EPA 910/9-89-001

WATER QUALITY STUDY OF TEN MARINAS IN PUGET SOUND

ROUGH DRAFT

By

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U.S. Environmental Protection Agency, Region 10

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I. INTRODUCTION

Each year natural resource and regulatory agencies review permits for the construction of boat moorages or marines. Until recently, it has proven difficult to perform an adequate review due to a lack of technical information. In many instances the resulting project has sacrificed other water uses in favor of commercial and recreational boating. The formulation of guidelines, specifying siting and design criteria, are necessary if other water uses are to be protected, as well.

The Washington State Department of Fisheries (1971) have developed guidelines which provide primarily for the passage of fish, but do address other water uses. Bowerman and Chen (1971) studied a number of water quality parameters in a California marina, but did not attempt to relate their field measurements to the hydraulic characteristics of the marina. Layton (1971), Lewis (1972) and Nece and Richey (1972) have used hydraulic models to analyze the flushing characteristics of specific marine configurations, but did not attempt to generalize their findings. Brandsma et al (1973) have used the Lagrangian numerical model developed by Fischer (1970) to examine the flushing characteristics of Marina del Ray.

The purpose of the present study was to examine the water quality characteristics in marinas of various designs, The results of the study to be used to ~~establish~~ develop guidelines for ~~the~~ siting and ~~design~~ designing of marinas. The study was performed during the summer of 1973 with the assistance of the U. S. Army Corps of Engineers, Seattle District.

II. DESIGN OF STUDY

The field studies were divided into two ~~groups.~~ phases The first ~~group~~ phase consisted of an intensive study of duration usually two days, of five marinas in Puget Sound. These

five marinas and, the days on which they were studied are given in Table 2.1.
Their location
Measurements of currents, temperature, salinity, dissolved oxygen, and water clarity were made at various stations in each marina during progressive stages of the flood tide. Surface samples were taken at various locations to determine the levels of total coliform bacteria, total grease and oil, and pesticides. Locations of the marinas are shown in Figure 2.1. See NOTE TABLE 2.2

The second group consisted of a one day float trip (September 5, 1973) during which five marinas were visited. The five marinas and the time during which samples were taken are given in Table 2.2. Surface samples were taken at various locations in each marina for the purposes of determining the levels of total coliform bacteria and total grease and oil concentrations. A bioassay, using Pacific oyster larvae, was also performed on each sample. Location of the marinas are shown in Figure 2.1.

III. EXPERIMENTAL METHODS

Temperature, conductivity and dissolved oxygen were measured with a hydrolab multi-parameter probe, except at Squalicum Boat Basin in Bellingham Bay. An Industrial Instrument RS5-2A was used to measure temperature and conductivity at Squalicum and the modified Winkler method was used to measure dissolved oxygen.

* Presumptive counts of total coliform bacteria were obtained by means of the Millipore filter method.

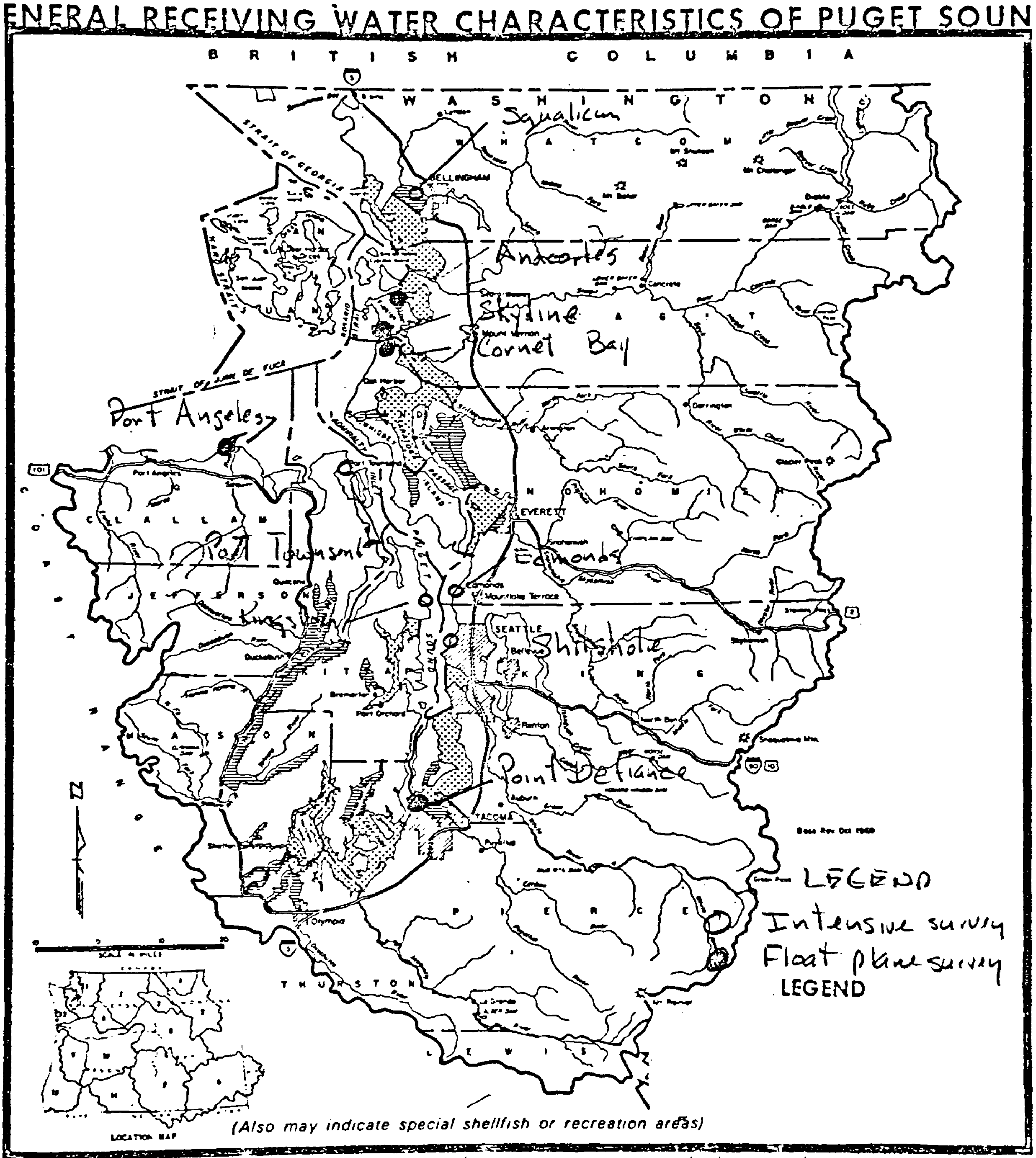
* The total grease and oil levels were measured by the chloroform extraction method.

* Pesticide levels were determined using gas chromotography.

Currents within each marina were measured at fixed locations with a Gurley - type current meter. Trajectories of water particles were followed at various depths with small drogues. The drogues were made by attaching

* [illegible]

GENERAL RECEIVING WATER CHARACTERISTICS OF PUGET SOUND



NOTE: Water quality problems associated with natural phenomena occur generally during the late summer—early fall only. While those associated with municipal or industrial wastes are continuous.

FIGURE 2.1 Location of marinas sampled during the period July - September 1973

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The addition of the method reference would be helpful for those interested.

MARINA	DATE OF STUDY
Port of Edmonds	July 10-11, 1973
Squalicum	July 26-28, 1973
Shilshole Bay	August 9-10, 1973
Port of Kingston	August 23-24, 1973
Port of Port Townsend	September 6-7, 1973

Table 2.1 Location and dates of marinas studied during the intensive survey

MARINA	SAMPLING TIME
Port of Port Angeles	0835 - 0940
Skyline	1015 - 1100
Cornet Bay	1110 - 1200
Port of Anacortes	1215 - 1300
Point Defiance	1400 - 1500

Table 2.2 Location and times of marinas studied during the September 5, 1973 float trip

My records show September 12th, 1973 as the date of the float trip.

neutrally buoyant vanes to a fishing float with nylon line.

Pacific oyster ~~larvae~~ embryos (Woelke, 1972) were used for bioassays.

The water quality standards for the State of Washington and selected water quality criteria recommended by the Federal Water Pollution Control Administration are given in Appendix I.

IV. RESULTS OF INTENSIVE SURVEYS

1. Port of Edmonds Marina

a. General

The Port of Edmonds marina is located on the main basin of Puget Sound approximately 12 miles north of Seattle. There are actually two separate marinas adjacent to each other. The water quality survey was restricted to the southerly most marina of the two. ~~Physical and tidal characteristics are given in Tables A.II.1 and A.II.2.~~ ~~The water classification for the area associated with the marina~~ site is Class AA (Extraordinary) ~~Marine~~.

The water quality of Puget Sound in the area of Edmonds is generally of high quality. Waste discharges in the area are primarily from small municipalities and light industries. Within the marina there are a number of discharges ~~of~~ unknown origin.

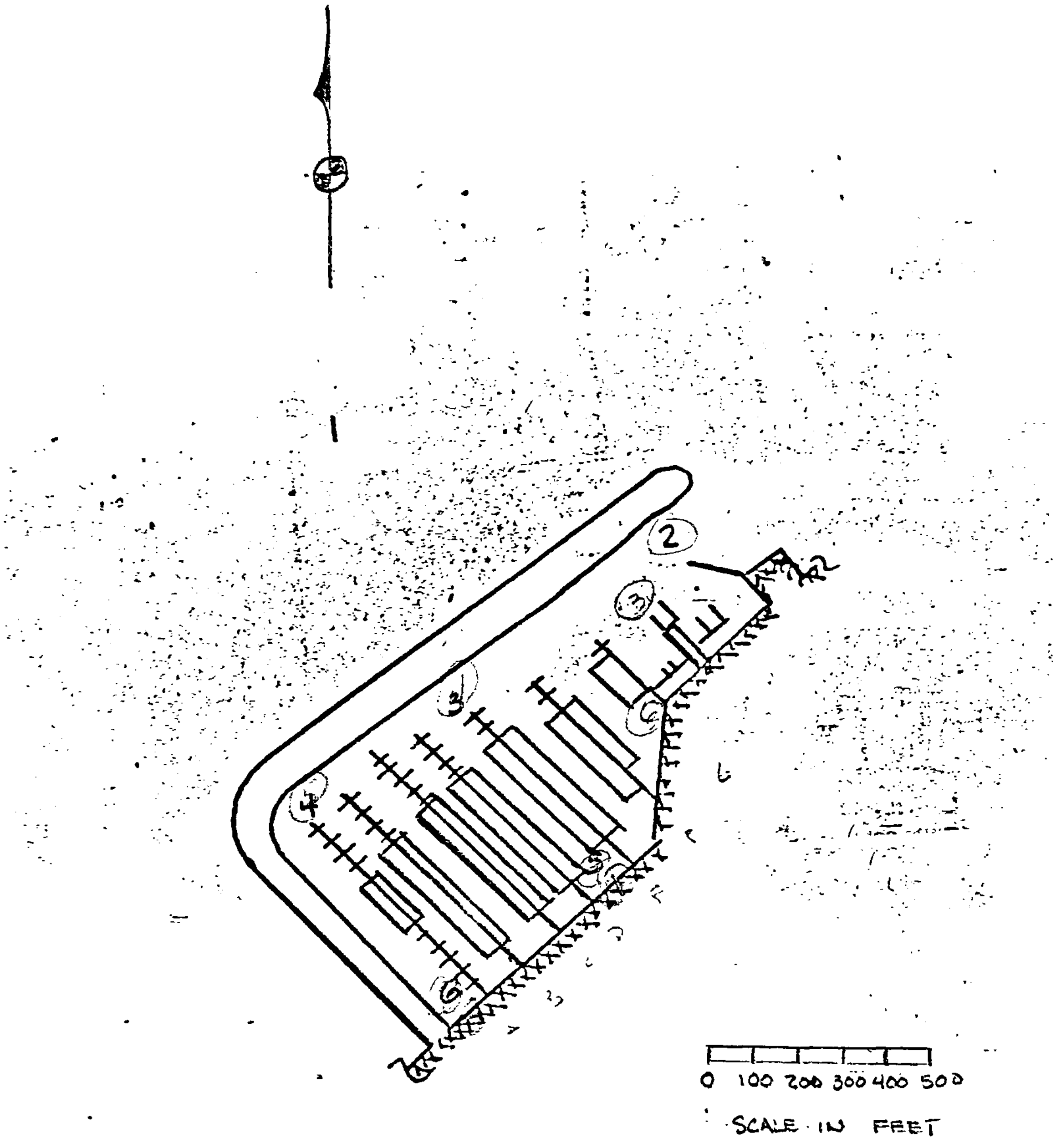
During the summer a bait herring operation in the southeast corner of the southern marina contributes organic matter to the marine waters.

Currents in the vicinity of the marina are influenced primarily by tidal action. Along the shore near the marina currents are generally in the same direction as in the main basin of Puget Sound but are somewhat weaker.

The intensive survey of the Edmonds marina was done July 10-11, 1973. Approximate station locations are shown in Figure 4.1.

b. Dissolved Oxygen

Table 4.1 summarizes the oxygen data for the Edmonds survey on July 11, 1973.



A scale and North-South marker would be helpful as far as relative size and orientation of the different marinas are concerned.

In general, the dissolved oxygen in the surface waters of both the marina and Puget Sound were near, or above, saturation. Presumably, the supersaturation in the surface waters was a result of photosynthesis.

At depth, the dissolved oxygen in the marina was for the most part, similar to that of water at the same depth in Puget Sound. Exceptions occurred at sample stations in the southeast corner of the marina Station No. 6, as well as at a point just inside the entrance under the boat launching equipment. These low values were obtained in the morning at locations where the water movement appeared to be most restricted. The dissolved oxygen measured at these three stations was lower than the water quality criterion of 7.0 mg/l for Class AA marine waters. The dissolved oxygen measured at these stations was also lower than any measurements from the control station. Most likely cause of the low dissolved oxygen was the respiration of algae. The organic loading associated with the bait herring operation and the discharge from assorted outfalls within the marina, may have had an impact, as well.

Is it really the most likely cause of the low D.O.s? The dark respiration rate (photosynthetic rate), of algae at Sta. 6 and Sta. 1 may have been the same; however, the oxidation of organics at Sta. 6 (not present at Sta. 1) could have resulted in the differences in minimum & max. D.O.s observed.

c. Temperature

Temperature data for the Port of Edmonds marina is summarized in Table 4.2. The surface temperature in the marina was generally higher than the surface temperature at the control station in Puget Sound. This disparity was greater at the innermost stations (Station No. 6, for example) than at the entrance to the marina.

The depth of the thermocline was approximately two meters. At depth, the water temperature of the marina was more nearly that of water at similar depth in Puget Sound.

