N00129.AR.000894
NSB NEW LONDON
5090.3a

DEPARTMENT OF THE NAVY
ENGINEERING FIELD ACTIVITY, NORTHEAST
NAVAL FACILITIES ENGINEERING COMMAND
10 INDUSTRIAL HIGHWAY
MAIL STOP, #82
LESTER, PA 19113-2090

IN REPLY REFER TO

5090
Code EV23/ME
October 30, 2001

Mr. Mark Lewis
Connecticut Department of Environmental Protection
Bureau of Water Management
Permitting, Enforcement, and Remediation Division
79 Elm Street
Hartford, Connecticut 06106-5127

Dear Mr. Lewis

SUBJECT: REQUEST FOR APPROVAL OF SITE-SPECIFIC DILUTION FACTORS FOR POLLUTANT MOBILITY CRITERIA AND SURFACE WATER PROTECTION CRITERIA, LOWER SUBASE FEASIBILITY STUDY, NAVAL SUBMARINE BASE NEW LONDON, GROTON, CT

As you know, EA Engineering, Science, and Technology, as environmental consultant to the U.S. Navy, is preparing a Feasibility Study for Lower Subase, Naval Submarine Base, New London, Groton, Connecticut. Based on review of subsurface geology and hydrological conditions of the adjacent Thames River estuary, the mobility and transport of constituents of concern in soil are affected by relatively high levels of dilution for ground water and surface water protection. Consistent with procedures outlined in Sections 22a-133k-2(c)(2)(E)(ii) and 22a-133k-3(b)(3) of the Connecticut Remediation Standard Regulations of January 1996, site-specific dilution factors have been developed to provide dilution-adjusted criteria for assessment of pollutant mobility from soil to ground water, and to generate alternative surface water protection criteria for constituents of concern in ground water discharging to the Thames River. A detailed description of these site-specific dilution factors is provided in Attachment A.

These dilution factors will be used in conjunction with other applicable or relevant and appropriate requirements as part of the risk assessment for the Lower Subase to identify constituents of concern and locations that will require development of remediation alternatives. The Remediation Standard Regulations require that dilution-adjusted criteria for pollutant mobility and alternative surface water protection

5090
Code EV23/ME
October 30, 2001

criteria be approved by the Commissioner for use in establishing preliminary remediation goals at sites with soil and ground water contamination. Therefore, the U.S. Navy requests your review and approval of these procedures and associated site-specific dilution factors for Lower Subase as described in Attachment A. The approach described was previously submitted (February 23, 2001) in preliminary form to your office and to Ms. Kymberlee Keckler (EPA Region I) for review; the current document (Attachment A) incorporates revisions based on comments received on that draft and have been integrated into the draft Feasibility Study distributed on September 28, 2001.

If you have any questions, please do not hesitate to contact me at (610) 595-0567 ext. 162.

Sincerely,

Mark Evans
Remedial Project Manager
By direction of the
Commanding Officer

Attachment: A. Development of Site-Specific Dilution Factors

Copy to:
Ms. Kymberlee Keckler, USEPA Region I
Mr. C. McLeod, EA - Newburgh

Attachment A

Development of Site-Specific Dilution Factors for Lower Subase, Naval Submarine Base New London, Groton, Connecticut

ATTACHMENT A

DEVELOPMENT OF SITE-SPECIFIC DILUTION FACTORS FOR LOWER SUBASE, NAVAL SUBMARINE BASE NEW LONDON, GROTON, CONNECTICUT

1. INTRODUCTION

The State of Connecticut Remediation Standard Regulations (RSRs) provide alternative procedures for use of site-specific dilution factors to develop alternative criteria for protection of ground water (pollutant mobility) and surface water. The Commissioner of the Connecticut Department of Environmental Protection (CTDEP) must approve site-specific dilution factors that are developed for remediation at sites with soil and/or ground-water contamination. This report provides detailed information on the dilution factors developed and proposed to assess for pollutant mobility and surface water protection at Lower Subase, Naval Submarine Base New London (NSB-NLON), Groton, Connecticut.

2. POLLUTANT MOBILITY STANDARDS

2.1 DEPTH OF AFFECTED SOILS

The State of Connecticut RSRs establish (Sections 2a-133k-2[c][1][A] and [B]) soil remediation criteria for pollutant mobility (PMC) to protect against mobilization of contaminants from soil to ground water. The ground-water classification at Lower Subase for compliance in this assessment is GB. Lower Subase is constructed, for the most part, on sand and gravel fill in the Thames River flood plain. The Phase I Remedial Investigation for NSB-NLON (Atlantic Environmental Services 1992) demonstrated that the elevation of the water table and the direction of ground-water flow at Lower Subase are affected by daily fluctuations associated with the tidal cycle of the Thames River. This influence on ground water was found up to 300 ft inshore from the quay wall. Atlantic Environmental Services reported that the tidal effect on ground-water elevation was approximately half the water surface elevation range during a tide cycle in the Thames River; specifically, a 2.22 ft rise in river elevation affected a 1.19 ft rise in ground-water elevation. The approximate twice daily tide cycle has a greater influence on ground-water movement than seasonal effects such as precipitation and infiltration in the flood plain fill material; therefore, PMC have been evaluated relative to Lower Subase soils above the high tide influenced water table.

2.2 SITE-SPECIFIC DILUTION

The hydraulic conductivity of the overburden/fill material is relatively high, typically in the range of 1-100 ft/day, but was measured as high as 576 ft/day at one location at Lower Subase. This is consistent with the observed synchronous tidal influence on ground-water elevation. The relatively rapid movement and flushing of ground water through the overburden/fill indicates that considerable dilution of infiltration occurs at Lower Subase. For polluted soils above the ground-water table in a GB area (excluding total petroleum hydrocarbons) the Connecticut RSRs (Sections 2a-133k-2[c][2][D] and [E]) identify several options for integration of site-specific dilution into determination of remediation standards including:

- Remediation to a level at which the results of Toxicity Characteristic Leaching Procedure/Synthetic Precipitation Leaching Procedure analysis do not exceed the ground-water protection criteria (GWPC) for a substance multiplied by a site-specific dilution factor

- Remediation to a level at which results of mass analysis do not exceed the PMC for a GA ground-water classification multiplied by a site-specific dilution factor.

