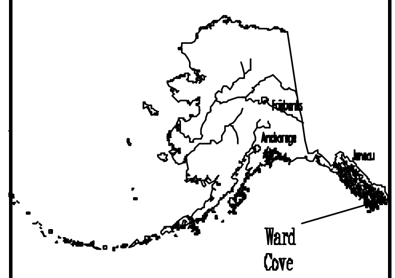
Ward Cove



BACKGROUND INFORMATION

Ward Cove is located in Southeast Alaska on the north side of Tongass Narrows about 5 miles northwest of the City of Ketchikan (Figure 1). The headwaters of the drainage start with Ward Creek which drops steeply from the mountains to the head of the Cove. Three small lakes provide brief stretches of calm in its otherwise rapid descent. Stream discharge is subject to wide variation, as the stream collects water from steep mountain slopes in the area. Ward Cove itself is 0.3 mile wide at the entrance, 0.5 mile wide at the widest point, and approximately 1 mile long. Centerline depths range from 9 meters at the head to over 50 meters at the mouth of the Cove.

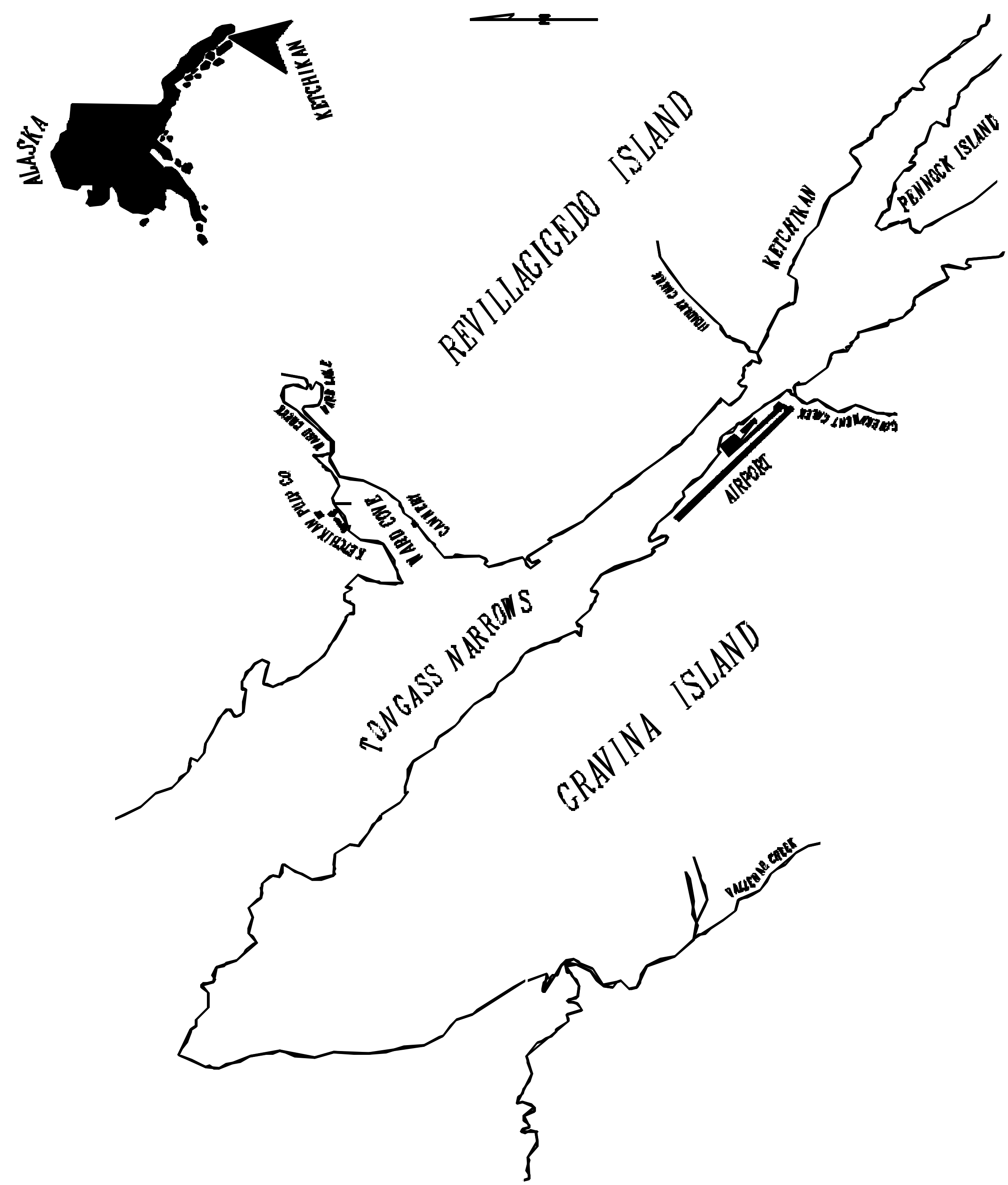
The physical setting and oceanography of Ward Cove characterize it as an estuary. There is no sill between Ward Cove and Tongass Narrows. As a result, water column stratification is expected to be similar to that in Tongass Narrows, apart from the effects of surface runoff and industrial discharges. Tongass Narrows is connected to the Gulf of Alaska through a series of larger channels leading to the waters of Dixon Entrance. Ward Cove is located in an area of heavy rainfall, receiving an average of 150 inches annually.

Land use adjacent to Ward Cove is dominated by industrial facilities. Ward Cove is the site of a pulp mill operated by the Ketchikan Pulp Company (KPC). KPC has been engaged in the manufacture of dissolving or paper grade wood pulp since the early 1950's. Ward Cove is also the site of a fish processing plant operated by Ward Cove Packing Company.

WATER QUALITY CONCERNS

Historically, Ward Cove supported a diverse and healthy aquatic community. With the onset of industrial operations in the early 1950's, water quality studies describe a picture of a declining marine environment in Ward Cove. Fish kills have been observed on occasion during summer months, providing further evidence of a decline in water quality. Ambient water quality monitoring data has shown that Ward Cove is water quality-limited due to periodic low dissolved oxygen levels.

Figure 1. Ward Cove Drainage



In response to the state's designation of Ward Cove as water quality-limited for dissolved oxygen, EPA has developed a detailed analysis of the dissolved oxygen (DO) deficit in the surface waters of Ward Cove. EPA recognizes that other problems have been documented in Ward Cove. These problems include sediment contamination, bottom deposits, low DO in bottom waters, and elevated chemical constituents in the water column. This Problem Assessment will be periodically updated to describe new information, technical analyses, and regulatory actions regarding these issues.

Segment of Concern

Water quality within the Ward Cove drainage is protected under Alaska's water quality standards. The following segment has been identified as water quality-limited for dissolved oxygen in Alaska's most recent Statewide Water Quality Assessment Report (1992):

Segment	Name	Location
10102-601	Ward Cove	Near Ketchikan

Although this segment was listed as water quality-limited based on dissolved oxygen and solids, recent data have shown that KPC's discharge could potentially cause violations of water quality standards for the following parameters: whole effluent toxicity, color, copper, mercury, manganese, total hydrocarbons, pH, sulfide, 2,3,7,8-TCDD, and chlorine.

Although Ketchikan Pulp Company's process discharge is the major influence on water quality the the drainage, other point and nonpoint sources also may contribute pollutants. Other point sources include the seafood processing facility and the log transfer activities. Nonpoint sources include runoff from adjacent industrial lands and forest lands.

Beneficial Uses Affected

The designated uses of Ward Cove are identified in Alaska's Administrative Code (AAC). Uses include water supply (aquaculture, seafood processing, industrial), aquatic life (growth and propagation), aquatic life harvesting, recreation (contact and secondary), and aesthetics. The beneficial use found to be at most risk in Ward Cove is the ability to support growth and propagation of fish, shellfish, other aquatic life, and wildlife. Recent and historic studies provide a picture of a biologically declining marine environment in the Cove. The studies document a gradual decline in biological activity and in water quality, in particular with respect to dissolved oxygen. There have also been a number of fish kills observed in the summer months, further indicating that the decline in water quality threatens the Cove's ability to support fish, shellfish, and other aquatic life.

Applicable Water Quality Standards

A number of water quality parameters have criteria values which have been adopted as regulatory standards for Ward Cove. Dissolved oxygen is a critical parameter for the protection of aquatic life. The State of Alaska water quality standards establish the following criteria for minimum concentrations of dissolved oxygen in marine waters:

> "Surface dissolved oxygen (D.O.) 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. D.O. shall not be reduced below 4 mg/l at any point beneath the surface. D.O. concentrations in estuaries and tidal tributaries shall not be less than 5.0 mg/l except when natural conditions cause this value to be depressed."

Ward Cove is considered both coastal and estuarine. As a result, the more stringent coastal criterion (6 mg/l) is applied at the surface, while the estuarine criterion (5 mg/l) is applied at depth.

