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THE EFFECT OF THE EVERETT WTP ON WATER QUALITY IN THE SNOHOMISH RIVER ESTUARY

by

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ABSTRACT

The existing Everett WTP discharge zone provides minimal initial dilution of effluent due to inadequate depth and lack of a diffuser. Total chlorine residual at NPDES permit levels may exceed acute-toxicity criteria within the existing discharge zone. Tide-induced multiple-dosing of the receiving water by WTP effluent appears to be insignificant. Water quality criteria can be met under maximum permitted WTP flow and minimum receiving water flow if complete dilution occurs. The two-outfall, equal-flow discharge option proposed for WTP upgrade may provide the highest overall water quality. However, complete compliance with Ecology Dilution Zone Guidelines is unlikely. The WTP may be a source of lead for receiving water sediments. However, metals in sediments are within acceptable levels.

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INTRODUCTION

The Everett Wastewater Treatment Plant (WTP) is reaching its designed capacity. It is subject to frequent hydraulic and organic overloading. The plant has been ordered by the U.S. Environmental Protection Agency (EPA) to increase the removal of biochemical oxygen demand (BOD) and total suspended solids (TSS) from the effluent by Compliance Order No. 1085-08-47-309. The city of Everett continues to grow in population. Growth may accelerate if the proposed U.S. Naval Home Port becomes reality. Additionally, the distribution and sources of toxic substances in Port Gardner and the Snohomish River have become important public issues. In view of these concerns, the Northwest Regional Office (NWRO) of the Department of Ecology requested the Department's Water Quality Investigations Section to perform a Class II inspection and a receiving water study on the WTP. This report covers results of the receiving water study. The report will complement current regional planning and will evaluate several proposals for WTP upgrade. The Class II inspection was reported by Reif (1987).

The objectives for the receiving water survey were as follows:

1. Estimate dilution and downstream dispersion characteristics of the effluent in the receiving waters.

2. Evaluate the distribution of the estuarine saltwater wedge and to look for oxygen gradients or "sags" caused by the WTP.

3. Calculate total maximum daily loads (TMDLs) for regulated discharge parameters under critical low-flow conditions.

4. Review chlorination practices and effects during and after periods of flapper gate closure.

5. Evaluate the WTP as a source of metals by sampling sediments and water in the WTP treatment lagoons and in the receiving waters.

Background

The Everett WTP is a lagoon system located on Smith Island on the east bank of the Snohomish River main channel (Figure 1). The plant consists of the headworks, two 15-acre aeration ponds, two facultative stabilization ponds (totaling 180 acres), and a two-acre chlorine contact pond. The final effluent flows through a 48-inch line westward about 1,000 feet to the Snohomish River estuary.

The discharge zone is described in terms of the Dilution Zone Guidelines (Ecology, 1985) in Appendix A. Because the discharge point is very close to the bank and within a few feet of the surface at low tide, the present discharge deviates from the Dilution Zone Guidelines. Thus, the present configuration of the discharge will be called "discharge zone" in the rest of this report to avoid confusion with a "dilution zone," a legally mandated configuration.

The end of the outfall pipe is equipped with a flapper gate. The gate is designed to close just before high water (Jones and Stokes, 1986). Singleton, et al. (1982) reported that the gate opened when the tide height was 10.3 feet. Computer analysis (Jones and Stokes, 1986) suggested that the incoming tide could carry a mass of mixed effluent and receiving water upstream for up to a mile from the outfall. But because the flapper gate is designed to minimize discharge during peak tidal inflows, effluent movement upstream is supposed to be limited to less than 1,000 feet.

However, the flapper gate does not presently perform as designed. According to Carl Baird, Everett WTP senior wastewater operator, a recent inspection has revealed that the end of the pipe has subsided, preventing its complete closure.

At present, planning is underway to upgrade treatment and expand capacity. The WTP upgrade will initially include installation of a recirculation system for the facultative ponds (Brown and Caldwell, 1986). Later a trickling filter/solids-contact plant and clarifier will be added.

Two effluent discharge schemes are currently being considered (Brown and Caldwell, 1986): (1) discharge of all effluent at the present

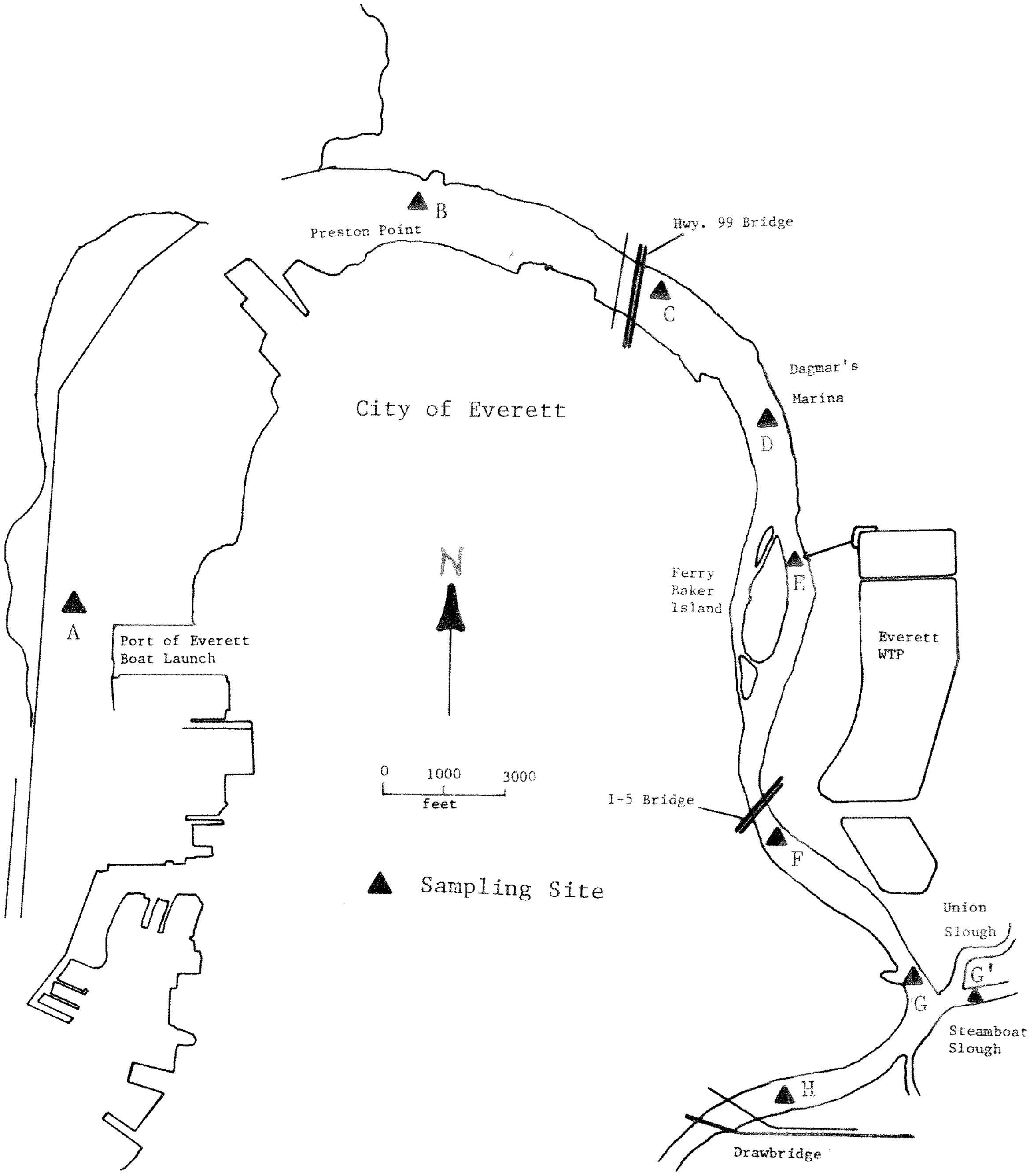

Figure 1. Snohomish River estuary showing Everett WTP and receiving water sampling sites.

outfall site, or (2) discharge through two outfalls; the additional outfall to be placed up-river near the present WTP headworks. The maximum summertime flow is predicted to be 18.8 MGD or 29.1 cubic feet per second (cfs). Under the two-outfall scheme, two effluent flow regimes are being considered. In the first, half of the maximum summertime flow (9.4 MGD or 14.5 cfs) will be sent through each outfall. In the second, 85 percent (15.9 MGD or 24.6 cfs) would be sent through the up-river outfall, and the remaining 15 percent (2.9 MGD or 4.5 cfs) through the northern existing discharge. All discharged effluent would meet secondary treatment goals of 30 mg/L each of BOD and TSS.

Estuary Description

The Snohomish River and tributaries drain about 1,780 square miles. The average annual discharge is about 11,000 cfs. The average 7-day low flow for the period from 1964-1979 for the Snohomish River at Monroe is about 1,900 cfs (Williams and Pearson, 1985). The Snohomish River contributes at least 30 percent of the freshwater flowing into Whidbey Basin and 20 percent of the total contribution to Puget Sound. The influence of tide extends nearly 18 miles upstream from Preston Point (Jones and Stokes, 1986).

The lower Snohomish River has three major channels (Main Channel, Ebey Slough, and Steamboat Slough) and one minor channel (Union Slough). According to Jones and Stokes (1986), Orlob, et al. (1949) estimated the relative proportions of flow through the channels to be: Steamboat Slough - 61 percent; Main Channel - 32 percent; and Ebey Slough - 7 percent. These estimates were based on cross-sectional areas of the channels. More recently Tang (1981) used a computer model to determine a freshwater budget for the channels based on average seven-day, ten-year low flows. Proportions based on his analysis were as follows: Main Channel - 70.3 percent; Ebey Slough - 19.2 percent; Steamboat Slough - 7.3 percent; and Union Slough - 3.2 percent. The difference between the Orlob and Tang estimates may be due to changes in channels over the years.

The Snohomish River is classified Class A in the Washington State Water Quality Standards (Chapter 173-201 WAC) from the confluence of the Skykomish and Snoqualmie Rivers (river mile [r.m.] 20) to Port Gardner. The water quality criteria for Class A waters are given in Table 1 for both fresh- and saltwaters. A special condition for fecal coliform has been set in this estuary (geometric mean = 200 FC/100 mL; less than 10 percent of samples to exceed 400 FC/100 mL). The salinity standard permits interpolation of fecal coliform and oxygen standards in estuaries.

The Snohomish River estuary can be oceanographically classified as stratified (Mills, et al., 1982). In this type of estuary, freshwater moving seaward rides over the top of a salt wedge formed by marine water brought into the estuary by tidal action. These movements

Table 1. Water quality parameters and associated standards (Ecology, 1982) for the Snohomish River estuary.

