United States
Environmental Protection Agency
Region 10
1200 Sixth Avenue
Seattle, Washington 98101

Total Maximum Daily Load (TMDL) for Biochemical Oxygen Demand (BOD_5) in the Waters of Akutan Harbor, Alaska

In compliance with the provisions of the Clean Water Act, 33 U.S.C. § 1251 et seq., as amended by the Water Quality Act of 1987, P.L. 100-4, the Environmental Protection Agency is hereby establishing a TMDL to limit discharges of biochemical oxygen demand to the waters of Akutan Harbor, Alaska.

This TMDL shall become effective immediately, and is incorporated into the water quality management plans for the state of Alaska under Clean Water Act § 303(e). Subsequent actions must be consistent with this TMDL.

Signed this 12th day of Feb, 1995.

Charles E. Findley
Charles E. Findley, Director
Water Division

Total Maximum Daily Load for

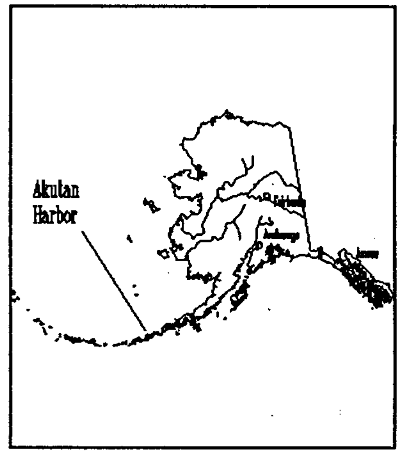
Biochemical Oxygen Demand

in the Waters of

Akutan Harbor, Alaska

TMDL AT A GLANCE:

Water Quality-Limited?	*Yes*
Segment Identifier:	*30102-604*
Standard of Concern:	*Dissolved oxygen*
Pollutant of Concern:	*Biochemical oxygen demand*
Primary Use Affected:	*Aquatic life*
Sources:	*Trident Seafoods and Deep Sea Fisheries*
Loading Capacity:	*149,100 lbs/day BOD5*
Deep Sea Fisheries WLA:	*1,000 lbs/day BOD5*
Trident Seafood WLA:	*133,200 lbs/day BOD5*
Margin of Safety:	*14,900 lbs/day BOD5*
Technical Basis for TMDL:	*"Environmental assessment of Deep Sea Fisheries shore plant and cumulative effects of seafood processing in Akutan Harbor" (EPA 1993); "Akutan Harbor water quality study" (Tetra Tech 1993); "Impacts of Trident Seafoods on the dissolved oxygen resources of Akutan Harbor" (EPA 1995)*



Background

Section 303(d)(1)(C) of the Clean Water Act (CWA) and the U.S. Environmental Protection Agency's (EPA) implementing regulations (40 CFR Part 130) require the establishment of Total Maximum Daily Loads (TMDL) for waters for which the technology-based controls required by Section 301 of the CWA or other legally required pollution control mechanisms are inadequate to ensure the achievement of state water quality standards. A TMDL is an implementation plan which identifies the degree of pollution control needed to attain and maintain compliance with state water quality standards using an appropriate margin of safety (EPA 1991). The focus of the implementation plan is the reduction of pollutant inputs to a level (or "daily load") that will meet the water quality standard and thus fully support the beneficial uses of a given waterbody. The mechanisms used to address water quality problems through the TMDL process can include effluent limits, best management practices and monitoring requirements in National Pollutant Discharge Elimination (NPDES) permits.

The State of Alaska has identified Akutan Harbor as being water quality-limited for seafood wastes in its 1992 303 (d) list. A major component of seafood wastes is organic matter which, when metabolized by microorganisms in the receiving water, leads to the consumption of dissolved oxygen (DO). This component is called biochemical oxygen demand (BOD). The magnitude of the oxygen demand associated with any discharge of organic wastes is generally described by two characteristics of the discharge. One of these is the BOD of the waste. It is widely accepted practice to quantify this demand in terms of a 5-day test of the oxygen demand of a waste, and the quantity so determined is defined as 5-day biochemical oxygen demand (BOD5). The second characteristic of the discharge which can represent oxygen demand is the DO concentration of the discharge. If the DO of the discharge is below that of the receiving water there is an oxygen demand, since additional DO is required to return the receiving water to its original concentration. When the DO of the effluent is greater than the receiving waters, the excess in DO can reduce the impact of the BOD5 in the effluent. Determinations of the total demand on DO of the receiving water must, therefore, account for both the BOD and DO of the discharge.

EPA Region 10 has conducted studies of water quality of Akutan Harbor (EPA Region 10, 1993; Tetra Tech, 1993; EPA, 1995). As a result of these studies, EPA Region 10 has concluded that the oxygen demand associated with the discharge of BOD5 from seafood processing contributes significantly to levels of DO below the applicable State of Alaska's water quality criterion of 5.0 mg/l at depth and 6.0 mg/l in the surface waters. Based on the water quality assessment of low DO in Akutan Harbor, a TMDL is established for BOD.

Loading Capacity and Wasteload Allocation

Loading Capacity

The capacity of Akutan Harbor to assimilate a BOD5 loading is dependent not only on the oxygen demand of point sources and nonpoint sources, but also the mixing properties of the receiving waters. The loading capacity for Akutan Harbor is defined in terms of both BOD5 and DO. It is also important to note that the loading capacity of Akutan Harbor is determined by the specific location of all discharge(s). This is because organic waste discharged into waters such as Akutan Harbor does not exert its entire demand instantaneously, but does so over a period of several days. Therefore, the impact on DO from waste discharge at any specific location will be determined by the transport and mixing of the waste during the period in which its oxygen demand is exerted. Because of this dependence on the location of the discharge(s), the loading capacity determined for this TMDL is inextricably bound to the locations associated with the existing discharges from Trident Seafoods and the two facilities operated by Deep Sea Fisheries. However, a different loading capacity, either greater or smaller than the one specified in this TMDL,could result by changing the location of any existing or proposed discharge(s). In addition to being determined by the specific location of existing discharges, the loading capacity was assessed by a modeling scenario in which mixing characteristics of the receiving waters were assumed to be similar to those observed during the 1993 water quality study conducted by EPA Region 10 (Tetra Tech, 1993). These data were used to develop a conceptual model of the fate and effect of BOD in Akutan Harbor. The mathematical model used in developing the TMDL for BOD was based on the following assumptions:

* Oxygen demanding wastes associated with the various seafood processing streams from each source are aggregated into a single category with uniform oxygen-demanding characteristics.

* The discharges from all sources reach equilibrium at a water depth determined from the application of a near-field dilution model. Based on the application of a near-field dilution model to existing data, this depth is estimated to be approximately 29 meters in the summer and 0 meters in the winter.

* Transfer of oxygen across the air-water interface is due to wind stress only.

* Rates of vertical and horizontal eddy diffusion are constant and can be computed from the results of studies conducted in Akutan Harbor (Tetra Tech, 1993) and other embayments.

* The circulation pattern in Akutan Harbor is in steady-state and can be described by a two-layer system with inflow at depths below 10 meters and outflow at the surface.

* Background BOD5 in the receiving waters is 1.5 mg/l based on results reported by Tetra Tech (1993).

* Levels of DO in all waste discharges are assumed to be 0 mg/l.

Results of the field studies conducted in September 1993 by EPA (Tetra Tech, 1993) were used to estimate important parameters for the mathematical model. Furthermore, comments received from the public were considered when estimating certain important parameters including the coefficients of eddy diffusivity and the reaeration rate. The mathematical modeling developed from these data (EPA, February, 1995), establishes a loading capacity of 149,100 lbs/day BOD5 for discharges to subsurface layers (25 to 30 meters depth) of Akutan Harbor at those locations where Trident Seafoods and Deep Sea Fisheries presently have permits to discharge.
This TMDLapplies only to the Summer season (May 1 - October 31). This is in addition to the background BOD loading of the coastal waters.

Wasteload Allocation

The BOD5 loading capacity of the subsurface layer of Akutan Harbor is allocated to the sources identified as contributing pollutant loads to that portion of the waterbody. In the case of Akutan Harbor, there are existing permits for the point sources, Trident Seafoods and two Deep Sea Fisheries facilities, the Deep Sea and the Clipperton. EPA Region 10 (EPA, 1993) has also received an application from Deep Sea Fisheries for a permit to discharge sea food processing wastes from a shore-based facility in Akutan Harbor.

In accordance with CWA §303(d)(1)(C) and federal regulations (40 CFR §130.7), a margin of safety was established to account for uncertainty in the data analyses. A margin of safety may be provided (1) by using conservative assumptions in the calculation of the loading capacity of the waterbody or (2) by establishing allocations that in total are lower than the defined loading capacity (so that the unalocated portion represents the margin of safety). In the case of the Akutan Harbor analysis, the latter approach was used to establish a safety margin. The following uncertainties were considered in establishing the margin of safety:

- Potential oxygen demand in the subsurface layer from the solids discharged by seafood processing facilities in the Harbor. Solid organic matter was observed throughout the inner portion of Akutan Harbor during September 1993 (Tetra Tech, 1993). As this material settles through the water column it represents a potential demand on DO. However, additional studies are required to determine rates of settling as well as rates of oxygen demand associated with these residues.

- Potential oxygen demand associated with organically rich bottom sediments. The extent of these sediments have been described qualitatively in various sources (EPA, 1993), but no comprehensive analysis of oxygen demand has been performed.

- Uncertainty about assumptions used in modelling the dissolved oxygen budget. Modeling results reported by EPA (1995) account for impacts on DO at depths less than 30 meters in the inner portions of Akutan Harbor, but do not account for impacts on DO observed at depth and at the end of Akutan Harbor. The under-prediction of impacts below 30 meters is approximately balanced by over-prediction of the horizontal extent of impacts above 30 meters.

Based on these uncertainties, 10% (14,900 lbs/day) of the BOD5 is allocated to the margin of safety which includes the effects of bottom sediments, the potential impacts of oxygen demand from settling residues and the inability of the mathematical model to account for all impacts on DO observed during the September 1993 study (Tetra Tech, 1993).

After providing for natural sources and an appropriate margin of safety, the allocation of the allowable wasteload to sources of pollution can follow one of three approaches: (1) equal allocations to all dischargers, (2) equitable allocations proportional to present or historical production of seafood products or discharges of pollutants, or (3) some other basis for allocation. The allocation for Akutan Harbor, for the Summer season (May 1-October 31) was based on historical considerations and equity. Analysis of BOD5 in the effluent (EPA, 1995) of Trident Seafoods waste discharge found that the median loading was 251,000 lbs/day of BOD5. The approximate BOD5 loading from the combined Deep Sea Fisheries facilities, as noted above, was less than 700 lbs/day during 1991 and 1992, when the facilities were in operation. Based on these estimates of historical levels, Deep Sea Fisheries was allocated 1000 lbs/day and Trident Seafoods was allocated 133,200 lbs/day of BOD5. The proposed allocation includes only those discharge locations for which there are existing NPDES permits: Trident Seafoods and the two Deep Sea Fisheries facilities. The proposed Deep Sea Fisheries shore-based facility was not included in the allocation because of the lack of certainty regarding the specific location of its discharge.

Based on comments received from the seafood industry, the allocation of DO for specific discharges was removed and the concentration of DO in all effluents was assumed to be 0 mg/l for purposes of the TMDL. The seafood industry commented that the specification of a minimum DO level places unnecessary restrictions on the discharge. This restriction is removed by assuming a DO of 0 mg/l in the discharge. Furthermore, it is conservative with respect to the allocation of BOD_5, since DO levels in the discharge greater than 0 mg/l will reduce the impact of the discharge on the DO of the receiving waters.

A recapitulation of the wasteload allocation for Akutan Harbor is given in the following table:

Source	BOD5 Allocation	(% of Total)	Minimum DO
Trident Seafood	133,200 lbs/day	(>89%)	0 mg/l
Deep Sea Fisheries	1,000 lbs/day	(<1%)	0 mg/l
Margin of Safety	14,900 lbs/day	(10%)	-

The allocation for Trident Seafoods and the Deep Sea Fisheries facilities should form the basis of the BOD5 limitations in the reissuance of any NPDES permits for either of these fish processing facilities.

No TMDL is established for the Winter season (November 1 - April 30) since the mathematical model predicts that water quality standards will be met at existing levels of BOD_5 discharge. These predictions are based on results of the studies conducted in

September 1993 and, therefore, do not necessarily reflect conditions representative of the Winter season. NPDES permits written for these water bodies should, therefore, include requirements of comprehensive monitoring programs during the Winter season when seafood processing is at or near maximum levels. The study design for such programs should include quality assurance programs approved by EPA.

References

U.S. Environmental Protection Agency. 1993. Environmental Assessment: Deep Sea Fishers Shore Plant and Cumulative Effects of Seafood Processing Activities in Akutan Harbor, Alaska. June 1993

U.S. Environmental Protection Agency. 1995. Impacts on the Dissolved Oxygen Resources of Akutan Harbor, Alaska. February, 1995.

Tetra Tech. 1993. Akutan Harbor Water Quality Study. Prepared for: U.S. Environmental Protection Agency Region X. September 1993

IMPACTS
ON THE
DISSOLVED OXYGEN RESOURCES
OF
AKUTAN HARBOR
ALASKA

Introduction

Akutan is an island within the Fox Island Group of the Aleutian Island chain approximately 35 miles east of Unalaska and 800 air miles west of Anchorage, Alaska. The island is of volcanic origin about 18 by 12 miles in size. The terrain of the island can be characterized as rugged with arctic-alpine vegetation below elevations of 1,000 feet. Akutan Peak, 4,275 feet above sea level, is the highest point. A sheltered bay, Akutan Harbor, on the east side of the island, provides protected waters for processing finfish and shellfish harvested by fishing vessels in Bristol Bay and the Bering Sea.

