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BELLINGHAM POST POINT POLLUTION CONTROL PLANT DILUTION ZONE ANALYSIS AND RECEIVING WATER STUDY

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ABSTRACT

A receiving water study was conducted by Ecology to evaluate dilution zone characteristics of the Bellingham Post Point Pollution Control Plant. The discharge did not appear to be violating water quality criteria in the receiving water during the Ecology survey. However, a hydrodynamic analysis of the outfall suggests that deeper portions of the diffuser may be susceptible to deposition of solids and possible clogging due to inadequate discharge velocities. Buoyant plume modeling suggests that the effluent plume is likely to surface during the wet season (November-April), although effluent dilution meets Ecology guidelines. During typical dry weather conditions (May-October), the plume is predicted to trap well beneath the surface, although effluent dilution is predicted to be less than Ecology guidelines.

INTRODUCTION

The City of Bellingham and surrounding metropolitan area have a population of approximately 60,000 (CH_2M-Hill, 1984). The metropolitan area is approximately 80 percent sewered. The Post Point Pollution Control Plant (PPPCP), which is located in southwest Bellingham (Figure 1), provides primary treatment of sewage flows from the metropolitan area. Treated effluent is discharged through a multiple port linear outfall diffuser at a depth of 23 meters (76 feet) below MLLW at the diffuser mid-point. The diffuser is 425 feet long and has 35 ports, each 12 feet apart (Figure 2; Appendix A).

The PPPCP outfall discharges treated sewage to Bellingham Bay, which is an eastern extension of the Strait of Georgia and Rosario Strait. The receiving waters are highly influenced by tidal action and exhibit seasonal estuarine characteristics.

A receiving water study was conducted by Ecology between August 24 and 27, 1987. The receiving water study was requested by John Glynn of Ecology's Northwest Regional Office. The survey was conducted by Tim Determan, with assistance from Will Kendra and Don Reif, all from Ecology's Environmental Investigations and Laboratory Services program. A Class II inspection of the treatment plant was conducted during the same period and is documented in a separate Ecology report (Reif, 1988).

METHODS

Receiving water studies in the vicinity of the PPPCP outfall consisted of three major components: 1) vertical profiles of water quality at the boundaries of the dilution zone, 2) dye studies of vertical and horizontal variability of effluent dilution; and 3) measurement of fecal coliform uptake in transplanted uncontaminated clams at several points along the shoreline.

Discharge-zone studies were conducted during slack (or minimal) tidal current, which is likely to produce worst-case conditions for dispersion of effluent. 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 attached to a float anchored at the approximate midpoint of the diffuser line. The diffuser line was located using a combination of position finding and systematic search with a recording depth sounder. Approximate dimensions were estimated using data in CH_2M-Hill (1984). The tethered line could float freely with the direction of surface current. Marks were placed at 50, 100, 200, and 300 feet. The marks were used to fix horizontal points within the grid accurately. A site located about 300 feet up-current from the discharge was also sampled.

Water Quality Sampling

Four water quality monitoring stations were occupied for determination of vertical profiles of temperature, pH, dissolved oxygen, salinity, total phosphorus, nitrate + nitrite N, ammonia N, turbidity and fecal coliform. The four stations included a background site in Bellingham Bay (Figure 1). The three other stations were located as follows: one 300 feet up-current from

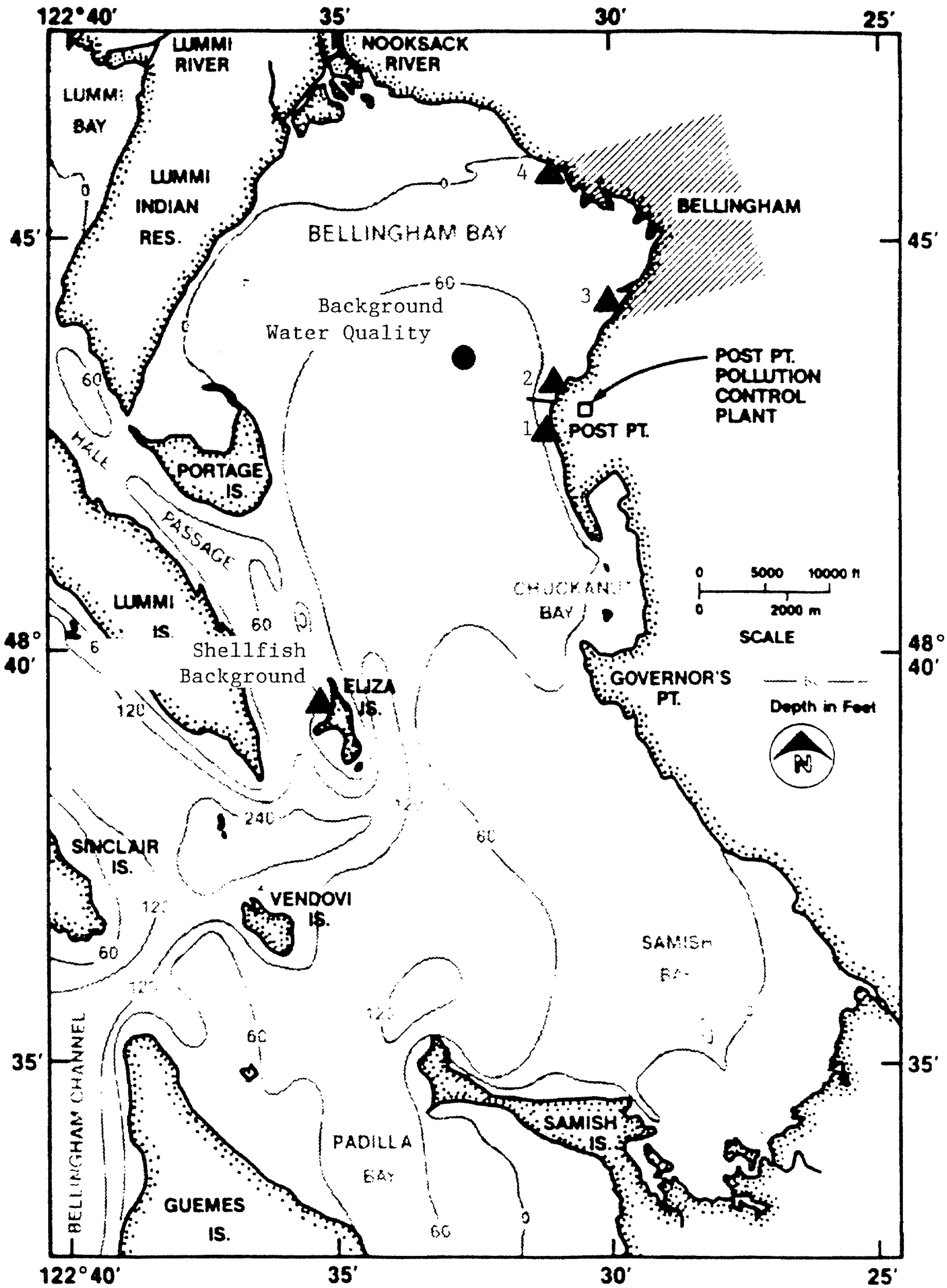


Figure 1. Location of Post Point Pollution Control Plant (CH2M-Hill, 1984). Shellfish incubation sites (▲) and water column background site (●) are shown.

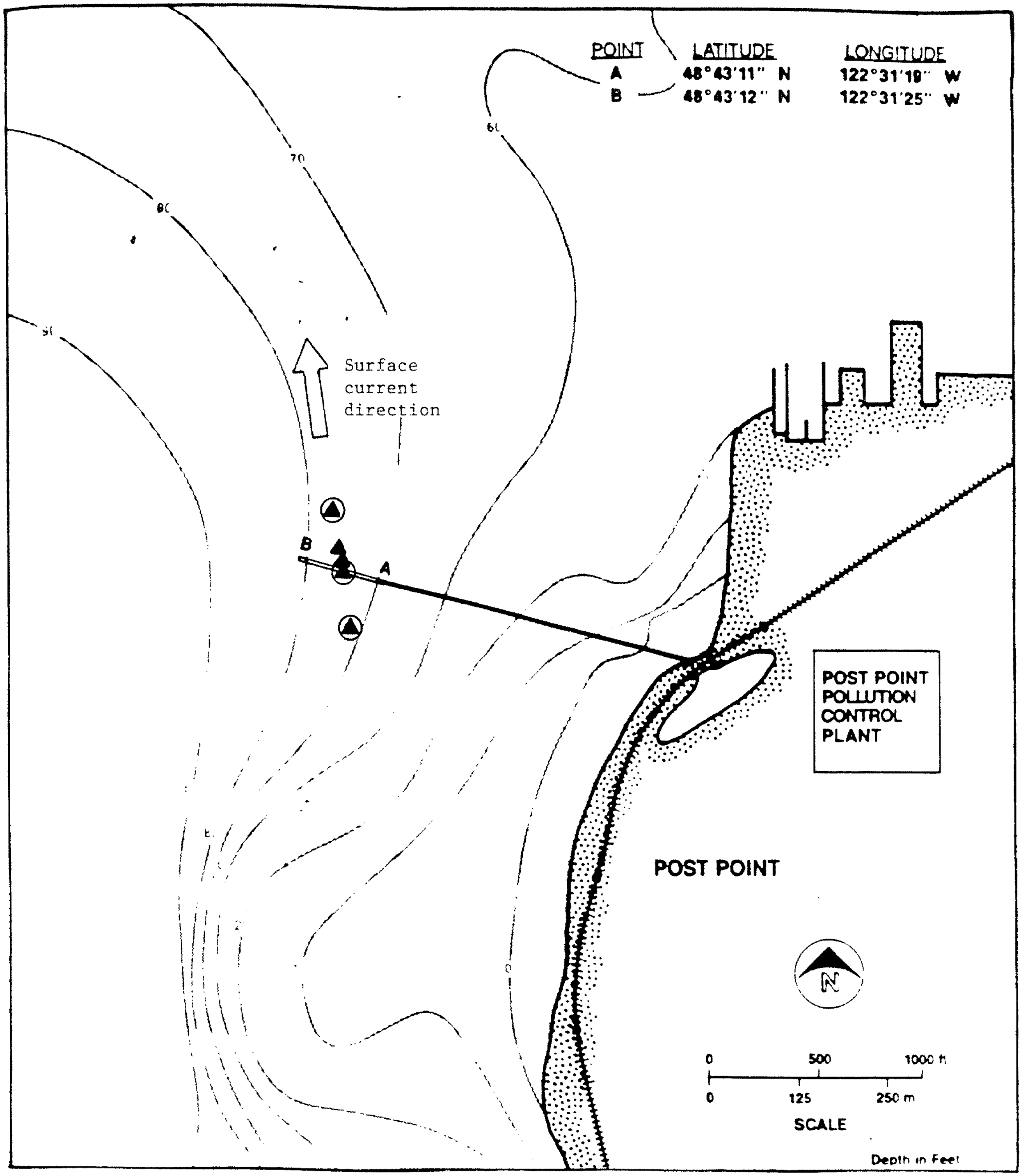


Figure 2. Post Point Pollution Control Plant outfall location, with diffuser section located between points A and B (CH2M-Hill, 1984). Ecology water quality (◯) and dye study (▲) stations are shown.

the diffuser midpoint, one directly over the diffuser midpoint, and one 300 feet down-current from the diffuser midpoint (Figure 2). Vertical sampling was conducted as described in Table 1. Temperature, pH, dissolved oxygen, and salinity were measured in-situ at one meter intervals from the surface to the bottom at each station. A Van Dorn sample bottle was used to collect discrete grab samples at the surface, 12 meter and 19 meter depths at each station for the other water quality parameters (Table 1). Samples were analyzed at Ecology's Manchester Laboratory using standard laboratory techniques (EPA, 1983; APHA *et al.*, 1985).

Dye Study

Rhodamine WT fluorescent dye was used to trace the effluent trapping layer within the discharge zone. A stock dye solution was prepared by thoroughly mixing on site about 12 liters of Rhodamine WT dye (20 percent solution) in a 55 gallon drum. The dye stock solution was injected into the effluent with a peristaltic pump at the Parshall flume at the end of the wastewater treatment plant (WTP) chlorine contact chamber (Reif, 1988). A sample of the injection stock solution was taken at start-up to determine the dye concentration later. The pump flow rate was measured at the beginning and end of injection with a graduated cylinder and a stopwatch. The average dye flow during the period was 0.64 L per minute.

The travel time from the injection point to the diffuser was estimated to be 54 minutes given the dimensions of the outfall line (CH_2M-Hill, 1984) and the average flow rate during the dye study. The WTP flow rate (8.5 MGD) during the dye study was determined from the WTP strip chart flow record. The dye was assumed to be thoroughly mixed with the effluent at the diffuser.

Measurements within the dilution zone (Figure 2) were begun after the dye was well established in the discharge zone. Measurements were taken with a Turner Model 10 fluorometer. Correction factors were determined on all scales at a mid Bellingham Bay point about two nautical miles west of Post Point. A high-volume, continuous flow door was used for sampling. Water was pumped through the sample cell with the pump (6.7 gallons per minute) attached to the end of a 30-meter length of 3/4-inch ID garden hose. The end of the hose was weighted and held vertically as it was lowered to the bottom at each marked reference point on the floating surface line. Measurements were made by moving up-current from the down-current end of the surface reference line. The arrangement permitted good position control within the zone. Vertical profiles of fluorescence were determined at one meter depth intervals from the surface to the bottom at six locations (Figure 2): 1) 300 feet up-current from the diffuser midpoint, 2) directly over the diffuser midpoint, and 3) 50, 100, 200, and 300 feet down-current from the diffuser midpoint.

