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Kitsap County Mixing Zone Study

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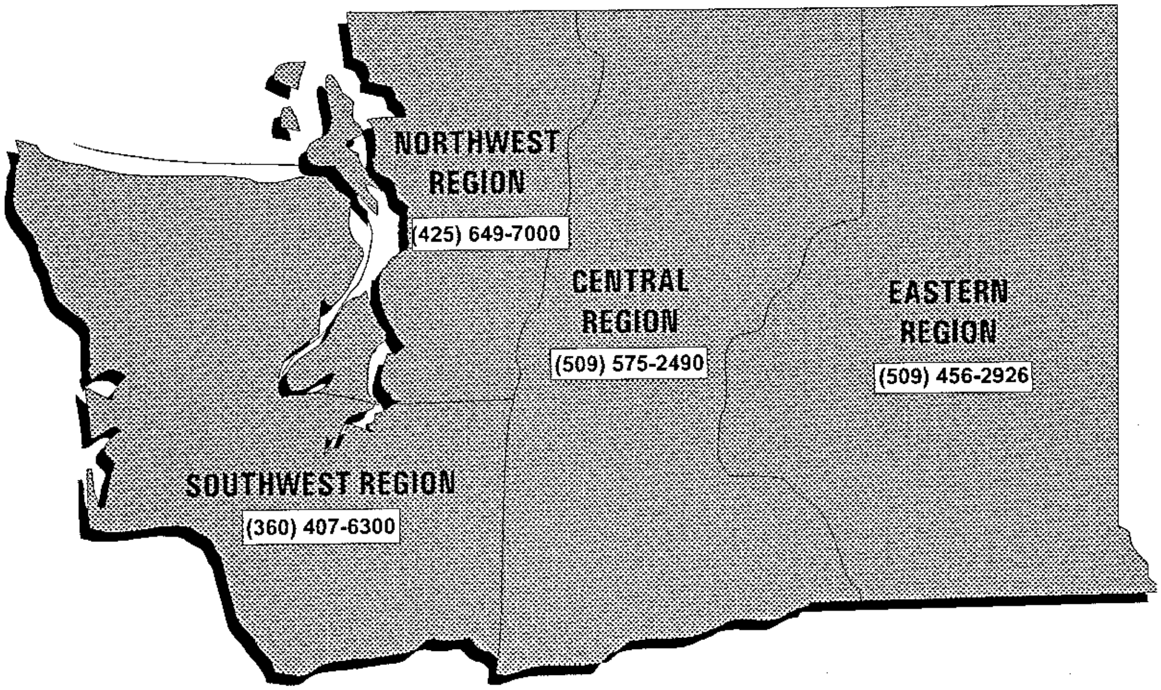

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Kitsap County Mixing Zone Study

by

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Abstract

This study began in late summer 1994 by characterizing receiving waters in the vicinity of six small municipal wastewater treatment plants discharging to the central basin of Puget Sound. The purposes of the study were to: 1) conduct mixing zone analyses and provide the input data and modeling results to permit managers; and 2) establish whether there is a need for costly site-specific data versus more readily available regional data. The study concluded that: 1) it is better to use regional stratification data sets like the ones available from Ecology's Ambient Monitoring Program than to attempt site-specific measurements of stratification; 2) it is better to collect a complete data set of site-specific current measurements; but if it will not be complete, then 3) the better approach is to conduct sensitivity analyses for acute and chronic mixing zones using a fine resolution of currents over a large range of values. A number of the important findings from this study were incorporated into Ecology's Guidance for Conducting Mixing Zone Analyses.

Introduction

General

This study characterizes the receiving waters in the vicinity of six wastewater treatment plant (WWTP) discharges to the central basin of Puget Sound. The six discharge sites are shown on Figure 1; descriptors are as follows (from north to south):

Permittee	WWTP identifier	Location
Pope and Talbot, Inc.	Port Gamble	Port Gamble
Kitsap County	Kingston	Apple Tree Cove
City of Bainbridge	Winslow	Bainbridge Is./ Wing Point
Kitsap County Sewer District (S.D.) # 7	Fort Ward	Bainbridge Is./ Bean's Point
Kitsap County	Manchester	Puget Sound
Vashon S.D.	Vashon	Vashon Island

Each of the six discharge domestic sewage operating under the terms of a National Pollutant Discharge Elimination System (NPDES) permit. Processing of the initial permit for Fort Ward and the re-issuance of the other permits will be aided by this receiving water survey data.

Ordinarily, permittees assume the responsibility and bear the costs for collecting receiving water survey data and conducting the mixing zone analyses. The data used are sometimes of questionable utility yielding analyses of questionable value. The Department would like to be assured that its requests for better quality analyses (probably resulting in additional expenditures) are prudent. It was decided that the best way to develop guidance was to first design and conduct a comprehensive survey to answer some basic questions about the impact of data utility on dilution zone analyses.

The Washington State Water Quality Standards (Ecology, 1992) and Permit Writer's Manual (Ecology, 1994a) address mixing zones. The terms "reasonable worst-case" and "critical condition" appear somewhat interchangeably. In this report, reasonable worst-case is used when referring to selected values for specific effluent and receiving water variables, *e.g.*, reasonable worst-case current; while critical condition is used when referring to a scenario (involving all the variables) which has been set up to run as a case in the mixing zone model (*e.g.*, critical condition to generate the most protective dilution factor at the chronic mixing zone boundary).

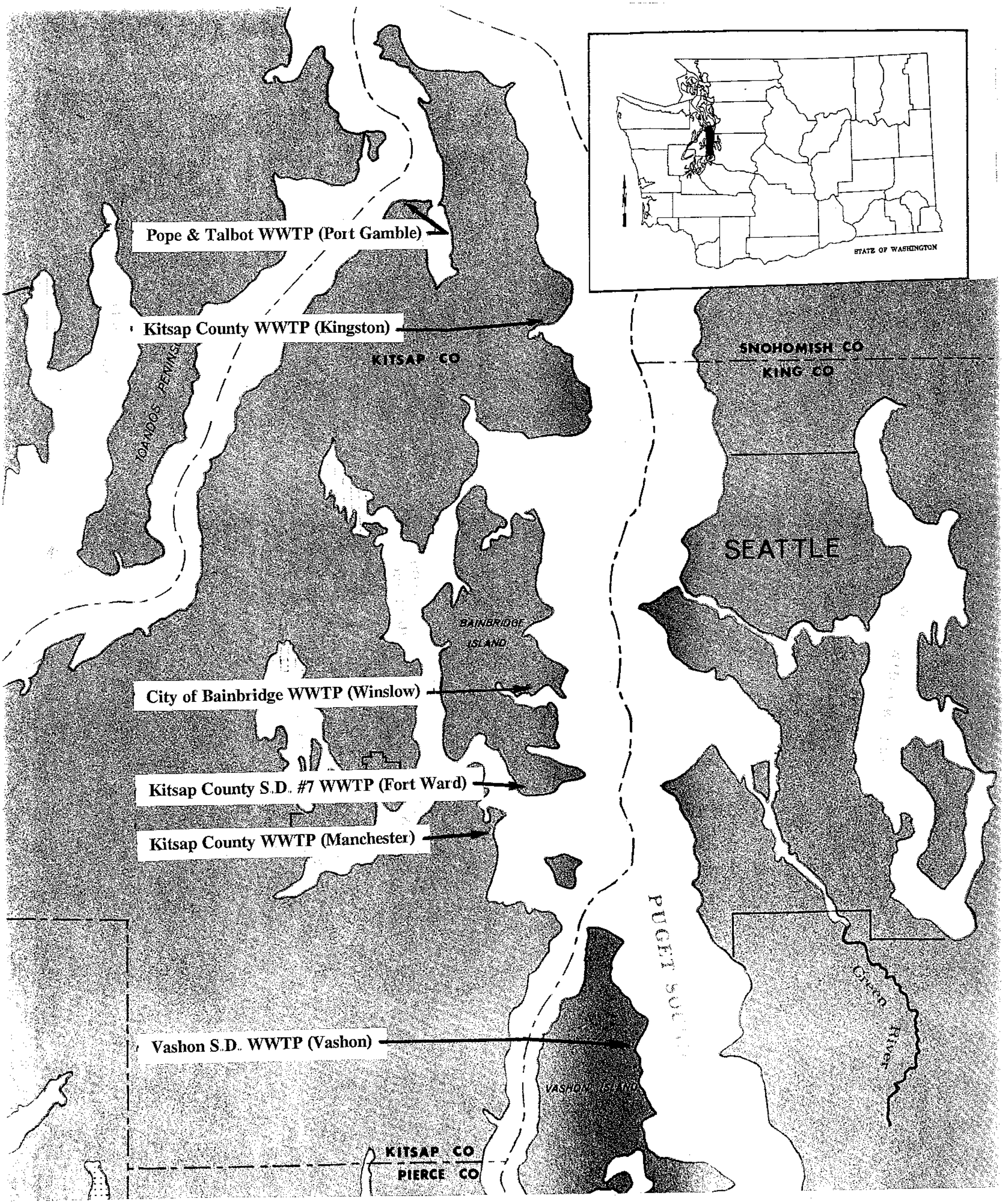

Figure 1. General location map

Goals and objectives

The goals of this study were to:

- Provide data for permit managers; and
- establish whether there is a need for costly site-specific data versus more readily available regional data.

A list of objectives to be met for each discharger location were as follows:

1. Identify the most appropriate regional data sets for current, stratification and ambient water quality; select the reasonable worst-case currents, stratification, and background concentration for each pollutant of concern from among these data sets; and establish the critical condition scenarios;
2. select the reasonable worst-case currents and stratification from each of the site-specific data sets, and use the measured background concentration of each pollutant of concern;
3. compare regional and site-specific data sets for current, stratification and water quality; and draw inferences about the relative merit of site-specific versus regional data;
4. run the 3PLUMES interface employing (1) the regional critical condition scenarios generated in objective 1, and then (2) best-available critical condition scenarios created by using the most appropriate data sets from objective 3 to compare dilution factors (DFs) at acute and chronic boundaries;
5. draw inferences from the comparison of DFs in objective 4 about the relative merit of regional versus site-specific data; and
6. provide the permit manager with a set of critical condition scenarios, and include model results for acute and chronic DFs.

This project was conducted at the request of Laura Fricke's Municipal Unit at the Northwest Regional Office and the Water Quality Program's Permit Management Section at headquarters. The Municipal Unit had permits in Water Resource Inventory Area (WRIA) 15 scheduled for re-issuance during FY96. The data was provided to these managers on time in draft form. The goal to be met for the study as a whole was to develop recommendations regarding regional versus site-specific data sets for establishment of critical condition scenarios. (*i.e.*, What approach Scopes of Work for mixing zone analyses should use depends upon whether: 1) regional data sets are adequate; 2) the best-available set of site-specific and regional data is appropriate; 3) site-specific measurements are necessary; or 4) a dye study is needed). Completing this goal took much longer than expected; thus the report is later than FY96.

Methods and Data Quality Assurance

Field sampling

Complete current and stratification data sets included eight measurements from both a neap and a spring tidal day at each site. The eight represented the following tide stages:

- Lower low;
- mid-tide between lower low and higher high (large flood);
- higher high;
- mid-tide between higher high and higher low (small ebb);
- higher low;
- mid-tide between higher low and lower high (small flood);
- lower high; and
- mid-tide between lower high and lower low (large ebb).

A complete data set of background concentrations for a site for purposes of this study involved sampling for the pollutants of concern once--on any tide stage. The more important factor was that collection be in the general vicinity of each of the sites, but outside the area affected by the effluent.

The six discharge sites were visited repeatedly during September and early October of 1994, in an effort to compile complete site-specific data sets. This was made difficult due to limitations imposed by the budget (*e.g.*, use of drogues rather than current meters), logistics (*e.g.*, distance between sites), boating safety (*e.g.*, boat launching, unfamiliar waters, passenger ferries), nighttime (necessity of eye contact with deployed drogues), and the two week cycle between neap and spring tides. Table 1 shows the itinerary and the completeness of effort.

Table 1. Dates and stages of tide when the field work was done at the six discharge sites.*

	Port Gamble		Kingston		Winslow		Fort Ward		Manchester		Vashon	
	Spring	Neap	Spring	Neap	Spring	Neap	Spring	Neap	Spring	Neap	Spring	Neap
1. Lower low				30-Sep		29-Sep	20-Sep	15-Sep	20-Sep	15-Sep	19-Sep	
2. Large flood				30-Sep		29-Sep	20-Sep	15-Sep	20-Sep	15-Sep	19-Sep	
3. Higher high	4-Oct	26-Sep		30-Sep		29-Sep		15-Sep		15-Sep	19-Sep	
4. Small ebb	4-Oct	26-Sep	22-Sep	30-Sep	21-Sep		5-Oct	27-Sep	5-Oct	27-Sep		
5. Higher low	4-Oct	26-Sep	22-Sep		21-Sep		5-Oct	27-Sep	5-Oct	27-Sep		
6. Small flood	4-Oct	26-Sep	22-Sep				5-Oct		5-Oct			
7. Lower high									20-Sep			
8. Large ebb												

* - Blanks indicate that no field work was done at that site during that particular stage of tide.

Current velocity and direction were tracked by releasing two drift drogues at each outfall site and tracking them over time. The drogues were deployed simultaneously--one near the surface and one at depth. Depths of the six outfalls vary from 15 to 60 feet at mean lower low water (MLLW). The surface drogue was deployed at 1 meter and the depth drogue at 3 meters above the bottom at the outfall location. Each deployment was for one hour or until the drogue encountered an obstacle (*e.g.*, seaweed or ferry). Beginning and ending locations of both surface and depth drogues were determined using a Magellan Pro Global Positioning System. Intermediate drogue locations were estimated by observation after 15 minutes and noted in the field log.

Stratification was determined by measuring salinity and temperature at multiple depths and times at each outfall site using a Hydrolab DataSonde® 3 (DS3). This unit was coupled to a Surveyor 3 Display/Logger unit, which allowed cable deployment with shipboard digital readout and logging.

Background sampling for pollutants of concern was at least ¼-mile away from effluent outfalls to ensure that the concentrations were truly background. Sampling was at a depth of 1 foot. The analytical methods selected ensured that comparisons could be made between the survey data, effluent results, regional data, and surface water quality standards. Ammonia was analyzed using Method 350.1 (EPA, 1983).

Dissolved metals at low detection limits were requested to allow comparison to the standards. Sample bottles used were 500 mL teflon, filled with distilled deionized water, and shipped from the Manchester Lab in sealed bags. Each was specially pre-cleaned as defined in the Manchester Lab Clean Room SOP. The deionized water was emptied from the bottle at the time of sampling. Samples were vacuum-filtered in the field through a 0.45 mm cellulose nitrate filter unit (Nalgene #450-0045, type S) before being acidified. The acid was sub-boiled purified nitric acid carried in small teflon vials, one per sample. Each sample was placed in a polyethylene bag and held on ice for transport to the laboratory. Samples were analyzed by the following methods: Zinc: ICP EP1-200.7; Lead: EP1-239.2; Silver: EP1-272.2; Copper: EP1-220.2. Preservation of samples and holding times were in accordance with the Lab User's Manual (Ecology, 1994b). The Manchester Laboratory <u>Quality Assurance Manual</u> (Ecology, 1988 (as revised)) describes appropriate laboratory QA/QC procedures.

Accuracy includes quantitative measures of two types of error: random and systematic. Random error is characterized as the precision, and systematic error as the bias, of the measurement. Replicates provide a way of estimating precision. Current measurement, stratification measurement, and water quality sampling were each duplicated at two sites. Duplication of current measurement involved returning to the outfall location and re-deploying both drogues near the surface for another hour. Duplication of stratification measurement involved repeating the same set of STD measurements. Duplication of water quality sampling involved repeating the same sampling procedure

Field blanks provided a way of estimating contamination bias in the metals sampling procedure. The filtration blank consisted of one of the specially pre-cleaned teflon containers filled with deionized water plus one empty container. The containers were carried to the field in the sealed bags where the filled container was handled in the same fashion as a sample except that the filtrate was put into the unused empty companion container and then preserved.

Salinity Methods

Calibration of the DS3 consisted of first using a YSI Model 33 S-C-T meter to measure temperature and salinity near the Vashon outfall at 10 meters depth. Next, a sample was retrieved from the same 10 meter depth using a Kemmerer sampler. A portion of the sample was poured into the calibrating cup for the DS3, and the standard operating procedure for calibrating was followed using the YSI 33 readings of:

temperature (°C)	13.5
salinity (ppt)	23.2

A sample was also sent to Ecology's Manchester Environmental Laboratory to be analyzed for salinity. The salinity result which arrived from the MEL after completion of field work was 31 ppt. Salinity results from three of Ecology's monitoring stations in the central basin obtained in 9/94 or 10/94, also at a depth of 10 meters, were as follows:

EAP001	30.7 ppt
PSB003	30.3 ppt
PMA001	30.7 ppt

This seemed to confirm that the DS3 had given systematically false readings of approximately 23 ppt. Accordingly, a multiplier of 1.32 was applied to all salinity readings taken with the DS3.

Data Analysis

The influence of tides, freshwater overflow, wind, eddies due to shape of the shoreline, and current patterns at depth, as well as surface, can cause dramatic differences between currents near an outfall and further out in the channel or embayment. For these reasons, estimates based on regional data can sometimes be little better than simply guessing. A limited number of measurements can render site-specific current data sets equally unreliable.

Ecology's "Guidance for Conducting Mixing Zone Analyses," located in Appendix 6.1 of the Permit Writer's Manual (1994a) suggests using the lowest and highest 10^{th} percentile current velocities derived from a cumulative frequency distribution analysis for analyses at the acute boundary. Since acute criteria are based on a duration of one hour, it is reasonable to assume that these extremes do occur for that length of time.

Ecology's mixing zone guidance suggests using 50th percentile current velocity, derived from the same cumulative frequency distribution analysis used above, for analyses at the chronic boundary. Criteria at the chronic boundary carry a duration of four days; a median current represents the reasonable worst-case current in a mixing zone model as though it is steady-state and unidirectional. All available velocities from both the regional and site-specific data sets were used for the cumulative frequency distribution analyses.

Dilution is strongly influenced by depth, especially when the stratification profile is well-mixed and the plume does not trap. However, the mixing zone guidance suggests that the mean lower low water (MLLW) always be used in mixing zone analyses. Alternatives to MLLW were not considered in this study.

Stratification is a water density phenomenon, based on salinity and temperature. Therefore, it is neither a data point nor a statistically derived single number, but a profile consisting of a series of densities (salinity and temperature readings) at various depths. For mixing zone studies, stratification profiles are best grouped by those that either: 1) allow the plume to surface quickly, or 2) trap the effluent plume--either at depth or near the surface. Those that surface quickly are likely to occur in a marine water column which is experiencing some combination of well-mixed, shallow, and/or ebbing/flooding tide stage. Those that trap at depth are likely to occur in a marine water column which is experiencing some combination of stratified, deep, and/or a slack tide stage.

The guidance suggests using the density profile that results in the lowest mixing. Seasonality is not a factor. In order to optimize the effort involved, profiles were grouped into "minimum" and "maximum." "Minimums" were characterized by profiles that were truncated, if necessary, in order to have a length similar to the depth of the outfall with: 1) the smallest differential between sigma-t values at the bottom and top of the profile; and 2) collectively, the highest sigma-t values. "Maximums" were characterized by profiles that were also truncated, if necessary, in order to have a length similar to the depth of the outfall with: 1) the largest differential between sigma-t values at bottom and the plume trapping depth; and 2) collectively, the lowest sigma-t values.

A visual examination of the profiles in each of the six site-specific stratification data sets suggested that they might be so closely clustered that there were no significant differences between them. This may be because all site-specific profiles were determined within a three-week period, which minimized the role of seasonal variability in the data set. There were also continual fluctuations in the salinity digital readout of the DS3 of ± 0.2 ppt which translated to a variation of ± 0.15 in sigma-t values.

In addition to current, depth, and stratification, a fourth factor in establishing critical receiving water conditions is background concentration of pollutants. This is an important variable which must be factored into the mass balance equation when determining allowable concentrations in effluent. Pollutants of concern to this study were ammonia, chlorine, copper, lead, silver, and zinc.

Acceptability of the regional current, stratification, and background water quality data was based on availability, completeness, proximity to the discharger location, and similarity in physical characteristics of the two areas. Current data sets were generated using <u>Tides and Currents for Windows, v1.03</u> (Nautical Software, 1994), which (in turn) incorporated published tide and current data from the National Oceanographic and Atmospheric Administration's (NOAAs) National Ocean Service. This version of the software delivered current data which were readily available and were complete time series at one minute intervals. However, they were for a choice of locations that was limited to a few easily recognized prominent features in Puget Sound. Regional currents were predicted for the same dates when the corresponding site-specific data were collected.

Regional stratification profiles and background water quality data were obtained from stations maintained by Ecology's Ambient Monitoring Program. Historical records were built at these stations through measurements taken once each month by float plane beginning in November 1989. Since then, *in situ* salinity-temperature-depth (STD) sensors have been used to obtain depth, temperature, salinity, pH, date and time data. Five stations were considered acceptable from a limited selection:

Station Description	Code Name	Sampling Period (in Wateryears)	WWTP Identifier
N. Hood Canal	HCB006	1989-95	Port Gamble
Port Madison	PMA001	1989-92; 1995	Kingston
Main Basin (WP)	PSB003	1989-95	Winslow
Sinclair Inlet	SIN001	1989-95	Fort Ward
Sinclair Inlet	SIN001	1989-95	Manchester
East Passage	EAP001	1989-91; 1995	Vashon

The stratification data set from each of these stations was readily available, but there was no way of assessing the completeness. The once per month measurements follow a consistent, predetermined schedule. It is not known how quickly or frequently stratification profiles change over the course of a month, or even a season. A minimum and a maximum stratification profile were selected from each data set.

Background concentrations of ammonia were available for three of the six locations - N. Hood Canal, Main Basin, and East Passage only. It was reported as total ammonium-N (mg/L) from 1973 until 1990, and dissolved ammonium-N (mg/L) from October 1990 to present. The entire data set was used. Metals were not measured at these ambient monitoring stations.

Acceptability of the site-specific current, stratification, and background water quality data was based on precision and bias. Precision of the current measurements was deemed acceptable based on a qualitative review (*i.e.*, no significant separation occurred between the two drogues deployed simultaneously near the surface.)

The acute and chronic velocities derived statistically from the cumulative frequency distribution analyses were biased. A review of the dates and stages of tide in Table 1 shows that no sampling was done during a large ebb, because they always occurred during darkness. This introduced bias into all distribution analyses, since large ebbs could have generated maximum currents. There was also no sampling during a large flood at Port Gamble, which compounds the likelihood of bias there.

Analyses of the stratification and water quality data sets for precision involved a review of field duplicate results. There were no marked differences between duplicate stratification measurements. The concentration of each pollutant in all duplicates was "not detected at or above the reported result." Matrix spike and matrix spike duplicate analyses were performed as necessary by Ecology's Manchester Environmental Laboratory (MEL) and all recoveries were within the acceptable limits of ±25%, except for silver. The silver results are qualified with "J" as estimates. Filtration blanks were used to assess bias in the metals sampling procedure. The blanks showed minor but acceptable contamination of metals samples.

Effluent flow rates used in each of the analyses were chosen consistent with Ecology's Mixing Zone Guidance. Seasonality was a factor. The flowrates used at Port Gamble, Winslow, Fort Ward, and Vashon Sewer District for analyses at the chronic boundary were highest monthly averages; and the flow rate used at Kingston was the dry weather design flow. For analyses at the acute boundary of these five dischargers, either the highest daily maximum flowrate was used or, in the case of Kingston, a derived peaking factor was used to determine the acute design flow. This factor was obtained from a published curve (Figure 5-1) in Metcalf & Eddy (1991).

Manchester's effluent flow rate is intermittent. The flowrate used for all analyses was the maximum that can occur. The model generated dilution factor for the acute boundary was then adjusted upward by a ratio of maximum flowrate to one-hour, time-averaged flowrate (because the maximum flowrate occurred for less than one hour). The dilution factor for the chronic boundary was adjusted upward by a ratio of maximum flowrate to four-day, time-averaged flowrate.

Results and Discussion

General

All available regional and site-specific current and stratification data for each of the six discharge locations were tabulated and plotted. This made a large quantity of data more manageable for qualitative analysis, for selecting the reasonable worst-case values, and for inclusion in the report. A location map, plotted data, reasonable worst-case values, and background concentrations for the pollutants of concern, for all six dischargers are in Appendices A through F. The tabulated raw data are not included, but are available on request.

A series of critical condition scenarios (involving reasonable worst-case values for current, stratification, and effluent flowrate) was created for each of the six dischargers. Each scenario (by itself) had a low probability of occurrence. The scenarios were arranged into sensitivity analyses, set up as cases in the 3PLUMES interface, and run using the UM and/or RSB models. Each sensitivity analysis was organized such that only one parameter in each scenario was changed while all others were held constant in a logical progression. Each analysis was arranged as shown in Table 2.

Cases 6 through 10 used the best-available reasonable worst-case values, regardless of whether the values came from regional or site-specific data sets. Regional stratification profiles were judged the reasonable worst-case maximum profiles at all six locations, and were the minimum profiles four of six times. Only two site-specific profiles, both minimums, were deemed reasonable worst-case.

There was no information to be gained by setting up a best-available, worst-case scenario with the same current and stratification profile used in one of the earlier cases (1-5). Since the regional profiles were used in almost all best-available scenarios, it was considered advantageous to use site-specific currents in these cases. There was some additional merit in doing this because it is quite difficult to predict which current velocity will contribute to the minimum dilution factor at a particular regulatory boundary. This is discussed further below.

There are individual discussions below for each of the six dischargers. Each discussion first draws inferences about the relative merit of regional versus site-specific data from the plotted current and stratification data. A table then presents the dilution factors generated from the sensitivity analysis. From a comparison of the dilution factors, inferences are once again drawn about the relative merit of regional versus site-specific data.

Table 2. Arrangement of each of the sensitivity analyses.

Case number	Source of data	MZ boundary	Effluent flow rate	Type of current	Type of stratification
1	regional	acute	HDM or PF x DWDF*	10^{th} %	minimum
2	"	"	"	"	maximum
3	"	"	"	90^{th} %	maximum
4	"	chronic	HMA or DWDF**	median	minimum
5	"	"	"	"	maximum
6	best-available	acute	HDM or PF x DWDF*	10^{th} %	minimum
7	"	"	"	"	maximum
8	"	"	"	90^{th} %	maximum
9	"	chronic	HMA or DWDF**	median	minimum
10	"	"	"	"	maximum

* - HDM means highest daily maximum.
 - PFxDWDF means peaking factor times dry weather design flow.
** - HMA means highest monthly average.
 - DWDF means dry weather design flow.