The State of Alaska also has a water quality standard for residues (floating solids, debris, sludge, deposits, foam, and scum). The standard for protection of aquatic life is the most inclusive and states:

> *Shall not, alone or in combination with other substances or wastes, make the water unfit or unsafe, or cause acute or chronic problem levles as determined by bioassay or other appropriate methods. Shall not, alone or in combination with other substances, cause a film, sheen, or discoloration on the surface of the water or adjoining shorelines; cause leaching of toxic or deleterious substances; or cause a sludge, solid, or emulsion to be deposited beneath or upon the surface of the water, within the water column, on the bottom, or upon adjoining shorelines.*

The state standard for toxic and other deleterious organic and inorganic substances references EPA's 1986 Quality Criteria for Water (or Gold Book). In addition, on December 22, 1992, EPA promulgated chemical-specific, numeric criteria for priority pollutants necessary to bring all states into compliance with the requirements of section 303(c)(2)(B) of the Clean Water Act (57 FR 60846). The state of Alaska was one of 14 states included in this "National Toxics Rule" (NTR). The rule updated Alaska's standards, where necessary, by establishing enforceable acute aquatic life criteria and human health criteria, based on current EPA criteria for toxic pollutants. The following are the most stringent of the state criteria (aquatic life or human health) for the toxic pollutants of concern in Ward Cove:

Pollutant	Criterion
Copper	2.9 ug/l
Manganese	100 ug/l
Mercury	.025 ug/l
2,3,7,8-TCDD	0.14 pg/l
Sulfide	2.0 ug/l

Other relevant state numeric criterion are as follows:

Pollutant	Criterion
Petroleum hydrocarbons	15 ug/l
Color	5 ug/l
Chlorine	2 ug/l
pH	6.5-8.5

In a letter dated March 24, 1992, the State of Alaska provided guidance to EPA in interpreting its standard for toxicity. The guidance states that EPA should follow the approach recommended in EPA's Technical Support Document for Water Quality-based Toxics Control, which defines "no chronic toxicity" as a no observable effect concentration (NOEC) of 100 percent at the edge of the mixing zone. This is equivalent to 1 chronic toxic unit (TUc) at the edge of the mixing zone.

Available Monitoring Data

Ward Cove has been monitored periodically since 1953. The focus and results of data collection efforts are described in Appendix C. In addition to these studies, KPC has been required to monitor water quality in Ward Cove as part of their NPDES permit.

Earlier studies (FWQA, 1970) in Ward Cove showed persistent, severe water quality impacts on dissolved oxygen in the surface waters, and higher organic loadings from KPC during that period corresponded to greater impacts. More recent data, including the results of water quality studies by KPC from 1987 through 1989, showed continued violations of the State of Alaska's dissolved oxygen standard.

In addition to dissolved oxygen impacts, studies have documented significant impacts to sediments from debris, enrichment, and contamination. Available studies have documented sediment impacts related to the following parameters:

Metals	Oil and Grease
Toxicity	Organic Carbon
Sulfides	Organic Nitrogen
Hydrocarbons	

The extent to which these impacts are due to current discharges to the cove is unknown.

Finally, data concerning the chemical constituents in the KPC discharge is included in the fact sheet for the National Pollutant Discharge Elimination System (NPDES) permit for KPC. The fact sheet compares reported effluent concentrations of each parameter with water quality criteria.

Parameters of Concern

Ward Cove has been identified as water quality-limited due to violations of the dissolved oxygen standard. Adequate dissolved oxygen in the water column is a fundamental measure of the ability of the waterbody to support aquatic life. Ambient water quality monitoring indicates that Ward Cove experiences periodic low dissolved oxygen levels during the summer months. During those times, point source discharges of pollutants have a major influence on water quality in the drainage.

In addition to discharges of oxygen-demanding materials, the discharge of toxic pollutants by KPC further stresses the marine ecosystem.

Finally, sediment impacts stress, alter, or eliminate the resident benthic community due to habitat loss and sediment toxicity.

POLLUTANT SOURCES

Pulp Mill

The Ketchikan Pulp Company (KPC) has been engaged in the manufacture of dissolving or paper grade wood pulp utilizing the magnesium base, acid bisulfite process, since the early 1950's. In addition, mill operations have resulted in extensive log-transfer activities in the cove.

An average of 34 million gallons per day of wastewater generated in the manufacturing process are discharged from three outfalls into Ward Cove. A description of the current discharge conditions at KPC is included in Appendix D.

Stormwater on the mill site is collected and discharged at several locations in Ward Cove. The volume and pollutant concentrations, including BOD_5, of these discharges are unknown. Potential sources of oxygen demanding materials in stormwater include runoff from the dredge disposal site, material storage areas, and vehicle maintenance yards.

The draft NPDES permit for KPC includes a stormwater monitoring program to provide quantitative data about these discharges.

The bottom of Ward Cove in the vicinity of the mill is covered by both large and small wood debris as well as fiber mats. Sediments are generally characterized as high in organic content and high in hydrogen sulfide, indicating anoxic conditions. The settled matter and sediments exert demand on the dissolved oxygen of the bottom waters of the Cove. Dredging operations in the Cove may result in localized impacts on dissolved oxygen due to sediment resuspension. While sediments affect DO in the deep waters of the Cove, the preponderance of data indicate that the impacts to surface DO are not typically linked to conditions near the bottom (Appendix E).

Other Sources

Ward Cove Packing Company operates a seafood processing facility near the mouth of Ward Cove. Seafood wastes are ground to 0.5 inch and discharged to Ward Cove at a depth of approximately 58 feet at Mean Lower Low Water (MLLW). The magnitude of seafood processing activity and resulting discharges is significant, and the discharge generally occurs during the critical months of July, August, and September. However, due to the depth of this discharge (58 feet at Mean Lower Low Water), its significance in relation to surface water dissolved oxygen is believed to be minor (Appendix E).

ACTIONS TO DATE

KPC's allowable discharge of BOD_5 and TSS has been reduced over the years due to statutory requirements. KPC installed a primary wastewater treatment facility in 1972 and a secondary biological wastewater treatment facility for selected waste streams in 1979. Since 1984, KPC has been required to implement additional modifications at the mill to reduce the quantity and mass loading of the discharge.

In 1980, KPC's permitted BOD_5 limit was set at an average of 120,000 lbs BOD_5/day. For the period 1981-1984, the average BOD_5 level was reduced to 52,500 lbs/day. In 1986 the limit was reduced to an average of 46,100 lbs/day. The 1987 allowable effluent limit was further reduced to an average of 40,600 lbs/day. Effective January 1988, effluent limits of an average 32,400 lbs BOD_5/day (62,400 lbs BOD_5/day maximum) and an average 52,900 lbs TSS/day (98,000 lbs TSS/day maximum) were placed on the mill to bring it into compliance with federal Clean Water Act mandates.

EPA is proposing to reissue the NPDES permit for KPC. The draft permit contains a number of limitations designed to insure compliance with water quality standards. Compliance with these water quality-based limitations will require significant reductions in pollutant discharges from the facility.

POLLUTION CONTROL STRATEGY

To date, the approach taken to pollution control in Ward Cove has focused on NPDES permits for point sources. While steps have been taken by KPC to reduce pollutant loads to local marine waters, monitoring data indicates that water quality problems still exist. It appears that the discharge of BOD_5 from the KPC mill remains the primary cause of dissolved oxygen depletion in the surface waters of Ward Cove. As a result, development of a Total Maximum Daily Load (TMDL) for BOD needs to be initiated.

In addition to dissolved oxygen, other parameters of concern are addressed in the proposed reissuance of the NPDES permit for KPC. Wasteload allocations and resulting permit limits for these parameters are based on an analysis of dilution within an authorized mixing zone. These wasteload allocations represent "simple" TMDLs, where only a single pollutant source is identified and regulated.

A TMDL is an implementation plan which identifies levels of pollution control needed to achieve water quality standards. The TMDL needs to consider all sources: point, nonpoint, and background. The components used to address water quality problems through the TMDL process include:

- Effluent Limits
- Monitoring Requirements
- Compliance Schedules
- Remedial Actions
- Special Conditions

The TMDL approach for Ward Cove will focus first on surface dissolved oxygen and BOD loading, and on achieving water quality standards for pollutants discharged from point sources that impact the water column. Development of the initial water quality management plan will occur in 1993 under the authorities of Alaska's Water Quality Standards (18 AAC 70) and the federal Clean Water Act. The plan will identify preventative and remedial actions which will reduce pollutant loads to local marine waters. The program areas identified for action will continue to include NPDES permits as well as nonpoint source management plans, as needed. Also, as information about other potential water quality problems in the Cove is collected and studied, the plan could be expanded to address other pollutants of concern.

A critical element for success of this plan is continued ambient water quality monitoring in Ward Cove by KPC. Information provided by this monitoring program will document improvements in water quality which result from efforts of the agencies and the regulated community. The monitoring program also provides information needed to focus future pollution reduction efforts.

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APPENDICES

APPENDIX A

EXPANDED BACKGROUND INFORMATION

General

Ward Cove is located in Southeast Alaska on the north side of Tongass Narrows about 5 miles northwest of the City of Ketchikan (Figure 1). The headwaters of the drainage start with Ward Creek which drops steeply from the mountains to the head of the Cove. Three small lakes provide brief stretches of calm in its otherwise rapid descent. Stream discharge is subject to wide variation, as the stream collects water from steep mountain slopes in the area. Ward Cove itself is 0.3 mile wide at the entrance, 0.5 mile wide at the widest point, and approximately 1 mile long. Centerline depths range from 9 meters at the head to over 50 meters at the mouth of the Cove.

The physical setting and oceanography of Ward Cove characterize it as an estuary. There is no sill between Ward Cove and Tongass Narrows. As a result, water column stratification is expected to be similar to that in Tongass Narrows, apart from the effects of surface runoff and industrial discharges. Tongass Narrows is connected to the Gulf of Alaska through a series of larger channels leading to the waters of Dixon Entrance. Ward Cove is located in an area of heavy rainfall, receiving an average of 150 inches annually.