The concentration of the stock injection solution was calculated by regression from serially diluted subsamples of the stock dye solution. Dye readings (percent fluorescence) from the field were converted to dye concentrations with calibration curves prepared by incrementally diluting aliquots from the sample of injection stock solution. Readings were made on all scales using the same sampling system used in the field.

Table 1. Summary of sampling methods.

Parameter	Sampling Method
Temperature	Hydrolab Surveyor 2, 1 meter intervals
pH	Hydrolab Surveyor 2, 1 meter intervals
Dissolved Oxygen	Hydrolab Surveyor 2, 1 meter intervals
Salinity	Hydrolab Surveyor 2, 1 meter intervals
Total Phosphorus	Van Dorn grabs at 0m, 12m, and 19m
Nitrate + Nitrite N	Van Dorn grabs at 0m, 12m, and 19m
Ammonia N	Van Dorn grabs at 0m, 12m, and 19m
Turbidity	Van Dorn grabs at 0m, 12m, and 19m
Fecal Coliform	Surface grab

Shellfish Sampling

Uncontaminated littleneck clams (*Protothaca sp.*) were obtained from a commercial grower. Fifty adult clams each were placed into plastic mesh bags with enough gravel to cover the clams. Duplicate bags were placed in excavations in the intertidal zone at five locations as shown in Figure 1. A subsample of the clams was immediately taken for fecal coliform analysis prior to transplanting. The transplanted clams were left in place for two weeks, after which they were retrieved and sampled for fecal coliform bacteria.

RESULTS AND DISCUSSION

Effluent Flows

The PPPCP is permitted to discharge a monthly average of 12 MGD from June through September, and 18 MGD from October through May. Daily average flows for the two-year period from January 1986 through December 1987 (Figure 3) were summarized (Table 2). During this period, the plant operated at an average annual flow of 10.26 MGD. Daily discharges ranged from a minimum of 6.91 MGD to a maximum of 39.7 MGD. Ninety percent of the daily average discharges during this period were less than or equal to 12.8 MGD.

Manifold Hydraulics

A multiple port diffuser is generally evaluated hydraulically as a manifold. The main purpose of a multiple port diffuser is to uniformly discharge effluent along the length of the diffuser. This goal is complicated by two major factors--density differences between effluent and seawater, and friction head losses in the diffuser pipe. For level diffusers, the first factor--density differences--does not influence manifold hydraulics. However, for significantly sloped diffusers such as the PPPCP diffuser, density differences may be the principle cause of non-uniform discharge per port along the diffuser (Fischer *et al.*, 1979).

The characteristics of the PPPCP outfall diffuser are presented in Table 3 and Appendix A. The diffuser length is 130 m (425 feet), with equally spaced, uniformly sized bell-mouthed ports. The distribution of discharges from each of the ports may be estimated for any total effluent flow based on a generally accepted hydraulic calculation procedure (Fischer *et al.*, 1979; Rawn *et al.*, 1960), which accounts for density, friction, and local hydraulic head losses. (The calculation procedure is summarized in Appendix B.)

The flow rates for each of the ports was estimated for the original design discharge of 18 MGD using the assumed design slope of the diffuser and the actual as-built slope (Figure 4). The design calculations provided by CH_2M-Hill (Appendix C) were verified (Appendix B), which indicates that the computation procedure used in the present study is the same as that used for the original design. The actual slope of the diffuser, which is approximately three times greater than the design condition, results in approximately a 50 percent difference in discharge from single ports at opposite ends of the diffuser in contrast to the design objective of only a 19 percent difference.

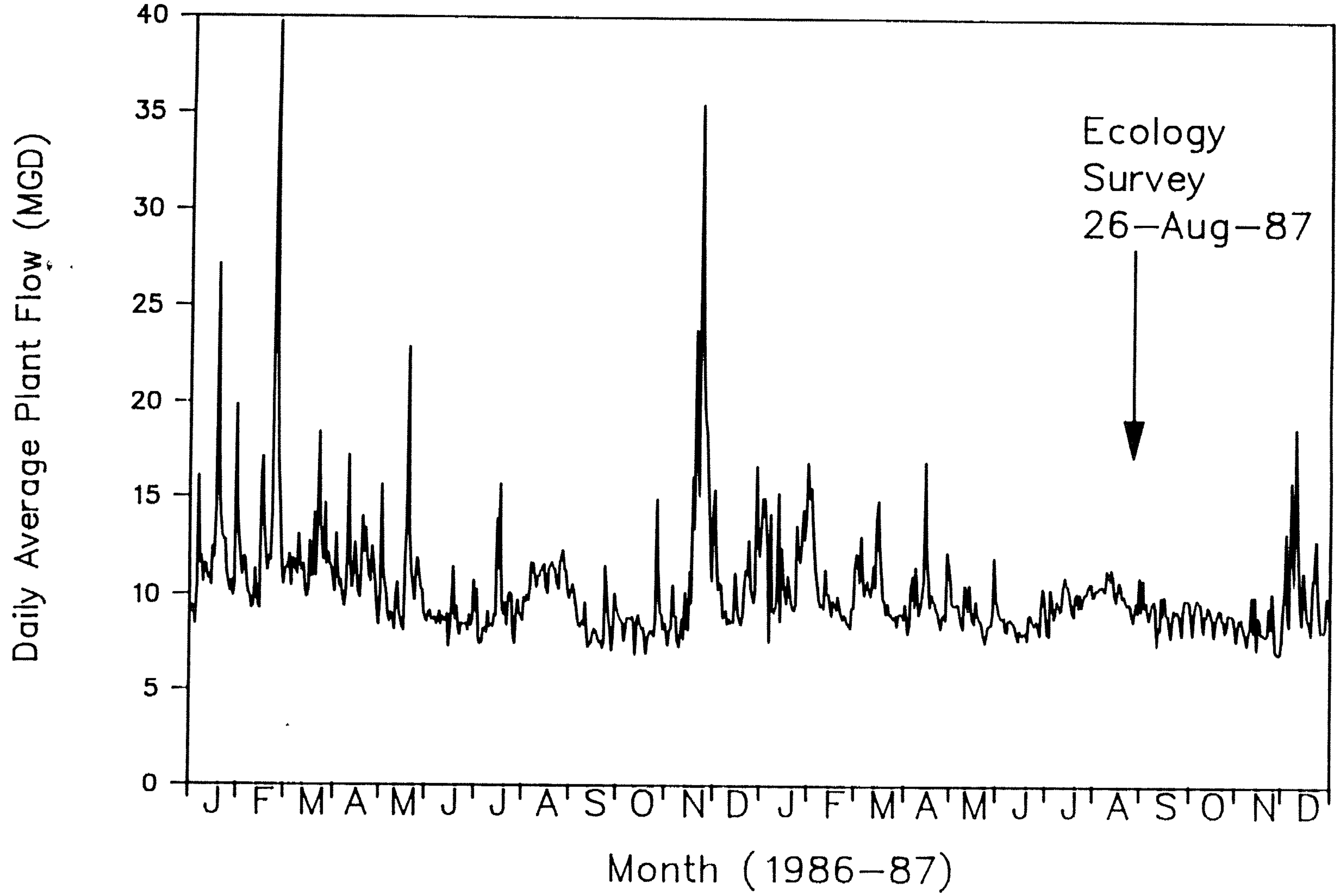


Figure 3. Daily average discharge records for the Post Point Pollution Control Plant for 1986 and 1987.

Table 2. Existing effluent flow characteristics.

Plant Flow Conditions (1)	<----- Flow Rate -----> MGD	CFS	CMS
Minimum Day Flow (2)	6.91	10.7	0.30
Average Dry Weather Flow (3)	9.36	14.5	0.41
Average Wet Weather Flow (3)	11.17	17.3	0.49
Average Canning Season Flow (4)	9.79	15.1	0.43
Average Noncanning Season Flow (4)	10.74	16.6	0.47
Annual Average Flow	10.26	15.9	0.45
Highest 90 percentile Flow (5)	12.82	19.8	0.56
Maximum Day Flow (6)	39.70	61.4	1.74

1) Based on daily plant operating records for January 1986 through December 1987.

2) Minimum daily flow was the 24-hour average recorded on October 12, 1986.

3) The dry weather season is defined as May through October, and the wet weather season is November through April.

4) The canning season is July through December, and the noncanning season is January through June.

5) The 24-hour average flow, at which only ten percent of the recorded flows were higher, recorded January 22, 1986.

6) Maximum daily flow was the 24-hour average recorded on February 24, 1986.

Table 3. Outfall characteristics (CH_2M-Hill, 1984).

Outfall Length (total)	724 m (2,375 ft)
Outfall Length (from shoreline)	613 m (2,010 ft)
Outfall Diameter	1.53 m (60 in)
Diffuser Length	130 m (425 ft)
Diffuser Depth (range)	20.7 m (68 ft) - 25.0 m (82 ft)
Diffuser Depth (midpoint)	23.2 m
Angles of Port Orientation from Horizontal (degrees)	34 @ 45° 1 @ 0°
Port Diameter	15.24 cm (6 in)
Number of Ports	35
Port Spacing	3.66 m (12 ft)
Design Flow Rate per Port	0.022 m^3/sec
Design Diffuser Slope (percent)	1.05
As-built Diffuser Slope (percent)	3.29

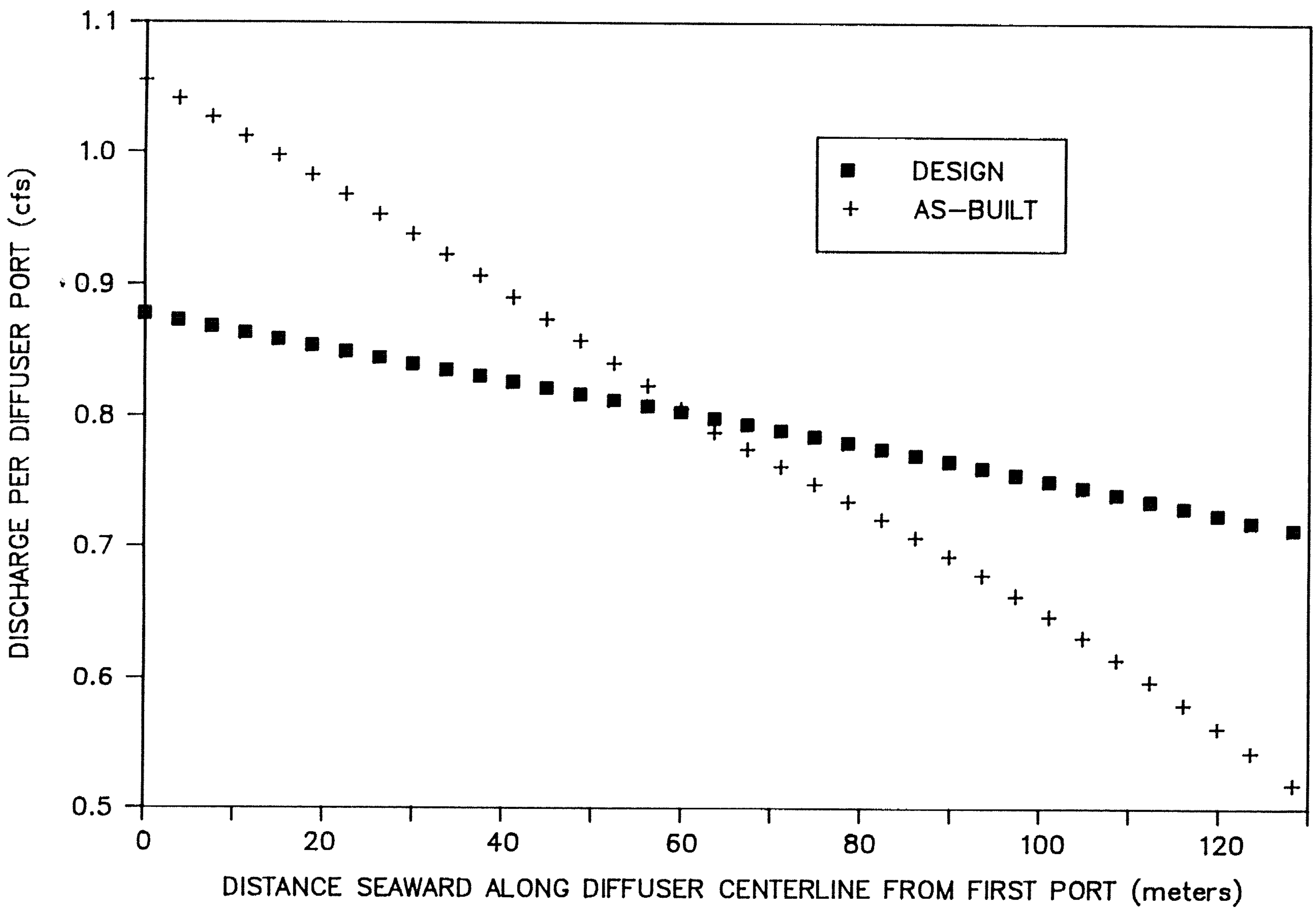


Figure 4. Comparison of diffuser discharge per port for initial design and actual as-built conditions for total plant flow of 18 MGD.

The division of discharge between diffuser ports should be fairly uniform. This objective is impossible to achieve at all flow rates with sloping diffusers, in which case it is generally advisable to achieve relatively uniform flow at average total flow rates and let deeper ports discharge greater than the average port discharge during high flow rates (Rawn *et al.*, 1960). This is typically accomplished by varying port sizes along the diffuser, or using a "Y" or "T" configuration. Allowing substantially less than average discharge from deeper ports is considered to be unsafe because of possible clogging of the deeper part of the diffuser.