The RSRs stipulate several conditions that must be met in order to apply a site-specific dilution factor to PMC:

- Non-aqueous phase liquid is not present in the soil

- The water table is at least 15 ft above the surface of bedrock

- Downward ground-water flow velocity is not greater than horizontal ground-water flow velocity

- The dilution factor has been approved by the CTDEP Commissioner.

Data collected during the Phase I Remedial Investigation for NSB-NLON and the Lower Subase Remedial Investigation indicate that the first three conditions are satisfied at Lower Subase. Atlantic Environmental Services (1992) reported that light or dense non-aqueous phase liquids were not found at NSB-NLON as part of the Phase I Remedial Investigation. These findings were reinforced in the Lower Subase Remedial Investigation (Brown & Root 1998). The bedrock surface at NSB-NLON dips steeply toward the river beneath Lower Subase. The majority of monitoring wells installed at Lower Subase were drilled to 20 ft below grade or at least 10 ft below the water table. Bedrock was not encountered in most of these wells except for a few locations in Zones 5 and 7 along the east boundary of Lower Subase where the ground surface begins to rise above the flood plain. Considering the large number of wells and their spatial distribution at Lower Subase, it is apparent that the ground-water table is generally at least 15 ft above bedrock. Due to the influence of the river and the relatively flat ground-water surface gradient, downward ground-water flow is relatively small compared to horizontal velocity.

An equation for calculation of the site-specific dilution factor is provided in Section 22a-133k-2(c)(2)(E)(ii). This equation uses the hydraulic gradient and conductivity (Brown & Root 1997), an infiltration rate based on type of geologic material, a cross-sectional dimension of the site **(Table 1),** and a constituent-specific ground-water background adjustment **(Table 2):**

$$DF = (1 + ((K \times i \times d)/(I \times L)))(1 - F_{adj}))$$

DF = Site-specific dilution factor
K = Hydraulic conductivity (ft/year)
i = Horizontal hydraulic gradient (ft/ft)
d = Thickness of overburden water table (15 ft)

I = Infiltration rate (ft/year)
L = Length (ft) of the release area parallel to the direction of ground-water flow
F_{adj} = Background concentration for ground water divided by the GWPC.

The hydraulic conductivity ranged from 1.7 to 576 ft/day among the seven zones (Brown & Root 1997). Considering the similarity of subsurface characteristics of the sand and gravel fill overlying the glacial material at Lower Subase, the estimated hydraulic conductivity for Zone 3 (1.7 ft/day) appears to be anomalously low. In order to be more representative of typical conditions, the next higher estimate (74 ft/day) of hydraulic conductivity that occurred at adjacent Zone 2 was used for Zone 3 to calculate the zone-specific dilution factor. The width of Lower Subase from the railroad on the east to the Thames River averages approximately 350 ft. The entire width at a given cross-section is not a contaminant source, and infiltration is limited because most of the ground surface at Lower Subase is covered by impervious paving or buildings. It has been assumed that ground water flowing across the width of Lower Subase will be exposed on average to a contaminant source via infiltration over approximately half this width; therefore, the value of L in the calculation was set at half the width of Lower Subase, i.e., 175 ft.

An adjustment for constituent-specific background concentrations in ground water was made consistent with Section 22a-133k-2(c)(2)(E)(ii); this adjustment represents a fractional reduction in the GWPC due to the presence of background contaminant concentrations in ground water entering the upgradient boundary of the site. The average of all data from 3 monitoring wells (13MW6, MW1-6RI, and MW2-4RI) was used to represent background concentrations of chemical constituents in ground water entering Lower Subase along the east site boundary. These 3 wells **(Figure 1)** were selected based on the following criteria:

- Wells located near the railroad along the east side of the flood plain and site boundary
- Wells located upgradient of any known Installation Restoration sites at Lower Subase
- Wells not in the immediate vicinity of any buildings at the site.

There were 11 total sets of analyses for metals and 6 analyses for volatile and semivolatile organics. There were only 8 detections of organic compounds for these analyses. The background adjustment factor was calculated for each constituent by dividing the average background value by the GWPC; data listed with a "U" qualifier (non-detect) were used in the calculation of the background adjustment at one-half the detection limit. When the background value was equal to or greater than the GWPC, the calculation returns a zero or negative dilution factor. This typically occurred for constituents that were not detected in any samples at a detection limit of 10 µg/L or greater, but with GWPC less than 1 µg/L. In those situations, the dilution factor was set to 1 and the PMC were not adjusted for dilution. The calculated zone- and constituent-specific dilution factors are shown in **Table 3**.

3. SURFACE WATER PROTECTION CRITERIA

3.1 SITE-SPECIFIC DILUTION FACTORS

CTDEP regulations establish that a pollutant concentration in a ground-water plume that discharges to surface water should be at or below surface water protection criteria (SWPC) (Section 22a-133k-3[b]). Section 22a-133k-3(b)(3)(A) of the regulations provides a process for

calculation of alternative SWPC using a site-specific dilution factor ($0.25 \times 7Q10/Q_{plume}$). This calculation, while appropriate for a discharge to a non-tidal river, does not take into account the significant additional dilution that occurs at Lower Subase associated with cyclic tidal inflow (tidal prism) to the Thames River.

Waste Load Allocation guidance (U.S. EPA 1990) provides methods for development of site-specific dilution factors in an estuarine environment. Waste Load Allocation guidance is designed for the derivation and modeling of the dilution of point discharges into the estuarine environment, primarily through discharge pipes or diffusers. Although this guidance is not directly applicable to the discharge of ground water into a river, it does provide a generic process to assess the dilution of a contaminant discharged into a tidal estuary such as the Thames River in the vicinity of Lower Subase.

The guidance provides for use of a modified tidal prism model as a screening method to estimate tidal dilution from the total amount of water entering the estuary or a segment of the estuary from tidal inflow. The method is applied by dividing the estuary into segments; segment volumes are calculated summing the low tide volume and tidal inflow (i.e., the tidal prism). For each segment, the tidal prism is compared with the total segment volume to estimate the flushing potential in that segment over a tidal cycle assuming that complete mixing of tidal inflow occurs (Martin and McCutcheon 1998; Thomann and Mueller 1987; and U.S. EPA 1990). A simplified analytical model was developed to estimate the potential for dilution of ground-water plume constituents that discharge into the Thames River Estuary at Lower Subase. The data requirements for the modified tidal prism method are as follows:

- River freshwater flow
- Tidal elevation range
- Pollutant mass loading rate.