Parameter	Water Quality Standard (Class A)
Fecal Coliform Bacteria (FC/100 mL)	Freshwater: Special condition from river mouth to river mile 8.1 (at south end of Ebey Island): not to exceed a geometric mean of 200 FC per 100 mL, with not more than 10 percent of samples to exceed 400 FC per 100 mL.
Temperature ($^{\circ}$C)	Not to exceed 18.0°C (freshwater) or 16°C (seawater) due to human activities. When natural conditions exceed 18.0°C (freshwater) or 16.0°C (seawater), no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3°C.
Salinity (o/oo)	In brackish waters of estuaries, where fresh- and marine water quality criteria differ within the same classification, the criteria shall be interpolated on the basis of salinity; except that the marine water quality criteria shall apply for dissolved oxygen when the salinity is one part per thousand or greater and for fecal coliform organisms when the salinity is ten parts per thousand or greater.
Dissolved Oxygen (mg/L)	Freshwater: shall exceed 8.0 mg/L. Seawater: shall exceed 6.0 mg/L; when natural conditions (e.g., upwelling) depress D.O. near or below 6.0 mg/L, natural D.O. levels can be degraded by up to 0.2 mg/L by man-caused activities.
Nutrients (mg/L) NO_3-N; NO_2-N; NH_3-N; O-PO_4-P; T-PO_4-P	No current state standard.
pH (S.U.)	Shall be within the range of 6.5 to 8.5 (freshwater) or 7.0 to 8.5 (seawater) with a range of less than 0.5 unit.
Total Suspended Solids or Total Non-filterable Residue (mg/L)	No numerical standard. Sufficient light is essential to aquatic plant growth. Excessive suspended material may stress plants and animals by light reduction or smothering.
Turbidity (NTU)	Not to exceed 5 NTU over background if background is 50 NTU or less, or have more than a 10 percent increase in turbidity when background turbidity is more than 50 NTU. Sufficient light is essential to aquatic plant growth. Excessive suspended material may stress plants and animals by light reduction or smothering.

induce mixing along the boundary between the fresh- and saltwater layers. According to Pritchard (1969), the flow of marine water in the bottom layer decreases from the mouth to the head of the estuary since saltwater is being transferred upward into the surface layer through entrainment and mixing. As a result, the surface layer increases in flow and salt content from the head to the mouth of the estuary. Thus, removal efficiency of pollutants from any point in an estuary through flushing and tidal exchange increases as the distance between the point and the mouth of the estuary decreases.

METHODS

All survey tasks are described below. The timing of each task in relation to tide stage is shown on Figure 2.

Discharge Zone Studies

Discharge-zone studies were conducted during low-flow periods and when tidal range was minimal. These factors are likely to produce worst-case conditions for dispersion of effluent. Discharge-zone studies were composed of two parts: (1) physical and chemical measurements, and (2) dye injection. A sampling grid was set up within the discharge zone. The grid was designed to bracket the dimensions of the "initial dilution zone" governed by criteria given in Ecology (1985). The grid was formed by a 300-foot line anchored at the flapper gate such that the line could float freely with the direction of flow. Marks were placed at 50, 100, 200, and 300 feet. The marks were used to fix horizontal points accurately. The grid also included a site about 300 feet up-flow from the discharge.

Physical and Chemical Measurements

On August 12, vertical profiles of temperature, salinity, dissolved oxygen, and pH were taken at each site on the sampling grid using a Hydrolab Surveyor II. Water samples were taken at the surface and bottom for laboratory analysis of nitrate+nitrite, ammonia, total phosphorus, total suspended solids, turbidity, and fecal coliform. Fecal coliform samples were taken at the surface only using sterilized bottles treated with sodium thiosulphate to remove chlorine. The samples were iced and sent to Ecology's Manchester Environmental Laboratory. Methods of analysis conformed to APHA (1985) and EPA (1979).

Dye Injection Studies

On August 13, Rhodamine wt fluorescent dye was used to evaluate mixing within the discharge zone. Dye was injected with a peristaltic pump at a constant rate into the standpipe at the end of the WTP chlorine contact ditch. Singleton, *et al*. (1982) estimated the travel time from the head of the line to a manhole

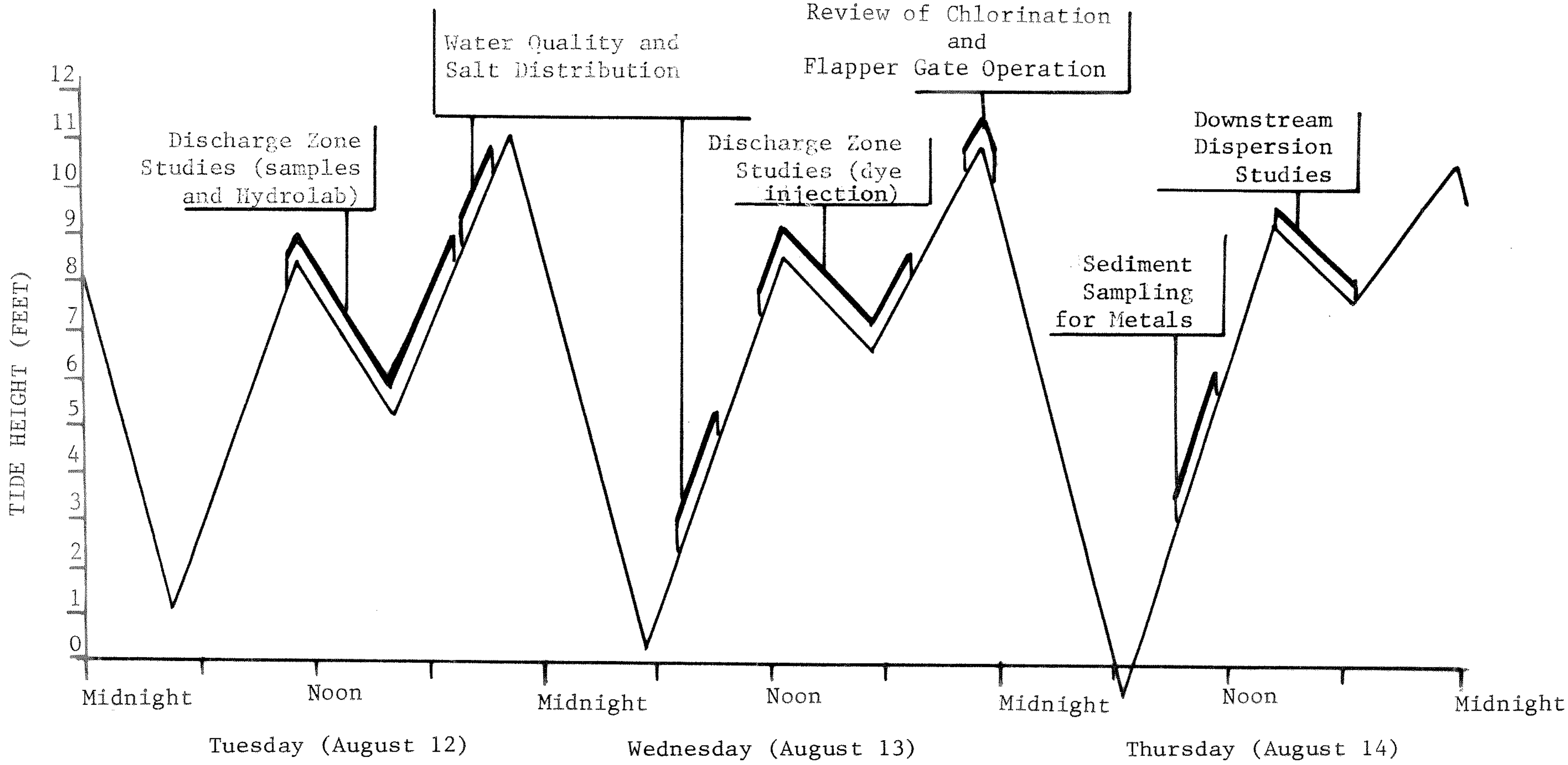

Figure 2. Timing of tasks conducted during a receiving water study of the Everett WTP on August 12-14 showing the relation to tide stage (peaks are Port Gardner corrections to Seattle predictions. In-between heights are represented by straight lines for simplicity and are slightly inaccurate.)

above the Snohomish River to be six minutes--adequate time for complete mixing of dye and effluent. At the manhole, replicate samples were taken for measurement of dye concentration. The discharge flow rate was estimated as follows:

$$Q = q\ c/C' \times f \qquad (1)$$

where Q = flow rate of the discharge (cfs)
q = flow rate of dye solution (cfs)
c = concentration of dye solution
C' = concentration of dye at the manhole
f = (1/1699)cfs /L/min (conversion factor)

Dye measurements (Turner Model 10 fluorometer) were taken in the discharge zone using the sampling grid described earlier. Measurements were made during a tide reversal so that dilution characteristics could be evaluated.

Downstream Dispersion

On August 14, two dye drops were made on the outgoing tide. First, 500 mL of Rhodamine wt dye were dropped mid-channel into the river near the site of the proposed outfall. Fluorometer readings were taken 7,600 feet downstream at the north end of Dagmar's Marina (Figure 3). The second drop of 300 mL was made at the existing outfall, and the fluorometer placed 6,000 feet downstream at the State Highway 99 bridge. The data were used to calculate time of travel and downstream dispersion according to Furfari (1979). The procedure is in Appendix B.

Distribution of Salt and Oxygen

Special sampling was done to detect discharge-related effects of extended darkness (night) and extreme tide change on water quality and the distribution of salt in the estuary. Water quality data were collected at nine mid-channel sites between r.m. 1.1 (Port of Everett boat launch) and r.m. 6.8 (Figure 1). At each site, vertical profiles of temperature, salinity, dissolved oxygen, and pH were made with the Hydrolab Surveyor II. Water samples for analysis of dissolved nutrients, turbidity, and total suspended solids were taken just below the surface and near the bottom. Fecal coliform samples were taken at the surface only. This work was done during early evening of August 13 on the incoming higher high tide. Hydrolab readings only were taken the following morning during lower low slack water.

Metals Distribution

Water samples were taken from the plant influent and effluent (as part of the Class II inspection) and from surface receiving waters 300 feet above the discharge point. Sediment samples were collected from two

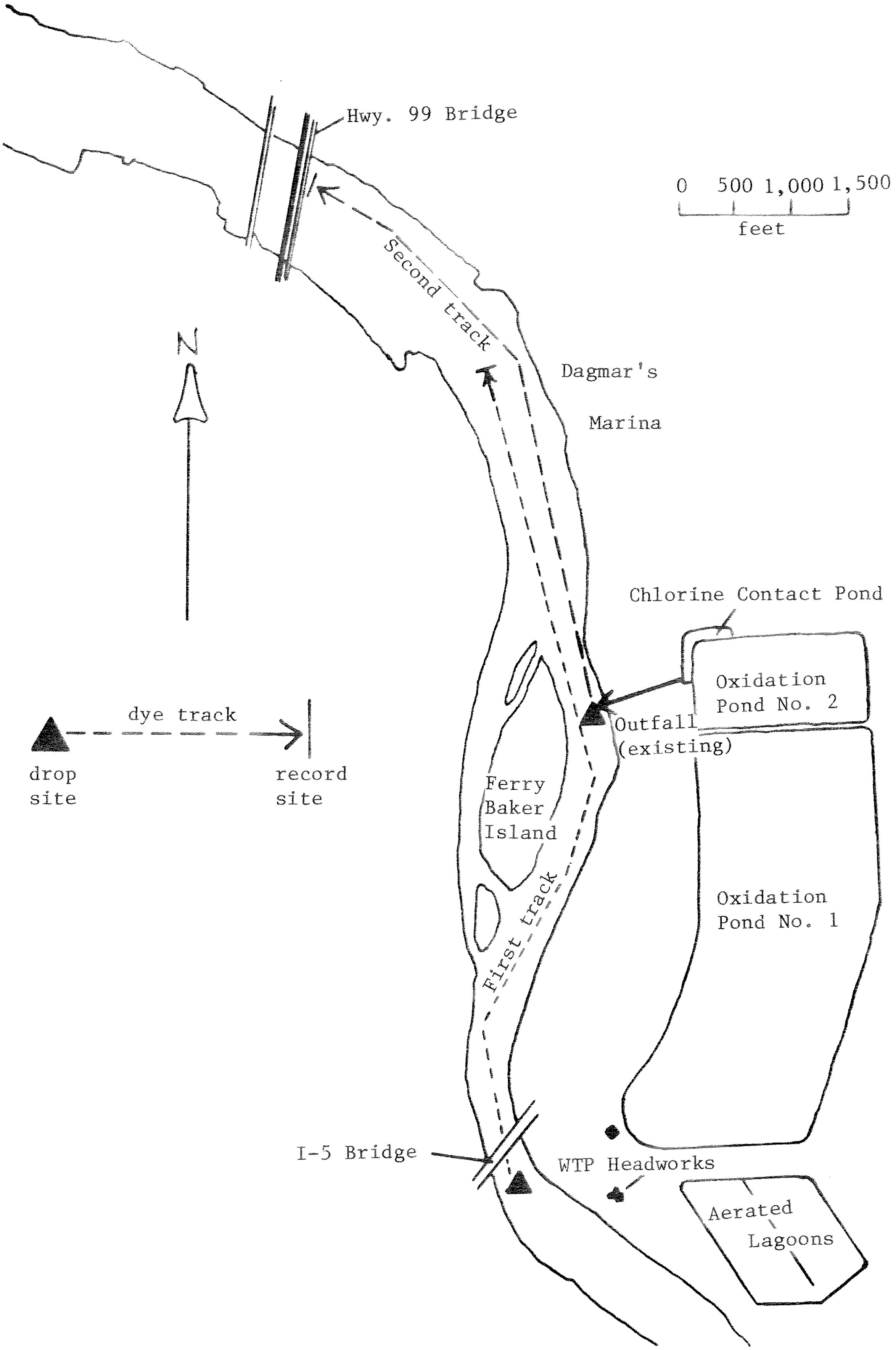

Figure 3. Sites used to drop and record dye during a study of downstream dispersion in the Snohomish River estuary on August 14, 1986.