The hydraulic analysis for various conditions of total effluent discharge indicates that deeper ports probably do not discharge any effluent under average flow conditions (Figure 5). Of the 35 ports in the diffuser, the last six are predicted to discharge no effluent at the average annual flow rate of 10.26 MGD. For the wet weather and the dry weather average flow rates of 11.17 and 9.1 MGD, the last three and eight ports, respectively, are predicted to discharge no effluent. Therefore, the deepest ports of the diffuser are not expected to discharge effluent most of the time. Uniform flow rates from all ports are expected to be approached only at extremely high discharge rates. Based on the hydraulic analysis, the PPPCP diffuser does not appear to maintain adequate velocities in the deeper portion of the diffuser pipe to prevent deposition of solids and possible clogging of the lower section.

Initial Dilution Considerations

Discharges of municipal wastewater into an estuarine environment generally are buoyant plumes that quickly rise toward the surface and entrain ambient saline water. Initial dilution, which is the rapid turbulent mixing of wastewater with seawater, is influenced primarily by the momentum and buoyancy of the effluent (EPA, 1985).

When effluent is discharged from a diffuser port, buoyancy and momentum cause a plume to develop with increasing size as it rises toward the surface and entrains more and more seawater. As this process occurs, the entrainment slows down until the plume either reaches a neutrally buoyant position or reaches the water surface. If the vertical density gradient in the estuary is sufficient (e.g, a pycnocline), the plume can be trapped at a level of neutral buoyancy below the water surface. Otherwise, the diluted effluent plume can reach the water surface. The plume at this point becomes influenced largely by ambient advective and diffusive process of current movement. The dilution of effluent, therefore, occurs in two initial stages: first as a rapidly mixed buoyant plume, and next as a horizontally transported and diffused plume that is dependent on ambient currents.

The zone of rapid initial mixing of the buoyant plume is commonly referred to as the zone of initial dilution (ZID). The ZID is defined as the region of initial mixing surrounding the outfall diffuser and includes the underlying seabed (EPA, 1982). The ZID defines a discrete concentration isopleth for each discharge rate, density, and current velocity profile. In practice, the ZID defined for Clean Water Act Section 301(h) is regularly shaped (e.g., rectangular, circular, or "Y" shaped) to encompass the range of theoretically calculated dimensions (EPA, 1985).

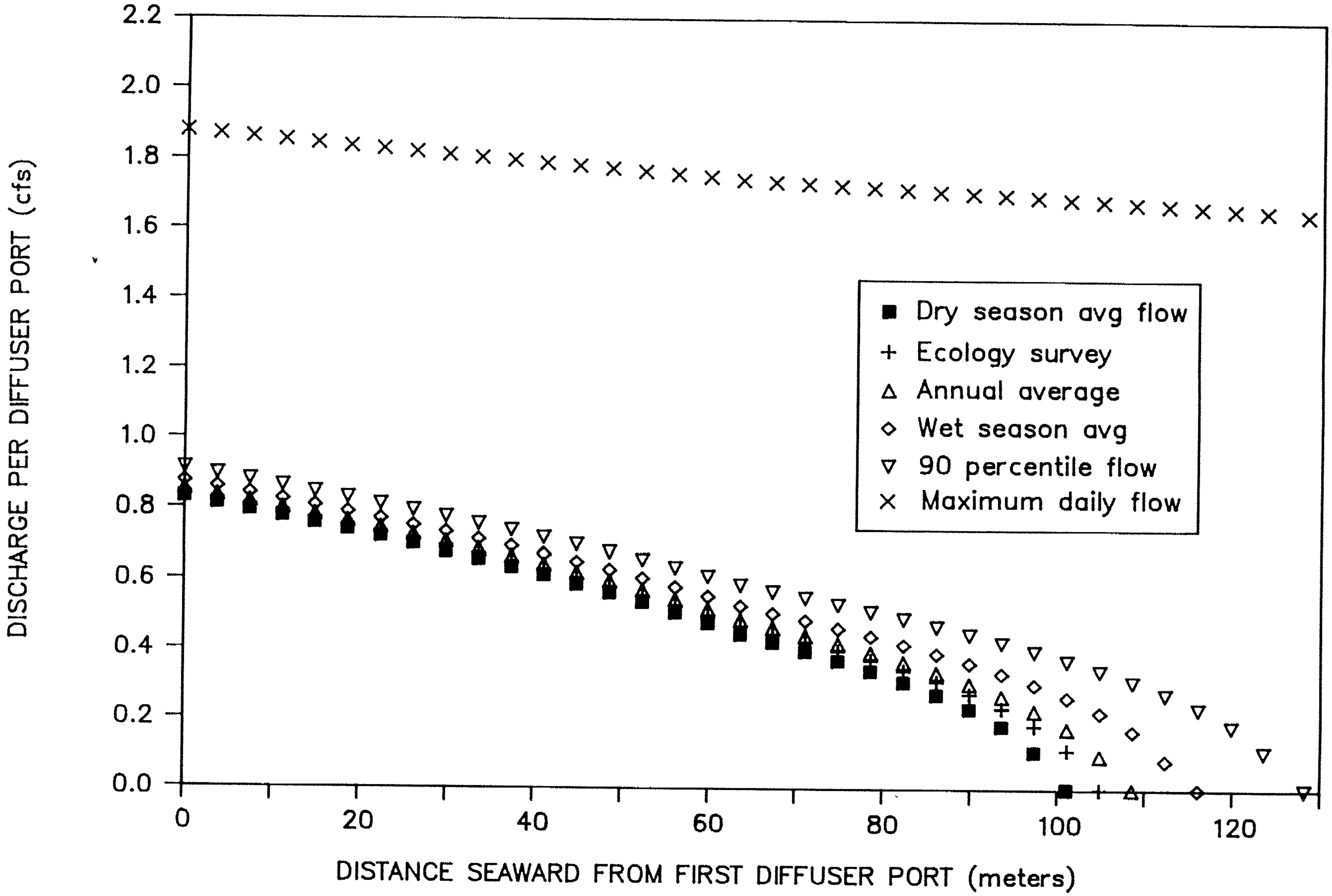


Figure 5. Diffuser discharge per port for various effluent discharge flow rates.

The State of Washington has established general requirements for boundaries of dilution zones (Ecology, 1985). The required dilution zone boundary (Figure 6) represents a rectangular region inside of which water quality criteria may be exceeded. However, water quality criteria must be met outside of the regulatory ZID boundary. The regulatory ZID dimensions and location establish a sampling perimeter at which conformance with water quality criteria is evaluated by monitoring.

Dilution is usually defined as follows (Fischer *et al.*, 1979):

$$S = \frac{\text{total volume of a sample}}{\text{volume of effluent contained in the sample}}$$

Therefore, dilution (S) is the reciprocal of the volume fraction of effluent contained in a sample (e.g., a dilution factor of 100 corresponds to one percent effluent; dilution of 20 is five percent effluent; etc.). The concentration of any pollution contained in the effluent can be estimated in the dilution zone as follows (Fischer *et al.*, 1979):

$$C = C_b + (1/S)(C_e - C_b)$$

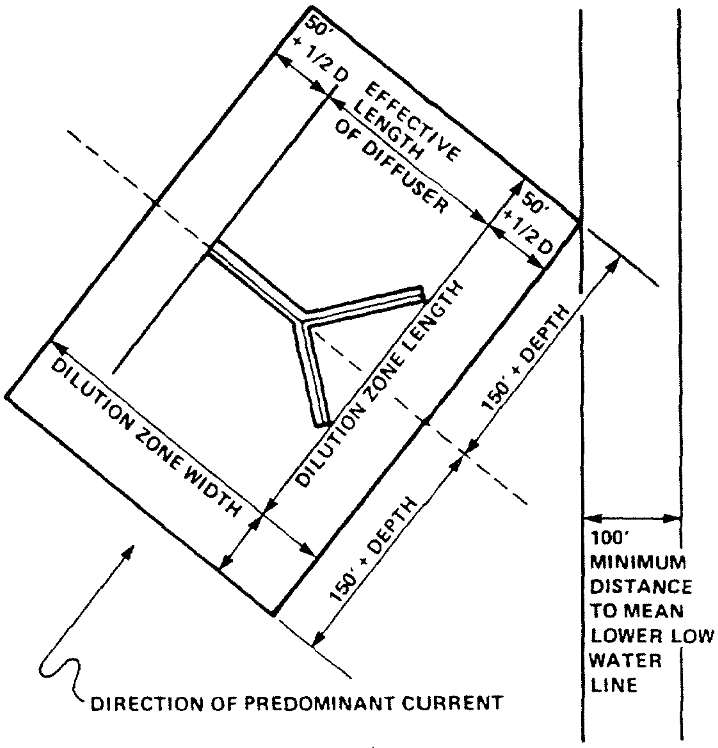
where C = pollutant concentration after dilution
C_b = background ambient pollutant concentration
C_e = effluent pollutant concentration
S = effluent dilution.

A minimum dilution of 100 is generally recommended at the boundary of the regulatory ZID (Ecology, 1985). The dilution guideline of 100 is based on comparison of the range of toxicant levels in municipal wastewater effluents throughout the United States with existing water quality criteria (Joy, 1985).

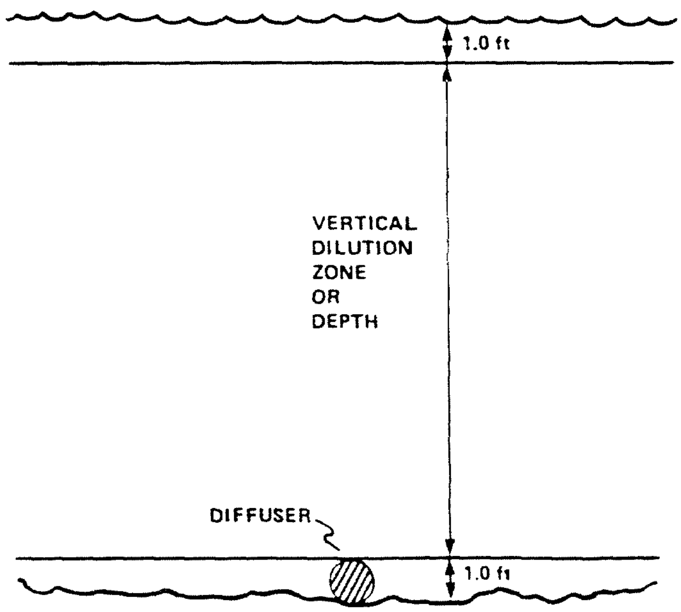
Plume Modeling

Initial dilution can be calculated with several mathematical models available from EPA (EPA, 1985). The major factors which affect initial dilution include discharge depth, flow rates, effluent density, ambient density profiles, ambient current speed and direction, and diffuser port sizes, port spacing, and port orientation. Ambient density profiles are generally determined from monitoring data. For the PPPCP outfall, an intensive study of seasonal density profiles was conducted in 1984 (CH_2M-Hill, 1984). Vertical density gradients were found to be minimally stratified in January, and maximum stratification was observed in August (Figure 7). This finding was consistent with previous studies in Bellingham Bay (Collias *et al.*, 1966) and throughout Puget Sound.

The annual cycle of density gradients in Bellingham Bay is controlled by the inflowing ocean water from the Strait of Juan de Fuca and the seasonal changes in freshwater discharges, primarily from the Nooksack River. The winter period of minimal density gradients and summer stratification represent two distinct scenarios which are expected to result in different initial mixing characteristics for a given effluent discharge. Therefore, initial dilution was

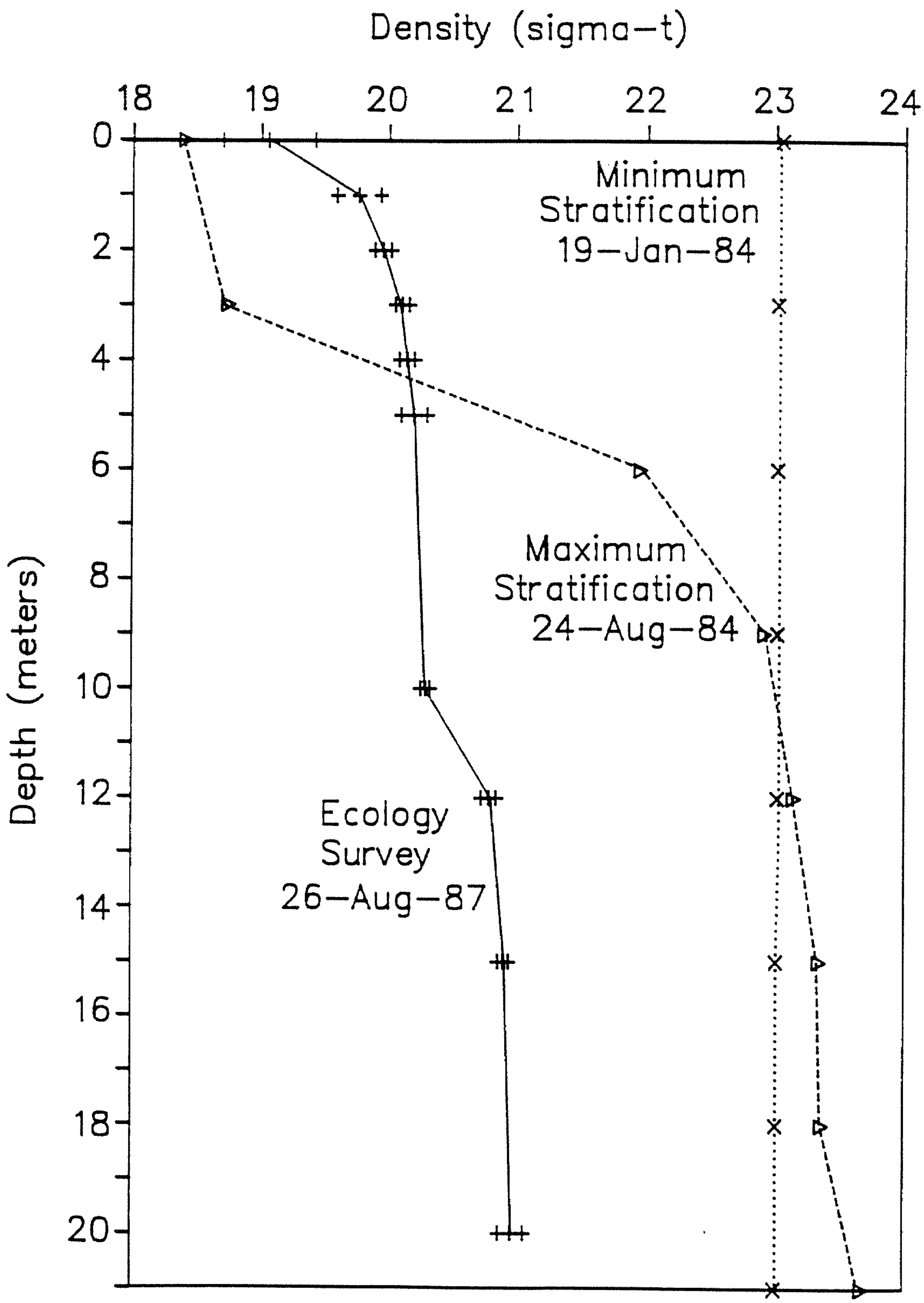


ESTUARY DIFFUSER SECTION ORIENTATION



ESTUARY AND MARINE WATER
VERTICAL DILUTION ZONE

Figure 6. Ecology guidelines for horizontal and vertical boundaries of estuarine dilution zones (Ecology, 1985).