3.1.1 River Freshwater Flow

The minimum daily freshwater flow (Q_R) in the Thames River at Norwich (1.51×10^6 ft^3/day) (Tolderlund 1975) was used to represent low flow conditions. Use of the minimum daily flow as a surrogate for the 7Q10 is a conservative assumption that results in an underestimate of freshwater volume during low flow conditions. This is the same value accepted in the Final Feasibility Study for the Defense Reutilization and Marketing Office (DRMO) site located immediately upstream of Lower Subase.

3.1.2 Tidal Prism Calculations

Lower Subase is located in an estuarine environment that is subject to a tidal elevation range of 2.6 ft (Tolderlund 1975). Because of the diurnal tidal flux in the Thames River, dilution factors have been derived primarily on the volume of the tidal prism. A conservative estimate of the area for dilution was established, bounded by the north and south extent of the NSB-NLON, and extending from the eastern shoreline to approximately the middle of the Thames River (blue shaded area of **Figure 1**). This represents only a portion of the longitudinal extent of an individual tide cycle. The area of this dilution zone was approximated as 7.68×10^6 ft^2. Given a range in tidal elevation of 2.6 ft (Tolderlund 1975), the volume of one tidal excursion in this reach is calculated as:

$$7.68\times10^{6}\,\text{ft}^{2}\times2.6\text{ft}=2.0\times10^{7}\,\text{ft}^{3}$$

Given that the tide cycles approximately two times every day, the volume of the tidal prism (Q_{TV}) is calculated as:

$$Q_{TV}=\frac{2.0\times10^{7}\,\text{ft}^{3}}{\text{cycle}}\times\frac{2\text{ cycles}}{\text{day}}=4.0\times10^{7}\,\text{ft}^{3}/\text{day}$$

The calculated tidal prism is an order of magnitude greater than the minimum daily freshwater flow. As noted earlier, Section 22a-133k-3(b)(3)(A) states that 25 percent of freshwater flow is available for dilution. Connecticut regulations allow for dilution and mixing of ground water in the derivation of alternate SWPC; however, no specific guidance is provided except the above noted freshwater flow dilution. A typical mixing factor that is used for comparison to chronic ambient water quality values is 10 percent of total tidal flux. The use of a 10 percent mixing factor is consistent with other States, for example, the State of Maryland allows a 10 percent factor for dilution according to the Code of Maryland Regulations 26.08.02.05 C and D. On this basis, the total tidally averaged flow available for dilution (Q_A) is:

$$Q_A=0.25Q_R+0.10Q_{TV}$$

$$Q_A=(0.25\times1.51\times10^{6})+(0.10\times4.0\times10^{7})=4.4\times10^{6}\,\text{ft}^{3}/\text{day}$$

3.1.3 Ground-Water Discharge Volume

The third piece of information necessary for computation of these dilution factors is the estimation of the daily average discharge from the ground-water plume (Q_{plume}). This parameter was calculated consistent with Section 22a-133k-2(c)(2)(E)(ii) using estimates of the hydraulic gradient (i) and hydraulic conductivity (K) **(Table 4)** presented in the Lower Subase RI (Brown & Root 1998); the derivation of these data was reported in the subsection for each zone entitled *Soil Characteristics, Geology, and Hydrogeology*. Brown and Root (1998) estimated the values of K from slug tests at various locations across the site; when estimates were available from several wells in a zone, the geometric average was used for the zone. Ground water was assumed to discharge to the Thames River at the ground-water flow rate (K × i) across the entire cross-section of the zone parallel to the shoreline bulkhead.

$$Q_{plume}=K\times i\times L\times d$$

The thickness of the saturated ground-water zone (d) was assumed to be approximately 12 ft across all zones. The length (L) of each zone was measured along a straight line perpendicular to the direction of ground-water flow and parallel to the flow of the River.

The hydraulic conductivity ranged from 1.7 to 576 ft/day among the seven zones. The hydraulic conductivity for Zone 3 (1.7 ft/day) results in a very low estimate of ground-water discharge (32.3 ft^3/day) relative to the other zones at Lower Subase, although the artificial fill and underlying glacial drift are similar throughout Lower Subase. Because an underestimate of ground-water flow would result in an overestimate of dilution, the flow from the adjacent Zone 4 (Q_{plume} = 5,391 ft^3/day), the maximum Q_{plume} among all zones, was substituted for Zone 3, providing a conservative value for calculation of dilution for this zone.

3.1.4 Steady State Mass Balance Model for Estuarine Dilution

Assuming complete mixing within the dilution zone highlighted in blue on **Figure 1**, the tidally averaged mass balance equation for a conservative material given a single point source within the mixing zone is estimated by:

$$\frac{1}{V}\frac{dC}{dt} = \dot{m}_{in} - \dot{m}_{out} = Q_R C_R + Q_{TV} C_{TV} + Q_{plume} C_{plume} - (Q_R + Q_{TV} + Q_{plume})C$$

where

C	=	Concentration of pollutant in estuary segment (µg/L)
t	=	Time (days)
V	=	Volume of the mixing zone (ft^3)
$\dot{m}_{in}$	=	Pollutant mass flux into the mixing zone (µg/day)
$\dot{m}_{out}$	=	Pollutant mass flux out of the mixing zone (µg/day)
C_R	=	Concentration of pollutant in river freshwater (µg/L)
C_{TV}	=	Concentration of pollutant in the tidal inflow (µg/L)
C_{plume}	=	Concentration of pollutant in ground-water plume (µg/L)
Q_R	=	Minimum daily Thames River freshwater flow (ft^3/day)
Q_{TV}	=	Tidal prism volume (ft^3/day)
Q_{plume}	=	Discharge volume of ground-water plume (ft^3/day).

The steady-state solution ($dC/dt = 0$) to the above mass balance equation is:

$$(Q_R + Q_{TV} + Q_{plume})C = Q_R C_R + Q_{TV} C_{TV} + Q_{plume} C_{plume}$$

Assuming that $C_R \approx 0$, $C_{TV} \approx 0$, and $Q_{plume} << (Q_R + Q_{TV})$, the model reduces to the following approximation:

$$(Q_R + Q_{TV})C = Q_{plume} C_{plume}$$

The assumption is that C_R and C_{TV} are based on surface water sampling from the Thames River in the vicinity of Lower Subase. The Lower Subase Remedial Investigation (Brown and Root 1998; Figure 11-4 and Tables 11-14 and 11-15) reported analytical results for six Thames River surface water samples collected upstream, adjacent to, and downstream of Lower Subase. None of the polycyclic aromatic hydrocarbon compounds detected in ground water at Lower Subase were detected in the Thames River samples. Lead was detected at 1.5 µg/L in surface and bottom water at one of the six Thames River locations.