sites in the Snohomish River and one in the WTP chlorine contact pond on August 14 (Figure 1). The river "control" site was located up-river of the junction of the Snohomish River and Ebey Slough (r.m. 11.2). The second site was located about 200 yards south of the present outfall near the south end of Dagmar's Marina. The sampling method was adapted from procedures described in Tetra Tech (1986a), using a stainless steel Petite Ponar grab sampler ($0.02m^2$). Several grabs were combined, mixed in a stainless steel pitcher, and subsampled.

Metals analyses (cadmium, chromium, copper, lead, mercury, nickel, silver, and zinc) in both water and sediment were all performed by the Manchester laboratory using atomic-absorption spectrophotometry. Grain-size analysis on sediment samples was performed by Parametrix, Inc.

RESULTS AND DISCUSSION

Discharge Zone Studies

Physical and Chemical Measurements

Table 2 summarizes Hydrolab measurements within the discharge zone for a different time, state of tide, and current direction. At the times of measurement, the discharge was injected at depth into the salt layer.

Temperature generally decreased with depth at all sites. Surface waters tended to gain temperature throughout the day and consistently exceeded the water quality standard for both fresh- and saltwater (Table 1); however, the cause does not appear to be human activities. Waters deeper than six feet generally complied and tended to be stable. Temperature data showed little evidence of the presence of a discharge.

Salinity showed a vertical gradient similar to temperature. The maximum rate of change with depth appeared to be about six feet despite changing tide and current. There was a general decline in surface salinity at lower tides. Salinity showed only limited evidence of a discharge. The vertical gradient appeared to be generally uniform. However, slightly depressed salinity occurred at mid-depth 50 to 100 feet down-flow from the discharge point during higher low outgoing and slack tides (Tables 2C and 2D, respectively). This is evidence of an effluent plume.

Salinity and temperature data showed a salt wedge in the vicinity of the discharge zone. A wide mixed boundary between the fresh and salt layers was located at about six feet deep.

Table 2. Vertical-profile measurements in the discharge zone of the Everett WTP under various conditions of tide and current on August 12, 1986. (Values are means of 10 to 20 observations).

A. TIDE: LOWER HIGH CURRENT: SLACK TIME: 1039 - 1115

DEPTH (FT)	300 FEET UP-FLOW	OUTFALL	200 FEET DOWN-FLOW
PARAMETER: TEMPERATURE (^{o}C)			
0	18.4	17.2	18.1
3	16.7	17.0	16.8
6	16.3	16.3	*
9	16.0	15.8	15.8
12	*	*	*
15	15.6	15.3	15.6
PARAMETER: SALINITY (PPT)			
0	9.8	13.0	11.8
3	17.7	16.6	17.0
6	19.0	18.7	*
9	20.3	20.8	21.1
12	*	*	*
15	21.3	22.8	21.5
PARAMETER: DISSOLVED OXYGEN (PPM)			
0	9.0	8.5	8.6
3	8.5	8.5	8.5
6	8.5	8.4	*
9	8.4	8.3	8.4
12	*	*	*
15	8.4	8.4	8.4
PARAMETER: pH (UNITS)			
0	7.4	7.6	7.4
3	7.4	7.6	7.5
6	7.4	7.5	*
9	7.5	7.5	7.5
12	*	*	*
15	7.5	7.5	7.5

*Measurements not taken at this depth.

Table 2 - continued.

B. TIDE: LOWER HIGH CURRENT: OUTGOING TIME: 1152 - 1435

DEPTH (FT)	300 FEET UP-FLOW	OUTFALL	50 FEET DOWN-FLOW	100 FEET DOWN-FLOW	300 FEET DOWN-FLOW
PARAMETER: TEMPERATURE (^{o}C)					
0	19.9	20.0	19.9	19.9	19.9
3	19.9	19.8	19.9	19.9	19.7
6	18.0	17.2	18.9	19.4	17.2
9	15.0	15.0	17.0	16.9	15.3
12	*	*	*	*	*
15	14.9	14.9	15.0	15.0	**
PARAMETER: SALINITY (PPT)					
0	0.6	1.3	0.9	1.1	1.3
3	2.2	3.2	0.9	1.1	2.3
6	12.5	17.5	9.3	4.2	15.2
9	24.4	24.7	16.0	17.7	23.2
12	*	*	*	*	*
15	24.7	25.0	24.8	24.7	**
PARAMETER: DISSOLVED OXYGEN (PPM)					
0	8.8	9.0	9.1	8.8	9.1
3	8.5	8.7	8.9	8.7	8.7
6	7.9	7.9	8.2	8.3	7.7
9	7.8	7.6	7.9	7.8	7.2
12	*	*	*	*	*
15	7.7	7.9	7.5	7.7	**
PARAMETER: pH (UNITS)					
0	7.2	7.2	7.3	7.3	7.2
3	7.1	7.6	7.3	7.2	7.2
6	7.2	7.6	7.5	7.5	7.3
9	7.4	7.4	7.5	7.4	7.4
12	*	*	*	*	*
15	7.5	7.5	7.4	7.5	**

*Measurements not taken at this depth.
**Insufficient depth for sampling.

Table 2 - continued.

C. TIDE: HIGHER LOW CURRENT: OUTGOING TIME: 1505 - 1645

DEPTH (FT)	300 FEET UP-FLOW	OUTFALL	50 FEET DOWN-FLOW	100 FEET DOWN-FLOW	300 FEET DOWN-FLOW
PARAMETER: TEMPERATURE (^{o}C)					
0	19.6	19.6	19.7	19.7	19.8
3	19.3	19.5	19.6	19.6	19.4
6	18.3	18.6	18.4	18.2	17.9
9	15.8	15.3	15.3	15.4	*
12	*	*	*	*	14.9
15	15.2	14.9	14.8	14.8	**
PARAMETER: SALINITY (PPT)					
0	4.6	3.8	3.2	3.0	2.4
3	6.1	4.5	3.9	3.7	5.2
6	11.6	9.5	11.4	11.4	12.6
9	21.4	23.0	23.0	23.0	*
12	*	*	*	*	24.9
15	23.2	24.4	24.7	24.6	**
PARAMETER: DISSOLVED OXYGEN (PPM)					
0	8.6	8.5	8.8	8.8	8.6
3	8.5	8.5	8.5	8.5	8.5
6	8.3	8.4	8.3	8.2	8.1
9	8.1	7.9	7.9	7.9	*
12	*	*	*	*	7.8
15	8.1	8.0	8.0	7.9	**
PARAMETER: pH (UNITS)					
0	7.2	7.2	7.2	7.2	7.2
3	7.2	7.2	7.2	7.2	7.3
6	7.3	7.7	7.7	7.6	7.5
9	7.4	7.5	7.5	7.5	*
12	*	*	*	*	*
15	7.5	7.5	7.5	7.2	**

*Measurements not taken at this depth.
**Insufficient depth for sampling.

Table 2 - continued.

D. TIDE: HIGHER LOW CURRENT: SLACK TIME: 1735 - 1815

DEPTH (FT)	300 FEET UPFLOW	OUTFALL
PARAMETER: TEMPERATURE (^{o}C)		
0	20.4	20.4
3	19.8	18.9
6	16.9	19.2
9	15.3	16.2
12	*	*
15	15.2	15.4
PARAMETER: SALINITY (PPT)		
0	1.5	0.7
3	4.0	9.9
6	18.0	11.8
9	23.8	17.3
12	*	*
15	24.0	23.2
PARAMETER: DISSOLVED OXYGEN (PPM)		
0	8.9	9.4
3	8.5	8.3
6	7.7	8.0
9	7.9	7.8
12	*	*
15	7.9	7.6
PARAMETER: pH (UNITS)		
0	7.4	7.5
3	7.3	7.3
6	7.4	7.7
9	7.5	7.5
12	*	*
15	7.5	7.5

*Measurements not taken at this depth.

Table 2 - continued.

E. TIDE: HIGHER LOW CURRENT: INCOMING TIME: 1803 - 1913

DEPTH (FT)	300 FEET UPFLOW	OUTFALL	100 FEET DOWNFLOW	300 FEET DOWNFLOW
PARAMETER: TEMPERATURE (^{o}C)				
0	20.4	20.1	20.2	20.1
3	19.8	16.5	18.8	19.0
6	16.9	15.2	15.2	15.7
9	15.3	15.0	*	15.2
12	*	*	**	**
15	15.2	**	**	**
PARAMETER: SALINITY (PPT)				
0	1.5	3.4	2.9	2.6
3	4.0	8.5	9.6	14.4
6	18.0	24.8	24.4	23.1
9	23.8	25.1	*	24.4
12	*	*	**	**
15	24.0	**	**	**
PARAMETER: DISSOLVED OXYGEN (PPM)				
0	8.9	8.7	9.0	9.0
3	8.5	8.0	8.4	7.5
6	7.7	7.9	8.0	7.9
9	7.9	8	*	7.9
12	*	*	**	**
15	7.9	**	**	**
PARAMETER: pH (UNITS)				
0	7.4	7.4	7.4	7.4
3	7.3	7.6	7.6	7.5
6	7.4	7.6	7.5	7.5
9	7.4	7.6	*	7.5
12	*	*	**	**
15	7.5	**	**	**

*Measurements not taken at this depth.
**Insufficient depth for sampling.

Dissolved oxygen decreased with increasing depth during all tide states. There was no evidence of oxygen depletion anywhere in the discharge zone.

Generally, pH increased with depth. There appears to be a mid-depth maximum within the discharge zone (Tables 2B and 2C). Up-current values tended to be lower. Effluent pH averaged 9.4 units (Class II inspection preliminary data; average of two daytime grabs). This mid-depth maximum might be due to the presence of effluent.

During lower high slack sampling (Table 2A), a pH maximum (7.6 units) occurred near the surface above the discharge. This is evidence of a surfaced plume. Although not supported by temperature, salinity, or D.O. data, laboratory results (discussed later) tend to reinforce this evidence.

