Section 6
Water Quality Analyses

6.1 Introduction

The section examines the water quality implications of various wastewater treatment options considered by the Town of Stonington. Currently, Stonington operates three WPCFs – Mystic, Stonington Borough, and Pawcatuck – discharging to the Mystic River, Stonington Harbor, and Pawcatuck River, respectively.

6.1.1 Mystic River

The Connecticut Department of Environmental Protection (CTDEP) performed water quality analyses of the Mystic River from 1988-1990 in response to a request from Stonington to increase the Mystic WPCF's permitted flow from 0.88 mgd to 1.3 mgd. The results of these analyses are summarized in a report entitled "*Water Quality Analysis of Mystic Harbor - A Water Quality Model and Waste Load Allocation*" (June 1990). The report states that:

"The Department's data shows that Mystic Harbor exhibits excellent water quality, exceeding Class SB Standards and Criteria. The estuary has high recreational value and is an important resource for wildlife, aquatic vegetation, finfish, and shellfish. Connecticut's anti-degradation policy, contained in the Water Quality Standards, specifies that surface waters with a classification goal of B or SB, with existing quality better than established standards for that Class, <u>will be maintained at their existing high quality</u>. For such waters, the Commissioner of Environmental Protection may require of the discharge permit applicants, a minimum level of treatment which exceeds the applicable standards of performance for new sources, or other special treatment requirements deemed necessary to prevent pollution and which will maintain existing uses made of, or presently possible in such waters. The anti-degradation policy clearly applies to the Mystic Harbor due to its classification and high water quality.

The Harbor has experienced nuisance algae blooms, most recently in May of 1989, when a signicant portion of the inner harbor was comverted with matted algae. The algae posed an aesthetic problem, caused noxious odors, and interfered with recreational boating activity.

Expansion of the Stonington-Mystic STP without additional treatment would result in a marked increase in nutrient loading to Mystic Harbor. Therefore, the Department concluded that nitrogen removal should be required at the Mystic STP to protect the water quality of Mystic Harbor. During the prime growth season for algae, nutrient loadings have been limited to levels currently input to the estuary by the STP."

As noted above, the report indicated that, although the Mystic Harbor generally exhibits excellent water quality, nutrient loadings intermittently cause algae blooms. Since Water Quality Standards require that Mystic Harbor's water quality not be allowed to degrade, increases in flow to the Mystic WPCF outfall would be accompanied by tighter restrictions on effluent quality such that nutrient loading

would not increase above existing levels. In addition, the report indicated that nutrient removal would likely be required in the future as a result of the Long Island Sound Study.

As a result of the findings of this report, a portion of the flow from the Mystic WPCF was diverted to the Borough WPCF for treatment in lieu of expansion of the Mystic WPCF. Additionally, future discharges from Mystic WPCF would also be limited to levels existing at the time of the study.

6.1.2 Stonington Harbor and Pawcatuck River

Because of the Mystic Harbor study by CTDEP, the scope of this section of the Wastewater Facilities Plan includes analyses only of Stonington Harbor and the Pawcatuck River. The wastewater treatment alternatives are described in detail in Section 7. **Table 6-1** describes the possible water quality scenarios that would result from these treatment alternatives.

Table 6-1

Description of Treatment Conditions

Water Quality	***Description of Water Quality Scenario***
Existing	Representative of current flows and loads to each of the three WPCF outfalls.
WQ Scenario 1	Representative of projected flows and loads at each of the three WPCF outfalls.
WQ Scenario 1a	Represents projected flows with a 0.28 mgd diversion from the Mystic WPCF to the Borough WPCF with the Pawcatuck WPCF operating normally.
WQ Scenario 2/4	Represents projected flows with all flow from the Mystic WPCF transferred to the Borough outfall for discharge. Mystic outfall would be abandoned with the Pawcatuck WPCF discharging normally.
WQ Scenario 3	Represents projected flows with all flow from the Mystic and Borough WPCFs transferred to the Pawcatuck WPCF for treatment. Mystic and Borough facilities would be abandoned.
WQ Scenario 5	Represents projected flows with all flow from the entire Town transferred to the Borough WPCF outfall for discharge after treatment. Mystic and Pawcatuck facilities would be abandoned.

The NPDES permits for the Stonington Borough and Pawcatuck WPCFs were renewed in 2005. The NPDES permit for the Mystic WPCF is up for renewal. WPCA has filed a renewal application and expects the permit to be removed in 2006. The permits included limits for BOD, TSS, coliform bacteria, chlorine, and whole effluent

toxicity testing. They also included monitoring requirements for metals and phosphorus compounds. Future permits could include limits for these compounds if they are shown to be a potential water quality concern. The three facilities are also required to comply with the *General Permit for Nitrogen Discharges*. Thus, this water quality investigation focuses on determining if future discharges can meet water quality standards for (1) conventionals (i.e., dissolved oxygen) and (2) toxics.

The remainder of this section is organized as follows:

- Section 6.2 describes the two study areas and the existing discharge structures.
- Section 6.3 presents and discusses existing water quality data available for these assessments.
- Section 6.4 describes the dissolved oxygen analysis.
- Section 6.5 presents the results of the toxics analysis, including the results of the initial dilution modeling.