This location was approximately 200 ft offshore from the DRMO upstream of Lower Subase; lead was not detected at another location approximately 500 ft offshore of the DRMO. In addition, a review of available information for the Lower Subase Remedial Investigation (Brown and Root 1998; Figure 11-1) indicated that no significant discharges to surface water occur within 1 mi of Lower Subase.

The principal of superposition can be used to extend the model to multiple point sources which, when solved for the constituent concentration in the estuary, yields:

$$C = C_{plume} \frac{\sum Q_i}{Q_A} = C_{plume} \div DF$$

where

$\sum Q_i$ = Sum of the individual plume discharges (ft^3/day)
DF = Dilution factor
Q_A = Total tidally averaged flow, $(Q_R + Q_{TV})$.

In this equation, it is assumed that the pollutant concentration (C_{plume}) is the same in all sources, and that the sources are close enough together that they are well mixed within the modeled mixing zone. In this case, a conservative assumption was made that ground water discharges at a constant rate; this does not account for the ground-water flow reversal around the two high tide periods and will overestimate discharge and underestimate dilution.

3.2 CALCULATION OF ALTERNATE SURFACE WATER PROTECTION CRITERIA

Alternate SWPC is calculated as follows:

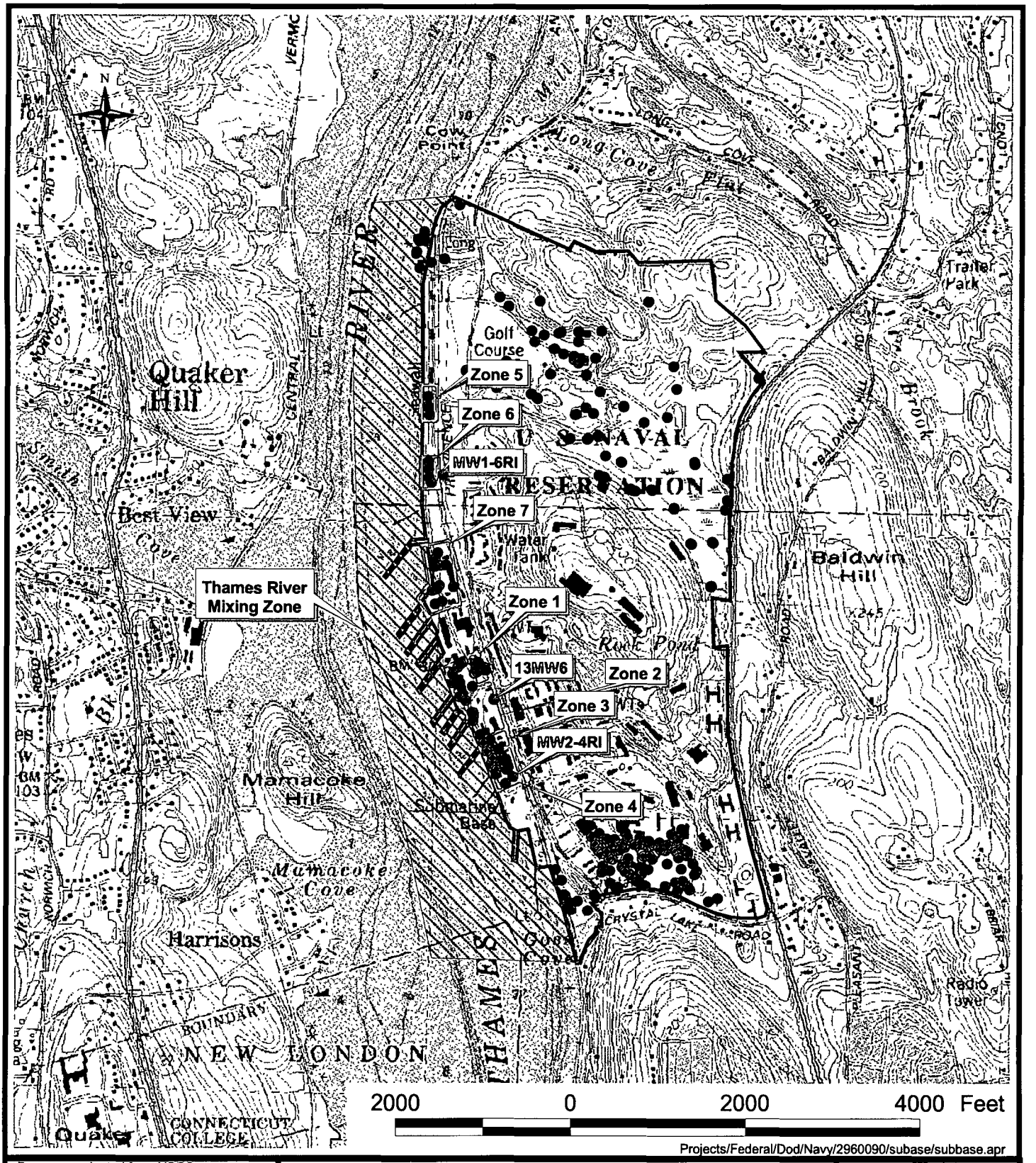
Alternate SWPC (µg/L) = CTWQC × DF

where

CTWQC = Connecticut Water Quality Criteria (µg/L)
DF = Zone-specific dilution factor.

The Connecticut Water Quality Criteria for all the polycyclic aromatic hydrocarbon constituents of potential concern are the same (0.031 µg/L) which is the concentration in water predicted to result in a 1×10^{-6} cancer risk to humans consuming organisms living in that water.