Water quality in Akutan Harbor has deteriorated due to substantial increases in seafood processing by floating processors in the Harbor and by the shore-based Trident Seafoods facility. As a result, the State of Alaska has designated Akutan Harbor as a water-quality limited segment with dissolved oxygen and benthic waste accumulations as the parameters of concern. The Clean Water Act requires that Total Maximum Daily Loadings (TMDL) be determined for those pollutants related to the parameters of concern. The analysis described in this report focuses on the determination of the TMDL for Biological Oxygen Demand, Five-Day (BOD_5), a parameter which affects oxygen levels in receiving waters such as Akutan Harbor.

Water Quality in Akutan Harbor

Several studies of the impact of seafood processors have been conducted in Akutan Harbor. Results of these studies have been reported by Jones & Stokes (1983), EPA (1984), Tetra Tech (1986) and EPA (1993). These studies have documented many aspects of the impacts of the seafood processing industry on Akutan Harbor including the loss of benthic habitat and the increase in pollution-tolerant species. However, none of the studies were performed while the seafood processors were working at full capacity. As a result, little was known about the impact of seafood processors on ambient water quality.

During the period September 3-8, 1993, the US. Environmental Protection Agency Region 10 (EPA) conducted an extensive field study of water quality in Akutan Harbor while the Trident Seafood facility was in full production. This was the first comprehensive study of water quality conditions during a period of high organic loading to the Harbor. The results of this study have been reported by Tetra Tech (1993) and form the basis for the determinations of the TMDL for BOD_5 in Akutan Harbor.

The study focused on the water quality of the Harbor and of the various effluent streams at the Trident Seafood facility. During the six-day study period, the following parameters were collected in the water column and from the various waste streams of the Trident Seafood facility:

Temperature
Conductivity/Salinity
Dissolved Oxygen
pH
Total Phosphorus
Ammonium-Nitrogen
Nitrate+Nitrite-Nitrogen
Total Kjeldahl Nitrogen
Total Organic Carbon
Oil & Grease
Total Suspended Solids
BOD (5-, 10-, 15-, 20-day)

In addition, a survey was conducted on September 7, 1993 for purposes of estimating the discharge of freshwater sources into Akutan Harbor. A number of drogues were also released on September 8, 1993 and tracked for a period of approximately one hour.

The complete set of data is presented in the report by Tetra Tech (1993). Data from the September 1993 study which have been particularly valuable in the development of this TMDL include temperature, salinity, dissolved oxygen and long-term BOD of the receiving waters and long-term BOD of the whole effluent from the Trident Seafoods facility.

The dissolved oxygen collected during the September 1993 study show that Akutan Harbor was experiencing substantial DO depressions as a result of organic loadings. Data stratified by day and by location either west of 165° 46' W (Inner Akutan Harbor) or east of 165° 46' W (Outer Akutan Harbor) are shown in Figures 1-5. DO in the Outer Harbor was approximately uniform from surface to bottom, generally varying from 80 to 90% of saturation. In the Inner Harbor, DO was generally less than 80% of saturation, with some values less than 30% of saturation. Impacts on DO of this magnitude occur only when there is a large organic loading to the system.

The only known source of organic loading to Akutan Harbor during the period of the field study was the Trident Seafood facility. The pollock processing season had begun just prior to the start of the field study. Based on a comparison of the results from the September 1993 study and information provided by the company in Discharge Monitoring Reports

(DMR's) for this period, the facility appeared to be operating at or near its normal capacity. As a result, the conceptual model for characterizing impacts of organic loading to Akutan Harbor during September 1993 was based on knowledge of the mixing characteristics of Akutan Harbor, the nature of organic loadings from the Trident Seafood facility and the nature of background organic loadings from the coastal region in the vicinity of Akutan Harbor. The conceptual model, used in conjunction with data collected during the September 1993 study, forms the basis for the TMDL for BOD in Akutan Harbor.

Conceptual Model

The conceptual model for estimating the impact of seafood processing on the dissolved oxygen (DO) has been developed from the results of several studies conducted in Akutan Harbor, as well as from studies of estuarine circulation in other parts of Alaska and the Pacific Northwest. From studies conducted in Akutan Harbor (Jones & Stokes, 1983; EPA, 1993), circulation patterns are influenced by wind stress during periods of moderate to high winds (10-20 meters/second). During periods of weak winds (less than 5 meters/second), numerical model simulations show that currents associated with wind-driven circulation are low (EPA, 1993). Based on studies of estuaries such as Silver Bay in Alaska. Alberni Inlet on Vancouver Island and the Strait of Juan de Fuca-Strait of Georgia system (Rattray, 1967); Hood Canal in Washington and Knight Inlet in British Columbia (Winter, 1973), gravitational convection can be an important component of the circulation during periods high freshwater runoff.

During EPA's September 1993 field study of Akutan Harbor, wind speeds were low and freshwater discharge was sufficiently high such that the Inner Akutan Harbor (West of 165° 46' W') had hydrographic characteristics of a fjord-like estuary. This is demonstrated by the relationship between temperature and salinity for hydrographic stations stratified according to day of observation and whether the station was west or east of 165° 46' W. Temperature-salinity (T-S) plots for September 3-7, 1993 for stations west of 165° 46' W. and stations east of 165° 46' W' are shown in Figures 6-10. With the exception of one observation made on September 5, 1993 (Figure 8), the stations east of 165° 46' W, the T-S diagrams show the water to be typical of coastal waters. T-S diagrams for stations west of 165° 46' W show the influence of coastal water at depth, but water is fresher and warmer on the surface. These are characteristics typically found in fjord-like estuaries (Rattray, 1967; Winter, 1973). Conditions of low wind stress and low tidal mixing, as was the case in Akutan Harbor during the September 1993 study, would lead to a circulation pattern of inflow of coastal water at depth and outflow of brackish water at the surface.

Based on this information, the conceptual model for circulation Akutan Harbor was taken to be that of steady-state, two-layer circulation driven by estuarine processes (gravitational convection) as shown schematically in Figure 11. In addition, the conceptual model includes diffusion-like mixing processes derived from the energy in tidal exchange and low-level wind stress.

For purposes of determining the impacts of the seafood processors on DO in Akutan Harbor, it is necessary to couple the physical mixing processes with the mass balance equations for DO and the oxygen demanding properties of the seafood waste. The accepted methods for developing mass balance equations of this kind are described by Ambrose et al (1991). The methods are based on the assumption that the oxygen-demanding properties of waste discharge can be described in terms of biological oxygen demand (BOD). In addition, important processes in the mass balance for BOD and DO are:

- Horizontal and vertical advection
- Horizontal and vertical diffusion
- Consumption of DO as microorganisms metabolize BOD in the water column
- Transfer of DO across the air-water interface (reaeration) by various processes including mixing due to wind stress
- Introduction of BOD from external sources such as seafood discharges
- Introduction of DO and BOD across boundaries between the Harbor and the open ocean

Invoking standard assumptions regarding turbulent fluxes and kinetics of BOD stabilization and DO reaeration, the appropriate equations for the mass balance of BOD and DO in Akutan Harbor are:

$$\begin{aligned}\frac{\partial L}{\partial t} = & -\frac{\partial}{\partial x}(U_x L) - \frac{\partial}{\partial y}(U_y L) - \frac{\partial}{\partial z}(U_z L) \\ & + \frac{\partial}{\partial x}\left(E_x \frac{\partial L}{\partial x}\right) + \frac{\partial}{\partial y}\left(E_y \frac{\partial L}{\partial y}\right) + \frac{\partial}{\partial z}\left(E_z \frac{\partial L}{\partial z}\right) \qquad (1) \\ & - k_1 L + S_L\end{aligned}$$

$$\frac{\partial C}{\partial t} = -\frac{\partial}{\partial x}(U_x C) - \frac{\partial}{\partial y}(U_y C) - \frac{\partial}{\partial z}(U_z C) + \frac{\partial}{\partial x}(E_x \frac{\partial C}{\partial x}) + \frac{\partial}{\partial y}(E_y \frac{\partial C}{\partial y}) + \frac{\partial}{\partial z}(E_z \frac{\partial C}{\partial z}) - k_1 L + S_C + k_2(C_{sat} - C) \tag{2}$$

where

L	=	concentration of BOD, mg/l,
C	=	concentration of DO, mg/l,
C_{sat}	=	saturation level of DO, mg/l,
t	=	time, seconds,
x,y,z	=	spatial coordinates, meters
E_x,E_y,E_z	=	longitudinal, lateral, and vertical coefficients of eddy diffusivity, meters^2/second,
U_x,U_y,U_z	=	longitudinal, lateral, and vertical velocities, meters/second,
S_L	=	source of BOD, mg/l/second,
S_C	=	source of DO, mg/l/second,
k_1	=	deoxygenation rate, seconds^{-1},
k_2	=	reaeration rate, seconds^{-1}.

Equations (1) and (2) are solved numerically using a finite difference method in which Akutan Harbor is idealized by a number of parallelepipeds, all of the same size. This grid was based on a bathymetric coverage developed and described in EPA (1993) and is shown in Figure 12. Each grid is 247 x 247 meters in the horizontal and 5 meters thick. Primary considerations in choosing the grid size were (1) ability to resolve important water quality features associated with the various discharges and (2) the need to keep required computer resources at a reasonable level. The plan of the grid used to define the horizontal extent of these segments is shown in

Figure 12. The vertical extent of the segmentation varies from location to location depending on the average water depth associated with the horizontal segmentation. Mass balances for BOD and DO are performed on these segments, using the explicit, finite difference formulation of Equations (1) and (2). The software implementing this model has been used previously to develop mixing zones and NPDES permit conditions in Silver Bay, Alaska (Yearsley, 1991) and Ward Cove, Alaska (Yearsley, 1990). The simplified methodology uses the same basic approach as WASP4 when the EUTRO4 module of WASP4 is applied at Complexity Level 1 (Table 2.4.1 in Ambrose et al, 1991).

The elements of the conceptual model described were used to simulate BOD and DO in Akutan Harbor. Elements of the conceptual model that are specific to the implementation of the methodology in Akutan Harbor include:

- Oxygen demanding wastes associated with the various seafood processing streams from each source are aggregated into a single category with uniform oxygen-demanding characteristics.

- The discharges from all sources have come to equilibrium at a water depth determined from the application of a near-field dilution model.

- Transfer of oxygen across the air-water interface is due to wind stress only.

- Steady-state advection is due to estuarine processes (gravitational convection) only

- Diffusion-like mixing processes derive their energy from low-level wind stress and tidal mixing

Parameter Estimation

Implementation of the model which solves the finite difference analog of Eqs (1) and (2) for the geometry of Akutan Harbor can be done only after inputs to the system have been identified and model parameters have been estimated. It is generally the case, and this analysis is no exception, that the number of parameters which must be estimated is greater than the number of equations which can be written to describe the system. This means that additional constraints must be placed on the analysis before a "unique" solution results. Constraints placed on the parameter estimation process for this analysis include the following:

- Horizontal mixing is homogeneous

- **Vertical mixing is homogenous**
- **Deoxygenation rates are constant throughout the water body**
- **Reaeration occurs only in the top 5 meters of the water column**

Under these constraints, system inputs and parameter estimates were determined in the following manner:

Boundary conditions

Inputs from the coastal waters surrounding the Akutan Harbor estuary were determined from the data collected during the September 1993 field study. Depth-distributions of temperature, salinity, DO and BOD for the coastal water boundary condition are given in Table 1.

k_1 - rate of deoxygenation

Field samples collected from the waters of Akutan Harbor by EPA (Tetra Tech, 1993) were used to estimate values of the rate of deoxygenation, k_1. The downhill simplex method of Nelder and Mead (1973) was used to find the minimum-squared error solution to fitting the 107 BOD time series measurements made by Tetra Tech (1993). The average deoxygenation rate computed in this manner was 0.2135 $days^{-1}$, estimated at 20^{o} C.

S_L - point source BOD loadings

Point source BOD loadings were estimated from the 40 time series measurements of whole effluent BOD made by Tetra Tech (1993). The downhill simplex method of Nelder and Mead (1973) was used to find the minimum-squared error solution fitting the deoxygenation rate and the ultimate BOD. The empirical cumulative distribution function for ultimate BOD of the whole effluent, estimated by this method, is shown in Figure 13. The median value (6000 mg/l) was chosen to represent the BOD during the period of analysis. Average flow rate for the facility was obtained from the Discharge Monitoring Reports compiled by Trident Seafoods. The average flow rate for all waste streams during the month of September 1993 was 7.7 mgd or .338 $meters^3$/sec.

S_C- point source DO loading

Measurements of the whole effluent during the September 1993 study showed that the DO level in the whole effluent was consistently at levels equal to 10 mg/l.

Location of discharge point

The point at which the effluent enters the water column is an important factor in determining the fate of the pollutants and their impact on water quality. The x-y (horizontal coordinates) of the Trident discharge, using the indices for the finite difference grid defined by Figure 12, was taken to be i=9 (x-coordinate), j=10 (y-coordinate). The vertical coordinate of the discharge was determined by the density profile in the receiving, water, the diameter and depth of the outfall, and the density and momentum of the effluent discharge. Density profiles of the receiving water were obtained from measurements of temperature and salinity made during the September 1993 study (Tetra Tech, 1993). The PLUMES methodology (Baumgartner et al, 1993) was used to estimate the trapping depth of the discharge based on environmental data collected September 7, 1993 study (Tetra Tech, 1993) in the vicinity of the Trident discharge (Station T-1). The results from the PLUMES analysis are given in Table 1. Based on these results, it was assumed the effluent came to equilibrium at a depth of approximately 30 meters. This corresponds to a vertical index in the finite difference grid of k=6 (k=1 is the surface), since each finite difference element is 5 meters in thickness.