STATION NUMBER	#1	#2	#3	#4	#5	#6
MAXIMUM DISSOLVED OXYGEN (MG/L)	8.6	9.3	9.1	9.9	9.6	9.0
DEPTH OF MAXIMUM DISSOLVED OXYGEN (METERS)	0.0	0.0	0.0	0.0	1.5	0.0
TIME OF MAXIMUM DISSOLVED OXYGEN	0900 7/11/73	0900 7/11/73	1500 7/11/73	1430 7/11/73	1550 7/11/73	1300 7/11/73
AVERAGE DISSOLVED OXYGEN (MG/L)	- -	8.2	8.4	8.6	8.5	7.9
MINIMUM DISSOLVED OXYGEN (MG/L)	7.2	7.1	7.8	7.7	7.7	6.5
DEPTH OF MINIMUM DISSOLVED OXYGEN (METERS)	6.1	4.6	6.1	3.0	4.3	2.7
TIME OF MINIMUM DISSOLVED OXYGEN	1120 7/11/73	0900 7/11/73	1600 7/11/73	1030 7/11/73	1330 7/11/73	0830 7/11/73

TABLE SUMMARY OF DISSOLVED OXYGEN DATA FOR THE EDMONDS MARINA
JULY 11, 1973

STATION NUMBER	#1	#2	#3	#4	#5	#6
MAXIMUM TEMPERATURE (°C)	13.0	14.0	14.0	14.7	15.1	15.5
DEPTH OF MAXIMUM TEMPERATURE (METERS)	0.0	0.0	0.0	0.0	0.0	0.0
TIME OF MAXIMUM TEMPERATURE	1410 7/11/73	1300 7/11/73	1345 7/11/73	1430 7/11/73	1550 7/11/73	1310 7/11/73
AVERAGE TEMPERATURE (°C)	- -	12.8	13.0	13.2	13.3	13.3
MINIMUM TEMPERATURE (°C)	11.2	11.8	12.0	12.1	12.1	12.1
DEPTH OF MINIMUM TEMPERATURE (METERS)	12.2	4.5	5.2	5.5	4.3	3.7
TIME OF MINIMUM TEMPERATURE	1120 7/11/73	0945 7/11/73	1345 7/11/73	1430 7/11/73	1330 7/11/73	1130 7/11/73

TABLE SUMMARY OF TEMPERATURE DATA FOR EDMONDS MARINA
JULY 11, 1973

the MPN method is what they call the multi-tube method. I don't think you can use the term (MOST PROBABLE NUMBER) with membrane filter counts. u might check with Jay to see just how

d. Total Coliform Bacteria

aning of results

the actual counts would be more meaningful

Total coliform concentrations in the Edmonds marina were at low levels, except for the area around the gas dock. The Washington State Water Quality Standards require that the median value for total coliforms be less than 70 MPN/100 ml when associated with a fecal source. The median value at the gas dock exceeded 70 MPN/100 ml but there were no measurements of fecal coliforms made. It is therefore not clear that a standards violation occurred. It does indicate, however, a potential problem area and should receive further attention.

the Stds

e. Total Grease and Oil

Total grease and oil were less than 1.0 mg/1 in the Edmonds Marina, with the exception of the area just inside the entrance. A maximum value of 3.0 mg/1 of total grease and oil was measured at Station No. 5.

~~f. Pesticides~~

& concentrations?

~~Measurable levels of Lindane, DDT, DDE and Dieldrin were detected within the Edmonds marina.~~

g. Aesthetics and Land Use

Aesthetic qualities, in terms of water quality were fair to good. A certain amount of debris, including empty soft drink cans, small pieces of styrofoam and some food stuffs were observed during the period of the survey. Oil slicks were seen at various locations in the marina, but were most common in the area shaded (A) Figure in the area of the gas dock. Mats of algae were observed during a later visit to the marina. Organic debris and flotsam was most conspicuous in the area shaded areas, (B), Figure 1.

The area around the marina is primarily used for light industry, marine-related sales, and parking space for automobiles and boats. Walking dogs in the parking area is specifically prohibited, as is trespassing or fishing on piers where boats are docked.

The piers are not enclosed, however, and children were observed fishing from them during the survey, despite the signs. People were also fishing from the breakwater and from the public pier which has been constructed at the entrance to the marine. The only access to the water for boats not moored in the marina was by means of a sling operated by the Port of Edmonds. ~~The launching fees are shown in Table 4.3.~~

put the whole

This launching fee table seems to detract from your presentation. It doesn't add much — unless you discuss the economics of marine operations

Boat Length	Launching Fee
Less than 17'	5.00
17' - 19'	6.00
20' - 21'	7.00
22' - 23'	8.00
24'	9.00
25'	10.00
26'	12.00
27'	14.00

Table 4.3 Schedule of Launching fees for the Port of Edmonds marina

Both are rather subjective terms as used.

h. Aquatic Life

A qualitative examination of the marine life at Edmonds was performed on October 1, 1973, ~~(see Appendix IV).~~ A The ~~healthy diverse~~ community of marine organisms w~~as recorded, including~~ included sea anomones, sea cucumbers, starfish, sea squirts, mussels, kelp crabs, sponges and various polychaetes or marine worms.

2. Squalicum Boat Basin

a. General

The Squalicum Small Boat Basin is located in Bellingham Harbor near the City of Bellingham, Washington (Figure 4.2). The marina is operated by the Port of Bellingham. Physical and tidal characteristics of the marina are given in Tables ~~A.II.3 and A.II.4 of Appendix II~~. The water quality classification, for the portion of Bellingham Bay in which the marina is located, is Class A (excellent) marine.

The water quality of Bellingham Bay is poor. reference? Discharge of large amounts of toxic, high-organic wastes from the Georgia-Pacific Company Pulp Mill, municipal discharges from the City of Bellingham and untreated wastes from food processors within the marina all contribute to the degradation of water quality. (reference)?

Currents within Bellingham Bay are influenced by tidal action and the discharge of the Nooksack River, which empties into the northwest corner. Studies by Collias et al (1966) show a counterclockwise current in the bay during flood tide. Flushing time of Bellingham Bay, as estimated from 1960-1961 data by Collias et al (1966) varied from 1 day to 11 days to depending upon the season of the year. The minimum time occurred during December when the freshwater discharge of the Nooksack River was high. The maximum time occurred during August when the discharge was low.

Current measurements by the U. S. Army Corps of Engineers showed water entering through both entrances to the marina on flood tide and leaving through both entrances on the ebb tide. Typical current speeds were of the order of 0.1 to 0.2 meters per second.

STATION NUMBER	#1	#2	#3	#4	#5	#6
MAXIMUM DISSOLVED OXYGEN (MG/L)	5.4	5.2	5.8	7.8	4.7	6.3
DEPTH OF MAXIMUM DISSOLVED OXYGEN (METERS)	0.0	0.0	4.6	4.3	3.0	0.0
TIME OF MAXIMUM DISSOLVED OXYGEN	1115 7/28/73	1230 7/28/73	1210 7/27/73	1145 7/27/73	1220 7/28/73	1200 7/28/73
AVERAGE DISSOLVED OXYGEN (MG/L)	3.6	3.2	2.7	3.0	2.4	4.1
MINIMUM DISSOLVED OXYGEN (MG/L)	0.7	0.6	0.2	0.1	0.3	0.0
DEPTH OF MINIMUM DISSOLVED OXYGEN (METERS)	0.0	0.0	0.0	0.0	0.0	0.0
TIME OF MINIMUM DISSOLVED OXYGEN	1235 7/27/73	1230 7/27/73	0950 7/27/73	1600 7/27/73	1000 7/27/73	1300 7/27/73

TABLE SUMMARY OF DISSOLVED OXYGEN DATA FOR SQUALICUM SMALL BOAT BASIN
JULY 27 & 28, 1973

STATION NUMBER	#1	#2	#3	#4	#5	#6
MAXIMUM TEMPERATURE (°C)	23.5	22.9	21.9	21.4	21.5	22.2
DEPTH OF MAXIMUM TEMPERATURE (METERS)	0.0	0.0	0.0	0.0	0.0	0.0
TIME OF MAXIMUM TEMPERATURE	1645 7/27/73	1530 7/27/73	1610 7/28/73	1445 7/27/73	1520 7/28/73	1610 7/27/73
AVERAGE TEMPERATURE (°C)	14.4	14.5	14.7	14.8	14.9	14.4
MINIMUM TEMPERATURE (°C)	10.7	10.7	10.8	11.1	11.2	10.5
DEPTH OF MINIMUM TEMPERATURE (METERS)	6.1	7.6	4.6	4.6	6.1	7.3
TIME OF MINIMUM TEMPERATURE	1650 7/27/73	1530 7/27/73	1210 7/27/73	1250 7/27/73	1520 7/27/73	1615 7/27/73

TABLE SUMMARY OF TEMPERATURE DATA FOR SQUALICUM SMALL BOAT BASIN
JULY 27 & 28, 1973

was

f. Pesticides

The concentration of DDT, 0.004 µg/l, ~~were~~ was greater

Measurable levels of DDT were detected in one of the samples obtained

~~than the level of~~ de in one sample collected at Station #5

from the Squalicum Boat Basin. Chlorinated hydrocarbon concentrations were below the limits of detection ~~at~~ in all the other samples

g. Aesthetics and Land-Use

Aesthetic qualities were extremely poor. Debris associated with boat use was floating in the water near the Port Office. Oil slicks were common throughout the marina and large amounts of foam were being generated by the raw waste discharge from the food processing plants. A brown slime ~~(leptomyces)~~ was common throughout the marina. It was attached to docks and pilings, and, in at least one instance, to the outboard motor of a moored boat. One dead fish ~~(tentatively identified as a dogfish)~~ was seen floating in the marina for several hours.

The marina is used both for commercial boating and recreational boating. The area adjacent to the marina is used for food processing, light industry, marine sales, storage for commercial fishing gear and parking area for boats and automobiles. The parking area was also being used as an area for fishing net maintenance. Boating was the only form of recreation observed at the Squalicum marina during the period of study.

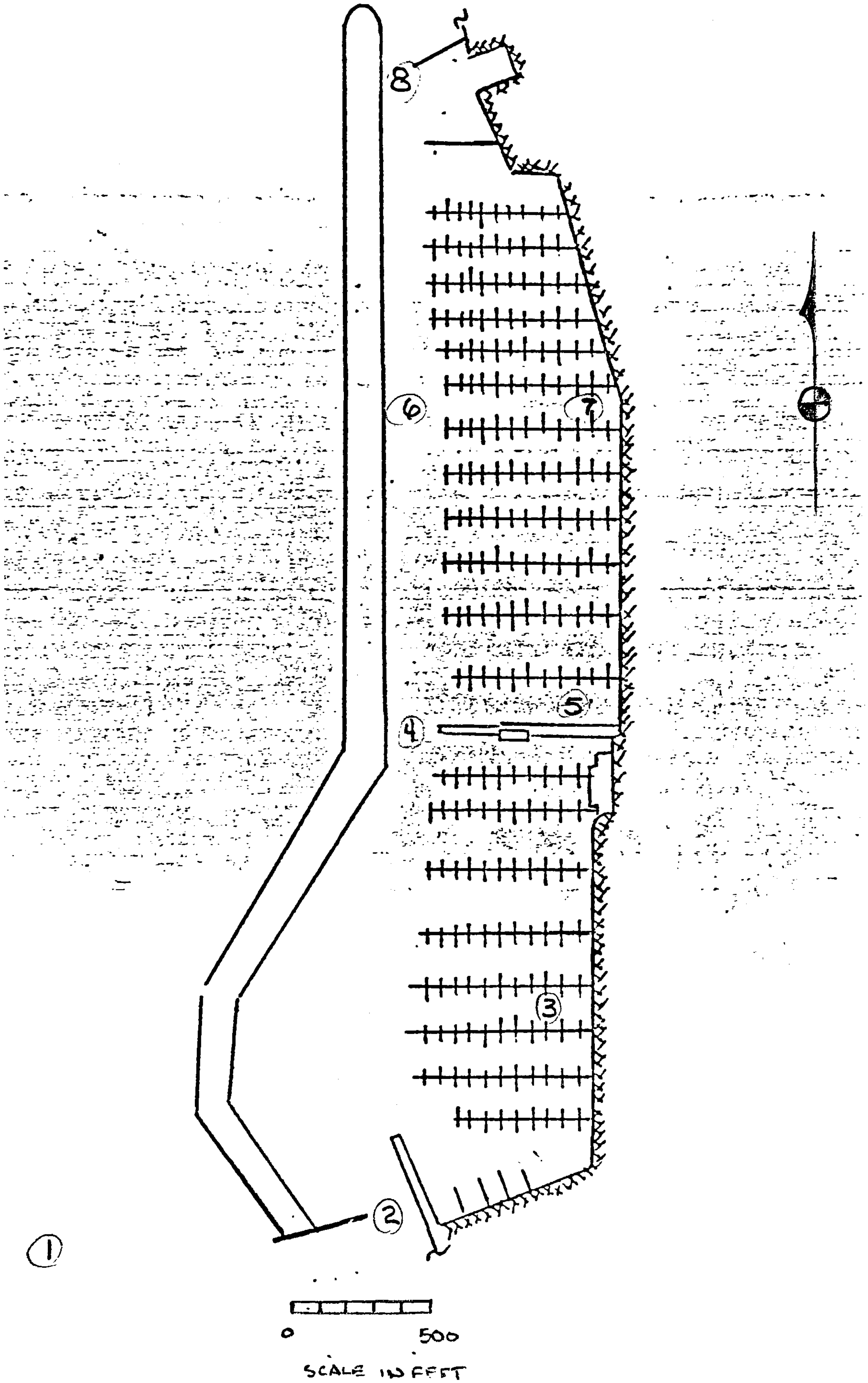
h. Aquatic Life

A qualitative examination of the Squalium marina was made October 27, 1973. Mussels and a brown slime or fungus were the dominant organisms.

3. Shilshole Bay

The Shilshole Bay marine is located just north of the entrance to the Lake Washington Ship Canal (Figure 4.3). The marina is operated by the Port of Seattle. Physical and tidal characteristics for the marina are given in Tables A.II.5 and A.II.6 of Appendix II. The water classification for the waters associated with the marina site is Class AA (Extraordinary) Marine.