Port Gamble

The Port Gamble wastewater treatment plant is an extended-aeration package treatment plant with an average design flow of 0.025 MGD. The infiltration/inflow contribution during storm events produces a dilute effluent of 0.090 MGD, with a peaking factor of 3.6. Discharge is from a single port diffuser located about 1,150 feet offshore at a depth of 15 feet below mean lower low water (MLLW).

A cursory examination of the plotted current data in Appendix A shows that there is no similarity between regional and site-specific currents. In retrospect, this was predictable because the regional current data is for the Port Gamble Bay entrance, an easily recognized feature of prominence. The data are influenced by and more accurately reflect flow into and out of the bay, ¾ mile east of the discharge site. As was pointed out earlier in the report, the site-specific data at this location may not have included the maximum currents.

The regional stratification data set produced classic minimum and maximum stratification profiles (Appendix A). The minimum profile occurred in February (1993); the maximum also occurred in February (1992). The site-specific profiles all look quite similar to each other. This suggests that stage of tide may not be an important factor when identifying the two extreme stratification profiles.

Table A-1 contains the reasonable worst-case parameters that were selected from among the regional and site-specific data sets. The background concentration of ammonia shown (0.04 mg/L as N) is the 90th percentile from the same Hood Canal monitoring station. Table 3 shows the dilution factors from all the critical condition scenarios.

Table 3 Dilution Factors for Port Gamble

Case number	Regional data set Acute	Regional data set Chronic	Case number	Best-available data set Acute	Best-available data set Chronic
1	75		6	57	
2	83		7	57	
3	69		8	124	
4		1,580	9		888
5		275	10		274

Two best-available, worst-case scenarios generated the lowest DF at the acute boundary. The site is so shallow and the worst-case site-specific current so slow that the plume surfaced well before the acute boundary. This resulted in a foreshortened plume trajectory and hydrodynamic mixing zone, which is the phase when a jet-plume entrains the most ambient fluid. This occurred in spite of a maximum stratification in case 7 (the trapping level was reached just one meter from the surface at a horizontal distance of 2.5 meters).

Case 10 produced the lowest DF at the chronic boundary. This particular combination of effluent flow rate, median current, and maximum stratification caused the plume to trap a short distance from the port. The plume never surfaced, explaining in part why the path to the chronic boundary and dilution were minimized with this combination of parameters.

Kingston

Kingston has an activated sludge WWTP with a design flow of 0.15 MGD. A peaking factor of 4.0 was applied to arrive at a flowrate of 0.60 MGD for analyses at the acute boundary. The discharge site is about 1,700 feet offshore at a depth of 43.5 feet below MLLW. The diffuser has three ports: two with 6-inch ports opposing horizontally, and one with a 4-inch port discharging upward. This configuration can only be roughly simulated by the UM and RSB models in the PLUMES interface, or any other model.

The four graphics of current data in Appendix B show that there is reasonable similarity between regional and site-specific current velocities, although the directions differ significantly. The closest feature of prominence for which regional data were available was ½ mile east of Apple Cove Point, in the main channel. This produced both maximums and minimums which were more extreme than those measured during field work; but the medians were similar. Regional and site-specific stratification profiles for Kingston are also in Appendix B. The minimum regional profile occurred in December (1991); the maximum occurred in June (1992).

Table B-1 contains the reasonable worst-case parameters that were selected from among the regional and site-specific data sets. Table 4 shows the dilution factors from all the critical condition scenarios.

Table 4. Dilution Factors for Kingston

Case number	Regional data set Acute	Regional data set Chronic	Case number	Best-available data set Acute	Best-available data set Chronic
1	39		6	58	
2	39		7	58	
3	67		8	85	
4		1,060	9		945
5		1,060	10		956

Two regional scenarios using a 10th percentile current generated the lowest DF at the acute boundary. The model RSB (in the PLUMES interface) was used because it more accurately simulates this unique outfall configuration. It was operating outside its range of experiments (*i.e.*, the experimental design developed by the authors) when used with the chronic cases (Ecology, 1994a). The DFs generated by RSB were dramatically lower than those from UM. It is unlikely that stratification alone explains the large disparity in dilutions from the two models.

Winslow

This wastewater treatment plant is a conventional activated sludge plant with a maximum monthly design flow of 1.00 MGD. The peak design flow of 2.87 MGD was used for analyses at the acute boundary. The discharge site is about ¼ mile offshore at a depth of 42.4 feet (MLLW). The two-port diffuser is a unique "Y" design; each port has a diameter of 16 inches.

The plots in Appendix C show the dramatic differences between regional and site-specific data, in both velocity and direction for corresponding tidal stages. Regional current data is for a location in the main channel (0.6 miles ESE of Restoration Point), a considerable distance away. Of course, it is a complete data set, while the site-specific data were collected during only five of the 16 possible stages of tide. The minimum and maximum regional current velocities were much more extreme than site-specific, but (as expected) the medians used for chronic analyses were quite similar.

The regional stratification data is from a monitoring station in the central basin. The minimum regional profile occurred in March (1993); the maximum occurred in May (1991). Table C-1 contains the reasonable worst-case parameters that were selected from among the regional and site-specific data sets.

The model could only roughly simulate Winslow's diffuser configuration. The effluent flow rate for the chronic analyses had to be increased somewhat in order to raise the Froude # closer to 1.0 and allow the model to perform correctly. This is because the large diameter ports don't have nozzles. The 90th percentile worst-case ammonia from Ecology's monitoring station was quite high (0.09 mg/L as N). Table 5 shows the dilution factors from all the critical condition scenarios.

Table 5 Dilution Factors for Winslow

Case	Regional data set		Case	Best-available data set	
number	Acute	Chronic	number	Acute	Chronic
1	36		6	37	
2	28		7	34	
3	39		8	53	
4		314	9		243
5		95	10		89

Scenarios that included the maximum stratification profile 1) modeled plumes which trapped at depth, and 2) generated the lowest DFs at both acute and chronic boundaries. As was the situation at Port Gamble, these scenarios involved low current velocity (which minimized entrainment) and maximum stratification (with trapping that foreshortened the trajectory.)

Fort Ward

Kitsap County Sewer District #7 recently completed construction of a new WWTP and miles of sewer line at Fort Ward. The design flow is 0.114 MGD; the peak flow is only 0.285 MGD because of the reduced infiltration/inflow in the new sewer lines. The discharge site is about 500 feet offshore at a depth of 60 feet (MLLW). The 12-inch pipe has a single 6-inch port.

This location (Rich Passage East end) is considered a prominent feature in Puget Sound. Consequently, Tides and Currents (Nautical Software, 1994) was able to simulate current velocities similar to the field measurements. Plots in Appendix D show the movement of the regional currents as linear back-and-forth (much as the tidally-influenced mouth of a river), while the site-specific currents appear to rotate with the tide.

The closest regional stratification profiles were from Ecology's station in Sinclair Inlet at a depth of about 14 meters, while the depth at the outfall location is about 18 meters (refer to Figure D-1). All of the plots were vertical for the deepest four meters indicating a well-mixed water column at this depth; this simplified extrapolation of the profiles to 18 meters. This example does emphasize that similarity in physical characteristics of the two areas is as important a criterion in determining acceptability of regional data as proximity to the discharger location. The minimum regional profile occurred in February (1993); the maximum occurred in May (1993).

Table D-1 contains the reasonable worst-case parameters that were selected from among the regional and site-specific data sets. Table 6 shows the dilution factors from all the critical condition scenarios.

Table 6. Dilution Factors for Fort Ward

Case number	Regional data set Acute	Regional data set Chronic	Case number	Best-available data set Acute	Best-available data set Chronic
1	278		6	279	
2	198		7	198	
3	66		8	79	
4		2,962	9		2,869
5		1,614	10		2,111

The tides are robust, which makes this high energy area a good location for an outfall. The maximum current velocity contributed to the lowest dilution at the acute boundary. Dilution at the chronic boundary is extraordinarily high.

Manchester

Manchester has a sequencing batch reactor (SBR) WWTP which discharges intermittently. There are two tanks, which each serve as a combined aeration tank and clarifier. Each tank of the SBR discharges 25,000 gallons for 25 minutes, once every three hours. Discharging takes place 24-hours per day, but the pumped flow rate may drop from 1,000 gallons per minute (gpm) to 600 gpm during lower volume periods. Acute criteria specify a duration (averaging period) of one hour, but the longest duration of discharge from the two SBRs is 50 minutes. A reasonable worst-case flowrate would be 50,000 gallons every 50 minutes, or 1.44 MGD.

Records of effluent flow rates for the period June through October from the past three years were examined. An October flow of 4.6677 million gallons was the highest. This gave a highest monthly average of 0.151 MGD.

The most recent set of design drawings (April, 1966) indicate that the outfall is about 880 feet long (from the last manhole) and discharges in 60 feet of water (MLLW). The surfacing plume was observed in about 38 feet of water (HLW) during field work for this study. Recent field work by the County's consultant confirmed that the outfall ends considerably closer to shore in about 34 feet of water (MLLW). The end consists of a 12-inch port discharging vertically against a two-foot square deflector plate located six inches away.

A cursory examination of the plotted current data in Appendix E shows that there is no similarity between regional and site-specific currents. The regional currents are the same Rich Passage East end data used at Fort Ward. The 90th percentile and median values are considerably higher than the comparable site-specific data. They are less representative of water movement in this small embayment, which is more languid. The site-specific data reveal a slight eddying effect.

The regional profiles in Appendix E were from Ecology's monitoring station in Sinclair Inlet, the same ones used for analyses at Fort Ward. The water column was well-mixed vertically during the field work, as can be seen from the site-specific data. The discussion pertaining to stratification under Fort Ward applies to Manchester as well. Table E-1 contains the reasonable worst-case parameters that were selected from among the regional and site-specific data sets.

It proved to be a challenge to model this outfall configuration and chronic effluent flow rate. PLUMES cannot simulate a deflector plate. A dye study to calibrate the model and/or reconfiguration of the diffuser to optimize momentum and entrainment is necessary.

Several alternative assumptions for modeling were explored. It seemed reasonable to end initial dilution when the jet was stripped of most of its momentum at the plate. However, not all momentum is dissipated at this point. This was accounted for by assuming an un-deflected jet and ending initial dilution at the cessation of the zone of flow establishment (approximately six feet) (Fischer *et al.*, 1979), rather than at the actual distance of six inches. This is a reasonable alternative because it is actually the first point along the plume's trajectory where the velocity profile across the jet assumes a Gaussian distribution and UM is actually simulating plume performance.

The chronic effluent flow rate was so low that the Froude # was considerably below 1.0, giving an error message indicating misapplication of the laws of hydrodynamics in the model. Kitsap County officials had mentioned that the frequency of discharge from the SBRs will increase to once every 1.5 hours during the next five years because of population growth. So, the flowrate was increased in the model until the error message disappeared, to a highest monthly flow rate of 0.452 MGD. This is the reasonable worst-case value that was used for chronic analyses. Planning is underway for an expansion of the WWTP. Table 7 shows the dilution factors from all of the critical condition scenarios.

Table 7. Dilution Factors for Manchester.

Case number	Regional data set Acute	Regional data set Chronic	Case number	Best-available data set Acute	Best-available data set Chronic
1	5		6	6	
2	5		7	6	
3	51		8	5	
4		124	9		17
5		122	10		17

These acute dilution factors are extraordinarily low. Nothing can be inferred about dilutions produced by reasonable worst-case regional versus best-available scenarios, since each delivered a minimum DF. The much lower site-specific median current contributed to the lowest chronic DFs. It is not known whether the PLUMES model was simulating the present situation correctly. However, it was clear during field sampling that the effluent creates a boil at the water surface.

Vashon

This wastewater treatment plant is an oxidation ditch (extended aeration) with a highest monthly average flow rate of 0.166 MGD and a maximum daily average of 0.264 MGD. The discharge location is 400 feet offshore (from the MLLW line) at a depth of 30 feet (MLLW). The diffuser has three opposing ports with four-inch diameters spaced seven feet apart.

The most appropriate regional currents shown in Appendix F are from the northwest corner of Vashon Island. There were a limited number of site-specific current measurements taken (three stages on the spring tide cycle). Any comparisons and inferences are of limited value. However, the three stages were: 1) a lower low water, 2) a large flood, and 3) a higher high water; these may have encompassed the reasonable worst-case current conditions. Velocity was only 8 cm/sec during the large flood.

Current direction was as informative as velocity. During these three consecutive stages, the plume would have gone (1) south at 3.5 cm/sec, (2) south at 5.5 cm/sec, and then (3) north at 8 cm/sec. Northerly movement on a large flood stage may be indicative of an eddy at work.

Regional and site-specific stratification profiles are also in Appendix F. The regional profiles came from the East Passage monitoring station. The minimum profile occurred in November (1994); the maximum occurred in September (1995). Table F-1 contains the reasonable worst-case parameters that were selected from among the regional and site-specific data sets.

This outfall configuration is appropriately modeled by either UM or RSB in the PLUMES interface. Table 8 shows the dilution factors from all the cases.

Table 8. Dilution Factors for Vashon

Case number	Regional data set Acute	Regional data set Chronic	Case number	Best-available data set Acute	Best-available data set Chronic
1	54*		6	58*	
2	50*		7	55*	
3	152*		8	152*	
4		927	9		473
5		926	10		475
* - Generated by RSB					

The ten scenarios were run using both models UM and RSB. RSB generated significantly lower dilution factors for all scenarios: typically one-third the value of DFs generated by UM. However, RSB was operating slightly outside the range of its original experiments for the chronic analyses, so the results were not useable. This large disparity between the results from the two models should be examined more thoroughly. A regional scenario using a 10th percentile current and maximum stratification produced the lowest DF at the acute boundary.

Synthesis of Results

One goal of the study was to establish whether there is a need for costly site-specific data versus more readily available regional data for stratification, current, and water quality. The sensitivity analyses conducted for the six dischargers were all arranged in the same repetitive pattern, simplifying an examination of the bigger picture.

The definitions of minimum and maximum stratification profiles developed for this report factor in the differential in density values top-to-bottom as well as the values themselves. The site-specific stratification profiles shown in Appendices A-F included measurements from only one season. There were no significant variations in the profiles. They seem to most closely resemble the definition for minimum stratification suggesting that the water column was probably well-mixed throughout the five weeks of field work. This reinforces the emerging premise that stratification is more influenced by seasons of the year than by stages of tide. The regional data sets included measurements from all seasons; they produced the maximum profiles.

NOAA (1981) produced a series of nested graphs, each graph showing density variations by month at a specific depth, for the central basin of Puget Sound. The graphs showed that in the top 20 meters of the water column the highest values for density occurred in October and November, while the lowest values occurred in June and July. They said nothing about the differential in density (top-to-bottom), but did further reinforce the premise that significant variations in stratification profiles are loosely associated with seasons of the year.

Maximum stratification profiles from the regional data sets contributed to the minimum dilution factors generated by the model(s) in all six sensitivity analyses. This suggests that a maximum stratification profile will be the reasonable worst-case stratification of choice in marine water whenever the MLLW (depth) is greater than about 15 feet. Emphasis must be placed on obtaining maximum profiles.

It is better to use the maximums from a large regional stratification data set, if one exists, than to attempt field measurements. Ecology's ambient monitoring stations provide readily-available, good quality data. The five used in this study proved to be superior to the site-specific data sets, particularly when identifying the all-important maximum stratification profiles. The sampling frequency is only once per month, so they are not complete data sets. This may be one reason why only two of the 12 minimum and maximum profiles selected from the regional data sets actually occurred in the months when they were predicted to occur by the NOAA report. However, this is also an argument against attempting to guess when to conduct field measurements.

Regional (simulated) current velocities were higher than their comparable site-specific (measured) velocities about 75% of the time. This disparity is to be expected since the discharges are near shorelines, and the site-specific data sets are incomplete. NOAA acknowledges that its simulated velocities are less accurate, and generally higher for the ebb and flood stages than actual velocities that can be measured near shorelines.

"Similarity in physical characteristics of the two areas" should receive equal weight with "proximity to the discharger location" as a criterion. The two most important factors in "similarity . . . " are shoreline and bottom constraints (promontories and bathymetry). "Proximity . . ." is about ½ mile or less.

Determining the reasonable worst-case current in tidally-influenced water is deceptively difficult. It is true that dilution factors at the end of the hydrodynamic mixing zone (also referred to as end of initial dilution or end of near-field) are increased by increased current velocities (assuming other variables are held constant). Conversely, the lower the current velocity, the lower the dilution factor at the end of near-field. Early EPA guidance (*e.g.*, that guidance written for the 301(h) waiver application process) suggested that currents approaching zero contributed to critical condition scenarios. However, what is true at the end of a hydrodynamic mixing zone is not necessarily true at a regulatory mixing zone boundary (EPA, 1994).

There were serious shortcomings in both the regional and site-specific current data sets. The regional sets were complete, but only the set for Fort Ward was representative of velocity and/or direction of currents at the discharge location. The site-specific sets were not complete, and therefore, were biased, as mentioned under Data Analysis.

Ecology's (1994a) Guidance for Conducting Mixing Zone Analyses now states that the cumulative frequency distribution analysis should be produced from a data set consisting of periodic readings taken by an instrument deployed over a neap and spring tide cycle. This is the conventional approach. (The budget was not adequate to lease six instruments for this study.)

The guidance also offers an alternative approach in the absence of a comprehensive field data set. Sensitivity analyses can be run using a wide range of possible velocities; any one of which could reasonably occur during a 1-hour duration (acute), and be a 4-day average velocity (chronic). The velocities which are parameters in the two critical condition scenarios that produce the lowest acute and chronic dilution factors should be considered the reasonable worst-case currents.

It was decided to use the alternative approach at all of the discharger locations, except Manchester, and compare dilution factors to those obtained from the conventional approach. (The vertical port/deflector plate arrangement at Manchester was too different to allow for a meaningful comparison.) Four analyses were set up for each of the five dischargers. Analyses number one and two were acute; three and four were chronic. One and three used the best-available minimum stratifications throughout; two and four used the best-available maximum stratifications. The acute analyses used 25 currents to create a relatively fine resolution between .001 meter per second (m/s) and .50 m/s; the chronic analyses used 18 currents between .004 m/s and .35 m/s. Table 9 is a comparison between dilution factors generated by the two approaches.

Table 9. Comparison of dilution factors generated by the two different approaches.

Approach	Port Gamble Acute	Port Gamble Chronic	Kingston Acute	Kingston Chronic	Winslow Acute	Winslow Chronic	Fort Ward Acute	Fort Ward Chronic	Vashon Acute	Vashon Chronic
Conventional	57	274	39	945	28	89	66	1,614	50	473
Alternative	44	270	39	418	25	55	67	479	50	375

The only significant difference between acute dilution factors from the two approaches was at Port Gamble. A current of 0.036 m/s contributed to the DF of 57, while a current of 0.02 m/s was involved in the DF of 44. Interestingly, 0.02 m/s was the current involved in the lowest DFs at four of the five dischargers (including Port Gamble). The only exception was Fort Ward. This is a good illustration of the point made earlier that current and dilution factors are not directly correlated at regulatory boundaries. The last (highest) current used in the acute alternative analysis for Fort Ward (0.50 m/s) confirmed that the 90th percentile current used in the conventional analysis (0.51 m/s) was, coincidentally, a reasonable worst-case current.

There were significant differences between chronic dilution factors from the two approaches at Kingston, Winslow, and Fort Ward. As could be expected, significant differences in the median currents used accounted for the differences. Currents selected from the distribution analyses were 0.15, 0.14, and 0.33 m/s, respectively. Currents from the alternative approach which contributed to the lowest DFs were 0.04, 0.06, and 0.04 m/s, respectively. The field data sets were incomplete; so under the circumstances it was appropriate to use DFs from the alternative approach, which should always be as low or lower.

There were other noteworthy findings:

- RSB generated significantly lower dilution factors than UM whenever it was operating within its range of experiments, such that the results were useable.

- Dilution factors at the acute boundary dropped steadily in all ten analyses as increasing currents from 0.001 to 0.02 m/s were input to the UM model. Then, with additional increases in current from 0.03 to about 0.10 m/s the DFs rose, before again dropping steadily through the remainder of the currents (0.50 m/s).

- No predictable pattern between currents and dilution factors emerged at the chronic boundary. Stratification appeared to play a more important role at the chronic than at the acute boundary.

Conclusions and Recommendations

1. Ecology's Mixing Zone Guidance suggests using the density profile that results in the lowest mixing. The authors developed definitions for a "minimum" and a "maximum" that should satisfy the intent of the guidance, while simplifying the approach and optimizing the effort involved in determining the reasonable worst-case stratification profiles.

2. There is no way of assessing the completeness of a stratification data set (*i.e.*, determining whether it will contain the minimum and maximum stratification profiles). The authors are aware of only one study (NOAA, 1981) showing that minimum and maximum densities are each loosely correlated to a particular season of the year: In the top 20 meters of the water column, the highest densities occur in October and November; the minimum densities occur in June and July.

3. Stratification profiles obtained from regional data sets were determined to be the reasonable worst-case maximum profiles at all six locations and were the minimum profiles four of six times. Minimum profiles obtained from site-specific data sets were deemed the best-available at the other two locations.

4. As a general rule for small dischargers to marine waters, a "maximum" density profile will result in the lowest DF at the chronic boundary when the depth of water (at Mean Lower Low Water) is more than 15 feet. A "minimum" profile will be critical when the depth is less than 10 feet.

5. It is better to use a regional stratification data set, if an appropriate one exists, than to attempt field measurements. It is recommended that the stratification data sets available from Ecology's Ambient Monitoring Program be considered the most complete and that minimum and maximum profiles extracted from one of these sets be considered the best-available, until such time as more understanding has been gained on the duration and frequency of changes in profiles.

6. The site-specific stratification profiles seemed to more closely fit the definition for minimum profiles. This stems from the fact that the water column was well-mixed throughout the five weeks of field work and that there is little or no correlation between changes in stages of tide and changes in profiles. This tends to reinforce findings in the NOAA study.

7. Only two of the 12 minimum and maximum stratification profiles selected from the regional data sets actually occurred in the months when they were predicted to occur by the NOAA report. This argues against the findings in the report, but it also argues against attempting to conduct field measurements with an objective of catching the maximum.

8. Emphasis and deliberate thought must be given to selecting maximum profiles. Profiles showing the major pycnocline near the water surface, reflecting freshwater overflow, may not be reasonable worst-case maximums. If a regional profile for much deeper water than exists at the discharge location must be used, then the top portion of the profile should be used.

9. Regional (simulated) current velocities were higher than their comparable site-specific (measured) velocities about 75% of the time, particularly during ebb and flood stages. This disparity is to be expected since the discharges are near shorelines where simulated velocities are less accurate and generally higher than actual velocities that can be measured.

10. There were serious shortcomings in both the regional and site-specific current data sets. The regional sets were complete, but only the set for Fort Ward was representative of velocity and/or direction of currents at the discharge location. The site-specific sets were not complete. Cumulative frequency distribution analyses derived from these site-specific data sets were biased.

11. There is no way to determine bias introduced to the cumulative frequency distribution analyses, or significance of the bias to acute and chronic velocities derived statistically from these distribution analyses when incomplete data sets are used.

12. The authors devised an alternative approach to be used in the absence of a complete current data set: separate sensitivity analyses can be run for acute and chronic using a wide range of possible velocities--to include any that could reasonably occur during a 1-hour duration (acute), or be a 4-day average velocity (chronic). The velocities which are parameters in the two critical condition scenarios that produce the lowest acute and chronic dilution factors should be considered the reasonable worst-case currents.

13. In theory, it is quite difficult to predict which current velocity will contribute to the minimum dilution factor at a particular regulatory boundary. It is true that dilution factors at the hydrodynamic boundary (end of near-field) are increased by increased current velocities (assuming other variables are held constant). Conversely, the lower the current velocity, the lower the dilution factor at the end of near-field. However, what is true at the end of near-field is not necessarily true at a regulatory mixing zone boundary.

14. Dilution factors at the acute boundary dropped steadily in all ten analyses as increasing currents from 0.001 to 0.02 m/s were input to the UM model (using the alternative approach). Then, with additional increases in current from 0.03 to about 0.10 m/s the DFs rose, before again dropping steadily through the remainder of the currents (0.50 m/s). No predictable pattern between currents and dilution factors emerged at the chronic boundary.

15. Minimum currents that approached zero (*e.g.*, 0.001 m/s), resulted in significantly higher DFs at the acute boundary and should not be the preemptory choices as reasonable worst-case values.

16. "Similarity in physical characteristics of the two areas" is as important a criterion in determining acceptability of regional stratification and current data as "proximity to the discharger location."

17. As a general rule, the combination of stratification and current velocity that minimizes the length of trajectory of the plume will result in the lowest DFs.

18. The acute and chronic DFs for permitting purposes are as follows:

Permittee	WWTP Identifier	Acute	Chronic
Pope and Talbot, Inc.	Port Gamble	44	270
Kitsap County	City of Kingston	39	418
City of Bainbridge	Winslow	25	55
Kitsap County Sewer District (S.D.) # 7	Fort Ward	66	479
Kitsap County	Town of Manchester	5	17
Vashon S.D.	Town of Vashon	50	375

19. RSB generated significantly lower dilution factors than UM whenever it was operating within its range of experiments, such that the results were useable. The several extraordinarily large disparities between results from the two models (Kingston and Vashon) should be examined more thoroughly. These two data sets should be shared with the chief authors of the two models.

20. Accurate modeling of the Manchester diffuser is not possible because of a complex configuration. The diffuser is also located closer to shore and in shallower water than shown on the as-built drawings. It is recommended that all mixing zone analyses be accompanied by a physical examination of the outfall/diffuser and confirmation that the as-built drawings are accurate.

