Temperature Modeling for the Steam Condensate Discharge at Naval Weapons Station Earle, NJ

Draft Technical Memorandum

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Enclosure (8)

Introduction

Discharge modeling for the steam condensate discharge at Earle, NJ was conducted and evaluated by SPAWAR Systems Center San Diego, Environmental Sciences Branch. We used a simple, but well-accepted two-dimensional mixing model to predict temperature changes in ambient waters resulting from the steam condensate discharge. The predictions are based on diffusive mixing equations developed in Fischer et al. (1979), the classic treatise on mixing in coastal and inland waters. The model predicts the two-dimensional, steady-state dispersion of concentration (or heat) assuming that (1) the discharge is mixed vertically to a prescribed mixing depth after the discharge plunges into the ocean from above, (2) dispersion is dominated by lateral mixing following discharge, (3) there is no further vertical mixing after discharge (consistent with strong stratification associated with a warm, fresh discharge), (4) stream-wise mixing is negligible relative to lateral mixing, and (5) there is no heat exchange with the atmosphere. These generally conservative assumptions greatly simplify the hydrodynamic equations and are quite reasonable given the scenario.

Model

The two-dimensional mixing equation used to predict the heat distribution was:

$$H_{(x,y)} = [M/\mu(d(4\pi\xi_t x/\mu)^{1/2}]\exp\text{-}(y^2\mu/4\xi_t x)$$

where:

$H_{(x,y)}$ = heat content associated with the discharge as a function of x and y
M = effluent heat flux
μ = ambient current speed
d = mixing depth
ξ_t = transverse mixing coefficient
x = distance downstream
y = lateral distance

and the effluent heat flux was calculated as

$$M = \rho Q C_p \Delta T$$

where:

ρ = water density
Q = discharge rate
C_p = heat capacity of water
ΔT = temperature difference between discharge and ambient

Following mixing, the temperature distribution ($T_{(x,y)}$) was then calculated as:

$$T_{(x,y)} = T_a + H_{(x,y)}/\rho C_p$$

where:

T_a = ambient temperature

Inputs to the Model

The discharge parameters in the model included a mixing depth of 0.05 m (~ 2"), and a fixed effluent discharge rate of 0.00038 L/s (8.64 gpd) at a temperature of 100 °C. The mixing depth chosen reflects a realistic minimum depth at which a temperature measurement would be made and is thus a conservative value. The temperature on hitting the water is also a conservative assumption given that the droplets would lose heat during their fall to the water surface.

We ran two scenarios to evaluate temperature changes observable at 100 m given that the New Jersey Department of Environmental Protection (NJDEP) identified two regulatory seasonal requirements:

Winter: September through May (Delta Temperature limit of 2.2 °C) and

Summer: June through August (Delta Temperature limit of 0.8 °C).

The NJDEP futher requested that the temperature values be based on 95th percentile value for summer and winter conditions over a three-year data set. We collected historical ambient temperaure data from NOAA's Ports historical data retrieval system (http://tidesandcurrents.noaa.gov) for its Sandy Hook, NJ site (Station ID: 8531680), a site that is only a few miles from the discharge area. The roughly 230,000 data records from 2005 through 2007 are shown in Figure 1. The 5th and 95th percentile ambient water temperatures from the dataset were respectively 1.08 °C and 25.74 °C (Figure 2).

The NJDEP requested using the 95th percentile value for salinity as well. However, the model conservatively assumes that the plume remains at the surface (vertically stratified) and salinity is therefore not a parameter used in the model calculations.

The NJDEP requested that 20-min average current speeds be used for the modeling. We do not have access to measured current data. However, we were able to evaluate modeled current speed data from the New York Harbor Observing and Prediction System (NYHOPS) system and the Center for Maritime Systems, Stevens Institute of Technology (http://hudson.dl.stevens-tech.edu/maritimeforecast/maincontrol.shtml). We stepped through the model graphical results (roughly 15-min interval data) for two recently completed spring-neap tide (max-min tide) cycles for the area off of the Sandy Hook, NJ site. Current speeds were all below 0.5 m/s (1 kt) over the time period. Because we did not have actual current data, and particularly, the 10th percentile values as requested by the NJDEP, we ran the model incrementally for current speeds between 0.01 and 0.5 m/s (0.02 to 1 kt). Given that current speeds less than 0.01 m/s are not measurable, the range covers all expected conditions for the site, including the 10th percentile value.