Table 3 shows results for samples taken just before lower high tide when the current slackened. WTP effluent data from the Class II inspection (Reif, 1987) are included for comparison. The fecal coliform result is the geometric mean of grabs taken from the effluent in the morning and afternoon of August 12. The other data are from a 24-hour composite. The level of fecal coliform in the effluent was low and well within the permit requirement (200 org/100 mL). This is typical of dry-weather conditions. A review of the WTP's monthly reports revealed that the final effluent exceeded the limit value (200 org/100 mL) 12 percent of the days of the year. Nearly 80 percent of these occurred in late fall and winter and were likely related to overloading during heavy rainfall.

In addition to fecal coliform limits, the current interim permit BOD_5 (33 mg/L) and TSS (63 mg/L) limits were met. The NPDES permit requires that chlorine levels in the discharge not exceed 0.5 mg/L. Total residual chlorine was difficult to measure during the day because dense concentrations of phytoplankton clouded color intensity in the test. However, several samples taken at night in the chlorination pond ("WTP chlorination and flapper gate operation," this study) averaged 0.3 mg/L.

The effects of the discharge on the receiving water are clearly evident. The results indicated that effluent reached the surface.

Total suspended solids were also higher. Ammonia and total phosphorus were one to two orders of magnitude higher than up-flow of the discharge.

Un-ionized ammonia levels were calculated with a computer program developed in Yake and James (1983). Assuming a temperature of $17^{\circ}C$ and a pH of 7.6 at the surface (Table 2A), un-ionized ammonia concentration is 0.02 mg/L-N or about 1 percent of total ammonia. This meets the four-day-average criterion (0.019 mg/L-N) proposed

Table 3. Laboratory results from samples taken in the discharge zone during lower high slack tide (10-39 - 1115) on August 12, 1986. Samples were taken from the surface (S) and bottom (B) only.

PARAMETER	WTP EFFLUENT CONC.	DEPTH (FT)	300 FEET UP-FLOW	OUTFALL	300 FEET DOWN-FLOW
NITRATE+NITRITE-N (MG/L)	0.24	S	0.12	0.18	0.13
		B	0.13	0.14	0.13
AMMONIA-N (MG/L)	11.00	S	0.06	2.00	0.23
		B	0.04	0.46	0.04
TOTAL PHOSPHORUS-P (MG/L)	2.70	S	0.04	0.72	0.17
		B	0.05	0.31	0.05
TOTAL SUSP. SOLIDS (MG/L)	42	S	6	26	4
		B	11	7	7
TURBIDITY (UNITS)	9	S	1	3	1
		B	2	2	1
FECAL COLIFORMS (COL./100 ML)	25	S	24	34	28

by EPA for waters supporting salmonids and other sensitive freshwater species (EPA, 1986). (There is no marine standard at this time. According to Hazel, et al. [1971], increasing salinity decreases the un-ionized ammonia fraction.)

It is possible that during slack tide, un-ionized ammonia levels could exceed the chronic (four-day) standard at the surface above the outfall (technically outside the dilution zone), particularly during lower low tide. But the duration of slack water is short. Complete reversal during the survey occurred within 15 to 20 minutes. It is unlikely that random sampling over four days would detect a violation of the four-day-average criterion.

Results during slack tide contrast sharply with those obtained when current was moving through the discharge zone. Under these conditions, values within the discharge zone were not different from results up-flow of the discharge and were similar to those measured elsewhere in the Snohomish River (refer to Table 8, page 30). This is an artifact of the sampling depths, however. The dye-injection studies indicated that samples taken at the surface and at the bottom missed the plume during all tide stages except low slack when the plume surfaced.

Fecal coliform levels in the receiving water were generally higher than the effluent. All FC samples were taken at the river surface where salinity was less than 10 ppt. Under terms of the special condition, the appropriate FC standard for this range of salinity is 200 org/100 mL (Table 1). All receiving water samples complied with this standard.

Dye Injection Studies

Continuous dye injection into the outfall line began at 1304 hours on August 13, 1986, during an outgoing tide. Results of fluorometer readings taken in the discharge zone are on Table 4. Dye concentrations in the effluent were quite uniform throughout the day. Dye concentrations were generally greatest at a depth of six feet. This corresponds to the depth of the mixed layer discussed earlier. The data confirm earlier observations that when there is current through the discharge zone, the freshwater plume rises through the saltwater layer and levels off at about six feet.

Dye levels downstream from the discharge point were highest after higher low tide (Table 4C); likely due to the shallower depth. Dye levels up-flow from the discharge were found to be elevated soon after tide reversal occurred (Tables 4A and 4C). This is probably receiving water that passed the discharge point immediately before tide reversal, stopped, and moved back toward the discharge point. Dispersion and mixing in this case was minimal. On the other hand, two hours after tide reversal (Table 4B), dye levels up-flow from the discharge were virtually zero. After reversals, it appears that buildup of effluent due to multiple dosing is not significant.

Table 4. Fluorometer measurements taken in the discharge zone on August 13, 1986, during various tide conditions. (Measurements are dye levels in parts per billion.)

A. TIDE: LOWER HIGH CURRENT: EBBING
TIME: 1325-1420 EFFLUENT CONCENTRATION: 99

DEPTH	100 FEET UP-FLOW	OUTFALL	100 FEET DOWN-FLOW	200 FEET DOWN-FLOW	300 FEET DOWN-FLOW
0	5.0	8.2	8.2	7.7	8.2
3	4.6	38.3	18.2	13.9	48.3
6	7.5	102.6	76.9	65.4	36.8
9	7.3	74.0	16.7	10.1	**
12	*	*	*	*	**
15	**	**	**	**	**

B. TIDE: HIGHER LOW CURRENT: EBBING
TIME: 1623-1750 EFFLUENT CONCENTRATION: 107

DEPTH	200 FEET UPFLOW	OUTFALL	100 FEET DOWNFLOW	300 FEET DOWNFLOW
0	0.0	5.0	29.7	10.1
3	0.0	*	27.3	*
6	0.0	*	79.6	62.6
9	0.4	*	*	8.6
12	0.0	*	*	*
15	*	*	*	*

C. TIDE: HIGHER LOW CURRENT: FLOODING
TIME: 1900-1958 EFFLUENT CONCENTRATION: 107

DEPTH	200 FEET UPFLOW	OUTFALL	150 FEET DOWNFLOW	250 FEET DOWNFLOW
0	6.4	30.1	4.4	7.6
3	9.7	23.1	23.1	15.0
6	7.1	<52.0	76.9	105.3
9	5.2	47.0	14.4	44.9
12	5.3	6.9	4.8	5.9
15	*	*	*	*

*Measurements not taken at this depth.
**Insufficient depth for sampling.

Ecology (1985) defines the dilution ratio of a discharge to be the ratio of the receiving water flow to effluent flow.

$$R = Q / q \qquad (2)$$

where Q = receiving water flow upstream of the discharge;
and q = WTP flow

The average instantaneous flow into the WTP during the Class II inspection was 16.2 cfs or 10.5 MGD. (This was slightly below the permitted flow of 10.6 MGD.) The flow was estimated by dye concentrations to be 19 cfs (standard deviation = 0.2, n = 7) or 12.3 MGD. The higher flow may be due to increased hydraulic head related to dropping tide.

A "theoretical" receiving water flow (Q) passing the discharge point was estimated as follows:

$$C \times Q + c \times q = C' (Q + q) \qquad (3)$$

where (in addition to the variables in Equation 2 above, we have:

C = depth-averaged dye concentration up-flow from the discharge;

c = average dye concentration discharged from the WTP;

C' = depth-averaged dye concentration beyond the down-flow end of the discharge zone (300 feet).

After transposing, we have the following:

$$Q = q (C' - c) / (C - C') \qquad (4)$$

The relationship was solved with values shown in Table 4. The theoretical flows were substituted into Equation (2). The dilution ratios for Tables 4A-C were 2.7, 2.9, and 1.9, respectively. The average of the three ratios was about 2.5:1.

These ratios were far less than the 100:1 criterion set by Ecology (1985). Qualitative observations during preliminary dye testing suggested that the plume did not exceed a width of 20 feet 300 feet downstream. The present discharge zone uses less than 44 percent of the dilution zone width (45 feet). The lack of a diffuser, the limited depth of the discharge, and the proximity of the shoreline (particularly during lower tide) confined the effluent and thus limited dilution.

Dye was observed to emerge among the rocks of the bank riprap from a buried leak in the buried outfall line. WTP upgrade should include repair of the line.

Theoretical Discharge-Zone Performance

As discussed earlier, samples taken from the surface and bottom missed the plume except during lower high slack conditions (Table 3). Because of the lack of meaningful sample results, concentrations of pollutants at the downstream edge discharge zone were estimated from a derivation of Equation 3 as follows:

$$C' = (C \times Q + c \times q) / (Q + q) \qquad (5)$$

Table 5 includes the predicted effective discharge zone effluent concentrations based on a 2.5:1 dilution ratio. WTP effluent data from the Class II inspection and depth-averaged surface and bottom data from the up-flow site (Table 3) were evaluated for several parameters using the effective dilution ratio of 2.5:1 at the edge of the dilution zone.

The estimated total ammonia at the down-flow edge of the discharge zone was 3.2 mg/L-N. Typical conditions 300 feet down-flow at the surface were as follows (Tables 2B through 2E): temperature: 20^{o}C; pH: 7.3; salinity: 1.8 ppt. At the bottom, temperature averaged 15^{o}C, pH averaged 7.5, and salinity was 24 ppt. Calculated un-ionized ammonia at the surface averaged 0.028 mg/L (0.88 percent of total ammonia) and at the bottom 0.026 mg/L. These values were calculated assuming salinity was zero. However, Hazel, et al. (1971) noted that dissolved salts reduce levels of un-ionized ammonia. Thus, the estimates represent worst-case conditions. EPA (1986) specifies a one-hour criterion of 0.118 mg/L-N and 0.105 mg/L-N for surface and bottom conditions, respectively. The estimated levels were within the criterion.

The level of chlorine specified in the NPDES permit (0.5 mg/L) was used to calculate the level present at the edge of the discharge zone. Total residual chlorine at this point was estimated to be 140 ug/L. This is nearly ten times higher than the criterion of 13 ug/L (1-hour average) for seawater set by EPA (1986). The results suggest that chlorine may reach high levels within the existing discharge zone. Yet, as discussed above, the discharge zone encompassed a relatively narrow corridor of the river.

Downstream Dispersion

Figure 4 shows the results of dispersion studies using instantaneous dye drops. The two dye-drop points correspond to the locations of two proposed outfalls serving the WTP in the future ("Background," this study). The calculated mean time of travel from the WTP headworks to the north end of Dagmar's Marina (7,600 feet) (Figure 3) was 108 minutes with a mean velocity of 1.1 feet per second. The mean time of travel from the WTP discharge point to State Highway 99 bridge was 56 minutes. This gives an average velocity of 1.8 feet per second.

Table 5. Calculated levels of several water quality parameters downflow from the Everett WTP discharge zone assuming a dilution ratio of 2.5:1.