6.2 Description of Study Areas and Outfalls

Stonington Harbor is the receiving water for the Stonington Borough WPCF. The study area for Stonington Harbor is illustrated in **Figure 6-1**. This harbor is a well-mixed estuary, receiving saltwater from the Long Island Sound tide and freshwater from its watershed. Design drawings for the outfall indicate it should be a 185-foot long, 24-inch diameter diffuser pipe, with ten T-shaped, 10-inch risers of two 4-inch ports each. The ports are "not less than one foot" above the top of the main line, according to the plans provided. This description differs somewhat from that found during an outfall inspection by Shoreline Diving of Noank, Connecticut performed on April 30, 2001. While the divers verified the dimensions of the riser pipes and port outlets, they reported that the outfall pipe had only eight riser pipes spaced 25 feet apart. Further, they reported that only the last two risers are currently active; the remaining six having been capped. The active risers are those at the end of the diffuser pipe. The 2001 inspection also indicated that the next to last riser had broken off and was discharging from a 10-inch diameter orifice. This was fixed in May 2005, when the broken riser was capped and another opened.

The diffuser is located approximately 415 feet from the shore at its closest point, and 600 feet at the farthest point. The Borough WPCF discharges its effluent into the harbor near location 5 (see Figure 6-1). While the coastal chart for Stonington Harbor indicates the water depth should be about 12 feet deep, the diver inspectors provided a water depth of 8 feet deep at mean low water (MLW); the 8-foot depth was used for initial dilution modeling (see Section 6.5).

The Pawcatuck River, the receiving water for the Pawcatuck WPCF, is illustrated in **Figure 6-2**. This river is typically a stratified estuary, receiving saltwater from the

See Figure 6-1

See Figure 6-2

Rhode Island and spans all the way to the mouth of the river. The Pawcatuck WPCF discharges its effluent into the estuarine portion of the Pawcatuck River. The Pawcatuck outfall is a single 24-inch diameter pipe, and according to the dive inspection the terminus appears to be encased in a concrete box. The outfall discharges horizontally into a dredged section next to the navigation channel approximately at location 10 (see Figure 6-2). As noted in this figure, an additional WPCF - the Westerly WPCF - discharges to the river about 1 kilometer upstream of the Pawcatuck WPCF.

6.3 Data Used in This Study

CDM used several sources of data to conduct the analyses in this study:

- Water quality data collected in the harbor and river by the Town on September 7, September 22, and October 6, 2000.
- Water quality data from April to October 1993 published in *An Assessment of the Current Status of Water Quality and Pollution Sources in the Pawcatuck River Estuary and Little Narragansett Bay* (Desbonnet, 1990).
- Water quality data from *Dissolved Oxygen Concentrations in the Northern Pawcatuck River Estuary: A Seasonal Characterization* (Desbonnet and Banister, 1994).
- Water quality data for the Pawcatuck River collected each September from 1993 to 2000 by the students of Pine Point School (Banister, unpublished data).
- Water quality and flow data collected by the United States Geological Survey at their gauging station (01118500) located in Westerly, Rhode Island on the Pawcatuck River, as indicated in Figure 6-2.
- Effluent data from each of the treatment plants from their Data Monitoring Reports (DMRs) from March 2000 to February 2001.
- Effluent data for the Westerly, RI WPCF was gathered from the Internet at EPA's Surf Your Watershed Website (www.epa.gov/surf) using the Permit Compliance System (PCS). These were data collected from January 2000 to December 2000.

As a part of this study, receiving water quality data (temperature, depth, dissolved oxygen, and conductivity) were collected by the Town on three dates in Stonington Harbor and the Pawcatuck River. The data are shown in **Tables 6-2 and 6-3**, along with some calculated parameters (salinity, dissolved oxygen saturation and percent dissolved oxygen saturation). These data were used to describe the estuaries to create input to the various model and analytical scenarios that were used. The sampling locations for each of the study areas are illustrated in Figures 6-1 and 6-2.

The temperature and salinity data for Stonington Harbor show that the harbor is relatively uniform both horizontally and vertically. This well-mixed characteristic is

See Table 6-2

See Table 6-3 (page 1)

See Table 6-3 (page 2)

due to the wide mouth between the harbor and Long Island Sound and the harbor's relatively small watershed. Dissolved oxygen (DO) levels in the harbor were good with almost all readings above 80 percent saturation. The exception was Station 3 on September 22, 2000, which showed declining oxygen with depth (bottom value 72 percent saturation). Since the data were collected on an outgoing tide, the profile represents water quality from the embayment north of the railroad tracks and is likely not attributable to the discharge of effluent in the harbor.

The water quality data collected by the Town in the Pawcatuck River estuary indicate very different conditions from Stonington Harbor (all data collected north of Pawcatuck Rock). The estuary is complex both in terms of hydrodynamics and dissolved oxygen dynamics. All samples were taken in the dredged channel; because most of the width of the estuary is quite shallow, the low oxygen concentrations are only found in a small area of the estuary.

While temperature profiles indicate weak thermal structure (likely because of the shallow water depth), salinity profiles show strong salt stratification. In the two September data sets, the stratification was accompanied by depleted oxygen in the lower saline layer. Further, the oxygen levels in this lower layer declined with depth, suggesting that the sediments could be a significant source of oxygen demand. Several of the September 7, 2000 profiles had hypoxic oxygen levels (DO < 3 mg/L) near the bottom, levels that would cause stress to aquatic life. The data also indicate a horizontal variation in water quality, with the lowest oxygen conditions found at the head of the estuary.

