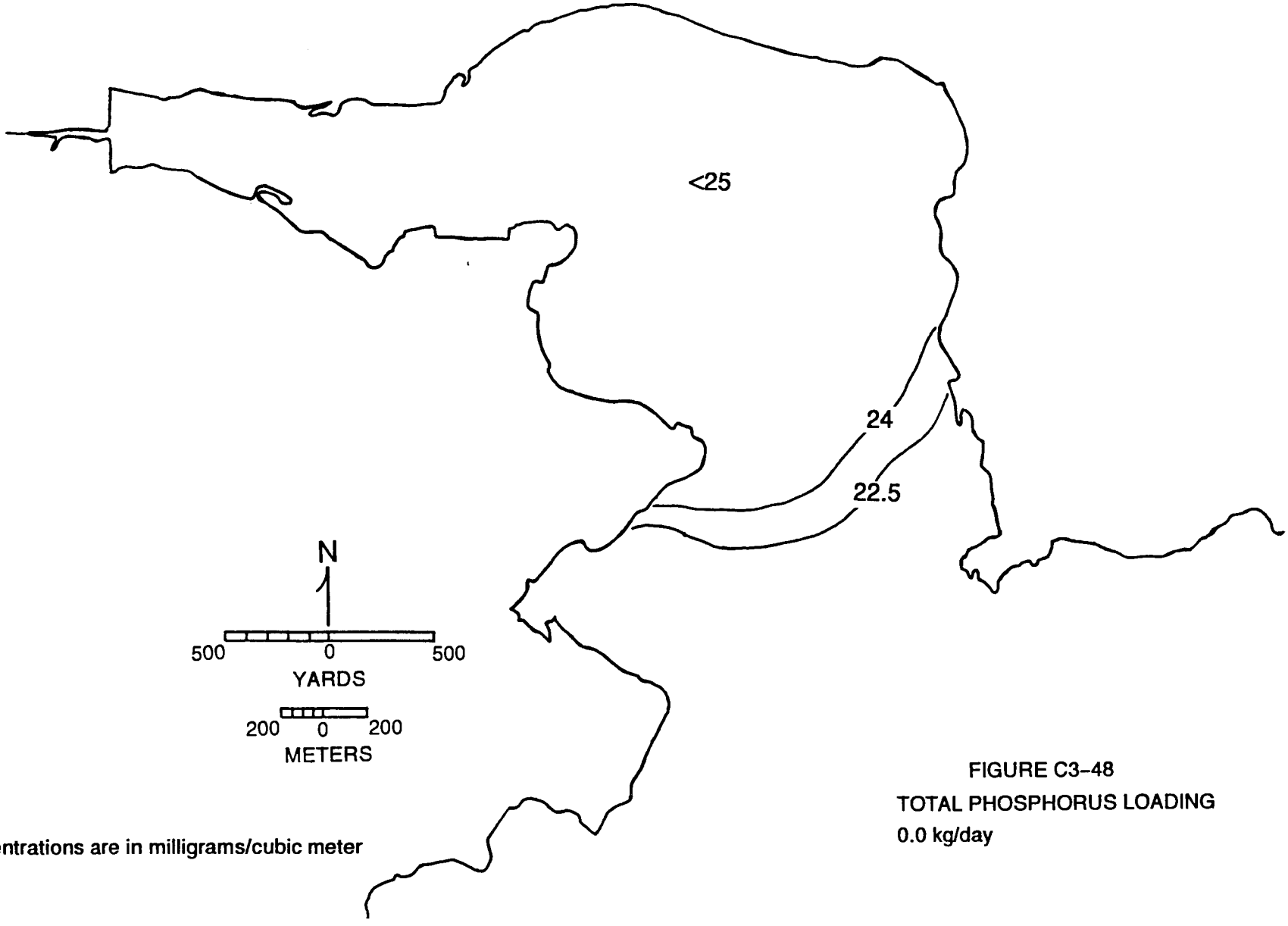
Concentrations are in milligrams/cubic meter