PARAMETER	WTP EFFLUENT CONCENTRATION (MG/L)	SNOHOMISH RIVER UP-FLOW CONCENTRATION (MG/L)	DOWN-FLOW CONCENTRATION (MG/L)
BOD_5	12	4	6
NITRATE+NITRITE-N (MG/L)	0.24	0.14	0.17
AMMONIA-N (MG/L)	11.00	0.11	3.2
TOTAL PHOSPHORUS-P (MG/L)	2.70	0.08	0.83
TOTAL CHL. RES. (MG/L)	0.50	0.00	0.14
TOTAL SUSP. SOLIDS (MG/L)	42	8	18
FECAL COLIFORMS (#/100ML)	25	23	24

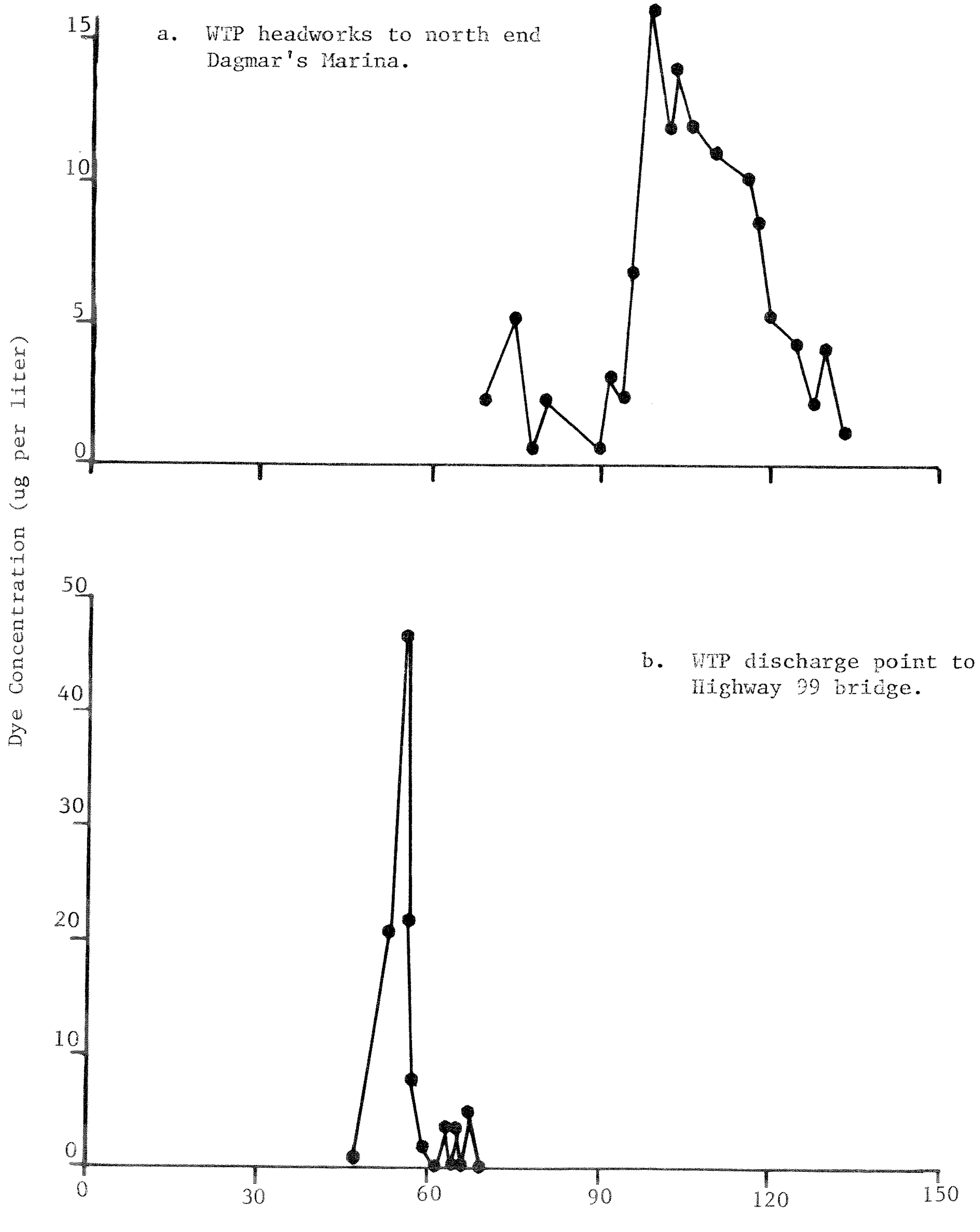

Figure 4. Dye concentrations in the Snohomish River estuary following instantaneous dye drops at points upstream.

Dilutions for both proposed outfall locations were similar--9:1 down-flow from the proposed outfall and 7:1 down-flow from the existing outfall. The average dilution ratio was 8:1. These ratios provide a measure of the estuary's ability to disperse WTP effluent after passing through each dilution zone. Installation of a diffuser would improve dilution and dispersion.

The flows estimated in the existing discharge zone (2.5:1) and in the estuary proper (8:1) included only limited fractions of stream width. An attempt to estimate total flow was made using the dimensions of the main channel. The width near the WTP discharge is about 300 feet (NOAA Chart No. 6441). The average depth (15 feet) was estimated using Figure 4 in Jones and Stokes (1986). The surface velocity during ebbing tide averaged 1.5 feet per second. Although quantitative data are lacking, informal observations suggest that the velocity decreased with depth during ebb tide. Thus the average over all depths was assumed to be 0.75 feet per second. The flow (q) of about 3,000 cfs was estimated using:

$$q = h\ w\ v \qquad (6)$$

where h = average depth (feet)
w = stream width (feet)
v = average velocity (feet per second)

Only part of this was attributable to river flow, however. The fraction of freshwater in the total flow was estimated using Mills, et al. (1982) as follows:

$$f = (S - S') / S \qquad (7)$$

where f = the fraction of fresh water
S = salinity of local seawater
S' = depth-averaged salinity upstream of the discharge

Upstream salinity (S') was estimated to be 14.6 ppt (Tables 2A and 2C). Local seawater (S) was 27 ppt (refer to Station B at depth, Table 6, page 28). The freshwater fraction was 44 percent of the flow or about 1300 cfs. This agrees well with the 7-day, 10-year low flow (1,382 cfs) for the main channel calculated by Tang (1981). The Snohomish River flow at Monroe averaged 1486 cfs during the present survey (R. Williams, USGS, personal communication). The share of river flow through the main channel using Tang's (1981) factor of 70 percent yielded a flow of 1,040 cfs; well below the 7-day, 10-year low flow value of 1382 obtained using the same computer model. It appears that the Snohomish River flow was near the design condition at the time of the survey.

The potential dilution ratio based on 3000 cfs and assuming complete initial dilution (substituted for Q in Equation 2) was 158:1 during a period of relatively minimal tidal ebb (Figure 2, August 14). The dilution ratio using the 7-day, 10-year low flow (1382 cfs) would be 73:1 (based on freshwater flow only).

During slack water, initial dilution would be minimal because the receiving water motion becomes zero. The discharge plume would be likely to surface. Thus dilution during critical low-flow periods depends on the degree of tidal movement in the estuary in addition to the amount of river discharge. Considering oscillating tidal motion, a properly designed diffuser may provide sufficient dilution of 100:1 (Ecology, 1985) during part of a tidal day, but it is unlikely during slack periods of up to two hours a day. This is particularly true during lower tides when the depth would be inadequate for a dilution zone dimensioned as required in Ecology (1985). Thus planning during the upgrade should consider a method to prevent WTP discharge during slack water.

Multiple Dosing

Dye-injection studies in the discharge zone suggest that buildup of wastewater in the vicinity of the outfall following two tide reversals was insignificant. An attempt was made to evaluate this issue over a longer time using a mathematical approach.

The model considered the effects of downstream dispersion and tidal exchange as factors. Tidal exchange was assumed to be one-sixth the volume of the estuary per tide cycle (J. Murray, Univ. of Wash., Dept. of Oceanography, personal communication). Initial dilution in the existing discharge zone was set to 3:1 ("Theoretical Discharge-Zone Performance," this study). Downstream dispersion was assumed to be 8:1 per hour of drift ("Downstream Dispersion," this study) over one tide cycle (6 hours) or 48:1. The concentration of dye in the effluent was 100 ug/L (Tables 4A and 4C). The model consisted of solving Equation 5 iteratively over 12 tide cycles. The results (Figure 5) demonstrate that dispersion and (to a lesser degree) tidal exchange are important in controlling the level of pollutant over time. Although not shown on Figure 5, the model predicts that the effluent fraction after 30 days (60 tide cycles) would be 72 percent from downstream dispersion alone and 62 percent with dispersion and tidal exchange together. Without dispersion and tidal exchange (Curve a), effluent builds rapidly so that the effluent fraction was about 60 percent after only three cycles. This result is similar to that observed by Bernhardt and Yake (1981) at Renton WTP on the Green River, nearly eight miles upstream from Puget Sound, where downstream dispersion and tidal exchange is minimal.

The issue of effluent buildup through multiple dosing is more important in the upper end of estuarine rivers where there are tidally induced flow reversals but dispersion processes are limited and tidal exchange is absent. Dispersion and tidal exchange help prevent multiple dosing by effluent in the Snohomish River estuary.

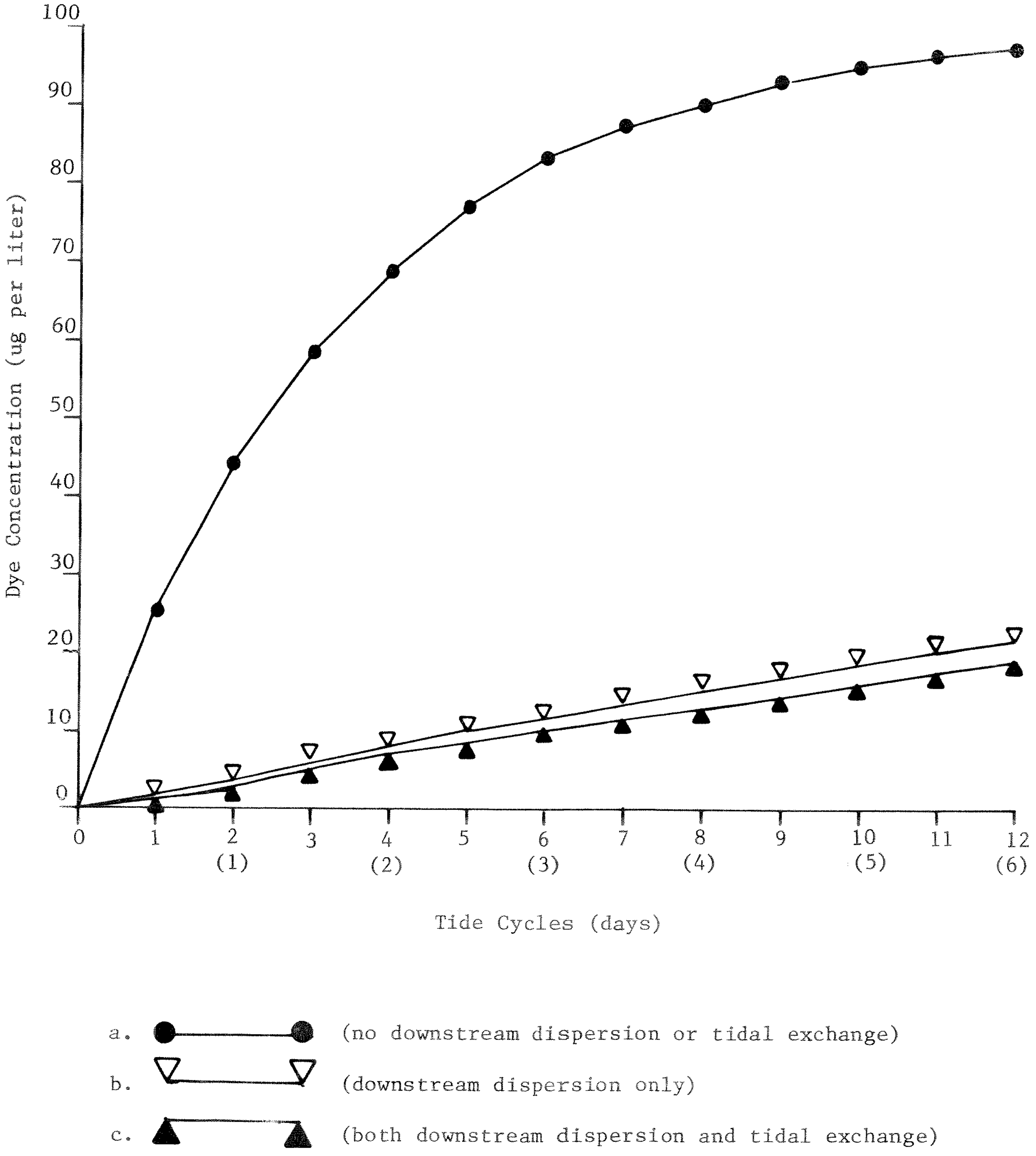

Figure 5. Theoretical buildup of rhodamine wt dye in the vicinity of the Everett WTP discharge due to multiple dosing related to tidal flow reversals.