Land use adjacent to Ward Cove is dominated by industrial facilities. Ward Cove is the site of a pulp mill operated by the Ketchikan Pulp Company (KPC). KPC has been engaged in the manufacture of dissolving or paper grade wood pulp since the early 1950's. The Cove is also site of a fish processing plant operated by Ward Cove Packing Company.

Water Quality Concerns

Historically, Ward Cove supported a diverse and healthy aquatic community. With the onset of industrial operations in the early 1950's, water quality studies describe a picture of a declining marine environment in Ward Cove. Fish kills have been observed on occasion during summer months, providing further evidence of a decline in water quality. Ambient water quality monitoring data has shown that Ward Cove is water quality-limited due to periodic low dissolved oxygen levels.

APPENDIX B

APPLICABLE WATER QUALITY STANDARDS

Ward Cove has been designated as water quality-limited for dissolved oxygen as well as benthic accumulations of waste from historical activities in the watershed.

Within the State of Alaska, water quality standards are published pursuant to Title 46 of the Alaska Statutes (AS). The Alaska Department of Environmental Conservation (DEC), under authority vested by AS 46.03.010, 46.03.020, 46.03.070, 46.03.080, 46.03.100, and 46.03.110, can adopt rules, regulations, and standards as are necessary and feasible to protect water quality. Regulations dealing with water quality, to implement AS 46.03.020 and 46.03.080 are found in Title 18, Chapter 70, of the Alaska Administrative Code (AAC). Through the adoption of water quality standards, Alaska has defined the beneficial uses to be protected in each of its drainage basins and the criteria necessary to protect these uses

Segments of Concern

Water quality within the Ward Cove drainage is protected under Alaska's water quality standards. The following segment has been identified as water quality-limited in Alaska's most recent Statewide Water Quality Assessment Report (1992):

Segment	Name	Location
10102-601	Ward Cove	Near Ketchikan

Water quality in the drainage is affected by both point and nonpoint source discharges. Point sources include a major pulp mill complex as well as a seafood processing facility. Nonpoint sources include runoff from adjacent industrial lands as well as forest practices.

Beneficial Uses Affected

Designated uses for the Ward Cove drainage are found in Alaska's water quality standards [18 AAC 70.020(a)]. For marine systems, these include water supply, water recreation, growth & propagation of fish and other aquatic life, and harvesting for consumption of raw mollusks or other raw aquatic life. This list of beneficial uses was established by the Alaska Department of Environmental Conservation (DEC) pursuant to Title 46 of the Alaska Statutes and are identified in Table B-1. As charged by AS 46, DEC has adopted rules and standards that are necessary to protect the recognized beneficial uses. In practice, standards have been set at levels to protect the most sensitive of the uses: aquatic life and human health protection.

The beneficial use found to be at most risk in Ward Cove is the ability to support growth and propagation of fish, shellfish, other aquatic life, and wildlife. Recent and historic studies provide a picture of a biologically declining marine environment in the Cove. The studies document a gradual decline in biological activity and in water quality, in particular with respect to DO. State of Alaska officials have also observed a number of fish kills in the summer months, further indicating that the decline in water quality threatens the Cove's ability to support fish, shellfish, and other aquatic life.

Applicable Water Quality Criteria

A number of water quality parameters have criteria values which have been adopted as regulatory standards for Ward Cove. Included are temperature, turbidity (also referred to as total suspended solids or TSS), pH (a measure of

Table B-1 . Uses Protected by Alaska's Water Quality Standards

18 AAC 70.020(2)	Marine Water Uses
(A)	Water Supply
(i)	aquaculture
(ii)	seafood processing
(iii)	industrial
(B)	Water Recreation
(i)	contact recreation
(ii)	secondary recreation
(C)	Growth and propagation of fish, shellfish, other aquatic life, and wildlife
(D)	Harvesting for consumption of raw mollusks or other raw aquatic life

acidity), dissolved oxygen, fecal coliform bacteria, and dissolved chemical substances. Parameters of concern for Ward Cove include both dissolved oxygen and accumulated waste deposits on the bottom of the Cove from historical activities in the watershed.

Dissolved Oxygen: Dissolved oxygen is a critical parameter for the protection of aquatic life. The applicable dissolved oxygen criteria for Ward Cove are:

> "Surface dissolved oxygen (D.O.) concentrations in coastal waters 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. D.O. shall not be reduced below 4 mg/l at any point beneath the surface. D.O. concentrations in estuaries and tidal tributaries shall not be less than 5.0 mg/l except when natural conditions cause this value to be depressed."

Ward Cove is considered both coastal and estuarine. As a result, the more stringent coastal criterion (6 mg/l) is applied at the surface. The estuarine criterion is applied at depth.

Benthic Deposits: The general water quality criteria state that residues, sludge, and deposits, "shall not, alone or in combination with other substances or wastes, make the water unfit or unsafe, or cause acute or chronic problem levels as determined by bioassay or other appropriate methods." [18 AAC 70.020(b)]. Sediment problems are closely tied to benthic accumulations. For marine waters, Alaska's water quality criteria which describe sediment state that there shall be: "No measurable increase in concentration above natural conditions." The criteria for sediment in freshwater helps describe the intent by first addressing percent accumulations in gravel beds used by anadromous or resident fish for spawning. This criteria continues by stating that: "In all other surface waters no sediment loads (suspended or deposited) shall be present which can cause adverse effects on aquatic animal or plant life, their reproduction or habitat."

Although no specific numeric criteria for benthic accumulations of waste discharges have been established, the intent for protection of aquatic life is clear. Studies have documented biologically stressed benthic communities in Ward Cove. Solids from historical activities have infiltrated or covered bottom areas historically used by aquatic life. Although the specific effects on benthic communities in Ward Cove have not been quantified, burrowing and attached benthic organisms have been observed to be completely eliminated from areas covered by wastes deeper than about 1 inch in other Alaskan marine waters.

Alaska's water quality standards do allow for permitted "Zones of Deposit" for marine waters. Procedure to be followed are described in 18 AAC 70.033 which state:

"(a) In its discretion, the department will issue or certify a permit that allows deposit of substances on the bottom of marine waters within limits set by the department. The water quality criteria of 18 AAC 70.020(b) and the antidegradation requirement of 18 AAC 70.010(c) may be exceeded in a zone of deposit. However, the standards must be met at every point outside the zone of deposit. In no case may the water quality standards be violated in the water column outside the zone of deposit by any action including leaching from, or suspension of, deposited materials. Limits of deposit will be defined in a short-term variance issued under 18 AAC 70.015 or a permit issued or certified under 18 AAC 15.

(b) In deciding whether to allow a zone of deposit, the department will consider, to the extent it deems appropriate,

(1) alternatives that would eliminate, or reduce, any adverse effects of the deposit;

(2) the potential direct and indirect impacts on human health;

(3) the potential impacts on aquatic life and other wildlife, including the potential for bioaccumulation and persistence;

(4) the potential impacts on other uses of the water body;

(5) the expected duration of the deposit and any adverse effects; and

(6) the potential transport of pollutants by biological, physical, and chemical processes.

(c) The department will, in its discretion, require an applicant to provide information that the department deems necessary to adequately assess (b)(1) - (b)(6) of this section. In all cases, the burden of proof for providing the required information is on the person seeking to establish a zone of deposit."

There are currently no zones of deposit which have been designated by the Alaska Department of Environmental Conservation (DEC) for Ward Cove.

APPENDIX C

AVAILABLE MONITORING DATA

Ward Cove has been monitored periodically since 1953. In addition to these studies, KPC has been required to monitor water quality in Ward Cove as part of their NPDES permit.

Review of Historical Data

Ward Cove studies were published in 1953, 1957, 1965, 1970, 1975, and 1989. KPC's discharge monitoring reports (DMRs), which are required as a part of their NPDES permit, provide additional evidence of conditions within the Cove between 1980 and 1989. Monitoring site locations are shown in Figure C-1. Field data collected by KPC show persistent, severe water quality impacts on dissolved oxygen in the surface waters (depth < 1 meter) of Ward Cove (Figure C-2). ADEC found that, for the months of July through September, the percentage of times measurements were less than the water quality standard ranged from 55% to 100%. Earlier studies (FWQA, 1970) in Ward Cove showed similar results, although the magnitude and extent of the water quality impacts were greater at that time. During the late 1960's and early 1970's, organic loadings from KPC were higher. More recent data, including the results of water quality studies by KPC from 1987 through 1989, show continued violations of the State of Alaska's dissolved oxygen standard.

The principal analyses of water quality conditions in Ward Cove are contained in the following reports:

Alaska Water Pollution Control Board (1953,1957)

Federal Water Pollution Control Administration (1965)

Federal Water Quality Administration (1970)
Environmental Protection Agency (1975)

KPC Discharge Monitoring Reports (1980-Present)

Jones and Stokes Associates (1989)

A summary of these reports is presented below.

1953

Ward Cove was surveyed by the Alaska Water Pollution Control Board (1953) to obtain information on the chemical, physical, hydrological, and biological conditions of the Cove before wastes from the pulp mill were discharged. The survey was conducted from October 1951 through September 1952, with over 940 chemical, 100 bacteriological, 60 bottom, and 70 plankton samples taken from eight stations in the Cove. The following information is summarized from the Board's report.