Because of the low oxygen concentrations found in the Town's data, CDM researched additional sources of water quality data for the river. These data sets (Desbonnet, 1990; Desbonnet and Banister, 1994; Banister, unpublished data) confirmed the data collected by the Town. These data present a consistent picture of water quality in the estuary.

Stratification is seasonal and related to freshwater flows in the Pawcatuck River. In the spring, high river flows result in the whole depth of the upper end of the estuary being freshwater; dissolved oxygen values are near saturation. The drop in dissolved oxygen in the bottom waters occurs shortly after the arrival of the lower salt water layer at the top of the estuary. Oxygen in this lower layer drops throughout the summer, and in 1993 reached hypoxic levels in late July. These very low levels only occur in about the upper third of the northern estuary. In the vicinity of the Pawcatuck WPCF outfall (about two-thirds of the way down the northern estuary – Figure 6-2), oxygen in the bottom waters is also depressed (typically 4 to 5 mg/L) but not as significantly as in the head of the estuary.

Desbonnet and Banister (1994) conclude that their data suggest that the occurrence of low dissolved oxygen concentrations in the northern Pawcatuck River estuary are the result of physical constraints – the lack of tidal exchange and stratification of the water column. Hypoxic oxygen levels were found over half of the stratified season in

1993. At the other end of the estuary (in the vicinity of Pawcatuck Rock), the exchange of new water during tidal changes is sufficient to allow oxygen to be at levels that are non-stressful to aquatic life on a continual basis.

Conditions near the outfall discharge are intermediate of these extremes; there is some tidal exchange that allows for a replenishment of oxygen in the bottom waters. Initial dilution modeling (Section 6.5) indicates that the discharge from the Pawcatuck outfall will remain trapped in these waters. The dissolved oxygen analysis (Section 6.4) indicates that even if this did occur, the oxygen demand from the Pawcatuck effluent is a minor contributor to the oxygen demand in the estuary.

6.4 Dissolved Oxygen Analysis

6.4.1 Approach

The approach taken to assess future dissolved oxygen conditions in Stonington Harbor and the Pawcatuck River was to:

- review existing data in the harbor and the river (see Section 6.3),
- develop current and future flows and loads, and
- apply an analytical technique to estimate DO deficit for current and future scenarios.

The goal of the analytical technique is not to predict actual DO deficits (as this would require model calibration for which data do not exist), but to select a method that would allow for a valid comparison among the scenarios.

6.4.2 Flows and Loads

Flow and loads were developed for the Stonington Borough and Pawcatuck WPCFs, the freshwater inflow to the river, and the Westerly, Rhode Island WPCF.

Tables 6-4 and 6-5 summarize the loads for the Borough and Pawcatuck WPCFs, respectively, for each of the water quality scenarios described in Table 6-1. The flows are as presented in Section 3. The equivalent biochemical oxygen demand (BOD) load is a sum of the BOD loads presented in Section 3 plus the additional BOD load caused by ammonia nitrogen. The additional ammonia nitrogen BOD load is calculated by multiplying the ammonia nitrogen concentration by a factor of 4.57. This additional ammonia nitrogen load comprises a much larger portion of the equivalent BOD load than the BOD load itself.

Table 6-4
Flows and Loads for Stonington Borough WPCF Outfall

WQ Scenario	WPCF Flow (mgd)	BOD (mg/L)	Ammonia (mg/L)	Equivalent BOD Load (lb/day)
Existing	0.496	10	15	325
WQ Scenario 1	0.299	10	1	36
WQ Scenario 1a	0.579	10	1	70
WQ Scenario 2/4	1.025	10	1	125
WQ Scenario 3	--	--	--	--
WQ Scenario 5	1.964	10	1	239

Table 6-4 shows that future equivalent BOD loads will be less than the existing conditions because the ammonia nitrogen concentrations for the future scenarios (WQ Scenarios 1-5) are to be reduced significantly. This occurs because in every scenario the discharge is assumed to meet the nitrogen removal requirements of the Long Island Sound Study and the *General Permit for Nitrogen Discharges*. Effluent meeting these requirements will have significantly reduced the ammonia nitrogen concentrations, leading to a significant reduction in the combined BOD loading.

Table 6-5
Flows and Loads for Pawcatuck WPCF Outfall

WQ Scenario	WPCF Flow (mgd)		BOD (mg/L)		Ammonia (mg/L)		Equivalent BOD Load (lb/day)	
	Paw	West	Paw	West	Paw	West	Paw	West
Existing	0.493	2.34	13	17	13	14	297	1580
WQ Scenario 1	0.939	2.34	10	17	1	14	114	1580
WQ Scenario 1a	0.939	2.34	10	17	1	14	114	1580
WQ Scenario 2/4	0.939	2.34	10	17	1	14	114	1580
WQ Scenario 3	1.964	2.34	10	17	1	14	239	1580
WQ Scenario 5	0	2.34	10	17	1	14	0	1580

Paw = Pawcatuck WPCF; West = Westerly RI WPCF

As in Table 6-4, Table 6-5 shows that even though the future flow from the Pawcatuck WPCF is planned to increase under the future scenarios, the equivalent BOD loading is actually going to decrease.

For both the existing and future conditions, CDM assumed that the freshwater inflow from the Pawcatuck River had a background equivalent BOD loading rate of 1.17 mg/L (1 mg/L of BOD and .037 mg/L of ammonia nitrogen). These data were based on the annual average (1998-99) of the water quality data collected by the USGS at the Westerly gauging station. In addition, the future freshwater input into each of the estuaries was assumed to be 7Q10, again providing a "worst case scenario."