Diurnal Changes in the Distribution of Salt and Oxygen

Tables 6 and 7 show how several parameters are distributed along the axis of the main channel of the estuary. Table 6 shows results on a rising tide. A salt wedge was evident at all sites, but as expected, the estuary showed reduced stratification toward its head.

The data in Table 7 show conditions the following morning when the tide was near lower low water and rising. Values were uniformly distributed and salinity sharply reduced compared to the previous evening. Evidence of a salt wedge was found only at Station A. A moraine or bar located near Point Preston (observed by depth sounder during the June reconnaissance) separated Station A from the rest of the estuary upstream. This moraine may limit saltwater intrusion during extremely low tides.

Recent work by NORTEK, Inc. suggests that a strong counterclockwise gyre in Port Gardner may minimize the return of mixed water taken out during previous tides (L. Larsen, University of Washington, Department of Oceanography, personal communication). McGary and Lincoln (1977) show the gyre occurring at higher high tide.

In order to determine how the WTP affects oxygen distribution, oxygen levels during the day were compared to values following night when primary productivity was absent. Dissolved oxygen at depth (>6 feet) averaged 8.4 (s.d. = 0.4, n=13) on the evening of August 13 (Table 6). The next morning (Table 7), D.O. at depth averaged 8.2 mg/L (s.d. = 0.2, n=12). The difference was not significant (t's = 0.28, t-test for means with unequal variances; Sokal and Rohlf, 1969). Thus oxygen demand from the plant and other possible sources produced minimal effects in the estuary. This outcome may be typical when extreme tide change aids flushing at night. However, during minimal tide change, flushing may not be as effective.

Table 8 summarizes laboratory analyses of late-afternoon samples. Ammonia was generally higher at the surface than at depth. The other nutrients, turbidity, and TSS were generally uniformly distributed horizontally and vertically. Fecal coliform densities were greatest in the vicinity of the outfall (Station E, Figure 1). However, total phosphorus and TSS were quite high at depth in the vicinity of the outfall. The opposite was true at Station F up-river.

Total Maximum Daily Load

Table 9 analyzes daily load from the Everett WTP using current effluent quality.

Loads of chemicals and materials including metals were calculated using IHD-WHO (1978) as follows:

$$L = fcq \qquad (7)$$

where L = load (lb/day)
c = concentration (mg/L)
q = flow (cfs)
f = 5.39 (conversion factor)

Table 6. Vertical-profile of several parameters at several sites on the Snohomish River on August 13, 1986, between 1928-2036 hours. The tide was rising after higher low water.

DEPTH (FT)	STN. B	STN. C	STN. D	STN. E	STN. F	STN. G
PARAMETER: TEMPERATURE (°C)						
0	20.0	19.4	19.0	20.4	18.8	19.4
3	18.5	16.9	16.9	19.8	17.8	18.8
6	15.2	15.0	15.7	16.9	15.6	16.8
9	14.9	*	*	15.3	*	*
12	*	14.8	*	*	*	*
15	14.7	*	15.0	15.2	15.2	15.9
PARAMETER: SALINITY (PPT)						
0	6.0	9.6	9.8	1.5	9.8	5.4
3	20.1	23.0	18.2	4.0	14.1	8.2
6	26.2	26.4	24.8	18.0	17.8	19.0
9	27.2	*	*	23.8	*	*
12	*	26.8	*	*	*	*
15	27.2	*	26.2	24.0	25.0	21.4
PARAMETER: DISSOLVED OXYGEN (PPM)						
0	8.9	9.0	8.7	8.9	8.7	8.9
3	8.7	8.9	8.6	8.5	8.6	8.5
6	8.9	8.8	8.6	7.7	8.5	8.0
9	8.8	*	*	7.9	*	*
12	*	8.7	*	*	*	*
15	*	*	8.7	7.9	8.5	7.8
PARAMETER: pH (UNITS)						
0	7.5	7.5	7.5	7.4	7.6	7.4
3	7.6	7.6	7.7	7.3	7.6	7.5
6	7.6	7.6	7.6	7.4	7.7	7.5
9	7.6	*	*	7.5	*	*
12	*	7.6	*	*	*	*

*Measurements not taken at this depth.

Table 7. Vertical-profile of several parameters at several sites on the Snohomish River on August 14, 1986, between 0730-0900 hours. The tide was rising after lower low water. The current was nearly slack.

DEPTH (FT)	STN. A	STN. B	STN. C	STN. D	STN. E	STN. F	STN. G	STN. G'	STN. H
PARAMETER: TEMPERATURE (°C)									
0	17.8	18.3	18.5	18.5	18.4	18.4	18.1	17.9	18.0
3	16.9	18.3	18.5	18.6	18.5	18.4	18.1	17.9	18.0
6	14.9	18.3	18.5	18.6	18.5	18.4	18.1	*	*
9	14.8	18.3	18.5	**	18.5	18.4	*	*	18.0
12	*	**	**	**	18.5	**	**	**	**
15	*	**	**	**	**	**			
PARAMETER: SALINITY (PPT)									
0	9.5	3.0	2.0	1.4	0.7	<0.1	<0.1	<0.1	<0.1
3	15.4	5.4	2.4	1.6	0.7	<0.1	<0.1	<0.1	<0.1
6	25.8	6.0	2.8	1.7	0.6	<0.1	<0.1	*	*
9	26.8	6.1	3.0	**	0.6	<0.1	*	*	<0.1
12	*	**	**	**	0.5	**	**	**	**
15	*	**	**	**	**	**			
PARAMETER: DISSOLVED OXYGEN (PPM)									
0	8.5	8.5	8.6	8.3	8.5	8.4	8.7	8.3	8.7
3	8.0	8.1	8.2	8.2	8.3	8.3	8.4	8.3	8.4
6	8.4	8.0	8.1	8.2	8.3	8.3	8.4	*	*
9	8.5	7.9	8.1	**	8.3	8.3	*	*	8.3
12	*	**	**	**	8.3	**	**	**	**
15	*	**	**	**	**	**			
PARAMETER: pH (UNITS)									
0	7.4	7.4	7.4	7.2	7.6	7.5	7.6	7.6	7.7
3	7.5	7.2	7.2	7.2	7.3	7.4	7.4	7.5	7.5
6	7.6	7.2	7.2	7.2	7.3	7.3	7.4	*	*
9	7.7	7.2	7.2	**	7.2	7.3	*	*	7.4
12	*	**	**	**	7.2	**	**	**	**
15	*	**	**	**	**	**			

*Measurements not taken at this depth.
**Insufficient depth for sampling.

Table 8. Laboratory results from samples collected at several sites on the Snohomish River on August 13, 1986, between 1928-2036 hours. The tide was rising after higher low water. Samples were collected at the surface (S) and the bottom (B).

PARAMETER	DEPTH (FT)	STN. B	STN. C	STN. D	STN. E	STN. F	STN. G	AVG. CONC.
NITRATE+NITRATE-N	S	0.13	0.13	0.13	0.14	0.14	0.14	0.14
(MG/L)	B	0.11	0.11	0.11	0.14	0.12	0.14	0.12
AMMONIA-N (M)	S	0.06	0.08	0.07	0.07	0.12	0.09	0.08
(MG/L)	B	0.02	0.02	0.01	0.03	0.02	0.05	0.03
TOTAL PHOSPHORUS-P	S	0.05	0.05	0.05	0.05	0.09	0.07	0.06
(MG/L)	B	0.04	0.04	0.05	0.12	0.05	0.06	0.06
TOTAL SUSP. SOLIDS	S	4	1	1	5	15	1	4
(MG/L)	B	1	9	2	18	1	4	7
TURBIDITY	S	1	1	1	1	1	1	1
(UNITS)	B	6	1	1	3	1	2	2
FECAL COLIFORMS (COL./100 ML)	S	9	24	12	68	21	25	26

Table 9. Analysis of loads from the Everett WTP from data taken in August, 1986 for several conditions of river flow.

EVERETT WTP/SNOHOMISH RIVER
WTP FLOW: 19 CFS

	EVERETT WTP			SNOHOMISH RIVER			
PARAMETER	CONC. (MG/L)	FLOW (CFS)	LOAD (LBS/DAY)	CONC. (MG/L)	FLOW (CFS)	LOAD (LBS/DAY)	DOWNSTREAM CONC.(MG/L
A. RIVER FLOW: 1382 CFS							
BOD-5	12	19.0	1,200	4	1,382	30,000	4
NITRATE+NITRITE-N	0.24	19.0	25	0.14	1,382	1,000	0.14
AMMONIA-N	11.00	19.0	1,130	0.10	1,382	740	0.25
TOTAL PHOSPHORUS-P	2.70	19.0	277	0.08	1,382	600	0.12
TOTAL CHL. RES.	0.50	19.0	51	0.00	1,382	0.0	0.01
TOTAL SUSP. SOLIDS	42	19.0	4,300	8	1,382	60,000	8
FECAL COLIFORMS	25	19.0	1.2E+10	23	1,382	7.8E+11	23
	(#/100 ML)		(#/DAY)	(#/100 ML)		(#/DAY)	(#/100 ML)
B. RIVER FLOW: 3000 CFS							
BOD-5	12	19.0	1,200	4	4,500	98,000	4
NITRATE+NITRITE-N	0.24	19.0	25	0.14	4,500	3,400	0.14
AMMONIA-N	11.00	19.0	1,130	0.11	4,500	2,700	0.16
TOTAL PHOSPHORUS-P	2.70	19.0	277	0.08	4,500	1,900	0.09
TOTAL CHL. RES.	0.50	19.0	51	0.00	4,500	0.0	0.00
TOTAL SUSP. SOLIDS	42	19.0	4,300	8	4,500	19,000	8
FECAL COLIFORMS	25	19.0	1.2E+10	23	4,500	2.6E+12	23
	(#/100 ML)		(#/DAY)	(#/100 ML)		(#/DAY)	(#/100 ML)

The same equation was used for fecal coliform loads as adapted from Kittrell (1969) with the following substitutions:

L = fc load (no./day)
c = fc concentration (no./100 mL)
f = 24,600,000 (conversion factor)

Data from upstream surface sites were averaged to minimize marine water influence (Stations F and G, Table 8). Analyses were made under two theoretical values for stream flow: 1382 cfs (7-day, 10-year low flow, URS, Inc.) which is consistent with past analyses (Singleton, et al., 1982); and 3000 cfs which was based on the cross-sectional area and average velocity of the river described earlier. It was assumed in the case of 3,000 cfs, that the entire flow of the river was available for dilution. Table 9 predicts the concentration of pollutant assuming complete initial dilution. This implies an adequate diffuser is installed. The prediction was calculated from Equation 5. Neither theoretical flow produces serious short-term impacts. Concentrations of BOD_5 and fecal coliform are virtually unchanged downstream. The fecal coliform level complies with the water quality standards.