To be conservative, the maximum concentration among the seven ground-water plumes was used for C_{plume}. Only those constituents identified as exceeding standard Connecticut SWPC in the ground water, without accounting for dilution, were evaluated for each zone to calculate alternate SWPC **(Table 5).** For example, acenaphthylene was found to be above the standard SWPC in ground water from Zones 1, 5, 6, and 7. The maximum average acenaphthylene concentration was 5.29 µg/L in Zone 7. Therefore, for acenaphthylene, C_{plume} = 5.29 µg/L, $\sum Q_i = Q_1 + Q_5 + Q_6 + Q_7$ = 14,608 ft^3/day, $DF = Q_A/Q_{plume}$ = 299, $C = C_{plume}/DF$ = 0.02 µg/L, and *Alternate SWPC* = *CTWQC* × *DF* = 9.27 µg/L. **Table 6** lists C_{plume}, $\sum Q_i$, *DF*, *C*, and *Alternate SWPC* for all of the identified constituents of potential concern in ground water at Lower Subase.



Projects/Federal/Dod/Navy/2960090/subase/subbase.apr

Base map adapted from USGS Topographic Quad Uncasville, Connecticut

Ground-water Sampling Locations
Zone Boundaries
Subase Boundary

Figure 1
Location map showing Thames River mixing zone used for calculation of Alternative Surface Water Protection Criteria and ground-water w lls us d to represent background conditi ns for dilution-adjust d P llutant Mobility Crit ria, Lower Subase Feasibility Study, Naval Submarine Bas , N w L ndon, Connecticut.

TABLE 1 SUMMARY OF PARAMETERS USED TO CALCULATE ZONE-SPECIFIC DILUTION FOR ESTIMATION OF DILUTION-ADJUSTED POLLUTANT MOBILITY

Zone	Hydraulic Gradient i (ft/ft)	Hydraulic Conductivity K (ft/day)	Depth d (ft)	Infiltration Rate I (ft/yr)	Length L (ft)	Dilution 1 + (Kid/[IL])
1	0.00476	158	15	0.5	175	48.06
2	0.00318	74	15	0.5	175	15.72
3	0.00792	74	15	0.5	175	37.67
4	0.0039	576	15	0.5	175	141.56
5	0.0092	74	15	0.5	175	43.60
6	0.0092	74	15	0.5	175	43.60
7	0.00527	74	15	0.5	175	25.40

TABLE 2 SUMMARY OF DATA USED TO ESTIMATE BACKGROUND ADJUSTMENT FOR CALCULATION OF SITE-SPECIFIC DILUTION FACTORS FOR DILUTION-ADJUSTED POLLUTANT MOBILITY CRITERIA

Parameter	N	Hits	Minimum	Maximum	Average	Ground-Water Protection Criteria-GA	Constituent Background Adjustment
Antimony	11	2	1.25	12.5	4.58	6	0.236
Arsenic	11	0	1	1.5	1.23	50	0.975
Barium	11	10	11.3	344	86.75	1,000	0.913
Beryllium	11	0	0.055	0.5	0.24	4	0.939
Cadmium	11	0	0.11	1	0.31	5	0.939
Chromium	11	1	0.34	2.5	0.93	50	0.981
Cobalt	11	4	0.4	2.5	1.36	420	0.997
Copper	11	2	0.37	9.1	1.89	1,300	0.999
Cyanide	1	0	2.5	2.5	2.50	200	0.988
Lead	11	3	0.5	17.2	2.96	15	0.803
Mercury	11	0	0.005	0.1	0.04	2	0.982
Nickel	11	5	0.375	18.7	5.11	100	0.949
Selenium	11	1	0.95	2.3	1.22	50	0.976
Silver	11	0	0.55	3.5	1.05	36	0.971
Thallium	11	1	0.5	6.5	2.35	5	0.531
Vanadium	11	0	0.275	10	1.60	50	0.968
Zinc	11	6	1.45	105	32.25	5,000	0.994
1,2,4-Trichlorobenzene	6	0	5	6	5.50	70	0.921
1,2-Dichlorobenzene	6	0	5	6	5.50	600	0.991
1,3-Dichlorobenzene	6	0	5	6	5.50	600	0.991
1,4-Dichlorobenzene	6	0	5	6	5.50	75	0.927
2,4,5-Trichlorophenol	6	0	12.5	15	13.83	700	0.980
2,4,6-Trichlorophenol	6	0	5	6	5.50	10	0.450
2,4-Dichlorophenol	6	0	5	6	5.50	20	0.725
2,4-Dimethylphenol	6	0	5	6	5.50	140	0.961
2,4-Dinitrophenol	6	0	12.5	15	13.83	50	0.723
2,4-Dinitrotoluene	6	0	5	6	5.50	14	0.607
2,6-Dinitrotoluene	6	0	5	6	5.50	10	0.450
2-Chloronaphthalene	6	0	5	6	5.50	560	0.990
2-Chlorophenol	6	0	5	6	5.50	36	0.847
2-Methylnaphthalene	6	0	5	6	5.50	49	0.888
2-Methylphenol	6	0	5	6	5.50	350	0.984
2-Nitroaniline	6	0	12.5	15	13.83	50	0.723
2-Nitrophenol	6	0	5	6	5.50	56	0.902
3,3'-Dichlorobenzidine	6	0	5	6	5.50	10	0.450
3-Nitroaniline	6	0	12.5	15	13.83	50	0.723
4,6-Dinitro-2-methylphenol	6	0	12.5	15	13.83	0.7	-18.762
4-Bromophenyl phenyl ether	6	0	5	6	5.50	410	0.987
4-Chloro-3-methylphenol	6	0	5	6	5.50	350	0.984
4-Chloroaniline	6	0	5	6	5.50	28	0.804
4-Chlorophenyl phenyl ether	6	0	5	6	5.50	410	0.987
4-Methylphenol	6	0	5	6	5.50	35	0.843
4-Nitroaniline	6	0	12.5	15	13.83	21	0.341
4-Nitrophenol	6	0	12.5	15	13.83	56	0.753

TABLE 2 (Continued)