Dissolved oxygen (DO) concentrations were generally >80 percent of saturation during the winter and spring months. Although the water temperature increased during the summer months, the upper water layer became supersaturated with oxygen as a result of photosynthesis. The increase in DO was observed in water to the depths of over 100 ft. There was a decline in DO in lower depths in the fall, coinciding with the end of the heavy plankton bloom. Biochemical oxygen demand (BOD_5) varied from a low of almost 0 ppm to a high of almost 1.0 ppm in late summer, coinciding with the end of the plankton bloom and a high input of dead plankton and plant material.

Figure C-1 . KPC Monitoring Site Locations

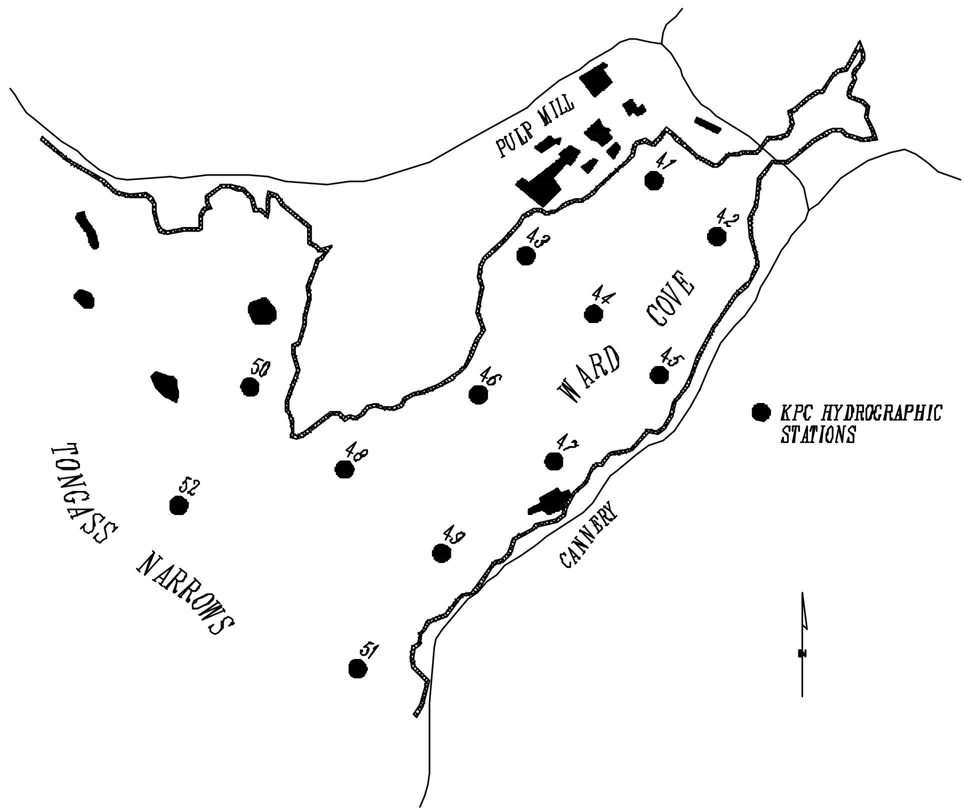

Figure C-2 . Dissolved Oxygen in Ward Cove (KPC Monitoring: 1980-87)

Winter plankton samples were dominated by filamentous algae, fragments of Ulva sp. and Fucus sp., ctenophores, and many species of diatoms. With the increasing temperatures of summer, many pelagic eggs and larvae were represented in the samples. Larval clams, starfish, barnacles, and snails as well as diatoms and other plankton reached such high abundances that the surface of the water looked smokey.

Bottom samples were taken from depths of 20-185 ft. Collections contained limpets, calcareous tube worms, clams (including Macoma), nermerteans, polychaetes, brittle stars, and algae. The substrate varied from a rocky bottom through sand and gravel to a "slimy" mud at the cove entrance. It was noted that some benthic samples contained well-preserved sawdust (still brown and solid to touch) originating from a sawmill which operated in the 1920s.

The results of the 1952 study strongly indicate that Ward Cove supported a typical marine ecosystem, but the persistence of sawdust suggested a limited ability to decompose woody organic material.

1957

A follow-up study by the Alaska Water Pollution Control Board, suggested in the 1953 report, was implemented in 1955 after the pulp mill had been in partial operation for 15 months and at full capacity (525 tons pulp processed per day) for 4 months. A total of 258 samples were collected from 10 stations in August and December 1955 and March 1957 (Alaska Water Pollution Control Board 1957).

Oxygen depletion was noted at night time in cove waters near the pulp mill, although phytoplankton activity replenished the oxygen in the day. During the winter, when planktonic activity was low, dying fish were occasionally observed during the study, and fish kills were reported to the scientists by fishermen and U.S. Fish and Wildlife personnel. Bottom samples, collected near the outfall, included clams, of which approximately 50 percent were dead.

1965

Water samples were collected at 13 stations on 28 August 1965 by the Federal Water Pollution Control Administration (1965). The cove water was well stratified (density increasing with depth), which inhibited downward mixing of surface discharged wastes. At this time, the main effluent discharge averaged 34.4 mgd. The effluent had a BOD_5 of 610 mg/l, a sulfite waste liquor (SWL) content of 7,285 mg/l, suspended solids content of 2,800 mg/l, and a volatile solids content of 160 mg/l.

The maximum DO concentrations were found between 5 and 10 m depth, with values of 7.33 mg/l (85 percent saturation) in Tongass Narrows and 5.59 mg/l (64 percent saturation) in Ward Cove. DO in Ward Cove decreased to 1.76 mg/l (21 percent saturation) towards the surface and 1.96 mg/l at 40 m depth. Near-surface depressions in DO were attributed to the presence of pulp mill wastes, while near-bottom decreases in DO were attributed to the high oxygen demand of settleable solids in the pulp mill discharge (Federal Water Pollution Control Administration 1965).

1970

A total of 413 DO measurements were taken during the study by the Federal Water Quality Administration (1970). Of the total, 37 percent were below 6 mg/l. High SWL concentrations were found in Ward Cove and Tongass Narrows. Of 276 water samples taken in the top 20-m layer from May 1968 through May 1969, 50 percent had SWL concentrations greater than 44 ppm, 35 percent had SWL concentrations greater than 100 ppm, and 11 percent were greater than 500 ppm.

1975

A total of 266 water samples were taken by EPA from nine stations in Ward Cove and nine stations in Tongass Narrows at depths of 1, 7, 10, and 12 m for one week in September 1974 (EPA 1975). Mill discharges at this time were 42 mgd.

Data from the studies revealed that 24 percent of all samples had less than 6.0 mg/l of dissolved oxygen, and that 69 percent of near-surface samples (1 m) had DO values below 6.0 mg/l. On one of four observations at the head of Ward Cove near the water surface, DO was 1.0 mg/l. EPA concluded that there had been no major improvements in the DO concentrations in Ward Cove since the 1968-1969 study by its predecessor (Federal Water Pollution Control Administration).

The report also notes that SWL at concentrations of 50 mg/l are toxic to phytoplankton and fishfood organisms; at concentrations of 10 mg/l they cause damage to immature fish and shellfish (Department of the Interior 1967). SWL was distributed in the upper 7 m of water with the highest concentrations at the surface. All the water samples taken at 1-m depth had SWL concentrations of 50 mg/l or more at least once, and 10 mg/l concentrations were observed 97 percent of the time at all 1-m samples except those from two areas with apparently strong flushing or dilution. The maximum SWL concentration recorded was 872 mg/l, and 41 of 64 surface samples had concentrations over 100 mg/l.

Chemical analyses of bottom sediment showed high concentrations of organic nitrogen (0.36-0.75 percent) and total sulfides (0.15-0.43 percent). The chemical oxygen demand ranged from 147-655 percent (dry weight) and volatile solids from 11.1-46.9 percent (dry weight). The highest values were downstream of the main outfall. As a reference, the report noted that uncontaminated marine deposits have values of less than 0.1 percent organic nitrogen and sulfides, and less than 5 percent of both volatile solids and chemical oxygen demand.

Visual observations of the benthos revealed a paucity of organisms; with the majority being pollution-tolerant polychaetes. No macroscopic animals were observed at the head of the Cove.

1980-1989

Since 1980, KPC has monitored dissolved oxygen, salinity, and temperature in Ward Cove in accordance with its NPDES permit. Some of this data is used for validation of the computer model outlined in the technical analysis section of this document. Figure C-2 depicts the results of KPC's data collection.

1989

The Jones and Stokes (1989) report included a review of the previous studies as well as field work to assess water quality impacts. Water quality sampling again indicated that Ward Cove dissolved oxygen fell below the state standard.

In addition to dissolved oxygen impacts, this study documented significant impacts to sediments from debris, enrichment, and contamination. Sediment monitoring focused on the following parameters:

Metals	Oil and Grease
Toxicity	Organic Carbon
Sulfides	Organic Nitrogen
Hydrocarbons	

Data Interpretation

The State of Alaska's Department of Environmental Conservation (ADEC) tabulated the number of times the DO measured by KPC in the surface water was less than the State of Alaska water quality standard (DO = 6.0 mg/l) during the years 1985-87. Results of this information is presented in Table C-1.