For this evaluation we also developed flows and loads for the Westerly RI WPCF using data gathered from EPA's Permit Compliance System at the time out evaluation was conducted. For the future scenarios (Scenarios 1-5) we assumed that the Westerly plant would continue to operate under present conditions. This is a conservative estimate because the Westerly plant has implemented denitrification since this work was completed, reducing the ammonia nitrogen concentrations and significantly reducing the additional ammonia nitrogen-associated BOD load.

6.4.3 Analytical Technique

The Streeter Phelps equation describes the dissolved oxygen deficit caused by the BOD loadings to receiving waters. We chose to use this analytical technique because it could provide reasonable relative DO deficits to compare the results of the scenarios. The Streeter Phelps equation was applied for the full water depth at both Stonington

Harbor and the Pawcatuck River even though we know that the Pawcatuck River is a two-layer system during critical summer DO months. We believe this approach is valid because the goal of the study was to make a relative comparison among the scenarios (and other sources of BOD).

CDM used the following Streeter Phelps relationship, as described in S*urface Water-Quality Modeling* (Chapra, 1997) to estimate the dissolved oxygen deficit in the Pawcatuck River and Stonington Harbor:

DO deficit $D = f(k_d, k_a, k_r, W, Q, j_r, j_a, \alpha_r, \alpha_a)$ Equations 21.26 – 21.34

where:

$j_r = f(U, E, \alpha_r)$
$j_a = f(U, E, \alpha_a)$
$\alpha_r = f(U, E, k_r)$
$\alpha_a = f(U, E, k_a)$

The following are definitions of the parameters used:

W = loading rate
Q = flow rate of source
U = mean estuarine velocity
E = dispersion rate
k_d = deoxygenation rate
k_r = BOD removal rate
k_a = aeration rate

Using the receiving water quality data gathered, the following equations were used to estimate the dispersion rates for the Pawcatuck River and Stonington Harbor:

$E = f(\Delta S, U, x)$ Equation 15.13
$k_d = f(H, T)$ Equation 19.28
$k_r = f(k_d, v_s, H)$ Equation 19.27
$k_a = f\ (U, U_w, H, T)$ Equation 20.52

where:

S = salinity
x = distance
H = depth
T = temperature
v_s = settling velocity of effluent
U_w = wind velocity

Conservative estimates were used for the deoxygenation rate (k_d), BOD removal rate (k_r), reaeration rate (k_a), and settling velocity (v_s) to provide a realistic "worst case

scenario" for each of the estuaries. The dispersion rate was estimated using the salinity data collected in each of the receiving waters. The values are shown in **Table 6-6**. These estimates were representative of dispersion rates observed in other similar estuaries.

Table 6-6
Parameters used in Streeter Phelps Equations

Parameter	Stonington Harbor	Pawcatuck River
Deoxygenation Coefficient, k_d	0.38/day	0.38/day
BOD Removal Rate, k_r	0.41/day	0.42/day
Reaeration Coefficient, k_a	0.005/day	0.10/day
Settling Velocity, v_s	0.1 m/day	0.1 m/day
Dispersion Coefficient	448,000 cm^2/s	16,600 cm^2/s

For existing condition, the freshwater input into each of the estuaries was based on the flow observed at the USGS gauging station in Westerly, Connecticut. To estimate the flow observed in the Pawcatuck River at the point of discharge of the Pawcatuck WPCF, the flow observed at the USGS gauging station was increased proportionally to the additional watershed upstream of the Pawcatuck WPCF not incorporated at the gauging station. The gauging station accounted for approximately 295 square miles (mi^2). The additional contributing watershed upstream of the Pawcatuck WPCF was approximately 4 mi^2. The flow observed at the USGS gauging station was multiplied by a factor of 299/295.

The freshwater inflow into Stonington Harbor is not gauged. This inflow was estimated by transposing the flow from the Pawcatuck River onto the Stonington Harbor watershed. The Stonington Harbor watershed is approximately 5.5 mi^2. The Pawcatuck River flow was multiplied by a ratio of 5.5/295 to estimate the freshwater inflow into Stonington Harbor, observed at the Borough WPCF.

For future conditions, the freshwater flow into each of the estuaries was based on the 7Q10 flow observed at the USGS gauging station, which was calculated to be 65.3 cubic feet per second (cfs). This flow was then transposed by the same ratios described above to estimate the 7Q10 flow observed at each of the WPCFs. Using the

7Q10 flow will provide a conservative estimate of the response of the estuary to the future changes in WPCF operations.

The reaeration rate is highly dependent upon the observed wind speed. For present conditions, CDM assumed an average wind speed of 1 meter per second (approximately 2 miles per hour). For the future condition, CDM assumed a much more conservative estimate of 0 meter per second. This reduced the reaeration rate from approximately 0.35/day to 0.10/day.

6.4.4 Application and Results of the Dissolved Oxygen Analysis

Because there are insufficient data for calibration of the Streeter Phelps equation to the conditions in Stonington Harbor and the Pawcatuck River, the application of this technique relied on use of typical parameters for the model coefficients. We did attempt to match the model to the existing data (the "Existing" scenario in **Table 6-7**). This effort was reasonably successful in Stonington Harbor; it was not successful in the Pawcatuck River estuary most likely due to (1) use of a single layer model in a two-layer system and (2) absence of other potential significant sources of oxygen demand, such as sediment oxygen demand.