Parameter	N	Hits	Minimum	Maximum	Average	Ground-Water Protection Criteria-GA	Constituent Background Adjustment
Acenaphthene	6	0	5	6	5.50	420	0.987
Acenaphthylene	6	0	5	6	5.50	420	0.987
Anthracene	6	0	5	6	5.50	2,000	0.997
Benz(a)anthracene	6	0	5	6	5.50	0.06	-90.667
Benzo(a)pyrene	6	0	5	6	5.50	0.2	-26.500
Benzo(b)fluoranthene	6	0	5	6	5.50	0.08	-67.750
Benzo(g,h,i)perylene	6	0	5	6	5.50	210	0.974
Benzo(k)fluoranthene	6	0	5	6	5.50	0.5	-10.000
Benzoic acid	2	0	25	25	25.00	50,000	1.000
Bis(2-chloroethyl)ether	6	0	5	6	5.50	12	0.542
Bis(2-chloroisopropyl) ether	6	0	5	6	5.50	12	0.542
Bis(2-ethylhexyl)phthalate	6	0	5	7	5.75	2	-1.875
Butylbenzyl phthalate	6	2	0.7	6	3.90	1,000	0.996
Carbazole	6	0	5	6	5.50	10	0.450
Chrysene	6	0	5	6	5.50	4.8	-0.146
Di-n-butyl phthalate	6	0	5	6	5.50	700	0.992
Di-n-octyl phthalate	6	0	5	6	5.50	100	0.945
Dibenz(a,h)anthracene	6	0	5	6	5.50	0.5	-10.000
Dibenzofuran	6	0	5	6	5.50	28	0.804
Diethyl phthalate	6	0	5	6	5.50	5,600	0.999
Dimethyl phthalate	6	0	5	6	5.50	5,600	0.999
Fluoranthene	6	0	5	6	5.50	280	0.980
Fluorene	6	0	5	6	5.50	280	0.980
Hexachlorobenzene	6	0	5	6	5.50	1	-4.500
Hexachlorobutadiene	6	0	5	6	5.50	0.45	-11.222
Hexachlorocyclopentadiene	6	0	5	6	5.50	49	0.888
Hexachloroethane	6	0	5	6	5.50	3	-0.833
Indeno(1,2,3-cd)pyrene	6	0	5	6	5.50	0.5	-10.000
Isophorone	6	0	5	6	5.50	37	0.851
N-nitroso-di-n-propylamine	6	0	5	6	5.50	10	0.450
N-nitrosodiphenylamine	6	0	5	6	5.50	10	0.450
Naphthalene	6	0	5	6	5.50	280	0.980
Nitrobenzene	6	0	5	6	5.50	10	0.450
Pentachlorophenol	6	0	12.5	15	13.83	1	-12.833
Phenanthrene	6	0	5	6	5.50	280	0.980
Phenol	6	0	5	6	5.50	4,000	0.999
Pyrene	6	0	5	6	5.50	200	0.973
1,1,1-Trichloroethane	5	1	2.5	5	4.10	200	0.980
1,1,2,2-Tetrachloroethane	5	0	2.5	5	4.50	0.5	-8.000
1,1,2-Trichloroethane	5	0	2.5	5	4.50	5	0.100
1,1-Dichloroethane	5	0	2.5	5	4.50	70	0.936
1,1-Dichloroethene	5	0	2.5	5	4.50	7	0.357
1,2-Dichloroethane	5	0	2.5	5	4.50	1	-3.500
1,2-Dichloroethene (total)	5	0	2.5	5	4.50	140	0.968
1,2-Dichloropropane	5	0	2.5	5	4.50	5	0.100
2-Butanone	5	0	5	5	5.00	400	0.988
2-Hexanone	5	0	5	5	5.00	280	0.982
4-Methyl-2-pentanone	5	0	5	5	5.00	350	0.986

TABLE 2 (Continued)

Parameter	N	Hits	Minimum	Maximum	Average	Ground-Water Protection Criteria-GA	Constituent Background Adjustment
Acetone	5	0	5	5	5.00	700	0.993
Benzene	5	0	2.5	5	4.50	1	-3.500
Bromodichloromethane	5	0	2.5	5	4.50	0.56	-7.036
Bromoform	5	0	2.5	5	4.50	4	-0.125
Bromomethane	5	0	5	5	5.00	9.8	0.490
Carbon disulfide	5	0	2.5	5	4.50	700	0.994
Carbon tetrachloride	5	0	2.5	5	4.50	5	0.100
Chlorobenzene	5	0	2.5	5	4.50	100	0.955
Chloroethane	5	0	5	5	5.00	12	0.583
Chloroform	5	2	2.5	23	11.30	6	-0.883
Chloromethane	5	0	5	5	5.00	2.7	-0.852
cis-1,3-dichloropropene	5	0	2.5	5	4.50	0.5	-8.000
Dibromochloromethane	5	0	2.5	5	4.50	0.5	-8.000
Ethylbenzene	5	0	2.5	5	4.50	700	0.994
Methylene chloride	5	0	2.5	5	4.50	5	0.100
Styrene	5	2	1	5	2.90	100	0.971
Tetrachloroethene	5	1	2	5	3.90	5	0.220
Toluene	5	0	2.5	5	4.50	1,000	0.996
Trichloroethene	5	0	2.5	5	4.50	5	0.100
Vinyl chloride	5	0	5	5	5.00	2	-1.500
Xylenes, total	5	0	2.5	5	4.50	530	0.992

TABLE 3 ZONE- AND CONSTITUENT-SPECIFIC DILUTION FACTORS ADJUSTED FOR BACKGROUND CONCENTRATIONS IN GROUND WATER USED TO CALCULATE ALTERNATIVE SURFACE WATER PROTECTION CRITERIA