U_x, U_y, U_z - horizontal and vertical velocities

The conceptual model for Akutan Harbor is based on the notion of a steady-state, two-layer estuarine flow. This two-layer estuarine flow is driven by the flux of buoyancy associated with the discharge of freshwater into the higher density waters of Akutan Harbor. In the absence of other forces, such as wind stress and tidal currents, this flux of buoyancy will give rise to a seaward transport in the surface layer and landward transport at depth. The theory for this conceptual model, as well as a computer program (CIRCMOD) to implement the theory, was developed by Program Research (1977). Implementation of the theory requires the following information:

- Estimates of the longitudinal variation in the average salinities of the upper and lower zones
- Estimates of wind stress
- Estimates of the freshwater discharge
- A description of the geometric characteristics of the water body.

Hydrographic and hydrologic data collected during the September 1993 were used to develop parameters for applying CIRCMOD.

Depth-averaged salinity for the surface (0-10 meters) and bottom (10 meters - bottom) were computed at each of the hydrographic stations on each day of the study. The depth-averages at each station were used to estimate the parameters for a relationship between average salinity and distance of the following form:

$$\bar{S}_i(x) = \bar{S}_{i0}\, e^{\alpha x}$$

where,

$\bar{S}_i(x)$ = the depth-averaged salinity in the i^{th} layer at a distance, x, o/oo

x = the distance from the origin as defined in the grid shown in Figure 12, meters

$\bar{S}_{i0}$ = the depth-averaged salinity in the i^{th} layer at the origin, (x=0.0), o/oo

α = the wave number of the depth-averaged salinity, meters^{-1}

The salinity parameters for the circulation model, obtained from the field studies, are given in Table 3.

Freshwater runoff to Akutan Harbor was estimated at 2.08 meters^3/second during a survey conducted on September 7, 1993.

The wind stress was assumed to be negligible.

Estimated transports in the surface and bottom layers as a function of distance from the origin (coordinate system as defined in Figure 12) using data from September 3-7, 1993 are given in Table 4.

Typical current speeds resulting from the application of CIRCMOD are on the order of 0.5 cm/sec in the bottom and one cm/second in the surface. These are of the same order as low-level current speeds found in field data collected by Evans-Hamilton (EPA, 1993). Evans-Hamilton reported average currents of approximately 1 cm/sec. Drogues were released at depths of 5 and 15 meters in the vicinity of the Trident Seafoods main discharge on September 8, 1993 and tracked for approximately one hour. The trajectories of the two drogues released at 15 meters was toward the west at speeds of estimated to be approximately four cm/sec. The two drogues released in the surface layer (5 meters) were moving in a clockwise direction at similar speeds. Since the time scale associated with the drogue observations was small compared to the time-scale of the quasi-steady state system response (EPA, 1984), it is likely that tidal forces and light wind stress were affecting the drogue trajectories. Nevertheless, the trajectory of the drogues is consistent with the conceptual model, both in terms of direction of currents and their magnitude.

E_x, E_y, E_z- coefficients of horizontal and vertical eddy diffusivity

Data from the EPA field study of September 1993 was used to estimate coefficients of both vertical and horizontal eddy diffusivity in Akutan Harbor. Data collected on September 7, 1993 was chosen as the data set to be used for estimating these coefficients. Receiving water data collected on this date was the most comprehensive in terms of coverage of Akutan Harbor. These data were also more probably representative of equilibrium conditions resulting from startup of the fish processing facilities.

As described above, the DO data for September 7,1993 (Figure 5) were stratified according to whether or not the sample was collected west of 165° 46' W or east of 165° 46' W. The sample set for the Inner Harbor was used to estimate the magnitude of the horizontal eddy diffusivity. The fixed parameters, determined from other data collected during the September 1993 study or from literature values, as described above, are given in Table 5. For the choice of fixed parameters given in Table 5, and assuming that the horizontal coefficients of eddy viscosity are homogeneous and isotropic, the estimate of the coefficients was that which resulted in a minimum DO of 3.0 a depth of 30 meters.

The parameter estimation process for determining the coefficients of eddy diffusivity was to adjust the values of the coefficients of horizontal and vertical eddy diffusivity in an iterative manner until the model results predicted the minimum DO observed at depths of 30 meters, as observed on September 7, 1993. The parameter estimation process was constrained, as discussed above, so that the coefficients of horizontal and vertical eddy diffusivity were both constant throughout the water column.

k_2 - rate of reaeration

The reaeration rate, k_2, was determined from use of a transfer rate, k_L, using the relationship

$$k_2 = k_L/H$$

where,

H = the depth of the finite difference element, meters.

The value of k_L was estimated to be equal to 2.0 meters/day. This is one of the values reported in Table 3-11 of Bowie et al (1985) and is due to DiToro and Connolly (1980). The resulting value of the reaeration rate, k_2,, for a finite difference element 5 meters in thickness, is 0.4 $days^{-1}$.

Results of the Parameter Estimation Process

The results of the parameter estimation process, following the steps described above, are given in Table 5. The predicted results for the location with the minimum DO are compared with all the observations as shown in Figure 14. The predicted minimum DO occurs at location I=2, J=10 (see Figure 12). Predicted values at I=2, J=10; I=5, J=10 and I=8, J=10 are compared with observed DO at specific locations in Figures 15, 16, and 17, respectively.

Determination of TMDL

The first step in the determination of a TMDL is to define the criteria which protect water uses for the water body of concern. In the case of the BOD TMDL, the water uses affected are those which have an impact on DO. The State of Alaska's water quality standard for DO is stated as (Alaska Department of Environmental Conservation, 1989):

> "Surface dissolved oxygen (DO) concentrations in coastal water shall not be less than 6.0 mg/l for a depth of one meter except when natural conditions cause this value to be depressed. DO shall not be reduced below 4 mg/l at any point beneath the surface. DO concentrations in estuaries and tidal tributaries shall not be less than 5.0 mg/l except where natural conditions cause this value to be depressed. In no case shall DO levels above 17 mg/l be permitted......."

Pritchard (1967) defines an estuary as:

> "An estuary is a semi-enclosed coastal body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage"

Akutan Harbor satisfies all of these criteria, as the earlier discussion of estuarine flow and temperature-salinity relationships shows. The estuarine classification is also supported by limited biological survey reviewed by EPA (1993).

For this BOD TMDL, the water quality standards which apply to Akutan Harbor are:

> (1) DO concentrations shall not be less than 6.0 mg/l for a depth of one meter except when natural conditions cause this value to be depressed.

(2) DO concentrations shall not be less than 5.0 mg/l except where natural conditions cause this value to be depressed.

The capacity of Akutan Harbor to assimilate the organic loading from any source is dependent on the oxygen demand of the sources, and the mixing properties of the receiving waters. It is also dependent on the specific location of all discharges(s). This is because organic waste discharge into waters such as Akutan Harbor does not exert itself instantaneously, but does so over a period of several days. Therefore, the impact on DO from waste discharge at a specific location will be determined by where the receiving water transports or mixes the waste during the period in which the oxygen demand of the waste is exerted. This also means that the minimum DO resulting from any discharge will not necessarily coincide with the actual discharge point.

Because of this dependence on the location of the discharge(s), the loading capacity determined for this TMDL was developed with locations associated with the existing discharges from Trident Seafood's and the two facilities operated by Deep Sea Fisheries. It should be noted that a different loading capacity, either greater or smaller than the one determined from using the existing discharges could result from changing the locations of the discharges.

Historical considerations (EPA, 1993) show that seafood processing and organic waste loading in Akutan Harbor can occur during most seasons of the year. Two seasonal conditions were considered in establishing the TMDL for BOD in Akutan Harbor. The two seasons were chosen so as to represent: (1) the period when vertical stratification in the Harbor is at or near a maximum and water temperatures are highest. Based on weather data (TRC, 1992) from Akutan, these conditions can probably occur from May 1 to October 31; (2) the period when vertical stratification in the Harbor is at a minimum and waste discharges are most likely to reach the surface. These two seasons will be called Summer and Winter, respectively.

The EPA September 1993 is the only comprehensive study of Akutan Harbor conducted under Summer conditions when the seafood processing was at or near full capacity. There are no similar studies for Winter conditions. Because of this, parameter estimates obtained from the September 1993, as described above, was used to characterize the Winter conditions, with the following exceptions:

Boundary conditions

Winter boundary conditions for temperature and salinity were obtained from data reviewed by EPA (1993). These boundary conditions are given in Table 7.

S_C- point source DO loading

Based on comments received from the applicants, the DO levels in all discharges was assumed to be 0 mg/l during both the Summer and Winter seasons.

S_L - point source BOD loadings

Point sources included in the TMDL analysis were those for which there are existing NPDES permits. This includes the Trident Seafoods shore plant, Deep Sea Fisheries MV Deep Sea and Deep Sea Fisheries MV Clipperton.

Location of discharge point

The location of the Trident Seafoods facilities was assumed to be the same as described earlier, while the location of the Deep Sea Fisheries facilities was based on information obtained from the permittee. In addition, for the Winter season, it was assumed the discharge from all three facilities reached the surface. The coordinates for the three discharges for both Summer and Winter are given in Table 8.

Near-field modeling of effluent discharge reported by EPA (1993) showed that the effluent reached the surface during Winter conditions.

U_x, U_y, U_z - horizontal and vertical velocities

Available hydrographic data (EPA, 1993) shows that Akutan Harbor is probably well-mixed during the Winter season. Furthermore, freshwater runoff is likely to be small. As result, estuarine circulation of the type described previously is also likely to be small. In the absence of data to test this hypothesis, it was assumed for this TMDL that horizontal and vertical velocities due to estuarine circulation are zero.

TMDL Analysis

The TMDL analysis was performed for Summer and Winter using the set of parameters for each season as described, above. Since the allocation of waste loads and the TMDL cannot be treated independently, for the reasons mentioned above, the following procedure was used for each season:

1. Fix the discharge at the location of the two Deep Sea facilities at a level approximately equal to 1100 lbs/day. After including a margin of safety of 10% this would allow an allocation of total discharge from the MV Deep Sea and MV Clipperton of 1000 lbs/day. This would accommodate the historical levels of discharge (670 lbs/day BOD_5)

from the MV Deep Sea (EPA; 1993) and would allow for an additional discharge from the MV Clipperton of approximately 330 lbs/day BOD_5.

2. Using the mathematical model described above in an iterative process, find the loading of BOD_5 at the location of the Trident shore-based facility discharge which would meet the State of Alaska's water quality standard for DO of 5 mg/l during the Summer when the discharge was at approximately 30 meters depth and 6 mg/l in the Winter when discharge was at the surface.

For the Summer season, it is apparent that a reduction of existing loads is necessary, since water quality standards for DO are exceeded at these levels. Table 9 gives the combination of loadings at the discharge locations described above for which water quality standards for DO are satisfied during the Summer season. This is the Total Maximum Daily Loads for BOD_5 loads for the Summer season in Akutan Harbor.

For the Winter season, the model predicts that for the discharge of organic loads comparable to those observed during the September 1993 study, the water quality standards for DO will not be exceeded. The minimum predicted DO profile for Winter Conditions and median loading from Trident Seafoods observed in the September 1993 study is shown in Figure 18. For the model parameters estimated from existing data, the model predicts water quality standards for DO will be met in Akutan Harbor given the existing configuration of waste discharges during the Winter season.

Margin of Safety

As stated in the Clean Water Act §303 (d)(1)(C) and the federal regulations (40 CFR §130.7), a margin of safety can be established to account for uncertainty in the data analyses. The margin of safety used for this TMDL includes variability and uncertainty from several sources.

Uncertainty in Eddy Diffusivity

Levels of DO in Akutan Harbor for September 1993 conditions were estimated using coefficients of horizontal eddy diffusivity of 20.0 meters^2/second and vertical eddy diffusivity of 4x10 meters^2/second. Bowie et al (1985) report values of these coefficient ranging over three orders of magnitude.

Variability in k_1 - rate of deoxygenation

Estimates of the deoxygenation rate, k_1, using data collected during the September 1993 study. vary from 0.01 $days^{-1}$ to 0.40 $days^{-1}$.

Variability in k_2 - rate of reaeration

Estimates of the reaeration rate, k_2, were obtained from the literature (Bowie et al, 1985). However, a wide range of values is given in the literature. The parameter estimate used in this analysis is based on the results from other studies and leads to predicted results consistent with those observed during the September 1993 study. However, the estimate of this parameter is dependent on the conceptual model. Parameter estimates of this parameter based on different conceptual models could result in model predictions for the Winter season which required establishment of a TMDL for BOD_5. Since no comprehensive water quality data have been collected during the Winter season while the seafood processors has been at full production, there is little basis for rejecting the conceptual model described above. Such a study should be conducted during the Winter season to more thoroughly test the present hypothesis and to ensure that water quality standards for DO are met at all times.

Variability in Point Source BOD_5

Estimates of the ultimate BOD from the Trident Seafood facility, based on data collected during the September 1993 study, vary from 1800 mg/l to 49,000 mg/l.

Uncertainty in Model Predictions

The results from the model predict minimum levels of DO similar to those observed at a depth of 30 meters on September 7, 1993 (Figure 14). The model does not predict the low DO levels in the water column below 30 meters at any of the locations in the Inner Harbor (Figures 16-18). Figures 16-18 also show that the while the model predicts the minimum DO well above 30 meters, it also predicts that DO will be lower over a wider area than was actually observed on September 7, 1993. The over-prediction at depth appears to balance the under-prediction above 30 meters, suggesting that mechanisms other than those included in the conceptual model are affecting the distribution of the seafood processing wastes. This could be due to an incomplete knowledge of the current structure, incomplete knowledge of the distribution and impact of solids discharged by the seafood processors or by incomplete knowledge of DO demand associated with the bottom sediments.