FIGURE C3-46
TOTAL PHOSPHORUS LOADING
100 kg/day MIDDLE HARBOR
25 kg/day OUTER HARBOR



Concentrations are in milligrams/cubic meter

FIGURE C3–47
TOTAL PHOSPHORUS LOADING
150 kg/day MIDDLE HARBOR
25 kg/day OUTER HARBOR



Concentrations are in milligrams/cubic meter

FIGURE C3-48
TOTAL PHOSPHORUS LOADING
0.0 kg/day

APPENDIX C-4

MODEL CODE

PT121.BAS MODEL CODE

```
PIE = 3.14159265
cls
dim TP(30),XA(30),TB(30),TQ(30),PQOUT(20,30),AX(30),DVOL(30),QX(30),VX(30)
dim TYDE(2000,2),PQ(30)
dim CI(30),EK(30),KD(30),NPL(30),IS%(30),IE%(30),D(20,30),IB%(80),JB%(80)
dim PSL(20,30),BCN%(80),IOUT%(20),JOUT%(30),DVDT(20,30)
dim COLD(20,30),CNEW(20,30),TG%(20,30),BG%(20,30),RG%(20,30),LG%(20,30)
dim IN%(30),
AI(20,30),AJ(20,30),VIJ(20,30),DCDT(9,20),QIN(20,30),QOUT(20,30)
print "Default Job Control List File Name is JCLPT121."
print "Press <RETURN> with No Entry to Use this File."
input "Otherwise Enter File Name then <RETURN>";JCLNAM$
if JCLNAM$ = "" then JCLNAM$ = "JCLPT121"
NRUN% = 1
NEXTCASE:
print "NOW READING JOB CONTROL DATA."
open JCLNAM$ for input as #2
input #2, JCLNAM$
input #2, NCASES%
for N% = 1 to NRUN%
   input #2, HYDNAM$
   input #2, TIDNAM$
   input #2, WQNAM$
   input #2, OUTFILE$
   input #2, HYOUTFILE$
   input #2, PTOUTFILE$
   for I% = 1 to 3: input #2, TITLE$(I%): next I%
   input #2, IMAX%,JMAX%
   input #2, DT,DX
   input #2, IDAY0%,IDAYN%
   input #2, NOUT%,NTIDE%
   input #2, IOC%(1)
   for I% = 2 to IOC%(1): input #2, IOC%(I%): next I%
   for J% = 0 to JMAX%
      for I% = 0 to IMAX%
         PQOUT(I%,J%)=0
         PSL(I%,J%)=0
      next I%
   next J%
   for J% = 1 to NOUT%
      input #2, JOUT%(J%),IOUT%(J%)
      input #2, PQOUT(IOUT%(J%),JOUT%(J%)),PSL(IOUT%(J%),JOUT%(J%))
   next J%
next N%
close #2
NRUN% = NRUN% + 1
if IOC%(2) = 1 then gosub OUTTITLE:
print "NOW READING HYDRO DATA."
open hydnam$ for input as #2
input #2, hydnam$
for I% = 1 to JMAX%
   input #2, XA(I%),TP(I%),TB(I%)
next I%
for J% = 1 to JMAX%
   PQ(J%) = 0
   for I% = 1 to IMAX%
```

```
      PQ(J%) = PQ(J%) + PQOUT(I%,J%)
   next I%
   TQ(J%) = 3600 * (TB(J%) + 0.043813*PQ(J%))
next J%
close #2
if IOC%(3) = 1 then gosub OUTHYDRO:
open TIDNAM$ for input as #2
input #2, TIDNAM$
print "NOW READING TIDES."
for I% = 1 to NTIDE%
   input #2, TYDE(I%,1),TYDE(I%,2)
next I%
close #2
if IOC%(4) = 1 then gosub OUTTIDE:
print "NOW READING WATER QUALITY DATA."
open WQNAM$ for input as #2
input #2, WQNAM$
for J% = 0 to JMAX%
   input#2, J,CI(J%), EK(J%), KD(J%), NPL(J%)
next J%
for J% = 1 to JMAX%-1
  input #2, J,IS%(J%),IE%(J%)
  IN%(J%) = IE%(J%) - IS%(J%) + 1
next J%
IS%(0) = IS%(1): IE%(0) = IE%(1): IN%(0) = IN%(1)
IS%(JMAX%) = IS%(JMAX%-1): IE%(JMAX%) = IE%(JMAX%-1)
IN%(JMAX%) = IN%(JMAX%-1)
for J% = 0 to JMAX%
   input #2, J
   for I% = 0 to IMAX%
      input #2, D(I%,J%)
      D(I%,J%) = D(I%,J%)*0.3048
      VIJ(I%,J%) = D(I%,J%)*DX*DX
   next I%
next J%
input #2, NBC%
for KB% = 1 to NBC%
   input #2, KB%,IB%(KB%),JB%(KB%),BCN%(KB%)
next KB%
close #2
if IOC%(5) = 1 then gosub OUTWQ:
IPOINT = 1
IDAY%  = IDAY0%
IHR%   = 0
T      = (IDAY0%-1)*24
gosub PAGOTIDE
TOLD = T
HOLD = H
for J% = 0 to JMAX%
   for I% = 0 to IMAX%
      COLD(I%,J%) = CI(J%)
   next I%
next J%
for J% = 1 to JMAX%-1
   for I% = IS%(J%) to IE%(J%)
      TG%(I%,J%) = 1
      BG%(I%,J%) = 1
      LG%(I%,J%) = 1
      RG%(I%,J%) = 1
```

```
   next I%
next J%
for KB% = 1 to NBC%
   I%=IB%(KB%)
   J%=JB%(KB%)
   select case BCN%(KB%)
   case 1
      LG%(I%,J%) = 0
      BG%(I%,J%) = 0
   case 2
      BG%(I%,J%) = 0
   case 3
      RG%(I%,J%) = 0
      BG%(I%,J%) = 0
   case 4
      LG%(I%,J%) = 0
   case 5
      RG%(I%,J%) = 0
   case 6
      LG%(I%,J%) = 0
      TG%(I%,J%) = 0
   case 7
      RG%(I%,J%) = 0
      TG%(I%,J%) = 0
   case 8
      TG%(I%,J%) = 0
   end select
next KB%
IHRMAX% = int(24/DT)
if 24/DT <> int(24/DT) then
   print "TIME INCREMENT MUST BE INTEGER FRACTION OF DAY"
   print "Program run has been terminated!!"
   stop
end if
print "BEGINNING SIMULATION."
if IOC%(7) > 0 then gosub OUTCONCALC
for IDAY% = IDAY0% to IDAYN%
   for IHR% = 1 to IHRMAX%
      T = T + DT
      gosub HYDRO:
      CSTEP% = CSTEP% + 1
      if IOC%(6) = 0 then
         exit if
      elseif CSTEP%/IOC%(6) = int(CSTEP%/IOC%(6)) then
         gosub OUTHYDCALC:
      end if
      gosub CONCCALC:
      if IOC%(7) = 0 then
         exit if
      elseif CSTEP%/IOC%(7) = int(CSTEP%/IOC%(7)) then
         gosub OUTCONCALC:
      end if
   next IHR%
next IDAY%
if NRUN% =< NCASES% then goto NEXTCASE:
END
HYDRO:
gosub PAGOTIDE:
HNEW = H
```

```
DH = HNEW - HOLD
DVOL(JMAX%-1) = ((TP(JMAX%)+TP(JMAX%-1))*.5*DX*DH)
QX(JMAX%-1) = (DVOL(JMAX%-1) / DT) - TQ(JMAX%-1)
for J% = (JMAX%-2) to 1 step -1
   DVOL(J%) = ((TP(J%)+TP(J%+1))*.5*DX*DH)
   QX(J%) = (DVOL(J%) / DT) - TQ(J%) + QX(J%+1)
next J%
for J%= 1 to (JMAX%-1)
   AX(J%) = XA(J%) + HNEW * TP(J%)
   VX(J%) = QX(J%) / AX(J%)
next J%
AX(JMAX%) = XA(JMAX%) + HNEW * TP(JMAX%)
QX(JMAX%) = 0.0
VX(JMAX%) = 0.0
HOLD = HNEW
TOLD = T
for J% = 1 to JMAX%-1
   if DH = 0 then
      QIN(I%,J%)  = 0
      QOUT(I%,J%) = 0
      goto NOFLOW:
   elseif DH > 0 then
      if IN%(J%) = IN%(J%-1) then
         for I% = IS%(J%) to IE%(J%)
            QIN(I%,J%) = (QX(J%)/IN%(J%))
         next I%
      elseif IN%(J%) < IN%(J%-1) then
         for I% = IS%(J%) to IE%(J%)
            QIN(I%,J%) = (QX(J%)/IN%(J%))
         next I%
      elseif IN%(J%) > IN%(J%-1) then
         RCN% = IN%(J%)/2
         QSF% = IN%(J%-1)/2
         QIN(IS%(J%),J%) = (QX(J%)/IN%(J%))
         QIN(IE%(J%),J%) = (QX(J%)/IN%(J%))
         RCN% = RCN%-1
         for I% = (IS%(J%)+1) to (IS%(J%)+(IN%(J%)/2)-1) step 1
            QIN(I%,J%) =   (QX(J%)/IN%(J%-1))_
                         - (RCN%/QSF%)*(QX(J%)/IN%(J%))_
                         + ((RCN%-1)/QSF%)*(QX(J%)/IN%(J%))
            RCN% = RCN%-1
         next I%
         RCN% = IN%(J%)/2-1
         for I% = (IE%(J%)-1) to (IE%(J%)-(IN%(J%)/2)+1) step -1
            QIN(I%,J%) =   (QX(J%)/IN%(J%-1))_
                         - (RCN%/QSF%)*(QX(J%)/IN%(J%))_
                         + ((RCN%-1)/QSF%)*(QX(J%)/IN%(J%))
            RCN% = RCN%-1
         next I%
      end if
   elseif DH < 0 then
      if IN%(J%) = IN%(J%+1) then
         for I% = IS%(J%) to IE%(J%)
            QIN(I%,J%) = -(QX(J%+1)/IN%(J%))
         next I%
      elseif IN%(J%) < IN%(J%+1) then
         for I% = IS%(J%) to IE%(J%)
            QIN(I%,J%) = -(QX(J%+1)/IN%(J%))
         next I%
```

```
   elseif IN%(J%) > IN%(J%+1) then
      RCN% = IN%(J%)/2
      QSF% = IN%(J%+1)/2
      QIN(IS%(J%),J%) = -((QX(J%+1)/IN%(J%)))
      QIN(IE%(J%),J%) = -((QX(J%+1)/IN%(J%)))
      RCN% = RCN%-1
      for I% = (IS%(J%)+1) to (IS%(J%)+(IN%(J%)/2)-1) step 1
         QIN(I%,J%) = - (QX(J%+1)/IN%(J%+1))_
                      + (RCN%/QSF%)*(QX(J%+1)/IN%(J%))_
                      - ((RCN%-1)/QSF%)*(QX(J%+1)/IN%(J%))
         RCN% = RCN%-1
      next I%
      RCN% = IN%(J%)/2-1
      for I% = (IE%(J%)-1) to (IE%(J%)-(IN%(J%)/2)+1) step -1
         QIN(I%,J%) = - (QX(J%+1)/IN%(J%+1))_
                      + (RCN%/QSF%)*(QX(J%+1)/IN%(J%))_
                      - ((RCN%-1)/QSF%)*(QX(J%+1)/IN%(J%))
         RCN% = RCN%-1
      next I%
   end if
end if
if DH > 0 then
   if IN%(J%) = IN%(J%+1) then
      for I% = IS%(J%) to IE%(J%)
         QOUT(I%,J%) = -((QX(J%+1)/IN%(J%)))
      next I%
   elseif IN%(J%) < IN%(J%+1) then
      for I% = IS%(J%) to IE%(J%)
         QOUT(I%,J%) = -((QX(J%+1)/IN%(J%)))
      next I%
   elseif IN%(J%) > IN%(J%+1) then
      RCN% = IN%(J%)/2
      QSF% = IN%(J%+1)/2
      QOUT(IS%(J%),J%) = -((QX(J%+1)/IN%(J%)))
      QOUT(IE%(J%),J%) = -((QX(J%+1)/IN%(J%)))
      RCN% = RCN%-1
      for I% = (IS%(J%)+1) to (IS%(J%)+(IN%(J%)/2)-1) step 1
         QOUT(I%,J%) = -(QX(J%+1)/IN%(J%+1))_
                      + (RCN%/QSF%)*(QX(J%+1)/IN%(J%))_
                      - ((RCN%-1)/QSF%)*(QX(J%+1)/IN%(J%))
         RCN% = RCN%-1
      next I%
      RCN% = IN%(J%)/2-1
      for I% = (IE%(J%)-1) to (IE%(J%)-(IN%(J%)/2)+1) step -1
         QOUT(I%,J%) = -(QX(J%+1)/IN%(J%+1))_
                      + (RCN%/QSF%)*(QX(J%+1)/IN%(J%))_
                      - ((RCN%-1)/QSF%)*(QX(J%+1)/IN%(J%))
         RCN% = RCN%-1
      next I%
   end if
elseif DH < 0 then
   if IN%(J%) = IN%(J%-1) then
      for I% = IS%(J%) to IE%(J%)
         QOUT(I%,J%) = ((QX(J%)/IN%(J%)))
      next I%
   elseif IN%(J%) < IN%(J%-1) then
      for I% = IS%(J%) to IE%(J%)
         QOUT(I%,J%) = ((QX(J%)/IN%(J%)))
      next I%
```

```
      elseif IN%(J%) > IN%(J%-1) then
         RCN% = IN%(J%)/2
         QSF% = IN%(J%-1)/2
         QOUT(IS%(J%),J%) = ((QX(J%)/IN%(J%)))
         QOUT(IE%(J%),J%) = ((QX(J%)/IN%(J%)))
         RCN% = RCN%-1
         for I% = (IS%(J%)+1) to (IS%(J%)+(IN%(J%)/2)-1) step 1
            QOUT(I%,J%) = + (QX(J%)/IN%(J%-1))_
                          - (RCN%/QSF%)*(QX(J%)/IN%(J%))_
                          + ((RCN%-1)/QSF%)*(QX(J%)/IN%(J%))
            RCN% = RCN%-1
         next I%
         RCN% = IN%(J%)/2-1
         for I% = (IE%(J%)-1) to (IE%(J%)-(IN%(J%)/2)+1) step -1
            QOUT(I%,J%) = + (QX(J%)/IN%(J%-1))_
                          - (RCN%/QSF%)*(QX(J%)/IN%(J%))_
                          + ((RCN%-1)/QSF%)*(QX(J%)/IN%(J%))
            RCN% = RCN%-1
         next I%
      end if
   end if
   NOFLOW:
next J%
return
PAGOTIDE:
if T < TYDE(1,1) or T > TYDE(NTIDE%,1) then
   print "TIDAL ERROR DUE TO INPUT START/STOP DAYS.  PROGRAM ABORTED."
   stop
end if
if T < TYDE(IPOINT,1) then IPOINT = 1
TIDESEARCH:
KP = IPOINT
KP1 = KP + 1
TL = TYDE(KP,1)
TR = TYDE(KP1,1)
if TL  <= T and T <= TR then
   HL = TYDE(KP,2)
   HR = TYDE(KP1,2)
   A  = 0.5 * (HL - HR)
   B  = 0.5 * (HL + HR)
   DTRL = TR - TL
   C  = PIE * (T - TL) / DTRL
   H  = B + A * COS(C)
else
   IPOINT = IPOINT + 1
   goto TIDESEARCH:
end if
H = H / 3.28084
return
CONCCALC:
for J%=1 to JMAX%-1
   for I% = IS%(J%) to IE%(J%)
      DVDT(I%,J%) = QIN(I%,J%) + QOUT(I%,J%) + (TQ(J%)/IN%(J%))
      VIJ(I%,J%) = VIJ(I%,J%)  + (DVDT(I%,J%)*DT)
      AI(I%,J%) = (((D(I%-1,J%)+D(I%,J%))/2)+DH)*DX
      AJ(I%,J%) = (((D(I%,J%-1)+D(I%,J%))/2)+DH)*DX
   next I%
next J%
for J%=1 to JMAX%-1
```

```
   for I% = IS%(J%) to IE%(J%)
     DCDT(1,I%) = -COLD(I%,J%)*DVDT(I%,J%)/VIJ(I%,J%)
   next I%
   gosub ADVECTION:
   for I% = IS%(J%) to IE%(J%)
     if BG%(I%,J%) = 0 then
        DCDT(4,I%) = 0
     else
        DCDT(4,I%) = -(AJ(I%,J%)*EK(J%)/VIJ(I%,J%)) *
((COLD(I%,J%)-COLD(I%,J%-1))/DX)
     end if
     if TG%(I%,J%) = 0 then
        DCDT(5,I%) = 0
     else
        DCDT(5,I%) = (AJ(I%,J%+1)*EK(J%+1)/VIJ(I%,J%)) *
((COLD(I%,J%+1)-COLD(I%,J%))/DX)
     end if
     if LG%(I%,J%) = 0 then
        DCDT(6,I%) = 0
     else
        DCDT(6,I%) = -(AI(I%,J%)*EK(J%)/VIJ(I%,J%)) *
((COLD(I%,J%)-COLD(I%-1,J%))/DX)
     end if
     if RG%(I%,J%) = 0 then
        DCDT(7,I%) = 0
     else
        DCDT(7,I%) = (AI(I%+1,J%)*EK(J%)/VIJ(I%,J%)) *
((COLD(I%+1,J%)-COLD(I%,J%))/DX)
     end if
     DCDT(8,I%) = -KD(J%)*COLD(I%,J%)
     if I% = IS% or IE% then NPS=(NPL(J%)/2)*(10^6/24) else NPS=0
     if PSL(I%,J%) > 0 then PSS=PSL(I%,J%)*(10^6/24) else PSS=0
     DCDT(9,I%) =  (NPS+PSS)/VIJ(I%,J%)
  next I%
  for I% = IS%(J%) to IE%(J%)
     DCDT=0
     for K%=1 to 9: DCDT=DCDT+DCDT(K%,I%): next K%
     CNEW(I%,J%) = COLD(I%,J%) + DT*DCDT
     if CSTEP%/IOC%(7) = int(CSTEP%/IOC%(7)) then
         print IDAY%;IHR%;I%;J%;cnew(i%,j%)
     end if
   next I%
next J%
for J% = 1 to JMAX%-1
   for I% = IS%(J%) to IE%(J%)
      COLD(I%,J%)=CNEW(I%,J%)
   next I%
next J%
return
   ADVECTION:
   if DH = 0 then
      goto NOADVECT:
   elseif DH > 0 then
      if IN%(J%) = IN%(J%-1) then
         for I% = IS%(J%) to IE%(J%)
            DCDT(2,I%) = ((QX(J%)/IN%(J%))*COLD(I%,J%-1))/VIJ(I%,J%)
         next I%
      elseif IN%(J%) < IN%(J%-1) then
         for I% = IS%(J%) to IE%(J%)
```

```
            DCDT(2,I%) = ((QX(J%)/IN%(J%))*COLD(I%,J%-1))/VIJ(I%,J%)
         next I%
      elseif IN%(J%) > IN%(J%-1) then
         RCN% = IN%(J%)/2
         QSF% = IN%(J%-1)/2
         DCDT(2,IS%(J%)) =
((QX(J%)/IN%(J%))*COLD(IS%(J%)+1,J%))/VIJ(IS%(J%),J%)
         DCDT(2,IE%(J%)) =
((QX(J%)/IN%(J%))*COLD(IE%(J%)-1,J%))/VIJ(IE%(J%),J%)
         RCN% = RCN%-1
         for I% = (IS%(J%)+1) to (IS%(J%)+(IN%(J%)/2)-1) step 1
            DCDT(2,I%) = (QX(J%)/IN%(J%-1))*COLD(I%,J%-1)_
                         - (RCN%/QSF%)*(QX(J%)/IN%(J%))*COLD(I%,J%)_
                         + ((RCN%-1)/QSF%)*(QX(J%)/IN%(J%))*COLD(I%+1,J%)
            DCDT(2,I%) = DCDT(2,I%)/VIJ(I%,J%)
            RCN% = RCN%-1
         next I%
         RCN% = IN%(J%)/2-1
         for I% = (IE%(J%)-1) to (IE%(J%)-(IN%(J%)/2)+1) step -1
            DCDT(2,I%) = (QX(J%)/IN%(J%-1))*COLD(I%,J%-1)_
                         - (RCN%/QSF%)*(QX(J%)/IN%(J%))*COLD(I%,J%)_
                         + ((RCN%-1)/QSF%)*(QX(J%)/IN%(J%))*COLD(I%-1,J%)
            DCDT(2,I%) = DCDT(2,I%)/VIJ(I%,J%)
            RCN% = RCN%-1
         next I%
      end if
   elseif DH < 0 then
      if IN%(J%) = IN%(J%+1) then
         for I% = IS%(J%) to IE%(J%)
            DCDT(2,I%) = -((QX(J%+1)/IN%(J%))*COLD(I%,J%+1))/VIJ(I%,J%)
         next I%
      elseif IN%(J%) < IN%(J%+1) then
         for I% = IS%(J%) to IE%(J%)
            DCDT(2,I%) = -((QX(J%+1)/IN%(J%))*COLD(I%,J%+1))/VIJ(I%,J%)
         next I%
      elseif IN%(J%) > IN%(J%+1) then
         RCN% = IN%(J%)/2
         QSF% = IN%(J%+1)/2
         DCDT(2,IS%(J%)) =
-((QX(J%+1)/IN%(J%))*COLD(IS%(J%)+1,J%))/VIJ(IS%(J%),J%)
         DCDT(2,IE%(J%)) =
-((QX(J%+1)/IN%(J%))*COLD(IE%(J%)-1,J%))/VIJ(IE%(J%),J%)
         RCN% = RCN%-1
         for I% = (IS%(J%)+1) to (IS%(J%)+(IN%(J%)/2)-1) step 1
            DCDT(2,I%) = (QX(J%+1)/IN%(J%+1))*COLD(I%,J%+1)_
                         - (RCN%/QSF%)*(QX(J%+1)/IN%(J%))*COLD(I%,J%)_
                         +
((RCN%-1)/QSF%)*(QX(J%+1)/IN%(J%))*COLD(I%+1,J%)
            DCDT(2,I%) = -DCDT(2,I%)/VIJ(I%,J%)
            RCN% = RCN%-1
         next I%
         RCN% = IN%(J%)/2-1
         for I% = (IE%(J%)-1) to (IE%(J%)-(IN%(J%)/2)+1) step -1
            DCDT(2,I%) = (QX(J%+1)/IN%(J%+1))*COLD(I%,J%+1)_
                         - (RCN%/QSF%)*(QX(J%+1)/IN%(J%))*COLD(I%,J%)_
                         +
((RCN%-1)/QSF%)*(QX(J%+1)/IN%(J%))*COLD(I%-1,J%)
            DCDT(2,I%) = -DCDT(2,I%)/VIJ(I%,J%)
            RCN% = RCN%-1
```

```
            next I%
         end if
      end if
      if DH > 0 then
         if IN%(J%) = IN%(J%+1) then
            for I% = IS%(J%) to IE%(J%)
               DCDT(3,I%) = -((QX(J%+1)/IN%(J%))*COLD(I%,J%))/VIJ(I%,J%)
            next I%
         elseif IN%(J%) < IN%(J%+1) then
            for I% = IS%(J%) to IE%(J%)
               DCDT(3,I%) = -((QX(J%+1)/IN%(J%))*COLD(I%,J%))/VIJ(I%,J%)
            next I%
         elseif IN%(J%) > IN%(J%+1) then
            RCN% = IN%(J%)/2
            QSF% = IN%(J%+1)/2
            DCDT(3,IS%(J%)) =
-((QX(J%+1)/IN%(J%))*COLD(IS%(J%),J%))/VIJ(IS%(J%),J%)
            DCDT(3,IE%(J%)) =
-((QX(J%+1)/IN%(J%))*COLD(IE%(J%),J%))/VIJ(IE%(J%),J%)
            RCN% = RCN%-1
            for I% = (IS%(J%)+1) to (IS%(J%)+(IN%(J%)/2)-1) step 1
               DCDT(3,I%) = -(QX(J%+1)/IN%(J%+1))*COLD(I%,J%)_
                            + (RCN%/QSF%)*(QX(J%+1)/IN%(J%))*COLD(I%-1,J%)_
                            - ((RCN%-1)/QSF%)*(QX(J%+1)/IN%(J%))*COLD(I%,J%)
               DCDT(3,I%) = DCDT(3,I%)/VIJ(I%,J%)
               RCN% = RCN%-1
            next I%
            RCN% = IN%(J%)/2-1
            for I% = (IE%(J%)-1) to (IE%(J%)-(IN%(J%)/2)+1) step -1
               DCDT(3,I%) = -(QX(J%+1)/IN%(J%+1))*COLD(I%,J%)_
                            + (RCN%/QSF%)*(QX(J%+1)/IN%(J%))*COLD(I%+1,J%)_
                            - ((RCN%-1)/QSF%)*(QX(J%+1)/IN%(J%))*COLD(I%,J%)
               DCDT(3,I%) = DCDT(3,I%)/VIJ(I%,J%)
               RCN% = RCN%-1
            next I%
         end if
      elseif DH < 0 then
         if IN%(J%) = IN%(J%-1) then
            for I% = IS%(J%) to IE%(J%)
               DCDT(3,I%) = ((QX(J%)/IN%(J%))*COLD(I%,J%))/VIJ(I%,J%)
            next I%
         elseif IN%(J%) < IN%(J%-1) then
            for I% = IS%(J%) to IE%(J%)
               DCDT(3,I%) = ((QX(J%)/IN%(J%))*COLD(I%,J%))/VIJ(I%,J%)
            next I%
         elseif IN%(J%) > IN%(J%-1) then
            RCN% = IN%(J%)/2
            QSF% = IN%(J%-1)/2
            DCDT(3,IS%(J%)) =
((QX(J%)/IN%(J%))*COLD(IS%(J%),J%))/VIJ(IS%(J%),J%)
            DCDT(3,IE%(J%)) =
((QX(J%)/IN%(J%))*COLD(IE%(J%),J%))/VIJ(IE%(J%),J%)
            RCN% = RCN%-1
            for I% = (IS%(J%)+1) to (IS%(J%)+(IN%(J%)/2)-1) step 1
               DCDT(3,I%) = -(QX(J%)/IN%(J%-1))*COLD(I%,J%)_
                            + (RCN%/QSF%)*(QX(J%)/IN%(J%))*COLD(I%-1,J%)_
                            - ((RCN%-1)/QSF%)*(QX(J%)/IN%(J%))*COLD(I%,J%)
               DCDT(3,I%) = -DCDT(3,I%)/VIJ(I%,J%)
               RCN% = RCN%-1
```

```
         next I%
         RCN% = IN%(J%)/2-1
         for I% = (IE%(J%)-1) to (IE%(J%)-(IN%(J%)/2)+1) step -1
            DCDT(3,I%) = -(QX(J%)/IN%(J%-1))*COLD(I%,J%)_
                         + (RCN%/QSF%)*(QX(J%)/IN%(J%))*COLD(I%+1,J%)_
                         - ((RCN%-1)/QSF%)*(QX(J%)/IN%(J%))*COLD(I%,J%)
            DCDT(3,I%) = -DCDT(3,I%)/VIJ(I%,J%)
            RCN% = RCN%-1
         next I%
      end if
   end if
   NOADVECT:
   return
OUTTITLE:
open OUTFILE$ for output as #1
if OUTFILE$="LPT1:" then lprint chr$(27)+"&a10L"
for I% = 1 to 3
   print #1, TITLE$(I%)
next I%
print #1,
print #1, "Job Control File is:                ";JCLNAM$
print #1, "Hydrodynamics/Geometric File is:  ";HYDNAM$
print #1, "Tidal Data File is:                 ";TIDNAM$
print #1, "Water Quality/Geometric File is:  ";WQNAM$
print #1, "Output File is:                     ";OUTFILE$
print #1, "Hydro Output File is:               ";HYOUTFILE$
print #1, "Concentrations Output File is:    ";PTOUTFILE$
print #1,
print #1, "Model grid is";IMAX%; "wide and";JMAX%; "long."
print #1,
print #1, "Time Increment in hours           =";
print #1, using "##";DT
print #1, "Length Increment in meters        =";
print #1, using "####";DX
print #1, "Start day in tide table           =";IDAY0%
print #1, "End day in tide table             =";IDAYN%
print #1, "Number of point source discharges =";NOUT%
print #1, "Number of tidal extrema used      =";NTIDE%
print #1,
print #1, "I/O control string is:";
for I% = 1 to IOC%(1): print #1, using "##";IOC%(I%);: next I%
print #1, chr$(12)
close #1
return
OUTHYDRO:
open "A", #1,OUTFILE$
if OUTFILE$="LPT1:" then lprint chr$(27)+"&a10L"
for I% = 1 to 3
   print #1, TITLE$(I%)
next I%
print #1,
print #1,
print #1, "Node  Surface    Cross-sectional    Nonpoint   Point source
Total"
print #1, " No.   Width          Area           Inflow       Inflow
Inflow"
print #1, "       (m)           (m^2)          (m^3/s)       (mgd)
(m^3/hr)"
print #1, "----  --------   ---------------    ---------  ------------
```

```
--------"
K% = 1
for I% = 1 to JMAX%
   print #1, using "###";I%;
   print #1, using "   ######";TP(I%);
   print #1, using "     ##########";XA(I%);
   print #1, using "         ###.###";TB(I%);
   if JOUT%(K%) = I% then
      print #1, using "      #####.##";PQ(I%);
      K% = K% + 1
   else
      print #1, "              ";
   end if
   print #1, using "     ####.###";TQ(I%)
next I%
print #1, chr$(12)
close #1
return
OUTTIDE:
open "A", #1,OUTFILE$
if OUTFILE$="LPT1:" then lprint chr$(27)+"&a10L"
for I% = 1 to 3
   print #1, TITLE$(I%)
next I%
print #1,
print #1,
print #1, "Number of Tidal Extrema Used =";NTIDE%
print #1,
for J% = 1 to 3: print #1, "  Time    Elevation  ";: next J%: print #1,
for J% = 1 to 3: print #1, "  (hrs)   (ft)  (m)  ";: next J%: print #1,
for J% = 1 to 3: print #1, "-------  ----  ----  ";: next J%: print #1,
for I% = 1 to NTIDE% step 3
   for J% = 0 to 2
      print #1, using "####.##";TYDE(I%+J%,1);
      print #1, using "###.##";TYDE(I%+J%,2);
      print #1, using "###.##  ";TYDE(I%+J%,2)*0.3048;
   next J%
   print #1,
next I%
print #1, chr$(12)
close #1
return
OUTWQ:
open "A", #1,OUTFILE$
if OUTFILE$="LPT1:" then lprint chr$(27)+"&a5L"
for I% = 1 to 3
   print #1, TITLE$(I%)
next I%
print #1,
print #1,
print #1, "Cell  Initial   Diffusivity  Decay   Nonpoint  Point Souce"
print #1, "Line   Conc       Coeff.      Rate   Loading     Loading  "
print #1, "      (mg/m^3)   (m^2/hr)    (1/hr)  (kg/day)    (kg/day) "
print #1, "----  --------  -----------  ------  --------  -------------"
for J% = JMAX%-1 to 1 step -1
   print #1, using "###   ";J%;
   print #1, using " ###.##   ";CI(J%);
   print #1, using "  #######    ";EK(J%);
   print #1, using "#.####  ";KD(J%);
```

```
   print #1, using " ##.### ";NPL(J%);
   for I% = IS%(J%) to IE%(J%)
      if PSL(I%,J%) <> 0 then
         print #1, tab(47)
         print #1, using "##### ";PSL(I%,J%);
         print #1, " @ I=";
         print #1, I%
      end if
   next I%
   print #1,
next J%
print #1, chr$(12)
print #1, "Table of Cell Depths in Meters"
print #1,
print #1, "J/I ";
for I% = 0 to IMAX%: print #1, using "  ### ";I%;: next I%: print #1,
print #1, "___ ";
for I% = 0 to IMAX%: print #1, "_____ ";: next I%: print #1,
for J% = JMAX% to 0 step -1
   print #1, using "### ";J%;
   for I% = 0 to IMAX%
      print #1, using "##.## ";D(I%,J%);
   next I%
   print #1,
next J%
print #1, chr$(12)
print #1, "Table of Boundary Conditions"
print #1,
for J% = 1 to 3: print #1, "  I     J     BC    ";: next J%: print #1,
for J% = 1 to 3: print #1, " ----  ----  ----   ";: next J%: print #1,
for I% = 1 to NBC% step 3
   for J% = 0 to 2
      print #1, using " ###  ";IB%(I%+J%);JB%(I%+J%);BCN%(I%+J%);
      print #1, "  ";
   next J%
   print #1,
next I%
print #1,
print #1,
print #1, "(BC is Boundary Condition Designator)"
print #1, chr$(12)
close #1
return
OUTHYDCALC:
open HYOUTFILE$ for append as #3
if HYOUTFILE$="LPT1:" then lprint chr$(27)+"&a10L"
for I% = 1 to 3
   print #3, TITLE$(I%)
next I%
print #3,
print #3,
print #3, "Day:                ";IDAY%
print #3, "Hour:               ";IHR%
print #3, "Time (hrs):         ";:print #3, using "######.##";T
print #3, "Water Level (m):    ";:print #3, using "####.####";HNEW
print #3, "Output Interval:    ";:print #3, IOC%(6)
print #3,
print #3, "Cell  Change in Volume  Flow Rate  XSection Area  Velocity"
print #3, "           (m^3)         (m^3/hr)      (m^2)        (m/hr)
```

```
print #3, "----  ----------------  ---------  -------------  --------"
for J% = JMAX% to 1 step -1
   print #3, using "###";J%;
   print #3, using "       ######";DVOL(J%);
   print #3, using "       ########";QX(J%);
   print #3, using "        #####";AX(J%);
   print #3, using "     ####.##";VX(J%)
next J%
print #3, chr$(12)
close #3
return
OUTCONCALC:
open PTOUTFILE$ for append as #4
if PTOUTFILE$ = "LPT1:" then lprint chr$(27)+"&a5L"
for I% = 1 to 3
   print #4, TITLE$(I%)
next I%
print #4,
print #4,
print #4, "Day:                ";IDAY%
print #4, "Step in Day:        ";IHR%
print #4, "Time (hrs):         ";:print #4, using "######.##";T
print #4, "Water Level (m):    ";:print #4, using "######.##";H
print #4, "Output Interval:    ";:print #4, IOC%(7)
print #4,
print #4, "Table of Concentrations in mg/m^3"
print #4,
print #4, "J/I ";
for I% = 0 to IMAX%: print #4, using "  ### ";I%;: next I%: print #4,
print #4, "___ ";
for I% = 0 to IMAX%: print #4, "_____ ";: next I%: print #4,
print #4, using "### ";JMAX%;
for I% = 0 to IS%(JMAX%-1)-1:print #4, "      ";:next I%
for I% = IS%(JMAX%-1) to IE%(JMAX%-1)
   if TG%(I%,JMAX%-1)=1 then print #4, spc(6); else print #4, "______";
next I%
print #4,
for J% = JMAX%-1 to 1 step -1
   print #4, using "### ";J%;
   for I% = 0 to IMAX%
      if I% =(IS%(J%)-1) then
         print #4, "     |";
      elseif I% =(IE%(J%)+1) then
         print #4, "|";
      elseif I% < (IS%(J%)-1) or I% > (IE%(J%)+1) then
         print #4, spc(6);
      elseif I%=>IS%(J%) and I%=<IE%(J%) then
         print #4, using "##### ";COLD(I%,J%);
      end if
   next I%
   print #4,
next J%
print #4, using "### ";0;
for I% = 0 to IMAX%
   print #4, using "##### ";COLD(I%,0);
next I%
print #4,
print #4, chr$(12)
close #4
return
```