With the exception of urban run-off during periods of heavy rainfall,there are no waste discharges within the immediate vicinity of the marina. Within the marina, there is the discharge of untreated water associated with


8
6
7
5
4
3
2
1
0
500
SCALE IN FEET

Exchange Ratio	0.49	
Flushing Time	2.05	Tidal Cycles
Time to i/e for High Range	0.33	Days
Time to i/e for Mid Range	0.75	Days
Time to i/e for Low Range	1.29	Days
Characteristic Diffusion Time	0.7	Days

TABLE A II.8 EXCHANGE CHARACTERISTICS OF THE KINGSTON COVE MARINA

STATION NUMBER	#1	#2	#3	#4	#5	#6	#7	#8
MAXIMUM TEMPERATURE (°C)	15.1	15.5	15.5	15.1	15.5	15.0	15.5	15.0
DEPTH OF MAXIMUM TEMPERATURE (METERS)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TIME OF MAXIMUM TEMPERATURE	1615 8/10/73	1445 8/10/73	1435 8/10/73	1545 8/10/73	1455 8/9/73	1445 8/9/73	1550 8/9/73	1550 8/10/73
AVERAGE TEMPERATURE (°C)	13.0	13.7	13.6	13.4	13.4	13.2	13.3	12.9
MINIMUM TEMPERATURE (°C)	12.0	12.4	12.4	12.3	12.2	12.3	12.4	12.0
DEPTH OF MINIMUM TEMPERATURE (METERS)	6.1	5.5	4.6	4.6	6.1	6.1	4.3	- -
TIME OF MINIMUM TEMPERATURE	0930 8/9/73	0920 8/9/73	0910 8/9/73	0900 8/9/73	1000 8/9/73	1140 8/9/73	0830 8/9/73	Numerous

TABLE SUMMARY OF TEMPERATURE DATA FOR THE SHILSHOLE BAY MARINA
AUGUST 9 & 10, 1973

STATION NUMBER	#1	#2	#3	#4	#5	#6	#7	#8
MAXIMUM DISSOLVED OXYGEN (MG/L)	8.3	8.2	8.3	7.7	8.3	7.7	7.9	7.7
DEPTH OF MAXIMUM DISSOLVED OXYGEN (METERS)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TIME OF MAXIMUM DISSOLVED OXYGEN	0925 8/9/73	0915 8/9/73	0905 8/9/73	1030 8/9/73	1015 8/9/73	0830 8/9/73	0820 8/9/73	0935 8/9/73
AGERAGE DISSOLVED OXYGEN (MG/L)	5.6	5.8	5.6	5.7	5.9	5.9	6.0	6.4
MINIMUM DISSOLVED OXYGEN (MG/L)	5.0	4.8	4.3	4.9	4.8	5.5	5.1	5.4
DEPTH OF MINIMUM DISSOLVED OXYGEN (METERS)	6.1	5.5	4.8	3.0	4.5	6.1	3.5	4.9
TIME OF MINIMUM DISSOLVED OXYGEN	1400 8/9/73	0915 8/9/73	1045 8/9/73	1330 8/9/73	0845 8/9/73	1135 8/9/73	0820 8/9/73	0810 8/9/73

TABLE SUMMARY OF DISSOLVED OXYGEN DATA FOR SHILSHOLE BAY MARINA
AUGUST 9, 1973 ONLY

the heating system for the marina offices and restaurant. There are also a number of storm drains which discharge into the marina.

The marina has been constructed with two openings, one at the north end and one at the south end. The prevailing tidal currents are essentially north and south (Brown and Caldwell (1958)). Current measurements made by the U. S. Army Corps of Engineers indicate that the current pattern within the marina is complex, and that currents do not flow in the same direction at all depths and all locations within the marina. The maximum flushing efficiency of the marina is, therefore, not realized.

The water quality survey and current measurement programs were conducted August 9-10, 1973. Station locations are shown in Figure 4.3. Table and gives the tidal and weather conditions during the survey

b. Dissolved Oxygen

The dissolved oxygen probe in the Hydrolab behaved erratically after 1400 on August 9, 1973. An examination of the instrument afterwards disclosed a short in one of the circuits. Only that data obtained prior to 1400 on August 9, 1973 has been used in the summary given in Table 4.7.

insert Ⓐ

c. Temperature

Temperature data for the Shilshole Bay marina study is summarized in Table 4.8. In general, the surface temperature was greater than 13.5°C (56.2°F) throughout the marina. The exception to this occurred at the north entrance to the marina, where the temperature was 12.5°C for at least two hours on August 9, 1973 and 13.0°C for at least two hours on August 10, 1973. These low temperatures did not propagate into the marina to any extent. ~~indicating that water exchange between the marina and the main basin of the sound was not [illegible] efficient~~. Water temperatures at depths greater than ~~[illegible]2 meters~~ (5 feet) did not change substantially during the study.

insert Ⓑ

[illegible]

d. Total.coliform bacteria

Total coliform bacteria counts in the surface waters of the Shilshole Bay were at background levels in the outer edges but high in the middle and in the southeast corner. The highest counts, median value of 223 MPN/100 ml, were observed near the marina office complex and restaurant. The highest values at all stations occurred during low tide. The total coliform counts were significantly lower at high tide, presumably as a result of dilution from the incoming water. This implies that NOT NECESSARILY the source of the high coliform counts was somewhere inside the marina.

e. Total Grease and Oil

Total grease and oil was less than 1.0 mg/l at all locations except in the area of the marina office complex (Station #5) where a maximum value of 1.6 mg/l was observed. Table __ shows total grease and oil measurements at those stations which we sampled

f. Pesticides

Detectable levels of DDT (.001 µg/l) and DDE (.001 µg/l) were measured in one out of the twelve samples from the Shilshole Bay Marina. ~~[illegible]~~ levels in those samples collected at Station #3

g. Aesthetics and Land Use

Aesthetic qualities were generally good in the Shilshole Bay Marina. In two areas, however, one just north of the marina office complex and the other in the southeast corner of the marina, debris was collecting and did not appear to be removed on the outgoing tide. These areas (marked (D) on Figure. were unsightly, as was the open pipe discharge under the marina office. Oil slicks were seen in the area of the gas pumps and, in one instance, a boat owner pumping his own gas at the gas dock accidently discharged gasoline to the marina for several seconds.

The area in the vicinity of the marina is devoted primarily to parking space for automobiles. A restaurant and marina office are also part of the marina complex.

Trespass and fishing are prohibited on most of the piers where boats were berthed. Two piers are open to the public and a large number of people took advantage of this to examine boats and enjoy the water. A historical ship exhibit at the open

At the north end of the marina there are a public boat ramp and fishing pier. Both of these facilities were well used. At the south end of the marina there is space for working on boats, as well as hydraulic cranes for use in launching and retrieving boats. ~~There is no charge for the use of this equipment.~~

4. Kingston Cove

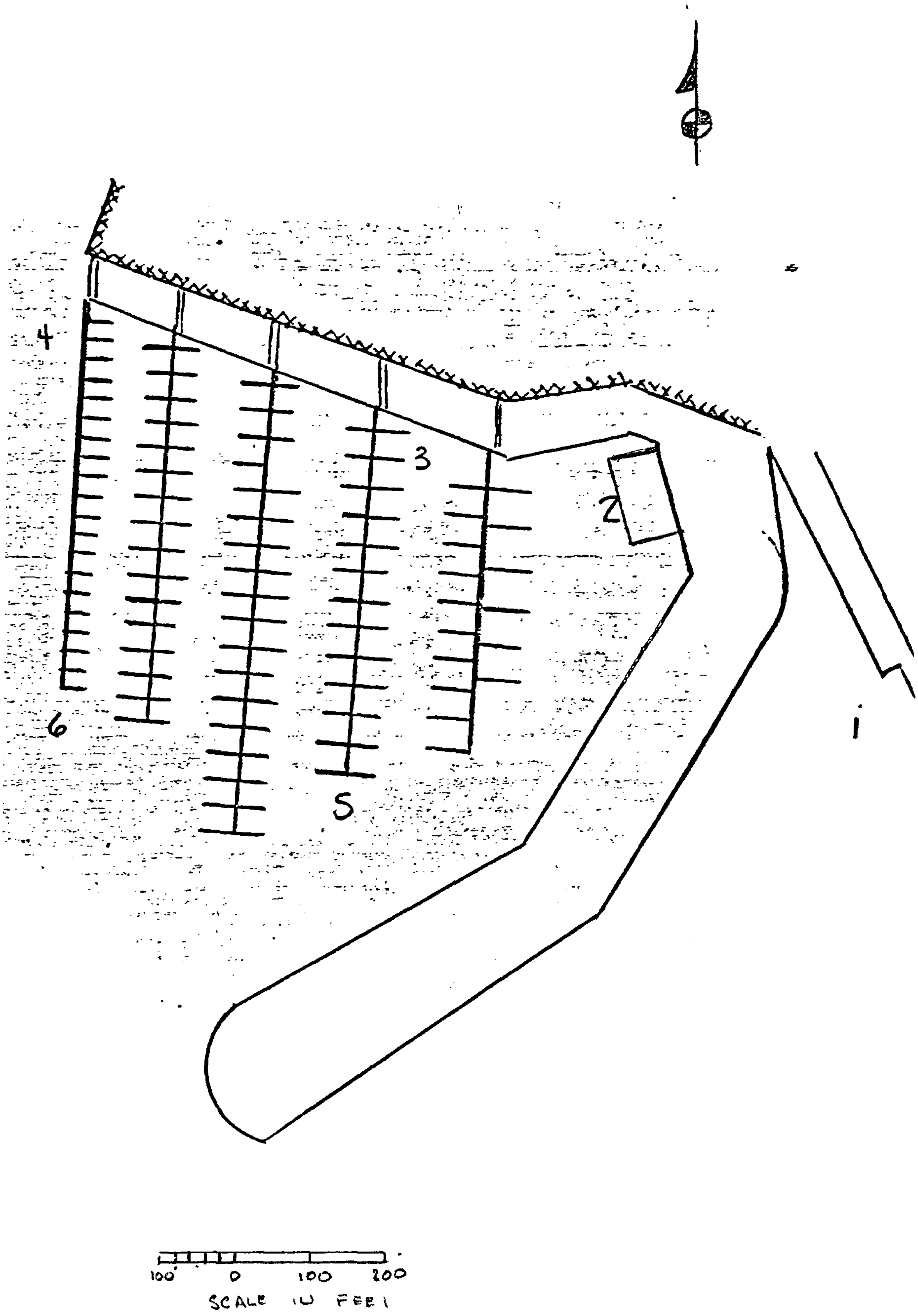
a. General

The Kingston Cove marina is located on the west side of the main basin of Puget Sound directly west of Edmonds.

Physical and tidal characteristics for the Kingston Cove Marina are given in Tables A.II.7 and A.II.8 of Appendix II. Water classification for the marina is Class AA (extraordinary) marine.

A float study by the U. S. Army Corps of Engineers during June of 1972 shows that mixing is generally good in the marina, with the exception of the northeast corner near the gas dock. Currents measured in the northeast corner were approximately one-tenth as large as those in the rest of the marina.

The water quality survey of the Kingston Cove marina was done August 23 - 24, 1973. Problems with the outboard motor on August 23, 1973 made it difficult to obtain a complete set of dissolved oxygen and temperature data on


4
3
2
1
6
5
100'
0
100
200
SCALE IN FEET

that day. Station locations are shown in Figure 4.4.

b. Dissolved Oxygen

Dissolved oxygen measurements for Kingston Cove are summarized in Table 4.11. Dissolved oxygen in the marina was equal to or greater than 7.0 mg/l, the Washington State criterion for Class AA during the morning of August 24, 1973. During the afternoon the dissolved oxygen was lower than 7.0 mg/l at number of stations, particularly at depth. The dissolved oxygen in the marina did not appear to be significantly less than at the control station outside the marina
outside ~~the marina, however, implying that the water in Puget Sound was limiting.~~

c. Temperature

The temperature data for Kingston Cove is summarized in Table 4.12. Surface temperatures were generally higher in the marina than at the control. This difference was not so noticeable in the water at 1 1/2 meters (5.0 feet) and below.

d. Total coliform bacteria

One measurement within the marina showed a total coliform count greater than 70 MPN/100 ml. The highest count was observed outside the marina near the ferry dock, Station #1,

e. Total grease and oil

Total grease and oil did not exceed 1.0 mg/l at any of the locations sampled.

f. Pesticides

[illegible]

Pesticides were below the level of detection at all locations sampled.

g. Aesthetics and land use

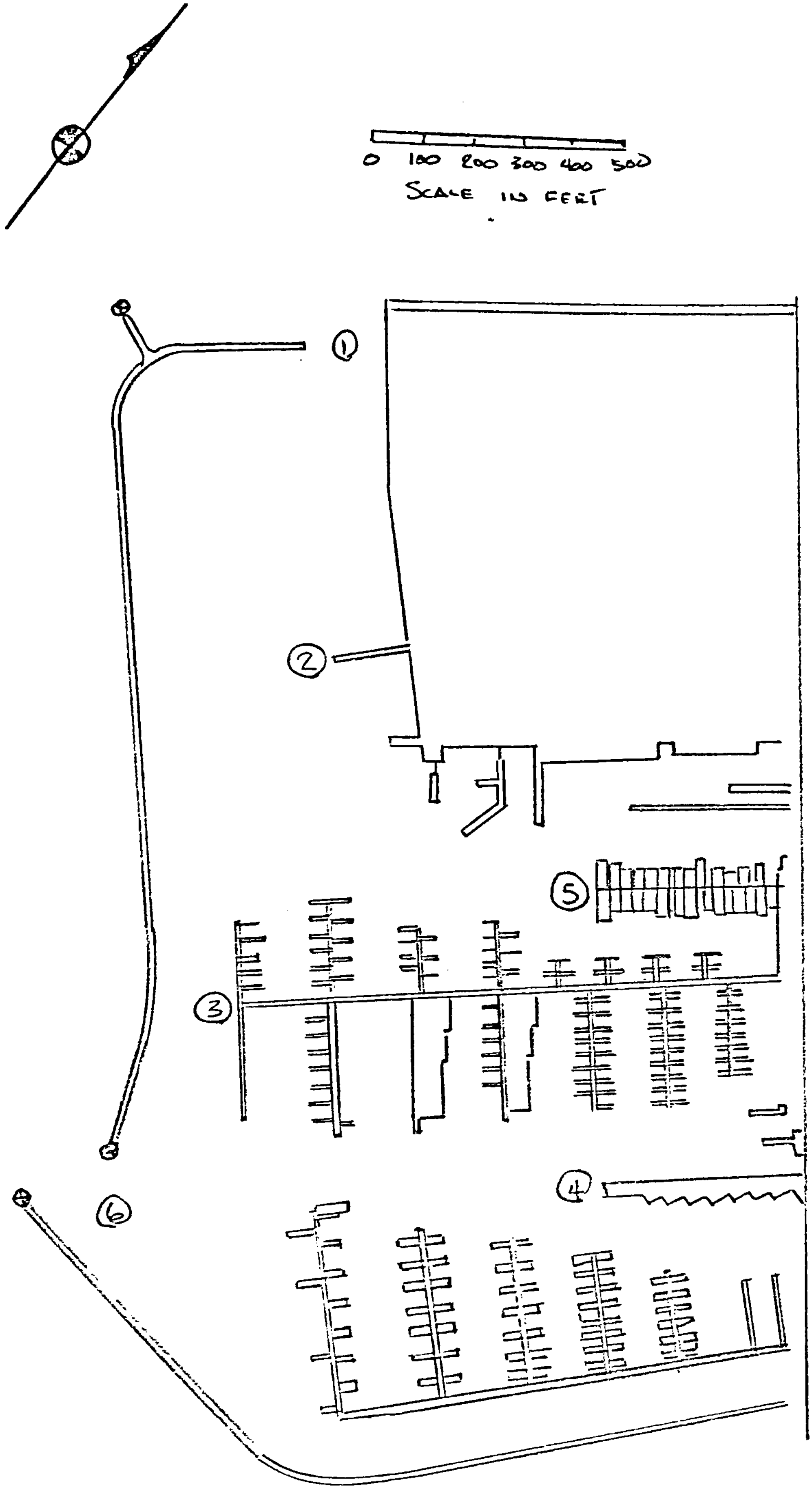
Aesthetic qualities were generally good in the water of the Kingston Cove marina. Some small debris and a few oil slicks were seen, but these problems did not persist for long periods.