Parameter	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7
Antimony	11.36	3.72	8.90	33.46	10.31	10.31	6.00
Arsenic	46.88	15.34	36.75	138.09	42.53	42.53	24.78
Barium	43.89	14.36	34.40	129.28	39.82	39.82	23.20
Beryllium	45.13	14.77	35.38	132.94	40.94	40.94	23.85
Cadmium	45.11	14.76	35.36	132.86	40.92	40.92	23.84
Chromium	47.16	15.43	36.97	138.93	42.79	42.79	24.93
Cobalt	47.90	15.67	37.55	141.10	43.46	43.46	25.32
Copper	47.99	15.70	37.62	141.35	43.54	43.54	25.36
Cyanide	47.46	15.53	37.20	139.79	43.05	43.05	25.08
Lead	38.58	12.62	30.24	113.63	35.00	35.00	20.39
Mercury	47.20	15.44	37.00	139.02	42.82	42.82	24.95
Nickel	45.60	14.92	35.75	134.32	41.37	41.37	24.10
Selenium	46.88	15.34	36.75	138.10	42.53	42.53	24.78
Silver	46.65	15.26	36.57	137.41	42.32	42.32	24.66
Thallium	25.51	8.35	20.00	75.16	23.15	23.15	13.49
Vanadium	46.53	15.22	36.47	137.04	42.21	42.21	24.59
Zinc	47.75	15.62	37.43	140.65	43.32	43.32	25.24
1,2,4-Trichlorobenzene	44.28	14.49	34.71	130.44	40.17	40.17	23.41
1,2-Dichlorobenzene	47.62	15.58	37.33	140.26	43.20	43.20	25.17
1,3-Dichlorobenzene	47.62	15.58	37.33	140.26	43.20	43.20	25.17
1,4-Dichlorobenzene	44.53	14.57	34.91	131.18	40.40	40.40	23.54
2,4,5-Trichlorophenol	47.11	15.41	36.93	138.76	42.74	42.74	24.90
2,4,6-Trichlorophenol	21.63	7.08	16.95	63.70	19.62	19.62	11.43
2,4-Dichlorophenol	34.84	11.40	27.31	102.63	31.61	31.61	18.42
2,4-Dimethylphenol	46.17	15.11	36.19	136.00	41.89	41.89	24.40
2,4-Dinitrophenol	34.76	11.37	27.25	102.40	31.54	31.54	18.37
2,4-Dinitrotoluene	29.18	9.55	22.87	85.95	26.47	26.47	15.42
2,6-Dinitrotoluene	21.63	7.08	16.95	63.70	19.62	19.62	11.43
2-Chloronaphthalene	47.59	15.57	37.30	140.17	43.17	43.17	25.15
2-Chlorophenol	40.72	13.32	31.92	119.93	36.94	36.94	21.52
2-Methylnaphthalene	42.66	13.96	33.44	125.67	38.70	38.70	22.55
2-Methylphenol	47.30	15.48	37.08	139.34	42.91	42.91	25.00
2-Nitroaniline	34.76	11.37	27.25	102.40	31.54	31.54	18.37
2-Nitrophenol	43.34	14.18	33.97	127.66	39.32	39.32	22.91
3,3'-Dichlorobenzidine	21.63	7.08	16.95	63.70	19.62	19.62	11.43
3-Nitroaniline	34.76	11.37	27.25	102.40	31.54	31.54	18.37
4-Bromophenyl phenyl ether	47.41	15.51	37.17	139.66	43.01	43.01	25.06
4-Chloro-3-methylphenol	47.30	15.48	37.08	139.34	42.91	42.91	25.00
4-Chloroaniline	38.62	12.64	30.27	113.75	35.03	35.03	20.41
4-Chlorophenyl phenyl ether	47.41	15.51	37.17	139.66	43.01	43.01	25.06
4-Methylphenol	40.51	13.25	31.75	119.32	36.75	36.75	21.41
4-Nitroaniline	16.40	5.37	12.86	48.31	14.88	14.88	8.67
4-Nitrophenol	36.19	11.84	28.37	106.59	32.83	32.83	19.13

TABLE 3 (Continued)

Parameter	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7
Acenaphthene	47.43	15.52	37.18	139.71	43.03	43.03	25.07
Acenaphthylene	47.43	15.52	37.18	139.71	43.03	43.03	25.07
Anthracene	47.93	15.68	37.57	141.17	43.48	43.48	25.33
Benzo(g,h,i)perylene	46.80	15.31	36.69	137.85	42.46	42.46	24.74
Bis(2-chloroethyl)ether	26.03	8.52	20.41	76.68	23.62	23.62	13.76
Bis(2-chloroisopropyl) ether	26.03	8.52	20.41	76.68	23.62	23.62	13.76
Butylbenzyl phthalate	47.87	15.66	37.52	141.01	43.43	43.43	25.30
Carbazole	21.63	7.08	16.95	63.70	19.62	19.62	11.43
Di-n-butyl phthalate	47.68	15.60	37.38	140.45	43.26	43.26	25.20
Di-n-octyl phthalate	45.42	14.86	35.60	133.77	41.20	41.20	24.00
Dibenzofuran	38.62	12.64	30.27	113.75	35.03	35.03	20.41
Diethyl phthalate	48.01	15.71	37.63	141.42	43.56	43.56	25.38
Dimethyl phthalate	48.01	15.71	37.63	141.42	43.56	43.56	25.38
Fluoranthene	47.11	15.42	36.93	138.78	42.74	42.74	24.90
Fluorene	47.11	15.42	36.93	138.78	42.74	42.74	24.90
Hexachlorocyclopentadiene	42.66	13.96	33.44	125.67	38.70	38.70	22.55
Isophorone	40.91	13.39	32.07	120.52	37.12	37.12	21.63
N-nitroso-di-n-propylamine	21.63	7.08	16.95	63.70	19.62	19.62	11.43
N-nitrosodiphenylamine	21.63	7.08	16.95	63.70	19.62	19.62	11.43
Naphthalene	47.11	15.42	36.93	138.78	42.74	42.74	24.90
Nitrobenzene	21.63	7.08	16.95	63.70	19.62	19.62	11.43
Phenanthrene	47.11	15.42	36.93	138.78	42.74	42.74	24.90
Phenol	47.99	15.70	37.62	141.37	43.54	43.54	25.37
Pyrene	46.74	15.29	36.64	137.67	42.40	42.40	24.70
1,1,1-Trichloroethane	47.07	15.40	36.90	138.66	42.70	42.70	24.88
1,1,2-Trichloroethane	4.81	1.57	3.77	14.16	4.36	4.36	2.54
1,1-Dichloroethane	44.97	14.71	35.25	132.46	40.80	40.80	23.77
1,1-Dichloroethene	17.16	5.62	13.45	50.56	15.57	15.57	9.07
1,2-Dichloroethene (total)	46.51	15.22	36.46	137.01	42.20	42.20	24.59
1,2-Dichloropropane	4.81	1.57	3.77	14.16	4.36	4.36	2.54
2-Butanone	47.46	15.53	37.20	139.79	43.05	43.05	25.08
2-Hexanone	47.20	15.44	37.00	139.03	42.82	42.82	24.95
4-Methyl-2-pentanone	47.37	15.50	37.13	139.54	42.98	42.98	25.04
Acetone	47.72	15.61	37.40	140.55	43.29	43.29	25.22
Bromomethane	23.54	7.70	18.45	69.34	21.35	21.35	12.44
Carbon disulfide	47.75	15.62	37.43	140.65	43.32	43.32	25.24
Carbon tetrachloride	4.81	1.57	3.77	14.16	4.36	4.36	2.54
Chlorobenzene	45.90	15.02	35.98	135.19	41.64	41.64	24.26
Chloroethane	28.03	9.17	21.98	82.58	25.43	25.43	14.82
Ethylbenzene	47.75	15.62	37.43	140.65	43.32	43.32	25.24
Methylene chloride	4.81	1.57	3.77	14.16	4.36	4.36	2.54
Styrene	46.67	15.27	36.58	137.46	42.33	42.33	24.66
Tetrachloroethene	10.57	3.46	8.29	31.14	9.59	9.59	5.59
Toluene	47.84	15.65	37.50	140.92	43.40	43.40	25.29
Trichloroethene	4.81	1.57	3.77	14.16	4.36	4.36	2.54
Xylenes, total	47.65	15.59	37.35	140.36	43.23	43.23	25.19