APPENDIX D

INITIAL DILUTION MODEL

D-1 Initial Dilution Model Example Input/Output

D-2 Port Spacing Optimization Technical Memorandum

D-3 Low Effluent Rate Results Technical Memorandum

D-4 Subsequent Dilution Model Code

APPENDIX D-1

Initial Dilution Model Example Input/ Output

Table D1-1

INITIAL DILUTION MODEL EXAMPLE INPUT/OUTPUT

```
STARKIST-SAMOA ENGR FEAS INIT DIL MODEL: PROFILE #4, 1.4 mgd, 5 cm/sec
1,1,0,0,0,0,0,0,0,0
   (a) 0.061  (d) 5  (h) 0.1016  (k) 0  (m) 30.5
       0.0    (e) 90 (i) 4.6
(b) 15 (f) 10.20      29.4

(c)  0   (g) 35.5  (j) 27.3  (l) 0.05
     3       35.5      27.3      0.05
     6       35.6      27.2      0.05
     9       35.6      27.2      0.05
    12       35.7      27.2      0.05
    15       35.8      27.2      0.05
    18       35.8      27.2      0.05
    21       35.8      27.2      0.05
    24       35.9      27.2      0.05
    27       35.9      27.2      0.05
    30       35.9      27.2      0.05
    33       35.9      27.2      0.05
    36       35.9      27.2      0.05
    39       35.9      27.2      0.05
    61       36.0      27.2      0.05
UMERGE VERSION 1.0 AUGUST 1985.
..................  ..................  ..................  ..................
UNIVERSAL DATA FILE: NEWOUT5L.IN
CASE I.D. STARKIST-SAMOA WLA EVAL INIT DILUTION MODELING: PROFILE #4, 1.4 mgd, 5 cm/sec
RUN TITLE:  100' DEPTH

ASPIRATION ENTRAINMENT COEFFICIENT  =     .10    (DEFAULT)
NUMBER OF STEPS ALLOWED             =  5000      (DEFAULT)
ITERATION PRINTOUT FREQUENCY        =   150      (DEFAULT)
PRINT ARRAY AA (0=NO, 1=YES)        =     0      (DEFAULT)
PRINT ARRAY AB (0=NO, 1=YES)        =     0      (DEFAULT)
PRINT ARRAY AC (0=NO, 1=YES)        =     0      (DEFAULT)

INITIAL TEMPERATURE OF THE PLUME    =   29.44    DEGREES CENTIGRADE
INITIAL SALINITY OF THE PLUME       =   10.20    PPT
INITIAL DENSITY OF THE PLUME        =    3.4723  SIGMAT UNITS
FROUDE NUMBER                       =   10.7
TOTAL EFFLUENT FLOW                 =     .0610  CMS
NUMBER OF PORTS                     =    5
PORT DIAMETER                       =     .1016  M
PORT SPACING                        =    4.60    M
VERTICAL PORT ANGLE FROM HORIZONTAL =     .0     DEGREES
PORT DEPTH                          =   30.50    M

FIRST LINE OF OUTPUT ARE INITIAL CONDITIONS
```

(n) X (M)	(o) Z (M)	(p) PLUME DIAMETER (M)	(q) DILU-TION	(r) DENDIFF (SIGMAT)	(s) HORIZ VEL (M/S)	(t) VERT VEL (M/S)	(u) TOTAL VEL (M/S)	(v) AMBIENT CURRENT (M/S)
.00	30.50	.102	1.00	19.88	1.50	.00	1.50	.050
.00	30.50	.102	1.01	19.75	1.49	.00	1.49	.050
.45	30.49	.276	2.79	7.06	.56	.04	.57	.050
1.64	30.21	.693	7.86	2.50	.23	.10	.25	.050
3.52	28.64	1.385	22.21	.89	.11	.14	.18	.050
5.55	25.64	2.645	62.77	.31	.07	.12	.14	.050
*****MERGING BEGINS								
7.88	21.87	4.635	150.31	.09	.06	.09	.11	.050
8.50	20.95	5.368	177.52	.05	.06	.08	.10	.050
*****NOMINAL TRAPPING LEVEL REACHED								
14.16	13.84	12.617	383.15	.00	.05	.06	.08	.050
16.30	11.83	20.392	502.08	-.04	.05	.04	.06	.050

```
COMPUTATIONS CEASE:  VERTICAL PLUME VELOCITY IS LESS THAN 0

PLUMES MERGED BEFORE TRAPPING LEVEL REACHED
(w) TRAPPING LEVEL =  13.87 M BELOW SURFACE        (x) DILUTION = 382.08
```

(a) Discharge flow rate (m^3/sec)
(b) Number of data input points
(c) Water depth of input data (m)
(d) Number of ports on one side of diffuser
(e) Ambient current direction relative to ports
(f) Effluent density (grams/cm^3)
(g) Ambient salinity (ppt)
(h) Port diameter (meters)
(i) Adjecent port spacing (meters)
(j) Ambient temperature (Celsius)
(k) Discharge angle (degrees)
(l) Ambient current speed (m/sec)
(m) Diffuser port depth (meters)
(n) Horizontal distance of plume from port orifice (meters)
(o) Depth of plume from surface (meters)
(p) Plume diameter (meters)
(q) Plume dilution (ratio)
(r) Density of plume minus ambient density expressed in sigma-t units
(s) Horizontal component of plume's velocity (m/sec)
(t) Vertical component of plume's velocity (m/sec)
(u) Magnitude of plume's velocity (m/sec)
(v) Ambient current-horizontal (m/sec)
(w) Depth below surface (meters) where plume centerline reaches equilibrium
(x) Dilution (ratio) for diffuser

APPENDIX D-2

Port Spacing Optimization Technical Memorandum

APPENDIX D-2

Port Spacing Optimization Technical Memorandum

INTRODUCTION

This technical memorandum presents a revised (preliminary) recommendation on the outfall diffuser configuration for the Starkist Samoa outfall alternatives evaluation. Information on the configuration of the diffuser will be used in the engineering feasibility evaluation tasks of the project. Further analysis of was required to refine the recommended spacing between diffuser ports.

As in the previous initial dilution modeling effort, the dilution characteristics of the outfall diffuser were analyzed using U.S. EPA guidelines and the hydrodynamic models UMERGE and UDKHDEN. More detailed descriptions of the models and on the previous modeling effort can be found in the technical memorandum dated August 21, 1990.

Model simulations were conducted to determine the expected dilution ratio for various port spacings. These results and recommendations are presented in this memorandum.

EFFLUENT/RECEIVING WATER CHARACTERISTICS

The diffuser port spacing evaluation was done using the inner harbor density profile described in the technical memorandum which was mentioned earlier. Maximum effluent flow (2.2 mgd) and no ambient current (zero velocity) were used to represent a worst-case situation. Effluent salinity and density were calculated using the projected future (average) temperature of 85° F (29.44° C). Discharge depths of 100 and 150 feet (30.5 and 45.7 meters, respectively) were selected to approximate inner harbor depths.

RECOMMENDED DIFFUSER CONFIGURATION

Results from the initial dilution modeling recommended that the outfall diffuser was configured in the following way:

- Diffuser Pipe Diameter — 12-inch
- Number of Ports — 5
- Port Diameter — 4-inch
- Port Discharge Angle — Horizontal (0°)
- Port Spacing — 15 feet

This configuration was previously recommended as the baseline for the initial dilution modeling runs. In these additional modeling runs, only the port spacing (and discharge depth) have been varied to further refine the outfall diffuser configuration.