STATION NUMBER	#1	#2	#3	#4	#5	#6
MAXIMUM DISSOLVED OXYGEN (MG/L)	8.2 ✓	8.3 ✓	10.1 ✓	8.7 ✓	9.7 ✓	9.4 ✓
DEPTH OF MAXIMUM DISSOLVED OXYGEN (METERS)	0.0	4.9	0.0	0.0	0.0	0.0
TIME OF MAXIMUM DISSOLVED OXYGEN	1200 8/24/73	1020 8/24/73	1035 8/24/73	1100 8/24/73	1045 8/24/73	1055 8/24/73
AVERAGE DISSOLVED OXYGEN (MG/L)	6.8	6.8	6.7	6.4	7.2	6.9
MINIMUM DISSOLVED OXYGEN (MG/L)	6.4 ~~5.7~~	5.5 ✓	5.7 ✓	5.9 ✓	5.8 ✓	5.7 5.7
DEPTH OF MINIMUM DISSOLVED OXYGEN (METERS)	3.0	6.1	6.1	3.0	6.1	6.1
TIME OF MINIMUM DISSOLVED OXYGEN	1325 8/24/73	1340 8/24/73	1400 8/24/73	1430 8/24/73	1240 8/24/73	1255 8/24/73

TABLE SUMMARY OF DISSOLVED OXYGEN DATA FOR KINGSTON COVE MARINA
AUGUST 24, 1973

STATION NUMBER	#1	#2	#3	#4	#5	#6
MAXIMUM TEMPERATURE (°C)	13.7	14.2	14.3	14.0	14.4	14.0
DEPTH OF MAXIMUM TEMPERATURE (METERS)	0.0	0.0	0.0	0.0	0.0	0.0
TIME OF MAXIMUM TEMPERATURE	1445 8/24/73	1020 8/24/73	1400 8/24/73	11000 8/24/73	1415 8/24/73	1515 8/24/73
AVERAGE TEMPERATURE (°C)	12.9	13.0	13.2	13.0	13.3	13.2
MINIMUM TEMPERATURE (°C)	12.5	12.5	12.7	12.7	12.6	12.7
DEPTH OF MINUMUM TEMPERATURE (METERS)	6.1	6.1	4.6	4.6-6.1	6.1	6.1
TIME OF MINIMUM TEMPERATURE	1325 8/24/73	1210 8/24/73	1035 8/24/73	1305 8/24/73	1510 8/24/73	1515 8/24/73

TABLE SUMMARY OF TEMPERATURE DATA FOR KINGSTON COVE MARINA
AUGUST 24, 1973


0 100 200 300 400 500
SCALE IN FEET
①
②
③
④
⑤
⑥

The water quality survey and the current study of Bellingham Bay was done July 26-28, 1973. Station locations are shown in Figure 4.2. Figure — Shows tidal and weather conditions during the survey

b. Dissolved Oxygen

Oxygen data for the Squalicum marina are summarized in Table 4.4. The dissolved oxygen in the marina was generally below the criterion of 6.0 mg/l for Class A marine waters. The dissolved oxygen was much lower at the surface than at depth. The dissolved oxygen also showed a noticeable increase from Friday, July 27 to Saturday, July 28, 1973.

c. Temperature

Temperature data from the Squalicum marina are summarized in Table 4.5. Temperatures in the surface waters of the marina were higher, without exception, than the water quality criterion proposed by the State of Washington. Since no measurements were made outside the marina, it is difficult to determine how much of the increase in temperature is due to marina construction. Temperature measurements from earlier studies (Collias and Barnes (1962)) indicate that temperatures in excess of the proposed criterion (12.8°C or 55°F) are common in the surface waters of Bellingham Bay during the summer months.

d. Total coliform bacteria

Total coliform plate counts exceeded 70 MPN/100 ml at all locations within the Squalicum boat basin. Fecal coliforms were not measured during the survey. Therefore, it is not known that a violation of the Wash State water quality criterion ~~standards~~ violations occurred. Much of the problem can not attributed to ~~was, no doubt, associated~~ with the discharge of raw sewage by in the boat basin food processors rather than with the operation of the boat basin itself.

e. Total Grease and Oil

Total grease and oil ranged from 1.0 mg/l to 2.1 mg/l. The highest value was observed at the northwest entrance near one of the raw sewage discharge points. Table — gives the concentration of all the total grease and oil samples collected in the Squalicum Small Boat Basin

Land use in the vicinity of the marina included parking for automobiles and trailers, marine-related industry such as boat repair and sales. Trespass upon the piers where boats were berthed was specifically prohibited although access to these areas was not restricted by gates or fences. ~~A sling for launching and retrieving boats is available at Kingston Cove. The equipment is operated by the Port of Kingston. The fee schedule is shown in Table 4.12.~~

No public boat launching facilities, nor provision for any other form of marine - oriented recreation besides boating, are available at the Kingston Cove marina.

~~Boat Length~~	~~Launching Fee~~
~~Less than 19'~~	~~3.00~~
~~20~~	~~3.50~~
~~21~~	~~4.00~~
~~22~~	~~4.50~~
~~23~~	~~5.00~~
~~24~~	~~5.50~~
~~25~~	~~6.00~~
~~26~~	~~6.50~~

~~Table 4.12 Schedule of launching fees for the Kingston Cove Marina~~

5. Port Townsend

a. General

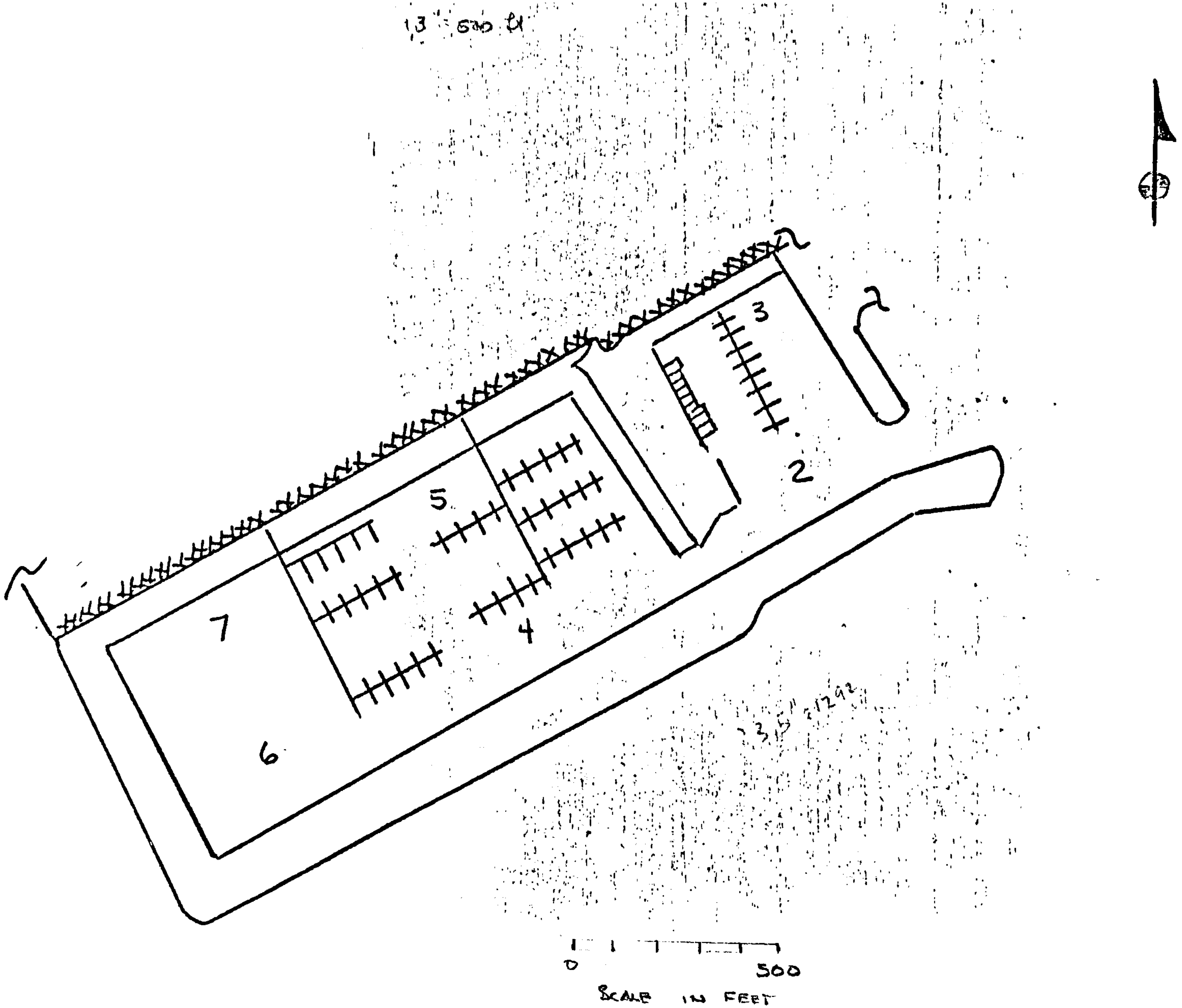
The Port Townsend marina is located in Port Townsend near the northern entrance to Puget Sound. The marina is operated by the Port of Port Townsend. Physical and tidal characteristics for this marina are given in Tables A.II.9 and A.II.10 in Appendix II. Water classification for the marina is Class A (Excellent) marina.

The water quality survey was done during the period September 6-7, 1973. Station locations are shown in Figure 4.5. The U. S. Army Corps of Engineers current study was done September 10-11, 1973.

Port Townsend receives the waste from the City of Port Townsend, Fort Flagler State Park and the Crown-Zellerbach pulp mill. There are no significant discharges within the marina. Water quality of Port Townsend is generally high due to its proximity to the entrance of Puget Sound. During certain times of the year, particularly late summer and early fall, ocean water with low dissolved oxygen enters Puget Sound. ~~This low dissolved oxygen can result in technical violations of the water quality standards.~~

Circulation patterns within Port Townsend are influenced primarily by the tides. During the early stage of each tide the current in Port Townsend runs in the same direction as the current in Admiralty Inlet. During the late stages of the tide the current in Port Townsend runs in the opposite direction from that in Admiralty Inlet.

Within the marina, the float study by the U. S. Army Corps of Engineers indicated that the current was generally clockwise throughout the marina during both flood and ebb. Typical speeds were 0.03-0.06 meters/second (0.1-0.2 feet per second).


1.3" = 500 ft
3
2
5
4
7
6
23.5" = 1292"
0
500
SCALE IN FEET

b. Dissolved Oxygen

Dissolved oxygen data for September 7, 1973 for Port Townsend are summarized in Table 4.13. Depth, time - averages of the September 7, 1973 dissolved oxygen data were similar at all locations within the marinas.

Time averages of the bottom two observations at each location indicate that dissolved oxygen at depth was about 0.9 mg/l less at the inner stations than at the control station.

c. Temperature

Temperature data for Port Townsend are summarized in Table 4.14. Depth time-averaged of the September 7, 1973 temperatures were approximately 9.4°C higher at the inner stations than at the control. The water temperature both inside and outside was decreasing relatively rapidly on September 6, 1973. The higher average temperatures inside the marina imply either that solar heating had a greater effect on the marine than on the control, or that the mixing processes within the marina were such as to prevent complete mixing within one tidal cycle. The fact that the average temperature within the marina increases with distance from the entrance supports the latter hypothesis.

d. Total coliform organisms

With the exception of one count of 86 MPN/100 ml, total coliform bacteria were less than 70 MPN/100 ml, the Washington State water quality standard for Class AA marine waters.

e. Total grease and oil

Total grease and oil were equal to or less than 1.0 mg/l at all locations within the Port Townsend marina.

f. Pesticide

STATION NUMBER	#1	#2	#3	#4	#5	#6	#7
MAXIMUM DISSOLVED OXYGEN (MG/L)	8.9	8.4	7.8	8.3	8.5	8.4	8.2
DEPTH OF MAXIMUM DISSOLVED OXYGEN (METERS)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TIME OF MAXIMUM DISSOLVED OXYGEN	1435 9/7/73	0740 9/7/73	0855 9/7/73	0905 9/7/73	0805 9/7/73	0815 9/7/73	1110 9/7/73
AVERAGE DISSOLVED OXYGEN (MG/L)	7.0	6.9	6.8	7.0	6.9	6.9	6.9
MINIMUM DISSOLVED OXYGEN (MG/L)	6.0	5.7	6.0	4.9	5.4	3.7	4.5
DEPTH OF MINIMUM DISSOLVED OXYGEN (METERS)	6.1	5.2	4.6	4.3	5.8	4.6	4.9
TIME OF MINIMUM DISSOLVED OXYGEN	1220 9/7/73	1040 9/7/73	0900 9/7/73	0910 9/7/73	1300 9/7/73	0920 9/7/73	0925 9/7/73

TABLE SUMMARY OF DISSOLVED OXYGEN DATA FOR THE PORT TOWNSEND MARINA
SEPTEMBER 7, 1973

STATION NUMBER	#1	#2	#3	#4	#5	#6	#7
MAXIMUM TEMPERATURE (°C)	11.8 12.8	11.8	12.0	12.5	12.7	12.5	13.0
DEPTH OF MAXIMUM TEMPERATURE (METERS)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TIME OF MAXIMUM TEMPERATURE	1435 9/7/73	1230 9/7/73	1450 9/7/73	1250 9/7/73	1515 9/7/73	1520 9/7/73	1525 9/7/73
AVERAGE TEMPERATURE (°C)	10.9	11.2	11.2	11.3	11.3	11.4	11.4
MINIMUM TEMPERATURE (°C)	10.6	10.8	10.8	10.8	10.8	10.9	10.9
DEPTH OF MINIMUM TEMPERATURE (°C)	6.1	5.2	6.1	5.2	6.1	6.1	4.6
TIME OF MINIMUM TEMPERATURE	1220 9/7/73	1040 9/7/73	1450 9/7/73	1050 9/7/73	1410 9/7/73	1520 9/7/73	1110 9/7/73

TABLE SUMMARY OF TEMPERATURE DATA FOR THE PORT TOWNSEND MARINA
SEPTEMBER 7, 1973

[illegible]

Pesticide concentrations were below the level of detection at all locations in the marina.