Estimated Margin of Safety

Given the approximate balance between under-prediction and over-prediction as described above, uncertainty in predicted impacts of seafood processing is believed to be of the order of 10% for the Summer season. Insufficient data are available to estimate the margin of safety for the Winter season. Model predictions based on existing data show that water quality standards for DO will not be violated under existing conditions of BOD_5 loadings from seafood processors. However, a comprehensive study of water quality during the Winter season, when seafood processors are at maximum production, should be conducted so as to provide a more quantitative test of the present hypothesis.

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Table 1. Boundary conditions used in Akutan Harbor model for parameter estimation and for establishing the BOD TMDL during the Summer season.

Depth (meters	Temperature (^oC)	Salinity (o/oo)	DO (mg/l)	BOD_u (mg/l)
0.0	8.9	31.5	9.40	1.5
5.0	8.5	31.6	9.40	1.5
10.0	8.3	31.7	9.40	1.5
15.0	8.2	31.8	9.10	1.5
20.0	8.2	31.9	9.00	1.5
25.0	8.1	31.9	8.60	1.5
30.0	8.0	31.9	8.60	1.5
35.0	8.0	31.9	8.50	1.5
40.0	8.0	32.0	8.40	1.5
45.0	7.9	32.0	8.20	1.5
50.0	7.8	32.0	7.70	1.5
55.0	7.7	32.0	7.70	1.5
60.0	7.7	32.0	7.70	1.5
65.0	7.7	32.0	7.70	1.5

Table 2. Calculation of near-field characteristics of Trident Seafoods discharge for hydrographic data collected on September 7, 1993 at Station T-1. Calculation uses the PLUMES methodology (Baumgartner et al, 1993.

Plume Depth meters	Plume Dia. meters	Conc	Dilution	CL Conc	Horiz Dist. meters
43.00	0.2032	100.00	1.000	100.00	0.000
43.00	0.2039	99.31	1.007	100.00	0.003 » **bottom hit**
41.92	6.2700	3.12	31.710	6.12	15.380 » **bottom hit**
31.16	14.4900	1.19	83.090	2.40	36.650 » **trap level**
22.68	24.9200	0.75	132.200	1.55	55.510 » **begin overlap**

Table 3. Parameters for depth-averaged salinity in the surface (i=1) and bottom (i=2) layers of Akutan Harbor

Date	$\overline{S}_{10}$	α_1	$\overline{S}_{20}$	α_2
9/3/93	31.782	-7.6873×10^{-7}	31.856	0.0
9/4/93	31.770	-2.2987×10^{-6}	31.900	0.0
9/5/93	31.482	-6.0000×10^{-6}	31.850	0.0
9/6/93	31.500	-2.0959×10^{-7}	31.859	0.0
9/7/93	31.600	-6.0338×10^{-6}	31.850	0.0
9/8/93	31.770	-9.0000×10^{-6}	31.850	0.0

Table 4. Estuarine transport in Akutan Harbor estimated by applying the CIRCMOD methodology to hydrographic and hydrologic data collected during September 1993. The index, I, defines the x-dependency of the transport in each layer based on the coordinate system given in Figure 12.

I	September 3, 1993		September 4, 1993		September 5,1993		September 6, 1993		September 7, 1993	
	Bottom (m^3/s)	Surface (m^3/s)	Bottom (m^3/s)	Surface (m^3/s)	Bottom (m^3/s)	Surface (m^3/s)	Bottom (m^3/s)	Surface (m^3/s)	Bottom (m^3/s)	Surface (m^3/s)
25	893.34	895.42	508.32	510.40	177.94	180.02	182.51	184.59	262.91	264.99
24	825.92	828.00	446.23	448.31	157.73	159.81	181.67	183.75	220.99	223.07
23	767.96	770.04	397.63	399.71	141.62	143.70	180.85	182.93	190.56	192.64
22	717.60	719.68	358.57	360.65	128.48	130.56	180.03	182.11	167.46	169.54
21	673.42	675.50	326.47	328.55	117.55	119.63	179.22	181.30	149.34	151.42
20	634.36	636.44	299.63	301.71	108.32	110.40	178.41	180.49	134.73	136.81
19	599.59	601.67	276.86	278.94	100.43	102.51	177.62	179.70	122.71	124.79
18	568.41	570.49	257.30	259.38	93.60	95.68	176.83	178.91	112.65	114.73
17	540.32	542.40	240.31	242.39	87.63	89.71	176.05	178.13	104.10	106.18
16	514.86	516.94	225.41	227.49	82.37	84.45	175.27	177.35	96.75	98.83
15	491.70	493.78	212.25	214.33	77.70	79.78	174.50	176.58	90.35	92.43
14	470.52	472.60	200.53	202.61	73.52	75.60	173.74	175.82	84.75	86.83
13	451.08	453.16	190.03	192.11	69.77	71.85	172.98	175.06	79.79	81.87
12	433.19	435.27	180.58	182.66	66.37	68.45	172.23	174.31	75.37	77.45
11	416.67	418.75	172.01	174.09	63.29	65.37	171.49	173.57	71.41	73.49
10	401.34	403.42	164.22	166.30	60.48	62.56	170.75	172.83	67.84	69.92
9	387.11	389.19	157.10	159.18	57.90	59.98	170.02	172.10	64.61	66.69
8	373.85	375.93	150.56	152.64	55.53	57.61	169.30	171.38	61.66	63.74
7	361.46	363.54	144.55	146.63	53.34	55.42	168.58	170.66	58.97	61.05
6	349.87	351.95	138.99	141.07	51.32	53.40	167.87	169.95	56.50	58.58
5	339.00	341.08	133.85	135.93	49.44	51.52	167.16	169.24	54.23	56.31
4	328.78	330.86	129.06	131.14	47.69	49.77	166.46	168.54	52.13	54.21
3	319.15	321.23	124.61	126.69	46.06	48.14	165.77	167.85	50.18	52.26
2	310.07	312.15	120.45	122.53	44.53	46.61	165.08	167.16	48.37	50.45

Table 5. Estimates for parameters used to assess impacts of seafood processors on DO in Akutan Harbor, Alaska

Parameter	Value	Units
E_x, coefficient of eddy diffusivity, x-direction	20.0	$meters^2/second$
E_y, coefficient of eddy diffusivity, y-direction	20.0	$meters^2/second$
E_z, coefficient of eddy diffusivity, z-direction	4.0×10^{-5}	$meters^2/second$
k_1, deoxygenation rate	0.2135	$days^{-1}$
k_L, surface transfer rate	2.0	meters/day

Table 6. Boundary conditions used in Akutan Harbor model for establishing the BOD TMDL during the Winter season.

Depth (meters	Temperature (°C)	Salinity (o/oo)	DO (mg/l)	BOD_u (mg/l)
0.0	4.0	32.0	10.7	1.5
5.0	4.0	32.0	10.7	1.5
10.0	4.0	32.0	10.7	1.5
15.0	4.0	32.0	10.7	1.5
20.0	4.0	32.0	10.7	1.5
25.0	4.0	32.0	10.7	1.5
30.0	4.0	32.0	10.7	1.5
35.0	4.0	32.0	10.7	1.5
40.0	4.0	32.0	10.7	1.5
45.0	4.0	32.0	10.7	1.5
50.0	4.0	32.0	10.7	1.5
55.0	4.0	32.0	10.7	1.5
60.0	4.0	32.0	10.7	1.5
65.0	4.0	32.0	10.7	1.5

Table 7. Indices for location of discharges during the Summer and Winter seasons in Akutan Harbor. The coordinate system is shown in Figure 12.

Name of Facility	I	J	K	
			Summer	Winter
M/V Deep Sea	3	10	6	1
M/V Clipperton	3	10	6	1
Trident Seafoods	9	10	6	1

Table 8. Total Maximum Daily Load for BOD_5 in Akutan Harbor for discharges at locations of existing NPDES permits. Applies to the Summer season spanning the period May 1 - October 31.

Index of X-Position for Discharge (see Figure 12)	Index of Y-Position for Discharge (see Figure 12)	Total Maximum Daily Load for BOD_5 (lbs/day)
3	10	1100
9	10	148000

Figure 1. Dissolved oxygen in Akutan Harbor using data collected September 3, 1993.

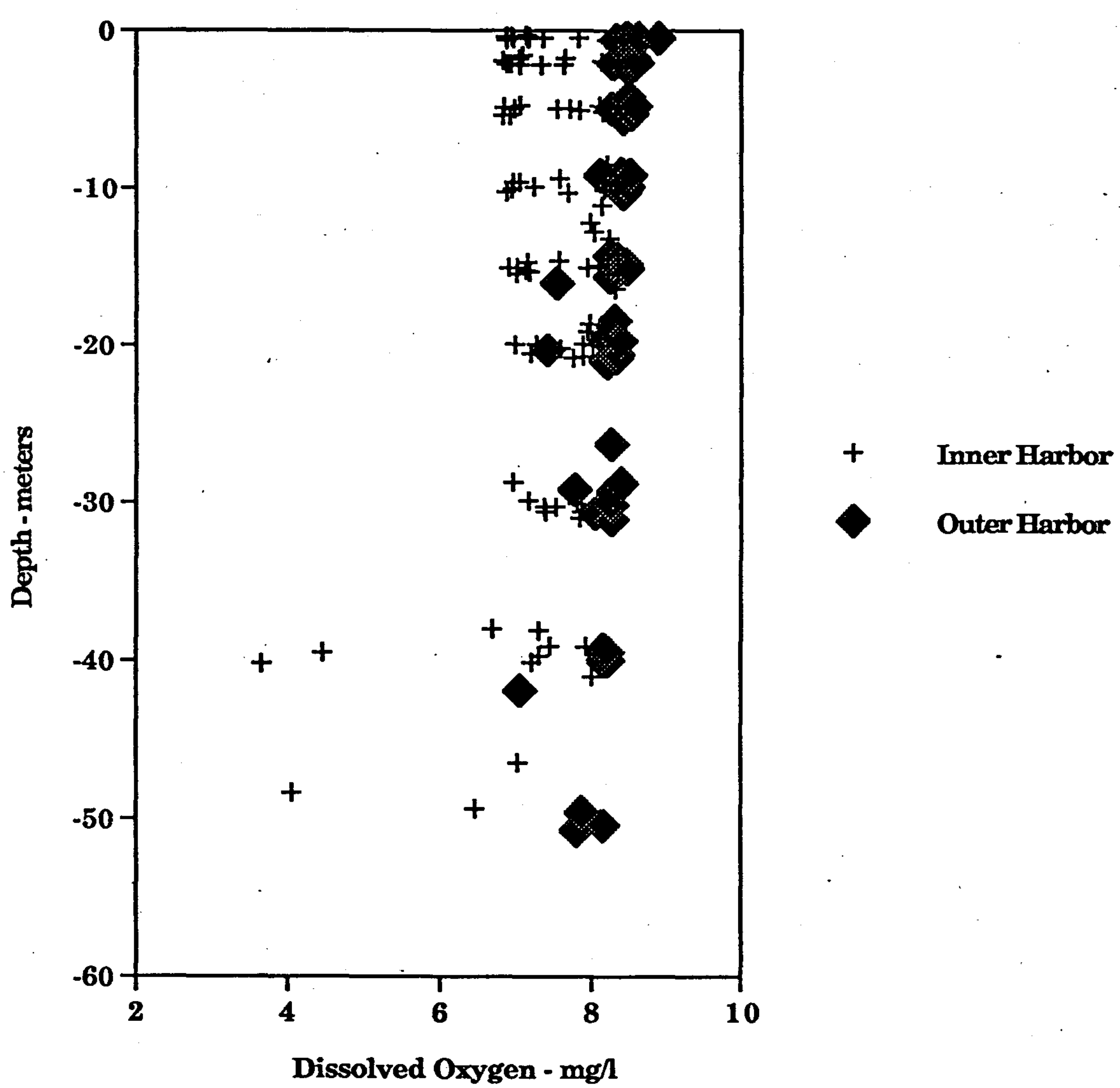


Figure 2. Dissolved oxygen in Akutan Harbor using data collected September 4, 1993