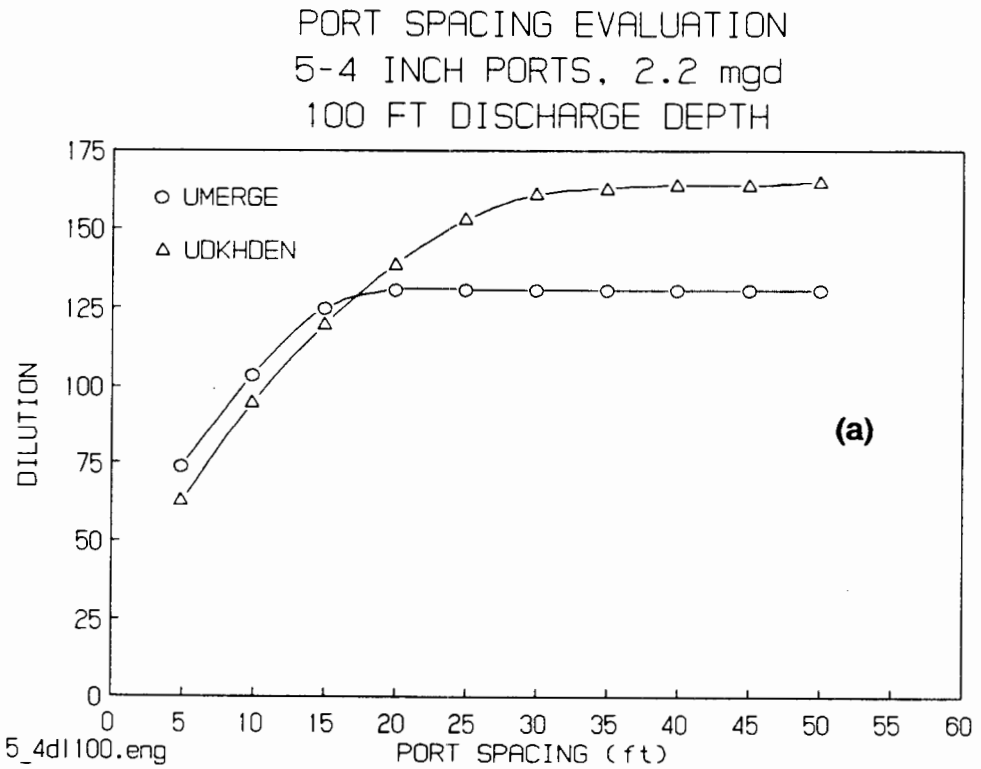
MODELING RESULTS

Predicted initial dilution and plume trapping level as functions of diffuser port spacing for both UMERGE and UDKHDEN model runs are shown in Figure 1. Discharge depths of 100 feet (Figure 1a) and 150 feet (Figure 1b) below MLLW were used. An effluent flow rate of 2.2 mgd and no ambient current were used for the recommended diffuser configuration of 5 4-inch diameter ports.

To obtain the maximum dilution ratio with a minimum of port spacing (thereby minimizing the total length of the diffuser), UMERGE predicts that the ports should be spaced about 20 to 25 feet apart; UDKHDEN, on the other hand, predicts an optimum port spacing of about 30 feet (Figure 1).

A port spacing should be selected that produces effluent plumes that will merge when the trapping level beneath the surface has been attained (ie. the plume reaches water of equal density). Both UMERGE and UDKHDEN predict when this situation occurs, but because of inherent differences between the models, slightly different port spacings are predicted. UDKHDEN tends to predict slightly more conservative estimates of initial dilution in comparison to UMERGE dilution estimates.

The proposed configuration of the diffuser is recommended above in the Recommended Diffuser Configuration Section. However, the optimum port spacing should be increased from 15 feet to 25 feet for maximum diffuser efficiency. This will result in an outfall diffuser section that will be approximately 100 feet in length. Following the geophysical survey, this diffuser configuration may need to be modified slightly to take into account outfall siting considerations such as location and discharge depth.



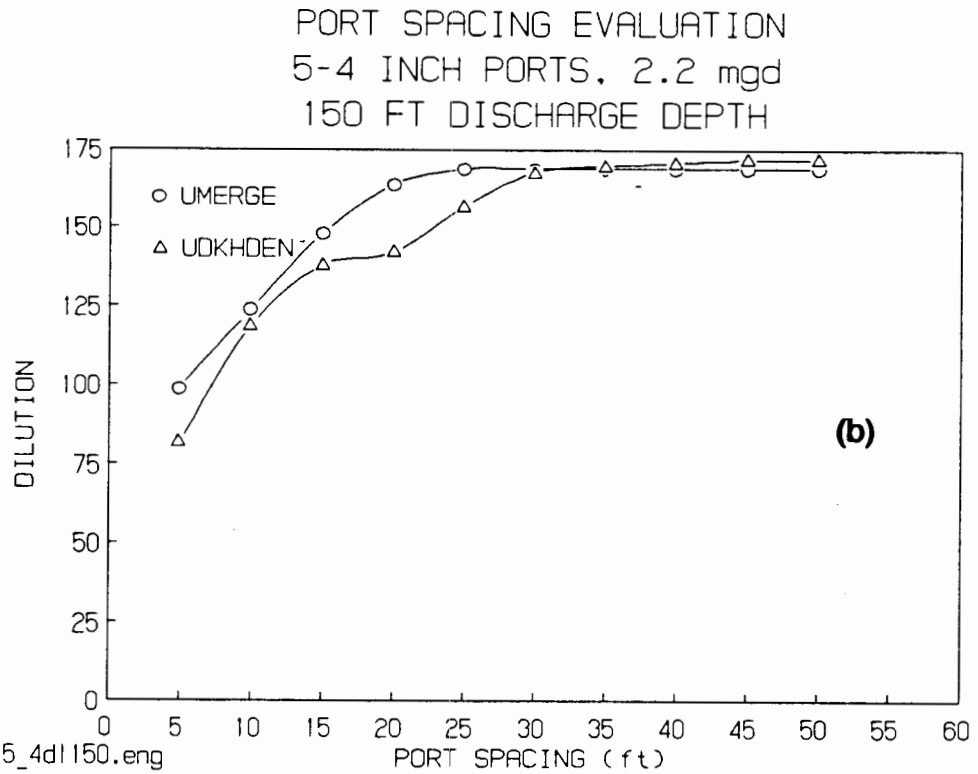


FIGURE 1
Predicted Port Spacing and Dilution for (a) 100 and (b) 150 ft Discharge Depth Using UMERGE and UDKHDEN

APPENDIX D-3

Low Effluent Rate Results Technical Memorandum

APPENDIX D-3

Low Effluent Rate Results Technical Memorandum

INTRODUCTION

This technical memorandum presents a summary of additional initial dilution modeling results for the Starkist Samoa outfall alternatives evaluation. As per Starkist's request, this is an expansion of the original initial dilution modeling effort. The purpose of the additional modeling was to investigate the effect of low effluent flow conditions (1 million gallon/day) on the performance of the outfall configuration that was previously recommended. Specifics on the characteristics of the receiving water characteristics and diffuser configuration can be found in the technical memorandum dated August 21, 1990, as these are the same as those used in the previous modeling.

As in the previous modeling effort, the dilution characteristics of the outfall diffuser were analyzed using U.S. EPA guidelines and the hydrodynamic models UMERGE and UDKHDEN. More detailed descriptions of the models can be found in the technical memorandum previously mentioned. The models were used to evaluate low effluent flow conditions for typical inner and outer harbor density profiles at various discharge depths.

OUTFALL EFFLUENT CHARACTERISTICS

As in the previous initial dilution modeling effort, the effluent density (grams per cubic centimeter) and salinity (parts per thousand) was again calculated using conservation of mass (salt) laws. An effluent flow rate of 1.0 million gallon/day (mgd), of which 0.5 mgd of the total flow is fresh water and 0.5 mgd is seawater was used in all of the new model runs. Density and salinity were calculated using the projected future (attainable) average effluent temperature of 85° F.

The salinity of the effluent was calculated using known values of effluent volume (weighted according to the percentage of the total flow). Influent density for freshwater and seawater at both average effluent temperatures were estimated using a seawater density nomograph. The results of these calculations are given below:

Flow (mgd)	Density (g/cm3)	Temp (°F)	Salinity (o/oo)
1.0	1.0093	85	17.74

OUTFALL DIFFUSER CONFIGURATION

UMERGE and UDKHDEN were used with the following parameters for the additional model runs:

- Effluent flow rate: 1.0 mgd
- Vertical angle of ports relative to the horizontal: 0 degrees
- Port depths: 50, 100, 150 feet (inner harbor); 100, 150, 200 feet (outer harbor)
- Ambient current speed and direction: 0 and 5 cm/sec (normal to the diffuser axis)
- Distance between adjacent ports: 15 feet
- Average effluent temperature: 85 degrees F
- Effluent salinity of 17.74 o/oo

The only parameters that were changed from the previous model runs was the effluent flow rate and effluent salinity.

MODELING RESULTS

Predicted plume trapping levels and predicted initial dilution as functions of discharge depth for both UMERGE and UDKHDEN model runs are shown in Table 1 and in Figures 1 and 2. Density profiles for the inner and outer harbor, an effluent flow condition of 1.0 mgd, and two current speeds (0 and 5 cm/sec) are the parameters used in the additional model runs. As before, only a zero velocity was used for the inner harbor.

As in the previous modeling, both UMERGE and UDKHDEN predict similar plume trapping levels and initial dilutions when the discharge depth is relatively shallow, as for the inner harbor profiles (Figures 1a and 2a). The models predict initial dilutions ranging between 120:1 and 180:1 when no ambient current is present.

For outer harbor conditions, both plume trapping level and initial dilution predicted by the two models are very similar when no current is present (Figures 1b and 2b). However, when a 5 cm/sec current was used (with all other conditions remaining the same), the models predict different trapping levels and dilutions. The only differences that are obvious between the model runs made previously and the additional model runs is that the dilutions and trapping levels predicted are generally higher and deeper, respectively. Once again, differences in UMERGE and UDKHDEN results can be explained in terms of basic differences between the models. These differences were explained in more detail in the previous memorandum.

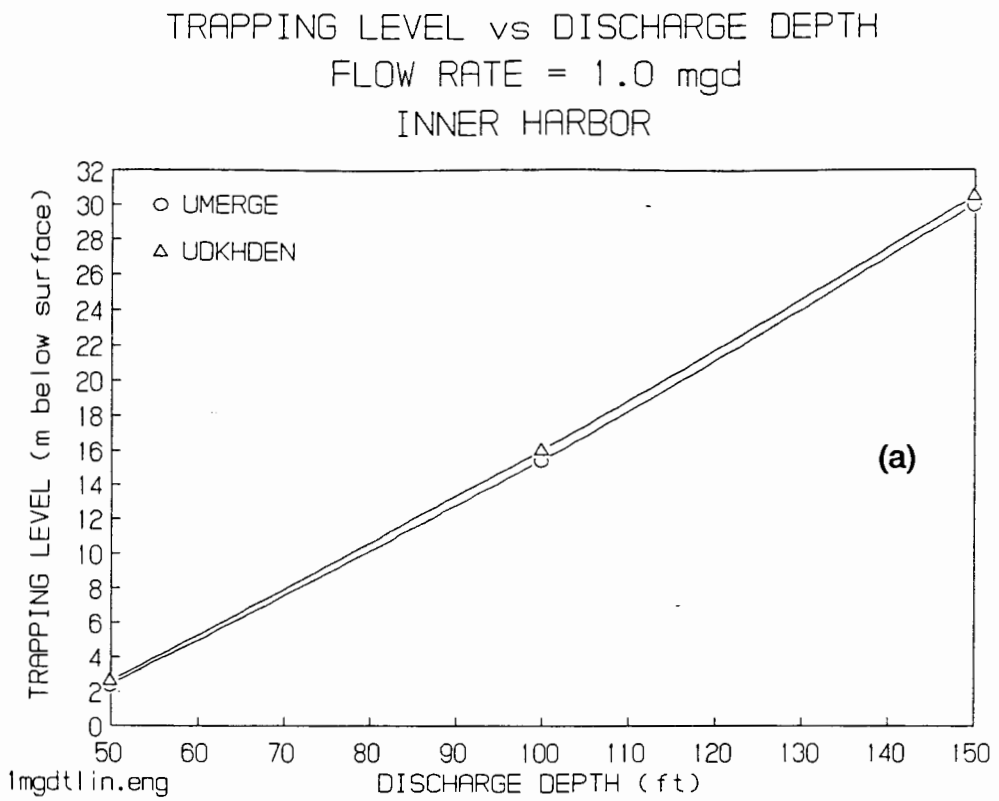
Dilution and trapping level differences as a result of lower effluent flow rates are expected. Lower flow rates transport less effluent in the same amount of time, thus resulting in higher dilutions. This can be seen when comparing the results of the additional model runs to those that were made previously. No significantly different trends are seen under low effluent flow

conditions (1.0 mgd) in comparison to higher flow conditions modeled earlier (1.4 and 2.2 mgd). As before, for both the inner ad outer harbor density stratification conditions, at either ambient current speed, the 5 4-inch multiport diffuser configuration will achieve dilutions well above 100:1 at lower flow rates. Plume trapping levels are also well beneath the surface.

Table 1
DILUTION AND TRAPPING LEVEL FOR FIVE 4-INCH
DIAMETER PORTS FOR VARIOUS DISCHARGE DEPTHS
UNDER LOW EFFLUENT FLOW CONDITIONS (1 mgd)

DENSITY PROFILE LOCATION	CURRENT SPEED (cm/sec)	DISCHARGE DEPTH (ft)	(m)	UMERGE DILUTION	UMERGE TRAP LEVEL	UDKHDEN DILUTION	UDKHDEN TRAP LEVEL
Inner Harbor	0	50	15.2	126	2.4	137	2.6
	0	100	30.5	165	15.4	169	16.0
	0	150	45.7	173	30.0	175	30.5
Outer Harbor	0	100	30.5	194	13.0	189	13.4
	0	150	45.7	284	21.9	270	22.0
	0	200	61.0	399	23.3	351	23.4
	5	100	30.5	264	21.1	393	22.4
	5	150	45.7	742	23.2	1127	23.6
	5	200	61.0	610	43.7	668	47.6

Note:
Dilution is the average initial dilution of plume
Trapping level is in meters below surface



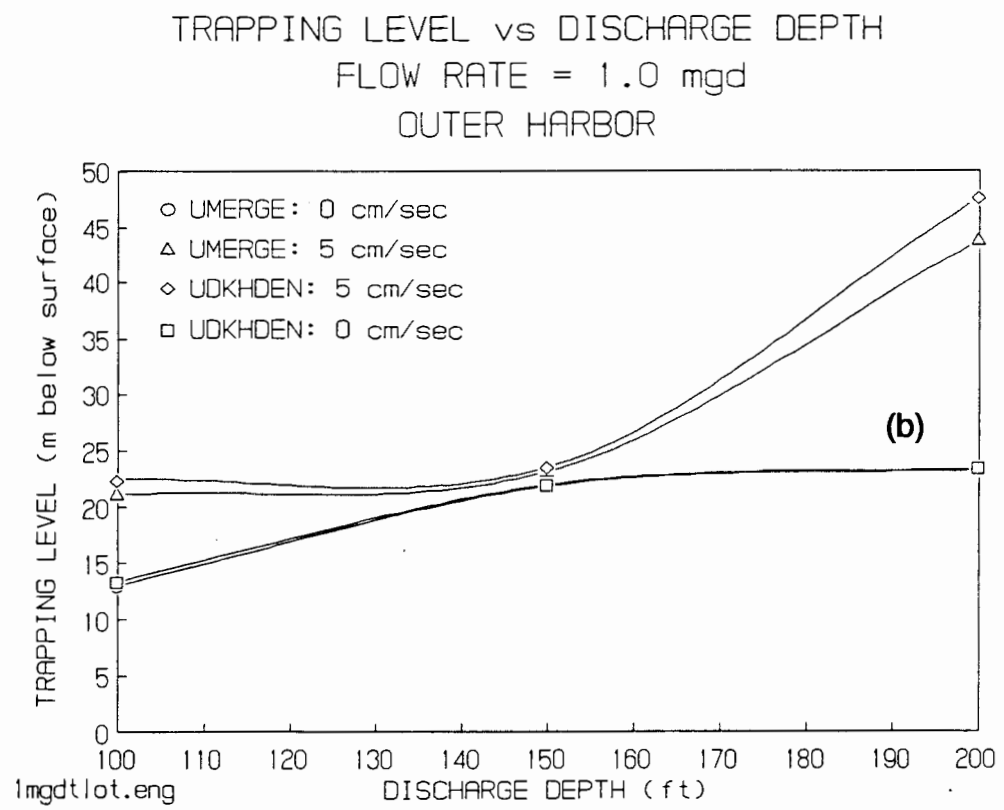
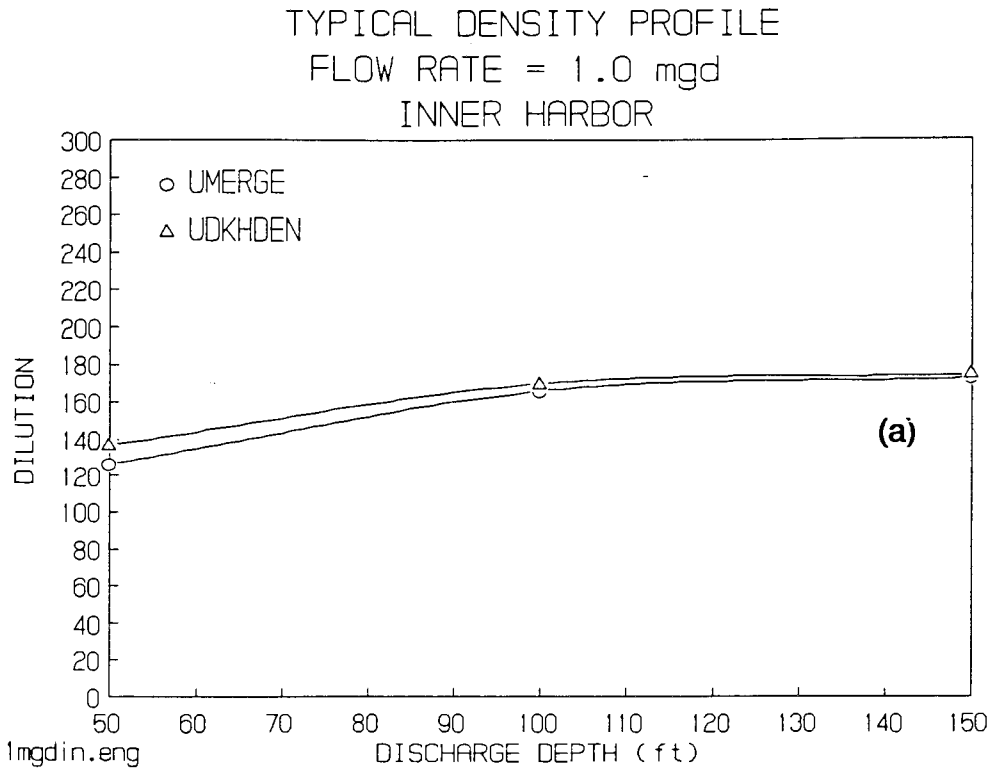