Firgure 7. Vertical density profiles in Bellingham Bay at the Post Point Pollution Control Plant outfall location.

estimated for wet weather and dry weather discharges separately, based on expected seasonal conditions of stratification and flow.

Since ambient currents may also affect initial dilution, a modest current velocity, usually the lowest ten percentile, is often used in plume predictive modeling. However, the sensitivity of many current measurements often does not allow detection of current velocities as low as the ten percentile velocity. Currents were monitored in Bellingham Bay as part of the outfall site evaluation by CH_2M-Hill, but the sensitivity of the meters used did not allow measurement of current velocities less than two to five cm/sec, which represented approximately the median velocity (CH_2M-Hill, 1984). Therefore, the conservative assumption of no current velocity was used in the present ZID modeling. The current data from CH_2M-Hill's study did indicate that current directions were predominantly along shore rather than on shore at the outfall site. However, during some periods of several days duration, there may be very little net transport in any direction and velocities may be very low at times.

The EPA model "UPLUME" (EPA, 1985) was used to estimate plume dilution for the PPPCP diffuser for various representative scenarios. The scenarios which were evaluated included:

- Maximum plant discharge (39.7 MGD) during the period of minimum stratification (January 19, 1984)

- Wet weather seasonal average plant discharge (11.17 MGD) during the period of minimum stratification (January 19, 1984)

- Dry weather seasonal average plant discharge (9.36 MGD) during the period of maximum stratification (August 24, 1984)

- Discharge (9.8 MGD) and vertical density profile (Figure 7) observed during the Ecology survey of August 1987.

The discharge from each port in the diffuser (Figure 8) was estimated based on hydraulic analysis (Rawn *et al.*, 1960). As discussed above, the discharge rate per port is predicted to vary considerably along the diffuser. Average initial dilution in the plume is also predicted to vary along the length of the diffuser (Figure 8), mainly because of decreasing discharge per port and increasing depth from the nearshore to the offshore end. The initial dilution predictions for the first port (maximum per port discharge based on hydraulic analysis) are summarized in Table 4.

The maximum discharge condition, which is assumed to coincide with minimal vertical density stratification, is predicted to result in initial dilution of 94 at the nearshore end to 101 at the offshore end (Figure 8). However, the plume is predicted to reach the water surface along the entire length of the diffuser. This scenario is also predicted to result in the largest plume. The ZID is predicted to intersect the surface with a width of about seven meters along the entire 130 meter length of the diffuser (Figure 8).

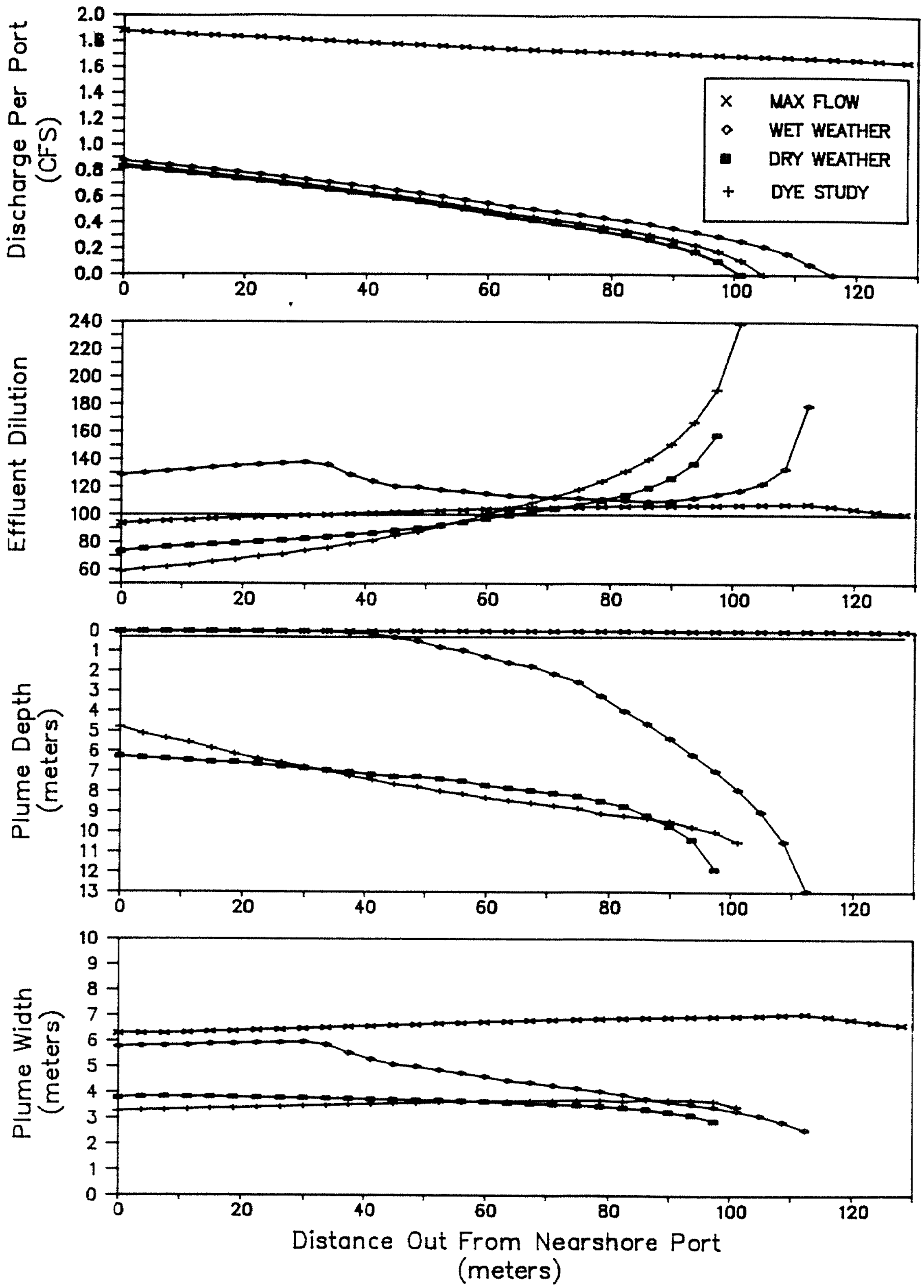


Figure 8. Predicted dilution zone characteristics for various discharge and ambient conditions.

Table 4. Average initial dilutions of effluent from the first port for various scenarios of total plant discharge (1986-87 conditions) and ambient stratification (CH_2M-Hill, 1984).

	Total Plant Flow (MGD)	Initial Dilution	Depth to Plume (m)
Minimum Stratification (January 19, 1984)			
Minimum Daily Flow	6.91	136	0
Dry Weather Average Flow	9.36	131	0
Annual Average Flow	10.26	130	0
Wet Weather Average Flow	11.17	129	0
90%tile Daily Flow	12.82	127	0
Maximum Daily Flow	39.70	94	0
Maximum Stratification (August 24, 1984)			
Minimum Daily Flow	6.91	76	6.3
Dry Weather Average Flow	9.36	74	6.2
Annual Average Flow	10.26	73	6.2
Wet Weather Average Flow	11.17	72	6.2
90%tile Daily Flow	12.82	71	6.1
Maximum Daily Flow	39.70	53	5.2
Ecology Guidelines	--	>100	>0.3

The wet season average discharge is also predicted to result in a surfacing plume (Figure 8). However, the seasonal average condition would result in higher initial dilution of 129 to 136 in the surfacing region of the plume and a smaller areal extent of the plume. In contrast to the maximum flow condition, the surfacing region of the ZID would be smaller, and would extend along the first 35 meters of the diffuser with a width of approximately six meters.

The dry season average discharge plume would be expected to trap well beneath the surface (Figure 8; Table 4) due to the expected vertical density profile. Although the plume would not reach the surface, the predicted initial dilution factors range from 74 at the nearshore end (maximum discharge per port) to 158 at the offshore end (nearly negligible discharge).

The discharge at the time of the Ecology survey was similar to the average during the canning season, which is somewhat higher than the dry season average (Table 2). The vertical stratification observed during the survey was less pronounced than the maximum observed stratification, although the pycnocline depth was lower (Figure 7). The combination of higher flow rates and lower pycnocline depth resulted in lower predicted initial dilution of only 56 at the nearshore end, but deeper trapping depth.

The depth of the pycnocline appears to exert an important influence on initial dilution. While discharge from the first diffuser port during the Ecology survey was nearly identical to that predicted for the dry weather average flow, initial dilution was predicted to be substantially lower during the Ecology survey (56 versus 74; see Table 4) due primarily to the lower pycnocline depth (Figure 7). Therefore, even though the vertical stratification was less pronounced, the ambient conditions during the Ecology survey appeared to be worse than those during observed maximum stratification.

The scenarios that were evaluated (Figure 8) probably represent the likely range of conditions at the PPPCP outfall. The major implications of the plume modeling were:

- Reasonable worst-case conditions during the wet season probably result in a surfacing plume, although the initial dilution is only slightly less than 100 for the maximum flow and greater than 100 on the average.

- Vertical stratification during the dry season probably results in plume trapping well beneath the surface with initial dilution probably less than 100.

- Hydraulic characteristics of the diffuser result in poorest dilution at the nearshore end, where discharge per port is greatest and port depth is shallowest. Initial dilution may be much less than 100 at the nearshore end during stratified ambient conditions.

Far-Field Dilution

After the period of initial dilution, the diluted effluent plume is influenced largely by ambient advective and diffusive processes of current movement. Subsequent dilution occurs as the plume drifts with ambient currents. The model of Brooks (1960) was used to predict far- field dilution of the plume, assuming an initial plume width of 100 meters. The Brooks model is dependent on an assumed horizontal diffu sion coefficient (K), which increases as some power of a length scale corresponding to initial plume width:

$$K = aL^n$$

where

$a = 0.01\ cm^{2/3}/sec$ (Fischer *et al.*, 1979; Williams, 1985)
L = plume width (cm)
n = exponent. Typical values for open coastal waters range from one to 4/3 (Williams, 1985).

Figure 9 presents the estimated far-field dilution for the range of expected horizontal diffusion. In general, far-field dilution is expected to increase overall dilution by a factor of one to 2.5 within the first two hours of plume travel with the ambient currents. For the typical current speeds of one to four cm/sec (CH_2M-Hill, 1984), the plume would be expected to reach the boundary recommended by Ecology (Figure 6) within 0.5 to two hours. Therefore, the additional dilution presented in Figure 9 probably represents the far-field contribution to overall dilution before the plume crosses the guidelines boundary. A conservative assumption of no far-field dilution (i.e., far-field dilution factor of one) appears to be justified given the range of values in Figure 9. Therefore, water quality criteria should be met by initial dilution estimated by the plume models discussed above.

Dye Study

A dye study was conducted to aid in the location of the diffuser. The results of the dye study also provide an estimate of initial dilution. However, the likely variation in discharge and initial dilution along the length of the diffuser was not known at the time of the survey. Only one transect of observations was made, which was across the midpoint of the diffuser in the direction of the along-shore surface current (Figure 2). Dye concentrations in the vicinity of the diffuser were measured at six locations, including four down-current from the diffuser (300 feet, 200 feet, 100 feet, and 50 feet down-current from the diffuser midpoint), one immediately above the diffuser midpoint, and one 300 feet up-current from the diffuser midpoint.

The dye measurements indicate that effluent was detected between depths of 11 and 24 meters (Table 5). The plume model discussed above predicted effluent trapping between five and 13 meters depth. The plume model predicts initial dilution of 59 to 239 along the diffuser. In comparison, the dye study found effluent dilution to range from 140 to 14,000 in the ZID vicinity. In general, the dye study indicated that effluent dilution probably was better than the Ecology guideline of 100, whereas the plume model predicts adequate dilution (239) at the far end of the diffuser, but less than adequate dilution (59) at the nearshore port.