Table C-1 . Summary of DO Values in Ward Cove (one meter depth)

Date	# of Samples Above 6 mg/L	# of Samples Below 6 mg/L	% of Samples Below 6 mg/L
May 1985	12	0	0%
May 1986	12	0	0%
May 1987	11	1	8%
June 1985	6	6	50%
June 1986	12	0	0%
June 1987	9	3	25%
July 1985	6	6	50%
July 1986	0	6	100%
July 1987	2	4	67%
August 1985	0	6	100%
August 1986	1	11	92%
August 1987	5	7	58%
September 1985	0	11	100%
September 1986	0	12	100%
October 1985	9	3	25%
October 1986	6	0	0%

Values were taken from the results of sampling surveys taken at stations 41-46 (See Figure 2 for map of station locations) during the period May through October for the years 1985-1986 and May through September of 1987.

Source: Kruse and Viteri, Alaska Department of Environmental Conservation

APPENDIX D

POLLUTANT SOURCES

Since the early 1950s, Ketchikan Pulp Company (KPC) has been engaged in the manufacturing of dissolving or paper grade wood pulp utilizing the magnesium base, acid bisulfate process. An average of 34 million gallons per day of wastewater generated in the manufacturing process are discharged from three outfalls into Ward Cove. The current National Pollutant Discharge Elimination System (NPDES) permit for the facility limits the discharge of biochemical oxygen demand (BOD_5) to an average of 32,400 pounds per day. As described in Appendix E, the available information indicates that KPC's discharge is the primary cause of depressed DO in the surface waters of Ward Cove.

Stormwater on the mill site is collected and discharged at several locations in Ward Cove. The volume and pollutant concentrations, including BOD_5, of these discharges are unknown. Potential sources of oxygen demanding materials in stormwater include runoff from the dredge disposal site, material storage areas, and vehicle maintenance yards. The draft NPDES permit for KPC includes a stormwater monitoring program to provide quantitative data about these discharges.

As described in the water quality studies listed earlier, the bottom of Ward Cove in the vicinity of the mill is covered by both large and small wood debris as well as fiber mats. Sediments are generally characterized as high in organic content and high in hydrogen sulfide, indicating anoxic conditions. The settled matter and sediments exert demand on the DO of the bottom waters of the Cove. Dredging operations in the Cove may result in localized impacts on DO due to sediment resuspension. While sediments affect DO in the deep waters of the Cove, the data indicate that the impact of the sediments on surface waters is not significant (see Appendix E).

Ward Cove Packing Company operates a seafood processing facility near the mouth of Ward Cove. Seafood wastes are ground to 0.5 inch and discharged to Ward Cove at a depth of approximately 58 feet at Mean Lower Low Water (MLLW). The magnitude of this discharge with respect to organic loading is significant. In 1988, for example, Ward Cove Packing Company reported that 3,847,117 pounds of fish were processed during a 35-day processing period. According to EPA (1975) guidelines, on the average, 45.5 pounds of BOD_5 are generated by every 1000 pounds of salmon processed. For the 1988 season, this corresponds to a daily average BOD_5 discharge from Ward Cove Packing Co. of approximately 5000 pounds. The discharge generally occurs during the critical months of July, August, and September. Due to the depth of this discharge (58 feet at Mean Lower Low Water), its significance in relation to surface water DO is believed to be minor (see Appendix E).

Point Sources

<u>Effluent Quality</u>. The quality of KPC's effluent is governed by their National Pollutant Discharge Elimination System (NPDES) permit. This permit limits the amount of 5-day biochemical oxygen demand (BOD_5), total suspended solids (TSS), temperature, and pH of the discharge. The BOD_5 and TSS in the discharge have traditionally been the Environmental Protection Agency's (EPA) main concern with regard to the mill's effluent composition. The permit also mandates a water quality monitoring program.

<u>Effluent Quantity and Temperature</u>. KPC discharges between 25-50 million gallons/day (mgd) of wastewater through three different outfalls into Ward Cove. These discharges are referenced in their NPDES permit as outfalls 001, 002, and 003.

Outfall 001 is the main outfall line. The effluent discharged through Outfall 001 normally accounts for at least 50 percent of the total discharge volume and receives no wastewater treatment. The temperature of the discharge runs from a low of 20°C to an average temperature of 32-35°C, although it can have a maximum daily average temperature approaching 40°C.

Outfall 002 is a combination of primary and secondary treated wastewater. The average discharge temperature, 25-30°C, is generally cooler than that of the main outfall.

Outfall 003 is the discharge from the mill's water supply treatment (filtration) plant. The mill's water supply is from Lake Connell, an impoundment basin which drains to Ward Creek. The water treatment plant's wastewater has an average flow of 5.4 mgd, with a high volume of 8 mgd. Its discharge temperature is essentially the same as that of Ward Creek.

Combined, these three discharges flow at a rate that is normally around 30-35 mgd on an average basis for each month and between 40-45 mgd as a monthly maximum. During summer months, when rainfall is small, the mill discharges can exceed the flow in Ward Creek.

Discharges 001 and 002 take place behind a log boom which confines the foam that is produced by the discharge to the area between the boom and the immediate vicinity of the mill. Log rafts and log booms along the west shore of the Cove effectively leave a narrow, open water channel along the shore out to Tongass Narrows.

Nonpoint Sources

Non-point source pollution typically results from agricultural, silvicultural, and land use development activities. Land use adjacent to Ward Cove is dominated by the pulp mill complex, and most runoff from these areas is collected and discharged as point source stormwater (see above). Upstream activities may lead to non-point contributions to Ward Creek. These impacts are not documented; limited data from the 1989 study indicate DO concentrations between 7.7 and 8.7 mg/l at the mouth of Ward Creek.

APPENDIX E

TECHNICAL ANALYSIS

The physical setting and oceanography of Ward Cove characterize it as an estuary. An estuary is defined as a:

> "semi-enclosed 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." (Pritchard, 1967)

Estuary settings range from coastal plain to steep-sided fjords, but all have the common feature of being a mixing region for fresh and salt water. Density differences between fresh and salt water can drive circulation and, hence, influence mixing and flushing in estuaries. The net circulation in an estuary depends on the amount and timing of fresh and salt water input as well as other influences such as winds, tides, topography, relation to continental shelf regions, and latitude. These influences can combine in various ways so that distinctly different circulations develop in otherwise similar estuaries.

Identification of Significant Sources

In Ward Cove there are a number of possible sources for low DO in the surface water. These sources include:

- respiration of phytoplankton
- upwelling of oxygen-depleted water from oceanic sources or Ward Cove bottom water
- discharge of organic, oxygen-demanding material by KPC and/or by the Ward Cove Packing Co.'s seafood processing plant

Oxygen demand associated with phytoplankton respiration is a function of the rate of primary productivity. Jones & Stokes (1989) measured rates of primary productivity in Ward Cove during August 1988. Their results showed that primary productivity was low; they concluded that oxygen production was minimal in Ward Cove. When oxygen production by phytoplankton is low, respiration is also low. Therefore, based upon the results of the Jones & Stokes studies (1989), phytoplankton respiration was assumed to be of little significance for the DO budget in Ward Cove.

Upwelling can cause low DO in the surface water of estuaries when the oceanic source water is low in DO or when the bottom water from the estuary itself has been depleted of oxygen by sediment demand. Low DO associated with oceanic source water in Tongass Narrows may occur, but has not been documented in the studies surveyed for this report . Low DO in the bottom water has been observed in several studies (e.g., EPA, 1975; Jones & Stokes, 1989). When low DO in the surface is a result of upwelled water, DO just below the surface should be equal to or less than surface DO.

Of the several data sets surveyed, only the Jones & Stokes (1989) DO data from August and September 1988 has characteristics which could be interpreted as being caused by upwelled water. However, the preponderance of the water quality data from Ward Cove, including measurements made by KPC, show DO increasing with depth. Under conditions for which DO increases with depth, the mechanism of upwelling does not explain low DO in the surface water. While Jones & Stokes (1989) concluded that their data support the hypothesis that upwelling can lead to low DO in the surface, the results of the other field studies support the hypothesis that the source of oxygen demand originates in the surface, or near-surface waters of the estuary.

Additional support for the hypothesis that the source of oxygen demand originates in the surface, or near-surface waters, and, furthermore, that it is associated with discharge from the KPC pulp mill is provided by the measurements of Pearl Benson Index (PBI) reported in KPC's receiving water monitoring program. Measurements of PBI provide an index of the amount of sulfite waste liquor present. Since the only source of sulfite waste liquor in Ward Cove is the KPC mill, one way of testing this hypothesis is to determine if there is a positive correlation between PBI measurements and DO deficit in Ward Cove. Such an analysis was performed, using KPC receiving water quality data for the calendar year 1986. KPC measures temperature, salinity, DO, pH and PBI at depths of 1 and 5 meters at the 12 locations shown in Figure E-1. Data collected on the dates shown in Table E-1 were included in the analysis. These data were used to make estimates of the total amount of PBI and DO deficit in a one- meter thick surface layer of Ward Cove.

Table E-1 .