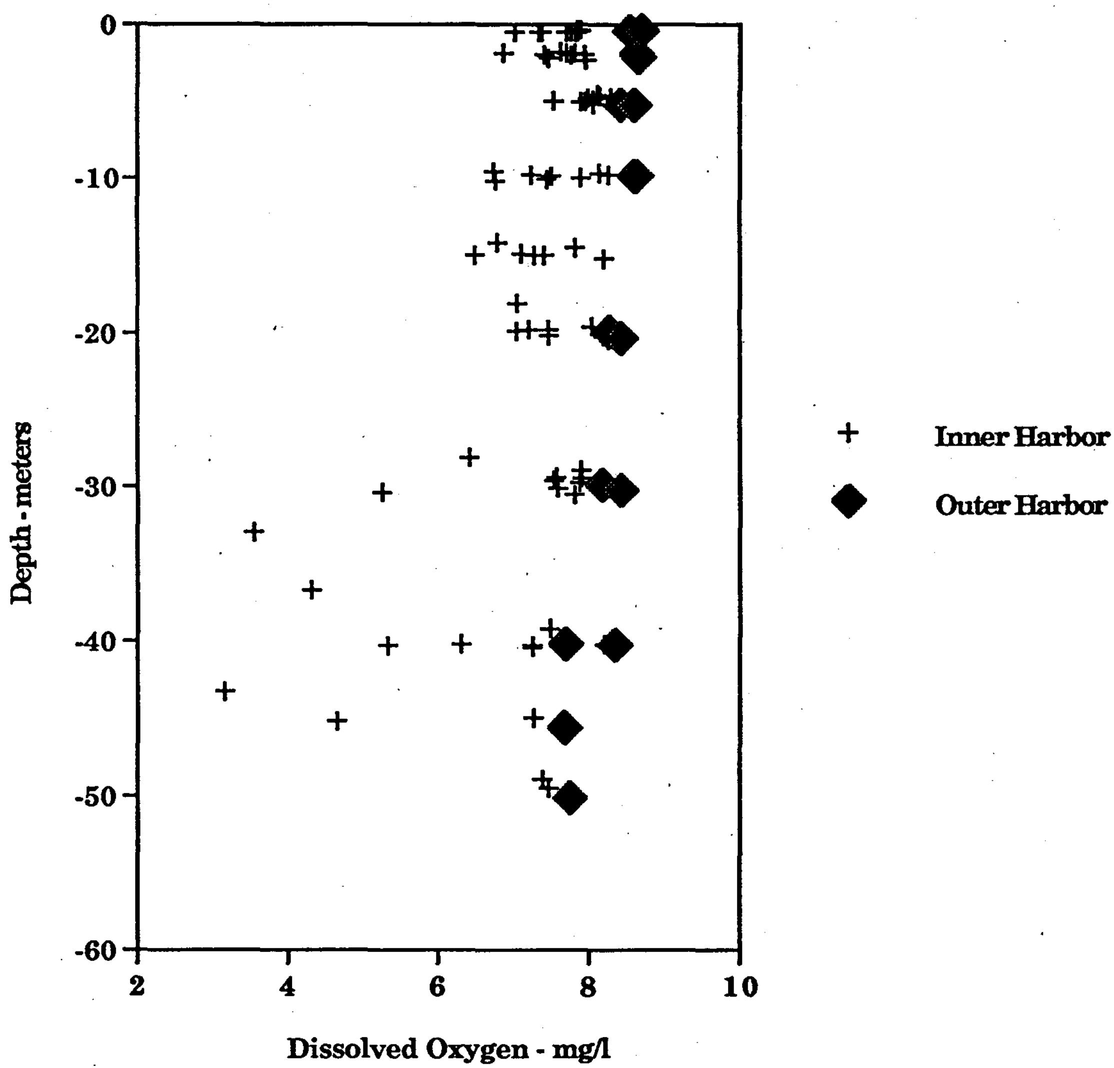


Figure 3. Dissolved oxygen in Akutan Harbor using data collected September 5, 1993

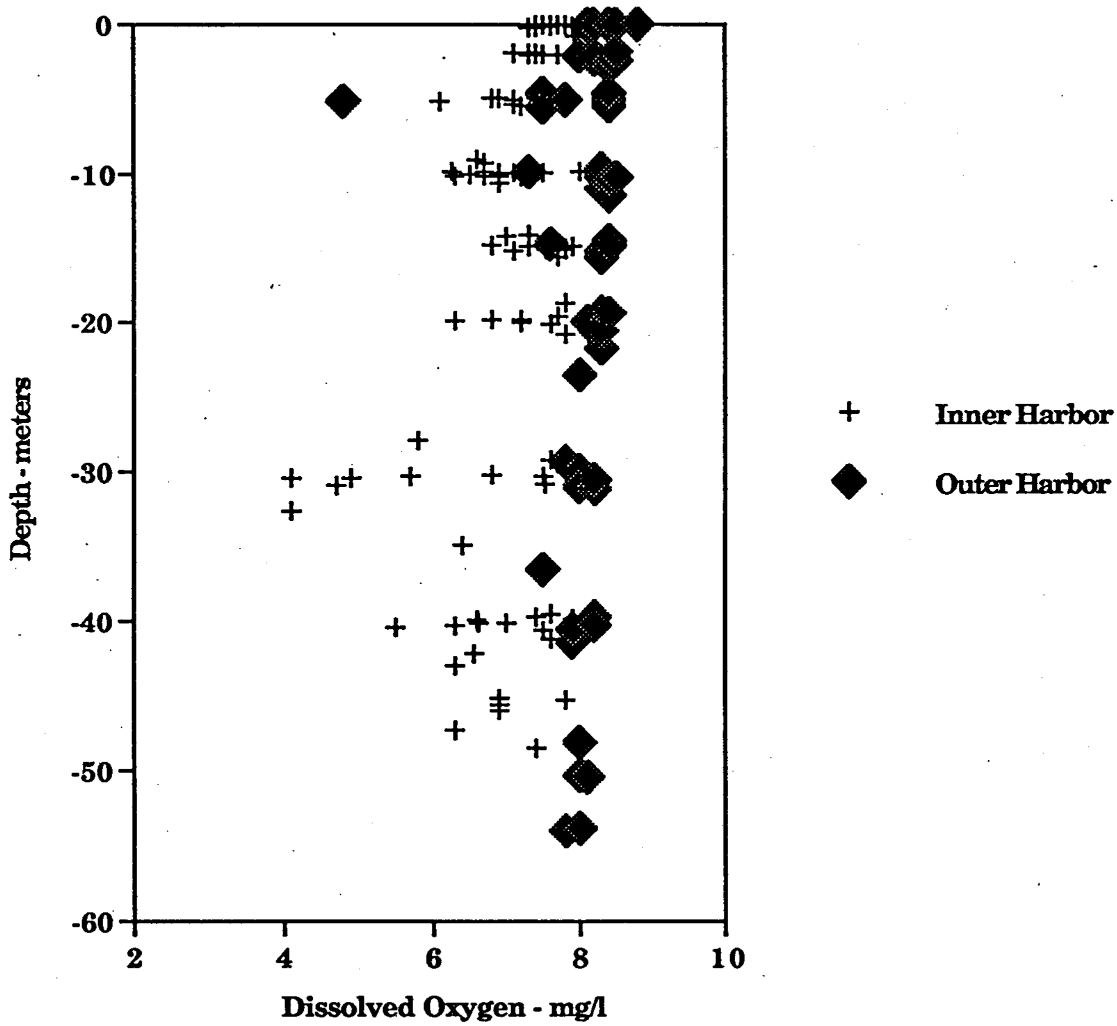


Figure 4. Dissolved oxygen in Akutan Harbor using data collected September 6, 1993

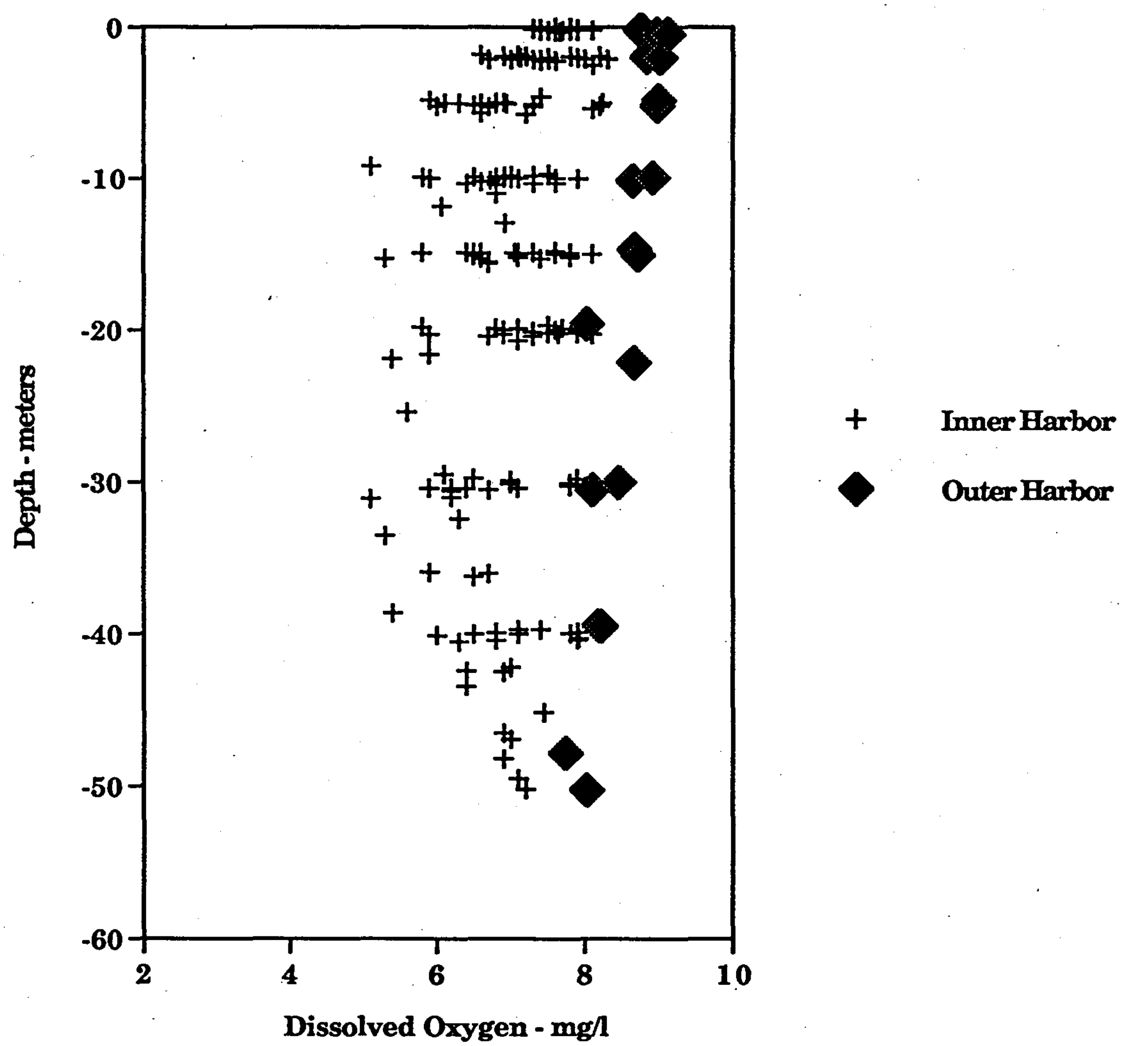


Figure 5. Dissolved oxygen in Akutan Harbor using data collected September 7, 1993