Part of the discrepancy between the dye study results and the plume model results may be due to imprecise location of the diffuser midpoint during the dye study. The dye study results are comparable to plume model results for diffuser ports about 22 meters (73 feet) offshore from the diffuser midpoint. Another possible source of error in the dye study could be the presumed current direction for the plume. Surface currents were assumed to indicate the direction of plume travel. Deeper currents may differ from surface currents, leading to erroneous

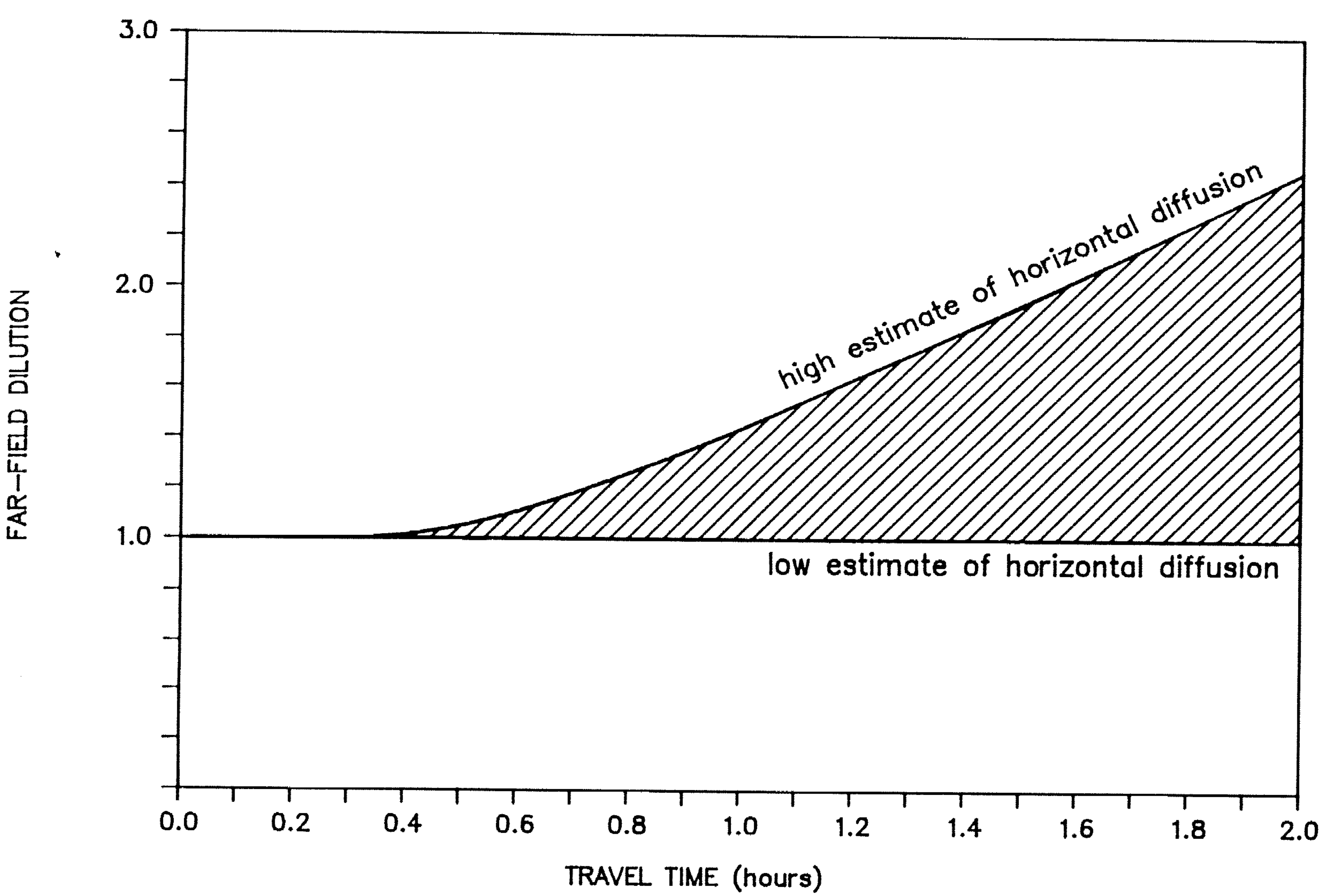


Figure 9. Predicted far-field dilution with travel time from initial dilution zone.

Table 5. Effluent dilution ratios based on results of Ecology survey dye study (e.g. effluent dilution ratio of 100 corresponds to one percent effluent, dilution ratio of 1000 is 0.1% effluent, etc.).

Depth (m)	Up-current 300 Feet	Directly Above Diffuser Midpoint	Down-Current 50 Feet	Down-Current 100 Feet	Down-Current 200 Feet	Down-Current 300 Feet
0	-	-	-	-	-	-
1	-	-	-	-	-	-
2	-	-	-	-	-	-
3	-	-	-	-	-	-
4	-	-	-	-	-	-
5	-	-	-	-	-	-
6	-	-	-	-	-	-
7	-	-	-	-	-	-
8	-	-	-	-	-	-
9	-	-	-	-	-	-
10	-	-	-	-	-	-
11	9,100	-	-	-	-	9,100
12	2,100	-	1,400	1,400	1,200	2,100
13	-	-	-	-	-	-
14	-	-	6,800	-	-	-
15	-	140	14,000	-	-	-
16	-	230	6,800	170	-	-
17	-	-	-	140	-	-
18	-	-	250	910	-	-
19	-	-	180	-	-	-
20	-	390	5,500	-	-	-
21	-	-	-	-	-	-
22	-	-	-	-	-	-
23	-	-	-	-	-	-
24	-	-	14,000	-	-	-
25	-	-	-	-	-	-
26	-	-	-	-	-	-
27	-	-	-	-	-	-

characterization of "up-current" and "down-current" sampling sites. Effluent was detected in equal concentrations at both the presumed "up-current" and "down-current" stations located 300 feet from the diffuser midpoint, which suggests that surface currents may not indicate the direction of currents at the depth of the plume.

Water Quality

Results of water quality sampling are presented in Table 6 and Table 7. The water column was stratified at the time of sampling (Figure 7 and Table 6). In general, the period of maximum stratification occurs in late summer (around August) when the combination of upwelling and surface warming produce the greatest vertical density gradients. Consequently, dissolved oxygen generally is depleted at lower depths and may be super-saturated in surface waters due to algal productivity. The conditions during the Ecology survey indicate no significant differences between background conditions and those in the vicinity of the outfall for dissolved oxygen profiles (Table 6). Nutrient concentrations at mid-depth (12 meters) appeared to be elevated near the outfall, and were similar to concentrations expected for an approximate dilution factor of 100 (Table 7). This finding is consistent with the theoretical effluent dilution and trapping layer discussed above.

Priority pollutant metals and organics were sampled (Reif, 1988) in a 24-hour effluent composite (Table 8). Of the metals and organics which were detected, the concentrations following initial dilution are predicted to be well below applicable aquatic life criteria. The complete list of compounds analyzed in the effluent samples are presented in Reif, 1988.

Shellfish Quality

Results of the clam implantation study are presented in Table 9. Poor survival of clams was noticed at the most distant stations in Bellingham Bay from the PPPCP outfall (Table 9, Figure 2). Survival was comparable at the Eliza Island background site and Stations 1 and 2 near the outfalls. The highest levels of fecal coliform were observed at Station 1 near the outfall. Fecal coliform levels at Station 1 exceeded FDA guidelines for shellfish quality after two weeks at the station, and were greater than ten times higher than the control and background (Eliza Island) samples. Elevations in clam fecal coliform content may have been due to loading from the outfall, although effluent and ZID levels during the Ecology survey were relatively low (Table 7). Other nearshore discharges may also have contributed to the observed increases in clam tissue fecal coliform.

Table 6. Vertical profiles of temperature, pH, dissolved oxygen and salinity.

Station	Date	Depth (meters)	Temperature (°C)	pH (SU)	Dissolved Oxygen (mg/L)	Dissolved Oxygen (% sat)	Salinity (ppt)
Background	26-Aug-87	0	17.34	8.46	10.58	129%	26.78
		1	16.72	8.48	10.50	127%	26.94
		2	15.76	8.45	10.45	124%	27.13
		3	14.82	8.37	9.54	111%	27.12
		4	14.66	8.33	10.26	119%	27.28
		5	14.63	8.21	10.17	118%	27.37
		10	13.54	8.05	8.69	99%	27.07
		12	12.99	7.91	7.19	81%	27.37
		15	12.43	7.76	5.70	63%	27.66
		20	11.93	7.62	6.13	67%	27.46
Up-current 300 feet	26-Aug-87	0	16.85	8.12	10.94	133%	27.69
		1	16.64	8.13	10.88	132%	27.55
		2	15.92	8.14	10.94	131%	27.34
		3	15.43	8.12	10.75	127%	27.52
		4	14.98	8.06	10.28	120%	27.34
		5	14.85	8.05	10.11	118%	27.43
		10	13.84	7.90	7.91	90%	27.36
		12	12.36	7.64	6.39	71%	27.50
		15	12.30	7.61	6.17	68%	27.70
		20	11.60	7.52	5.37	59%	27.95
Immediately Above Diffuser Midpoint	26-Aug-87	0	16.74	8.11	10.61	127%	25.43
		1	16.76	8.10	10.39	127%	27.93
		2	15.67	8.10	10.59	126%	27.42
		3	15.35	8.08	10.52	124%	27.37
		4	15.05	8.06	10.43	123%	27.61
		5	14.67	7.99	9.71	113%	27.67
		10	13.58	7.82	8.10	92%	27.24
		12	12.28	7.60	6.67	74%	27.43
		15	12.09	7.53	5.76	63%	27.53
		20	11.90	7.52	5.65	62%	27.53
Down-current 300 feet	26-Aug-87	0	16.55	8.13	10.72	129%	26.06
		1	16.79	8.10	10.08	122%	27.06
		2	16.47	8.12	10.67	129%	27.70
		3	15.75	8.13	10.91	130%	27.69
		4	15.29	8.10	10.55	124%	27.30
		5	14.83	8.06	10.14	118%	27.08
		10	13.80	7.86	8.03	92%	27.26
		12	12.60	7.67	6.45	72%	27.75
		15	12.17	7.63	6.41	71%	27.78
		20	11.86	7.55	5.63	62%	27.66

Table 7. Summary of water column nutrients, turbidity and fecal coliform.

Station	Date	Depth (M)	Total P (mg/L)	Nitrite-Nitrate N (mg/L)	Ammonia N (mg/L)	Turbidity (NTU)	Fecal Coliform (#/100mL)
BACKGROUND	26-Aug-87	0	0.04	0.01 K	0.01 K	1 K	1 K
		12	0.06	0.08	0.03	1 K	
		19	0.07	0.20	0.03	1 K	
UP-300FT	26-Aug-87	0	0.06	0.01 K	0.01 K	1	1 K
		12	0.08	0.16	0.05	1 K	
		19	0.01 K[2]	0.20	0.05	1 K	
OUTFALL	26-Aug-87	0	0.04	0.01 K	0.01 K	2	1
		12	0.13	0.17	0.18	2	
		19	0.08	0.20	0.06	1	
DN-300FT	26-Aug-87	0	0.05	0.01 K	0.01 K	1 K	2
		12	0.08	0.15	0.05	1 K	
		19	0.08	0.19	0.05	1 K	
EFFLUENT[1]	26-Aug-87						
Undiluted Composite Sample			4.95	0.12	15.50	28	47[3]
Calculated 100:1 Dilution			0.11	0.10	0.18	1	1

FOOTNOTE:

1) Average of Bellingham and Ecology 24-hour composite samples; except fecal coliform, which is average of three grabs (Reif, 1988). The calculated dilution is based on mixing of effluent with depth-averaged concentrations from the background site at 100:1 dilution.

2) "K" delimeter indicates value below lower limit of detection.

3) Average of three grab samples.

Table 8. Summary of effluent priority pollutants and initial dilution.

	Effluent Composite (25-Aug to 26-Aug)	Reasonable Worst-Case Dilution for 90%tile Effluent Flow (71:1)	Ecology Guideline Dilution (100:1)	EPA (1986) Saltwater Aquatic Life Chronic	EPA (1986) Saltwater Aquatic Life Acute
PRIORITY POLLUTANT METALS DETECTED					
Chromium	27	0.380	0.270	50	1100 *
Copper	44	0.620	0.440	2.9	2.9
Lead	8	0.113	0.080	5.6	140
Mercury	0.3	0.004	0.003	0.025	2.1
Zinc	60	0.845	0.600	86	95
PRIORITY POLLUTANT ORGANICS DETECTED					
Methylene Chloride	1 mb	0.014	0.010	12000	6400
Acetone	210	2.958	2.100	--	--
Chloroform	13	0.183	0.130	--	--
Benzene	2 j	0.028	0.020	700	5100
Toluene	17	0.239	0.170	5000	6300
Total Xylenes	8	0.113	0.080	--	--
Benzyl Alcohol	15 j	0.211	0.150	--	--
4-Methylphenol	84	1.183	0.840	--	--
Di-n-Butylphthalate	4 m	0.056	0.040	--	--

* = criteria for chromium(VI).
m = estimated value of analyte found and confirmed by analyst, but with low spectral match.
b = analyte was found in blank as well as sample.
j = estimated value when result is less than specified detection limit.

Table 9. Results of littleneck clam implantation studies in Bellingham Bay

Location	Percent Survival (%)	Fecal Coliform (#/100gm)	Sample Date	Comment
Control[a]	--	40	26 Aug 87	Not planted
Eliza[b]	57	<18	09 Sep 87	Collected after two weeks
1	58	490	09 Sep 87	Collected after two weeks
2	68	<18	09 Sep 87	Collected after two weeks
3	3	--	09 Sep 87	Collected after two weeks
4	0	--	09 Sep 87	Collected after two weeks
FDA Guideline	--	230	--	--

[a]Control samples were not implanted. The control sample represents a subsample of the transplanted clams prior to implantation in Bellingham Bay

[b]Background site located on northwest shore of Eliza Island, approximately 4.8 nautical miles southwest of Post Point (Figure 1).