TABLE 4 VALUES USED IN CALCULATION OF ZONE-SPECIFIC DILUTION FACTORS FOR IDENTIFICATION OF GROUND-WATER CONSTITUENTS OF CONCERN FOR SURFACE WATER PROTECTION AS SPECIFIED IN REMEDIATION OF CONNECTICUT STATE AGENCIES 22a-133k-3(b)(3)

Zone	Hydraulic Gradient i (ft/ft)	Hydraulic Conductivity K (ft/day)	Zone Length L (ft)	Saturated Zone Thickness d (ft)	Ground Water Discharge Q_{plume} (ft^3/d)	Zone-Specific Dilution Factor
1	0.00476	158	470	12	4,242	1,030
2	0.00318	74	495	12	1,398	2,854
3	0.00792	1.7	200	12	32.3 (5,391)	810
4	0.0039	576	200	12	5,391	810
5	0.0092	74	412	12	3,366	1,297
6	0.0092	74	362	12	2,957	1,477
7	0.00527	74	864	12	4,043	1,080

NOTE: $Q_{plume} = K \times i \times L \times d$
Zone-specific dilution factor = ([0.25 × freshwater flow] + [0.1 × reach tidal prism]) / Q_{plume}.
Thames River daily average minimum freshwater flow = 1.51E+06 ft^3.
Thames River tidal prism volume within Subase reach = 3.99E+07 ft^3.
Ground-water flow for Zone 4 (in parentheses) substituted for Zone 3.

TABLE 5 SUMMARY OF DATA AND IDENTIFICATION OF GROUND-WATER CONSTITUENTS OF POTENTIAL CONCERN FOR SURFACE WATER PROTECTION BASED ON STANDARD CONNECTICUT SURFACE WATER PROTECTION CRITERIA

Zone	Constituent of Potential Concern	Connecticut SWPC	Total Samples	Number of Detects	Constituent Concentration	
					Maximum Detected (µg/L)	Average (µg/L)
1	Acenaphthylene	0.3	33	1	1	5.16
	Phenanthrene	0.077	33	6	9	5.25
2	NS					
3	NS					
4	Arsenic	4	37	18	29.6	6.33
	Lead	13	32	18	2760	97.26
	Benz(a)anthracene	0.3	26	1	1	5.12
	Benzo(a)pyrene	0.3	26	1	0.8	5.11
	Benzo(b)fluoranthene	0.3	26	1	0.6	5.1
	Benzo(g,h,i)perylene	0.3	26	1	1	5.12
	Benzo(k)fluoranthene	0.3	26	1	1	5.12
	Chrysene	0.3	26	1	0.9	5.11
	Indeno(1,2,3-cd)pyrene	0.3	26	1	0.7	5.1
	Phenanthrene	0.077	26	2	1	4.93
5	Acenaphthylene	0.3	5	1	2	4.7
	Phenanthrene	0.077	5	2	2	3.9
6	Acenaphthylene	0.3	5	2	0.8	4.54
7	Arsenic	4	21	12	18.8	4.84
	Lead	13	21	11	117	15.17
	Acenaphthylene	0.3	17	2	1	5.29
	Chrysene	0.3	17	1	0.9	5.49
	Phenanthrene	0.077	17	2	9	5.71

NOTE: NS = No Constituents of Potential Concern based on standard Connecticut SWPC.
SWPC = Surface Water Protection Criteria.

TABLE 6 SUMMARY OF DATA AND CALCULATIONS FOR DETERMINATION OF GROUND-WATER COMPLIANCE WITH ALTERNATIVE SURFACE WATER PROTECTION CRITERIA

Constituent of Potential Concern	SWPC µg/L	Zone 1	2	3	4	5	6	7	SQ_i ft^3	DF	CTWQC µg/L	C_{plume} µg/L	C µg/L	Subase ASWPC	Screening Quotient
Arsenic	4				6.33			4.84	9434	463	0.14	6.33	0.014	64.8	0.098
Lead	13				97.26			15.2	9434	463	50	97.3	0.21	23150	0.004
Acenaphthylene	0.3	5.16				4.7	4.54	5.29	14608	299	0.031	5.29	0.018	9.27	0.571
Benz(a)anthracene	0.3				5.12				5391	810	0.031	5.12	0.006	25.11	0.204
Benzo(a)pyrene	0.3				5.11				5391	810	0.031	5.11	0.006	25.11	0.203
Benzo(b)fluoranthene	0.3				5.1				5391	810	0.031	5.1	0.006	25.11	0.203
Benzo(g,h,i)perylene	0.3				5.12				5391	810	0.031	5.12	0.006	25.11	0.204
Benzo(k)fluoranthene	0.3				5.12				5391	810	0.031	5.12	0.006	25.11	0.204
Chrysene	0.3				5.11			5.49	9434	463	0.031	5.49	0.012	14.35	0.383
Indeno(1,2,3-cd)pyrene	0.3				5.1				5391	810	0.031	5.1	0.006	25.11	0.203
Phenanthrene	0.077	5.25			4.93	3.9		5.71	17042	256	0.031	5.71	0.022	7.94	0.719

NOTE: SWPC = Surface Water Protection Criteria.
SQ_I = Sum of ground-water discharge for selected zones.
DF = Dilution Factor = Q_A / SQ_i. Q_A = Tidally averaged Thames River flow within mixing zone (4.4×10^6 ft^3/day).
CTWQC = Connecticut Water Quality Criteria for protection of human health (consumption of organisms).
C_{plume} = Maximum of zone average ground water concentrations.
C = Fully mixed concentration in mixing zone of Thames River (C_{plume}/DF).
ASWPC = Alternative SWPC (CTWQC × DF).
Screening Quotient = C_{plume}/ASWPC.