The dissolved oxygen deficits predicted by the Streeter-Phelps analysis are shown in Table 6-7. Again, the results are not meant to be actual predictions of DO deficit, but rather to permit a relative comparison among the scenarios.

Table 6-7

Predicted Relative DO Deficits (mg/L)

	Borough WPCF	**Pawcatuck WPCF**			
	Stonington Harbor	*Pawcatuck WPCF*	*Westerly WPCF*	*Background From River*	*Total for Pawcatuck River*
Existing	1.3	0.08	0.41	0.34	0.8
WQ Scenario 1	0.3	0.09	1.27	0.33	1.7
WQ Scenario 1a	0.5	0.09	1.27	0.33	1.7
WQ Scenario 2/4	0.6	0.09	1.27	0.33	1.7
WQ Scenario 3	--	0.19	1.27	0.33	1.8
WQ Scenario 5	0.9	--	1.27	0.33	1.6

For Stonington Harbor, the model shows that DO deficits will be lower in the future than under existing conditions. Since the harbor currently has high DO, water quality

conditions under any of the discharge scenarios should meet DO water quality criteria.

Predicted DO deficits for the Pawcatuck River indicate that the discharge from the Pawcatuck River is only a small (less than 10 percent) portion of the predicted maximum DO deficit. The largest source of oxygen demand is the Westerly WPCF discharge, though as noted above we did not assume an upgrade in treatment to control nitrogen at this plant.

6.4.5 Dissolved Oxygen Summary

These analyses indicate the following:

- Stonington Harbor has greater ability to assimilate treated wastewater discharges than the Pawcatuck River estuary.
- It appears that the harbor can handle combined flow from all WPCFs and meet state dissolved oxygen criteria.
- The Pawcatuck River estuary has existing water quality problems largely due to its physical setting. The role that wastewater effluent plays in the existing dissolved oxygen problems is unclear compared to other sources of DO demand (e.g., sediment oxygen demand).
- The effluent from the Pawcatuck WPCF is only a small contributor to the DO deficit seen in the estuary.
- Because of the existing dissolved oxygen levels in the estuary, it is possible that a future total maximum daily load (TMDL) study could require even more stringent treatment levels than are currently envisioned for the discharge from the Pawcatuck outfall.

6.5 Toxics Analysis

6.5.1 Introduction

While limits on toxic parameter discharges are not currently included in the NPDES permits for Stonington's treatment plants, there are likely to be considered for conclusion in the next round of permitting. Thus, it is prudent to evaluate toxics as part of these water quality impact analyses. The approach to a toxics analysis is to:

1. establish the appropriate water quality criteria,
2. review current effluent data to determine potential parameters of concern,
3. assess whether these effluent data have higher concentrations than the water quality criteria, and if they do determine the dilution needed to meet the criteria, and

4. determine the dilution available in the receiving waters.

In the case of Stonington's treatment plants, the toxics analysis focuses on metals and ammonia because these are the most common toxics of concern at small municipal treatment plants. They are also the parameters for which data are available.

6.5.2 Establishing the Appropriate Water Quality Criteria

The State of Connecticut has established numerical water quality criteria for most of the constituents tested at each of these plants. These acute and chronic criteria are reported in the State's Water Quality Standards. These limits are described as follows:

- **Acute limit:** Biological integrity is impaired by an exposure of one hour or longer to a concentration that exceeds the acute criteria more frequently than once every three years.
- **Chronic limit:** Biological integrity is impaired when the four-day average concentration exceeds the chronic criteria more frequently than once every three years.

The acute and chronic criteria are specific to fresh and salt water. The appropriate set of numerical criteria for each WPCF depends on whether the plant's receiving water is fresh or salt water. For this analysis the salt water criteria were used for Stonington Harbor and the Pawcatuck River, for the following reasons:

- The State of Connecticut has defined the receiving water for all three of the WPCFs to be saltwater (SA/SB or SC).
- Salinity data collected from Stonington Harbor during September and October 2000 indicate that the Borough plant's receiving water ranged from 24.7 to 29.3 parts per trillion (ppt), clearly estuarine.
- Salinity data collected from the Pawcatuck River during the same sampling period indicate that the receiving waters near the Pawcatuck plant discharge vary from 7.6 to 27.0 ppt, again clearly estuarine.

In addition to the salt and freshwater guidelines, the numerical criteria set for ammonia-nitrogen are dependent upon temperature. **Table 6-8** presents the temperature-dependent ammonia-nitrogen numerical criteria.

Table 6-8
Temperature Dependent Numerical Criteria for Ammonia Nitrogen

	0^0C	*5^0C*	*10^0C*	*15^0C*	*20^0C*	*25^0C*	*30^0C*
Acute Criteria (mg/L)	29.0	20.0	14.0	9.8	6.7	4.8	3.3
Chronic Criteria (mg/L)	4.4	3.0	2.1	1.5	1.0	0.72	0.31

Based on seasonal variations in temperature data collected from the New London NOAA tide buoy (#8461490), CDM designated the appropriate numerical criteria for ammonia nitrogen for each of the metal data sets. Long-term temperature data were not available for each of the WPCF's receiving water; therefore comparisons were made between intermittent receiving water data and the data from the New London tide buoy, located approximately 10 miles southwest of Stonington. The temperature data from the tide buoy, along with the average temperatures recorded in the Pawcatuck River and Stonington Harbor, during the sampling rounds conducted in September and October 2000 are illustrated in the Figure 6-1. The comparison indicates that the New London temperatures are representative of both the Pawcatuck River and Stonington Harbor data and are approximately 1°C greater than those recorded at either location. The appropriate temperature dependent numerical criteria for ammonia nitrogen for each month of the year are listed in **Table 6-9**.