CONCLUSIONS AND RECOMMENDATIONS

Bellingham's PPPCP plant did not appear to be violating water quality criteria in the receiving water during the Ecology survey. However, a hydrodynamic analysis of the outfall and buoyant plume modeling revealed the following:

- Typical conditions of discharge and ambient stratification probably result in a surfacing plume during the wet season (November-April), although initial dilution is probably better than the Ecology guideline.

- Typical conditions of discharge and ambient stratification during the dry season (May-October) probably result in plume trapping well beneath the surface. However, initial dilution in the trapping layer is probably less than the Ecology guideline of 100 at the ZID boundary.

- Hydraulic characteristics of the diffuser result in uneven distribution of discharge between ports along the diffuser. The deepest ports of the diffuser are not expected to discharge effluent most of the time. Based on the hydraulic analysis, the PPPCP diffuser does not appear to maintain adequate velocities in the deeper portion of the diffuser pipe to prevent deposition of solids and possible clogging of the lower section.

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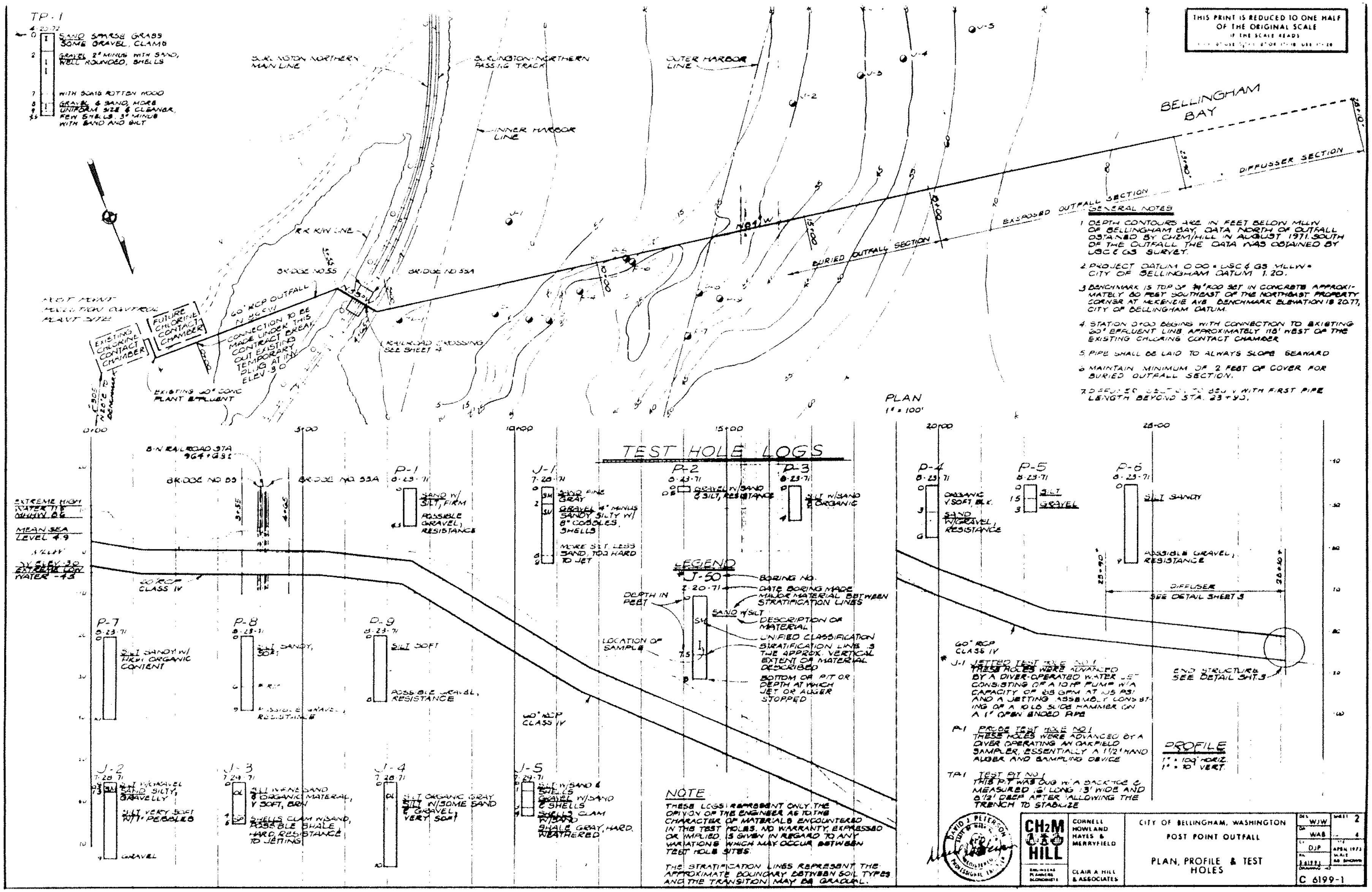
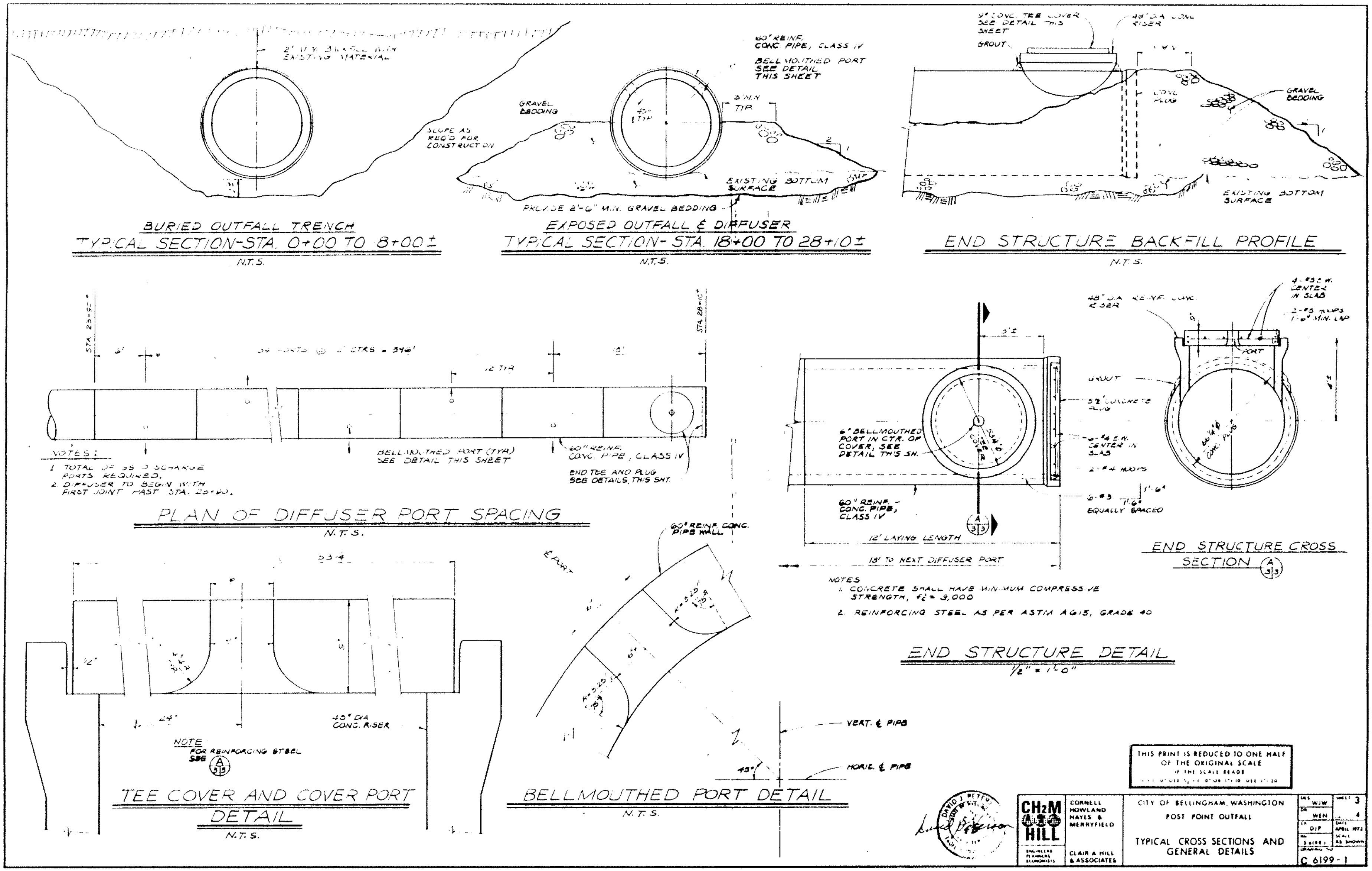
APPENDIX A

Diffuser Design


THIS PRINT IS REDUCED TO ONE HALF OF THE ORIGINAL SCALE
TP-1
SAND SPARSE GRASS SOME GRAVEL, CLAMS
BURLINGTON NORTHERN PASSING TRACK
OUTER HARBOR LINE
INNER HARBOR LINE
BELLINGHAM BAY
DIFFUSSER SECTION
EXPOSED OUTFALL SECTION
BURIED OUTFALL SECTION
R.R. R/W LINE
BRIDGE NO. 55
BRIDGE NO. 55A
60" RCP OUTFALL
EXISTING CHLORINE CONTACT CHAMBER
FUTURE CHLORINE CONTACT CHAMBER
RAILROAD CROSSING SEE SHEET 4
EXISTING 60" CONC PLANT EFFLUENT
GENERAL NOTES
1 DEPTH CONTOURS ARE IN FEET BELOW MLLW OF BELLINGHAM BAY. DATA NORTH OF OUTFALL OBTAINED BY CH2M/HILL IN AUGUST 1971. SOUTH OF THE OUTFALL THE DATA WAS OBTAINED BY USC & GS SURVEY.
2 PROJECT DATUM 0.00 = USC & GS MLLW = CITY OF BELLINGHAM DATUM 1.20.
3 BENCHMARK IS TOP OF ¾" ROD SET IN CONCRETE APPROXIMATELY 80 FEET SOUTHEAST OF THE NORTHEAST PROPERTY CORNER AT McKENZIE AVE. BENCHMARK ELEVATION IS 20.77, CITY OF BELLINGHAM DATUM.
4 STATION 0+00 BEGINS WITH CONNECTION TO EXISTING 60" EFFLUENT LINE APPROXIMATELY 118' WEST OF THE EXISTING CHLORINE CONTACT CHAMBER.
5 PIPE SHALL BE LAID TO ALWAYS SLOPE SEAWARD.
6 MAINTAIN MINIMUM OF 2 FEET OF COVER FOR BURIED OUTFALL SECTION.
PLAN
1" = 100'
TEST HOLE LOGS
EXTREME HIGH WATER
MEAN SEA LEVEL 4.9
EXTREME LOW WATER -4.5
60" RCP CLASS IV
LEGEND
BORING NO.
DATE BORING MADE
DEPTH IN FEET
LOCATION OF SAMPLE
DESCRIPTION OF MATERIAL
UNIFIED CLASSIFICATION
STRATIFICATION LINES
BOTTOM OF PIT OR DEPTH AT WHICH JET OR AUGER STOPPED
DIFFUSER SEE DETAIL SHEET 3
END STRUCTURE SEE DETAIL SHT. 3
PROFILE
1" = 100' HORIZ.
1" = 10' VERT.
NOTE
THESE LOGS REPRESENT ONLY THE OPINION OF THE ENGINEER AS TO THE CHARACTER OF MATERIALS ENCOUNTERED IN THE TEST HOLES. NO WARRANTY, EXPRESSED OR IMPLIED, IS GIVEN IN REGARD TO ANY VARIATIONS WHICH MAY OCCUR BETWEEN TEST HOLE SITES.
THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY BETWEEN SOIL TYPES AND THE TRANSITION MAY BE GRADUAL.
CH2M HILL
CORNELL HOWLAND HAYES & MERRYFIELD
CLAIR A. HILL & ASSOCIATES
CITY OF BELLINGHAM, WASHINGTON
POST POINT OUTFALL
PLAN, PROFILE & TEST HOLES
C 6199-1

A-2



BURIED OUTFALL TRENCH
TYPICAL SECTION-STA. 0+00 TO 8+00±
N.T.S.
60" REINF. CONC. PIPE, CLASS IV
BELLMOUTHED PORT SEE DETAIL THIS SHEET
GRAVEL BEDDING
EXISTING BOTTOM SURFACE
PROVIDE 2'-6" MIN. GRAVEL BEDDING
EXPOSED OUTFALL & DIFFUSER
TYPICAL SECTION- STA. 18+00 TO 28+10±
N.T.S.
GROUT
GRAVEL BEDDING
EXISTING BOTTOM SURFACE
END STRUCTURE BACKFILL PROFILE
N.T.S.
12 TYP.
NOTES:
BELLMOUTHED PORT (TYP.) SEE DETAIL THIS SHEET
60" REINF. CONC. PIPE, CLASS IV
END TEE AND PLUG SEE DETAILS, THIS SHT.
PLAN OF DIFFUSER PORT SPACING
N.T.S.
6" BELLMOUTHED PORT IN CTR. OF COVER, SEE DETAIL THIS SH.
60" REINF. CONC. PIPE, CLASS IV
12' LAYING LENGTH
18' TO NEXT DIFFUSER PORT
GROUT
6-#3
EQUALLY SPACED
END STRUCTURE CROSS SECTION
NOTES
1. CONCRETE SHALL HAVE MINIMUM COMPRESSIVE STRENGTH, f'c = 3,000
2. REINFORCING STEEL AS PER ASTM A615, GRADE 40
END STRUCTURE DETAIL
1/2" = 1'-0"
45" DIA CONC. RISER
NOTE
FOR REINFORCING STEEL SEE
TEE COVER AND COVER PORT DETAIL
N.T.S.
60" REINF. CONC. PIPE WALL
VERT. ℄ PIPE
HORIZ. ℄ PIPE
BELLMOUTHED PORT DETAIL
N.T.S.
THIS PRINT IS REDUCED TO ONE HALF OF THE ORIGINAL SCALE
CH2M HILL
CORNELL HOWLAND HAYES & MERRYFIELD
CLAIR A. HILL & ASSOCIATES
CITY OF BELLINGHAM, WASHINGTON
POST POINT OUTFALL
TYPICAL CROSS SECTIONS AND GENERAL DETAILS
C 6199-1

APPENDIX B

Diffuser Hydraulics Calculations
for Design Assumptions and As-built Conditions
at Total Plant Design Flow of 18 MGD

Appendix B. Manifold hydraulics calculation for estimating discharge from each diffuser port: CH2M-Hill design assumptions for 18 MGD total plant flow.