Estimates of Total PBI and DO Deficit in Surface Waters of Ward Cove (1986)

Date	PBI (kg)	DO Deficit (kg)
January 9	2273	3072
January 29	5497	2555
February 12	2716	3221
February 28	4965	4091
March 21	8841	3411
March 31	6358	2980
April 21	3936	1872
May 20	6157	2408
May 30	4770	3230
June 24	2625	2855
July 30	8887	5616
August 19	24300	4833
August 29	29680	7008
September 9	9971	4286
September 29	19070	6024
October 24	4205	2923
November 14	1173	2030
November 30	4402	2230
December 19	2879	2466
December 30	3272	3039

Note: Estimates obtained from water quality measurements made by KPC as part of their NPDES permit.

The DO deficit was defined as the difference between the 100% DO saturation level at the observed temperature and salinity and the observed DO. The total PBI and DO deficit in the surface layer for each of the survey dates were estimated in the following. First, Ward Cove was divided into several discrete, equal elements as shown in Figure E-1. Ordinary kriging (Journel, 1989) was then used to estimate the values of temperature, salinity, DO and PBI at the center of each of the discrete elements. The 100% saturation level of DO was determined for each element based upon the following relationship (Mills et al, 1985):

$$DO_{sat} = 14.6244 - 0.367134T + 0.0044972T^2 - 0.0966S + 0.0002739S^2$$

where,

DO_{sat} = the saturation concentration of dissolved oxygen, mg/l
T = the water temperature, ^{o}C
S = the salinity, parts per thousand (o/oo)

The DO deficit, DDO, for each element was estimated as

$$DDO = DO_{sat} - DO$$

Total estimated PBI and DO deficit in Ward Cove for each of the survey dates in Table E-1 are plotted as a time series in Figure E-2. A regression analysis was also performed on these data. Results are shown in Figure E-3. In spite of the fact that the processes leading to the decay of PBI and DO deficit are different, linear regression accounts for 74% of the variance in the analysis.

The other major source of organic loading to Ward Cove is the Ward Cove Packing Company. The magnitude of their discharge with respect to organic loading is significant. In 1988, for example, Ward Cove Packing Co. reported that 3,847,117 pounds of fish were processed during a 35-day processing period. According to EPA (1975) guidelines, on the average, 45.5 pounds of BOD_5 are generated by every 1000 pounds of salmon processed. For the 1988 season, this corresponds to a daily average BOD_5 discharge from Ward Cove Packing Co. of approximately 5000 pounds. The discharge generally occurs during the critical months of July, August, and September.

The discharge is made through a submerged outfall located at a depth of 58.0 feet below Mean Lower Low Water (MLLW). This discharge may have a significant impact upon dissolved oxygen levels in the intermediate and deep waters of Ward Cove. However, based upon the analysis of DO data, as described above, the contribution of Ward Cove Packing Co.'s discharge to water quality impacts in the

Figure E-1 . Finite Difference Grid for DO / BOD Model

Figure E-2 . Total PBI / DO Deficit Time Series
(Ward Cove Surface Layer: 1986)

Figure E-3 . PBI / DO Deficit Regression surface water was assumed to be of minor importance compared to the KPC discharge. In consideration of the factors described above, the analysis of DO in the surface waters of Ward Cove focus upon the organic loading from the KPC pulp mill and the physical, chemical and biological processes which describe the fate of oxygen-demanding material. The development of the model for characterizing the DO budget is described in the following section.

Model of the Dissolved Oxygen Budget

Model Structure

The model chosen for characterizing the DO budget of the surface waters of Ward Cove was a three-dimensional, steady-state finite-difference model which included the following processes:

- horizontal and vertical turbulent diffusion
- horizontal advection
- first-order stabilization of biological oxygen demand (BOD)
- first-order transfer of DO across the air-water interface

The justification for choosing a steady-state model was developed from an evaluation of local meteorologic and hydrologic data. Specific emphasis was given to the months of July, August and September, for which water quality impacts have historically been the greatest.

Continuous hydrologic data from Ward Creek, the primary source of freshwater, was only collected during the period 1949-1958. The record subsequent to October 1953 reflects the effects of diversion to KPC's water treatment plant upon streamflow in Ward Creek. For the months of July, August and September the records from 1953 to 1958 show that flow in Ward Creek remains relatively stable over periods of five to forty-five days.

Flow in Ward Creek responds primarily to precipitation in the watershed, but it is also controlled by the regulation of releases from Connell Lake Dam. Rainfall events in the watershed typically have a five to ten day recurrence during the critical months. The frequency response of the Ward Creek watershed is smoothed further by the operation of the dam, particularly during the summer low flow months.

Wind speed also appears to be an important factor in determining the level of DO in Ward Cove. Wind mixing provides a source of oxygen reaeration and is source of kinetic energy for turbulent mixing processes. Analysis of wind speed characteristics in the vicinity of Ward Cove have been done by Alaska Water Pollution Control Board (1957) and Jones & Stokes (1989). Although both of these reports consider only a limited data set, the results are consistent with the assumption that wind speeds are lowest during the critical months and that there are often periods of five to six days between meteorological events with wind speeds greater than 7 knots (Jones & Stokes, 1989).

Given these data and discretizing the water body of interest into volume elements as shown by the grid in Figure E-1, a material balance on each element (Figure E-4) for DO and BOD can be developed.

Figure E-4 . Typical Numerical Model Element

Parameter Estimation

Once the model structure has been defined, it is necessary to estimate the model parameters. In this case the parameters are K_1, K_2, k_x, k_y, k_z, $Q_{in,x}$, $Q_{out,x}$, $Q_{in,y}$, $Q_{out,y}$, (i,j,k), and A(i,j,k). In principle, each of these parameters must be estimated for every one of the discrete elements defined in Figure E-1. This cannot be done with the available data.

Estimates can be obtained, however, by placing certain restrictions upon the parameter set. The restrictions used in this analysis were:

> K_1, K_2, k_x, k_y, and k_z are constant throughout the estuary
>
> A(i,j,k), and (i,j,k) are non-zero only for the elements which receive the discharge from KPC and Ward Creek
>
> the magnitudes of $Q_{in,x}$, $Q_{out,x}$, $Q_{in,y}$ and $Q_{out,y}$ are a functions of the discharges from KPC and Ward Creek and location, only
>
> volume changes due to tidal fluctuations are negligible in the continuity equation when averaging over several tidal periods

Given these restrictions, available data were used in both a qualitative and quantitative manner to obtain parameter estimates. Following is a description of the way in which each of the parameters was estimated.

Horizontal Velocity Structure

Current structure was estimated using field data, where available, as a guide. Drogue tracks comprise most of the field data relating to the velocity. AWPCB (1953) used a Gurley-type meter to make current measurements in Ward Cove and reported only that most of the movement was in the surface water at depths less than three feet. Drogues released in Ward Cove (AWPCB, 1957; Jones & Stokes, 1989) have a more or less random pattern when released in the central portion of Ward Cove. Drogues released near the KPC discharge (AWPCB, 1957), however, tended to stay in the vicinity of the shore until they exited the estuary.

The two major sources of freshwater discharge in Ward Cove are the KPC discharge and Ward Creek. Based upon the qualitative information available from visual observations and measurements of drogue tracks, it was assumed in this study that the KPC discharge is initially distributed uniformly over the top two meters of the surface. Furthermore, it was assumed that the maximum horizontal velocity occurs near the discharge point and decreases in the direction of the opposite shore. In the seaward direction, it was assumed that the shape of this plume flattens out, or disperses with increasing distance from the discharge point.

A similar approach was used to characterize the horizontal current distribution associated with the Ward Creek Flow. It was assumed that the discharge from Ward Creek is to the surface layer of one meter thickness and is distributed approximately uniformly across the estuary.

Deoxygenation Rate (K_1)

Water samples were collected at Stations 43, 44 and 45 (Figure C-1) in Ward Cove on October 25, 1989, preserved and handled according to the quality assurance plan (Bodien, 1989) and shipped to the EPA Regional Laboratory at Manchester, Washington. Standard methods (American Public Health Service, 1985) were used to determine the 5-, 10-, 15- , 20- and 60-day BOD of each sample. The simplex method (Nelder and Mead, 1965) for minimizing a nonlinear function, using the FORTRAN software implementation given by

Press et al. (1986), was used to estimate both the rate constant, K_1, and the ultimate BOD of each sample. Estimates of these parameters are given in Table E-2.

Table E-2 .

Estimates of Ultimate BOD and Deoxygenation Rate, K_1, for Samples Collected at 3 Stations in Ward Cove (October 1989)

Station	Ultimate BOD (mg/l)	Deoxygen. Rate, K_1 ($days^{-1}$)
43	8.52	0.127
44	2.34	0.097
45	2.19	0.165

Note: Station numbers correspond to locations on Figure C-1.

Reaeration Rate (K_2)

According to Bowie et al (1985), there is very little research available for estimating the magnitude of the reaeration rates in lakes and estuaries. Their summary includes reaeration coefficients which are appropriate primarily for well-mixed estuaries. Bowie et al (1985) also summarize a number of reaeration formulae from lakes. These formulae for lakes are all given in terms of surface transfer rates and are either constant, first- or second-order functions of the wind speed. In view of the lack of available, reliable information regarding the reaeration rate, it was treated in this report as a variable to be estimated from the observations of dissolved oxygen.

BOD and DO Source Terms, A(i,j,k), (i,j,k)

The source terms for BOD and DO, A(i,j,k), and (i,j,k), are a function of discharge and concentration. For the KPC discharge, daily measurements of BOD_5 and flow rate are available as a requirement of the NPDES discharge permit. Five-day moving averages of these measurements were used to estimate the loadings. BOD_5 was converted to ultimate BOD using the rate constant obtained from the field measurement in the standard formulation:

$$BOD_{ultimate} = BOD_5/(1. - e^{-5. * K1})$$

It was assumed that the DO in the KPC discharge was 5.0 mg/l.