FIGURE 1
Predicted Trapping Level for (a) Inner Harbor and (b) Outer Harbor for Low Flow Conditions Using UMERGE and UDKHDEN



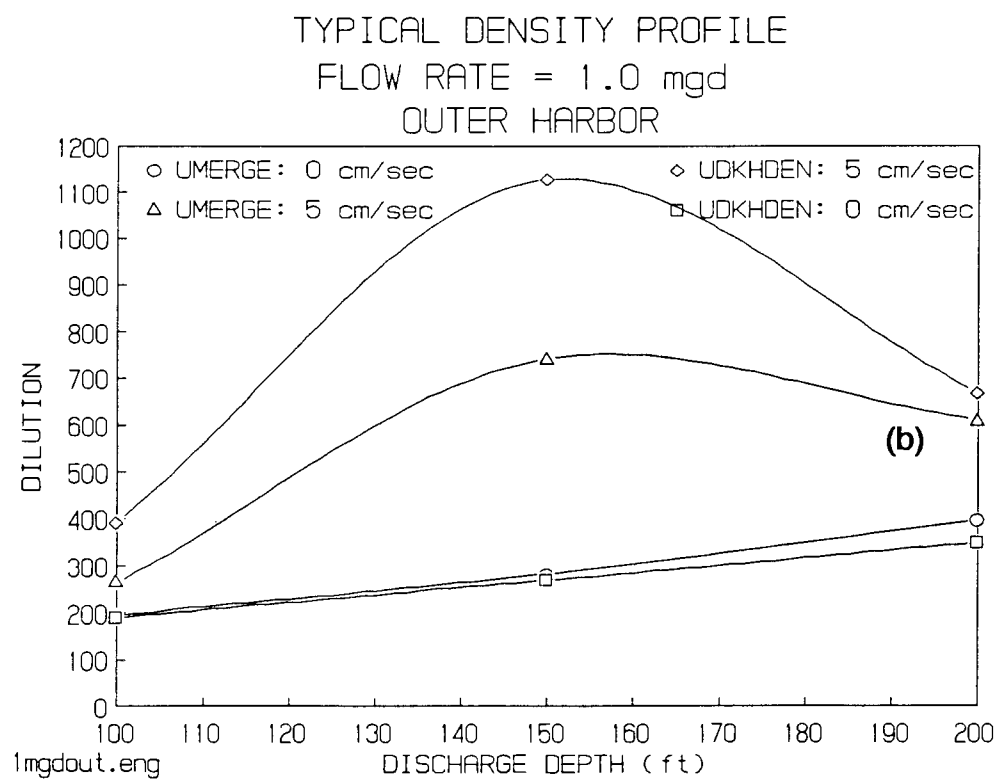


FIGURE 2
Predicted Initial Dilution for (a) Inner Harbor and (b) Outer Harbor for Low Flow Conditions Using UMERGE and UDKHDEN

APPENDIX D-4

Subsequent Dilution Model Code

```
C
C     THIS PROGRAM ESTIMATES THE RATE OF DISPERSAL OF SOME
C     CONSTITUENT DISCHARGED THROUGH A DIFFUSER INTO A COASTAL
C     ENVIRONMENT NEAR THE SHORELINE.  IMPORTANT PROCESSES ARE
C     LONGITUDINAL ADVECTION, LATERAL DIFFUSION AND FIRST-ORDER
C     DECAY OF THE CONSTITUENT.  THE METHOD OF IMAGES IS USED TO
C     OBTAIN SOLUTIONS AS A FUNCTION OF THE LONGITUDINAL DISTANCE
C     ALONG THE DIFFUSER CENTERLINE AND THE SHORELINE.  THREE DIFFERENT
C     FUNCTIONAL FORMS ARE AVAILABLE FOR SPECIFYING THE COEFFICIENT OF
C     LATERAL EDDY DIFFUSIVITY. FOR MORE INFORMATION SEE:
C
C          DIFFUSION IN NEAR-SHORE AND RIVERINE ENVIRONMENTS
C          EPA 910/9-87-168
C          EPA REGION 10
C
      REAL*4 KRATE
      DIMENSION DIL(50),TITLE(43),CONC(2),YP(2)
      CHARACTER*1 TITLE
      CHARACTER*20 OFILE
      DATA PI/3.14159/,OFILE/' '/,YP/0.0,0.0/,IOUT/2/
C
C     FUNCTION USED TO ESTABLISH INITIAL VALUE OF THE COEFFICIENT
C     OF LATERAL EDDY DIFFUSIVITY.  CORRESPONDS TO DISSIPATION FACTOR
C     ALPHA=0.001 FEET**4/3
C
      EPS(X)=0.01*((X*12.*2.54)**1.33)/(12.*2.54)**2
C
C     BEGIN
C
   10 CONTINUE
C
C     INPUT PROBLEM SPECIFICATIONS AND COMPUTE IMPORTANT CONSTANTS
C
      WRITE(*,4000)
 4000 FORMAT(' INPUT PROBLEM DESCRIPTION')
      READ(*,1100) TITLE
      WRITE(*,4020)
 4020 FORMAT(' SPECIFY FUNCTION FOR DIFFUSION'/
     .       ' 1=CONSTANT,2=F(X),3=F(X**4/3)')
      READ(*,*) ITYPE
      OPEN(IOUT,FILE=OFILE,STATUS='NEW')
      WRITE(IOUT,2100) TITLE
      WRITE(*,4100)
 4100 FORMAT(' DECAY RATE (1/DAYS-BASE E)')
      READ(*,*) KRATE
      XR=KRATE
      KRATE=KRATE/84600.
      WRITE(*,4200)
 4200 FORMAT(' DIFFUSER WIDTH(FT),CURRENT(FT/SEC)')
      READ(*,*) B0,U0
      EPS0=EPS(B0)
      CNST=1./(2.*SQRT(PI*EPS0))
      WRITE(*,4300)
 4300 FORMAT(' EFFLUENT CONCENTRATION, INITIAL DILUTION')
```

```
      READ(*,*) C0,S0
      C1=C0
      C0=C0/S0
      WRITE(*,4400)
 4400 FORMAT(' X-INCREMENT, DISTANCE TO SHORELINE')
      READ(*,*) DX,Y0
      YP(2)=Y0
      WRITE(*,4500)
 4500 FORMAT(' NUMBER OF X-INCREMENTS')
      READ(*,*) NX
      DYY=B0/100.
      BETA=12.*EPS0/(U0*B0)
C
C     WRITE HEADER FOR OUTPUT FILE ON UNIT=2
C
      WRITE(IOUT,2150) XR,B0,U0,Y0,C1,S0
C
C     BEGIN CALCULATION LOOP, INDEXING (I) ON THE LONGITUDINAL
C     DISTANCE, X
C
      DO 199 I=1,NX
      X=DX*I
      T0=X/U0
C
C     COMPUTE TRANSFORMED COORDINATE BASED UPON FUNCTIONAL FORM
C     FOR COEFFICIENT OF LATERAL EDDY DIFFUSIVITY
C
      TPRIME=XPRIME(BETA,X,B0,ITYPE)/U0
C
C     INDEX (ICC) ON THE TWO Y-COORDINATES FOR OUTPUT.
C     YP(1)=DIFFUSER CENTERLINE;  YP(2)=SHORELINE
C
      DO 129 ICC=1,2
      RATIO=0.0
C
C     INDEX (J) ON THE TWO MIRROR IMAGES OF THE DIFFUSER
C
      DO 99 J=1,2
      YSIGN=(-1.)**J
      IF(TPRIME.LT.1.0E-10) GO TO 80
      CONST=CNST/SQRT(TPRIME)
   80 CONTINUE
      SSHORE=1.0E10
C
C     INDEX (K) ON THE 100 DIFFUSER INCREMENTS WHICH APPROXIMATE
C     POINT SOURCES.
C
      DO 99 K=1,100
      YK=K
      YDFF=(YK-50.)*DYY
      YIMG=YSIGN*(Y0+YDFF)
      Y=YP(ICC)-YIMG
      A=-(Y**2)/(4.*EPS0*TPRIME)
      RATIO=RATIO+CONST*EXP(A)*DYY
```

```
   99 CONTINUE
C
C     ESTIMATE CONCENTRATION ON DIFFUSER CENTERLINE (ICC=1) AND
C     AT SHORELINE (ICC=2).  IF THE CONCENTRATION IS GREATER THAN
C     THE INITIAL CONCENTRATION, C0, THERE ARE NUMERICAL ERRORS.  THE
C     ERROR WILL GENERALLY BE SMALL AND OCCURS ONLY IN THE VICINITY
C     OF THE DIFFUSER.  ACCOUNTED FOR BY SETTING ESTIMATED CONCENTRATION
C     TO INITIAL CONCENTRATION.  INCREASING THE NUMBER OF DIFFUSER
C     INCREMENTS WILL ALSO SOLVE THE PROBLEM AT THE EXPENSE OF
C     COMPUTING TIME.
C
      CONC(ICC)=RATIO*C0*EXP(-KRATE*T0)
      IF(CONC(ICC).GT.C0) CONC(ICC)=C0
  129 CONTINUE
      SMAX=C1/CONC(2)
      IF(CONC(1).LE.1.0E-10) GO TO 150
      SSHORE=C1/CONC(1)
  150 CONTINUE
      WRITE(*,2200) X,CONC(2),CONC(1)
C
C     OUTPUT RESULTS TO UNIT=2
C
      WRITE(IOUT,2200) X,CONC(2),CONC(1),SMAX,SSHORE
  199 CONTINUE
C
C     CHECK TO SEE IF THERE IS ANOTHER PROBLEM,
C     IF THERE IS RETURN TO STATEMENT 10, IF NOT EXIT
C
      WRITE(*,4600)
 4600 FORMAT(' NEW PROBLEM (ENTER 1), OR QUIT (ENTER ZERO)')
      READ(*,*) I
      IF(I.GT.0) GO TO 10
 1100 FORMAT(80A1)
 2100 FORMAT(1H1///
     .' ****** DIFFUSION/ADVECTION MODEL FOR OCEAN DISCHARGE ******'/
     .' ******                    EPA REGION 10                 ******'/
     .' ******',1X,43A1,3X,'******'//)
 2150 FORMAT(
     .'                  DECAY RATE = ',F8.2,' DAYS**-1'/
     .'              DIFFUSER WIDTH = ',F8.0,' FEET'/
     .'               OCEAN CURRENT = ',F8.1,' FEET/SECOND'/
     .'       DISTANCE TO SHORELINE = ',F8.0,' FEET'/
     .'      EFFLUENT CONCENTRATION = ',F8.0,/
     .'            INITIAL DILUTION = ',F8.1//
     .'      DISTANCE     EST. CONCENTRATION      EST. DILUTION'/
     .'       (FEET)         C/L       S/L         C/L      S/L'//)
 2200 FORMAT(6X,F6.0,4X,F8.2,2X,F8.2,6X,F7.1,2X,F7.1)
      STOP
      END
      FUNCTION XPRIME(BETA,X,B0,ITYPE)
C
C     THIS FUNCTION COMPUTES THE VALUE OF THE TRANSFORMED X-COORDINATE
C     FOR THREE DIFFERENT FUNCTIONAL FORMS OF THE COEFFICIENT OF LATERAL
C     EDDY DIFFUSIVITY.  BASED UPON THE WORK OF BROOKS (1960)
```

```
C
      GO TO (20,40,60),ITYPE
   20 CONTINUE
      XPRIME=X
      RETURN
   40 CONTINUE
      XPRIME=B0*((1.+BETA*X/B0)**2-1.)/(2.*BETA)
      RETURN
   60 CONTINUE
      XPRIME=B0*((1.+2.*BETA*X/(3.*B0))**3-1.)/(2.*BETA)
      RETURN
      END
.)/(2.*BETA)
      R
```

APPENDIX E

PIPELINE COST ESTIMATE PROCEDURE

E-1 Marine Pipeline Option

E-2 Land Pipeline Option

E-3 Diffuser

Appendix E
PIPELINE COST ESTIMATE PROCEDURE

This appendix provides cost estimates and price documentation for two possible approaches to outfall construction in Pago Pago Harbor. Estimates are provided for a 10,000-foot-long-submerged pipeline (Appendix E-1) and a 14,000- to 16,000-foot-long land pipeline with a 1000-foot-long outfall (Appendix E-2). Unit costs are estimated for 12-, 14-, and 18-inch diameters. For the land pipeline, costs are also estimated for PVC, DI, and HDPE pipe. Shipping either by tug and barge or by container on an oceangoing freighter is considered for the land route. Estimated costs of the diffuser are presented in Appendix E-3.

The estimates presented here are applicable for a range of lengths and flow rates. The variation of cost with pipeline length is shown in Figure 5-6 for the marine route. These feasibility-level cost estimates have been prepared for guidance in project evaluation and implementation from the information available at the time of the estimate. The final costs of the project will depend on actual labor and material costs, actual site conditions, productivity, competitive market conditions, final project scope, final project schedule, the firm selected for final engineering design, and other variable factors. As a result, the final product costs will vary from the estimates presented here. The range of variation may be as great as 50 percent more to 30 percent less.