Port No.	Dist from End (ft)	Port Diam (in)	No.of Ports (m)	Port Area (ft2)	Pipe Diam (ft)	Total Head En (ft)	Ratio Vn^2/2g/En	Disch Coeff Cd	Port Disch qn	Incr Disch dQ=m*qn (cfs)	Incr Vel dV=qn*m/A (cfs)	Pipe Vel Vn (fps)	Vel Head Vn^2/2g (fps)	Frict Factor f (ft)	Dist to Next Port Ln (ft)	Head Loss hfn (ft)	Frict Depth Decrease dzn (ft)	Density Head ds/s/dzn (ft)	Total Head En (ft)
1	3	6	1	0.196	5	0.215	0.000	0.97	0.71	0.71	0.036	0.04	0.000020	0.024	12.5	0.000	0.13	0.003	0.218
2	18	6	1	0.196	5	0.218	0.000	0.97	0.72	0.72	0.037	0.07	0.000082	0.024	12.5	0.000	0.13	0.003	0.222
3	31	6	1	0.196	5	0.222	0.001	0.97	0.72	0.72	0.037	0.11	0.000187	0.024	12.5	0.000	0.13	0.003	0.225
4	43	6	1	0.196	5	0.225	0.001	0.97	0.73	0.73	0.037	0.15	0.000335	0.024	12.5	0.000	0.13	0.003	0.229
5	55	6	1	0.196	5	0.229	0.002	0.97	0.73	0.73	0.037	0.18	0.000527	0.024	12.5	0.000	0.13	0.003	0.232
6	68	6	1	0.196	5	0.232	0.003	0.97	0.74	0.74	0.038	0.22	0.000764	0.024	12.5	0.000	0.13	0.003	0.236
7	80	6	1	0.196	5	0.236	0.004	0.97	0.74	0.74	0.038	0.26	0.001048	0.024	12.5	0.000	0.13	0.003	0.239
8	92	6	1	0.196	5	0.239	0.006	0.97	0.75	0.75	0.038	0.30	0.001378	0.024	12.5	0.000	0.13	0.003	0.243
9	104	6	1	0.196	5	0.243	0.007	0.97	0.75	0.75	0.038	0.34	0.001757	0.024	12.5	0.000	0.13	0.003	0.246
10	117	6	1	0.196	5	0.246	0.009	0.97	0.76	0.76	0.039	0.38	0.002184	0.024	12.5	0.000	0.13	0.003	0.250
11	129	6	1	0.196	5	0.250	0.011	0.97	0.76	0.76	0.039	0.41	0.002661	0.024	12.5	0.000	0.13	0.003	0.253
12	141	6	1	0.196	5	0.253	0.013	0.97	0.77	0.77	0.039	0.45	0.003188	0.024	12.5	0.000	0.13	0.003	0.257
13	153	6	1	0.196	5	0.257	0.015	0.97	0.77	0.77	0.039	0.49	0.003767	0.024	12.5	0.000	0.13	0.003	0.260
14	166	6	1	0.196	5	0.260	0.017	0.97	0.78	0.78	0.040	0.53	0.004399	0.024	12.5	0.000	0.13	0.003	0.264
15	178	6	1	0.196	5	0.264	0.019	0.97	0.78	0.78	0.040	0.57	0.005083	0.024	12.5	0.000	0.13	0.003	0.268
16	190	6	1	0.196	5	0.268	0.022	0.97	0.79	0.79	0.040	0.61	0.005822	0.024	12.5	0.000	0.13	0.003	0.272
17	203	6	1	0.196	5	0.272	0.024	0.97	0.79	0.79	0.040	0.65	0.006616	0.024	12.5	0.000	0.13	0.003	0.275
18	215	6	1	0.196	5	0.275	0.027	0.97	0.80	0.80	0.041	0.69	0.007465	0.024	12.5	0.000	0.13	0.003	0.279
19	227	6	1	0.196	5	0.279	0.030	0.96	0.80	0.80	0.041	0.73	0.008371	0.024	12.5	0.001	0.13	0.003	0.283
20	239	6	1	0.196	5	0.283	0.033	0.96	0.81	0.81	0.041	0.78	0.009335	0.024	12.5	0.001	0.13	0.003	0.287
21	252	6	1	0.196	5	0.287	0.036	0.96	0.81	0.81	0.041	0.82	0.010357	0.024	12.5	0.001	0.13	0.003	0.291
22	264	6	1	0.196	5	0.291	0.039	0.96	0.82	0.82	0.042	0.86	0.011439	0.024	12.5	0.001	0.13	0.003	0.295
23	276	6	1	0.196	5	0.295	0.043	0.96	0.82	0.82	0.042	0.90	0.012581	0.024	12.5	0.001	0.13	0.003	0.299
24	289	6	1	0.196	5	0.299	0.046	0.96	0.83	0.83	0.042	0.94	0.013784	0.024	12.5	0.001	0.13	0.003	0.304
25	301	6	1	0.196	5	0.304	0.050	0.96	0.83	0.83	0.042	0.98	0.015050	0.024	12.5	0.001	0.13	0.003	0.308
26	313	6	1	0.196	5	0.308	0.053	0.96	0.84	0.84	0.043	1.03	0.016378	0.024	12.5	0.001	0.13	0.003	0.312
27	325	6	1	0.196	5	0.312	0.057	0.95	0.84	0.84	0.043	1.07	0.017771	0.024	12.5	0.001	0.13	0.003	0.317
28	338	6	1	0.196	5	0.317	0.061	0.95	0.84	0.84	0.043	1.11	0.019229	0.024	12.5	0.001	0.13	0.003	0.321
29	350	6	1	0.196	5	0.321	0.065	0.95	0.85	0.85	0.043	1.16	0.020753	0.024	12.5	0.001	0.13	0.003	0.326
30	362	6	1	0.196	5	0.326	0.069	0.95	0.85	0.85	0.044	1.20	0.022344	0.024	12.5	0.001	0.13	0.003	0.331
31	375	6	1	0.196	5	0.331	0.073	0.95	0.86	0.86	0.044	1.24	0.024004	0.024	12.5	0.001	0.13	0.003	0.336
32	387	6	1	0.196	5	0.336	0.077	0.95	0.86	0.86	0.044	1.29	0.025733	0.024	12.5	0.002	0.13	0.003	0.341
33	399	6	1	0.196	5	0.341	0.081	0.94	0.87	0.87	0.044	1.33	0.027532	0.024	12.5	0.002	0.13	0.003	0.346
34	411	6	1	0.196	5	0.346	0.085	0.94	0.87	0.87	0.044	1.38	0.029403	0.024	12.5	0.002	0.13	0.003	0.351
35	424	6	1	0.196	5	0.351	0.089	0.94	0.88	0.88	0.045	1.42	0.031346						
TOTAL										27.9						0.020	4.5	0.116	

Appendix B (cont.). Manifold hydraulic calculations: as-built condition for total plant flow of 18 MGD.

Port No.	Port Depth (m)	Dist from End (ft)	Port Diam (in)	No.of Ports (m)	Port Area (ft2)	Pipe Diam (ft)	Total Head En (ft)	Ratio Vn^2/2g/En	Disch Coeff Cd	Port Disch qn	Incr Disch dQ=m*qn (cfs)	Incr Vel dV=qn*m/A (cfs)	Pipe Vel Vn (fps)	Vel Head Vn^2/2g (fps)	Frict Factor f (ft)	Dist to Next Port Ln (ft)	Frict Head Loss hfn (ft)	Depth Decr dzn (ft)	Density Head ds/s/dzn (ft)	Total Head En (ft)
1	25.0	3	6	1	0.196	5	0.11	0.000	0.97	0.52	0.52	0.026	0.03	0.000011	0.024	12.5	0.000	0.42	0.011	0.125
2	24.9	18	6	1	0.196	5	0.12	0.000	0.97	0.54	0.54	0.028	0.05	0.000045	0.024	12.5	0.000	0.34	0.009	0.134
3	24.8	31	6	1	0.196	5	0.13	0.001	0.97	0.56	0.56	0.029	0.08	0.000106	0.024	12.5	0.000	0.34	0.009	0.143
4	24.7	43	6	1	0.196	5	0.14	0.001	0.97	0.58	0.58	0.030	0.11	0.000196	0.024	12.5	0.000	0.34	0.009	0.151
5	24.6	55	6	1	0.196	5	0.15	0.002	0.97	0.60	0.60	0.030	0.14	0.000316	0.024	12.5	0.000	0.34	0.009	0.160
6	24.5	68	6	1	0.196	5	0.16	0.003	0.97	0.61	0.61	0.031	0.17	0.000470	0.024	12.5	0.000	0.34	0.009	0.169
7	24.3	80	6	1	0.196	5	0.17	0.004	0.97	0.63	0.63	0.032	0.21	0.000659	0.024	12.5	0.000	0.34	0.009	0.178
8	24.2	92	6	1	0.196	5	0.18	0.005	0.97	0.65	0.65	0.033	0.24	0.000886	0.024	12.5	0.000	0.34	0.009	0.186
9	24.1	104	6	1	0.196	5	0.19	0.006	0.97	0.66	0.66	0.034	0.27	0.001154	0.024	12.5	0.000	0.34	0.009	0.195
10	24.0	117	6	1	0.196	5	0.20	0.007	0.97	0.68	0.68	0.034	0.31	0.001464	0.024	12.5	0.000	0.34	0.009	0.204
11	23.9	129	6	1	0.196	5	0.20	0.009	0.97	0.69	0.69	0.035	0.34	0.001820	0.024	12.5	0.000	0.34	0.009	0.213
12	23.8	141	6	1	0.196	5	0.21	0.010	0.97	0.71	0.71	0.036	0.38	0.002222	0.024	12.5	0.000	0.34	0.009	0.222
13	23.7	153	6	1	0.196	5	0.22	0.012	0.97	0.72	0.72	0.037	0.42	0.002674	0.024	12.5	0.000	0.34	0.009	0.231
14	23.6	166	6	1	0.196	5	0.23	0.014	0.97	0.73	0.73	0.037	0.45	0.003178	0.024	12.5	0.000	0.34	0.009	0.240
15	23.5	178	6	1	0.196	5	0.24	0.016	0.97	0.75	0.75	0.038	0.49	0.003736	0.024	12.5	0.000	0.34	0.009	0.249
16	23.4	190	6	1	0.196	5	0.25	0.017	0.97	0.76	0.76	0.039	0.53	0.004350	0.024	12.5	0.000	0.34	0.009	0.258
17	23.3	203	6	1	0.196	5	0.26	0.019	0.97	0.77	0.77	0.039	0.57	0.005022	0.024	12.5	0.000	0.34	0.009	0.267
18	23.2	215	6	1	0.196	5	0.27	0.022	0.97	0.79	0.79	0.040	0.61	0.005755	0.024	12.5	0.000	0.48	0.013	0.280
19	23.1	227	6	1	0.196	5	0.28	0.023	0.97	0.81	0.81	0.041	0.65	0.006557	0.024	12.5	0.000	0.48	0.013	0.293
20	22.9	239	6	1	0.196	5	0.29	0.025	0.97	0.82	0.82	0.042	0.69	0.007430	0.024	12.5	0.000	0.48	0.013	0.306
21	22.8	252	6	1	0.196	5	0.31	0.027	0.96	0.84	0.84	0.043	0.73	0.008378	0.024	12.5	0.001	0.48	0.013	0.319
22	22.6	264	6	1	0.196	5	0.32	0.030	0.96	0.86	0.86	0.044	0.78	0.009404	0.024	12.5	0.001	0.48	0.013	0.332
23	22.5	276	6	1	0.196	5	0.33	0.032	0.96	0.87	0.87	0.045	0.82	0.010511	0.024	12.5	0.001	0.48	0.013	0.345
24	22.3	289	6	1	0.196	5	0.34	0.034	0.96	0.89	0.89	0.045	0.87	0.011702	0.024	12.5	0.001	0.48	0.013	0.358
25	22.2	301	6	1	0.196	5	0.36	0.036	0.96	0.91	0.91	0.046	0.91	0.012980	0.024	12.5	0.001	0.48	0.013	0.371
26	22.0	313	6	1	0.196	5	0.37	0.039	0.96	0.92	0.92	0.047	0.96	0.014348	0.024	12.5	0.001	0.48	0.013	0.385
27	21.9	325	6	1	0.196	5	0.38	0.041	0.96	0.94	0.94	0.048	1.01	0.015810	0.024	12.5	0.001	0.48	0.013	0.398
28	21.7	338	6	1	0.196	5	0.40	0.044	0.96	0.95	0.95	0.049	1.06	0.017368	0.024	12.5	0.001	0.48	0.013	0.412
29	21.6	350	6	1	0.196	5	0.41	0.046	0.96	0.97	0.97	0.049	1.11	0.019026	0.024	12.5	0.001	0.48	0.013	0.426
30	21.4	362	6	1	0.196	5	0.43	0.049	0.96	0.98	0.98	0.050	1.16	0.020787	0.024	12.5	0.001	0.48	0.013	0.439
31	21.3	375	6	1	0.196	5	0.44	0.052	0.96	1.00	1.00	0.051	1.21	0.022654	0.024	12.5	0.001	0.48	0.013	0.453
32	21.1	387	6	1	0.196	5	0.45	0.054	0.95	1.01	1.01	0.052	1.26	0.024630	0.024	12.5	0.001	0.48	0.013	0.467
33	21.0	399	6	1	0.196	5	0.47	0.057	0.95	1.03	1.03	0.052	1.31	0.026719	0.024	12.5	0.002	0.48	0.013	0.481
34	20.9	411	6	1	0.196	5	0.48	0.060	0.95	1.04	1.04	0.053	1.36	0.028923	0.024	12.5	0.002	0.48	0.013	0.496
35	20.7	424	6	1	0.196	5	0.50	0.063	0.95	1.06	1.06	0.054	1.42	0.031246						
TOTAL											27.9						0.017	14.0	0.364	

APPENDIX C

CH_2M-Hill Design Letter for Diffuser Hydraulics

CH2M HILL Engineers Planners Economists Scientists

rec'd 4/19/88

April 18, 1988

Greg Pelletier
Washington Dept. of Ecology
7272 Clean Water Lane, MS:LU-11
Olympia, WA 98504

Dear Greg:

Attached is a copy of a letter and accompanying computer analysis sent to the Department of Ecology in May 1973 regarding the Post Point Outfall. This information is being sent at your request.