For the Ward Creek source terms, it was assumed that the ultimate BOD was zero and the DO was 90% of saturation. These values are consistent with measurements of water quality from Ward Cove prior to the operation of the KPC facility (AWPCB, 1953). The five-day average flow in Ward Creek was treated as a variable to be estimated from the water quality data.

Coefficients of Turbulent Diffusion: k_x, k_y, k_z.

Coefficients of horizontal and vertical turbulent diffusion were treated as variables to be estimated from the water quality data.

Estimation Method

Given limitations and assumptions described above, a total of five parameters remained to be estimated from the water quality data. These five parameters were:

k_x, k_y, and k_z; coefficients of turbulent diffusion
K_2; reaeration rate
$Q_{Ward\ Creek}$; the five-day average flow in Ward Creek.

KPC's water quality monitoring program includes observations of temperature, salinity, and DO at 12 locations in Ward Cove and Tongass Narrows (Figure C-1). Water quality samples collected on three different dates, August 19, 1986; August 29, 1986; and September 19, 1986, were chosen for the analysis. Data from these surveys were used to solve the inverse problem of finding values of the five unknown parameters which provide the best solution given the 12 observations.

For the purposes of this analysis, the best solution was defined as that which minimizes the sum of the squared differences between the observed and simulated state variables. Given a parameter set, q, with a cost function, J(q), defined as:

$$J(q) = (z - x)T(z - x)$$

where,

z = the vector of observations
x = the vector of state variables generated by the model,

the parameter estimate is the set of parameters, q*, for which:

$$J(q*) = \min (J(q))$$

The problem, as formulated, is a non-linear estimation problem, and, therefore, cannot be solved by standard least-squares methods (Larsen and Marx, 1981). In this case, a two-stage approach was used to find an optimal estimate of the parameters. The first step was an attempt to obtain an approximation to the optimal estimate. This was done by characterizing the five parameters as random variables with distributions estimated from available information. The reaeration rate, expressed in terms of a surface transfer rate, and the coefficients of eddy diffusivity were assumed to have log-normal distributions with mean and coefficient of variation as shown in Table E-3.

Empirical cumulative distribution functions (CDF) were computed for the five-day average flow in Ward Creek using the streamflow data collected at USGS gage 15062000 during the period 1953-1958. CDF's for the five-day average flow during the months of August and September, for this period, are shown in Figures E-5 and E-6.

Figure E-5 . Empirical CDF for 5-day Average August Streamflow in Ward Creek (USGS Gage 1506200: 1953-1958)

Table E-3 .

Means and Coefficients of Variation Used for Initial Estimate of Parameters

Parameter	Mean	Coefficient of Variation
k_x	10 m^2 /sec	1.0
k_y	1 m^2 /sec	1.0
k_z	$5x10^{-5}$ m^2 /sec	1.0
K_2	0.5 $days^{-1}$	2.0
$Q_{Ward\ Creek}$	1.0 m^3 /s	0.5

Values for the five parameters were then chosen at random, based upon the assumed distributions. Solutions were obtained with the full parameter set. The squared difference between observed and simulated state variables was calculated. 200 such simulations were performed with data from each of the three field studies. The parameters giving the minimum estimate of the cost function, J(q), were then used in the second step as the initial values for finding the best local minimum with the downhill simplex method (Nelder and Mead, 1965).

While this process of parameter estimation generally leads to a local minimum, it does not guarantee that such a minimum is unique. Nor does it guarantee that the resulting model is acceptable. Additional criteria must be developed to define model acceptability.

Figure E-6 . Empirical CDF for 5-day Average Sept. Streamflow in Ward Creek (USGS Gage 1506200: 1953-

1958)

For this study, two criteria were developed to define acceptability, one based upon the difference between simulated and observed at all sampling locations, the other based upon the mean of the differences. It was assumed that the errors were normally distributed and a confidence interval of 0.999 was chosen. For a confidence interval of 0.999, the specific criteria were:

> the difference between observed and simulated was less than ±3.3 standard deviations of the calibration error of the measurements

> the mean of the differences was less than ±3.3 times the standard error of the mean of the calibration error based upon 18 samples (the number used in the parameter estimation process).

Sampling error was estimated from calibration results performed in the August 1988 studies of Ward Cove (Jones & Stokes, 1989). Differences between KPC DO measurements and measurements made by two other sampling parties (Kinnetic Labs, Inc. and Alaska Department of Environmental Conservation) had standard deviation of 1.23 mg/l and 0.79 mg/l, respectively.

A standard deviation of 1.0 mg/l was chosen, implying that the standard error of the mean difference was $1.0/(18)^{1/2} = .236$. The resulting criterion for acceptability was a difference between observed and simulated DO levels at each sample location of no more than 3.3 mg/l and mean difference no greater than ±0.78.

The parameter estimates for each of the three studies, as a result of the second minimization step are given in Table E-4.

Table E-4 .

Optimal Parameter Estimates for WQ Measurements by KPC
(3 days during late summer of 1986)

Parameter	Aug. 19	Aug. 29	Sept. 9
k_x	6.83	4.45	4.36
k_y	3.73	1.10	3.68
k_z	$0.99x10^{-5}$	$1.99x10^{-5}$	$3.97x10^{-5}$
K_2	0.203	0.058	0.433
$Q_{Ward\ Creek}$	0.581	0.453	0.960

Parameter units are the same as given in Table E-3.

Predicted and observed DO levels for each station, as well as their differences, mean differences and standard error of the mean difference are shown in Tables E-5, E-6, and E-7. Parameter estimates for field studies on August 19, 1986 and September 9, 1986 lead to models which meet the criterion for model acceptability. The steady-state model, as formulated above, does not, however, meet this criterion for the August 29, 1986, due to an extremely low observation of DO at the surface of Station 49. The steady-state model was rejected for this set of data.

Table E-5 .

Comparison of Predicted vs. Observed
(8/19/86 KPC Data)

Station	Depth (meters)	Predicted DO (mg/l)	Observed DO (mg/l)	Difference (mg/l)
41	1	4.5	3.0	1.5

41	5	7.3	7.3	0.0
42	1	5.1	3.6	1.5
42	5	7.4	8.0	-0.6
43	1	3.9	6.3	-2.4
43	5	7.2	8.1	-0.9
44	1	4.3	2.2	2.1
44	5	7.3	8.8	-1.5
45	1	4.5	3.0	1.5
45	5	7.3	7.6	-0.3
46	1	5.1	4.6	0.5
46	5	7.5	8.4	-0.9
47	1	5.2	7.9	-2.7
47	5	7.5	6.8	0.7
48	1	7.2	6.9	0.3
48	5	7.9	7.3	0.6
49	1	6.9	5.3	1.6
49	5	7.8	7.0	0.8

Table E-6 .

Comparison of Predicted vs. Observed
(8/29/86 KPC Data)

Station	Depth (meters)	Predicted DO (mg/l)	Observed DO (mg/l)	Difference (mg/l)
41	1	2.9	2.8	0.1
41	5	4.9	6.1	-1.2
42	1	4.2	2.8	1.4
42	5	5.5	5.1	0.4
43	1	2.3	1.4	0.9
43	5	4.5	5.5	-1.0
44	1	3.2	1.7	1.5
44	5	5.1	6.3	-1.2
45	1	3.7	0.9	2.8
45	5	5.2	5.7	-0.5
46	1	4.0	1.4	2.6
46	5	5.7	6.4	-0.7
47	1	4.5	2.8	1.7
47	5	5.8	6.6	-0.8
48	1	6.8	7.3	-0.5
48	5	7.5	8.0	-0.5
49	1	6.5	2.0	4.5
49	5	7.1	7.2	-0.1

Table E-7 .

Comparison of Predicted vs. Observed
(9/9/86 KPC Data)

Station	Depth (meters)	Predicted DO (mg/l)	Observed DO (mg/l)	Difference (mg/l)
41	1	6.0	5.5	0.5
41	5	6.1	6.4	-0.3
42	1	6.4	5.5	0.9
42	5	6.4	6.6	-0.2
43	1	5.3	4.9	0.4
43	5	5.8	6.6	-0.8
44	1	5.6	4.5	1.1
44	5	6.0	6.1	-0.1
45	1	5.8	4.4	1.4
45	5	6.0	6.2	-0.2
46	1	6.3	5.5	0.8
46	5	6.6	7.0	-0.4
47	1	6.4	7.6	-1.2
47	5	6.6	7.7	-1.1
48	1	8.0	8.3	-0.3
48	5	8.1	8.2	-0.1
49	1	7.8	7.7	0.1
49	5	7.9	7.9	0.0

The parameter estimates for the acceptable models (Tables E-5 and E-7) can be used to develop an interpretation of the environmental factors which result in low water quality in Ward Cove. This can be done by examining the characteristic time scales of the various processes which comprise the model. For the parameter values, typical of those which resulted in the two acceptable models:

Turbulent diffusion coefficient, $k = 5.0$ meters^2/second
Freshwater inflow, $Q_{Ward\ Creek} = 1.0$ meters^3/second
Deoxygenation rate, $K_1 = 0.130$ days^{-1}
Reaeration rate, $K_2 = 0.200$ days^{-1}
Volume of top five meters, $V = 5.0 \times 10^6$ meters^3
Length, $L = 2 \times 10^3$ meters

the characteristic time scales are:

Diffusion:
$t_{diff} = L2/k = 4 \times 10^6/5 = 8 \times 10^5$ seconds = 9.3 days

Advection:
$t_{adv} = V/Q_{Ward\ Creek} = 5 \times 10^6/1. = 5 \times 10^6$ seconds = 57.9 days

Reaeration:
$t_{reaer} = 1/K_2 = 1/.2 = 5.0$ days

Deoxygenation:
$t_{deoxy} = 1/K_1 = 1/.130 = 7.7$ days

The role of turbulent diffusion is greater than that of freshwater discharge in terms of characterizing the exchange times of Ward Cove, while deoxygenation and reaeration have similar time scales approximately equal to the residence time implied by horizontal diffusion. The picture that emerges from this is one of poor exchange characteristics resulting from low runoff and low levels of energy from tides and winds. Low levels of energy available for turbulent mixing also give rise to longer time scales for reaeration, the transfer of oxygen from the atmosphere to oxygen-depleted surface waters.