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Appendix A

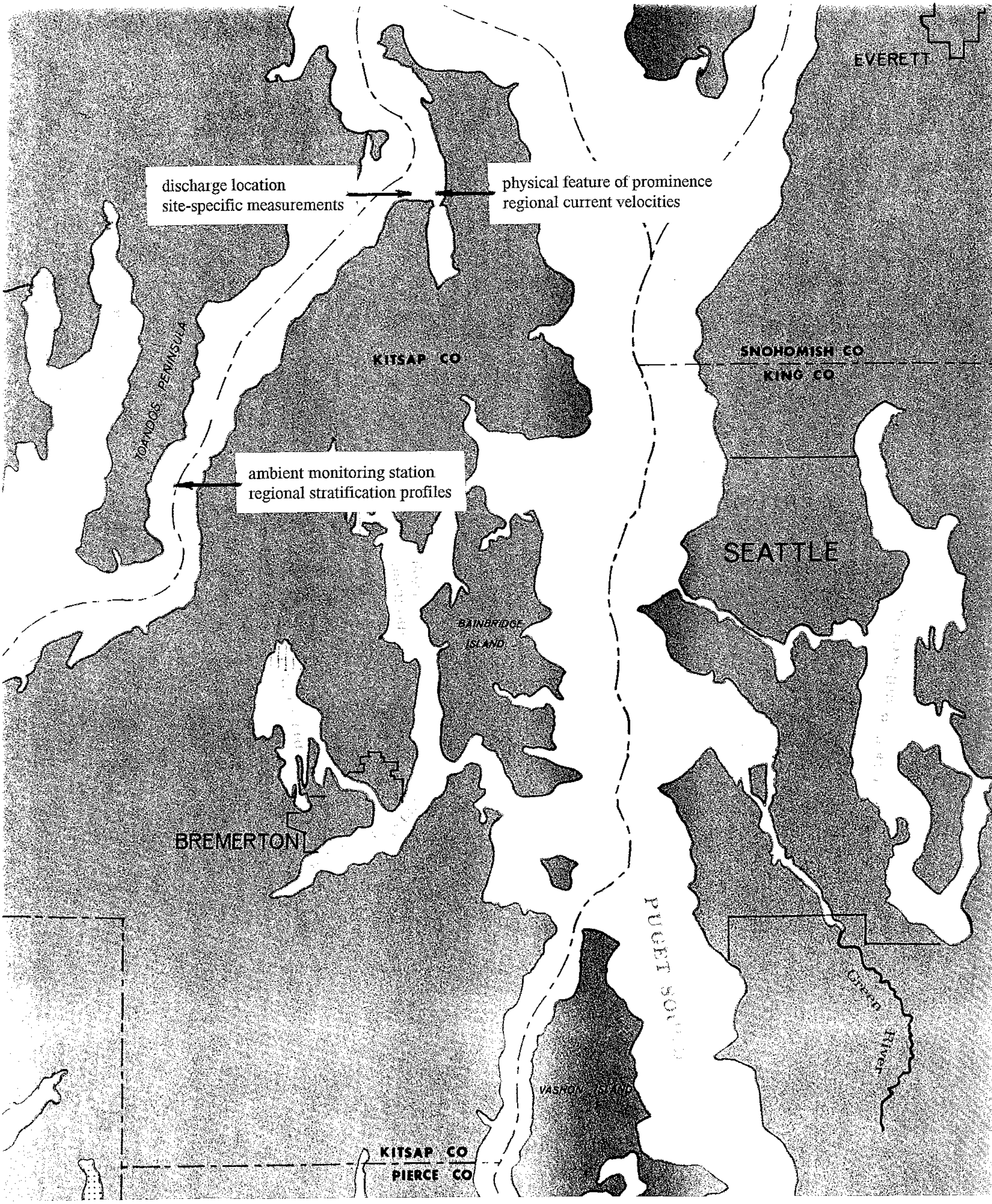
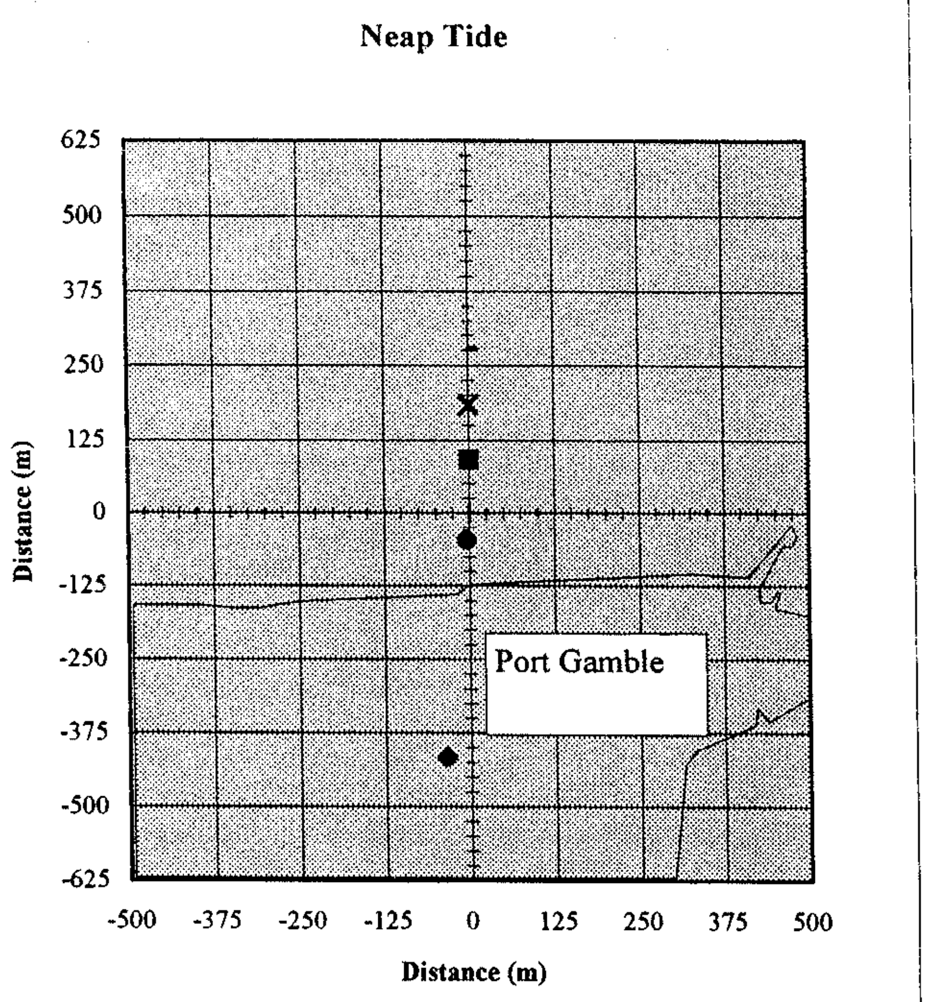
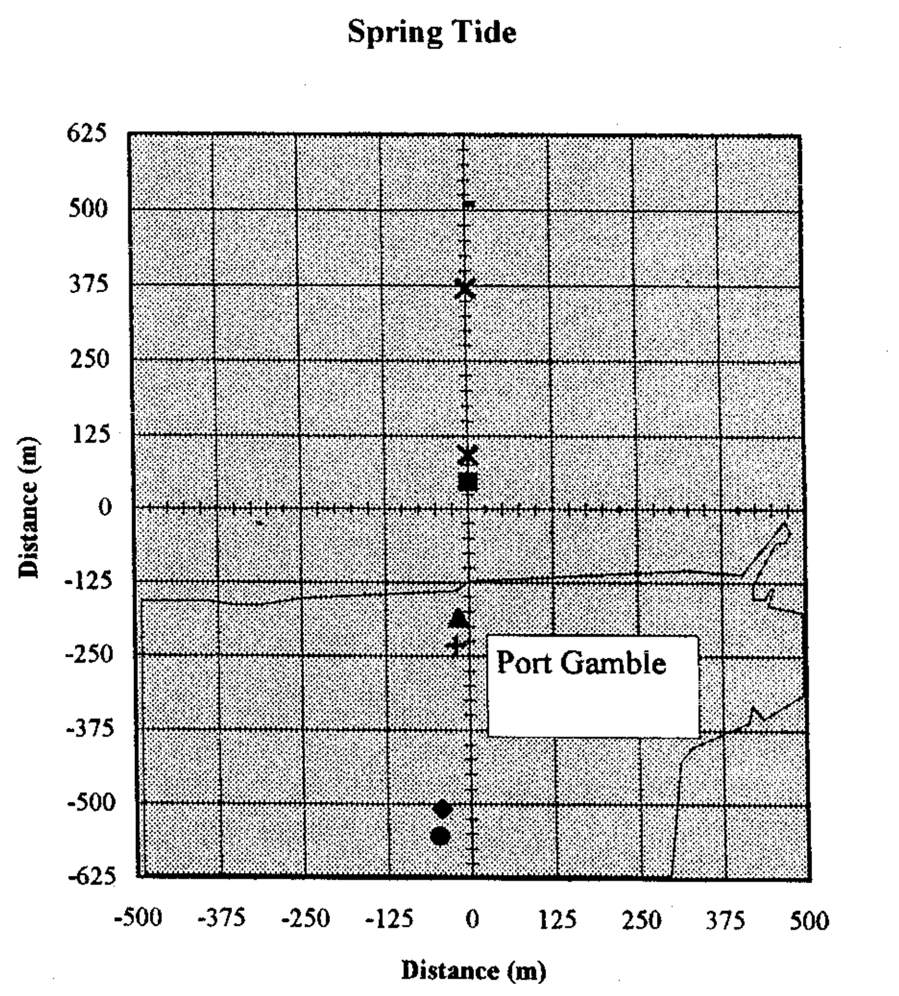


Figure A-1. Vicinity map - Port Gamble

Best-available regional current data for Port Gamble





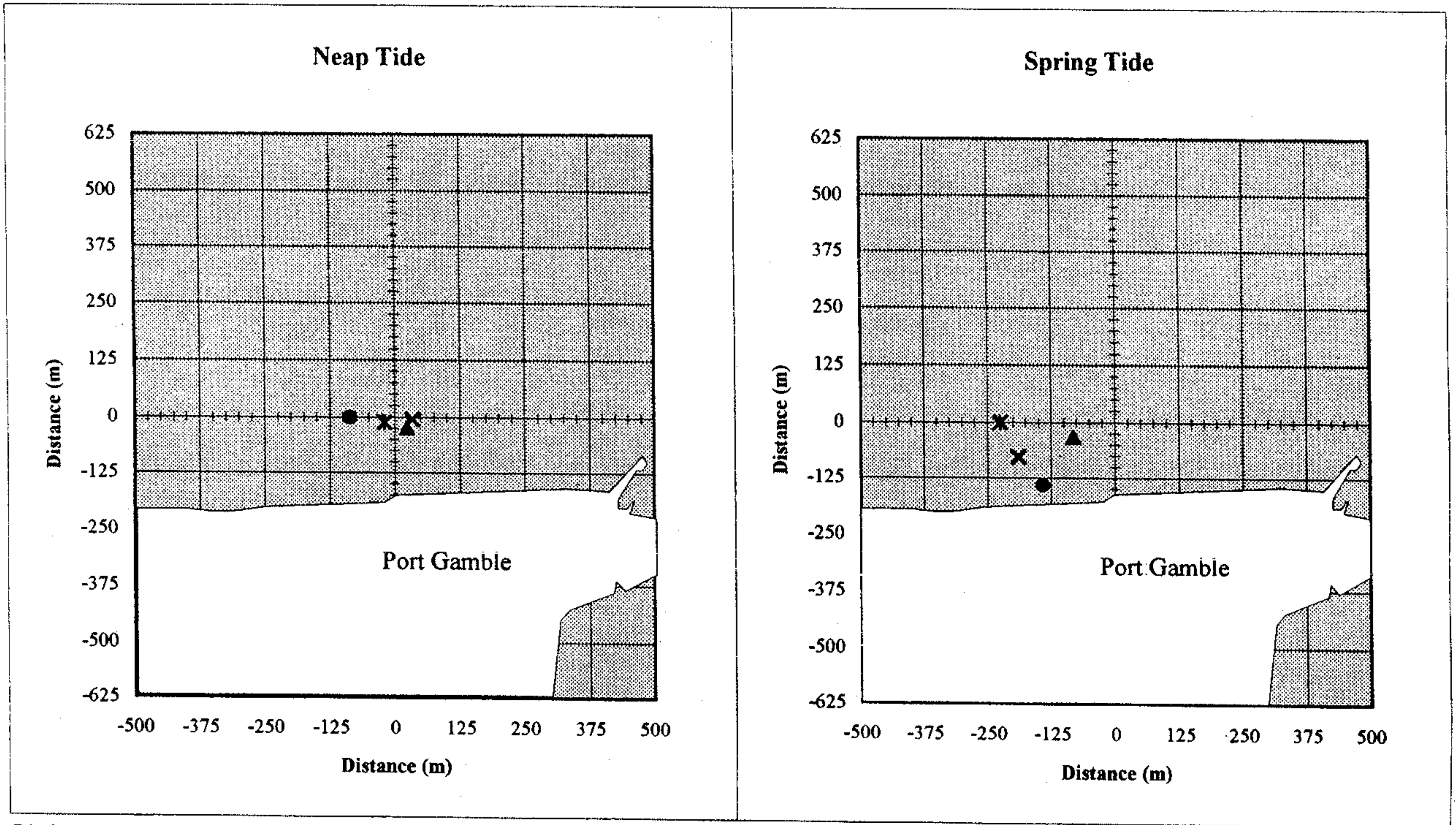
Discharge site is at X-Y coordinate (0,0). Orientation of Y-axis is true North-South.

Tide stage symbols:

■ Lower Low ◆ Large Flood ▲ Higher High ✕ Small Ebb ✱ Higher Low ● Small Flood + Lower High - Large Ebb

Location of tide stage symbols represents distance and direction that drogue travelled (or would have travelled) from discharge site in 15 minutes, at the velocity and direction of current at the discharge site.

Site-specific current data for Port Gamble



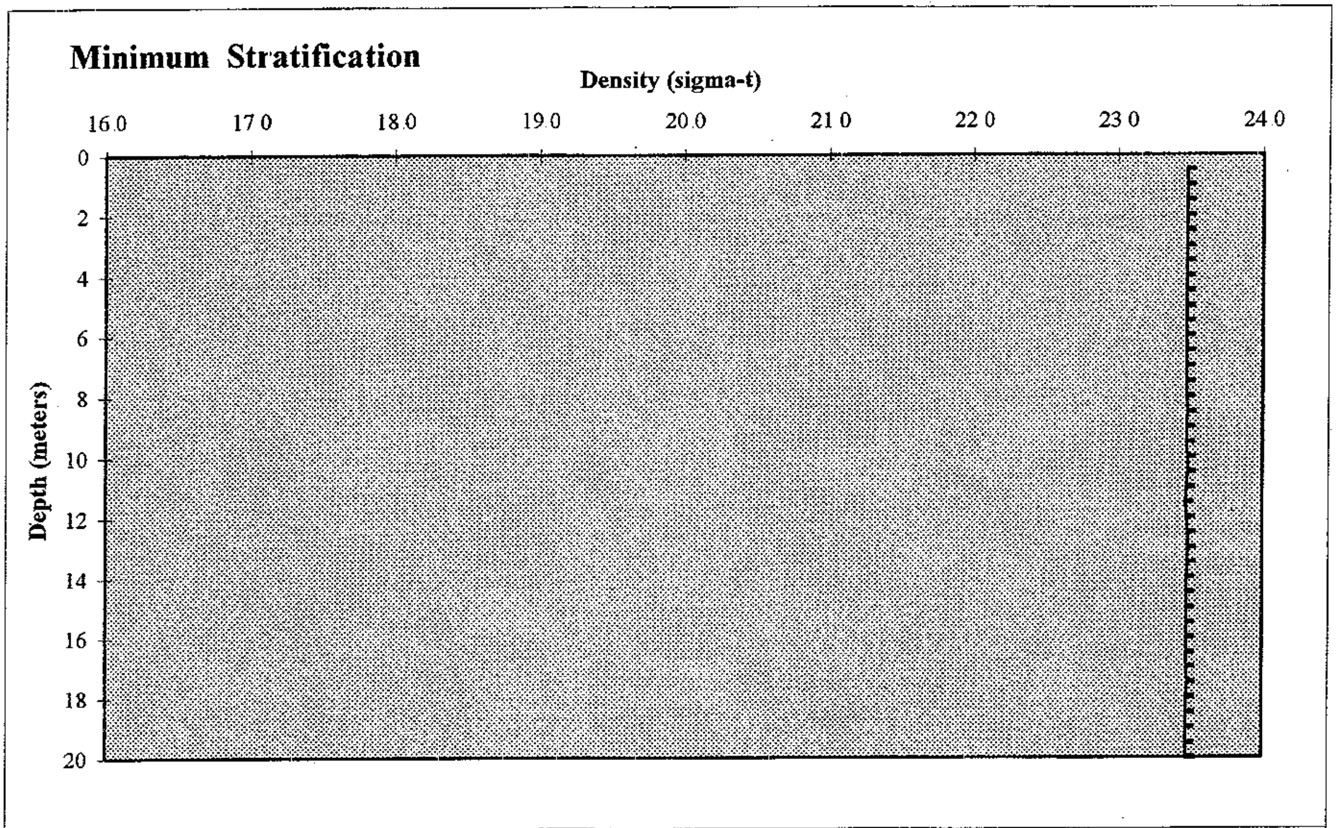
Discharge site is at X-Y coordinate (0,0). Orientation of Y-axis is true North-South.

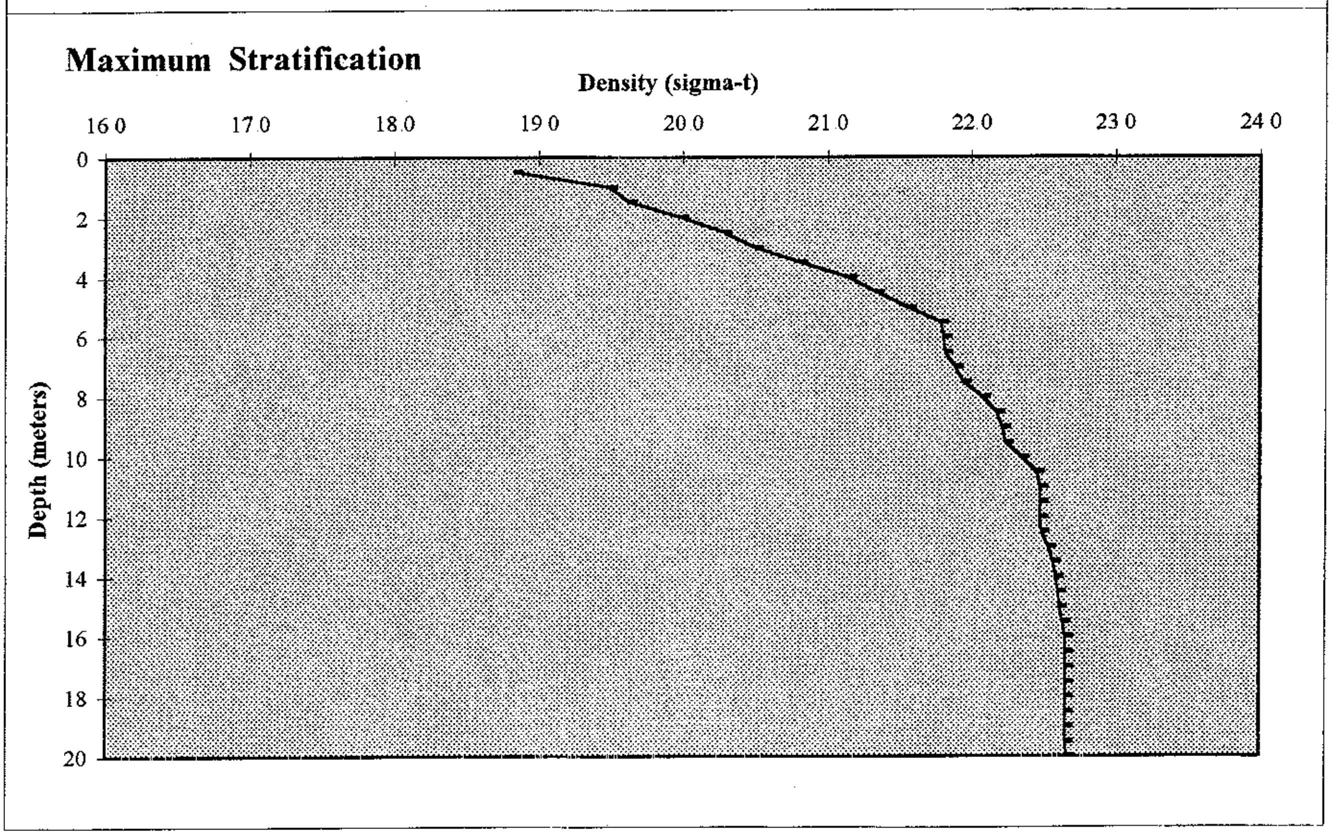
Tide stage symbols:

■ Lower Low ◆ Large Flood ▲ Higher High ✕ Small Ebb ✖ Higher Low ● Small Flood + Lower High - Large Ebb

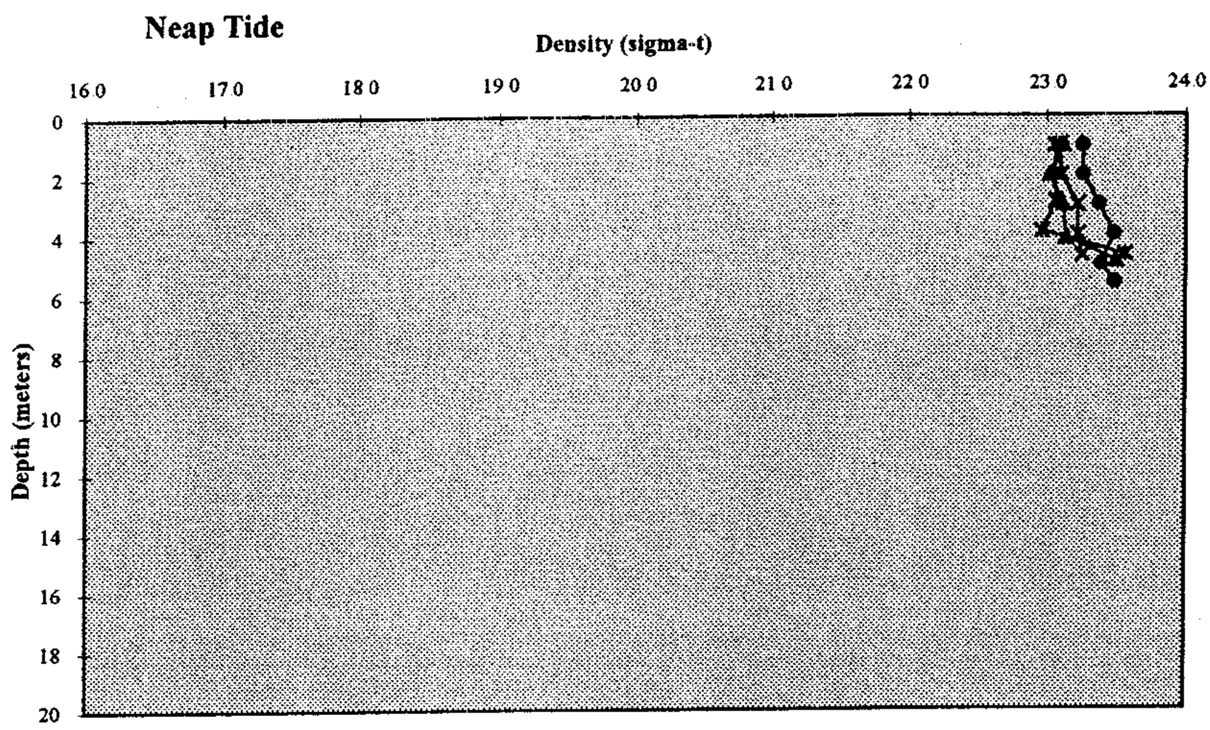
Location of tide stage symbols represents distance and direction that drogue travelled (or would have travelled) from discharge site in 15 minutes, at the velocity and direction of current at the discharge site.

Regional stratification data for Port Gamble





Site-specific stratification data for Port Gamble



Tide stage symbols:

- Lower Low
- Large Flood
- Higher High
- Small Ebb
- Higher Low
- Small Flood
- Lower High
- Large Ebb

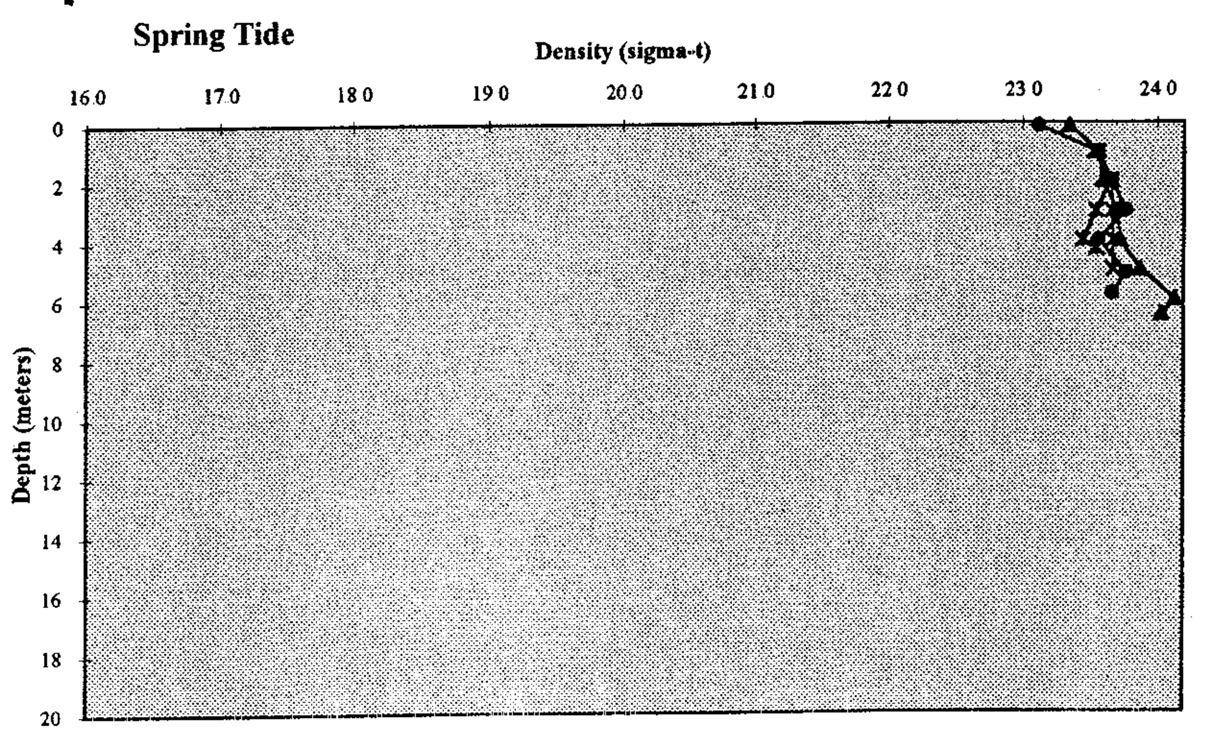


Table A-1. Reasonable worst-case data for Port Gamble.