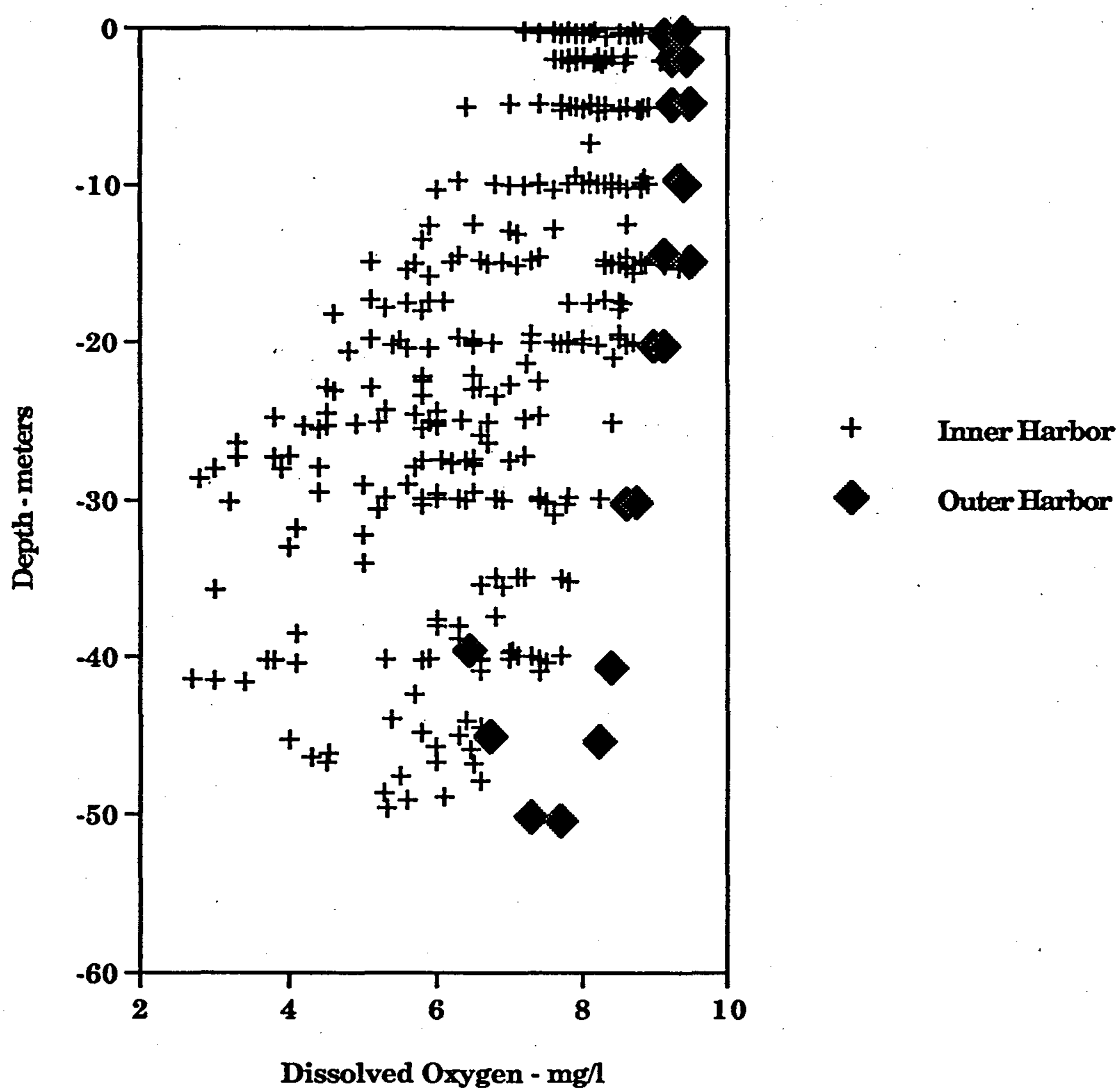


Figure 6. T-S diagram for Akutan Harbor using data collected September 3, 1993

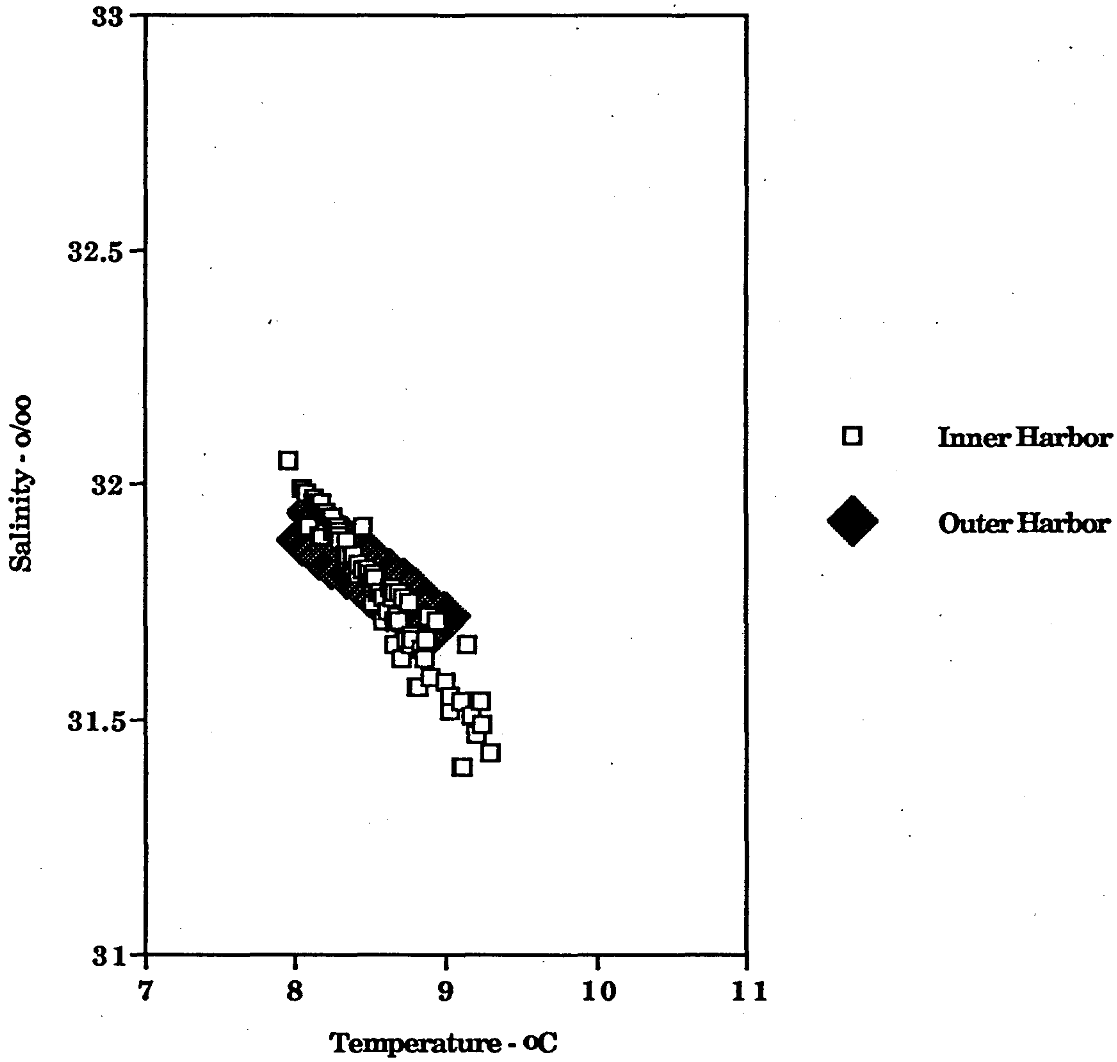


Figure 7. T-S diagram for Akutan Harbor using data collected September 4, 1993

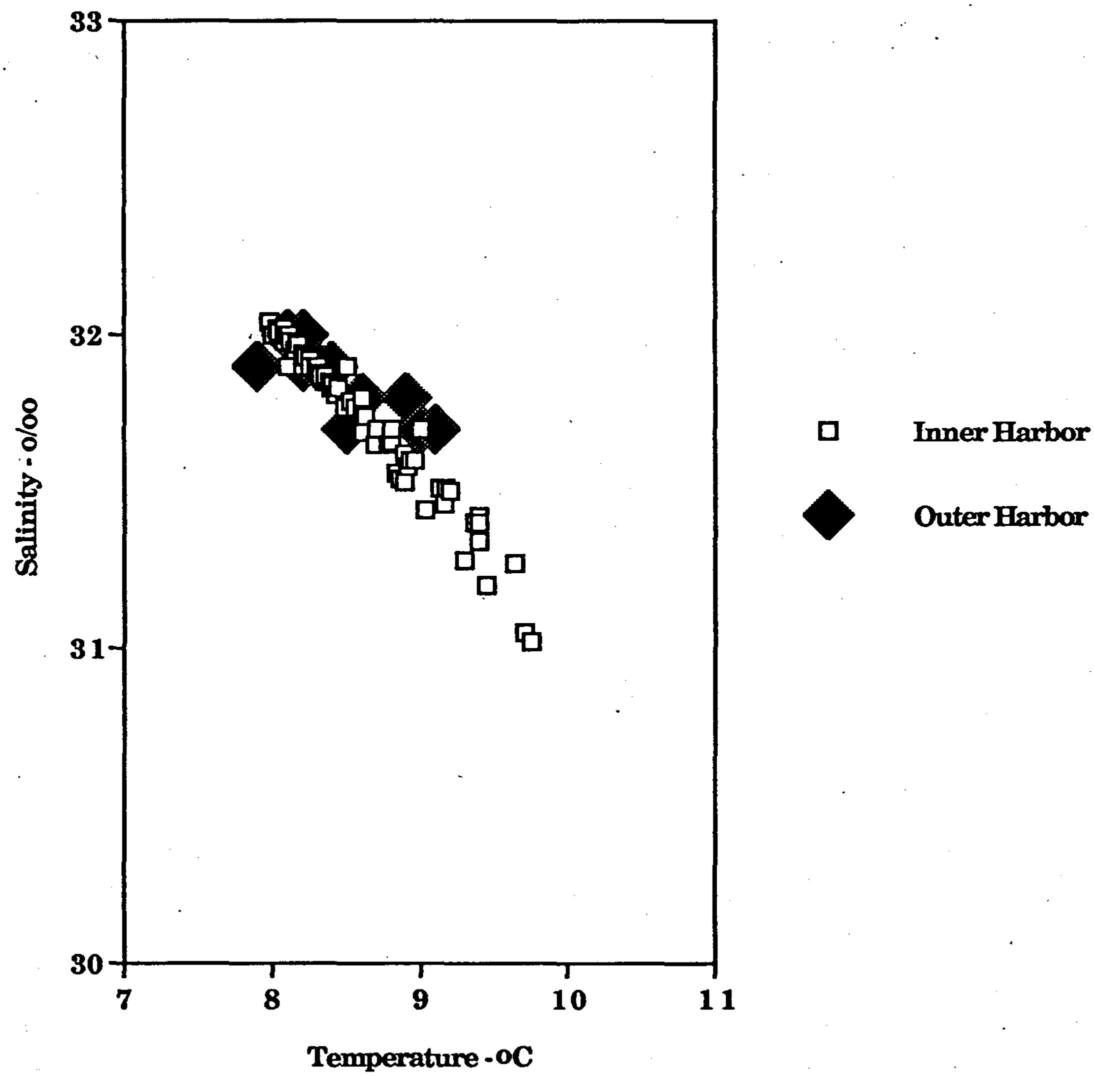


Figure 8. T-S diagram for Akutan Harbor using data collected September 5, 1993.