The in-stream concentration of ammonia is predicted to be 0.25 and 0.14 mg/L-N for 1382 and 3000 cfs, respectively. This is less than 20 percent of the chronic (4-day average) criteria set by EPA (1986) for total ammonia. The un-ionized component of 0.25 mg/L-N is about 1 percent or 0.003 mg/L-N (Yake and James, 1983). This is far below values for either the chronic (4-day) or acute (1-hour) criteria for un-ionized ammonia (EPA, 1986) for pH and temperature measured during the survey.

Total residual chlorine levels for both flows could meet the chronic (1-day average) and acute (4-day average) criteria set by EPA (1986) (0.0075 and 0.013 mg/L, respectively) most of the time. Exceptions may be during flapper gate closure (before and during HHW slack tide) and during other slack periods when discharge continues (see "WTP Chlorination and Flapper Gate Operation," this report).

Table 10 summarizes total maximum daily loads (TMDLs) for Everett WTP following implementation of one of the discharge options currently being considered (see "Background," this report). Permit requirements for effluent quality for the options are shown in the table. The analysis assumed a receiving water flow of 1,382 cfs (7-day, 10-year low flow).

In both dual-discharge options (Tables 10C-D, E-F, and G-H), initial dilution was assumed to be complete and downstream dispersion (as the stream approached the down-flow discharge) insignificant. For this reason, concentrations in the Snohomish River approaching down-flow discharge points (Tables 10D, F, and H) were set equal to the values shown in "Downstream Concentrations" in Tables 10C, E, and G.

Table 10. An analysis of loads from the Everett WTP for several outfall options. Calculations are based on WTP permit flows (as shown) and river flow of 1,382 cfs (7-day, 10-year flow (Tang, 1981). Selected water quality criteria are at the end of the table.

	EVERETT WTPOUTFALL		SNOHOMISH RIVER		
PARAMETER	CONC. (MG/L)	LOAD (LBS/DAY)	CONC. (MG/L)	LOAD (LBS/DAY)	DOWNSTREAM CONC. (MG/L)
A. SINGLE OUTFALL (19.0 MGD) PRESENT DAY		DILUTION RATIO: 73			
BOD$_5$	33	3,400	4	30,000	4
TOTAL SUSP. SOLIDS	63	6,400	8	60,000	9
TOTAL CHLOR. RES.	0.05	5	0	0	0.0007
CHROMIUM	0.1	10	<0.001	<7	0.002
COPPER	0.03	3	<0.001	<7	0.001
ZINC	0.42	43	<0.001	<7	0.007
LEAD	0.0014	0	<0.001	<7	0.001
FECAL COLIFORMS	200 (#/100 mL)	9.3E+10 (#/DAY)	23 (#/100 mL)	7.8E+11 (#/DAY)	25 (#/100 mL)
B. SINGLE OUTFALL (29.1 MGD) POST-UPGRADE		DILUTION RATIO: 47			
BOD$_5$	30	4,700	4	30,000	5
TOTAL SUSP. SOLIDS	30	4,700	8	60,000	8
TOTAL CHLOR. RES.	0.05	8	0	0	0.001
CHROMIUM	0.1	20	<0.001	<7	0.003
COPPER	0.03	5	<0.001	<7	0.002
ZINC	0.42	66	<0.001	<7	0.010
LEAD	0.0014	0	<0.001	<7	0.001
FECAL COLIFORMS	200 (#/100 mL)	1.4E+10 (#/DAY)	23 (#/100 mL)	7.8E+11 (#/DAY)	27 (#/100 mL)

Table 10 - continued.

PARAMETER	EVERETT WTP OUTFALL		SNOHOMISH RIVER		
	CONC. (MG/L)	LOAD (LBS/DAY)	CONC. (MG/L)	LOAD (LBS/DAY)	DOWNSTREAM CONC.(MG/L)
C. SOUTH OUTFALL (14.5 MGD)					
POST-UPGRADE, TWO OUTFALLS (EQUAL FLOW)			DILUTION RATIO: 73		
BOD_5	30	2,300	4	30,000	4
TOTAL SUSP. SOLIDS	30	2,300	8	60,000	8
TOTAL CHLOR. RES.	0.05	4	0	0	0.0005
CHROMIUM	0.1	8	<0.001	<7	0.002
COPPER	0.03	2	<0.001	<7	0.001
ZINC	0.42	33	<0.001	<7	0.005
LEAD	0.0014	0	<0.001	<7	0.001
FECAL COLIFORMS	200	7.1E+10	23	7.8E+11	25
	(#/100 mL)	(#/DAY)	(#/100 mL)	(#/DAY)	(#/100 mL)
D. NORTH OUTFALL (14.5 MGD)					
POST-UPGRADE, TWO OUTFALLS (EQUAL FLOW)			DILUTION RATIO: 95		
BOD_5	30	2,300	4	30,000	4
TOTAL SUSP. SOLIDS	30	2,300	8	60,000	8
TOTAL CHLOR. RES.	0.05	4	0.0005	4	0.001
CHROMIUM	0.1	8	0.002	15	0.003
COPPER	0.03	2	0.001	10	0.002
ZINC	0.42	33	0.005	40	0.010
LEAD	0.0014	0	0.001	7	0.001
FECAL COLIFORMS	200	7.1E+10	25	8.5E+11	27
	(#/100 mL)	(#/DAY)	(#/100 mL)	(#/DAY)	(#/100 mL)

Table 10 - continued.

	EVERETT WTP OUTFALL		SNOHOMISH RIVER		
PARAMETER	CONC. (MG/L)	LOAD (LBS/DAY)	CONC. (MG/L)	LOAD (LBS/DAY)	DOWNSTREAM CONC. (MG/L)
E. SOUTH OUTFALL (24.6 MGD) POST-UPGRADE, TWO OUTFALLS (UNEQUAL FLOW), CURRENT OUTGOING DILUTION RATIO: 73					
BOD_5	30	4,000	4	30,000	4
TOTAL SUSP. SOLIDS	30	4,000	8	60,000	8
TOTAL CHLOR. RES.	0.05	7	0	0	0.0009
CHROMIUM	0.1	10	<0.001	<7	0.003
COPPER	0.03	4	<0.001	<7	0.002
ZINC	0.42	56	<0.001	<7	0.008
LEAD	0.0014	0	<0.001	<7	0.001
FECAL COLIFORMS	200 (#/100 mL)	1.2E+11 (#/DAY)	23 (#/100 mL)	7.8E+11 (#/DAY)	26 (#/100 mL)
F. NORTH OUTFALL (4.5 MGD) POST-UPGRADE, TWO OUTFALLS (UNEQUAL FLOW), CURRENT OUTGOING DILUTION RATIO: 307					
BOD_5	30	730	4	30,000	4
TOTAL SUSP. SOLIDS	30	730	8	60,000	8
TOTAL CHLOR. RES.	0.05	1	0.0009	7	0.001
CHROMIUM	0.1	2	0.003	20	0.003
COPPER	0.03	1	0.002	11	0.002
ZINC	0.42	10	0.008	62	0.010
LEAD	0.0014	0	0.001	7	0.001
FECAL COLIFORMS	200 (#/100 mL)	2.2E+10 (#/DAY)	26 (#/100 mL)	8.8E+11 (#/DAY)	27 (#/100 mL)

Table 10 - continued.

	EVERETT OUTFALL		SNOHOMISH RIVER		
PARAMETER	CONC. (MG/L)	LOAD (LBS/DAY)	CONC. (MG/L)	LOAD (LBS/DAY)	DOWNSTREAM CONC.(MG/L)
G. NORTH OUTFALL (4.5 MGD) POST-UPGRADE, TWO OUTFALLS (UNEQUAL FLOW), CURRENT INCOMING DILUTION RATIO: 307					
BOD_5	30	730	4	30,000	4
TOTAL SUSP. SOLIDS	30	730	8	60,000	8
TOTAL CHLOR. RES.	0.05	1	0.001	0	0.0002
CHROMIUM	0.1	2	<0.001	<7	0.001
COPPER	0.03	1	<0.001	<7	0.001
ZINC	0.42	10	<0.001	<7	0.002
LEAD	0.0014	0	<0.001	<7	0.001
FECAL COLIFORMS	200	2.2E+10	23	7.8E+11	24
	(#/100 mL)	(#/DAY)	(#/100 mL)	(#/DAY)	(#/100 mL)
H. SOUTH OUTFALL (24.6 MGD) POST-UPGRADE, TWO OUTFALLS (UNEQUAL FLOW), CURRENT INCOMING DILUTION RATIO: 56					
BOD_5	30	4,000	4	30,000	4
TOTAL SUSP. SOLIDS	30	4,000	8	60,000	8
TOTAL CHLOR. RES.	0.05	7	0.0002	1	0.001
CHROMIUM	0.1	13	0.001	10	0.003
COPPER	0.03	4	0.001	8	0.002
ZINC	0.42	56	0.002	18	0.010
LEAD	0.0014	0	0.001	7	0.001
FECAL COLIFORMS	200	1.2E+11	24	8.2E+11	27
	(#/100 mL)	(#/DAY)	(#/100 mL)	(#/DAY)	(#/100 mL)

Water quality criteria (EPA 1986) for metals in saltwater is footnoted on Table 11.

Tables 10E and F show the dual-discharge unequal-flow option with receiving water current outgoing toward the mouth of the river. Tables 10G and H show the same option with river current incoming from Port Gardner. In this way, tide reversal (1/2 tide cycle) is simulated.

Examination of the "downstream concentration" columns of Tables 10B, D, F, and G suggests that the pollutant concentration in the receiving water would be theoretically the same after leaving any discharge system (one or two outfalls) regardless of current direction. Thus, the discharge option chosen should be based on the likelihood that each diffuser (single or part of a system) can achieve optimum dilution at a given site. The single-outfall option is the least desirable since the single discharge provides the least dilution potential (dilution ratio = 47:1). The dual-outfall, unequal-flow option produces relatively high concentrations between the two outfall sites during outgoing tide when the greater WTP flow came from the up-flow (south) outfall (Table 10E). Between-outfall concentrations were lower during incoming tide (Table 10G) because the up-flow outfall (in this case, the northerly one) discharged the lesser of the two WTP flows. The option most likely to achieve the desired result would be the dual-discharge, equal-flow option (Tables 10C and D) because each discharge by itself provides the best dilution (dilution ratio = 95:1).

Assuming that total initial dilution is achievable (through construction of an adequate diffuser), water quality criteria for metals (EPA, 1986) would be met regardless of discharge option. "Down-flow" values for BOD_5, TSS, and fecal coliform are little different from "up-flow" levels.

WTP Chlorination and Flapper Gate Operation

Singleton, et al. (1982) noted that when the flapper gate on the discharge line was closed and the WTP was not discharging, flash chlorination continued. As a result, chlorine levels in the effluent exceeded 5 mg/L, an order of magnitude higher than the permitted level.

Singleton, et al. (1982) also hypothesized the increased flow probably occurs due to the buildup of hydraulic head during the period of closure. This might result in underchlorination.

Just before midnight on August 13 at higher high tide (Figure 2), the flow out of the WTP chlorination basin seemed to be stopped. It is possible the flapper gate was not working and river water was backing up into the WTP (see Introduction). Total chlorine residual samples near the chlorinator building were 0.5 mg/L initially, but rose to 3.5 mg/L soon after midnight. The rise coincided with the start of a very slight outward movement of flow through the standpipe at the other end of the chlorination pond. The abrupt increase in TRC may be due to multiple dosing of effluent with chlorine during reversal of flow.