APPENDIX E-1

Marine Pipeline Option

APPENDIX E-1: MARINE PIPELINE OPTION

COST COMPARISON FOR 6-, 12-, 14-, AND 18-INCH PIPELINES

		6"	12"	14"	18"
1	Material Purchase				
1.1	Pipe SDR11 10,000 ft	$ 40,000	$ 140,000	$ 169,100	$ 280,000
1.2	Contractor markup and handling (10%)	4,000	14,000	16,910	28,000
1.3	Flanges and slip rings to 62 joints	6,820	23,870	28,832	47,740
1.4	Concrete weights	9,086	39,363	65,962	96,045
		$ 59,906	**$ 217,233**	**$ 280,768**	**$ 451,785**
	Mobilization and Demobilization				
2.1	Mobilization	$ 224,000	$ 224,000	$ 224,000	$ 224,000
2.2	Demobilization	180,100	180,100	180,100	180,100
2.3	Bonds and insurance	6,182	6,182	6,182	6,182
2.4	Crew from Hawaii, transportation	4,000	4,000	4,000	4,000
2.5	Pumps, generators, etc., California to Samoa	2,293	2,293	2,293	2,293
2.6	Pipe from California to Hawaii	9,126	36,503	50,565	82,137
		$ 425,701	**$ 453,078**	**$ 467,140**	**$ 498,712**
3	Pipe Connection in Hawaii				
3.1	Fusion of joints and flanges	$ 10,140	$ 13,485	$ 18,000	$ 18,000
3.1.1	Fusion technologist air ticket	800	800	800	800
3.1.2	Per diem	5,600	6,600	7,600	7,600
		$ 16,540	**$ 20,885**	**$ 26,400**	**$ 26,400**
4	Installation in Samoa				
4.1	Trenching in coral	$ 113,000	$ 113,000	$ 113,000	$ 113,000
4.2	Connecting, weighting, sinking pipe	251,700	377,550	503,400	503,400
4.3	Per diem	17,500	26,250	33,750	33,750
		$ 382,200	**$ 516,800**	**$ 650,150**	**$ 650,150**
5	Pump Station				
5.1	Generator and control panels	$ 33,000	$ 72,400	$ 72,400	$ 33,000
5.2	Pumps with floats and controls	30,000	60,000	60,000	40,000
5.3	Valves and vault	6,500	6,500	6,500	6,500
5.4.1	West well in place	18,000	18,000	18,000	18,000
5.4.2	Excavation and backfill	9,810	9,810	9,810	9,810
5.5	Building	6,000	10,800	10,800	6,000
5.6	Test pump system	4,000	4,000	4,000	4,000
5.7	Per diem and air fare pump testers	5,000	5,000	5,000	5,000
		$ 112,310	**$ 186,510**	**$ 186,510**	**$ 122,310**
6	Factor for work in Samoa (1.74)	**$ 76,449**	**$ 131,375**	**$ 131,357**	**$ 83,849**
	Subtotal	**$1,073,106**	**$1,525,881**	**$1,742,325**	**$1,833,206**
7	Contingency and allowance for undefined scope items @ 30%	**$ 321,932**	**$ 457,759**	**$ 522,698**	**$ 549,962**
8	Rounded Total	**$1,359,000**	**$1,984,000**	**$2,265,000**	**$2,383,000**
	Rounded Unit Cost	$140/ft	$200/ft	230/ft	$240/ft

COST ESTIMATE ASSUMPTIONS, CALCULATIONS, AND COMMENTS

1.1 Based on telephone quotes from Maskell-Robbins 8/2/90 and 1/16/91

1.2 Assumed 10% reasonable contractor markup and handling

1.3 Telephone quote from Maskell-Robbins 8/9/90; quoted cost for 18" pipe. Assumed percent was similar for other pipe diameters.

62 joints x 2 @ $270/adapter + $80/slip ring = $700 x 62 = $43,400	(47,740[1])
for 18" amount is $43,400/280,000 = 0.1550	
for 14" amount is 0.1550 x $169,100 = 26,210	(28,832[1])
for 12" amount is 0.1550 x $140,000 = $21,700	(23,870[1])
for 6" amount is 0.1550 x $40,000 = $6,200	(6,820[1])

[1]10% has been applied for contractor markup.

1.4 Estimate $250/cubic yard concrete and rebar, casted and ready for delivery. Apply to amount of weights 10 ft on center:

6"	157,000 lb/160 lb/cu ft = 981 cu ft = 36.3 cu yd = $9,086
12"	680,200 lb = 157.4 cu yd = $39,363
14"	1,608,000 lb = 263.7 cu yd = $65,926
18"	1,659,650 lb = 384.17 cu yd = $96,045

Assume weights cast in Hawaii, loaded on contractor's barge

2.1 American Diver's estimate, modified for loading concrete weights by increasing loadout time 3 days, and one extra day underway

Loadout and crew, 10 days @ $5,800	=	$ 58,000
Tiedown materials	=	20,000
Underway, 20 days @ $6,500/day	=	130,000
Unload and preparation, 4 days @ $4,000/day	=	16,000
		$224,000

2.2 Demobilization = $180,100 (estimated by American Divers)

2.3 1-1/2% of mobilization and demobilization is contractor's bond and insurance.

2.4 $800 round trip, Hawaii-Samoa (need five-man crew mobilized in)

2.5 Telephone quote from Polynesian Lines 8/8/90

2.6 Assume the Polynesian quote, although pipe is now assumed to go to Hawaii from California (same for California to Hawaii, and California to Samoa).

3.1 Three butt welds and two flange welds per 160-ft section x 62 sections. Assume welds take equal time for same diameter pipe.

Production:

6": 10 min/weld; 16/8-hr; (5 x 62)/16 = 20 days, say 26 days w/weekends; technician time = $300 per day, machine rate = $90 per day; 26 days x $390/day = $10,140

12": 15 min/weld; 14 welds/8-hr; (5 x 62)/14 = 23 days, say 31 days w/weekends; 31 days x $435/day = $13,485

14": 20 min/weld; 12 welds/day; (5 x 62)/12 - 26 day, say 36 w/weekend; 36 x $500 = $18,000

18": 20 min/weld; 12 welds/day; (5 x 62)/12 = 26 day, say 36 days w/weekend; 36 x $500 = $18,000

3.1.1 Air fare from mainland to Hawaii estimated $800 round trip.

3.1.2 Per diem rate @ $200 in Hawaii. Include 2 days' travel time with production time:

6"	38 days x $200	=	$ 7,600
12"	44 days x $200	=	$ 8,800
14"	38 days x $200	=	7,600
18"	51 days x $200	=	$10,200

4.1 American Divers estimate of 8/7/90

4.2 American Divers estimate of 8/7/90

4.3 $800 round trip, Hawaii/Samoa. Need five-man crew mobilized in. Days on site from American Diver's estimate; $125 (food and lodging) per diem. Include weekends in P.D.

6"	28 days x 5 men x $ 125/day	= $17,500
12"	42 days x 5 men x $ 125/day	= $26,250
14"	54 days x 5 men x $ 125/day	= $33,750
18"	54 days x 5 men x $ 125/day	= $33,750

5.1 6" 2 @ $16,500 (based on 700-gpm flow rate and prices of pump for 18" line)
12" 2 @ $36,200 cost in place stateside
14" 2 @ $36,200 cost in place stateside
18" 2 @ $16,500 cost in place stateside

5.2 6" 2 @ $15,000 cost in place stateside
12" 2 @ $30,000 cost in place stateside
14" 2 @ $30,000 cost in place stateside
18" 2 @ $20,000 cost in place stateside

5.3 Vault = $2,500; valves = $4,000

5.4.1 In-place cost

5.4.2 Excavation @ $ 50/cu yd. Layback slope 1H:4V in coral lower 10 ft of hole; 1H:1V in dirt upper 5 ft. Assume 12 ft x 12 ft at bottom; 17 ft x 17 ft at 10 ft above bottom; = 80 cu yd at surface excavation is 27 ft x 27 ft. Upper 5 ft of well require 94 cu yd. Backfill this amount minus volume of wet well (diameter 12 ft x 15 ft deep) = 174 cu yd - 63 cu yd = 111 cu yd @ $10/cu yd ($10 for backfill)

5.5 Estimate of 8/7/90

5.6 Estimate of 8/10/90: 2 men x 5 days
Estimate of 8/10/90: $50/hr equals $4,000
Per diem = 2 men x 9 days x $100/day = $2,250
Air fare $1,150

6 Apply factor 1.74 to in-place stateside prices to account for conditions in Samoa. Apply this to all pump station costs except pump testers' salary, per diem, and travel

7 Contingency: 30% used to account for price variability and unspecified items and expenses (for one example, the piping inside the pumphouse)

8 Rounded total is based on conceptual construction methods, no engineering drawings, and unspecified site conditions. The rounded total is an order-of-magnitude cost estimate for construction only and can statistically vary from 50% more to 30% less than that shown.

APPENDIX E-2

Land Pipeline Option

APPENDIX E-2: LAND PIPELINE OPTION

ESTIMATED COST FOR LEAST EXPENSIVE SCENARIO (SHIP AND INSTALL 6-INCH PVC PIPELINE AND 6-INCH HDPE OUTFALL TO TAFAGAMANU POINT)

1 MOBILIZATION			
1.1 Land Pipeline	1.1.3	Ship equipment	$ 59,100
	1.1.4	Purchase pipe	109,400
	1.1.5	Ship pipe (by volume)	13,400
	1.1.6	Crew air fare	15,000
	1.1.7	Crew per diem	168,800
	1.1.8	Pump station shipping	3,300
1.2 Ocean Outfall	1.2.1	Tug and barge transportation	130,000
	1.2.2	Barge load and unload	8,000
	1.2.3	Crew air fare	4,000
	1.2.4	Crew per diem	18,800
	1.2.5	Purchase pipe	4,400
	1.2.6	Ship pipe (by volume)	1,200
	1.2.7	Purchase weights	1,000
	1.2.8	Ship weights	1,200
	1.2.9	Purchase joint hardware	2,800
	1.2.10	Ship joint hardware	3,300
	TOTAL		**$543,700**
2 INSTALLATION			
2.1 Pipeline	2.1.1	Pipe (trench, install, backfill)	$312,400
	2.1.2	Pump station	196,600
	2.1.3	Road repair	283,300
2.2 Outfall	2.2.1	Trenching (in coral)	9,900
	2.2.2	Connecting, weighting, sinking	150,000
	TOTAL		**$952,200**
3 DEMOBILIZATION			
3.1 Pipeline	3.1.3	Ship equipment	$59,100
3.2 Outfall	3.2.1	Tug and barge transportation	123,500
	3.2.2	Barge load and unload	4,000
	TOTAL		**$186,600**

4	**BONDS AND INSURANCE**	$11,000
5	**CONTINGENCY (30%)**	$508,100
	TOTAL	**$2,201,600**

ESTIMATED COST FOR MOST EXPENSIVE SCENARIO TUG AND BARGE,[1] AND INSTALL 18-INCH DUCTILE IRON PIPELINE AND OUTFALL TO BREAKERS POINT

1	**MOBILIZATION**		
1.1	**Land Pipeline**	1.1.1.1 Tug and barge	$ 195,000
		1.1.1.2 Tug and barge standby for pipeline	
		1.1.4 Purchase pipe	600,000
		1.1.6 Crew air fare	552,700
		1.1.7 Crew per diem	15,000
			187,500
1.2	**Ocean Outfall**	1.2.3 Crew air fare	4,000
		1.2.4 Crew per diem	18,800
		1.2.5 Purchase pipe	35,200
		1.2.7 Purchase weights	10,000
		1.2.9 Purchase joint hardware	19,300
		TOTAL	**$1,637,500**
2	**INSTALLATION**		
2.1	**Pipeline**	2.1.1 Pipe (trench, install, backfill)	$ 659,400
		2.1.2 Pump station	214,100
		2.1.3 Road repair	313,200
2.2	**Outfall**	2.2.1 Trenching (in coral)	9,900
		2.2.2 Connecting, weighting, sinking	150,000
		TOTAL	**$1,346,600**
3	**DEMOBILIZATION**	3.1.1 Tug and barge	$182,000
		3.1.2 Load and unload barge	8,000
		TOTAL	**$190,000**
4	**BONDS AND INSURANCE**		$ 27,500
5	**CONTINGENCY (30%)**		960,500
		TOTAL	**$4,162,100**

[1]Tug and barge from California to Samoa carries all equipment, supplies, and material and is used to install outfall.

GENERAL ASSUMPTIONS

1. Project divided between pipeline from plant to start of outfall (land) and outfall (ocean).

2. Contractor for land pipeline from U.S. west coast, subcontractor for ocean outfall from Hawaii.

3. All material shipped from U.S. west coast; land pipeline equipment and crew from U.S. west coast; ocean outfall equipment and crew from Hawaii.

4. Land pipeline follows coast road from the plant to either Tafagamanu Point (14,200 feet) or Breakers Point (15,700 feet).

5. Ocean outfall is 1,000 feet long, with 500 feet trenched through coral and 500 feet laid on bottom.

6. Consider PVC, ductile iron, and HDPE for land pipeline.

7. Consider ductile iron and HDPE for ocean outfall.

8. Cost of land pipeline based on U.S. west coast in-place costs (includes trenching, pipe, installation, and backfill) times an add-on factor based on Samoan conditions.

9. Ocean outfall costs based on individual item costs.

10. Allow 95 working days and 135 total days to install land pipeline to Tafagamanu Point; 105 working days and 150 total days to install land pipeline to Breakers Point.

11. Allow 20 working days and 30 total days to install ocean outfall.

12. Crew of 20 to install pipeline: 10 from U.S. west coast, 10 from Samoa. Crew of 10 to install outfall: 5 from Hawaii, 5 from Samoa.

13. Trenching in hard, shallow (4 feet to 6 feet) soil.

14. Costs rounded up to nearest whole hundred dollars.

15. Pipeline laying rate of 150 feet per day, limited by trenching rate.

LINE ITEM CALCULATIONS

1 MOBILIZATION

1.1 Land Pipeline

1.1.1.1 Tug and barge underway (California to Samoa)
$6,500/day x 30 days = $195,000

1.1.1.2 Tug and barge standby for pipeline
Tafagamanu Point: $4,000/day x 135 days = $540,000
Breakers Point: $4,000/day x 150 days = $600,000

1.1.2 Load and unload barge
$4,000/day x 4 days = $16,000

1.1.3 Ship equipment (California to Samoa)
Less than container: (410 vol units) x $144 = $59,100

1.1.4 Purchase pipe

	6"	12"	18"
Tafagamanu Point			
PVC	$109,400	$218,700	$390,500
DI	186,500	312,400	499,900
HDPE	62,500	218,700	437,400
Breakers Point			
PVC	$120,900	$241,800	$431,800
DI	207,300	345,400	552,700
HDPE	69,100	241,800	483,600

1.1.5.1 Ship pipe (California to Samoa) by weight

	6"	12"	18"
Tafagamanu Point			
PVC	$ 5,600	$21,200	$35,100
DI	21,900	50,600	84,200
HDPE	5,900	21,800	44,300
Breakers Point			
PVC	$6,200	$23,400	$38,800
DI	24,200	55,900	93,100
HDPE	6,500	24,100	49,000

1.1.5.2 Ship pipe (California to Samoa) by volume

	6"	12"	18"
Tafagamanu Point			
PVC and DI	$13,400	$53,300	$119,900
HDPE	15,000	59,700	134,300
Breakers Point			
PVC and DI	$14,900	$58,900	132,500
HDPE	16,700	66,100	148,400

1.1.6 Crew air fare (California to Samoa and return)
$1,500/each x 10 = $15,000

1.1.7 Crew per diem in Samoa
$125/day x 10 x 135 days = $168,800 for Tafagamanu Point
$125/day x 10 x 150 days = $187,500 for Breakers Point

1.1.8 Pump station shipping
1 each x $3,300 = $3,300

1.2 Ocean Outfall

1.2.1 Tug and barge (Hawaii to Samoa)
$6,500/day x 20 days = $130,000

1.2.2 Load and unload barge
$4,000/day x 2 days = $8,000

1.2.3 Crew air fare (Hawaii to Samoa and return)
$800/each x 5 = $4,000

1.2.4 Crew per diem in Samoa
$125/day x 5 x 30 days = $18,800

1.2.5 Purchase pipe

	6"	12"	18"
DI	$13,200	$22,000	$35,200
HDPE	4,400	15,400	30,800

1.2.6.1 Ship pipe (California to Samoa) by weight

	6"	12"	18"
DI	$1,600	$3,600	$6,000
HDPE	500	1,600	3,200

1.2.6.2 Ship outfall pipe (California to Samoa) by volume

	6"	12"	18"
DI	$1,100	$3,800	$8,600
HDPE	1,200	4,200	9,600

1.2.7 Purchase weights
6-inch pipe: 16lb/lf x $0.06/lb x 1,000 lf = $1,000
12-inch pipe: 68lb/lf x $0.06/lb x 1,000 lf = $4,100
18-inch pipe: 166lb/lf x $0.06/lb x 1,000 lf = $10,000