Lastly, the relatively high water temperatures during the summer months lead to maximum deoxygenation rates by providing optimal conditions for the microorganisms which stabilize the BOD of organic material. Based on the available data, the parameter estimates support the hypothesis that these factors, in conjunction with high levels of organic loading, result in degradation of the water quality of Ward Cove.

Application of Model

The parameters estimated in the development of the model are diagnostic rather than predictive. That is, they are really only correct estimates for the data set used to make the estimate. Using these model results to estimate the effects that changes in loading from point sources will have upon water quality is predictive only if it is assumed that the hydrographic and meteorologic conditions for which the parameter estimates were made could occur again. This is a reasonable assumption, given that water quality problems in Ward Cove have historically been greatest during the late summer.

The steady-state BOD/DO model system was used to estimate the effect upon water quality for various BOD loading rates from the KPC mill. Such estimates were obtained for the optimal parameter sets from both the August 19, 1986 and the September 9, 1986 data sets.

Although it was assumed in the model development that the DO content of the KPC discharge was 5.0 mg/l, there was no direct measurement at that time to support the assumption. In the analysis, therefore, the DO level of the KPC was varied along with the BOD loading. An estimate of the minimum DO in Ward Cove was obtained as a function of BOD loading for several levels of discharge DO and for each of the two parameters sets. The minimum DO, as function of BOD_5 loading from KPC, for the various levels of discharge DO are shown in Figures E-7 and E-8. Information recently submitted by KPC indicates that aggregate DO levels in the discharges for the three outfalls into Ward Cove average approximately 6 mg/l.

The results of the analysis for the two acceptable parameter sets are similar. When the DO of the discharge is less than 1.0 mg/l, the model predicts that the minimum DO in Ward Cove will be less than 6.0 mg/l, even when the BOD_5 in the discharge is very close to zero. For DO levels in the discharge of 5.0 mg/l, the model estimates that DO will remain above the water quality standard for BOD_5 loadings as high as 20,000 pounds/day.

Figure E-7.

Minimum receiving water DO in Ward Cove as a function of BOD loading from KPC for various levels of DO in the discharge. Based upon model parameter estimates using August 19, 1986 sampling data.

Figure E-8.

Minimum receiving water DO in Ward Cove as a function of BOD loading from KPC for various levels of DO in the discharge. Based upon model parameter estimates using September 9, 1986 sampling data.

Conclusions

The following conclusions are based on the results of this analysis of the quality in the surface waters of Ward Cove:

Numerous water quality surveys, beginning soon after the construction of the KPC mill, have noted severe water quality problems in Ward Cove, particularly with respect to DO. These problems have continued over time, according to data collected by KPC in the late summers of 1987, 1988 and 1989.

Low DO in the surface waters of Ward Cove are associated with high levels of PBI, a constituent unique (in Ward Cove) to the discharge of the KPC pulp mill.

For two out of three water quality data sets, using data collected in August and September of 1986, a three-dimensional, steady-state model of DO and BOD was identified which satisfied specific criteria for the difference between observed and simulated values of DO.

Parameter estimates for the three-dimensional, steady-state model support the hypothesis that water quality problems, typified by conditions in August and September 1986, are due to conditions of reduced freshwater flow, low levels of mixing and exchange, relatively high water temperatures and high organic loadings from the KPC mill.

For environmental conditions in Ward Cove similar to those of August and September 1986, the State of Alaska's water quality standard for DO will be violated for any KPC discharge of average volumetric rate when the effluent DO is less than 1.0 mg/l or for a loading rate of approximately 20,000 pounds/day when the effluent DO is at least 5.0 mg/l.

APPENDIX F

WATERSHED MANAGEMENT PLAN DEVELOPMENT

Actions to Date

KPC's allowable discharge of BOD_5 and TSS has been reduced over the years due to statutory requirements. KPC installed a primary wastewater treatment facility in 1972 and a secondary biological wastewater treatment facility for selected waste streams in 1979. Since 1984, KPC has implemented additional modifications at the mill to reduce the quantity and mass loading of the discharge.

In 1980, KPC's permitted BOD_5 limit was set at an average of 120,000 lbs BOD_5/day. For the period 1981-1984, the average BOD_5 level was reduced to 52,500 lbs/day. In 1986 the limit was reduced to an average of 46,100 lbs/day. The 1987 allowable effluent limit was further reduced to an average of 40,600 lbs/day. Effective January 1988, effluent limits of an average 32,400 lbs BOD_5/day (62,400 lbs BOD_5/day maximum) and an average 52,900 lbs TSS/day (98,000 lbs TSS/day maximum) were placed on the mill to bring it into compliance with federal Clean Water Act mandates.

Pollution Control Strategy

To date, the approach taken to pollution control in Ward Cove has focused on NPDES permits for point sources. Steps have been taken by KPC to reduce pollutant loads to local marine waters. Continued improvements in further reducing pollutant loads discharged should be more focused and consider the watershed as a whole. Monitoring data indicates that water quality problems still exist. It appears that the discharge of BOD_5 from the KPC mill remains the primary cause of dissolved oxygen depletion in the surface waters of Ward Cove. As a result, development of a Total Maximum Daily Load (TMDL) needs to be initiated.

Water Quality Management Plan

A TMDL is an implementation plan which identifies levels of pollution control needed to achieve water quality standards. The TMDL needs to consider all sources: point, nonpoint, and background. The components used to address water quality problems through the TMDL process include:

- Effluent Limits
- Monitoring Requirements
- Compliance Schedules
- Special Conditions

The approach to be used to prepare the TMDL will focus first on dissolved oxygen and BOD loading to the Cove. Based on preliminary modelling results presented in Appendix E, a loading capacity of 20,000 lbs/day has been proposed for the surface layer of Ward Cove. The BOD loading capacity must be allocated to those sources identified as contributing pollutant loads to the surface waters.

Development of the initial water quality management plan will occur in 1993 under the authorities of Alaska's Water Quality Standards (18 AAC 70) and the federal Clean Water Act. The plan will identify preventative or remedial actions which will reduce pollutant loads to local marine waters. The program areas identified for action will continue to include NPDES permits as well as NPS management plans, as needed. Also, as information about other potential water quality problems in the Cove is collected and studied, the plan could be expanded to address other pollutants of concern.

The initial water quality management plan for Ward Cove will focus on three interim objectives. These include:

Full attainment of Alaska's water quality standards at key sites in the drainage so that the various water uses are protected.

Enforce compliance of NPDES permit conditions which are based on meeting water quality standards at key sites and implement BMP's to address identified nonpoint source problems.

A strategy for addressing existing benthic waste accumulation problems in areas where the State of Alaska has not authorized zones of deposit.

Water Quality Monitoring

A critical element for success of this plan is continued ambient water quality monitoring in Ward Cove by KPC. Information provided by this monitoring program will document improvements in water quality which result from efforts of the regulated community and the agencies. The monitoring program also provides information needed to focus future pollution reduction efforts. This includes resolving some of the questions about the fate and transport of pollutants in the area from a comprehensive point of view.

The ambient dissolved oxygen monitoring program by KPC will continue under the reissued permit, as will monitoring of process wastewater discharges for BOD. The draft permit also requires development of a stormwater monitoring program. This program will focus monitoring efforts on significant stormwater discharges, including those that contribute BOD loadings to Ward Cove. Elements of a continued data collection program might also include:

Water circulation information, which considers hydrodynamic interactions, in order to develop a better understanding of both existing and potential impacts.

Baseline data on benthic fauna at key areas in the system.

System-wide water quality data collected throughout the year which includes parameters such as dissolved oxygen, nutrients, etc.

Future data collection efforts must be focused on gathering information to meet clearly identified objectives. Example questions which have arisen include issues such as: interactions between pulp mill effluent, historical waste deposits, and seafood processing wastes, and other sources; relationship between total suspended solids (TSS) loading and biochemical oxygen demand (BOD).

Finally, the monitoring program must also address data analysis and assessment activities. There appears to be ongoing concerns over how information from the NPDES permits is used. Also, there has been no summation or analysis of monitoring data from a comprehensive, area-wide perspective. A process should be established for ongoing assessment of water quality information. The adequacy of the monitoring program must continually be reviewed and modified accordingly to address the problems.