Table 6-9

Monthly Ammonia Nitrogen Numerical Criteria

Month	Acute Criteria (mg/L)	Chronic Criteria (mg/L)
January	29.0	4.4
February	29.0	4.4
March	29.0	4.4
April	20.0	3.0
May	14.0	2.1
June	9.8	1.5
July	6.7	1.0
August	6.7	1.0
September	6.7	1.0
October	9.8	1.5
November	14.0	2.1
December	20.0	3.0

6.5.3 Effluent Data and Comparison to Water Quality Criteria

Stonington's WPCFs monitor for metal concentration in treated effluent on a quarterly basis and results are reported in the monthly data monitoring reports (DMRs), listed under monitoring location "T". Monitoring location "T" is located in the effluent

stream, prior to chlorination upstream of discharge. In addition to the quarterly metals testing, the Borough WPCF was required to test monthly for the first quarter of 2000, as reflected in the data. The Pawcatuck WPCF did not have metals data at location "T" for the month of December 2000. The data are shown in Tables **6-10 through 6-12**.

Connecticut's numerical criteria were compared to the metal effluent data collected at the three WPCFs. The results are also given in the Tables 6-10 through 6-12.

Copper and ammonia levels exceeded both the acute and chronic criteria for some of the sampling dates at each WPCF. There was also one exceedence of the chronic criteria for zinc for the Borough and Mystic WPCF's effluent. Copper, zinc, and ammonia are therefore the parameters of potential concern in the existing discharges.

The upgraded treatment plant(s) will nitrify the effluent, and ammonia concentrations will be significantly reduced to an estimated 1 mg/L. This is also the lowest water quality criterion for ammonia (Table 6-9) so it is reasonable to drop ammonia from further consideration.

It should also be noted that the detection limits for many of the analyses were above the chronic criteria limits, which does not allow for the data to be assessed against these criteria. This occurred for total cadmium, total copper, total cyanide, total lead, total mercury, and total nickel.

6.5.4 Determining Required Initial Dilution Ratios

The CTDEP allows initial dilution, rapid mixing that occurs at end of the effluent pipe, to be included in the assessment of whether water quality criteria for toxics are met. To determine the minimum initial dilution needed to meet the State's water quality criteria, we divided the effluent concentration by the chronic numerical criteria (the strictest criteria) for each of the metals. The highest of these ratios would correlate to the minimum initial dilution ratio required to meet these numerical criteria. The minimum dilutions required are shown below.

Total Copper

- Pawcatuck WPCF would require a 12.5:1 initial dilution ratio (0.03/0.0024 = 12.5)
- Borough WPCF would require a 25:1 initial dilution ratio (0.05/0.0024 = 25.0)
- Mystic WPCF would require a 21:1 initial dilution ratio (0.05/0.0024 = 20.8)

Total Zinc

- Mystic WPCF would require a 2:1 initial dilution ratio (0.09/0.0081 = 1.1)
- Borough WPCF would require a 2:1 initial dilution ration (0.09/0.0081 = 1.1).

See Table 6-10

See Table 6-11

See Table 6-12

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No dilution rate for the Pawcatuck WPCF is specified because zinc levels at this plant were not above the established water quality criterion for zinc (see Table 6-11).

Of these calculations, the initial dilution ratios required to meet the total copper chronic criteria correspond to the largest ratios needed for compliance. Based on these calculations, the following initial dilution ratios are needed at each WPCF:

- Pawcatuck WPCF -- 12.5:1
- Borough WPCF -- 25:1
- Mystic WPCF -- 21:1

Future scenarios assuming discharge of a mixed effluent through the Pawcatuck outfall would be required to meet more than 12.5:1 dilution.

6.5.5 Initial Dilution Analysis

Introduction

CDM used the EPA program CORMIX to determine initial dilution for many river/ocean conditions. The Cornell Mixing Zone Expert System (CORMIX) is an EPA-supported, software system for the analysis, prediction, and design of aqueous toxic or conventional pollutant discharges into diverse water bodies. Use of the program helps to determine what dilution can be expected from given outfall configurations, discharge concentrations, and receiving water characteristics.

Of interest for this study are the "near-field" dilutions. The near field is the region of the receiving water where the initial jet characteristics of momentum flux, buoyancy flux and outfall geometry influence the jet trajectory and mixing of the effluent discharge (*User's Manual for CORMIX*, September 1996). The near field gives way to the far field, which is the region of the receiving water where buoyant spreading motions and passive diffusion control the trajectory and dilution of the effluent discharge plume. The dilutions calculated and reported for this study are at the end of the near-field region.

For the Borough plant discharge, we also used the EPA-approved model UM described in *Initial Mixing Characteristics of Municipal Ocean Discharges* (EPA, 1985).