6. Composite Water Quality Score

For the purposes of comparing the total water quality of the five marinas, a composite water quality score was devised. Water quality parameters contained in the composite included total coliform bacteria, dissolved oxygen, temperature, total oil and grease, pesticides and aesthetics. For each constituent a perfect score would be ten (10). Deviations from perfection were measured in the following way:

Total coliform bacteria - The ratio of the number of measurements less than the pertinent water quality standard to the total number of measurements was mulplied by ten (10)

Dissolved oxygen - The ratio of the number of stations for which the minimum dissolved oxygen was equal to or greater than the control to the total number of stations was multiplied by ten (10).

Temperature - The ratio of the number of stations for which the maximum temperature was less than or equal to the control to the total number of stations was multiplied by ten (10).

Total oil and grease - The ratio of the number of stations for which total oil and grease was less than 1.0 mg/l to the total number of stations was multiplied by ten (10).

Pesticides - The ratio of the number of stations for which pesticide levels were not detectable to the total number of stations was multiplied by ten (10).

Aesthetics - A subjective evaluation with ten the highest possible score and zero (0) the lowest possible score.

The results of the scoring system are shown in Table 4.15.

[illegible]

	Edmonds	Squalicum	Shilshole	Kingston	Port Townsend
Bacteria	8	1	7	9	9
Dissolved Oxygen	7	0	5	9	1
Temperature	1	3	5	1	2
Total oil and grease	7	2	9	10	10
Pesticides	5	8	9	10	10
Aesthetics	~~7~~ 3	3	~~7~~ 4	8	~~7~~ 8
TOTAL	35	17	(42	((47	39

Table 4.15 Composite water quality scores for marinas studied in the intensive surveys

Flux due to

Land use Water Use Boats / sq foot tidal prism

V. RESULTS OF ONE-DAY SURVEY

The one-day survey was conducted on September 12, 1973. Five marinas were visited by float plane. Sample~~s~~ were taken at several locations in each marina for the purpose of determining the levels of total coliform bacteria, total grease and oil and for determining the effect of the water upon the development of Pacific oyster ~~larvae.~~ embryos. The schedule was planned such that each marina could be visited at low slack. water. However, the sampling took longer than anticipated and the marinas at the end of the schedule were not sampled until well into the flood stage of the tide.

1. Port Angeles

a. General

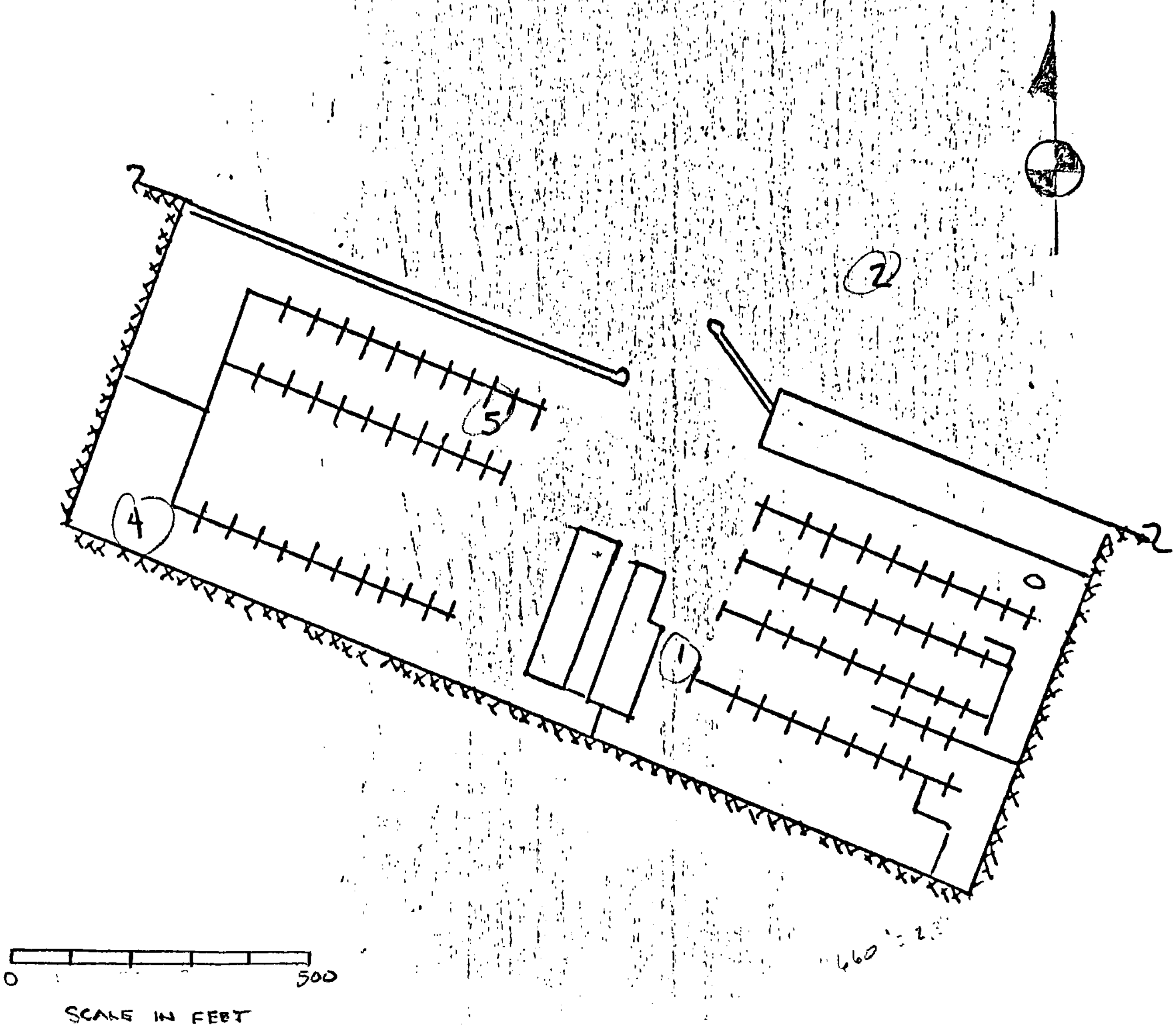
The Port Angeles marina is located in Port Angeles Harbor. Port Angeles Harbor is at the north shore of the Olympia Penninsula on the Straits of Juan de Fuca.

The Strait~~s~~ of Juan de Fuca ~~are~~ is a source of high quality water. However, water quality within Port Angeles is poor, due primarily to the discharge of large amounts of waste by the ITT Rayonier Company Pulp Mill. The Marina is at the west end of Port Angeles Harbor where exchange with the Strait~~s~~ of Juan de Fuca is a minimum.

Samples were taken at six locations within and in the vicinity of the marina. Samples were taken during the period between 0840 and 0940 on September 12, 1973. The water quality data is given in Table A.III.6.

The watercourse classification for Port Angeles Harbor is Class A with the special condition that total coliform organisms "... shall not exceed a median value of 240 with less than 20% of samples exceeding 1000 when associated with any fecal source".

③



b. Total Coliform Organisms

Total coliforms organisms were greater than 240 MPN/100 ml at two locations within the marina. Background levels prevailed at the two control stations, one in Port Angeles Harbor, the other in the Strait~~s~~ of Juan de Fuca.

c. Total Grease and Oil

Total grease and oil were less than 1.0 mg/l at all locations within the marina. The sample taken from the control station outside Port Angeles Harbor had a concentration of 3.0 mg/l total grease and oil.

d. Bioassay

Mean percent abnormal larvae exceeded 20 percent at two stations within the marina. The control inside Port Angeles Harbor also exceeded 20 percent.

2. Skyline Marina

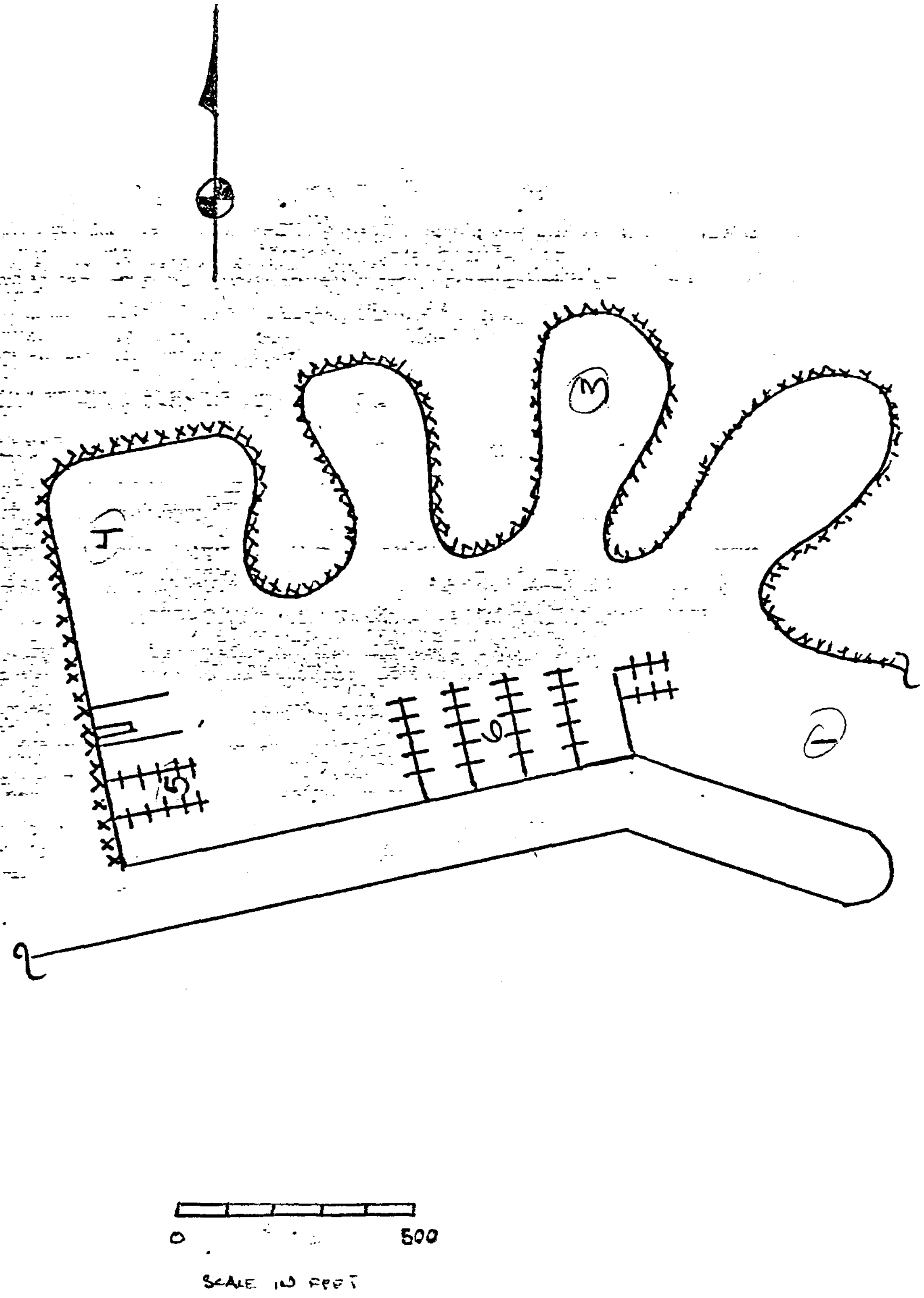
a. General

The Skyline Marina is located at Burrows Bay just south of Anacortes. Water Quality in Burrows Bay and Rosario Racine Straits is very good. There are no major sources of industrial or municipal waste discharge within the vicinity of the Skyline Marina. Samples were taken from 1015 to 1050 on September 12, 1973.

The water course classification for Burrows Bay is Class AA. (Extraordinary).

b. Total Coliform Organisms

Total coliform organisms were low at all stations sampled within and in the vicinity of the marina.


4
3
1
5
6
0
500
SCALE IN FEET

c. Total Grease and Oil

Total grease and oil concentrations were less than 1.0 mg/l at all stations sampled.

d. Bioassay

Mean percent abnormal larvae did not exceed 20 percent at any of the stations sampled.

3. Cornet Bay

a. General

The Cornet Bay Marina is located near Deception Pass, between Fidalgo and Whidbey Island. There are no major sources of municipal or industrial waste discharge in the vicinity of the marina.

The watercourse classification for Cornet Bay is Class AA (Extraordinary)

b. Total Coliform Organisms

Total coliform organisms were less than 70 MPN/100 at all of the stations sampled within and in the vicinity of the Cornet Bay Marina.

c. Total Grease and Oil

Total grease and oil concentrations were less than 1.0 mg/l at all sample locations.