Effluent flowrate (MGD)	Flowrate used for analyses at each MZ boundary: Acute	Chronic
	0.090	0.025

	Regional Data Set: Acute 10th%	Acute 90th%	Chronic Median	Site-specific Data Set: Acute 10th%	Acute 90th%	Chronic Median
Current						
velocity (m/sec)	0.051	0.550	0.200	0.036	0.220	0.097
horizontal angle (degrees)	45	45	45	120	112	90

Stratification	Regional Data Set: Min	Max	Site-specific Data Set: Min	Max
depth (m)	(sigma-t)	(sigma-t)	(sigma-t)	(sigma-t)
0	23.48	18.83	23.25	23.28
1	23.48	19.49	23.25	23.45
2	23.48	19.99	23.26	23.50
3	23.48	20.50	23.40	23.60
4	23.48	21.15	23.49	23.60
4.57 (MLLW)			23.39	23.73
5	23.49	21.56	23.50	23.95

Water quality (mg/L)	Regional Data Set	Site-specific Data Set
ammonia (total, as N)	0.04	Not detected at or above 0.010
copper (dissolved)	No data available	Not detected at or above 0.002
lead (dissolved)	" " "	" " " " " 0.005
silver (dissolved)	" " "	" " " " " 0.0025 (est.)
zinc (dissolved)	" " "	" " " " " 0.004

Appendix B

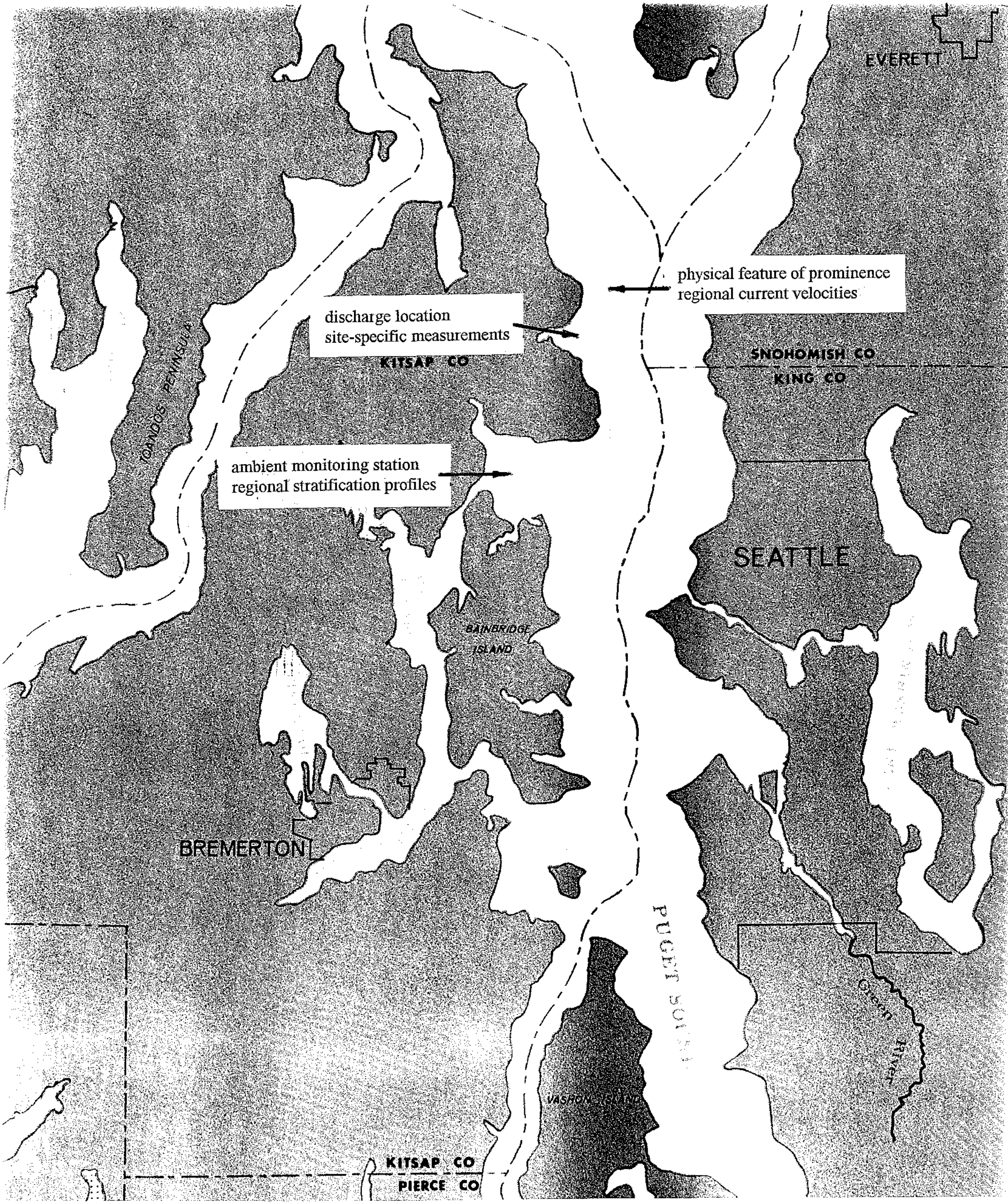
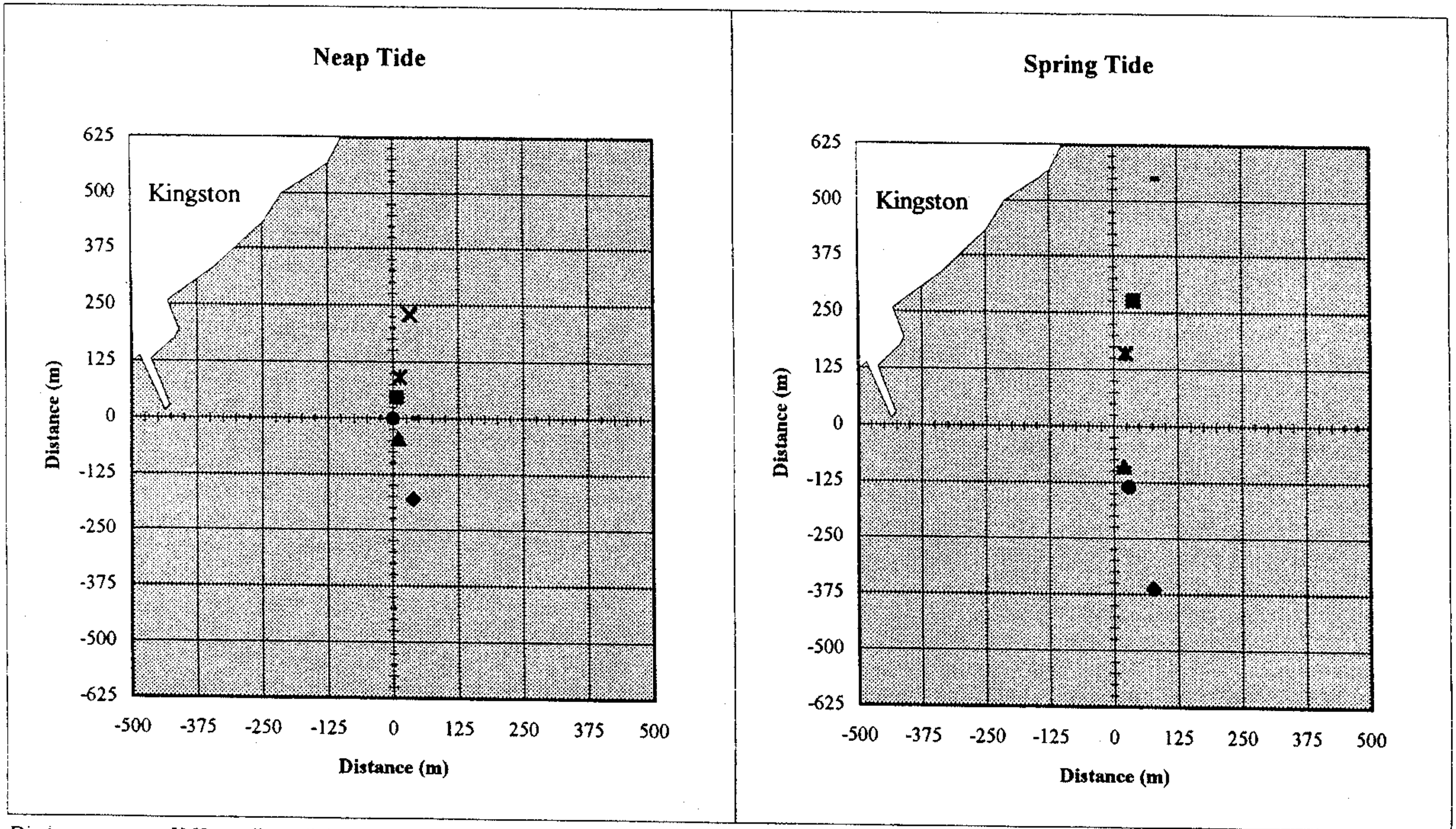


Figure B-1. Vicinity map - Kingston

Best-available regional current data for Kingston

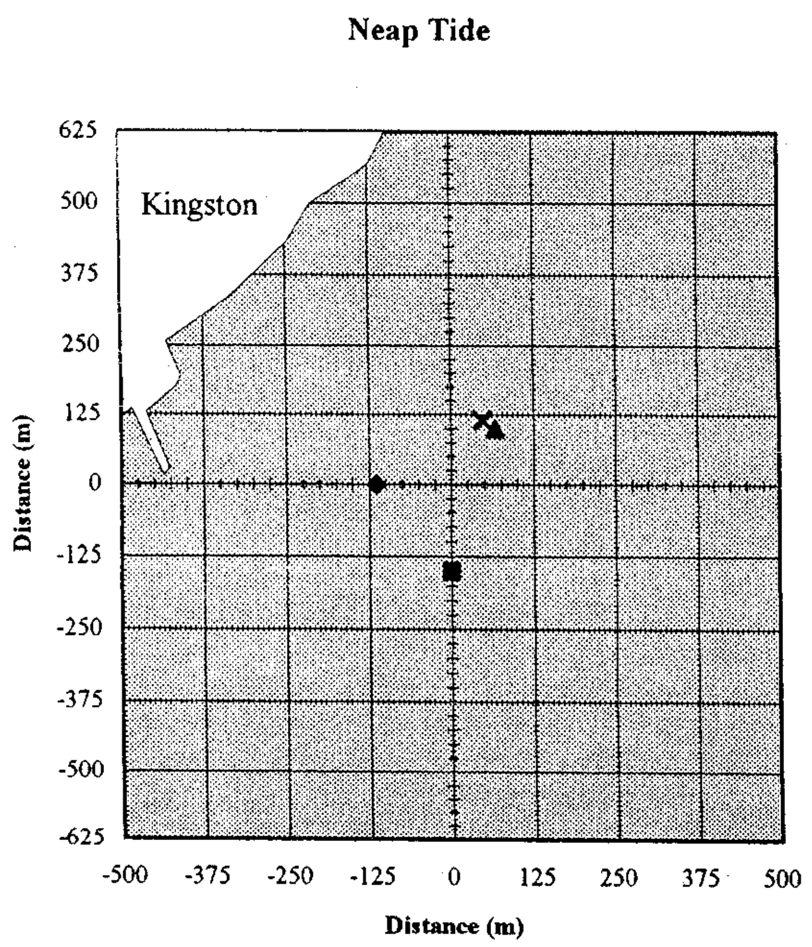


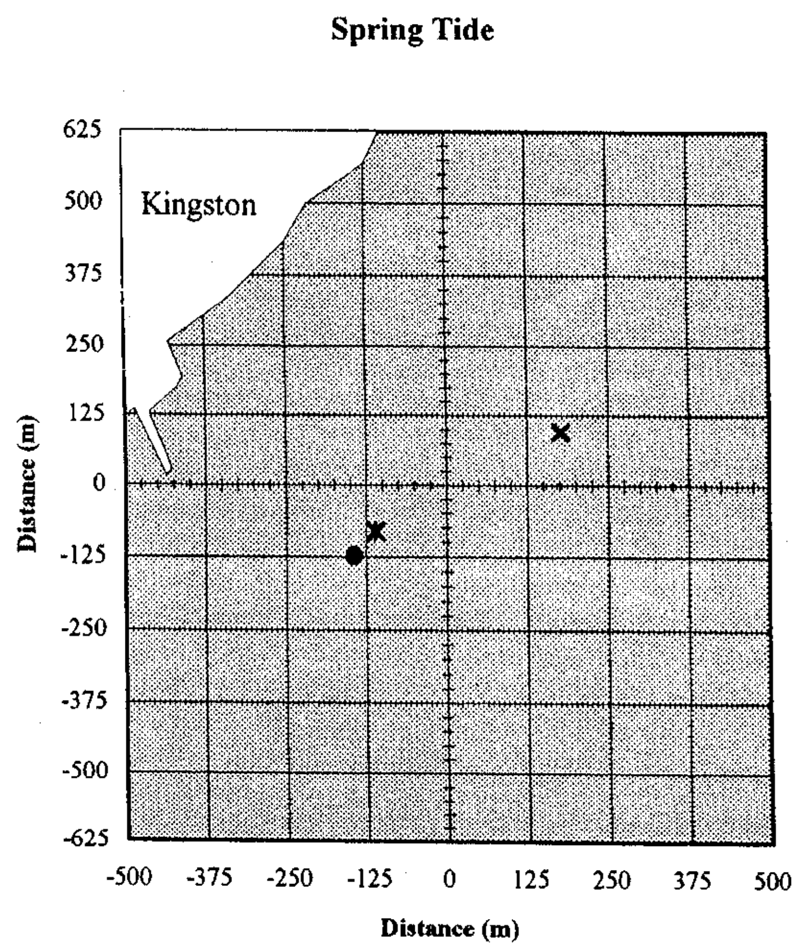
Discharge site is at X-Y coordinate (0,0). Orientation of Y-axis is true North-South.

Tide stage symbols: ■ Lower Low ◆ Large Flood ▲ Higher High ✕ Small Ebb ✱ Higher Low ● Small Flood + Lower High - Large Ebb

Location of tide stage symbols represents distance and direction that drogue travelled (or would have travelled) from discharge site in 15 minutes, at the velocity and direction of current at the discharge site.

Site-specific current data for Kingston





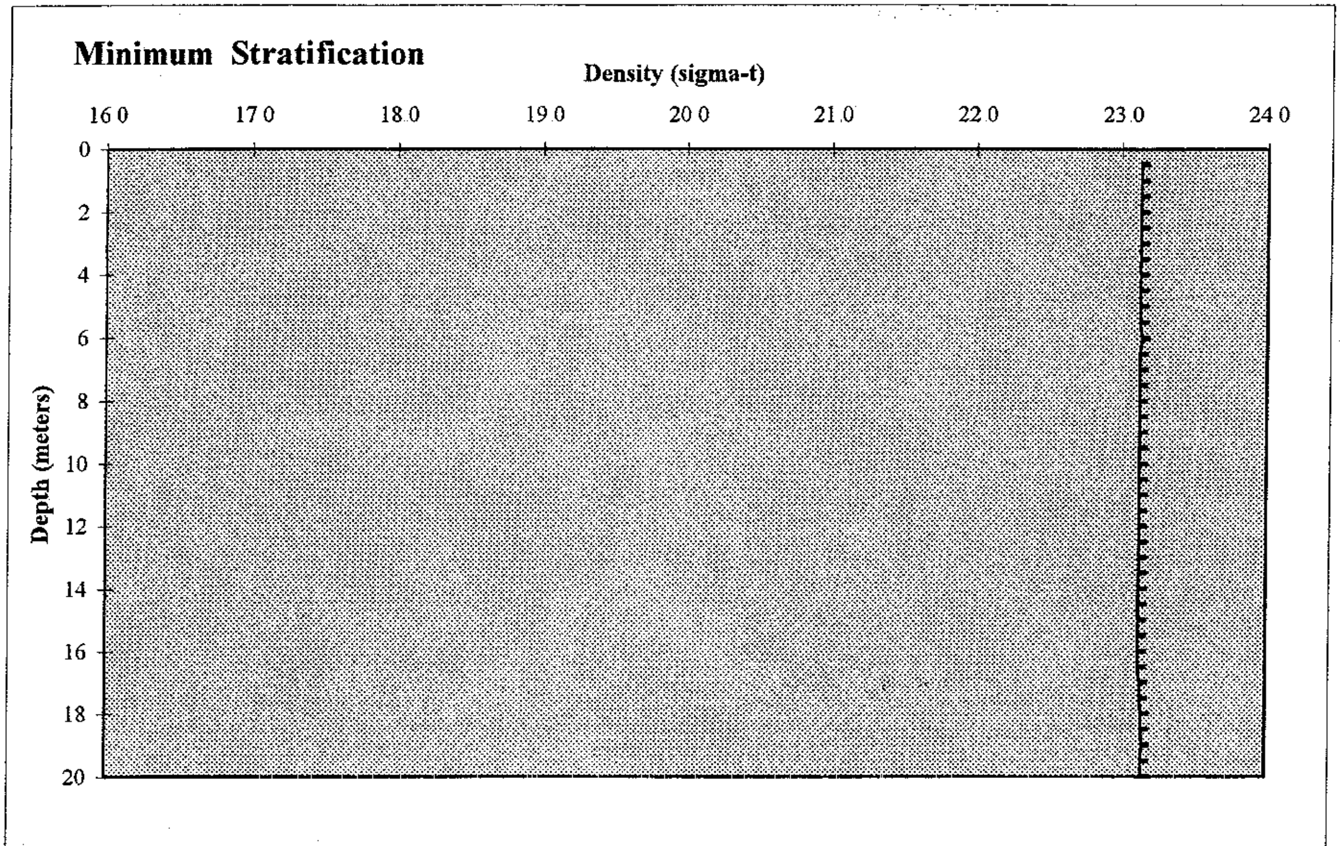
Discharge site is at X-Y coordinate (0,0). Orientation of Y-axis is true North-South.

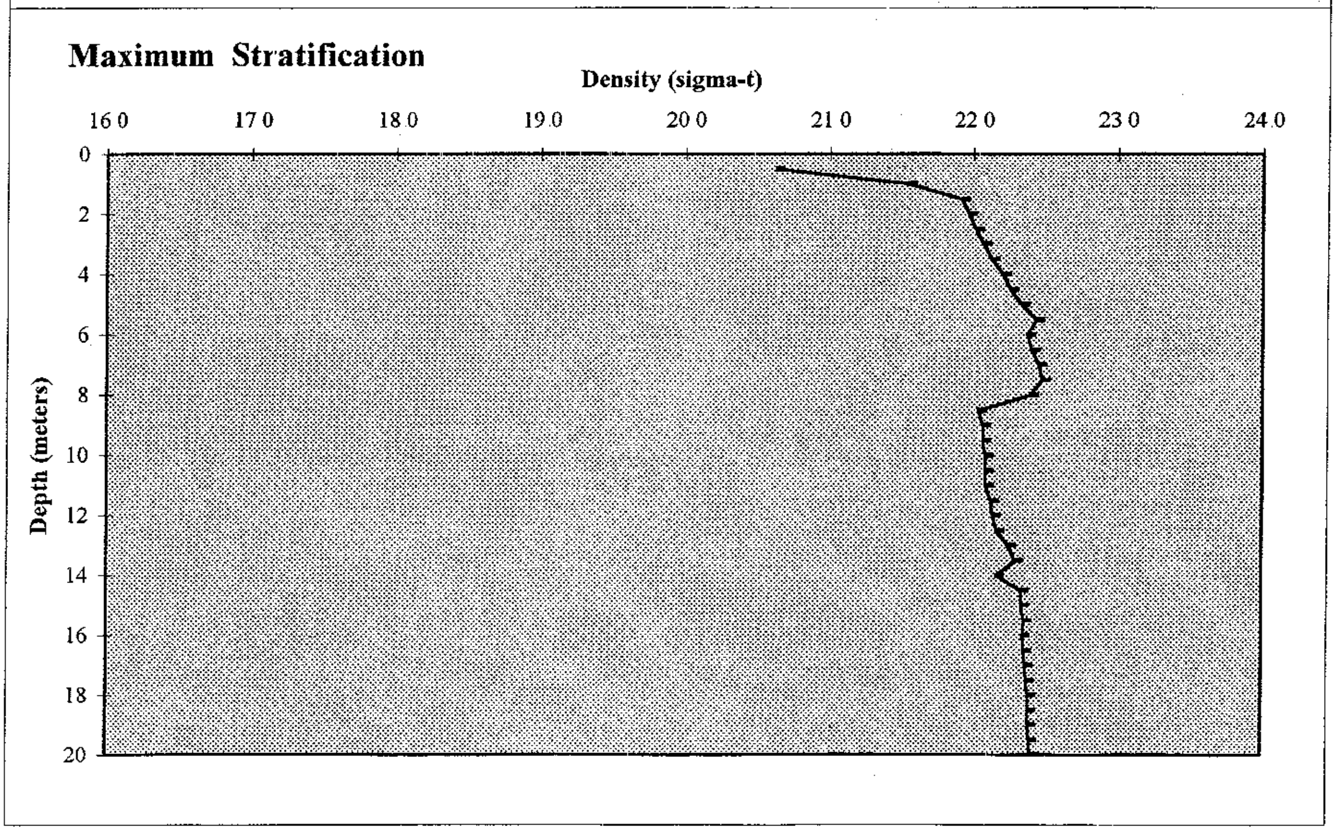
Tide stage symbols:

■ Lower Low ◆ Large Flood ▲ Higher High ✕ Small Ebb ✖ Higher Low ● Small Flood + Lower High - Large Ebb

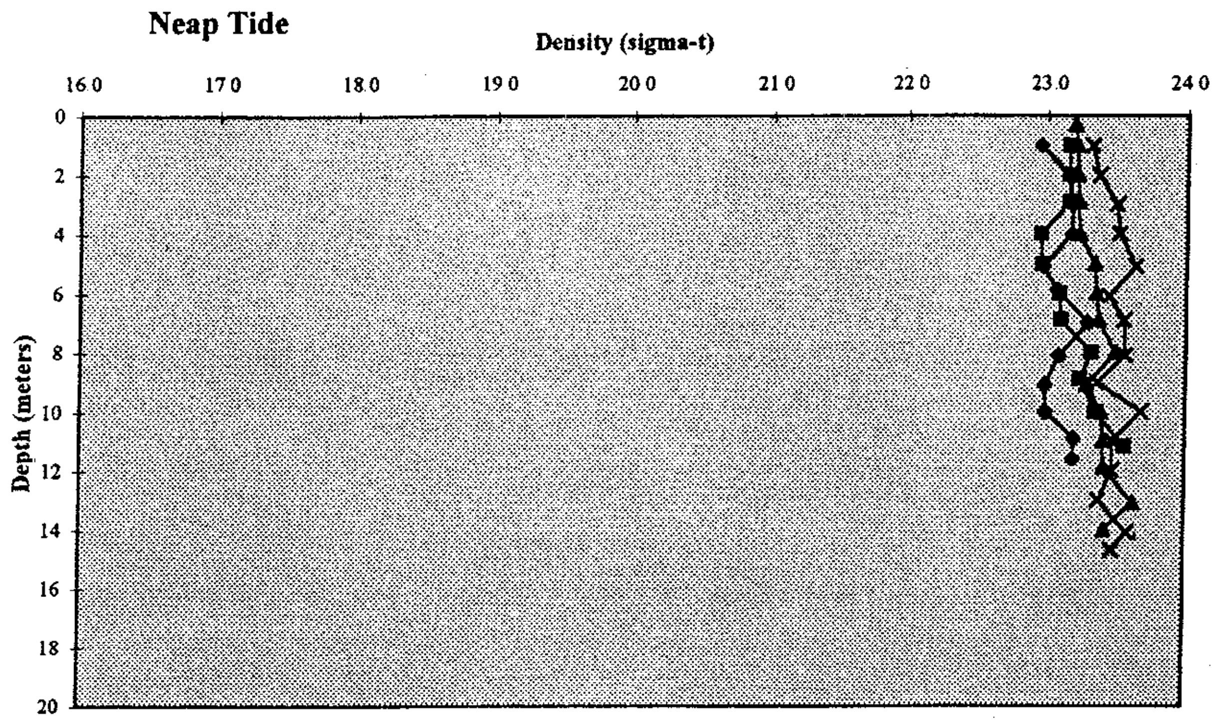
Location of tide stage symbols represents distance and direction that drogue travelled (or would have travelled) from discharge site in 15 minutes, at the velocity and direction of current at the discharge site.

Regional stratification data for Kingston





Site-specific stratification data for Kingston



Tide stage symbols: Lower Low, Large Flood, Higher High, Small Ebb, Higher Low, Small Flood, Lower High, Large Ebb

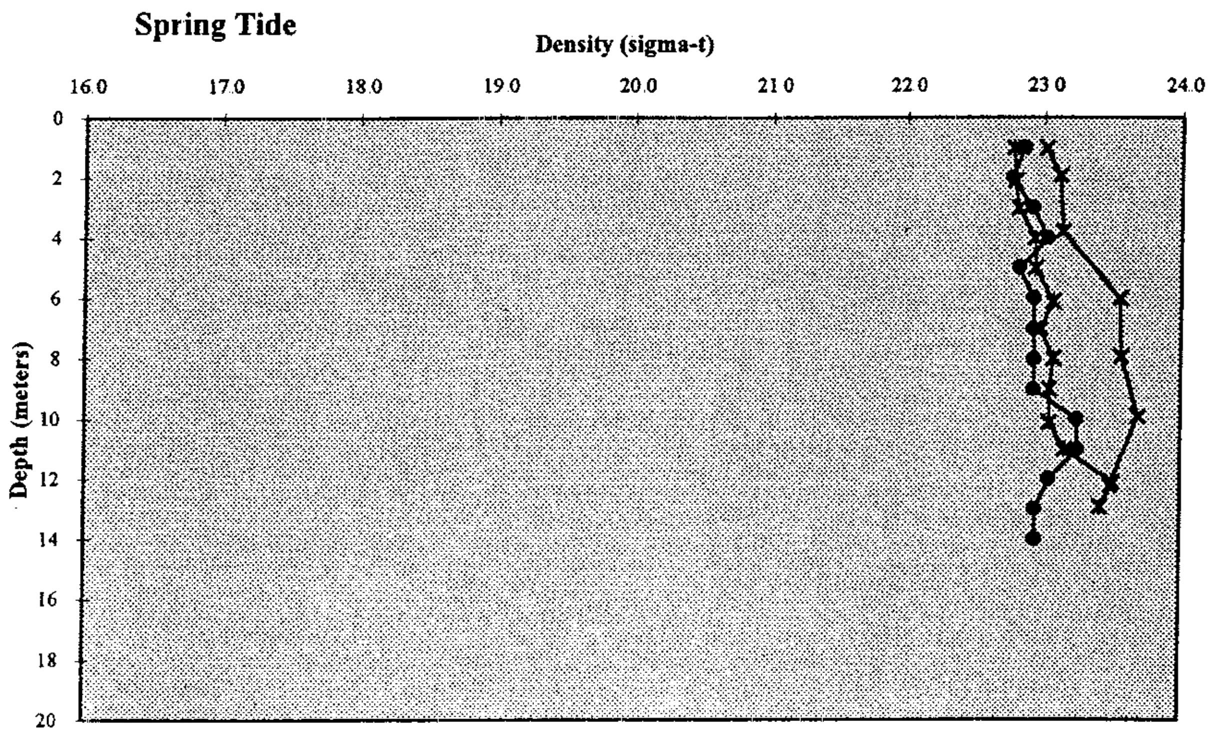


Table B-1. Reasonable worst-case data for Kingston.