Underchlorination following the opening of the flapper gate probably is not a problem. The area of the WTP ponds and lagoons is 210 acres or 9.15 million square feet. If the flapper gate was properly closed for four hours while the plant flow continued to discharge at 19 cfs (12 MGD), the pond would rise only about 0.04 foot. This added head should not develop sufficient accelerated flow to produce a significant dilution of injected chlorine.

In summary, a flow-paced chlorination system should be installed immediately to eliminate superchlorination episodes. According to Carl Baird, Everett WTP senior wastewater operator, flow-paced chlorination is planned for Phase I upgrade of the plant. Installation of this system should be done very early in this process. Eventually, a diffuser should be installed to reduce chlorine levels at any point in the dilution zone.

Metals Concentrations in Water and Sediment

Table 11 contains present and historic metals concentrations in the WTP effluent. WTP concentrations were obtained from composites (Reif, 1986; Singleton, et al., 1982).

The NPDES permit has limits on four metals (chromium, 100 ug/L; copper, 30 ug/L; zinc, 420 ug/L; and lead, 1.4 ug/L. Lead (20 ug/L) exceeded the limit fourteen-fold.

Copper, nickel, and lead were significantly higher than reported by Singleton, et al. (1982). Chromium, mercury, and silver were lower. Zinc and cadmium remained essentially the same.

"Up-flow" concentrations were obtained from the receiving waters after higher low tide (1505 - 1645, August 13).

All "up-flow" metals in the Snohomish River were below EPA's recommended water quality limits. The status of mercury is ambiguous because the minimum detectable level of mercury reported by the laboratory was greater than the EPA chronic criterion (0.025 ug/L).

Theoretical down-flow concentrations were calculated using Equation 5. Despite the very limited dilution ratio imposed by the existing discharge (2.5:1), the metals were within or likely near EPA criteria. Copper and mercury levels may be equal or below their criteria due to laboratory results that were below minimum detectability. Lead is nearly equal to the criterion. During slack water, however, higher levels may occur within the plume. Construction of an adequate diffuser and prevention of discharge during slack flow may control metals levels at these times.

Table 12 summarizes the results of sediment analysis for metals. The results at the two sites in the Snohomish River were lower than the apparent-effect-threshold (AET) levels described by Tetra Tech (1986b). An AET is the concentration of a material in the sediment above which significant negative effects are predicted to occur in Puget Sound benthic marine communities.

Table 11. Calculated levels of metals downstream from the Everett WTP dilution zone on 13 August, 1986. The results represent the average of several tide conditions and are compared to toxic criteria from EPA (1986).

PARAMETER	WTP CONC. REIF (1987) (ug/L)	WTP CONC. SINGLETON, ET AL. (1982) (ug/L)	UP-FLOW CONC. (ug/L)	THEORETICAL DOWN-FLOW CONC. (ug/L)	EPA (1986)[a] CHRONIC/ACUTE CRITERIA (ug/L)
COPPER[b]	14	2.7	<1	<5	2.9[c]
ZINC	39	33	<1	12	58/170[d]
NICKEL	20	4	<1	6	7.1/140[d]
CHROMIUM[e]	<1	78	<1	1	50/1100[f]
CADMIUM	1	<1	0.3	0.5	9.3/43[f]
LEAD	20	8	<1	6	5.6/140[f]
MERCURY[b,g]	<0.05	<0.2	<0.04	<0.04	0.025/2.1[f]
SILVER	1.1	2	0.2	0.3	2.3[h]

[a] Saltwater criteria.

[b] Indicates suspended, cancellor restricted by U.S. EPA Office of Pesticides and Toxic Substances.

[c] 1-hour avg. (not to be exceeded more than once in three years).

[d] 24-hour avg./maximum allowable at any time.

[e] Total chromium (CrIII + CrVI). CrVI criterion only; no CRIII criterion.

[f] 4-day avg./1-hour avg. (not to be exceeded more than once in three years).

[g] Mercury II.

[h] Maximum allowable at any time.

Table 12. Levels of metals in sediment relative to action levels given in Tetra Tech (1986b) at Everett WTP and two sites in the Snohomish River.

	SEDIMENT CONCENTRATION (ug/g DRY WT.)			
METAL	WTP CHLOR. LAGOON	DAGMAR'S MARINA	CONTROL (RM 11.2)	AET[1]
COPPER	107	17	19	310
ZINC	169	46	48	260
NICKEL	42	24	23	49
CHROMIUM	52	20	19	59
CADMIUM	4.1	0.1	0.14	5.8
LEAD	34	1.5	1.2	300

[1] Apparent Effects Threshhold.

There appears to be little difference between the two river sites despite difference in proximity to the WTP. However, metals levels in sediments are in part the result of proximity to the source and the mixture of grain sizes in the sediment. Smaller particles adsorb charged metals ions. The effect of particle size distribution must be eliminated to address the effect of the source. Horowitz (1984) describes a method for "normalizing" metals data to eliminate the effect of size distribution. This is done by dividing a metal concentration by the fraction of silts and clays in the sediment. It is important to note that "normalized" results are theoretical. They did not really exist in the field and it is inappropriate to compare them to AET values.

The sediments in the WTP chlorination pond were composed of 26 percent silt and clay. The river sites contained more sand and gravel. At the control site, silt and clay amounted to 2 percent. The fraction of fines at Dagmar's Marina was about 1 percent. The normalized data in Table 13 suggest that the fine sediments in the vicinity of Dagmar's Marina were higher than the same fraction at the control site upstream. The normalized concentrations in the chlorination pond were lower than either river site for all metals except cadmium. Lead from WTP sediments is comparable in value to lead near Dagmar's Marina. The WTP may be a contributor to the estuary of cadmium and perhaps lead. However, the important conclusion is that metals in estuary sediments are lower than levels that are likely to harm benthic communities.

CONCLUSIONS

1. A well-defined salt wedge was present in the area of the WTP discharge during the survey. The depth of the mixed layer between fresh- and saltwater layers was about six feet.
2. During periods of significant current movement, the plume generally rose to mid-depth. However, during lower high slack tide, the plume was observed to reach the surface.
3. During the time that the plume surfaced, total phosphorus and ammonia levels increased one to two orders of magnitude higher than receiving waters outside the plume. Un-ionized ammonia levels were within the EPA (1986) toxicity criteria.
4. Based on use of Rhodamine wt dye, the depth-averaged dilution ratio was 2.5:1 beyond the end of the discharge zone, far less than the 100:1 recommendation for discharges in estuaries (Ecology, 1985). The low level of dilution is due to the lack of a diffuser, insufficient depth of discharge, and insufficient distance from the bank. These factors produce a discharge zone much smaller than one conforming to Dilution Zone Guidelines (Ecology, 1985).
5. The average dilution ratio attributable to natural dispersion in the Snohomish River (between the I-5 and Highway 99 bridges) during moderate dropping tide was 8:1.

Table 13. Theoretical levels of metals in sediments assuming a composition of 100 percent fine grains (silts and clays smaller than 64 um).

METAL	NORMALIZED CONCENTRATION (ug/g 100% FINES) WTP CHLOR. LAGOON	DAGMAR'S MARINA	CONTROL (R.M. 11.2)
COPPER	410	1,700	900
ZINC	647	4,600	2,400
NICKEL	161	2,400	1,100
CHROMIUM	199	2,000	900
CADMIUM	16	10	7
LEAD	129	150	60
PERCENT FINES	26	1	2

6. Field results and mathematical analysis suggest that the buildup of effluent concentrations (assuming present discharge performance) in the receiving water through multiple dosing is insignificant. Flushing, downstream dispersion, tidal exchange, and circulation in Port Gardner are important factors that limit the long-term buildup of effluent in the Snohomish River estuary.

7. Among the several options described by Jones and Stokes (1986), the option to discharge equal flows at two sites about a mile apart will theoretically produce the highest water quality overall. However, all options produce similar overall water quality.

8. The analysis of total maximum daily loading suggests that water quality criteria will be met through the year 2005 for all permit parameters including metals and chlorine. This assumes that complete initial dilution is achievable and chlorination deficiencies corrected. Limited width and depth of the main channel may reduce the effective dilution volume of the stream.

9. Estimated total chlorine residual at permit levels in the effluent under normal operating procedures may produce receiving water values nearly ten-fold greater than the EPA acute toxicity criteria outside the present discharge zone. Continuous chlorination during flapper gate closure likely causes acutely toxic conditions in the receiving water following release of stored effluent.

10. The Everett WTP may be a source of lead to sediments near the WTP outfall. However, the metals concentrations in sediments are below apparent effects threshold values (Tetra Tech, 1986b).

RECOMMENDATIONS

1. The present chlorination system should be modified to prevent its operation during periods when the flapper gate is closed. This should not wait for the upgrade of the WTP. It should be done immediately.

2. Jones and Stokes (1986) describe several options for disposal of treated effluent. The option to discharge equal flows at two separate sites will probably produce the most favorable dilution within each discharge zone, although several dilution zone guidelines (Ecology, 1985) will be difficult to achieve.

3. The success of any proposed discharge option depends on obtaining maximum dilution. To ensure this, adequate diffusers should be provided for each outfall and a system that halts discharge during slack current should be considered. The WTP upgrade should include moving the present outfall away from the river bank into the center of the stream. A leak in the discharge line under the riprapped river bank should be located and repaired.

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Appendix A. Analysis of the Everett WTP discharge in terms of the effluent dilution zone guidelines (Ecology, 1985).

Guidelines	Comments
A. The overlapping of two or more dilution zones is not permitted.	
B. New facilities must achieve a dilution ratio (receiving water:effluent) of no less than 100:1 unless studies show that substantially less priority pollutants then typical of secondary treatment are discharged.	
C. Boundary shall be at least 100 feet from the shoreline (measured at MLLW).	At mean lower low water (MLLW) discharge is about 10 feet from shoreline.
D. Upper limit shall be one foot below the surface; lower limit shall be one foot above the bottom.	
E. Length (in the direction of flow) shall be 150 feet on each side of the diffuser plus water depth above diffuser (7-day, 10-year low flow to be used in calculation).	No diffuser present; measurement must be made from end of pipe. Discharge depth is about six feet at MLLW. Length would thus be 156 feet at MLLW.
F. Width (at right angle to flow) shall be the lesser of either of the following:	
1. Diffuser length plus the sum of 50 feet and half the water depth added to each end of diffuser.	NO diffuser present; width would be 53 feet with end of discharge pipe at midpoint.
2. 15 percent of estuary width.	Estuary width is 300 feet; width would be 45 feet; 22.5 feet on either side of the discharge point.

Appendix B. Estimation of dilution from instantaneous dye releases.

A. Time of travel

1. Drop dye at release point; note time (t_o);

2. Record dye concentrations at observation point located at a known distance D downstream;

3. Plot curve of dye concentrations vs. time;

4. Locate on graph the time when maximum levels of dye pass the observation point (Tmax)

$$T = Tmax - t_o$$

where T = travel time (min.)

$$V = D/T * f_i$$

where V = velocity (ft/sec)
D = distance (feet)
f_i = conversion factor (0.0167 min/sec)

B. Flow

1. Determine area under curve of dye levels vs. time.

$$Q = (M/A) * f_i * f_2 * f_3$$

where Q = flow (cfs)
M = weight of dye in 20 percent solution (g)
A = area under curve (ug/L/min)
f_1 = conversion factor (0.0167 min/sec)
f_2 = conversion factor (10^6 ug/g)
f_3 = conversion factor (0.035 cu. ft/liter)

C. Dilution Ratio

$$R = Q/q * f_4$$

where R = dilution ratio
Q = fow (cfs)
q = WTP flow (MGD)
f_4 = conversion factor (1.55 cfs/MGD)