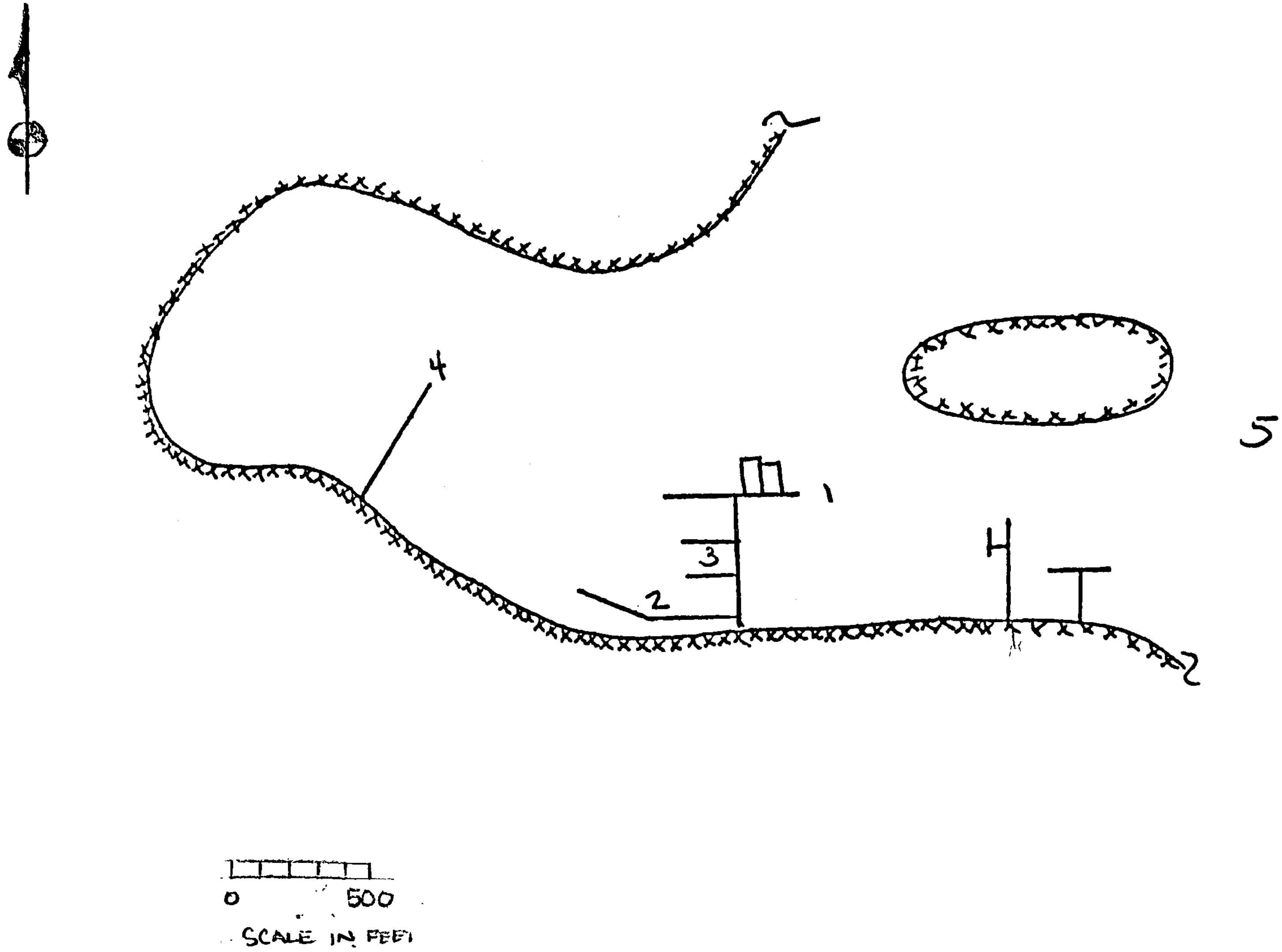
d. Bioassay

Mean percent abnormal Pacific oyster larvae were less than 20 percent at all sample locations.

4. Anacortes Marina

a. General

The Anacortes marina is located near adjacent to the City of Anacortes, Washington at the north end of Fidalgo Island. There are a number of industrial and municipal discharges in the vicinity of the marina. These include the Scott Paper Company Sulfite Mill, the City of Anacortes sewage treatment


4
1
3
2
5
0
500
SCALE IN FEET

plant, the Sebastian Stuart Fish Company and the Fisherman's Packing Corp.

The watercourse classification for the Anacortes Marina is Class A (Excellent).

The samples were collected in the Anacortes Marina between 1225 and 1300 on September 12, 1973. Water quality data for Anacortes is presented in organisms. ?

b. Total coliform

Total coliform organisms were greater than 240 MPN/100 ml at one location in the interior of the marina.

c. Total grease and oil

Total grease and oil concentration was 2.6 mg/l at the sample station near the U. S. Coast Guard Station. This was also the sample station with the high count for total coliform organisms. Total grease and oil concentration was less than 1.0 mg/l at all other sample stations within and ub the vicinity of the marinas.

d. Bioassay

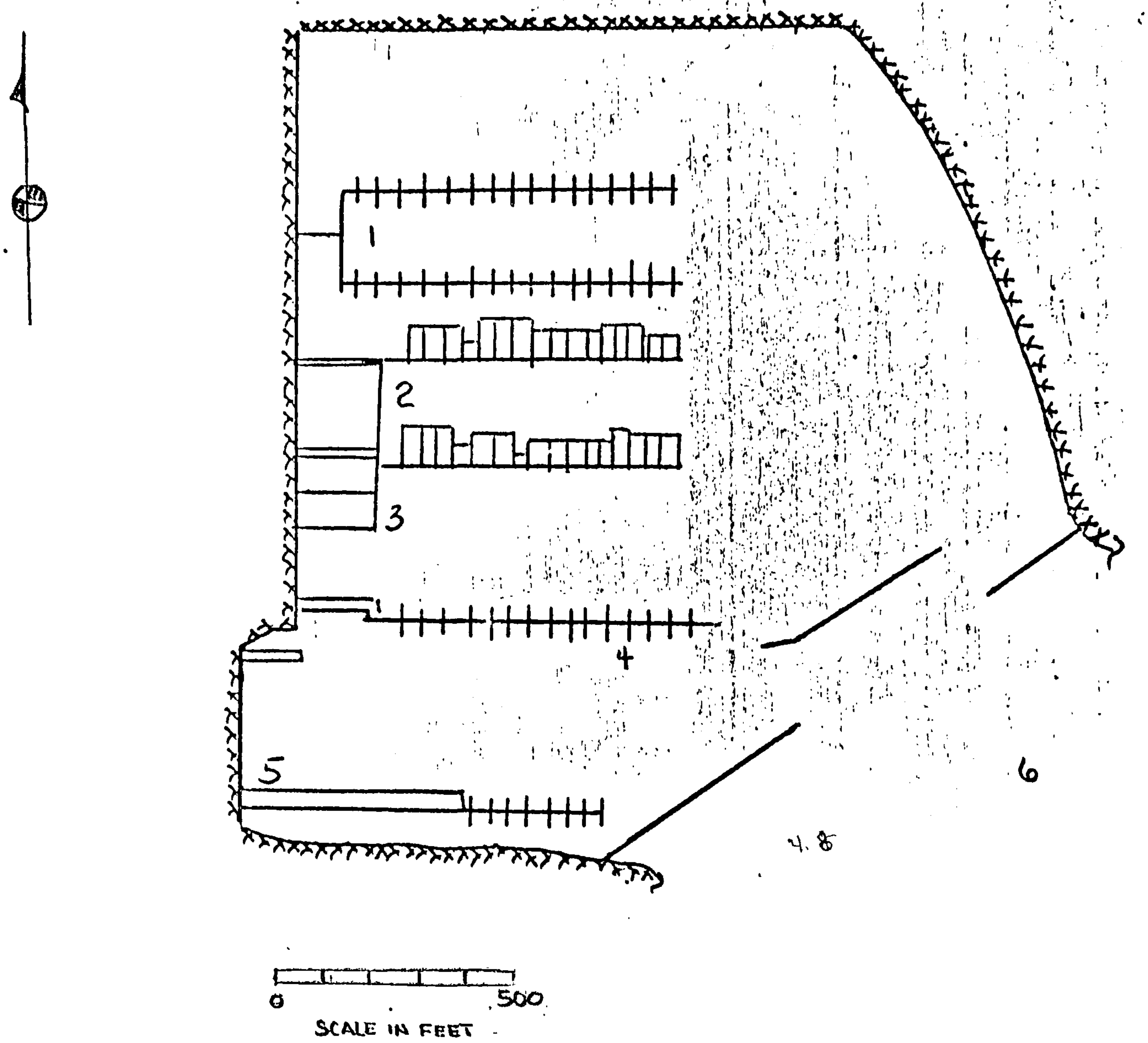
Mean percent abnormal Pacific oyster larvae exceeded 20 percent at only one station in the Anacortes marina. Relative survival, compared to the control group from Clam Bay was also very low at this sample station.

5. Point Defiance Marina

a. General

The Point Defiance Marina is located on Dalco Passage in Puget Sound near the City of Tacoma, Washington. The marina is adjacent to the ASARCO smelter. Leachates from slag and stormwater runoff resulting from the smelter operation provides a source of highly toxic waste.

The water course classification for the Point Defiance Marina is Class AA (Extraordinary).



4.8

Samples were taken at the Point Defiance Marina during the period between 1410 and 1505 on September 12, 1972. The data is contained in Table A.III.1) of Appendix III and in Appendix IV.

b. Total Coliforms Organisms

counts?

Total coliform organisms were low at all sample locations within and in the vicinity of the Point Defiance Marina. It is likely that the low counts are caused by the high toxicity of the tailing leachates, associated smelter operations and the marina itself, rather than by the absence of bacterial sources.

[illegible] not the [illegible] [illegible] although [illegible] be present. [illegible]

c. Total grease and oil

A maximum value of 3.1 mg/l total grease and oil was found at one station in the interior of the marina. Total grease and oil was less than 1.0 mg/l at all other stations.

d. Bioassay

Mean percent abnormality of Pacific oyster larvae development in samples taken from Point Defiance Marina exceeded 20% at every sample station, including the control. Percent mortality was also high at three of the four stations within the marina.

e. Aesthetics

The Point Defiance marina was the only marina visited during the summer surveys where water pollution was specifically encouraged. A well constructed and neatly painted sign, located on the bank, instructed marina users to "DUMP OLD OIL HERE" where it could run down the rocks into the waters of Puget Sound.

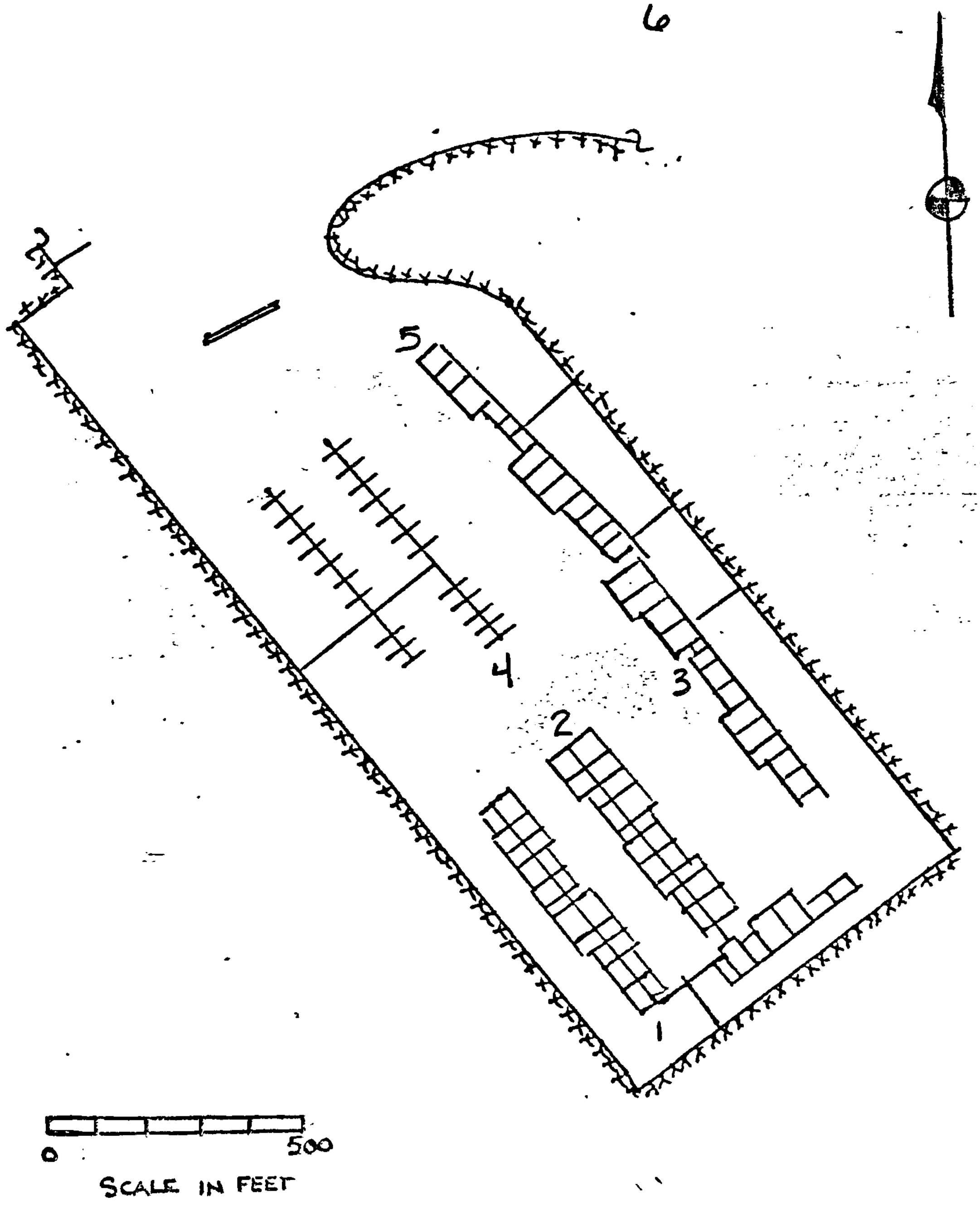
Some discussion of the results of the [illegible] survey is needed before going on to this general discussion.

VI. DISCUSSION

A composite water quality score could also be constructed for the [illegible]

The quality of water within a marina is determined by marina siting, design and operation, as well as by adjacent water and land use. Even under ideal circumstances, it is difficult to completely eliminate the discharge

It might be interesting to see if correlation existed between [illegible] score and TABLE 2 (BIOASSAY RESULTS)


6
2
2
5
4
3
2
1
0
500
SCALE IN FEET

of pollutants to a marina. Furthermore, the specific purpose of the marina as a shelter inhibits mixing and exchange. The net result of marina construction can only be, at best, the maintenance of existing water quality. Under less than ideal conditions, the construction of a marina can result in the deterioration of water quality.

The siting, design and operation of future marinas should be carefully planned. From the point of view of water quality the elements described in the following section should be included in the construction of any marina.

1. Siting

Mixing and exchange

From the standpoint of water quality, the best site locations for marinas are in areas where mixing and exhcange characteristics are good. Small, unrestricted embayments along open shorelines, or in estuary where there is an adequate high quality fresh-water flow are examples of good locations. Sites at the landward end of long or restricted embayments are examples of poor locations.