If you have any questions, please call me.

Sincerely yours,

Joseph L. Scott

Joseph L. Scott

CH2M HILL Seattle Office 777 108th Avenue, N.E., Bellevue, Washington
P.O. Box 91500, Bellevue, Washington 98009-2050 206.453.5000

17 May 1973

Project No. S6199.1

Washington State Department of Ecology
P.O. Box 829
Olympia, Washington 98501

Attention: Mr. Bob Ortblad

Gentlemen:

Subject: C53033 (WPC-WN-333)
City of Bellingham, Post Point Outfall

In regard to your telephone conversation with Dave Peterson of this office on 14 March, the information attached and following comments are presented.

1. Attached are six xerox copies of the computer printout (indicating head loss, etc.) from our outfall-diffuser analysis program. The following references may be of assistance to you in verifying the calculations.

   Rawn, A.M., F. R. Bowerman, and N. H. Brooks: Diffusers for Disposal of Sewage in Seawater, Proceedings, ASCE, vol. 86, no. SA2, 1960.

   University Extension and the College of Engineering, Program VII: Pollution of Coastal and Estuarine Waters, University of California, San Francisco, January 28-30, 1970.

   Burchett, Max E., George Tchobanaglous, and Allen J. Burdoin, A Practical Approach to Submarine Outfall Calculations, PUBLIC WORKS, May 1967.

2. The weir elevation in the chlorine contact chamber of the Post Point Pollution Control Plant is 19.25, City of Bellingham datum (20.45 MLLW). The top of the chlorine contact chamber walls is at 22.1, City datum (23.3 MLLW).

3. An emergency bypass from the chlorine contact chamber is connected to an existing city outfall. With the simultaneous occurrence of extreme high tides and peak flows, the bypass will become operative to prevent overtopping of the contact chamber walls.

4. The detailed design of a multiple port diffuser is primarily a problem of hydraulics. The effort is to achieve a desirable combination of port diameter, port spacing, discharge depth, and port discharge velocity as necessary to develop the desired discharge conditions. The port size must be small enough to get good flow distribution among all the ports, but not so small as to increase the total head unduly. As you can see, there are many combinations of port size, port spacing, the number of ports available to provide a satisfactory system. The combination used for final design best fits the head loss and dilution requirements for the City of Bellingham.

If we can be of further assistance to you, please call us.

Sincerely,

William J. Winter

rk

Attachment

OUTFALL - DIFFUSER ANALYSIS

DISCHARGE DEPTH	102.
EFFLUENT SP.GR.	0.9950
REC. WATER SP.GR.	1.0240
REC. WATER ELEV.	12.8
OUTFALL DIAMETER	60.
OUTFALL LENGTH	2395.
FRICTION FACTOR	0.024
AREA RATIO	0.350

PORT DIAM	NO.OF PORTS	PORT SPACING	PIPE DIAM	DIFF. SLOPE	TYPE OF PORT
6.00	35	12.0	60.0	0.0105	BELL MOUTH

DISCHARGE MGD	DISCHARGE CFS	HEAD LOSS DIF'SER	HEAD LOSS OUTFALL	DENSITY HEAD	TOTAL HEAD REQUIRED	ELEVATION REQUIRED
3.0	ALL PORTS WILL NOT FLOW FULL					
7.0	BEGINNING HEAD LOSS IS LESS THAN .001 FT					
10.0	15.5	0.2	0.1	3.0	3.2	16.0
18.0	27.8	0.4	0.4	3.0	3.7	16.5
30.0	46.4	0.9	1.0	3.0	4.8	17.6
40.0	61.9	1.5	1.8	3.0	6.2	19.0
55.0	85.1	2.8	3.4	3.0	9.1	21.9

DIFFUSER ANALYSIS - 18.0 MGD

DISCHARGE DEPTH	102.
EFFLUENT SP.GR.	0.9950
REC. WATER SP.GR.	1.0240
REC. WATER ELEV.	12.8
OUTFALL DIAMETER	60.
OUTFALL LENGTH	2395.
FRICTION FACTOR	0.024
AREA RATIO	0.350

PORT DIAM	NO.OF PORTS	PORT SPACING	PIPE DIAM	DIFF. SLOPE	TYPE OF PORT
6.00	35	12.0	60.0	0.0105	BELL MOUTH

PORT NO	PORT Q CFS	PORT V FPS	PIPE Q CFS	PIPE V FPS	HEAD LOSS FEET	COEF. OF DISCHARGE
1	0.71	3.60	0.71	0.04	0.21	0.98
3	0.72	3.66	2.14	0.11	0.22	0.97
6	0.73	3.74	4.32	0.22	0.23	0.97
9	0.75	3.82	6.56	0.33	0.24	0.97
12	0.77	3.90	8.85	0.45	0.25	0.97
15	0.78	3.98	11.18	0.57	0.26	0.97
18	0.80	4.06	13.55	0.69	0.27	0.97
21	0.81	4.13	15.97	0.81	0.29	0.96
24	0.83	4.21	18.43	0.94	0.30	0.96
27	0.84	4.28	20.94	1.07	0.31	0.95
30	0.85	4.35	23.49	1.20	0.33	0.95
33	0.87	4.43	26.08	1.33	0.34	0.94
35	0.88	4.48	27.84	1.42	0.35	0.94

DIFFUSER ANALYSIS - 55.0 MGD

DISCHARGE DEPTH	102.
EFFLUENT SP.GR.	0.9950
REC. WATER SP.GR.	1.0240
REC. WATER ELEV.	12.8
OUTFALL DIAMETER	60.
OUTFALL LENGTH	2395.
FRICTION FACTOR	0.024
AREA RATIO	0.350

PORT DIAM	NO.OF PORTS	PORT SPACING	PIPE DIAM	DIFF. SLOPE	TYPE OF PORT
6.00	35	12.0	60.0	0.0105	BELL MOUTH

PORT NO	PORT Q CFS	PORT V FPS	PIPE Q CFS	PIPE V FPS	HEAD LOSS FEET	COEF. OF DISCHARGE
1	2.41	12.30	2.41	0.12	2.47	0.98
3	2.42	12.31	7.25	0.37	2.48	0.97
6	2.42	12.33	14.50	0.74	2.49	0.97
9	2.42	12.34	21.77	1.11	2.50	0.97
12	2.42	12.35	29.04	1.48	2.52	0.97
15	2.43	12.35	36.32	1.85	2.53	0.97
18	2.43	12.36	43.60	2.22	2.55	0.96
21	2.43	12.37	50.88	2.59	2.58	0.96
24	2.43	12.39	58.18	2.96	2.61	0.96
27	2.44	12.41	65.49	3.34	2.65	0.95
30	2.44	12.44	72.81	3.71	2.69	0.95
33	2.45	12.48	80.15	4.08	2.74	0.94
35	2.46	12.51	85.06	4.33	2.78	0.94

INITIAL CONDITIONS

PORT ANGLE	45.0
FROUDE NUMBER	44.3
LENGTH FOR FLOW ESTABLISHMENT	2.59
INTERGRATION STEP LENGTH	0.576
PRINT OUT INTERVAL	5.00
XO	1.83
ZO	100.17
DISCHARGE DENSITY	1.00000
PORT DEPTH	102.00
FLOW RATE	0.80 ←
NUMBER OF PORTS	35.
DISCHARGE VELOCITY	4.07 ←
PLUME EDGE DILUTION	1000.00
PORT DIAMETER	6.00

DENSITY STRATIFICATION

DEPTH	RHO
0.0	1.02319
6.6	1.02320
13.1	1.02319
23.0	1.02319
32.8	1.02321
49.2	1.02320
65.6	1.02325
82.0	1.02331
105.0	1.02331

non-stratified
18 mgd

S	X	Z	ELEV	THETA	DILN	RAD
7.20	4.65	96.53	5.47	59.81	3.2	2.1
12.39	6.72	91.79	10.21	71.74	7.0	3.4
17.58	8.05	86.78	15.22	77.86	12.2	4.6
22.43	8.93	82.00	20.00	81.05	18.1	5.6
27.62	9.63	76.86	25.14	83.11	25.4	6.6
32.81	10.19	71.71	30.29	84.45	33.5	7.5
37.99	10.65	66.54	35.46	85.36	42.5	8.4
42.97	11.02	61.58	40.42	85.98	51.6	9.2
48.16	11.37	56.40	45.60	86.47	61.6	10.0
53.34	11.67	51.22	50.78	86.83	72.1	10.7
58.25	11.93	46.32	55.68	87.10	82.2	11.4
63.44	12.18	41.14	60.86	87.35	93.7	12.1
68.62	12.41	35.96	66.04	87.57	106.0	12.8
73.52	12.61	31.07	70.93	87.76	118.2	13.3
78.70	12.80	25.89	76.11	87.92	131.4	13.9
83.32	12.97	21.27	80.73	88.03	142.8	14.4
88.51	13.14	16.09	85.91	88.14	156.2	15.0
93.23	13.29	11.37	90.63	88.23	168.7	15.4
98.00	13.43	6.60	95.40	88.33	182.6	15.9
103.19	13.58	1.42	100.58	88.43	198.0	16.3

PLUME HITS SURFACE

104.60	13.62	0.00	102.00	88.45	202.1	16.4

LAST LINE IS MAXIMUM HEIGHT OF RISE

TRAPPING LEVEL NOT REACHED

INITIAL CONDITIONS

PORT ANGLE	45.0
FROUDE NUMBER	08.5
LENGTH FOR FLOW ESTABLISHMENT	2.77
INTERGRATION STEP LENGTH	0.576
PRINT OUT INTERVAL	5.00
XO	1.96
ZO	100.04
DISCHARGE DENSITY	1.00000
PORT DEPTH	102.00
FLOW RATE	2.43
NUMBER OF PORTS	35.
DISCHARGE VELOCITY	12.38
PLUME EDGE DILUTION	1000.00
PORT DIAMETER	6.00

DENSITY STRATIFICATION

DEPTH	RHO
0.0	1.02319
6.6	1.02320
13.1	1.02319
23.0	1.02319
32.8	1.02321
49.2	1.02320
65.6	1.02325
82.0	1.02331
105.0	1.02331

non-stratified
55 mgd

S	X	Z	ELEV	THETA	DILN	RHO
7.38	5.15	96.71	5.29	47.90	2.7	2.2
12.57	8.45	92.71	9.29	53.12	4.8	3.6
17.76	11.35	88.42	13.58	58.86	7.3	4.9
22.94	13.82	83.86	18.14	64.04	10.3	6.1
27.88	15.82	79.35	22.65	68.09	13.6	7.2
33.06	17.61	74.48	27.52	71.47	17.4	8.3
38.25	19.14	69.53	32.47	74.09	21.7	9.3
42.89	20.33	65.04	36.96	75.91	25.8	10.2
48.08	21.52	59.99	42.01	77.57	30.8	11.1
53.26	22.58	54.91	47.09	78.89	36.1	12.0
58.45	23.53	49.82	52.18	79.96	41.6	12.9
63.11	24.31	45.22	56.78	80.75	46.8	13.7
68.29	25.10	40.10	61.90	81.54	52.9	14.5
73.48	25.84	34.96	67.04	82.24	59.4	15.3
78.55	26.49	29.94	72.06	82.83	66.1	16.1
83.73	27.12	24.79	77.21	83.34	73.1	16.8
88.42	27.64	20.14	81.86	83.72	79.4	17.5
93.60	28.19	14.98	87.02	84.11	86.8	18.2
98.38	28.67	10.23	91.77	84.43	93.9	18.8
103.18	29.12	5.45	96.55	84.75	101.3	19.4
108.36	29.58	0.29	101.71	85.05	109.6	20.0

PLUME HITS SURFACE

108.65	29.61	0.00	102.00	85.07	110.1	20.0

LAST LINE IS MAXIMUM HEIGHT OF RISE

TRAPPING LEVEL NOT REACHED