1.2.8 Ship weights (California to Samoa)
6-inch pipe: 16,000lb → 8 tons x $144/ton = $1,200
12-inch pipe: 68,000lb → 34 tons x $144/ton = $4,900
18-inch pipe: 166,000lb → 83 tons x $144/ton = $12,000

1.2.9 Purchase joint hardware
6-inch pipe: $55/each x 50 (1,000*/20') = $2,800
12-inch pipe: $192/each x 50 = $9,700
18-inch pipe: $385/each x 50 = $19,300

1.2.10 Ship joint hardware (California to Samoa)
1 each container = $3,300

2 INSTALLATION

2.1 Pipeline

2.1.1 Pipe (trench, install, backfill)

	6"	12"	18"
Tafagamanu Point			
PVC	$312,400	$397,600	$553,800
DI	326,600	426,000	596,400
HDPE	411,800	553,800	752,600
Breakers Point			
PVC	$345,400	$439,600	$612,300
DI	361,100	471,000	659,400
HDPE	455,300	612,300	832,100

2.1.2 Pump station
6-inch pipe: $112,310 x 1.75 = $196,600
12-inch pipe: $186,510 x 1.75 = $326,400
18-inch pipe: $122,310 x 1.75 = $214,100

2.1.3 Road repair
Tafagamanu Point: 14,200 lf x $19.95/lf = $283,300
Breakers Point: 15,700 lf x $19.95/lf = $313,200

2.2 Outfall

2.2.1 Trenching in coral
500 lf x $11.30/lf x 1.75 = $9,900

2.2.2 Connecting weighting, sinking outfall
Equipment: $4,000/day x 20 days = $80,000
Crew: 10 x $200/day x 20 days x 1.75 = $70,000

3 DEMOBILIZATION

3.1 Pipeline

3.1.1 Tug and barge
$6,500/day x 28 days = $182,000

3.1.2 Load and unload barge
$4,000/day x 2 days = $8,000

3.1.3 Ship equipment
410 units x $144/unit = $59,100

3.2 Outfall

3.2.1 Tug and barge
$6,500/day x 19 days = $123,500

3.2.2 Load and unload barge
$4,000/day x 1 day = $4,000

4 BOND AND INSURANCE

1.5 percent of mobilization and demobilization

5 CONTINGENCY

30 percent of Items 1 through 4

UNIT COSTS

Tug and barge
Underway @ $6,500/day
Standby @ $4,000/day
Load and unload @ $4,000/day

Shipping (California to Samoa)
Container @ $3,300/each (20-foot)
Revenue ton @ $130/ton or 40 cu ft
Terminal charge @ $12/ton or 40 cu ft
Wharfage @ $2/ton or 40 cu ft
Length charge over 19 feet @ $6/6 feet

Air travel
California to Samoa = $1,500 per trip
Hawaii to Samoa - $800 per trip

Per diem @ $125/day

Samoa factor on labor @1.75

Pipeline Unit Costs

	6"	12"	18"
PVC (20-foot lengths)	DR 18	DR 18	DR 25
West coast cost[a]	$16.31/lf	$23.72/lf	$36.44/lf
Samoa cost[b]	$29/lf	$42/lf	$64/lf
Pipe cost[c]	$7/lf	$14/lf	$25/lf
Installation cost[d]	$22/lf	$28/lf	$39/lf
Pipe weight, lb/ft	5.2	19.9	32.9
DI (20-foot lengths)	Class 52	Class 52	Class 52
West coast cost[a]	$19.70/lf	$28.60/lf	$41.90/lf
Samoa cost[b]	$35/lf	$50/lf	$74/lf
Pipe cost[c]	$12/lf	$20/lf	$32/lf
Installation cost[d]	$23/lf	$30/lf	$42/lf
Pipe weight, lb/ft	20.5	47.5	79.1
HDPE (40-foot lengths)	DR 11	DR 11	DR 11
West coast cost[a]	$18.42/lf	$30.10/LF	$46.11/lf
Samoa cost[b]	$33/lf	$53/lf	$81/lf
Pipe cost[c]	$4/lf	$14/lf	$28/lf
Installation cost[d]	$29/lf	$39/lf	$53/lf
Pipe weight, lb/ft	4.9	18.2	37.1
Pump station[e]	$112,310	$186,510	$122,310
Joint hardware	$55/each	$192/each	$385/each
Reinforced concrete weights[f]	16lb/lf	68lb/lf	166lb/lf
HDPE fusion welding			
Welds per day	16	14	12
	Technician @ $300/day		
	Machine @ $90/day		

Road resurfacing @ $11.40/lf x 1.75 = $19.95/lf

Contractor equipment

Backhoe (225)	@	15 tons, 10' x 25' x 8'	= 2,000 cu ft
Loader (930)	@	10 tons, 10' x 20' x 10'	= 2,000 cu ft
Dozer (D4)	@	15 tons, 10' x 20' x 7'	= 1,400 cu ft
Loader/hoe (580)	@	6 tons, 8' x 15' x 6'	= 720 cu ft
Trucks (2 each)	@	20 tons, 2 (8' x 25' x 10')	= 5,000 cu ft
Asphalt batcher	@	3 tons, 15' x 20' x 15'	= 4,500 cu ft
Asphalt layer	@	2 tons, 10' x 12' x 6'	= 720 cu ft
Total		71 tons	16,340 cu ft
Round to		100 tons	410 units

[a]D. Van Kirk, CH2M HILL, August 30, 1990. Includes pipe purchase, trenching (hard to 4 to 6 feet), labor, backfill.
[b]West coast cost x 1.75 and rounded up to the whole dollar.
[c]West coast purchase price.
[d]Includes trenching (hard to 4 to 6 feet), labor, backfill.
[e]From marine pipeline option cost comparison, Item 5.
[f]Concrete @160 lb/ft^3, $250/yd^3 = $9.26/ft^3 = $0.06/lb.

APPENDIX E-3

Diffuser

APPENDIX E-3: DIFFUSER

		6"	12"	14"	18"
1	Material Purchase				
1.1	Pipe SDR11 120 ft	$ 480	$ 1,680	$ 2,029	$ 3,360
1.2	Contractor markup and handling (10%)	48	168	203	336
1.3	Flanges and slip rings for 62 joints	220	770	930	1,540
1.4	End gate	230	440	550	860
1.5	Concrete weights	719	472	792	1,153
		$ 1,697	**$ 3,530**	**$ 4,504**	**$ 7,749**
2	Mobilization and Demobilization (included in pipeline costs)				
3	Diffuser Fabrication				
3.1	Fusion of joints and flange adapters	$ 390	$ 435	$ 500	$ 500
3.2	Bore ports	460	880	1,100	1,720
3.3	End gate	230	440	550	860
		$ 1,080	**$ 1,755**	**$ 2,150**	**$ 3,080**
4	Installation in Samoa				
4.1	Connecting, weighting, sinking diffuser	$ 12,585	$ 12,585	$ 12,585	$ 12,585
4.2	Per diem	652	625	625	625
Subtotal		$ 16,014	$ 18,495	$ 19,864	$ 24,039
Contingency		4,800	5,500	6,000	7,200
Rounded Total		$ 20,800	$ 24,000	$ 25,800	$ 31,200
Rounded Unit Cost		$ 173/ft	$ 200/ft	$ 215/ft	$ 260/ft

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APPENDIX F

PERMITTING INFORMATION

F-1 Environmental Assessment Information Questionnaire, Department of the Army, U.S. Army Engineer District, Honolulu (Attachment for the Corps 404 Permit Application)

F-2 Letter of July 6, 1990, from the American Samoa Government Environmental Protection Agency, Concerning Federal and Local Permit Requirements for Ocean Outfalls

F-3 Land Use and Building Permit Application to the American Samoa Government Coastal Management Program Development Planning Office (A Local Permit Requirement for an Ocean Outfall)

F-4 Letter of December 27, 1990, from the American Samoa Government Coastal Management Program Economic Development Planning Office, Concerning the Requirement for an Environmental Impact Assessment for a Decision on the Land Use and Building Permit

APPENDIX F-1

Environmental Assessment Information Questionnaire,
Department of the Army, U.S. Army Engineer District,
Honolulu.
(Attachment for the Corps 404 Permit Application)

DEPARTMENT OF THE ARMY
U. S. ARMY ENGINEER DISTRICT, HONOLULU
FT. SHAFTER, HAWAII 96858-5440

REPLY TO
ATTENTION OF

Operations Branch

A complete Department of the Army Permit Application consists of the application form (Eng Form 4345), drawings, and environmental information. Based on our past experiences, the District Engineer has discovered that the necessary environmental information is often lacking when the application is submitted. As a result, delays in processing the permit application sometimes occur. In order to provide prompt processing of your permit application and thereby reduce the possibility for delays, the following questionnaire was developed to simplify your submittal of environmental assessment information.

If you should decide to answer these questions, please provide only that information that applies to your proposed project, using readily available information and answering the questions as best you can. The more information you provide, the quicker we can process your application.

Name of Applicant: _____

Prepared by: _____

Date: _____

A. **PROJECT DESCRIPTION** (Submit drawings)

1. WHAT IS THE BASIC PURPOSE OF YOUR PROPOSAL?

_____

_____

Project Location: _____

Waterbody Affected: _____

2. DO YOU PLAN TO DREDGE ANYWHERE IN THE WATER? _____

If so,

a. Where do you plan to dredge? _____

b. What type of material will be dredged? _____

_____

c. How long do you plan to dredge? _____

d. How much material will be dredged? _____

Volume _____

Area of Dredging _____

e. What methods will be used? _____

_____

f. Where do you plan to dispose of the dredged material? _____

_____

3. DO YOU PLAN TO DISCHARGE DREDGED OR FILL MATERIAL INTO WATER AREAS, INCLUDING WETLANDS?

a. What is the purpose of the discharge? _____

_____

b. Where do you plan to discharge the material? _____

_____

c. What is the source of the fill material? _____

d. What is the type and composition of the fill material? _____

_____

e. How much material will be discharged?

Area _____

Volume _____

f. How long do you plan to discharge? _____

g. What is the method of discharge? _____

_____

h. What types of structures or facilities would be constructed on the fill area? (Show on drawings their dimensions, layout, etc.). _____

_____

_____

4. DO YOU PLAN TO TRANSPORT DREDGED MATERIAL FOR THE PURPOSE OF DISPOSING IT IN THE OCEAN? _____

a. Where do you plan to dispose of the dredged material? _____

b. How much material will be disposed? _____

c. What is the type and composition of the material? _____

_____

d. How long do you plan to dispose of the material? _____

e. How will you transport the material to the ocean dump site? _____

_____

5. DO YOU PLAN TO CONSTRUCT ANY STRUCTURES IN THE WATER? If so,

a. What specific structures will be constructed (type and size)? _____

_____

_____

b. What will the structures be used for? _____

_____

6. ARE THERE OTHER ACTIVITIES IN THE AREA SIMILAR TO YOUR PROPOSED ACTIVITY? _____

_____

B. ALTERNATIVES

1. LIST OTHER SITES WHICH MAY BE SUITABLE FOR THIS PROPOSAL AND INDICATE WHETHER THESE ARE OR COULD BECOME AVAILABLE TO YOU. If none, explain why. _____

_____

_____

2. IF YOUR PROJECT INVOLVES THE DISCHARGE OF FILL MATERIAL TO CONVERT WETLANDS OR SUBMERGED AREAS TO FASTLAND (DRY LAND), LIST OTHER EXISTING FASTLAND SITES WHICH ARE OR COULD BECOME AVAILABLE TO YOU. If none, clearly explain why. _____

_____

_____

_____

3. LIST OTHER METHODS OF PROJECT DESIGNS WHICH WOULD FULFILL THE BASIC PURPOSE OF YOUR PROPOSAL. WHICH ONES ARE REASONABLE FOR YOU? If none, explain why. _____

_____

_____

_____

4. IF YOUR PERMIT APPLICATION WERE DENIED, WHAT OTHER ALTERNATIVES WOULD YOU HAVE? _____

_____

C. **EXISTING ENVIRONMENT** (submit photos if available)

1. PHYSICAL ENVIRONMENT

a. How would you generally describe the project area and surrounding area?

Level of development: _____

_____

Existing land and water use: _____

_____

Other general features: _____

_____

b. What kind of substrate (ground) is found at the project site? _____

_____

c. What is the range of water levels which occur (during normal tides and during storm or flood periods) at the project site? _____

_____

d. Describe the water currents and water circulation patterns at the project site.

_____

e. What is the salinity (salt, brackish, or fresh) of the water at the project site?

_____

f. What is the quality of the water at the project site? _____

_____

_____

g. Is this area a groundwater recharge area? _____

h. What is the history or possibility of contaminants/pollutants in the substrate (soil) at the source of fill material? _____

_____

i. Have there been problems with erosion at or near the project site? _____

_____

j. Is the project site located in or near a drainageway of flood plain? _____

If yes, describe. _____

k. What is the quality of the air at the project site? _____

l. What are the existing noise levels at the project site? _____

2. BIOLOGICAL ENVIRONMENT (attach biological survey reports, if available)

a. What kinds of plants are mainly found at or near the project site?

_____

_____

_____

b. What kinds of animals are mainly found at or near the project site?

_____

_____

_____

c. Please list any plants or animals found at or near the project area that are considered rare or otherwise important. _____

_____

3. SPECIAL SITES. IS THE PROJECT SITE LOCATED AT OR NEAR ANY OF THE FOLLOWING AREAS? (Show on vicinity drawings the extent of the special sites, if they are present, clearly labeling each type.)

	Dredge Site	Discharge Site	Const. Site
a. Sanctuaries and Refuges (protected wildlife area)	_____	_____	_____
b. Wetlands (swamps, marshes, bogs)	_____	_____	_____
c. Mudflats	_____	_____	_____
d. Vegetated Shallows (seagrass bed)	_____	_____	_____
e. Coral Reefs	_____	_____	_____
f. Riffle and pool complexes	_____	_____	_____

4. HUMAN USE CHARACTERISTICS

a. What is the existing land use zoning for the site and its vicinity?

_____

_____

_____

b. What is on the land (including dwellings, facilities, etc.) at or near the site?

_____

_____

_____

c. Do any of the following occur at or near the site?

	Dredge Site	Discharge Site	Const. Site
Local fresh water supply	_____	_____	_____
Fishing (recreational, commercial)	_____	_____	_____
Scenic areas	_____	_____	_____
Agriculture (type)	_____	_____	_____
Aquaculture (type)	_____	_____	_____
Historic sites (type)	_____	_____	_____
Other cultural resources (type)	_____	_____	_____
Parks, monuments, preserves, etc.	_____	_____	_____
Other (type)	_____	_____	_____

D. ENVIRONMENTAL EFFECTS

Briefly describe the environmental effects which may be expected as a result of your proposal, referring to the items listed in Section C Above.

1. PHYSICAL ENVIRONMENTAL (effects on land, water, air, soil, etc.)

_____

_____

_____

2. BIOLOGICAL ENVIRONMENTAL (effects on plants, animals, and habitats)

_____

_____

_____

3. SPECIAL SITES (effects on parks, ruins, monuments, etc.)

_____

_____

_____

4. HUMAN USE (how existing human activities would be affected)

_____

_____

_____

5. INDIRECT IMPACTS (Will the project eventually encourage or discourage residential, agriculture, urban, industrial, or resort activities?)

_____

_____

_____

6. CUMULATIVE IMPACTS (Is this project similar in purpose, characteristics, and location compared to previous projects? Will this project lead to or be followed by similar projects?)

_____

_____

_____

7. OTHER IMPACTS

_____

_____

_____

E. MITIGATION

What can you do to minimize adverse effects of your proposal on the environment?

_____

_____

_____

F. COORDINATION WITH OTHERS

List any agencies, organizations, or individuals with whom you have consulted regarding environmental concerns and other permit requirements.

_____

_____

_____

G. ADDITIONAL INFORMATION

Use this space to provide additional comments or to complete your response to items above (indicate item number).

_____

_____

_____

_____

_____

Thank you for your cooperation in this matter. If you have any questions, please contact the Corps of Engineers, Operations Branch at (808) 438-9258 in Honolulu or at (671) 344-5203 in Guam.

APPENDIX F-2

Letter of July 6, 1990 From the American Samoa Government, Environmental Protection Agency concerning federal and local permit requirements for ocean outfalls.