Data

The data described in previous sections were used to define input parameters for the receiving waters: effluent flow rate (Table 6-4 and 6-5) and stratification (Tables 6-1 and 6-2). Because no data on ambient current speed were available, this parameter was examined through a sensitivity analysis. Characteristics of the outfalls were provided by the Town: the Stonington Borough Plant and Pawcatuck River Plant drawings from February 1971, and supplemented by the dive inspection conducted in mid-2001.

Stonington Borough Outfall

The Borough WPCF discharges directly into Stonington Harbor. The riser configuration reported by the dive inspection team (see Section 6.2) was used for initial dilution modeling, though we assumed that the broken riser would be fixed.

The diffuser is located approximately 415 feet from the shore at its closest point, and 600 feet at the farthest point. The total width of the harbor was taken as 1,500 feet. Manning's coefficient of the harbor bottom is 0.025. Wind speed was taken to be 0 feet per second (ft/s).

No data were available regarding the local tidal velocities, so a range of velocities was modeled. Ambient tidal velocities of 0.0033 to 0.033 ft/s, one hour after the slack tide, with maximum tidal velocities of 0.33 to 3.3 ft/s, resulted in approximately 2 percent difference in the dilution calculated at the near-field boundary. Greater ambient tidal velocities, 1.1 ft/s one hour after the slack tide, resulted in an expanding of the near-field region, and a subsequent increase in the dilution at the outside boundary of the near-field region. An instantaneous velocity of 0.033 ft/s and a maximum velocity of 3.3 ft/s were used in the reported results.

Stratification was not observed in the harbor near the discharge. The water column was modeled as 8 feet deep at MLW with a constant density of 63.9 pounds per cubic foot (lb/ft^3).

Pawcatuck Outfall

The Pawcatuck WPCF outfall is a single 24-inch diameter pipe, which discharges into a dredged section next to the navigation channel. For modeling purposes, local shallow areas west of the outfall were ignored, and dilution in the channel only was considered. The width of the channel is approximately 180 feet. The depth of the channel is 10.5 feet.

Manning's coefficient of the channel was taken as 0.025 recommended for earth channels with some stones and weeds (page 31, *User's Manual for CORMIX*, September 1996). Wind speed was taken as 0 ft/s.

The Pawcatuck River is tidal, and stratified, so that a fresh water lens was seen lying over heavier salt water in the field data. As the effluent is released into the bottom of the channel, the ambient flow is heavily dependent upon the tidal velocity rather than on the freshwater flow in the river. Tidal velocities at one hour after slack tide from 0.03 ft/s to 0.15 ft/s, and maximum tidal velocities of 1.6 ft/s to 16 ft/s were considered. The variation in velocities resulted in a 6 percent variation in dilution. An instantaneous velocity of 0.03 ft/s and a maximum velocity of 1.6 ft/s were used in the reported results.

Densities of 62.4 pounds per cubic foot (lb/ft^3) for the surface fresh water and 64.0 lb/ft^3 for the bottom salty water were used. The interface between the fresh and salt water layers was modeled at 6 feet above the bottom of the channel, 4.5 feet from the

water surface. This approximates the stratification seen during the fall of 2000 sampling rounds.

Results

Stonington Borough Outfall

The dilutions expected in the harbor under the various scenarios described above are shown in Table 6-13 for both CORMIX and UM.

We initially modeled the discharge with CORMIX2, which simulates dilution from multiport diffusers. CORMIX2, however, makes simplifying assumptions about the diffuser ports that while reasonable for a well-designed diffuser in deep water are not reasonable for Stonington's existing diffuser. Specifically, in CORMIX2 the diffuser ports are treated as an equivalent slot and the discharge is directed vertically upward. Stonington's existing diffuser has such widely spaced ports that the individual effluent plumes do not merge prior to the end of the near-field region. Thus, CORMIX2 does not adequately simulate the initial dilution from the diffuser.

To more accurately model the dilution from the diffuser, we used CORMIX1, which simulates discharge from an individual port. This port was assumed to discharge one-fourth of the total flow and the discharge from the port was downstream (which describes Stonington's actual diffuser).

To add a measure of confidence for the use of CORMIX1 to determine initial dilution, we also simulated a single port and multiport diffuser in UM. UM does not simplify either direction or port shape for either the single or multiport diffusers. **Table 6-13** shows the same dilution for each scenario using both the single and multiport diffuser cases. In addition, the UM results compare well with the dilution predicted from the single port CORMIX results.

Table 6-13

Borough Outfall: Initial Dilution Results

			CORMIX	*UM Model*	
	Number of Ports	*Plant Flow, mgd*	*Single port Near-Field Dilution*	*Multiport Near-Field Dilution*	*Single port Near-Field Dilution*
Existing	4	0.496	10.0	9.8	9.9
WQ Scenario 1	4	0.299	11.6	12.7	12.7
WQ Scenario 1a	4	0.579	9.7	9.4	9.4
WQ Scenario 2/4	4	1.025	9.4	8.6	8.6
WQ Scenario 3	4	0	-	-	-
WQ Scenario 5	4	1.964	3.7	8.9	8.9
WQ Scenario 5a	6	1.964	9.7	8.6	8.6

The lower dilution (3.7:1) resulting from the CORMIX1 simulation of WQ Scenario 5 was unexpected. The lower dilution occurs because the higher velocity jet attaches to the seabed limiting the available water to be entrained into the plume. This phenomenon is called a Coanda bottom attachment. In general, plumes incorporate or "entrain" ambient seawater, resulting in increasing dilution farther from the discharge. The Coanda attachment occurs when the entrainment is strong due to high velocity and turbulence in the plume and when the discharge port is near the seabed. The attachment results in much lower dilution than would have otherwise been expected, because the bottom of the plume is located on the seabed preventing entrainment of seawater.