The last input to the model is the lateral mixing coefficient. Typical observed values can range over an order of magnitude or more under a variety of natural conditions (Fischer et al., 1979). We therefore ran the model incrementally for a range in mixing coefficient values between 0.01 and 0.5 m^2/s that bracket the values identified in Fischer et al., 1979. The ranges in these values bound all realistic conditions expected at the site.

Results

Results for representative Winter conditions are shown in Figures 3 through 5. Figure 3 shows the maximum temperature observed at 100 m downstream of the discharge point for an ambient water condition of 1.08 °C, an ambient current velocity of 0.1 m/s and a lateral mixing coefficient of 0.12 m^2/s. Figure 4 shows the spatial temperature distribution from the effluent discharge location to a distance of 100 m downstream under the same conditions used for Figure 3. Results for this representative case show a maximum temperature difference of ~0.002 °C at 100 m downstream. Figure 5 shows the maximum temperature predicted at 100 m downstream after varying the ambient velocity and lateral mixing coefficient over the full range of expected conditions at this location. The plot shows a maximum temperature differential of ~0.0022 °C for the entire range of conditions. The regulatory delta temperature limit of 2.2 °C during the September through May timeframe is met under all tested conditions.

Results for representative Summer conditions are shown in Figures 6 through 8. Figure 6 shows the maximum temperature observed at 100 m downstream of the discharge point for an ambient water condition of 25.74 °C, an ambient current velocity of 0.1 m/s and a lateral mixing coefficient of 0.12 m^2/s as an example. Figure 7 shows the spatial temperature distribution from the effluent discharge location to a distance of 100 m downstream under the same initial conditions used for Figure 6. Results for this representative case show a maximum temperature difference of ~0.0015 °C at 100 m downstream. Figure 8 shows the maximum temperature predicted at 100 m downstream after varying the ambient velocity and lateral mixing coefficient over the range of expected conditions at this location. The plot shows a maximum temperature differential of ~0.0015 °C for the entire range of conditions. The regulatory delta temperature limit of 0.8 °C and absolute limit of 29.4 °C during the June through August timeframe is met under all tested conditions.

Iterative model runs indicate that the discharge flow rate could be increased by over a factor of 600 before there would be a potential to exceed delta temperature limits.

References

Fischer, H.B., List, E.J., Koh, R.C.Y., Imberger, J., and Brooks, N.H., 1979, Mixing in Inland and Coastal Waters: Academic Press, Inc., Orlando, Florida, 483, p.