AMERICAN SAMOA GOVERNMENT
PAGO PAGO, AMERICAN SAMOA 96799
OFFICE OF THE GOVERNOR
ENVIRONMENTAL PROTECTION AGENCY

In reply refer to:
Serial: 291

July 6, 1990

Norman Wei
Star Kist Seafood Company
180 East Ocean Blvd.
Long Beach, California 90802

Dear Norman:

I received your memo dated July 6, 1990 with regard to a request for information on a copy of the waste load allocation model for Pago Pago Harbor and the permitting requirements for an ocean outfall. I have informed Charles Chamberlin of Hydro Resources International that he may release a copy of the water quality model to you.

The permitting requirements federally and locally are as follows:

Local Requirements

1. A mixing zone approval must be obtained from the Environmental Quality Commission (EQC). The procedure is contained in the draft Water Quality Standards which we expect to be finalized by July 30, 1990. When feasible, you may submit a letter of intent to apply for a mixing zone. This communication may be addressed to Pati Faiai, Executive Secretary, EQC.

2. A land use permit must be obtained from the American Samoa Coastal Management Program (ASCMP). It is likely the ASCMP will hold a scoping meeting to cover local requirements and let you know early in the permit process. Forms and procedure are available through:

   Lelei Peau, Manager
   American Samoa Environmental Protection Agency
   Development Planning Office
   American Samoa Government
   Pago Pago, American Samoa 96799
   (684) 633-5155
   Fax (684) 633-4195

3. A costal zone consistency certification will be necessary and information on this procedure may be obtained from the above address of the ASCMP.

4. A water quality certification from the EQC will be required and would be issued concurrent with the land use permit. Procedures are also contained in the draft Water Quality Standards. This may be addressed to Pati Faiai, Executive Secretary, EQC.

Federal Requirements

1. A permit for dredging and/or construction in navigable waters must be obtained from the U.S. Army Corps of Engineers (USACOE). I suggest you contact the following individual.

   Stanley Arakaki
   U.S. Army Corps of Engineers
   Honolulu District
   Bldg 230
   Fort Shafter, HI 96858

   The USACOE requires that you obtain the water quality certification and coastal zone consistency certification prior to issuance of a permit. It is preferable that the local land use permit is also in place.

2. If you change the location of your discharge point, you must obtain a modifacation of your National Pollutant Discharge Elimination System (NPDES) permit from the U.S. Environmental Protection Agency (USEPA). This requires the same water quality certification and coastal zone consistency described above the obtained prior to permit issuance. As your permit will expire in March, 1992, you must reapply to USEPA 180 days prior to permit expiration. It is likely you could combine these processes. Pat Young of the USEPA Region 9 Office of Pacific Island and Native American Programs at (415) 556-5069 can provide you with guidance on the proper contact person within their office.

An environmental assessment (EA) may be necessary for the local land use permit and/or the USACOE permit. The need for an EA for the land use permit will depend upon the alternative chosen. I am unsure of the criteria the USACOE uses to determine whether an EA is necessary. You may contact me for further assistance in any of these areas.

Sincerely,

Sheila Wiegman
Environmental Coordinator
American Samoa Environmental
Protection Agency

cc: Manager, ASCMP
Pat Young, USEPA
Environmental Coordinator
Enforcement Branch, ASEPA

APPENDIX F-3

Land Use and Building Permit Application to the American Samoa Government Coastal Management Program, Development Planning Office.
(A local permit requirement for an ocean outfall)

GOVERNMENT OF AMERICAN SAMOA
COASTAL MANAGEMENT PROGRAM
DEVELOPMENT PLANNING OFFICE

LAND USE & BUILDING PERMIT APPLICATION

NAME of person applying for permit: _____

MAILING ADDRESS: _____

PHONE NUMBER: _____

CERTIFICATE OF LAND OWNERSHIP

I _____ hereby certify that I am the owner of the land described in this permit application and grant permission to use the land as proposed.

_____ _____
(Signature of owner or matai, if communal land) *(Date)*

SITE INFORMATION

The land identified in this application is in which village and county?

_____ _____
(Village) *(County)*

The description of the land is? _____

_____

_____

COMPLETED BY DPO/DPW

T MAP NUMBER_____ AREA (Sq. ft.)_____
T MAP COORDINATES_____
PHYSICAL BOUNDARIES_____
_____
_____
SURVEYOR REFERENCES to LAND_____
_____
_____

The land identified in this application is: _____ GOVERNMENT _____ CHURCH _____ FREEHOLD _____ INDIVIDUALLY OWNED _____ COMMUNAL LAND
The Land Title is: ____ REGISTERED _____ NOT REGISTERED

VERIFICATION of LAND OWNERSHIP

Ownership of the land described by this permit application, as stated in the certificate of Land Ownership, is verified:

_____ _____
PULENU'U of:

_____
SECRETARY OF SAMOAN AFFAIRS

The ownership of the land described by this application is incorrect for the reasons described by the Secretary of Samoan Affairs: _____
_____
_____
_____

GOVERNMENT AUTHORITY

I declare that the property described in this application is owned and/or controlled by the Government of American Samoa. The department or agency proposing the use of the property as described below, has been authorized by me to undertake such action.

_____ _____

Governor of American Samoa *Date*

PROPOSED ACTIVITY

Describe what is to be built or done on the land: _____

_____

_____

_____

Check which activity listed below describes proposed action:

___ NEW CONSTRUCTION	___ EXCAVATION	___ PAVING
___ REPAIR	___ DREDGING	___ MINING
___ DEMOLITION	___ FILL	___ DRILLING
___ REMOVAL	___ GRADING	___ UTILITY INSTALLATION
___ EXTENSION	___ OTHER/DESCRIBE _____	

What type of structure(s) will be built? _____

Will it be for RESIDENTIAL use? What type? _____

COMMERCIAL use? What type? _____

DO YOU HAVE A BUSINESS LICENSE? YES NO If YES, number _____

INDUSTRIAL use? What type? _____

OTHER? _____

Expected start of project _____ Expected completed _____

Is any of the work underway or completed? _____ If 'YES' provide an explanation why and give starting/ending dates. Show what was done on the plans submitted with this application.

You are required to submit a site and location plan with this application.

☐ PLANS, SITE PLANS, SPECIFICATIONS ATTACHED

ESTIMATED VALUE OF WORK? _____ ASSESSED BY DPW

LAND USE COMPLIANCE

PRESENT LAND USE BY CODE ☐

FUTURE LAND USE BY LAND USE AND CODE ☐ ☐

FLOODPLAIN CHECK ☐

IS PROPOSED USE IN COMPLIANCE ☐

IS A ZONING CHANGE REQUESTED? TO WHAT? ☐

IS A VARIANCE REQUIRED? To allow _____

DATE REFERRED TO ZONING BOARD _____

DATE OF ZONING BOARD ACTION _____ APPROVED ☐ DISAPPROVED ☐

ZONING BOARD PERMISSION TO PERFORM THE WORK, DESCRIBED ABOVE, IS GRANTED:

_____ _____

CHAIRMAN *DATE*

COMPLETED BY DPO

Who will be doing the work?

Architect or Designer: _____ _____

Address/Phone No.: _____ _____

License No. _____

Engineer: _____

Address/Phone No.: _____

License No. _____

Contractor: _____

Address/Phone No. _____

License No. _____

Self-Built — You must conform to the Uniform Building Codes and your work will be inspected by the Dept. of Public Works.

Galuega ua fausiaina e oe. — E tatau ona e mulimuli pe tausisi i le tusi tulafono i mea tau fale ma o lau galuega o le a asiasiina pe su'esu'eina e le Ofisa o Galuega Lautele.

NOTICE

This is NOT a permit authorizing any building or physical work to be started on the property. This is an <u>Application</u> for a Land use permit. This application is subject to review by various departments within the American Samoa Government.

FA'AALIGA

E le'o se pemita lenei e fa'atagaina ai so'o se fale po'o se galuega fa'atino o le a amataina i luga o le laueleele. O lenei pepa o se talosaga mo se pemita mo eleele fa'aaoga. O lenei pepa talosaga e tatau ona iloilo e Matagaluega eseese o le Malo o Amerika Samoa.

CERTIFICATION

I certify that I am authorized to make this application on behalf of the owner of the property described. I have read this entire application and understands the contents. All of the information provided is true. Employees and representatives of the American Samoa Government are authorized to enter upon the property and inspect it and any permit or license issued according to this application.

FA'AMAONIGA O LE TALOSAGA

Ua ou sapasapaia o a'u ua fa'atonuina e faia lenei talosaga i le va lelei ma le e ona le eleele ua fa'amatalaina. Ua ou faitauina lenei talosaga i lona tino atoa ma malamalama i ona fuaitau. O fa'amatalaga uma ua folasia ua tonu. O tagata faigaluega ma sui o le Malo o Amerika Samoa ua fa'agafua e ulu atu i luga o lenei laueleele ma su'esu'e iai mo so'o se pemita po'o se laisene tu'uina atu e tusa ai ma lenei talosaga.

_____ _____

(Signature) *(Date)*

DPO USE ONLY

Application accepted by: _____ _____

(CRO) *(Date)*

Revenue Office Receipt No. _____ indicating payment of Application fees ($) and $_____ assessed by the Building Branch of Dept. of Public Works.

American Samoa
Power Authority

In reply refer to:

PROTECT YOUR DRINKING WATER
ITS THE LAW

TECHNICAL INFORMATION FACT SHEET

If your area is served by ASPA "Public Sewer", the site plan must show the nearest sewer mains and manholes.

1. All sewers from buildings which stand within 300 feet of any public sewers must be connected unless specifically exempted by ASPA-WASTEWATER.

2. Applications for connecting to the "Public Sewer", along with water and power are available at ASPA's customer service office in the Pago Plaza.

3. For further information contact ASPA-WASTEWATER.

If "Public Sewer" is not available, an alternate method of sewage disposal is required.

If a septic tank system is to be installed: the septic tank and drain field design, site plan location, construction method and materials must be submitted for review and approval to the Environmental Health Office, DIVISION OF PUBLIC HEALTH (DPH), before you submit your plans to DPW for a building permit. Standard septic tank plans must be adopted to your specific site location. Additional design information is available from ASPA-WASTEWATER.

THE ASG CODE REQUIRES

A Septic Tank is a water tight receptacle which receives the discharge of untreated sewage and is designed and constructed so as to retain solids, digest organic matter through a period of detention, and allow the treated liquids to discharge into an external leaching field or seepage pit.

The septic tank and drainfield must conform to the recommendations set forth in the latest edition of the U.S. Public Health Service Publication No. 526 "Manual of Septic Tank Practice."

The "Standard Septic Tank System For Houses" in American Samoa, Drawing No. 83004, dated 7-30-85 currently conforms to the above publication no. 526, and is available from DPW.

Cesspools are excavations which receive raw liquid sewage. Cesspools by design, allow sewage to seep into e underlying rock formation and pollute the groundwater. Although, these have been installed in American Samoa for years, instead of Septic Tank systems, Cesspools are not approved for American Samoa, and are against the law.

APPENDIX F-4

Letter of December 27, 1990 from the American Samoa Government, Coastal Management Program, Economic Development Planning Office concerning the requirement for an Environmental Impact Assessment for a decision on the Land Use and Building Permit.

AMERICAN SAMOA GOVERNMENT
PAGO PAGO, AMERICAN SAMOA 96799

In reply refer to:

ECONOMIC DEVELOPMENT PLANNING OFFICE
AMERICAN SAMOA COASTAL MANAGEMENT PROGRAM

December 27, 1990

CZM/ECD
Serial : 1089

Mr. Dave Simpson, P.E
Coastal Engineer
Ch2M HILL
777 108th Avenue, N.E.
P.O. Box 91500
Bellevue, Washington 98009-2050

YOUR REFERENCE: PDX307002.EN.EP

Dear Mr. Simpson:

Thank you for your query dated November 14, 1990 regarding permit requirements for a proposed extension to the existing Starkist Cannery outfall in Pago Pago Harbor. The Review Agencies of the Project Notification and Review System (PNRS) met on December 19, 1990 to discuss the proposal and to determine the necessary permits and best course for ensuring that all environmental impacts are addressed for a final permit decision. Mr. Ross Flemming from Starkist Samoa was in attendance at that meeting. I would like to provide guidance on local and some federal permitting requirements and information necessary for processing these permits.

It is the unanimous consensus of the PNRS Committee that an Environmental Impact Assessment will be required to make a decision on a Land Use Permit for the proposed project. The EIA should include all information necessary to address the construction and operation related impacts on land and water. The information needed to qualify for a mixing zone and water quality certification from the Environmental Quality Commission (EQC) should also be submitted and may be contained within the EIA. In particular, the EIA should contain, at a minimum, the following:

1. Description of the project and setting
   a. Purpose
   b. Location
   c. Actions the project will entail
   d. Permits required

2. Description of the existing related environment
   a. Physical and hydrological conditions
   b. Existing related infrastructure
   c. Biological aspects

d. Land use as applicable
e. Unique features

3. Alternatives reviewed and rationale for preferred alternative

4. Estimate the nature and magnitude of environmental changes caused by the project (including criteria used)
   a. Construction impacts during development
   b. Long term impacts directly caused by the project or through secondary effects
   c. Cumulative impacts

5. Mitigative measures for adverse impacts
   a. Short term
   b. Long term

The mixing zone and water quality certification application must provide information to show that the following conditions are met:

1. Dimensions and location of zone of mixing
2. The zone of mixing is in the public's best interest
3. The proposed discharge does not endanger human health or safety
4. Compliance with existing water quality standards at the point of discharge would produce serious economic hardships without equal or greater benefit to the public
5. Alterations generated by a proposed discharge do not disrupt the marine ecology of the receiving waters outside the zone of mixing
6. The water quality standards contained in 24.0207(a)(1)-(4), ASAC, must be met within the zone of mixing
7. Applicable water quality standards cannot be violated outside the proposed zone of mixing
8. The outfall and diffuser system must achieve the desired dispersion and assimilation in the receiving waters at worst case receiving water and transport conditions.

Most of the above required information has been previously obtained and should be cited. As the mixing zone is essential to the project, the various conditions to qualify for a mixing zone could be addressed in the EIA sections on project description and environmental changes caused by the project.

There are other federal requirements that you should be aware of in addition to those of the U.S. Environmental Protection Agency and the U.S. Army Corps of Engineers. Requirements under Section 106 of the National Historic Preservation Act will need to be met. For specific information on local archaeological site review and preservation requirements you may write directly to the Historic Preservation Officer, c/o Department of Parks and Recreation, American Samoa Government, Pago Pago, American Samoa, 96799; or call (684) 699-9614. For information regarding port requirements (local or federal) you may write Mr. Leroy Ledoux, Director, Port Administration, American Samoa Government, Pago Pago, American Samoa, 96799; or call (684) 633-4251.

The U.S. Coast Guard will review application for a U.S. Army Corps of Engineers permit. We are informed that Pago Pago Harbor has no "designated anchorages" that will require special consideration for your proposed project. However, you may want to send a description of your project to the following address for preliminary review and comment: Commander (OAN), 14th Coast Guard District, PJKK Federal Building, 300 Ala Moana Blvd., Honolulu, Hawaii 96850-4982, (808) 541-2319, Attention: Commander Henry Motekitis

Please note that territorial review of a Land Use Permit Application for a major project such as this generally requires a minimum of thirty (30) working days, not including delay time necessitated by a Public Hearing. A Public Hearing to gather comment on the EIA will be required, and a qualified representative of the project proponent should be available to describe the project and answer any concerns.

I hope that this information is helpful. Please do not hesitate to give either myself or Richard Volk a call (684-633-5155) if you have any further questions. Our FAX number is (684) 633-4195.

Lelei Peau
PNRS Chairman
ASCMP Manager

LP:RV

cc: Dyke Coleman, Chairman, EQC
Pati Fai'ai, Secretary, EQC/ASEPA
Lydia Faleafine, Director, EDPO
Richard Volk, ASCMP
David Herdrich, Territorial Archaeologist
Sheila, Wiegman, ASEPA
Leroy Ledoux, Director, Port Administration
Maurice Callaghan, Starkist
Norman Wei/Starkist
Virginia Gibbons, A.G.'s Office