Because of this low dilution result, we simulated the same discharge as Scenario 5 through 6 ports on the Stonington diffuser (Scenario 5a); currently the diffuser has 4 active ports and the remaining are capped. With the additional two diffusers the additional flow rate is sufficiently reduced to preclude the Coanda attachment. The dilution with 6 diffusers is predicted to be more than twice that of Scenario 5. Thus, if Scenario 5 is selected, we would also recommend that Stonington open additional ports on its existing diffuser.

Pawcatuck Outfall

The Pawcatuck WPCF has a 24-inch diameter outfall. The effluent flow seen in existing conditions, and even the flow expected under future scenarios, results in very small discharge velocities. Consequently, the ambient salt water may intrude up the pipe.

The effluent velocities modeled are low enough that the stratification seen in the river is important, and the effluent is trapped in the lower, salt-water layer, under the freshwater lens at the surface. In effect, this reduces the depth of water available for dilution.

Table 6-14 lists the water quality scenarios and results for the Pawcatuck River outfall. Near-field dilution achieved at the Pawcatuck outfall is very low. Dilution could be improved by increasing the velocities at the outfall pipe, either by reducing the diameter of the pipe (*i.e.*, adding a duck bill type valve to the outfall), or by pumping or otherwise increasing the discharge head. Increasing the exit velocity extends the near-field distance, and also therefore the volume available for dilution.

Table 6-14

Pawcatuck Outfall: Initial Dilution Results

	Plant Flow, mgd	*Near-field Dilution*	*Near-field Distance, feet*
Existing	0.493	2.7:1	5.3
WQ Scenario 1	0.939	2.1:1	5.3
WQ Scenario 1a	0.939	2.1:1	5.3
WQ Scenario 2/4	0.939	2.1:1	5.3
WQ Scenario 3	1.964	1.8:1	5.2
WQ Scenario 5	--	--	--

6.5.6 Toxics Summary

The toxic parameter of concern appears to be copper. To meet water quality criteria with the current level of copper in the effluent, the dilution in the receiving water would need to be between 12.5:1 and 25:1 depending on which water quality scenario is selected. Planned upgrades to the treatment plants will not alter effluent copper concentrations appreciably.

While ammonia is a parameter of concern at concentrations found in the existing effluent, the nitrification/denitrification processes to be added as part of the facilities upgrade will reduce ammonia levels to 1 mg/l, which is the same as the lowest water quality criterion for ammonia.

The Borough outfall gets greater dilution than the discharge to the Pawcatuck outfall estuary due to the increased depth of water available for mixing and the diffuser design. The lack of stratification in the harbor also allows mixing through the entire water column.

While initial dilution is larger in Stonington Harbor than in the Pawcatuck River estuary, none of the scenarios simulated would appear to have sufficient initial dilution to allow for the copper water quality criterion to be met.

In municipalities with little industry, corrosion household plumbing is typically the largest source of copper to the wastewater treatment plant. The best approach for lower copper levels is often to improve the level of corrosion control for the water supply.

If this does not prove adequate, it is possible that sufficient initial dilution can be obtained at the Borough plant's outfall by opening some of the capped risers. For example, a CORMIX simulation of Scenario 5 flows with 3 risers operational (6 ports open) resulted in an initial dilution of 22:1.

Dilution at the Pawcatuck outfall is primarily limited by the stratification in the estuary. It is possible, however, that additional dilution could be obtained by increasing the exit velocity of the pipe. Even with this sort of improvement, it is much less likely that the copper water quality criteria could be met at the Pawcatuck discharge location.

Lastly, we note again that the detection limits for several parameters were higher than the water quality criteria; the detection limits for total cadmium, copper, cyanide, lead, mercury and nickel are higher than the chronic criteria and may need to be lowered. The State could require these detection limits to be lowered to at or below the chronic criteria for each parameter. In addition, lowering the detection limits will also lead to more reliable data. A good rule of thumb is that the detection limit should be about one-third of the anticipated minimum value.

6.6 Water Quality Findings and Recommendations

Following is a list of findings and conclusions, based on the analyses described in this section:

- Water quality in the northernmost portion of the Pawcatuck River estuary is highly degraded. This condition appears to be a function of physical constraints of the estuary.

- Pawcatuck River water quality is only somewhat degraded near the Pawcatuck WPCF outfall. This appears to be because there is much better tidal exchange lower in the estuary than its mouth. The Pawcatuck WPCF discharge is a small contributor to the deficit of oxygen found in the estuary.

- Stonington Harbor is better suited for assimilating wastewater flows because:

  - It has greater mixing/flushing for conventional pollutants and

  - It offers greater dilution potential for meeting water quality criteria for toxic pollutants.

- Stonington Harbor should be able to handle the combined discharge from all three treatment plants and meet the State's water quality standard for dissolved oxygen.

- The Borough WPCF outfall diffuser has sufficient hydraulic capacity to handle the combined flow from all three plants.

- The Town should investigate whether influent copper concentrations in the wastewater could be reduced by improved corrosion control of the water supply.

- If the Town selects to implement Scenario 5 at the Stonington Harbor, then two additional ports should be opened on the existing Borough WPCF's outfall diffuser. This would not be required for the other scenarios.