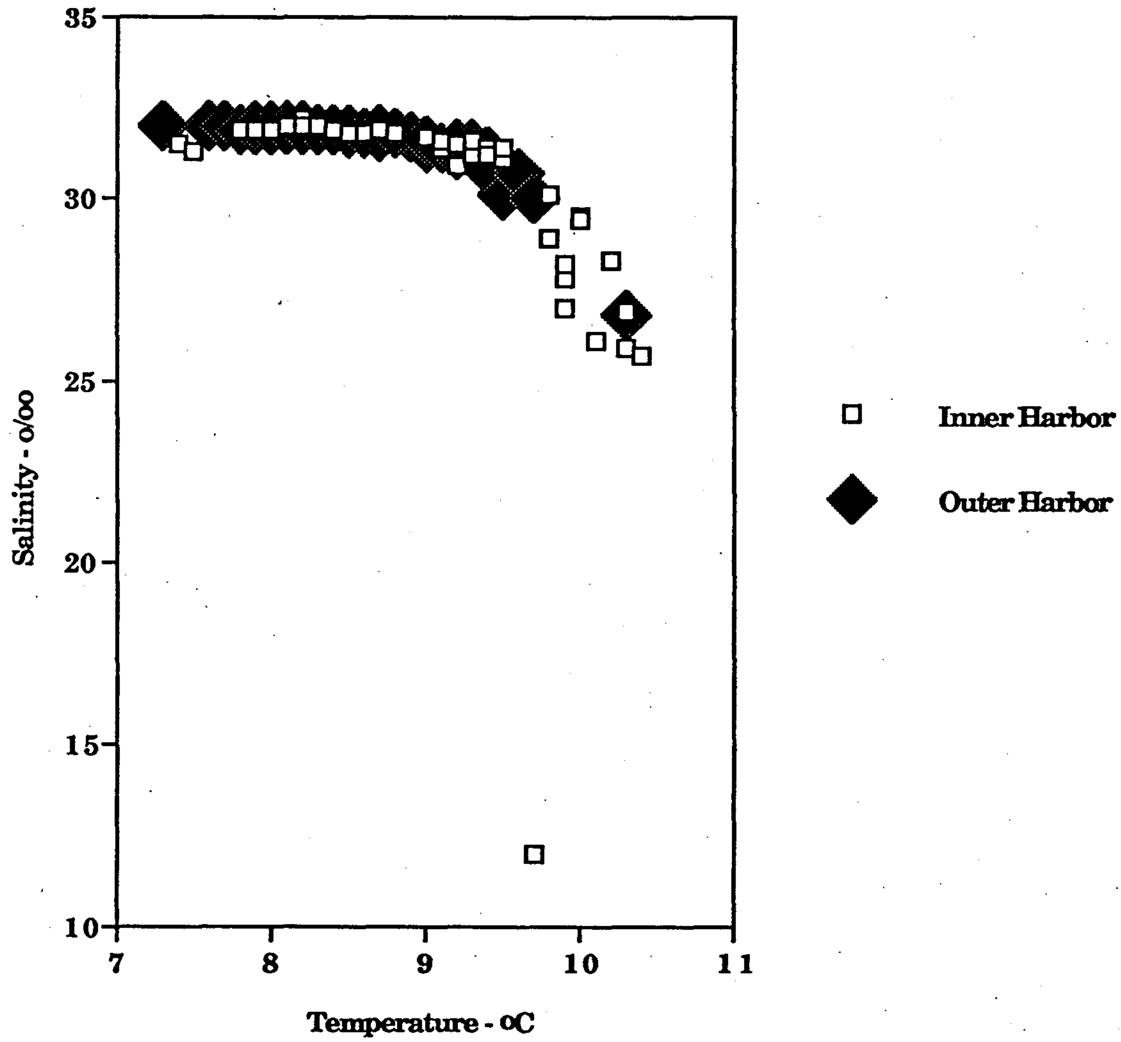


Figure 9. T-S diagram for Akutan Harbor using data collected September 6, 1993

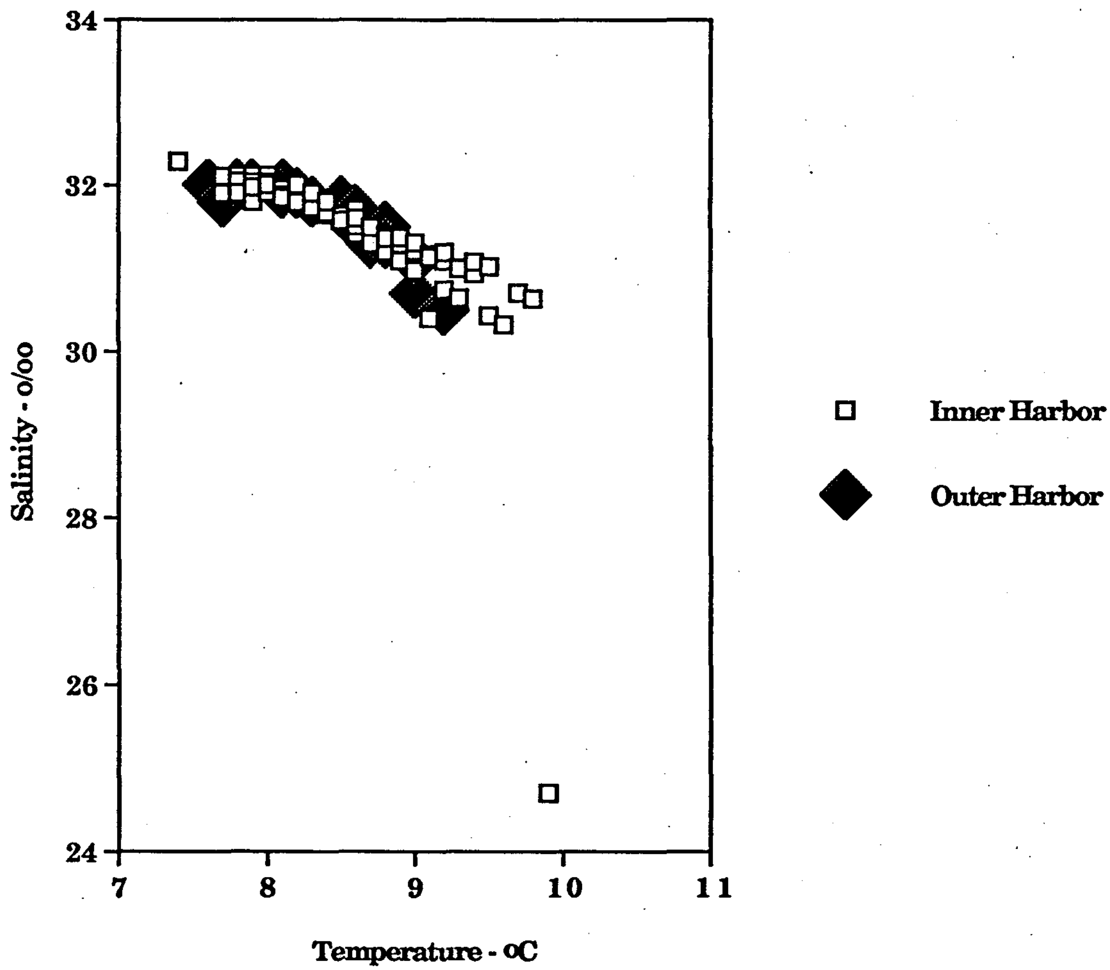
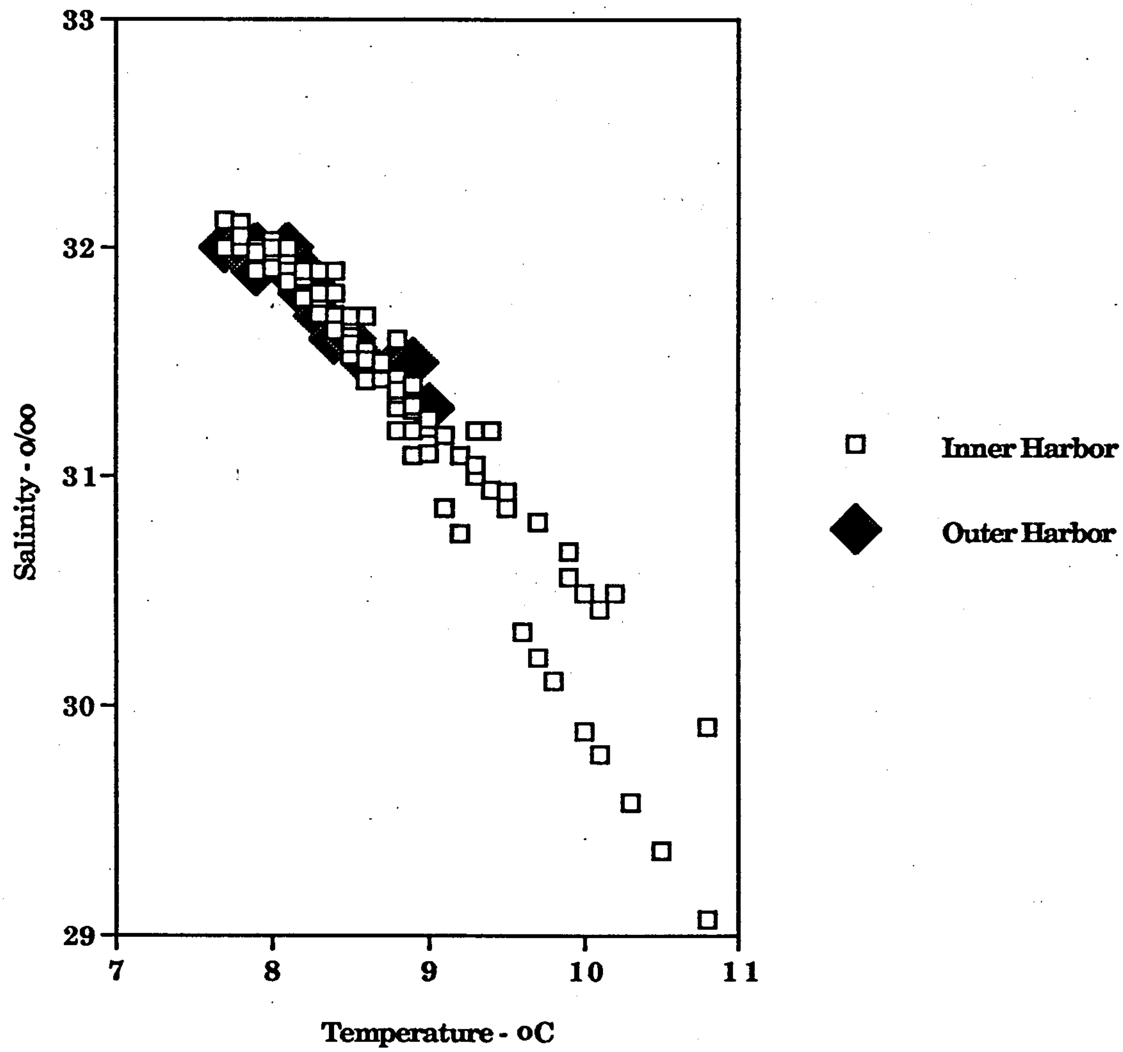


Figure 10. T-S diagram for Akutan Harbor using data collected September 7, 1993.



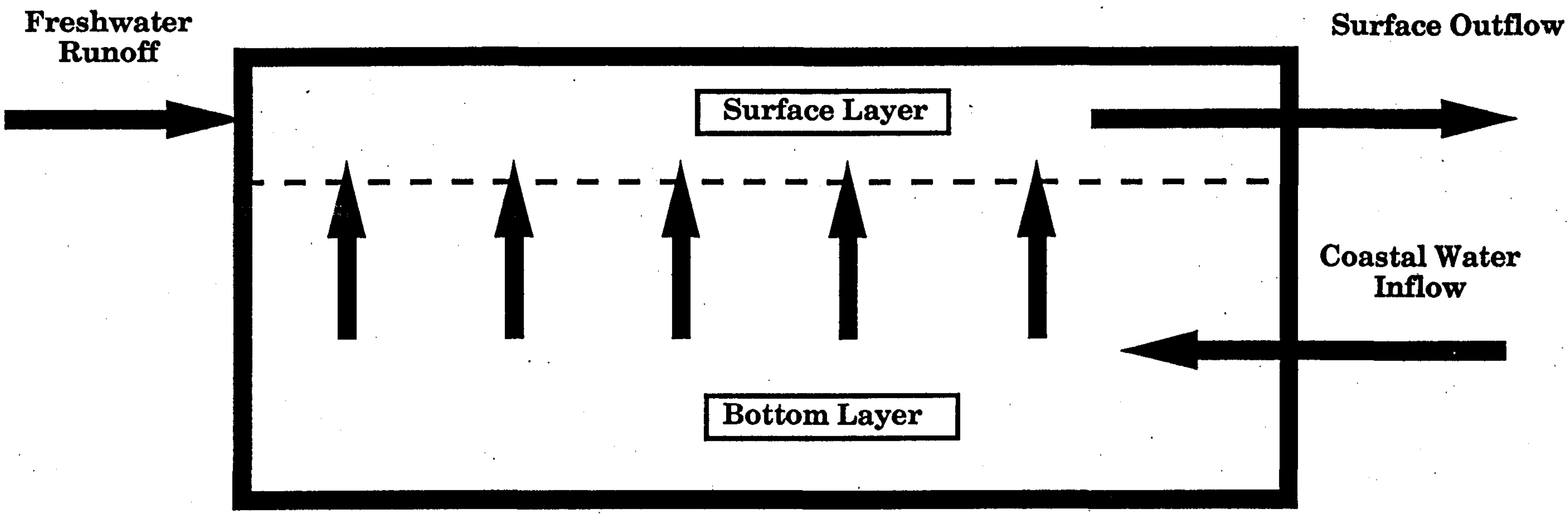


Figure 11. Schematic diagram of estuarine flow in Akutan Harbor during Summer season when stratification is present.

Scale - meters

0 1250 2500

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
16																									
15																						5	5	5	5
14																					5	10	10	10	10
13																				5	25	30	35	30	25
12																			5	25	30	40	40	40	45
11		10	15	15	10	20	5							5	10	20	30	25	35	35	50	55	50	50	55
10		30	35	35	40	45	45	40	35	5	5	20	35	40	40	45	45	50	55	55	55	60	60	60	60
9		25	35	40	40	45	45	45	50	45	45	45	45	45	40	50	50	55	55	55	55	55	60	60	60
8		25	24	30	20	35	40	45	45	45	50	50	45	45	45	45	50	50	55	55	55	55	55	60	60
7								15	20	35	45	45	45	45	45	50	50	55	55	50	55	55	55	55	55
6										5	20	45	40	45	45	50	50	55	55	50	50	50	50	55	45
5												10	5	5	20	30	35	45	45	45	45	45	45	35	35
4																10	10	5	15	20	30	35	25	20	15
3																				5	10	15	15	10	10
2																						5	5	5	
1																									

Figure 12. Grid used with finite difference model to characterize geometry of Akutan Harbor. Numbers along the bottom give the index (I) for references to x-coordinates. Numbers along the side give the index (J) for references to the y-coordinate. Numbers in cells show idealized depths in meters. The index (K) for references to the z-coordinate can be obtained by dividing the depth in meters by five (5).

Figure 13. Cumulative distribution function for the ultimate BOD of whole effluent from the Trident Seafoods facility in Akutan Harbor based on data of September 1993

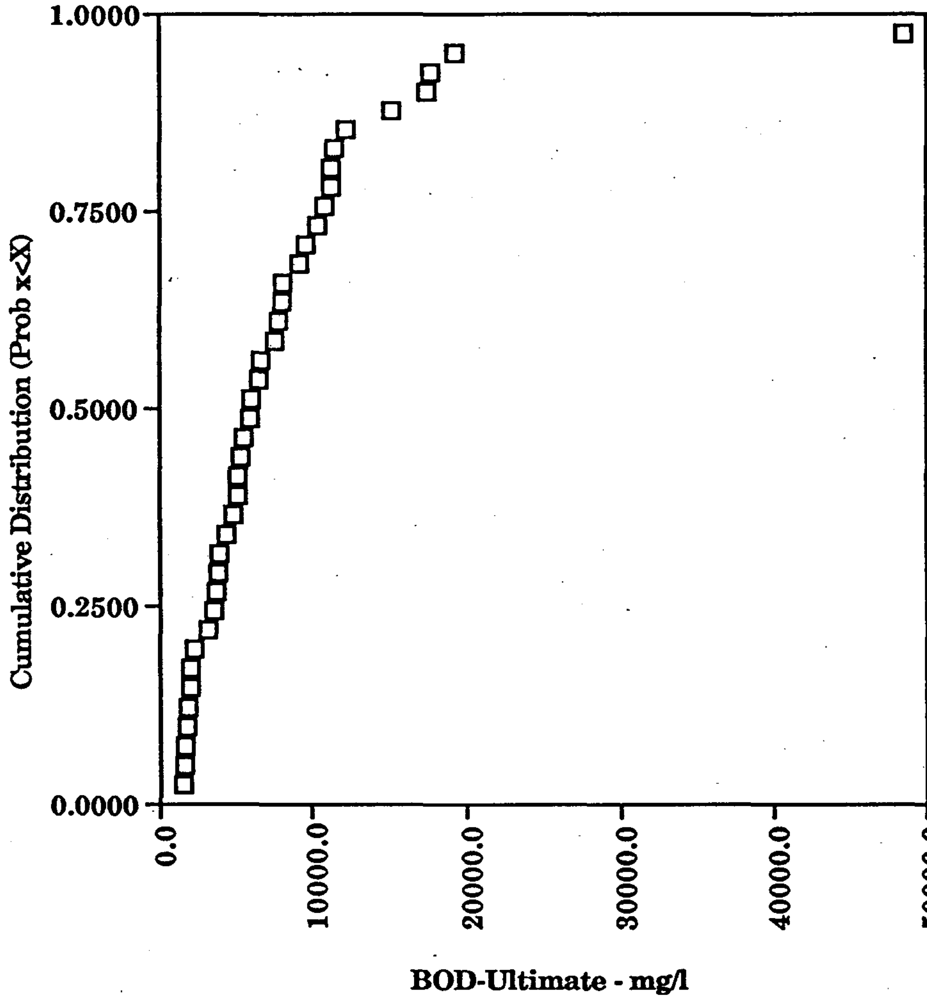


Figure 14. Comparison of minimum predicted DO with observed DO in Akutan Harbor west of 165o 46' W. Minimum occurs at I=2, J=10 at the west end of Akutan Harbor.