In general, the time required to renew the water in a tidally influenced embayment is a function of at least the following valuables:

Q_{tidal} The average discharge into the embayment due to tidal influences cubic meters/second,

V_{MLLW} The volume of the embayment of MLLW cubic meters

$\mathcal{K}$ The coefficient of eddy diffusivity, square meters/second,

A_{w} the cross-sectional area of the opening between the enbayment and open water, square meters,

L_{m} the distance from the opening to the marina site, meters,

Q_{fresh} The rate of discharge to the embayment from sources other than the tide, cubic meters/second

The renewal time, τ , of the embayment can be written as a function of at least three dimentionless valuables:

$$\frac{\tau}{T_o} = f\left(\frac{\tau_{diff}}{T_o}, \frac{\tau_{tide}}{T_o}, \frac{\tau_{fresh}}{T_o}\right)$$

where,

$$\tau_{diff} = \frac{V_{MLW}\ L_m}{\kappa\ A_w}$$

$$\tau_{tide} = \frac{V_{MLW}}{Q_{tide}}$$

$$\tau_{fresh} = \frac{V_{MLLW}}{Q_{fresh}}$$

$$T_o = \text{tidal period}$$

For a simple one-dimensional analysis, it can be shown by mass balance that a valid functional form for the time, τ , is:

$$\frac{1}{\tau} = \frac{1}{\tau_{diff}} + \frac{1}{\tau_{tide}} + \frac{1}{\tau_{fresh}}$$

The rate of decay of some conservative constituent, C , is then given approximately by:

$$C = C_o e^{-\frac{t}{\tau}}$$

where,

C_o = the initial concentrations

The steady-state concentration of the constituent, C , for the case of a constant discharge,

Q_{waste} , is:

τ =

$$C = \frac{\tau Q_{waste} C_{waste}}{V_{HLLW}}$$

where,

C_{waste} = the concentration of the discharge

For the marinas which were examined intensively, typical values of the various times, τ_{diff} and τ_{tidal} are given in Table 6.1

conservative constituent conc.,

Similarly, the composite water quality score, Σ ff^{m}, is plotted in Figure 6.1 as a function of the total flushing time, τ.

Adjacent water use

Due to the fact that marinas are designed to inhibit mixing, marinas should be located in areas where adjacent water use is not adversely affecting water quality. The construction of a marina tends to accentuate any water quality problems which are already in existence.

Of the marinas studied during the summer of 1973, adjacent water use was good at the Edmonds, Kingston, Shilshole Bay, Cornet Bay and Skyline marinas; fair at Port Townsend; and poor at Port Angeles, Squalicum and Point Defiance.

Adjacent Land Use

The use of land adjacent to the marina can also have an impact upon water quality. Marinas should, therefore, not be located where point and non-point discharges will contribute significantly to the marina waste load.

The only marina which was located well, with respect to adjacent land use was the Cornet Bay marina. Adjacent land use at Skyline marina is good at present, but this will not be the case if development proceeds as planned. Adjacent land use was fair at Edmonds, Shilshole, Port Townsend, Kingston, Port Angeles, Anacortes and Squalicum; and poor at Point Defiance.

2. Marina Design

Number and orientation of openings

The rate of exchange between a marina and the water outside the marina is a function of the number and orientation of the marina openings. If the marina has more than one opening, or has an exceptionally large opening, there may be some of the source water which flows completely through the marina during a tidal cycle. The amount of flow through will depend upon the opening sizes, the range of the tide compared to the depth of the marina and the orientation of the openings with respect to the direction the tidal current is moving.

If the inflowing water to the marina on the flooding stage of the tide is, Qin, and the outflow, Qout, then the volume rate of change within the Marina, V , is

$$Qin - Qout = \dot{V}$$

Assuming that the flow through ratio, α, where:

$$\alpha = \frac{Qout}{Qin}$$

is relatively constant over the tidal cycle, the effect of flow-through can be determined. The mass balance method, for a well mixed system (see Appendix II), has been used to analyze this effect for a typical marina and tidal conditions in Puget Sound. The results for values of α ranging from 0.0 to 0.95 are given in Figure 6.1 .

The two marinas with multiple openings which were part of the field study program were Shilshole and Squalicum. In both cases the orientation of the openings is such that maximum flushing efficiency is not attained. Current studies by the U. S. Army Corps of Engineers showed that there was almost no flow-through at Squalicum during the period of study. Flow-through at Shilshole was better, although half the current measurements showed no flow-through.

The water quality studies in Shilshole showed that the dissolved oxygen decreased and the temperature increased with distance from the openings. This implies that the flow-through design was not completely effective in renewing the marina waters. The data from Squalicum is not conclusive in this regard because no measurements were made at stations outside the marina.

Opening size and aspect ratio

It was shown in an earlier section that the diffusion time, τ_{diff}, could be written approximately as

	Characteristic Mixing Times	
	Diffusion, $\tilde{\tau}_{diff}$ (Days)	Tidal, $\tilde{\tau}_{tidal}$ (Days)
Edmonds	19.9	0.6
Squalicum	7.6	1.6
Shilshole	23.7	0.8
Kingston	0.7	0.8
Port Townsend	13.9	1.6

Table 6.1 Characteristic mixing times, $\tilde{\tau}$ diff and $\hat{\tau}$tide for each of the marinas studied by an intensive survey

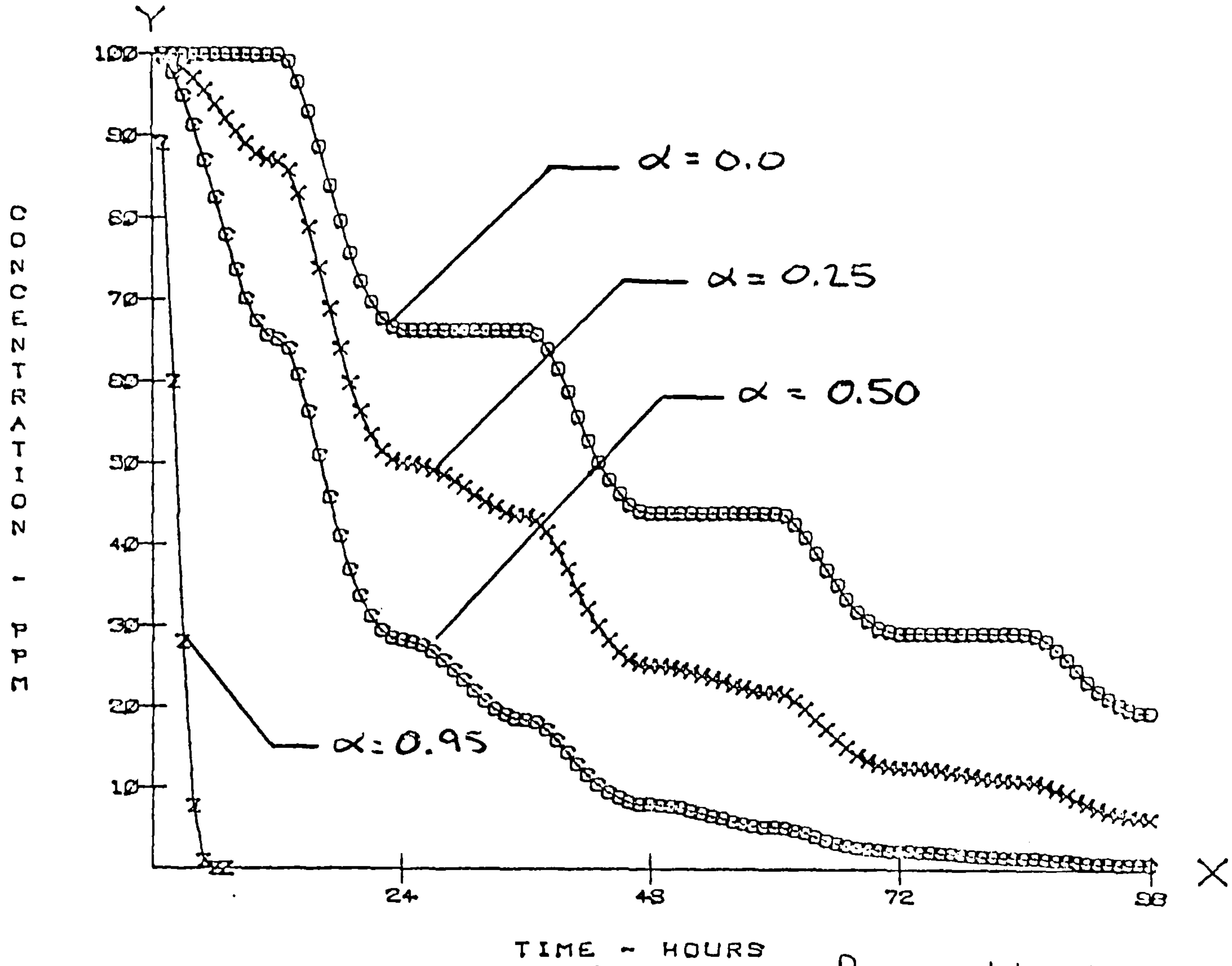


Figure 6.1. Rate of decay of constituent, C, for various values of flow-through, α, in a typical Puget Sound marina.

~~Although half the current measurements showed no flow-through,~~

~~The water quality studies in Shilshole showed that the dissolved oxygen decreased and the temperature increased with distance from the openings. This implies that flow-through was not completely effective in renewing the marina waters. The data from Squalicum is not conclusive in this regard because no measurements were made at stations outside the marina.~~

~~Opening size and aspect ratio~~

~~It was shown in an earlier section that the diffusion time, τ_{diff} could be written approximately as~~

$$\tau_{diff} = \frac{V_{MLLW}\ L_{max}}{\mathcal{K}\ A_x}$$

where, in this, instance,

A_x = The cross-sectional area of the opening between the embayment and open water, square meters,

V_{MLLW} = the volume of the marina at MLLW, cubic meters,

L_{MAX} = the maximum distance from any point in the marina to the opening, meters,

$\mathcal{K}$ = The eddy diffusivity, square meters/second

The coefficient of eddy diffusivity, $\mathcal{K}$, can be written as a function of some length scale. From an examination of a large number of field measurements Pearson (1956) obtained the relationship

$$\xcancel{\mathcal{K} = 4.64 \times 10^{-4} L_c^{4/3}}$$

where,

L_c = the characteristic size of some eddy, meters.

Typically, L_c could be taken as the minimum dimension of the embayment, L_{min}.

The diffusion, τ_{diff}, can then be written:

$$\tau_{diff} = \xcancel{\frac{V_{MLLW} \lambda}{A_x \, 4.64 \cdot 10^{-4} L_{min}^{1/3}}}$$

where,

$$\lambda = \frac{L_{max}}{L_{min}}$$

From Equation ( ), it is evident that the diffusion time, τ_{diff}, is directly proportional to the aspect ratio, λ, and inversely proportional to the cross-sectional area, A_x. Diffusion times can be minimized by decreasing the aspect ratio, λ, and increasing the entrance opening, A_x.

Kingston Cove, the marina with the highest composite water quality score, has an aspect ratio of approximately one and the width of the opening is very nearly equal to the maximum dimension of the marina.

It is also worth pointing out that a limited opening can restrict the flow and, therefore, the tidal exchange between the marina and open water. This problem is somewhat more difficult to analyze. Physical models such as those used by Lewis (1972) or numerical models (Callaway, Byram and Ditsworth (1969)) should be used to analyze this problem.

Pier length, spacing and design

Piers within the marina can also restrict mixing and have a particularly important effect upon floatable material, In the marinas for which the pier length was of the same order as the dimensions of the marina, floatable material remained for several tidal cycles.

At Shilshole Bay Marina, the existence of backwaters and stagnant eddies, resulted in the accumulation of unsightly debris. These backwaters were apparently a result of improper pier and bulkhead design.

3. Marina Operation

In most of the marinas studied during the survey, the operators seemed to have a genuine interest in making their marina compatible with environmental quality. The one notable exception to this was the marina at Point Defiance.

Three matters which deserve special attention in the operation of marinas are:

i The handling of fuel and other petroleum products

ii Control of litter

iii Control of discharge from ship-board toilets

Recommendations

Review of proposed marina projects should consider the following recommendations as minimum criteria for maintaining water quality:

1. Marinas should be sited in areas where exchange and mixing characteristics are adequate. The mixing time, $\hat{\tau}$, should be less than one day.

2. Land and water use adjacent to the proposed marina site should be of high quality.

3. Marinas should contain multiple openings. These openings should be oriented in such a way so as to obtain maximum flow through efficiency. Physical and/or numerical models should be used to determine the best opening orientation.

4. Cross-sectional area of openings between the marina and open water should be as large as practicable. The aspect ratio, or ratio of maximum length dimension to minimum length dimension should be near one.

5. The diffusion time, $\hat{\tau}_{diff}$, should be less than one day.

6. Pier lengths should be less than one-half the minimum length dimension of the marina and pier spacing should be greater than the pier length.

VII. BEYOND WATER QUALITY

Most of the remarks contained within this report have been directed towards preserving the quality of a water body. The guidelines developed by the State of Washington's Department of Fisheries address the problem of fish passage. These are only two aspects of a very complex problem, that of land and water use. There has been an attempt in this report to describe other aspects of the land and water use of marinas, but much work remains to be done. As competition for use of the shorelines increases, it is important that planning, developing and regulatory agencies attempt to maximize use options. The result may be less development in some instances. Coming to terms with this concept is an essential ingredient for planning future boat storage and launching facilities.

Appendix II

Calculations of various physical and tidal characteristics were made for each of the marinas studied with an intensive survey. These characteristics included:

1. Average depth at Mean Lower Low Water (MLLW)
2. Average Depth at Mean Tide Level (MTL)
3. Average Depth at Mean Higher High Water (MHHW)
4. Mean Tidal Range
5. Surface Area
6. Volume at Mean Lower Low Water (MLLW).
7. Volume at Mean Higher High Water (MHHW)
8. Tidal Prism

The tidal prism, V_p, is the difference between the volume at Mean Higher High Water and Mean Lower Low Water.

9. Approximate number of moorages

The approximate number of moorages was obtained from the

10. Exchange Ratio

The exchange ratio, R_e, is the ratio of the tidal prism, V_p, to the volume at MHHW, V_{mhhw}:

$$R_E = \frac{V_P}{V_{MHHW}} \qquad (A.II.1)$$

11. Flushing Time

The flushing time, T_e, is the number of tidal cycles required to completely exchange the water within an embayment. It is given by the reciprocal of the exchange ratio:

$$T_E = \frac{1}{R_E} \qquad (A.II.2)$$

12. Time to $1/e$ for High Range

The time required for a conservative constituent, C , in a marina to reach $1/e$ (0.368) of its original value was determined from the mass balance:

$$\frac{d(VC)}{dt} = Q_{in} C_{in} - Q_{out} C_{out} \qquad (A.II.3)$$

where

V = the total volume of the marina,

Q_{in} = the instantaneous rate of flow into the marina,

C_{in} = the concentration of constituent, C ,flowing into the marina

Q_{out} = the instantaneous rate of flow out of the marina

Equation (A.II.3) was solved for a high tidal range.

13. Time to $1/e$ for Mid Range

Similar to paragraph 12. above except that a medium tidal range was used.

14. Time to $1/e$ for Low Range

Similar to paragraph 12. above, except that a low tidal range was used.