Effluent flowrate (MGD)	Flowrate used for analyses at each MZ boundary: Acute	Chronic
	0.60	0.15

Current	Regional Data Set: Acute 10th%	Acute 90th%	Chronic Median	Site-specific Data Set: Acute 10th%	Acute 90th%	Chronic Median
velocity (m/sec)	0.051	0.408	0.168	0.13	0.21	0.150
horizontal angle (degrees)	122	45	90	96	99	90

Stratification depth (m)	Regional Min (sigma-t)	Regional Max (sigma-t)	Site-specific Min (sigma-t)	Site-specific Max (sigma-t)
0	23.13	20.63	23.27	22.73
1	23.13	21.55		
2	23.13	21.97	23.40	23.18
3	23.13	22.07		
4	23.13	22.21	23.54	23.18
5	23.13	22.34		
6	23.14	22.38	23.49	23.09
7	23.13	22.46		
8	23.13	22.40	23.58	23.09
9	23.13	22.07		
10	23.13	22.09	23.72	23.09
11	23.13	22.09		
12	23.13	22.14	23.49	23.18
13	23.13	22.25		
13.26 (MLLW)				
14	23.14	22.17	23.62	23.27

Water quality (mg/L)	Regional Data Set	Site-specific Data Set
ammonia (total, as N)	No data available	Not detected at or above 0.010
copper (dissolved)	" " "	Not detected at or above 0.002
lead (dissolved)	" " "	" " " " " 0.005
silver (dissolved)	" " "	" " " " " 0.0025 (est.)
zinc (dissolved)	" " "	" " " " " 0.004

Appendix C

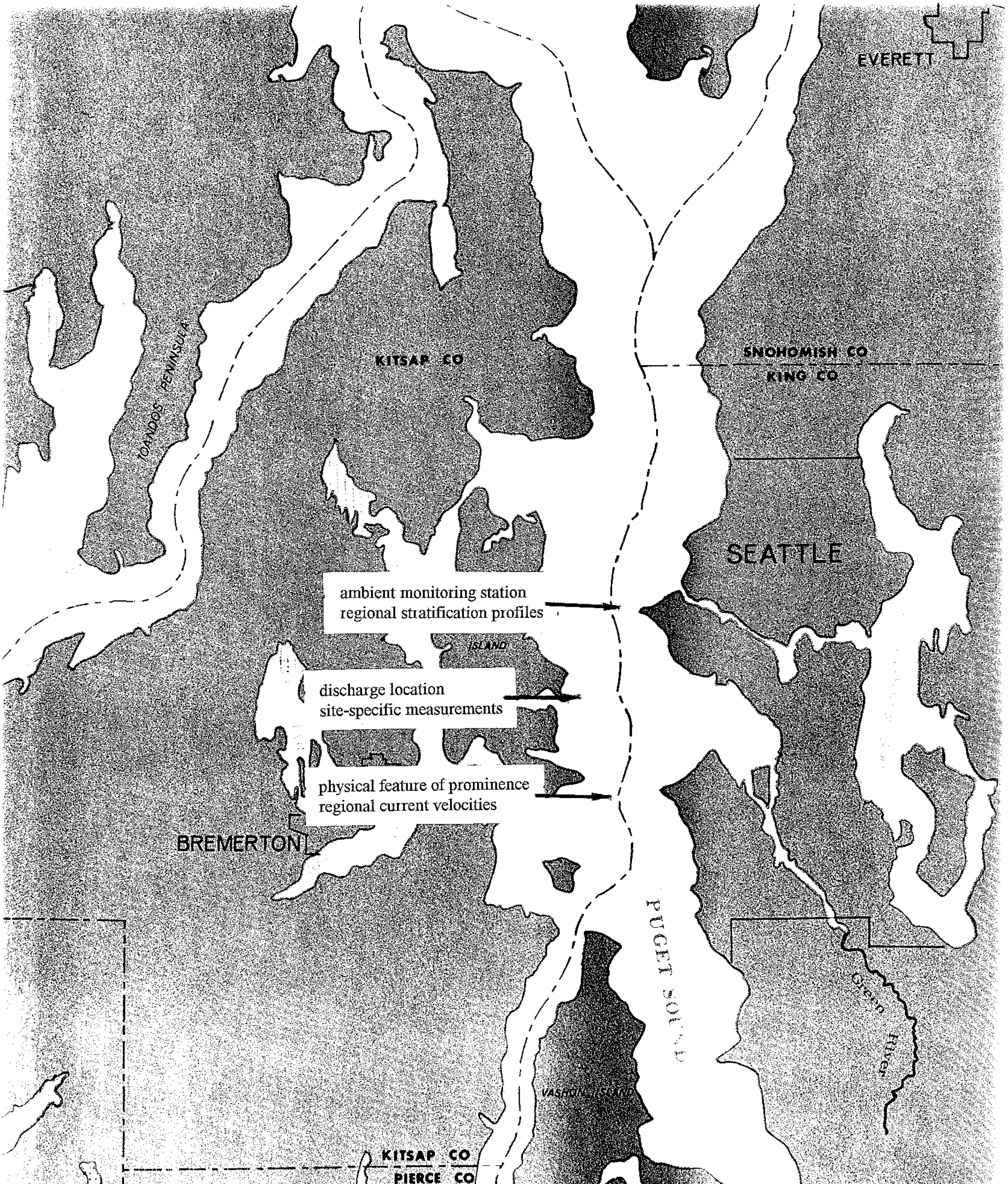
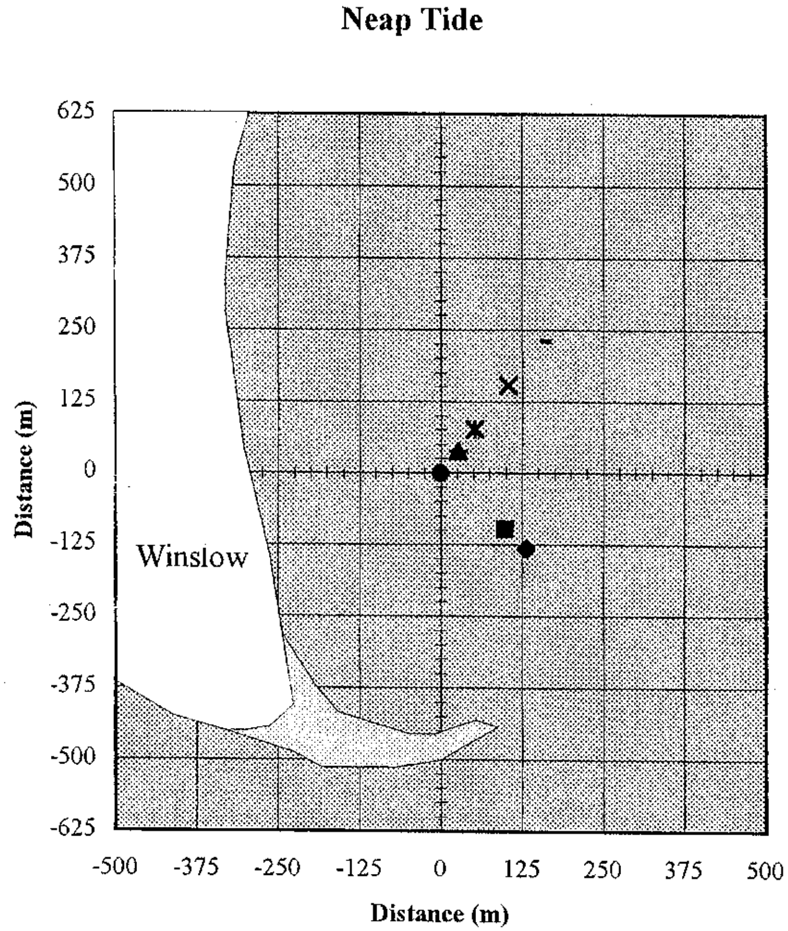
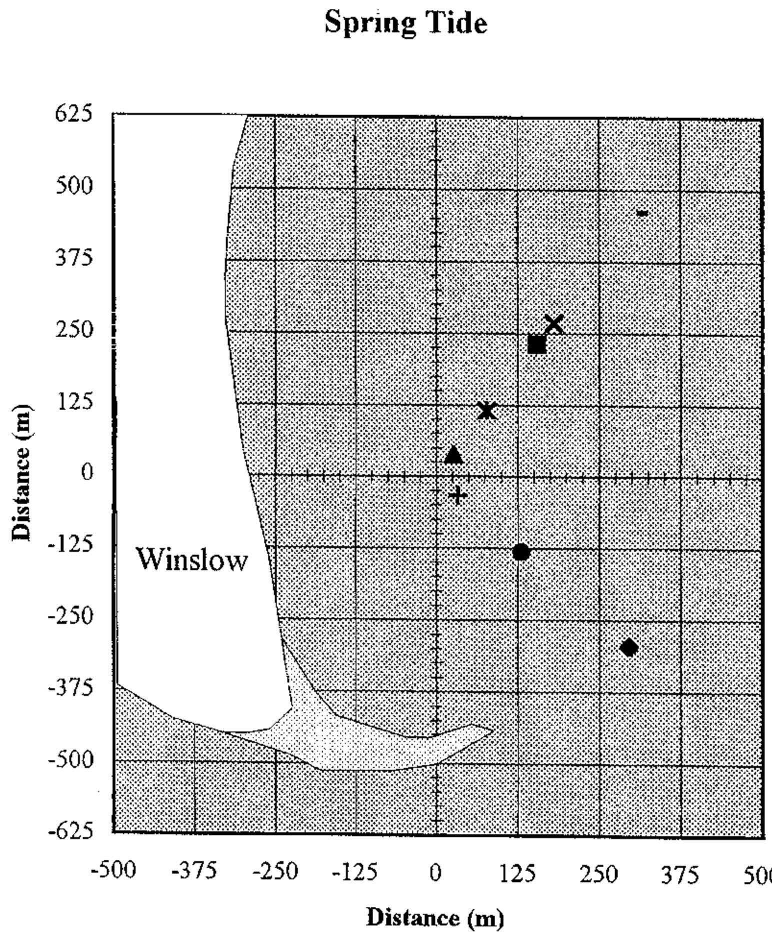


Figure C-1. Vicinity map - Winslow

Best-available regional current data for Winslow



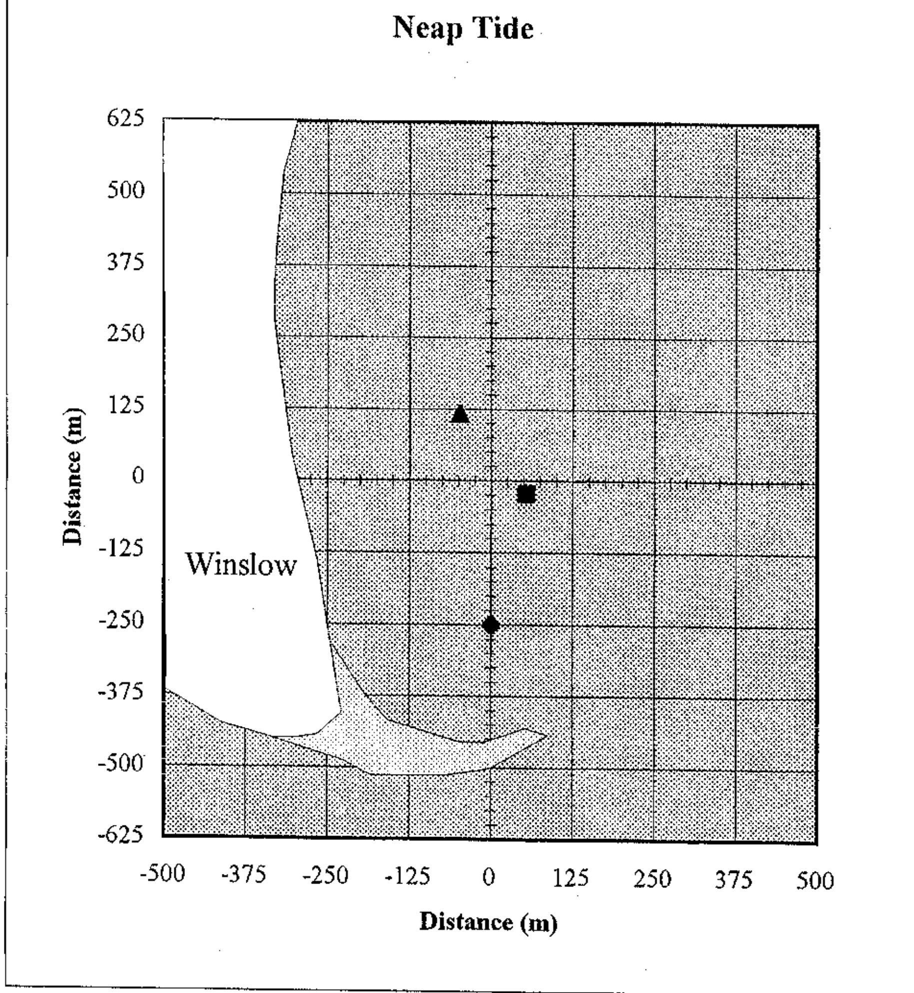


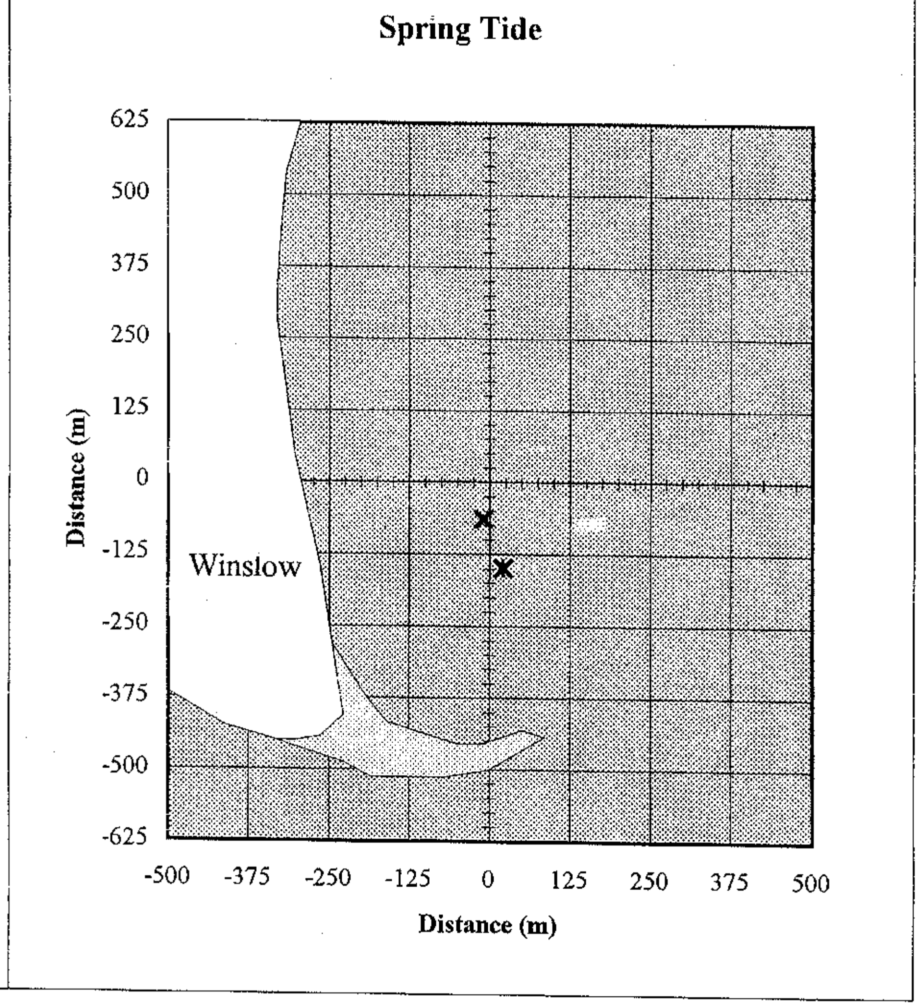
Discharge site is at X-Y coordinate (0,0). Orientation of Y-axis is true North-South.

Tide stage symbols: ■ Lower Low ◆ Large Flood ▲ Higher High ✕ Small Ebb ✖ Higher Low ● Small Flood + Lower High - Large Ebb

Location of tide stage symbols represents distance and direction that drogue travelled (or would have travelled) from discharge site in 15 minutes, at the velocity and direction of current at the discharge site.

Site-specific current data for Winslow





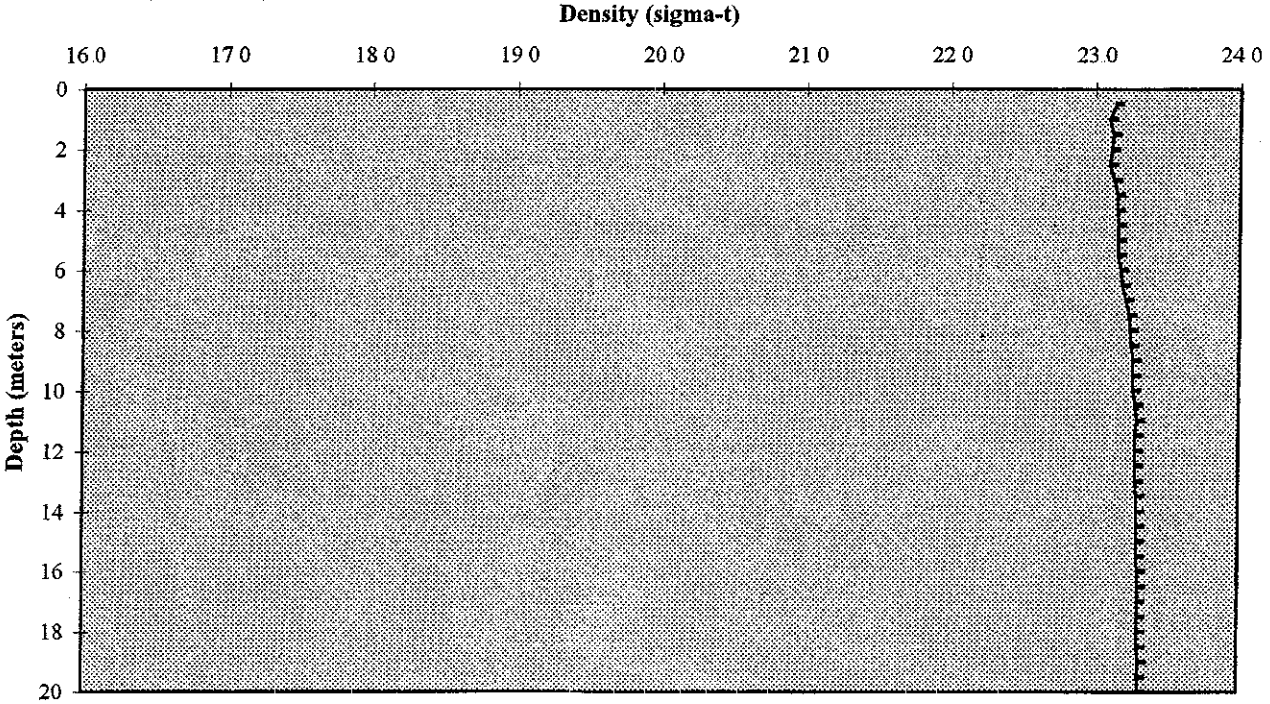
Discharge site is at X-Y coordinate (0,0). Orientation of Y-axis is true North-South.

Tide stage symbols: ■ Lower Low ◆ Large Flood ▲ Higher High ✕ Small Ebb ✱ Higher Low ● Small Flood + Lower High - Large Ebb

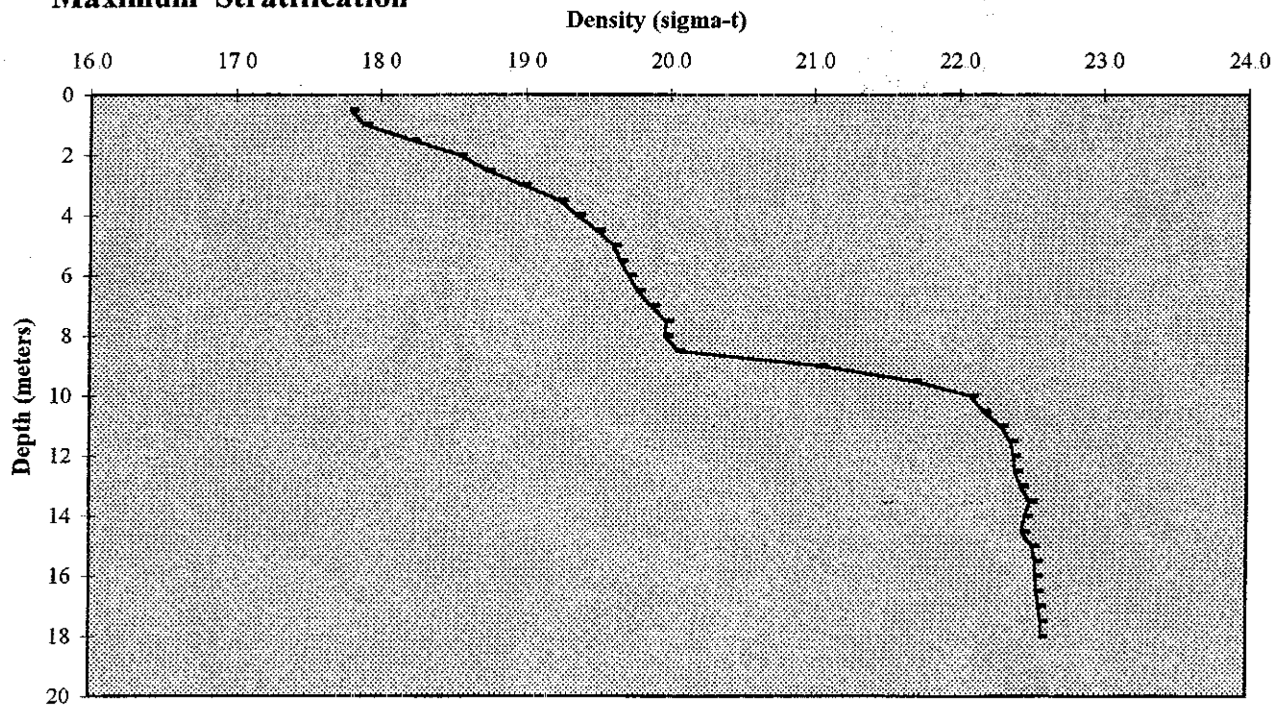
Location of tide stage symbols represents distance and direction that drogue travelled (or would have travelled) from discharge site in 15 minutes, at the velocity and direction of current at the discharge site.

Regional stratification data for Winslow

Minimum Stratification



Maximum Stratification



Site-specific stratification data for Winslow

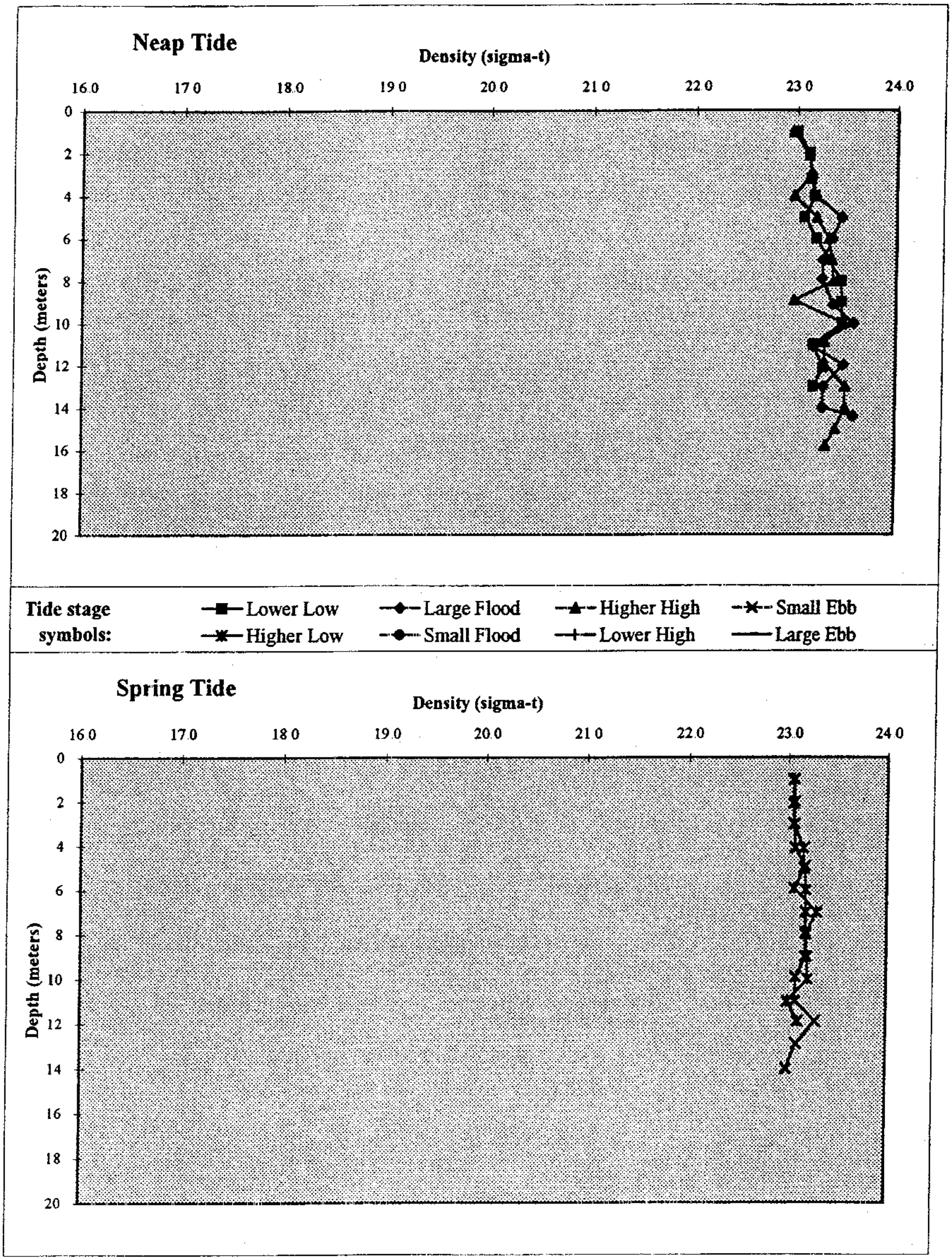


Table C-1. Reasonable worst-case data for Winslow.