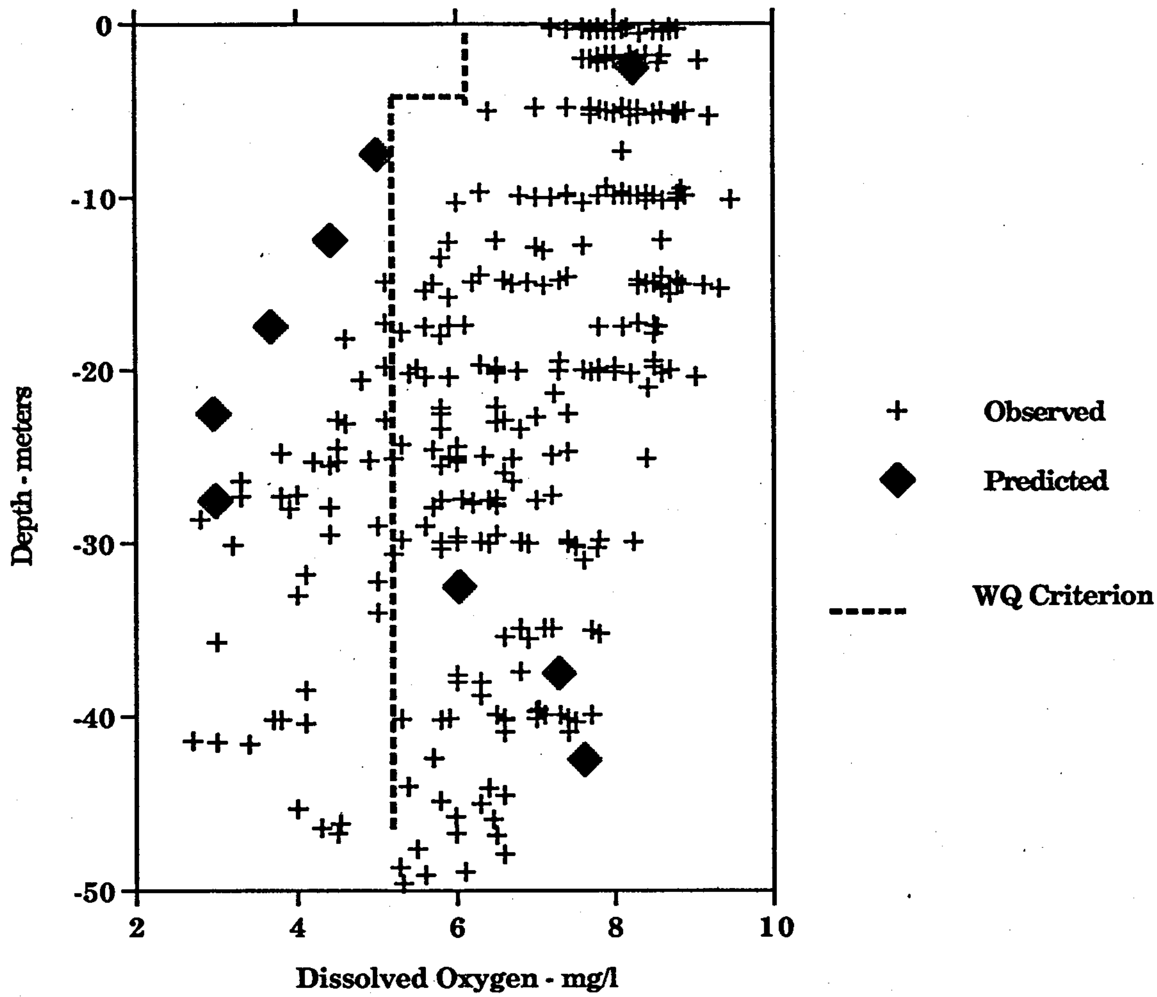


Figure 15. Predicted DO at I=2, J=10 compared with DO observations from September 7, 1993

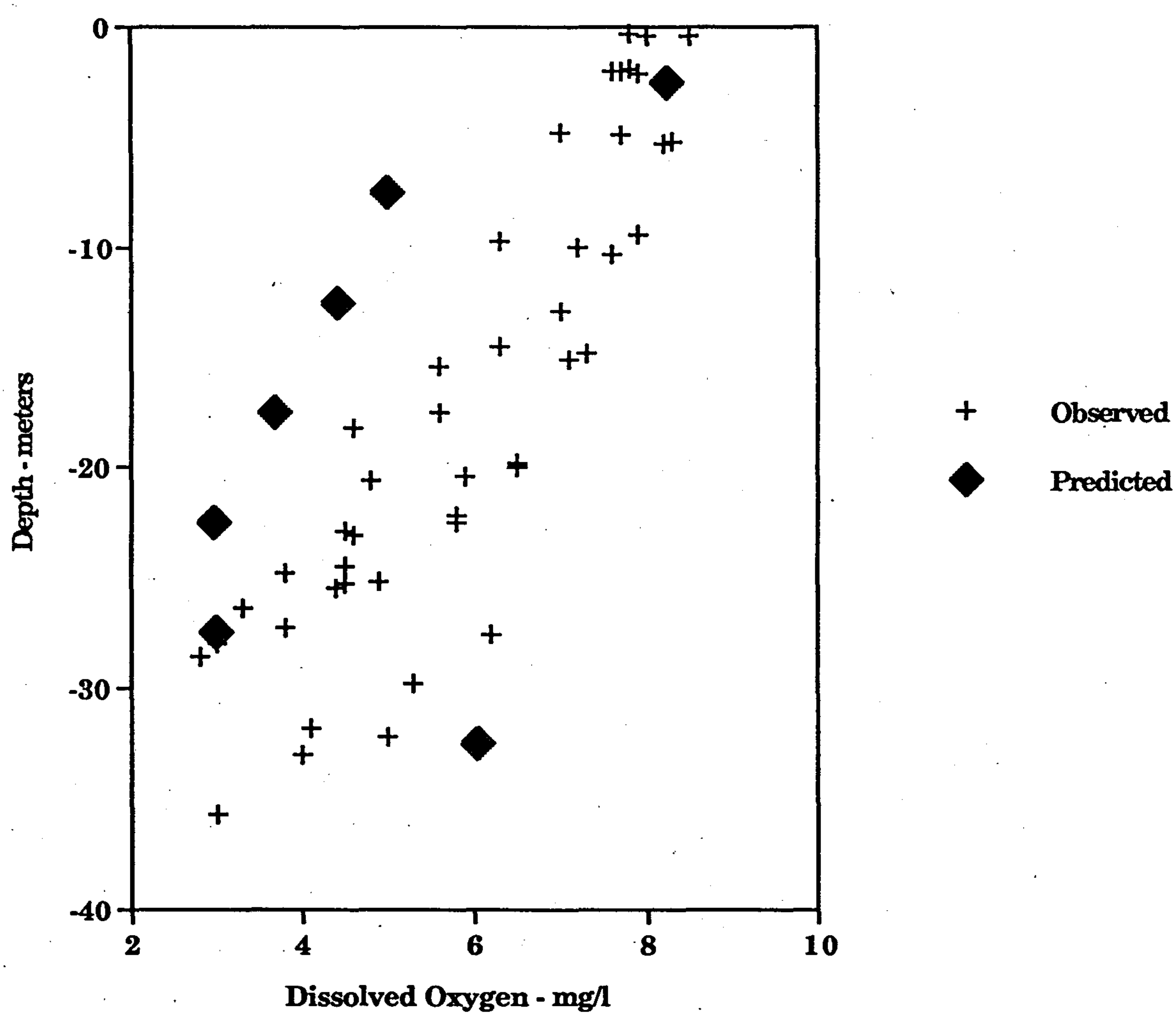


Figure 16. Predicted DO at I=5, J=10 compared with observed DO on September 7, 1993

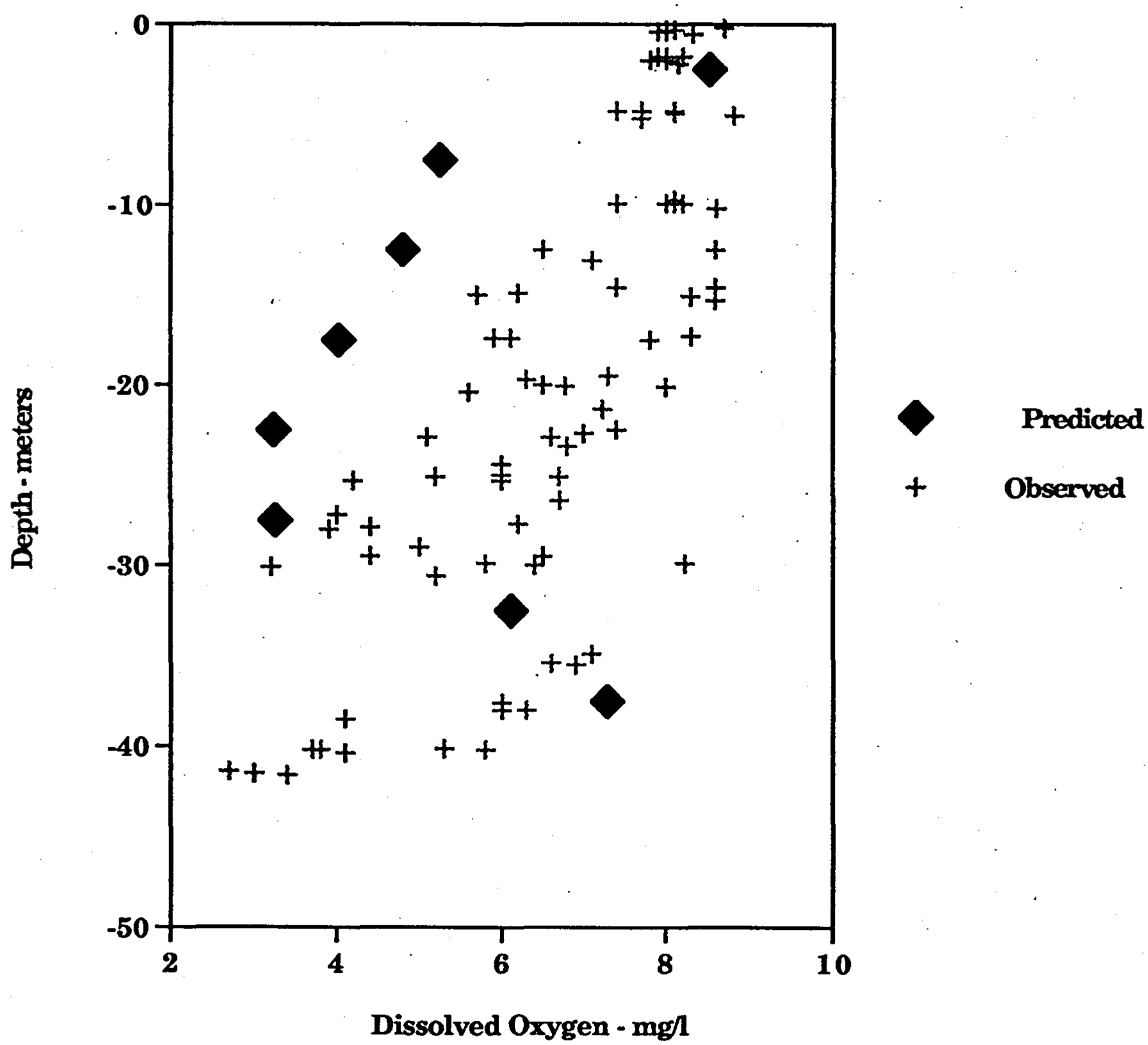


Figure 17. Predicted DO at I=8, J=10 compared with observed DO on September 7, 1993

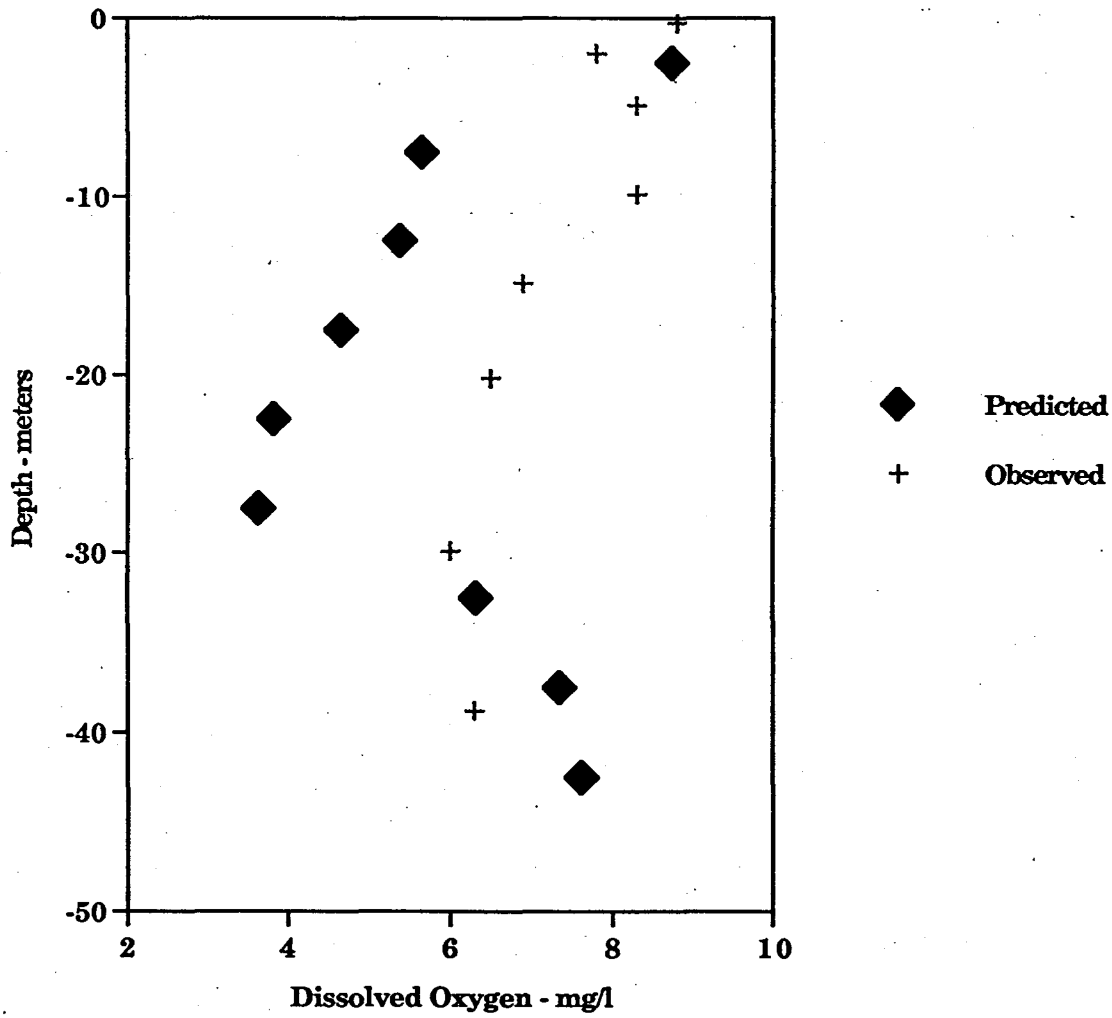


Figure 18. Predicted dissolved oxygen in Akutan Harbor during the Winter season under conditions of existing waste loadings from Trident Seafaoods.