15. Characteristic Diffusion Time

The characteristic diffusion time, τ_{diff}, is given by:

$$\tau_{diff} = \frac{V_{MTL} L_{MAX}}{A_x \chi} \qquad (A.II.4)$$

where:

V_{MTL} = the volume at Mean Tide Level

L_{max} = the maximum distance from any point in the marina to the entrance,

Average Depth at MLLW	2.9 Meters	(9.5 Feet)
Average Depth at MTL	4.9 Meters	(16.0 Feet)
Average Depth at MHHW	6.3 Meters	(20.6 Feet)
Mean Tidal Range	2.3 Meters	(7.5 Feet)
Surface Area	48496 Sq Meters	(522,000 Square Feet)
Volume at MLLW	140995 CuMeters	(4,979,000 Cubic Feet)
Volume at MHHW	305069 CuMeters	(10,773,000 Cubic Feet)
Tidal Prism	164074 Cu Meters	(5,794,000 Cubic Feet)
Approximate Number of Moorages		

TABLE A II.1 PHYSICAL CHARACTERISTICS FOR THE EDMONDS MARINA

Exchange Ratio	0.54	
Flushing Time	1.86	Tidal Cycles
Time to i/e for High Range	0.25	Days
Time to i/e for Mid Range	0.67	Days
Time to i/e for Low Range	1.21	Days
Characteristic Diffusion Time	19.9	Days

TABLE A II.2 EXCHANGE CHARACTERISTICS FOR THE EDMONDS MARINA

Average Depth at MLLW	3.5 Meters	(11.6	Feet)
Average Depth at MTL	5.1 Meters	(16.8	Feet)
Average Depth at MHHW	6.2 Meters	(20.2	Feet)
Mean Tidal Range	2.6 Meters	(8.6	Feet)
Surface Area	185848 Sq Meters	(2,000,400	Square Feet)
Volume at MLLW	658221 Cu Meters	(23,244,000	Cubic Feet)
Volume at MHHW	487152 Cu	(40,447,000	Cubic Feet)
Tidal Prism	487152 Cu Meters	(17,203,000	Cubic Feet)
Approximate Number of Moorages			

TABLE A II.3 PHYSICAL CHARACTERISTICS OF THE SQUALICUM SMALL BOAT BASIN

Exchange Ratio	0.43
Flushing Time	2.34 Tidal Cycles
Time to i/e for High Range	1.08 Days
Time to i/e for Mid Range	1.63 Days
Time to i/e for Low Range	2.21 Days
Characteristic Diffusion Time	7.6 Days

TABLE A II.4 EXCHANGE CHARACTERISTICS OF THE SQUALICUM SMALL BOAT BASIN

Average Depth at MLLW	5.5 Meters	(18.0 Feet)
Average Depth at MTL	7.5 Meters	(24.6 Feet)
Average Depth at MHHW	8.9 Meters	(29.3 Feet)
Mean Tidal Range	2.3 Meters	(7.6 Feet)
Surface Area	341892 Sq Meters	(3,680,000 Square Feet)
Volume at MLLW	1875776 Cu Meters	(66,240,000 Cubic Feet)
Volume at MHHW	3053347 Cu Meters	(107,824,000 Cubic Feet)
Tidal Prism	1177344 Cu Meters	(41,576,000 Cubic Feet)
Approximate Number of Moorages	1491	

TABLE A II.5 PHYSICAL CHARACTERISTICS OF THE SHILSHOLE MARINA

Exchange Ratio	0.39	
Flushing Time	2.59	Tidal Cycles
Time to i/e for High Range	0.55	Days
Time to i/e for Mid Range	0.79	Days
Time to i/e for Low Range	1.21	Days
Characteristic Diffusion Time	23.7	Days

TABLE A II.6 EXCHANGE CHARACTERISTICS
FOR THE SHILSHOLE MARINA

Average Depth at MLLW	3.5 Meters	(11.6 Feet)
Average Depth at MTL	5.5 Meters	(18.1 Feet)
Average Depth at MHHW	6.9 Meters	(22.7 Feet)
Mean Tidal Range	2.3 Meters	(7.5 Feet)
Surface Area	46453 Sq Meters	(500,000 Square Feet)
Volume at MLLW	164244 Cu Meter	(5,800,000 Cubic Feet)
Volume at MHHW	321408 Cu Meter	11,350,000 Cubic Feet)
Tidal Prism	157164 Cu Meters	(5,550,000 Cubic Feet)
Approximate Number of Moorages	316	

TABLE A II.7 PHYSICAL CHARACTERISTICS OF KINGSTON COVE MARINA

Average Depth at MLLW	3.4 Meters	(11.2 Feet)
Average Depth at MTL	4.9 Meters	(16.2 Feet)
Average Depth at MHHW	5.9 Meters	(19.5 Feet)
Mean Tidal Range	1.6 Meters	(5.3 Feet)
Surface Area	63815 Sq Meters	(686,880 Square Feet)
Volume at MLLW	217481 Cu Meter	(7,680,000 Cubic Feet)
Volume at MHHW	320558 Cu Meters	(11,320,000 Cubic Feet)
Tidal Prism	103077 Cu Meters	(3,640,000 Cubic Feet)
Approximate Number of Moorages		

TABLE A II.9 PHYSICAL CHARACTERISTICS OF THE PORT TOWNSEND MARINA

Exchange Ratio	0.32
Flushing Time	3.1 Tidal Cycles
Time to i/e for High Range	1.17 Days
Time to i/e for Mid Range	1.61 Days
Time to i/e for Low Range	2.21 Days
Characteristic Diffusion Time	13.9 Days

TABLE A II.10 EXCHANGE CHARACTERISTICS FOR THE PORT TOWNSEND MARINA

Jean — I don't think this thing adds much in its entirety. You're welcome to extract as much as you would like to. I do think your discussion need some explanation of the meaning of 20% abnormal i.e., Woelke's single sample criterion. Table 2 may also be useful as I mentioned earlier.

APPENDIX IV

MARINA WATER QUALITY
BASED ON PACIFIC OYSTER EMBRYO RESPONSE

General Approach

The quality of marina waters collected from selected sites in and around Puget Sound was determined by the oyster embryo bioassay. The development and survival of embryos of the Pacific oyster, *Crassostrea gigas*, served as the criteria for measuring the quality of these waters.

Methods

(Sample Collection)

Surface water samples were collected September 12, 1973 from sampling stations established within or near marinas located in Port Angeles, Burrows Bay, Cornet Bay, Anacortes, and at Point Defiance. The samples were transported by aircraft to the laboratory in 1-gallon polyethylene containers.

(Bioassay Procedure)

Duplicate 1-liter portions of each marina water sample were bioassayed immediately upon receipt according to the general bioassay procedure described by Woelke (1972). Seawater pumped from Clam Bay (below EPA pier, Manchester, Washington) was used as the "bioassay control."

Spawning was induced in oysters harvested from Cedrick's Beach and conditioned by personnel of the Washington State Department of Fisheries Shellfish Laboratory, Brinnon, Wash. Each liter of seawater was inoculated with approximately 2.99 X 10^4 developing oyster embryos. The cultures were covered with brown paper and incubated for 48 hours at about 18-20 C. Termination of the assay was achieved by filtering the cultures through a 35 µm Nitex screen. Materials retained by the screen were quantitatively transferred to glass vials and preserved with 5% formalin. Normal and abnormal oyster larvae were enumerated under a microscope at 100X.

Per cent abnormal larvae values were based on the proportion of abnormal larvae to the total number of larvae (normal and abnormal larvae) in each sample. Relative per cent survival values were based on the total number of larvae (normal and abnormal larvae) in each sample compared with the total number of larvae in the "bioassay control" sample.

Results

The response of Pacific oyster embryos to the various marina waters assayed is presented in Table 1.

Embryo responses to marina waters were generally characterized by higher rates of larval abnormality and embryo survival than were displayed by embryo populations exposed to Clam Bay water (bioassay control). These differences may indeed have reflected basic differences, other than pH, temperature, or salinity, in the ability of marina waters and Clam Bay water to support developing embryos. It is also possible, however, that differences in the collection and transport procedures used contributed to some of the differences observed.

Although these differences in response make interpretation of the assay results more difficult, they do not preclude the application of Woelke's (1972) proposed quality criterion for marine waters used for fish or shellfish reproduction, rearing, or harvesting. Accordingly, those marina waters yielding more than 20% abnormal larvae exceeded Woelke's single sample quality criterion. The proportion of water samples collected from each marina

Table 1. Continued

Sample Number	Culture Number	Time Collected	Sampling Location	pH	Salinity o/oo	Oyster Embryo Response Mean % Abnormal Larvae	Relative % Survival
			CORNET BAY MARINA				
37151	39-40	1155	Station 5 - Control	7.7	29.1	14.1	139
37154	35-36	1115	Station 1	7.8	30.2	8.96	106
37152	37-38	1120	Station 2 - Pier "A" Gas Dock	7.9	30.3	6.92	122
37150	41-42	1140	Station 4	7.4	30.1	11.8	121
			ANACORTES MARINA				
37155	43-44	1300	Station 6 - Control	7.5	29.7	7.74	120
37156	45-46	1225	Station 1 - Between "E" & "F", Near shore	7.8	29.4	11.2	106
37158	49-50	1240	Station 3 - Gas dock	7.7	29.1	28.0	3.23
37157	47-48	1230	Station 5	7.4	27.2	10.8	87.1
			POINT DEFIANCE MARINA				
37125	53-54	1505	Station 6 - Control	7.6	30.1	61.8	130
37126	51-52	1435	Station 1	7.9	28.5	100	18.3
37127	57-58	1415	Station 2	7.9	29.7	100	21.1
37124	55-56	1440	Station 3	7.5	28.2	----[b]	0
37129	59-60	1410	Station 4 - Gas dock	7.7	29.8	100	100

---

[b] 100% mortality

that were in this category is shown in Table 2.

Table 2. Proportion of marina water samples exceeding Woelke's (1972) proposed marine water quality criterion.

Marina Locations	Per Cent of Samples[a] Yielding >20% Abnormal Larvae
Burrows Bay	0
Cornet Bay	0
Anacortes	25
Port Angeles	50
Point Defiance	100

[a] Including marina controls

Water quality in the Burrows Bay and Cornet Bay marinas appeared to be relatively good. The Anacortes and Port Angeles marinas had water of only fair quality, while the quality of water in the vicinity of the Point Defiance marina appeared to be relatively poor.

More intensive sampling of these marinas on a seasonal basis would provide needed year-round information on marina water quality. Such an effort would also help determine if marina-associated activities were actually responsible for the deterioration in marina water quality observed during this survey.

References

Woelke, C.E. 1972. Development of a receiving water quality criterion based on the 48-hour Pacific oyster (*Crassostrea gigas*) embryo. Washington State Department of Fisheries, Technical Report No. 9, 93p.

Submitted by:

Joseph M. Cummins 12/7/73

Joseph M. Cummins, Biologist
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Manchester, Washington

Table 1. Response of Pacific oyster embryos to waters collected from selected marinas in and around Puget Sound.

Sample Number	Culture Number	Time Collected	Sampling Location	pH	Salinity o/oo	Oyster Embryo Response	
						Mean % Abnormal Larvae	Relative % Survival
-----	1-10	1130	Bioassay Control Clam Bay, Manchester	7.8	29.2	2.77	100[a]
			PORT ANGELES MARINA				
38103	17-18	0935	Inside Ediz Hook Control 1	7.7	31.6	33.8	110
38102	15-16	0940	Outside Ediz Hook Control 2	7.7	30.8	12.6	119
38100	11-12	0920	End pier "C" Opposite entrance	7.5	29.1	50.2	120
38101	13-14	0905	East tip pier "H" N.E. corner	7.7	24.2	30.8	123
38104	19-20	0850	West tip pier "N"	7.5	27.2	15.8	110
38105	21-22	0920	Pier "R" Middle berth	7.7	30.3	16.4	103
			BURROWS BAY MARINA				
38106	23-24	1050	Control	7.7	30.3	8.45	122
38107	25-26	1045	Station 1-Entrance	7.8	30.2	13.3	124
38109	29-30	1045	Station 3	7.9	30.1	16.2	117
38111	33-34	1015	Station 4	7.8	30.1	7.73	123
38110	31-32	1030	Station 5 (TB-17)	8.0	29.9	10.0	120
38108	27-28	1035	Station 6 (B-20)	7.9	30.2	12.6	130

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[a] Assigned a survival value of 100%

Bibliography

Bowerman, F. R., and Chen, K. Y.

1971. Marina del Ray: A study of environmental variables in a semi-enclosed coastal water. University of Southern California. Sea Grant Publication USC - SG-4-71.

Brandsma, M. G., Lee, J. J. and Bowerman, F. R.

1973. Marina del Ray: Computer simulation of Pollutant transport in semi-enclosed water body, University of Southern California. Sea Grant Publication USC - SG-1-73.

Brown and Caldwell

1958. Metropolitan Seattle sewerage and drainage survey. Report for the City of Seattle, King County and the State of Washington

Callaway, R. J., Byram, K. V. and Ditsworth, G. R.

1969. Mathematical model of the Columbia River from the Pacific Ocean to Bonneville Dam. Part I. U. S. Department of Interior. FWQA. Pacific Northwest Water Laboratory. Corvallis, Oregon 155 pp

Collias, E. E., Barnes, C. A., Murty, C. B. and Hansen, D. V.

1966. An oceanographic survey of the Bellingham - Spanish Bay system. Volume II - Analyses of data. University of Washington Department of Oceanography. Special Report No. 32. 142 pp.

Fischer, H. B.

1970. A method of predicting pollutant transport in tidal waters. University of California Water Resources Center. Contribution No. 132.

Layton, J. A.

1971. Hydraulic and flushing characteristics of a small craft harbor in Puget Sound. University of Washington M. S. thesis.

Lewis, L. L.

1972. A hydraulic model study of the tidal flushing characteristics of two alternative small boat basin designs. University of Washington. M. S. thesis.

Nece, R. E. and Richey, E. P.

1972. Flushing characteristics of small boat marinas. Proceedings of the thirteenth international conference on coastal engineering. Vancouver, Canada.

Woelke, C. F.

1972. Development of a receiving water quality criterion leased on the 48-hour Pacific oyster (*Crassostrea gigas*) embryo. Washington State Department of Fisheries. Technical report No. 9. 93 pp.

1970. Puget Sound and adjacent waters report, pleasure boating study, Report prepared for Puget Sound Task Force of Pacific Northwest River Basins Commission by Seattle District, U. S. Army Corps of Engineers and Pacific Northwest Region Bureau of Outdoor Recreation.

1971. Criteria governing the design of bulkheads, land fills and marinas in Puget Sound, Hood Canal and Strait of Juan de Fuca for protection of fish and shellfish resources. Olympia, Washington