Effluent flowrate (MGD)	Flowrate used for analyses at each MZ boundary: Acute	Chronic
	2.87	1.00

	Regional Data Set: Acute 10th%	Acute 90th%	Chronic Median	Site-specific Data Set: Acute 10th%	Acute 90th%	Chronic Median
Current						
velocity (m/sec)	0.051	0.46	0.178	0.071	0.16	0.138
horizontal angle (degrees)	45	70	90	125	107	90

Stratification depth (m)	Regional Min (sigma-t)	Regional Max (sigma-t)	Site-specific Min (sigma-t)	Site-specific Max (sigma-t)
0	23.10	17.70	23.03	22.82
1	23.10	17.89	23.03	22.95
2	23.11	18.54		
3	23.13	18.98	23.04	23.14
4	23.15	19.36		
5	23.16	19.61	23.18	23.20
6	23.18	19.72		
7	23.22	19.88	23.18	23.27
8	23.25	19.97		
9	23.27	21.05	23.18	23.36
10	23.27	22.09		
11	23.30	22.30	23.10	23.30
12	23.29	22.39		
12.91 (MLLW)				
13	23.29	22.44	23.1	23.49

Water quality (mg/L)	Regional Data Set	Site-specific Data Set
ammonia (total, as N)	0.09	Not detected at or above 0.010
copper (dissolved)	No data available	Not detected at or above 0.002
lead (dissolved)	" " "	" " " " " 0.005
silver (dissolved)	" " "	" " " " " 0.0025 (est.)
zinc (dissolved)	" " "	" " " " " 0.004

Appendix D

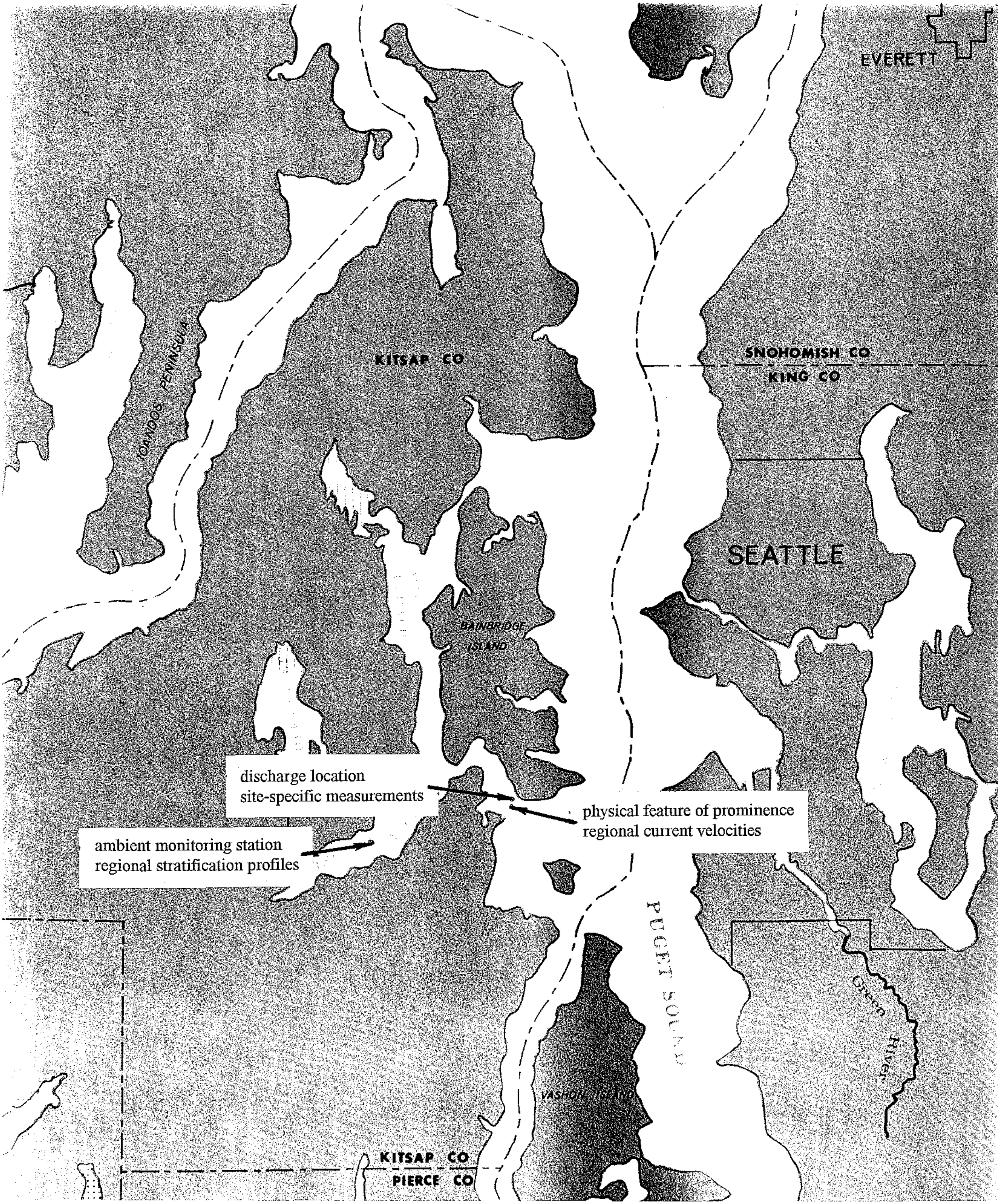
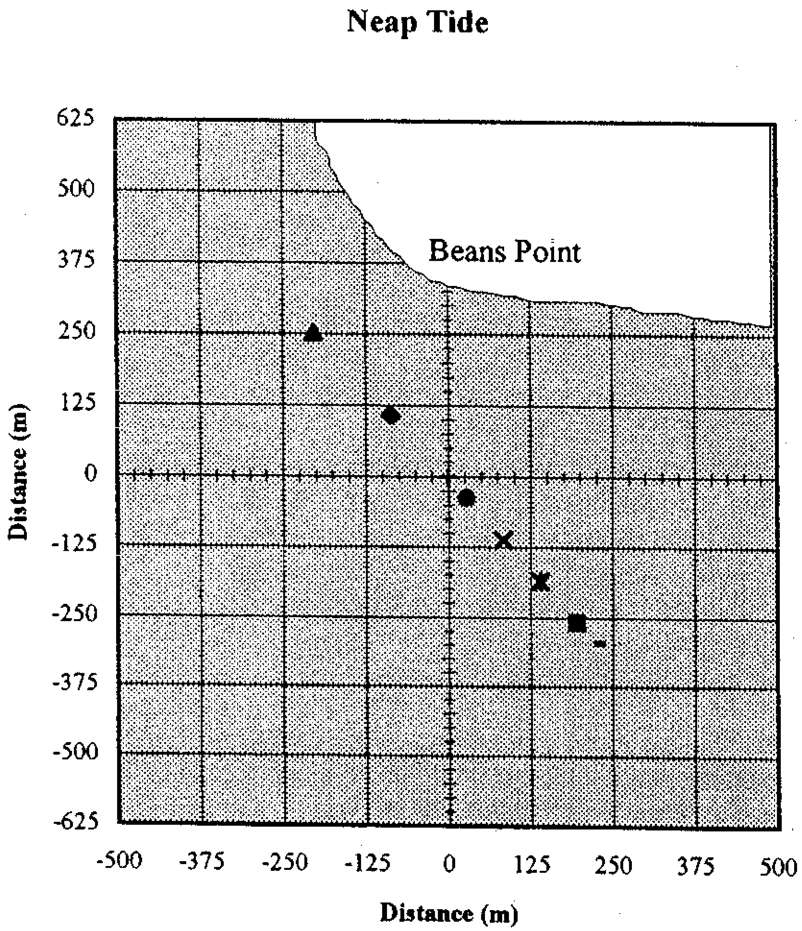
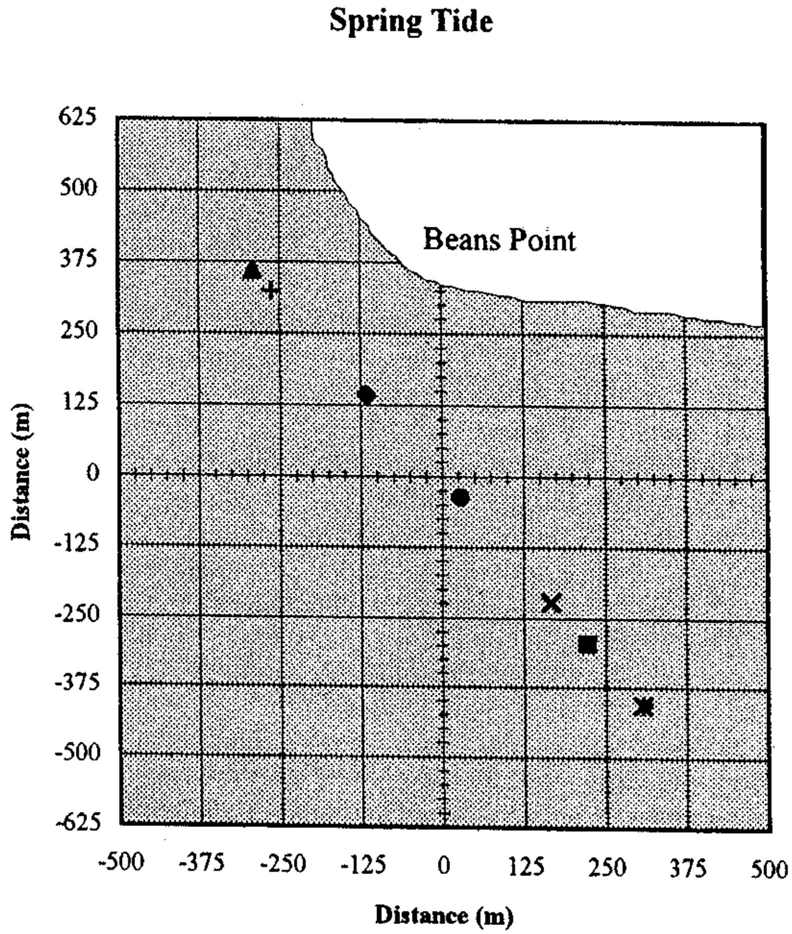


Figure D-1. Vicinity map - Fort Ward

Best-available regional current data for Fort Ward



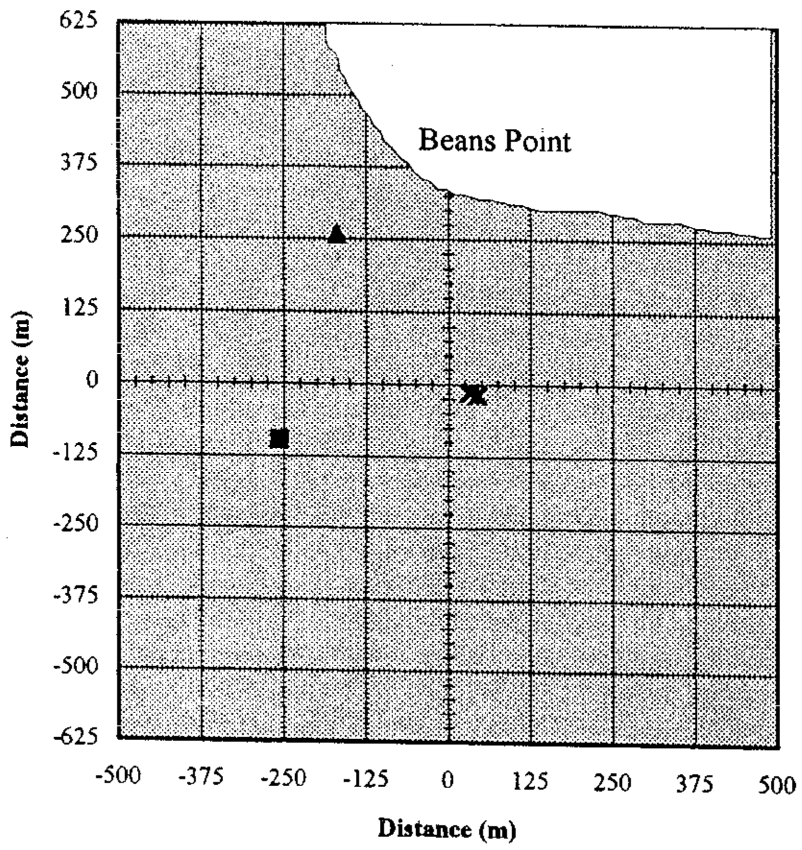


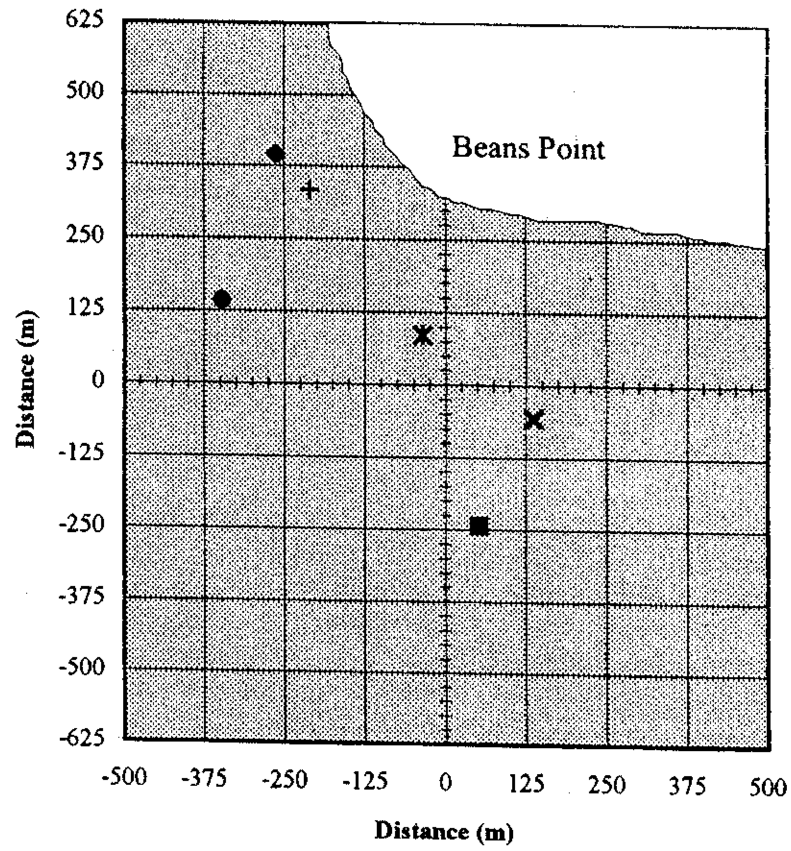
Discharge site is at X-Y coordinate (0,0). Orientation of Y-axis is true North-South.

Tide stage symbols: ■ Lower Low ◆ Large Flood ▲ Higher High ✕ Small Ebb ✱ Higher Low ● Small Flood + Lower High - Large Ebb

Location of tide stage symbols represents distance and direction that drogue travelled (or would have travelled) from discharge site in 15 minutes, at the velocity and direction of current at the discharge site.

Site-specific current data for Fort Ward



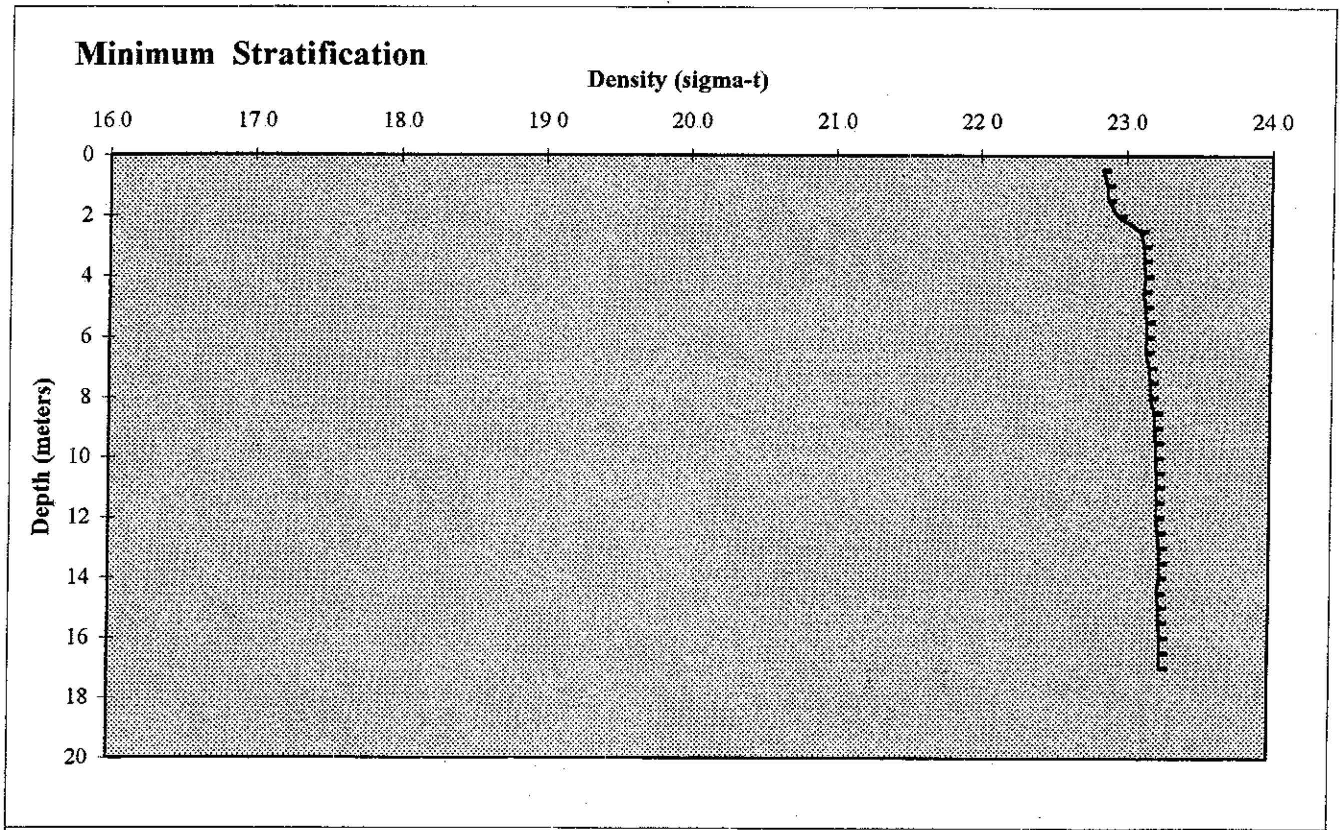


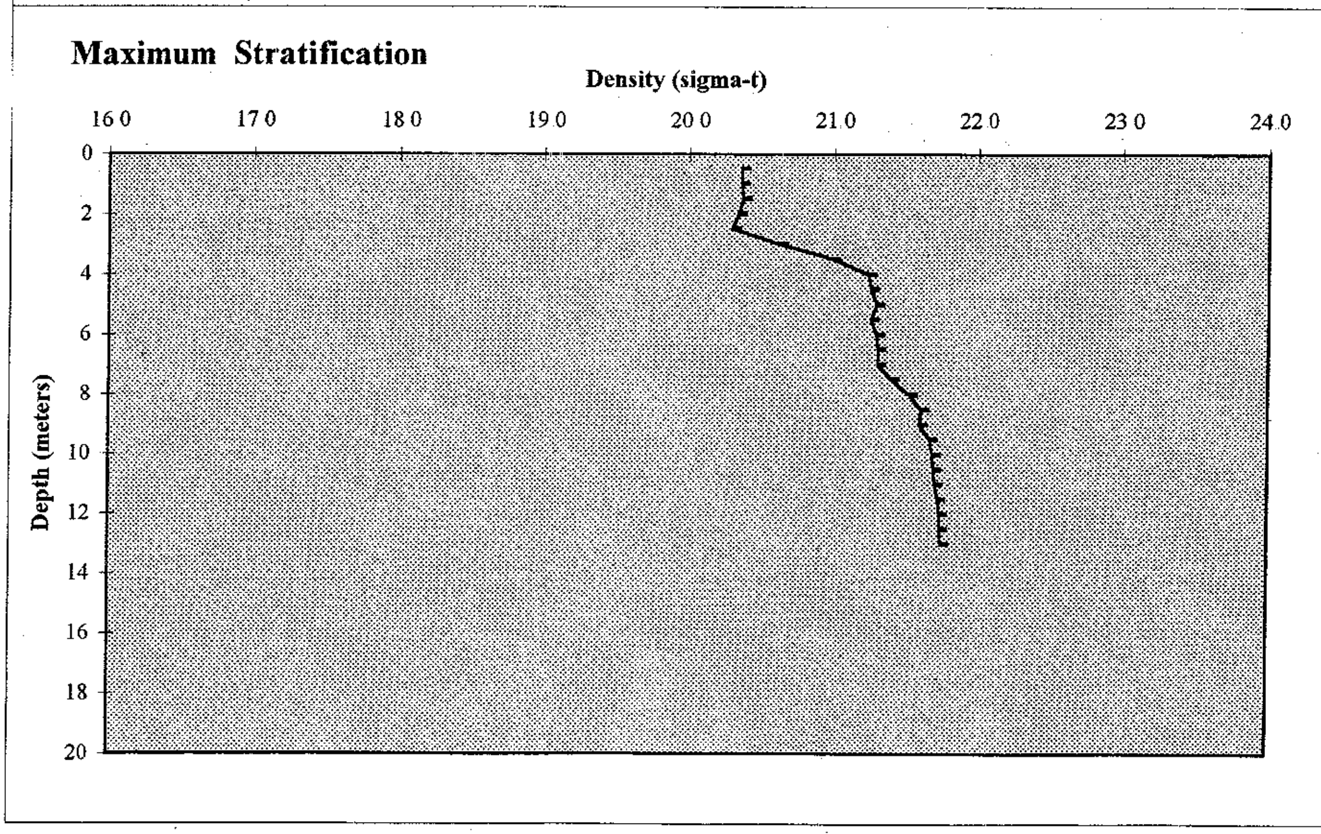
Discharge site is at X-Y coordinate (0,0). Orientation of Y-axis is true North-South.

Tide stage symbols: ■Lower Low ◆Large Flood ▲Higher High ✕Small Ebb ✱Higher Low ●Small Flood +Lower High -Large Ebb

Location of tide stage symbols represents distance and direction that drogues travelled (or would have travelled) from discharge site in 15 minutes, at the velocity and direction of current at the discharge site.

Regional stratification data for Fort Ward





Site-specific stratification data for Fort Ward

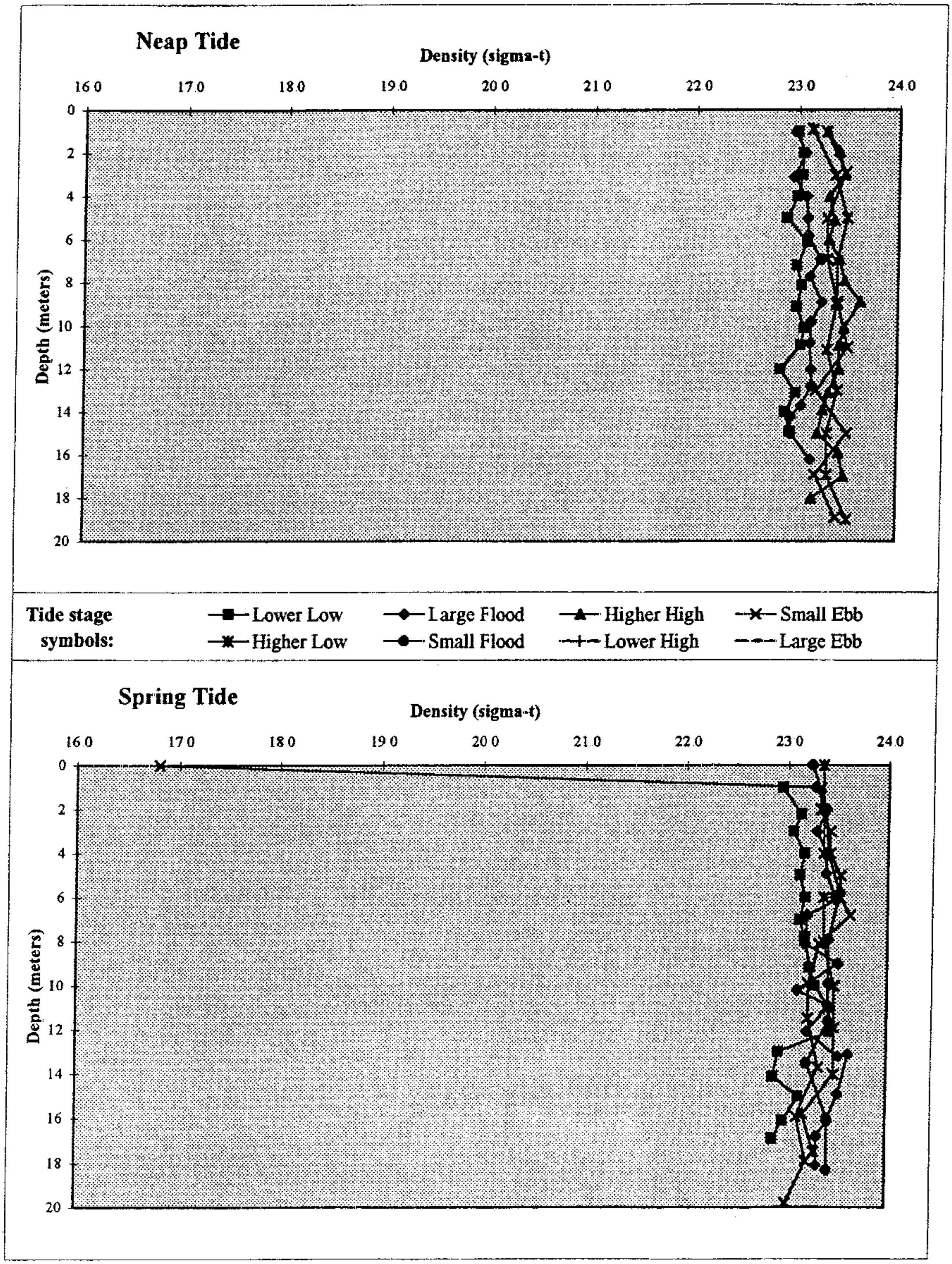


Table D-1. Reasonable worst-case data for Fort Ward.

Effluent flowrate (MGD)	Flowrate used for analyses at each MZ boundary: Acute	Chronic
	0.285	0.114

Current	Regional Data Set: Acute 10th%	Acute 90th%	Chronic Median	Site-specific Data Set: Acute 10th%	Acute 90th%	Chronic Median
velocity (m/sec)	0.051	0.51	0.33	0.051	0.41	0.29
horizontal angle (degrees)	90	90	90	90	90	90

Stratification depth (m)	Regional Data Set: Min (sigma-t)	Max (sigma-t)	Site-specific Data Set: Min (sigma-t)	Max (sigma-t)
0	22.80	20.36	23.18	23.03
1	22.87	20.36		
2	22.95	20.34		
3	23.13	20.62	23.45	23.36
4	23.14	21.24		
5	23.14	21.3	23.39	23.49
6	23.15	21.3		
7	23.17	21.31	23.36	23.38
8	23.18	21.53		
9	23.21	21.6	23.41	23.41
10	23.22	21.69		
11	23.23	21.71	23.40	23.45
12	23.23	21.74		
13	23.25	21.75	23.23	23.46
14	23.25			
15		21.79	23.52	23.44
16	23.26			
17		21.83	23.22	23.45
18				
18.28 (MLLW)				
19	23.27	21.88	23.42	23.54

Water quality (mg/l)	Regional Data Set	Site-specific Data Set
ammonia (total, as N)	No data available	Not detected at or above 0.010
copper (dissolved)	" " "	Not detected at or above 0.002
lead (dissolved)	" " "	" " " " " 0.005
silver (dissolved)	" " "	" " " " " 0.0025 (est.)
zinc (dissolved)	" " "	" " " " " 0.004

Appendix E

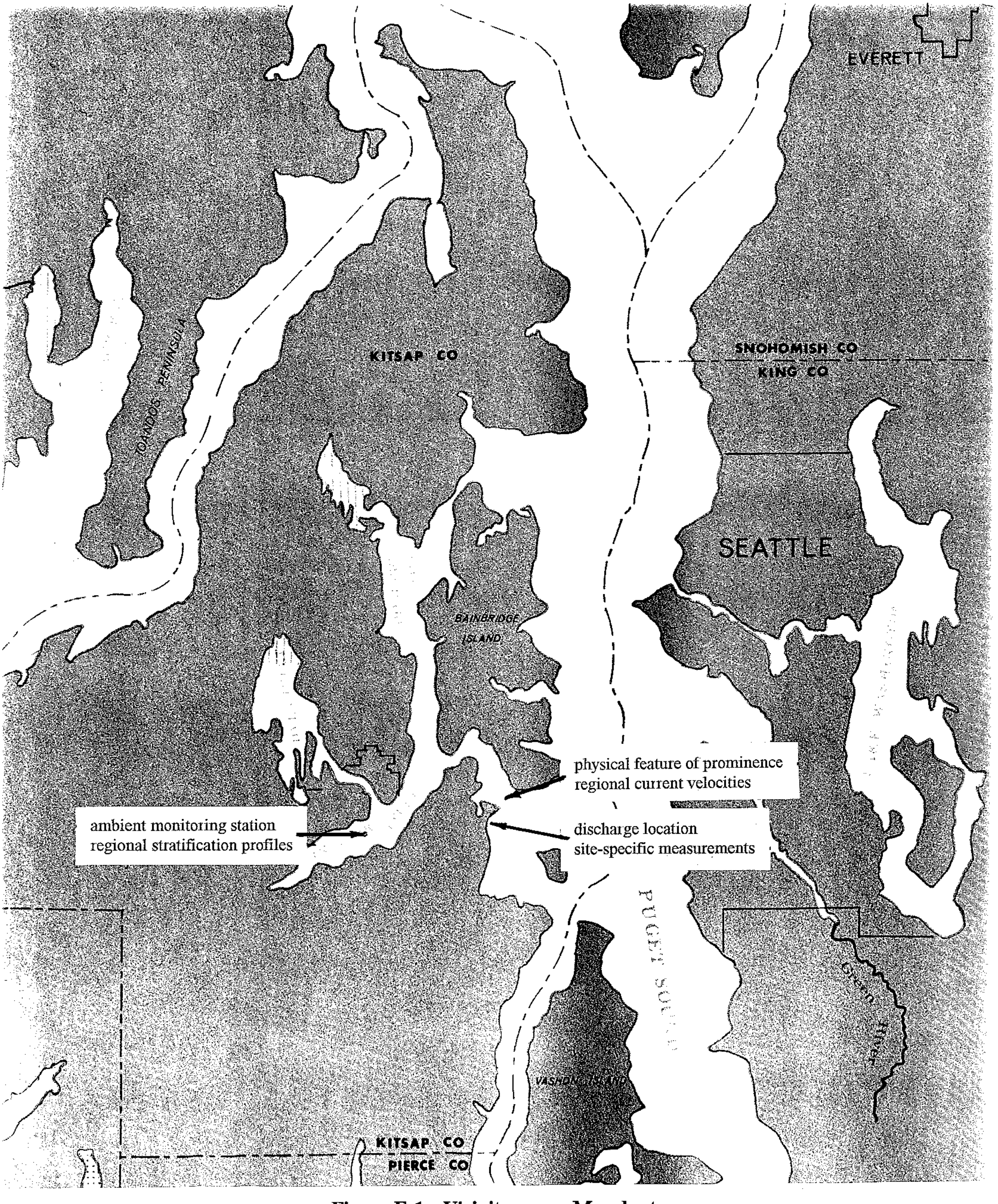
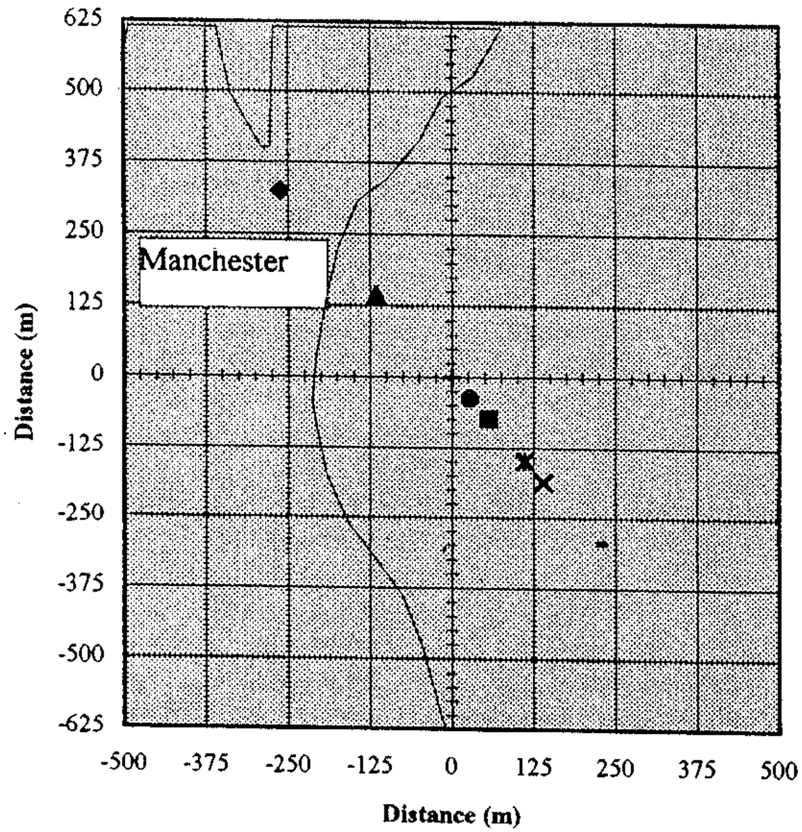


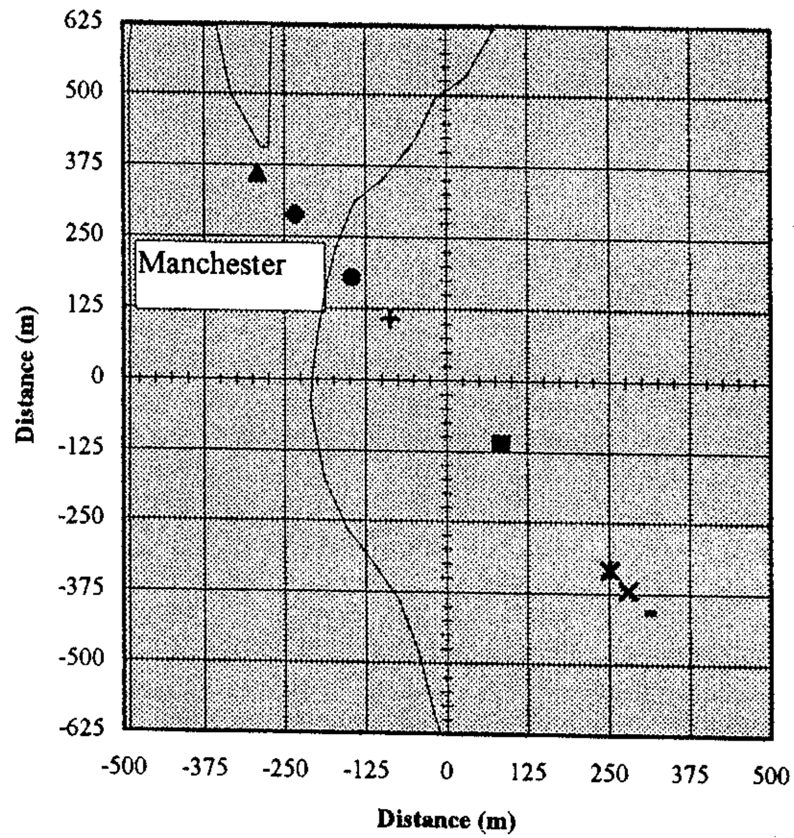
Figure E-1. Vicinity map - Manchester

Best-available regional current data for Manchester

Neap Tide



Spring Tide

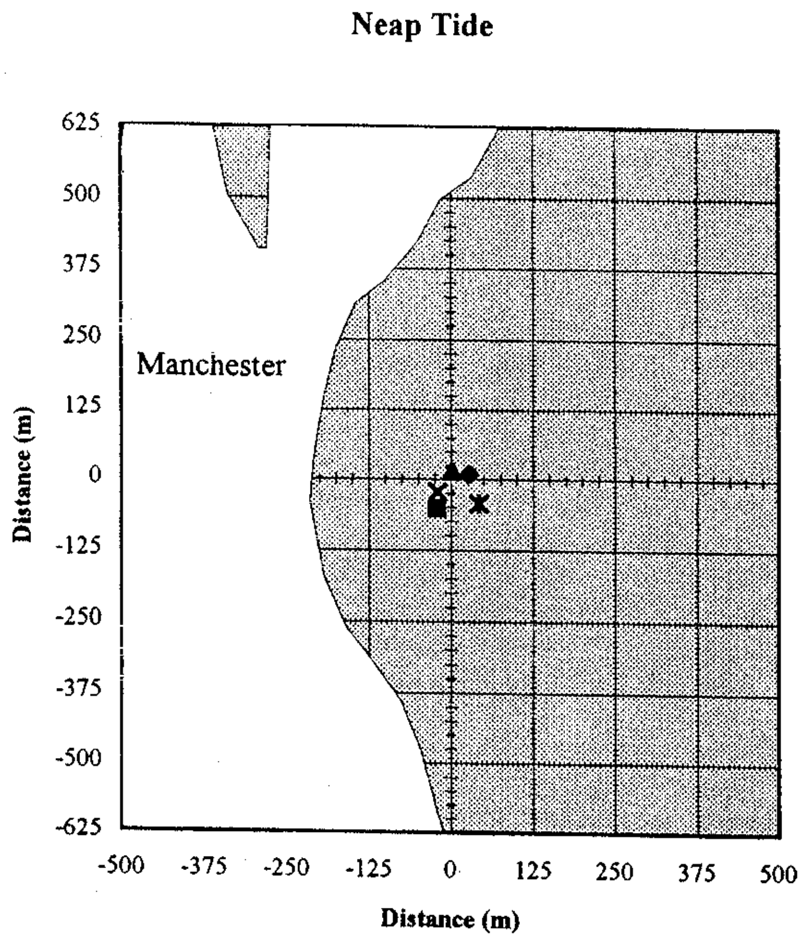


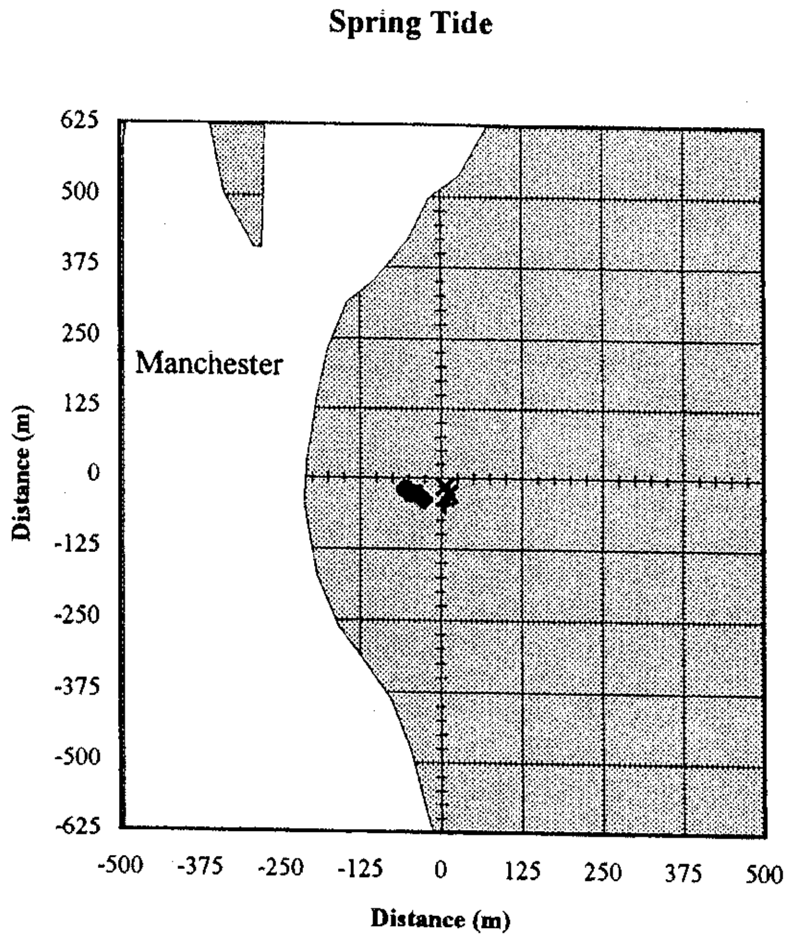
Discharge site is at X-Y coordinate (0,0). Orientation of Y-axis is true North-South.

Tide stage symbols: ■ Lower Low ◆ Large Flood ▲ Higher High ✕ Small Ebb ✖ Higher Low ● Small Flood + Lower High - Large Ebb

Location of tide stage symbols represents distance and direction that drogue travelled (or would have travelled) from discharge site in 15 minutes, at the velocity and direction of current at the discharge site.

Site-specific current data for Manchester





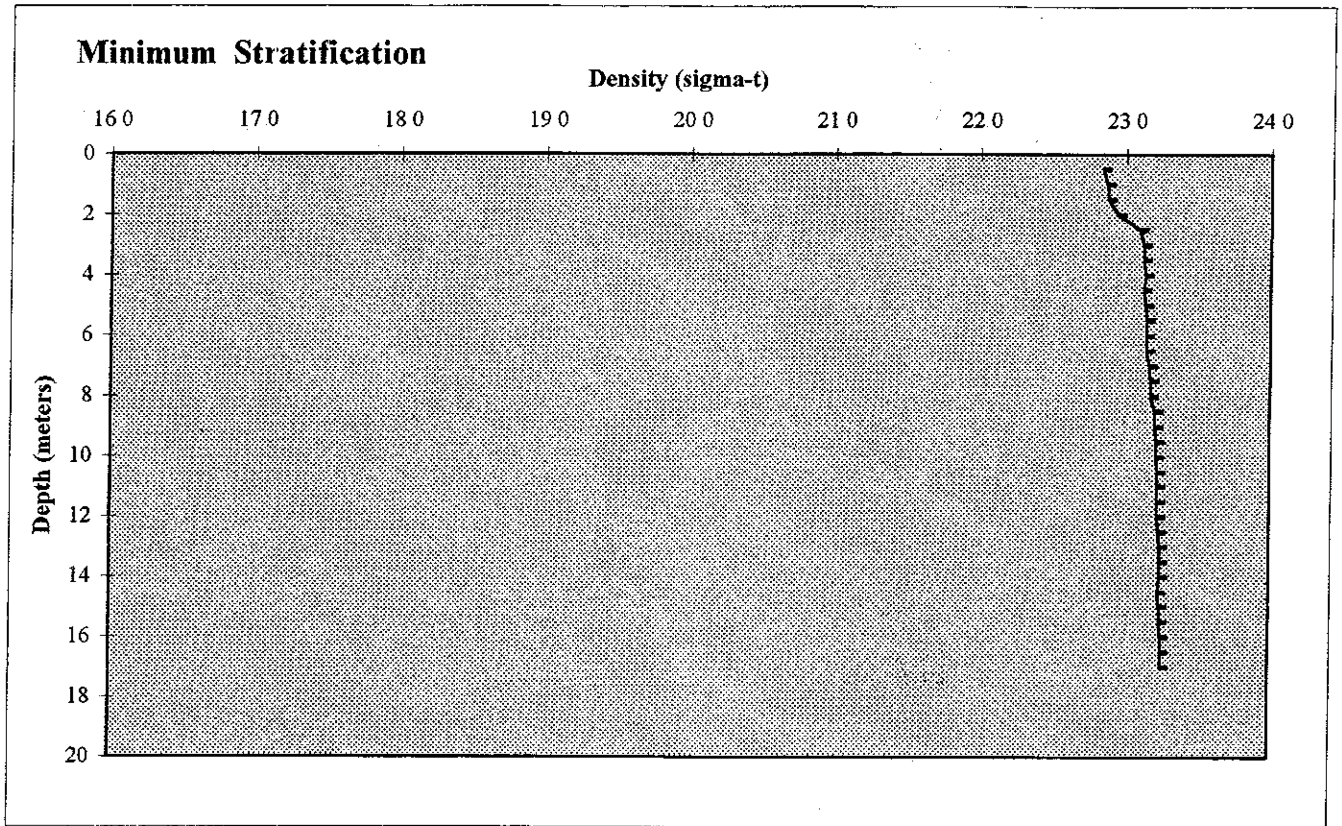
Discharge site is at X-Y coordinate (0,0). Orientation of Y-axis is true North-South.

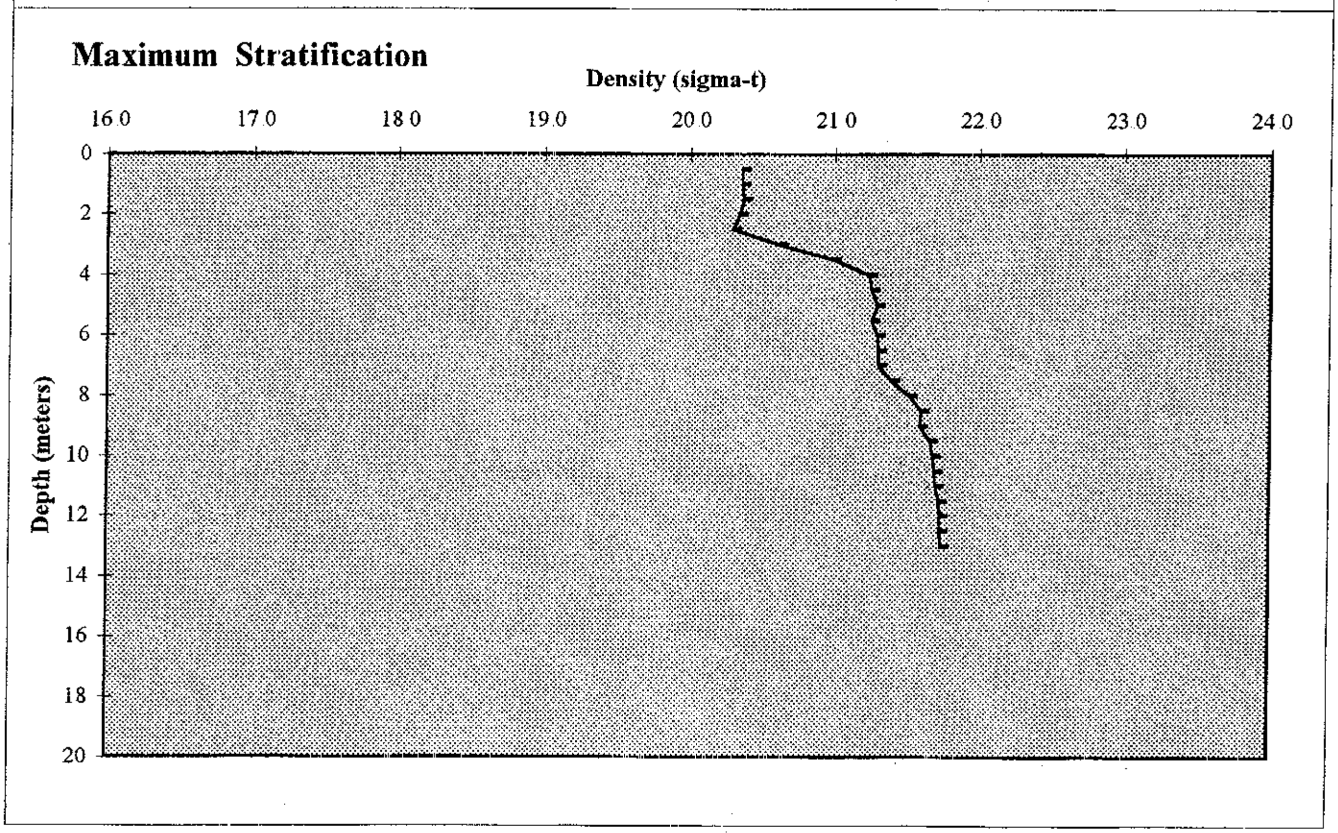
Tide stage symbols:

■ Lower Low ◆ Large Flood ▲ Higher High ✕ Small Ebb ✱ Higher Low ● Small Flood + Lower High – Large Ebb

Location of tide stage symbols represents distance and direction that drogue travelled (or would have travelled) from discharge site in 15 minutes, at the velocity and direction of current at the discharge site.

Regional stratification data for Manchester





Site-specific stratification data for Manchester

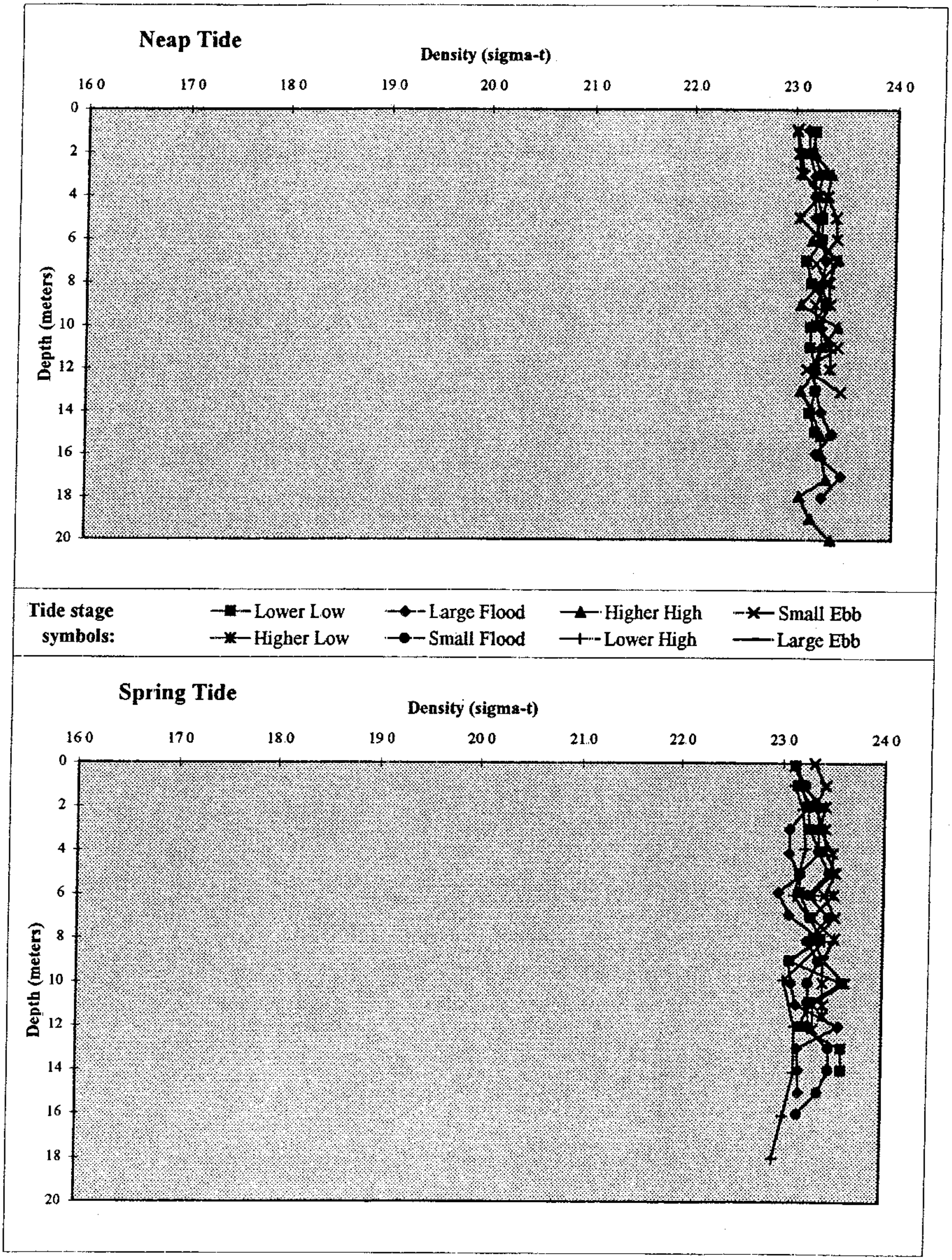


Table E-1. Reasonable worst-case data for Manchester.

Effluent flowrate (MGD)	Flowrate used for analyses at each MZ boundary: Acute	Chronic
	1.44*	0.45**

	Regional Data Set: Acute 10th%	Acute 90th%	Chronic Median	Site-specific Data Set: Acute 10th%	Acute 90th%	Chronic Median
Current						
velocity (m/sec)	0.051	0.51	0.33	0.02	0.061	0.051
horizontal angle (degrees)	90	90	90	90	90	90

Stratification depth (m)	Regional Min (sigma-t)	Regional Max (sigma-t)	Site-specific Min (sigma-t)	Site-specific Max (sigma-t)
0	22.80	20.36	23.31	23.18
1	22.87	20.36		
2	22.95	20.34	23.31	23.27
3	23.13	20.62		
4	23.14	21.24	23.45	23.36
5	23.14	21.30		
6	23.15	21.30	23.40	23.23
7	23.17	21.31		
8	23.18	21.53	23.40	23.41
9	23.21	21.60		
10	23.22	21.69	23.45	23.63
10.67 (MLLW)				
11	23.23	21.71		
12	23.23	21.74	23.36	23.63

Water quality (mg/L)	Regional Data Set	Site-specific Data Set
ammonia (total, as N)	No data available	Not detected at or above 0.010
copper (dissolved)	" " "	Not detected at or above 0.002
lead (dissolved)	" " "	" " " " " 0.005
silver (dissolved)	" " "	" " " " " 0.0025 (est.)
zinc (dissolved)	" " "	" " " " " 0.004

* - Intermittent flow.

** - Based on highest monthly average

Appendix F

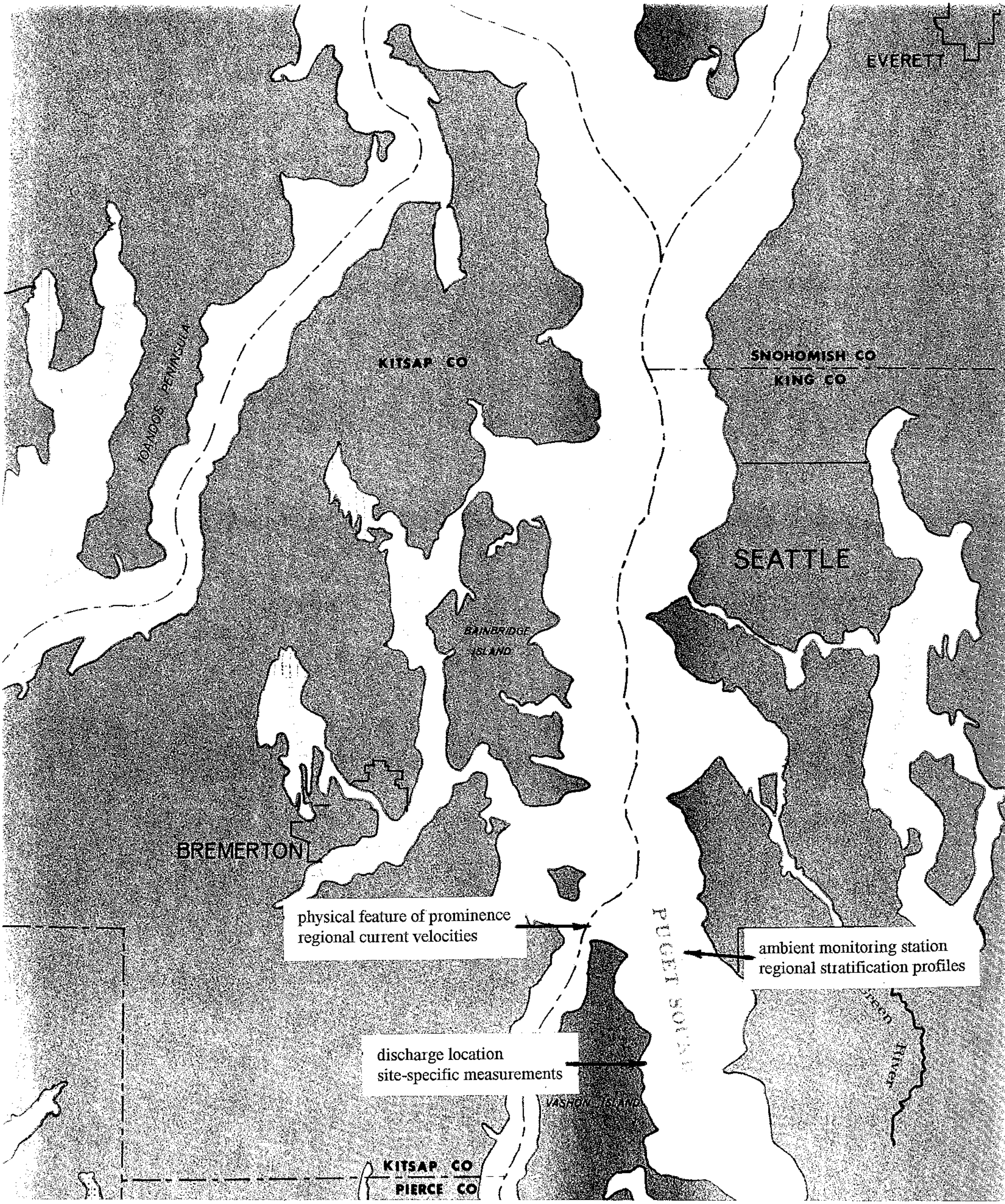
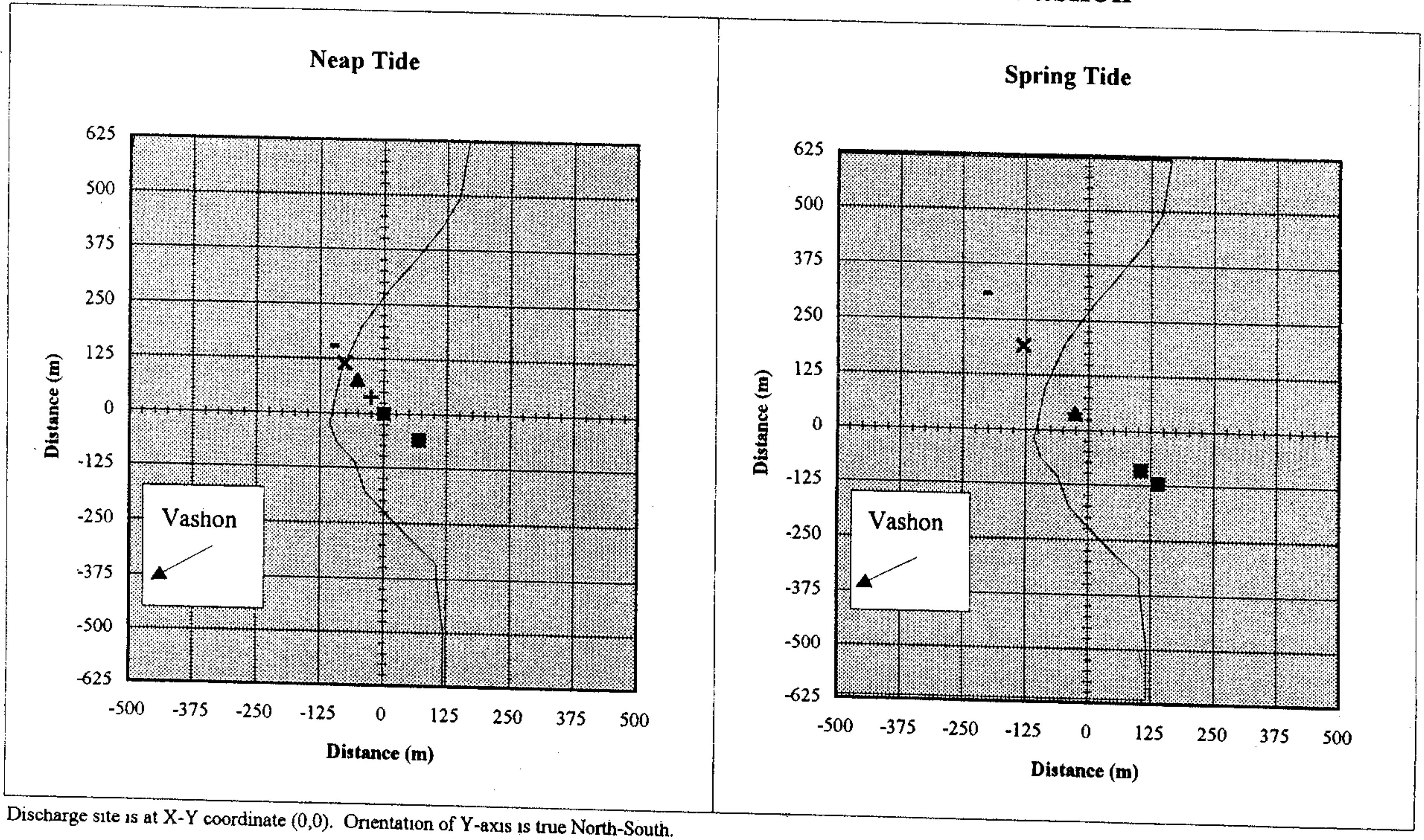


Figure F-1. Vicinity map - Vashon

Best-available regional current data for Vashon

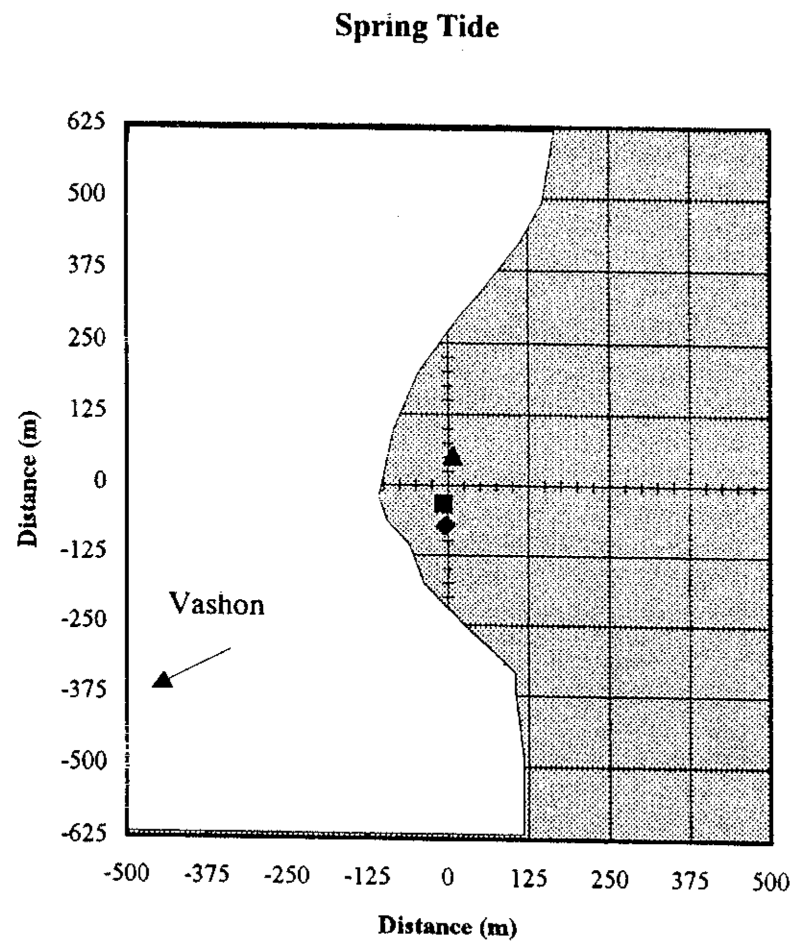


Discharge site is at X-Y coordinate (0,0). Orientation of Y-axis is true North-South.

Tide stage symbols: ■Lower Low ◆Large Flood ▲Higher High ✕Small Ebb ✱Higher Low ●Small Flood +Lower High -Large Ebb

Location of tide stage symbols represents distance and direction that drogue travelled (or would have travelled) from discharge site in 15 minutes, at the velocity and direction of current at the discharge site.

Site-specific current data for Vashon



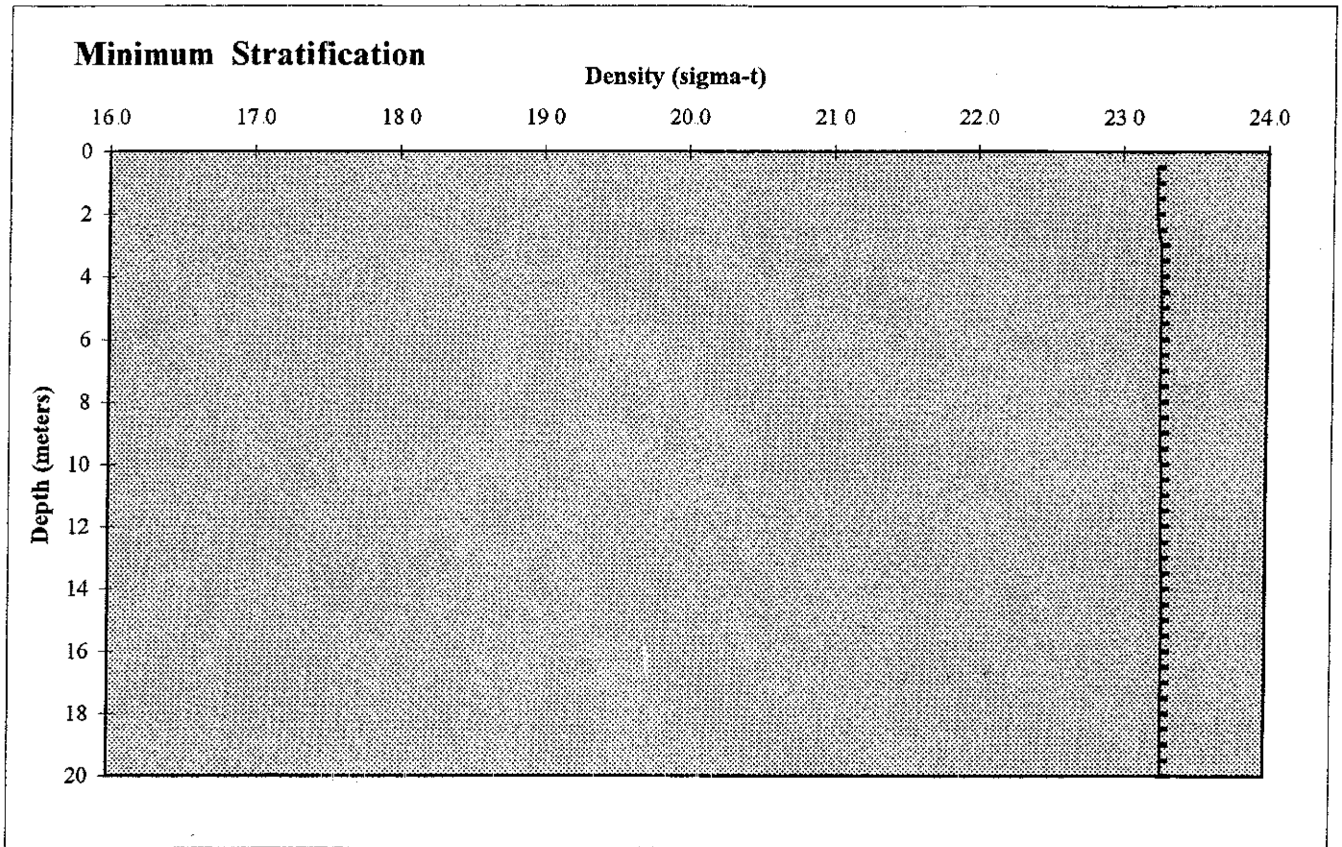
Discharge site is at X-Y coordinate (0,0). Orientation of Y-axis is true North-South.

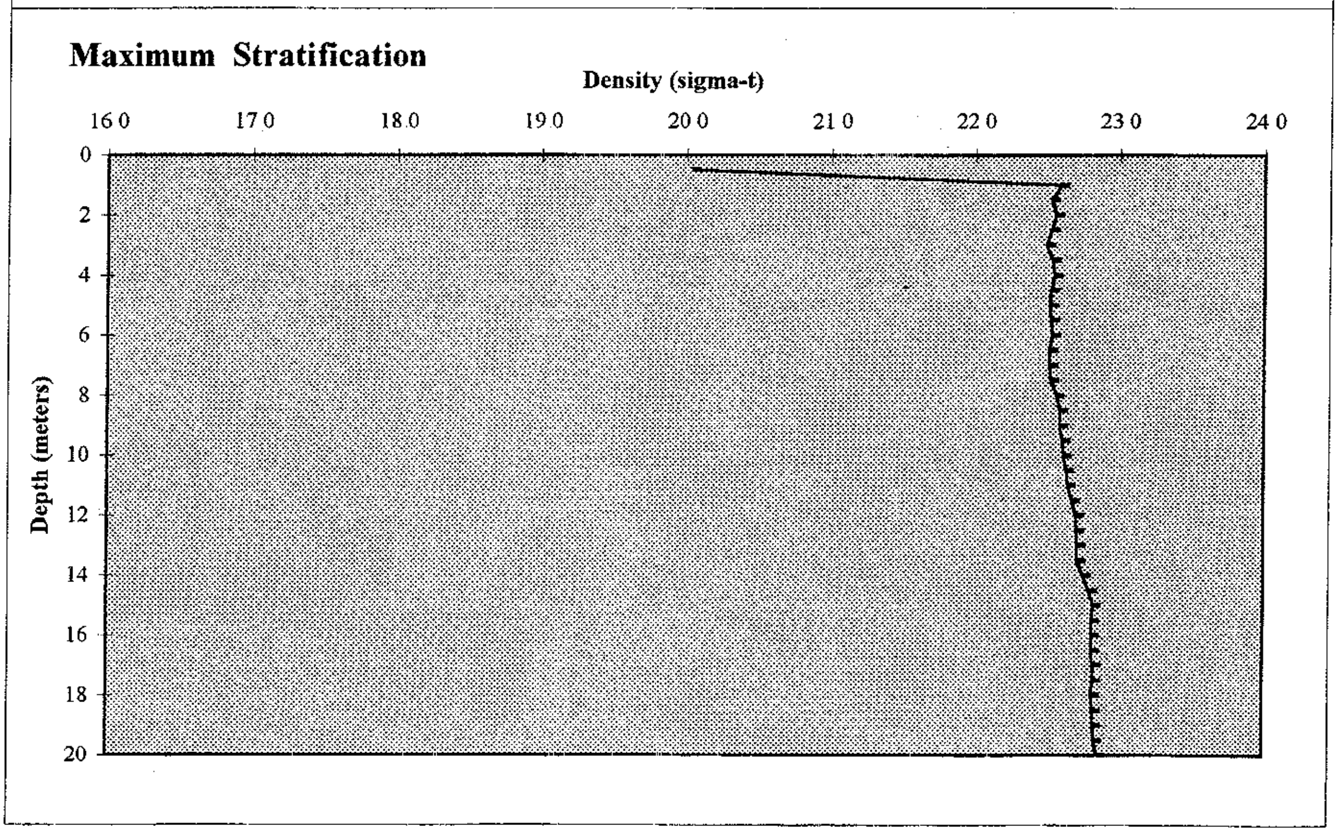
Tide stage symbols:

■Lower Low ◆Large Flood ▲Higher High ✕Small Ebb ✱Higher Low ●Small Flood +Lower High -Large Ebb

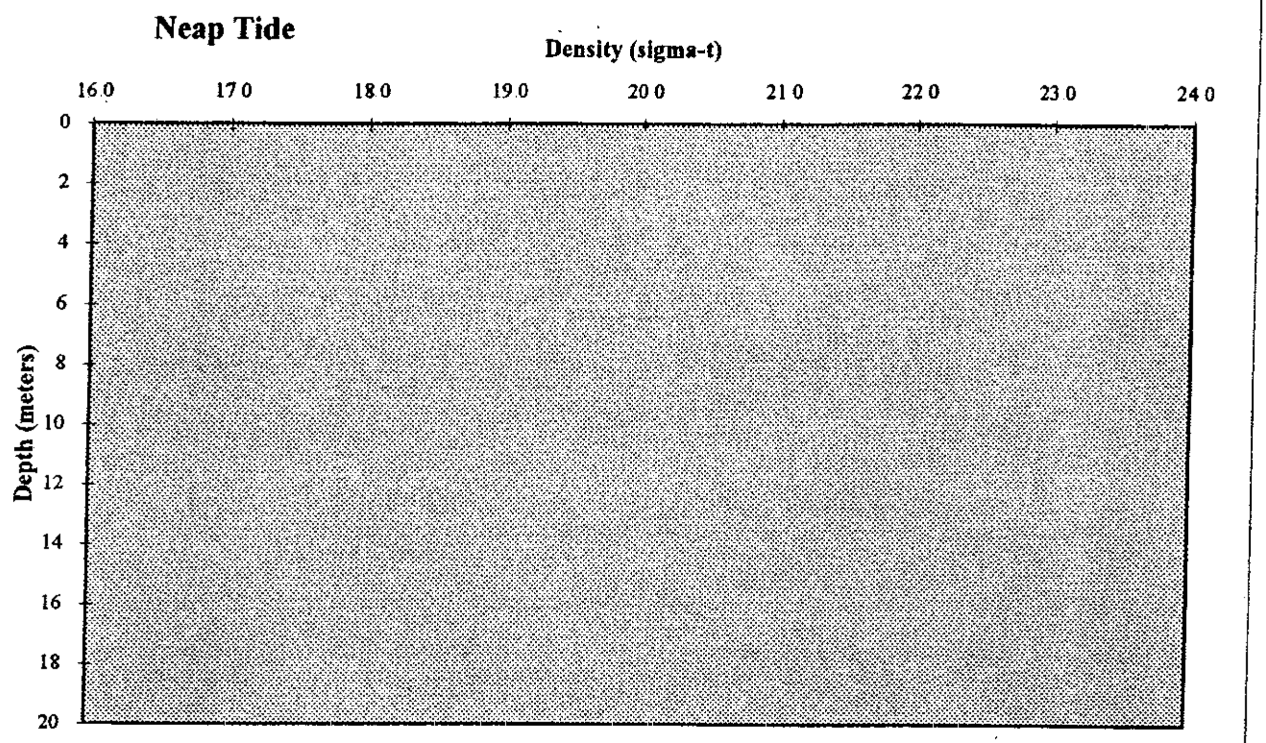
Location of tide stage symbols represents distance and direction that drogue travelled (or would have travelled) from discharge site in 15 minutes, at the velocity and direction of current at the discharge site.

Regional stratification data for Vashon





Site-specific stratification data for Vashon



Tide stage symbols: —■— Lower Low —◆— Large Flood —▲— Higher High —✕— Small Ebb —✱— Higher Low —●— Small Flood —+— Lower High —— Large Ebb

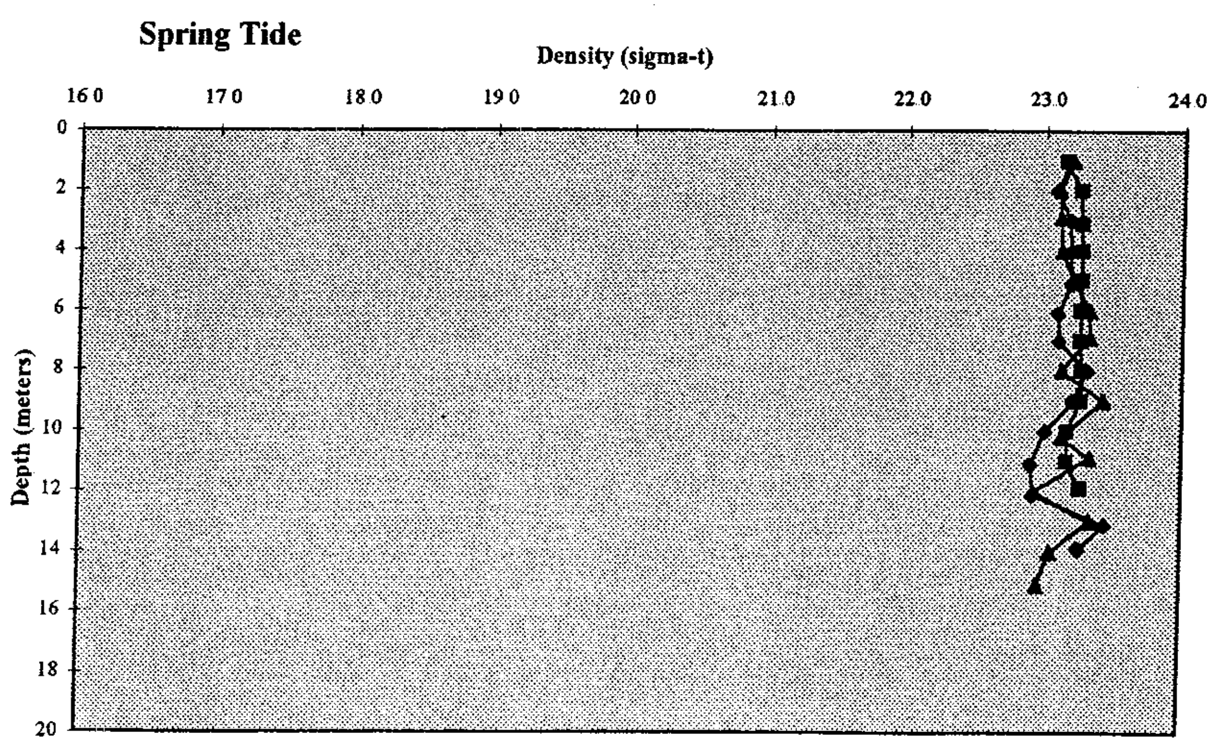


Table F-1. Reasonable worst-case data for Vashon.

Effluent flowrate (MGD)	Flowrate used for analyses at each MZ boundary: Acute	Chronic
	0.264	0.166

Current	Regional Data Set: Acute 10th%	Acute 90th%	Chronic Median	Site-specific Data Set: Acute 10th%	Acute 90th%	Chronic Median
velocity (m/sec)	0.051	0.26	0.128	0.056	0.056	0.056
horizontal angle (degrees)	45	45	90	97	97	97

Stratification depth (m)	Regional Min (sigma-t)	Regional Max (sigma-t)	Site-specific Min (sigma-t)	Site-specific Max (sigma-t)
0	23.23	20.00	23.10	23.23
1	23.24	22.59		
2	23.24	22.56	23.27	23.09
3	23.27	22.50		
4	23.27	22.55	23.29	23.13
5	23.27	22.52		
6	23.27	22.54	23.27	23.36
7	23.27	22.52		
8	23.27	22.57	23.29	23.46
9	23.27	22.59		
9.14 (MLLW)				
10	23.28	22.62	23.20	23.40

Water quality (mg/L)	Regional Data Set	Site-specific Data Set
ammonia (total, as N)	0.05	No data available
copper (dissolved)	No data available	Not detected at or above 0.002
lead (dissolved)	" " "	" " " " " 0.005
silver (dissolved)	" " "	" " " " " 0.0025 (est.)
zinc (dissolved)	" " "	" " " " " 0.004