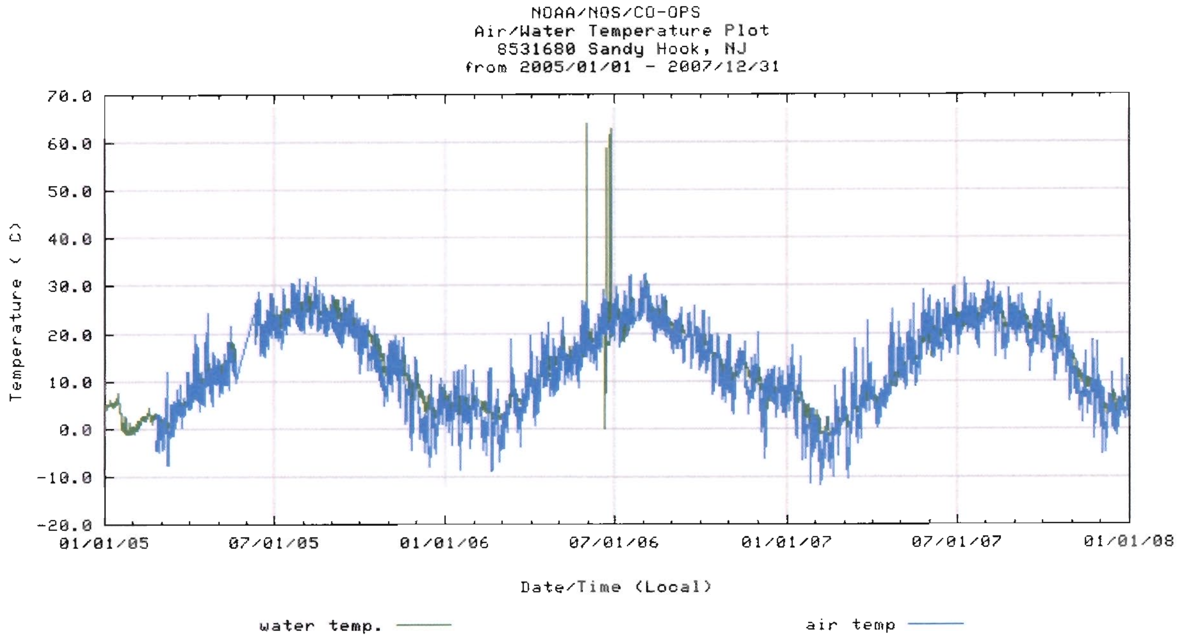

Figure 1. Three-year record of water temperature measurements derived from NOAA's CO-Ops Sandy Hook, NJ site (Station ID: 8531680).

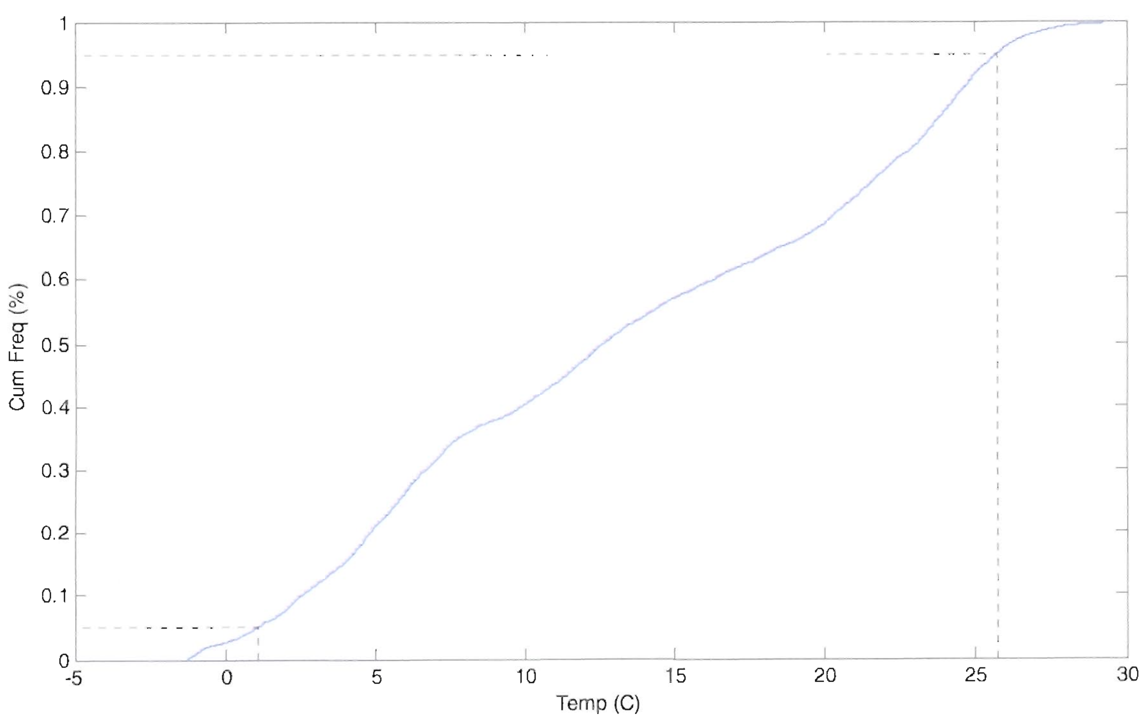

Figure 2. Cumulative frequency distribution for temperature at Sandy Hook, NJ site for the three year period 2005-2007. Dotted lines indicate the 5th and 95th percentile temperatures of 1.08 C and 25.74 C, respectively.

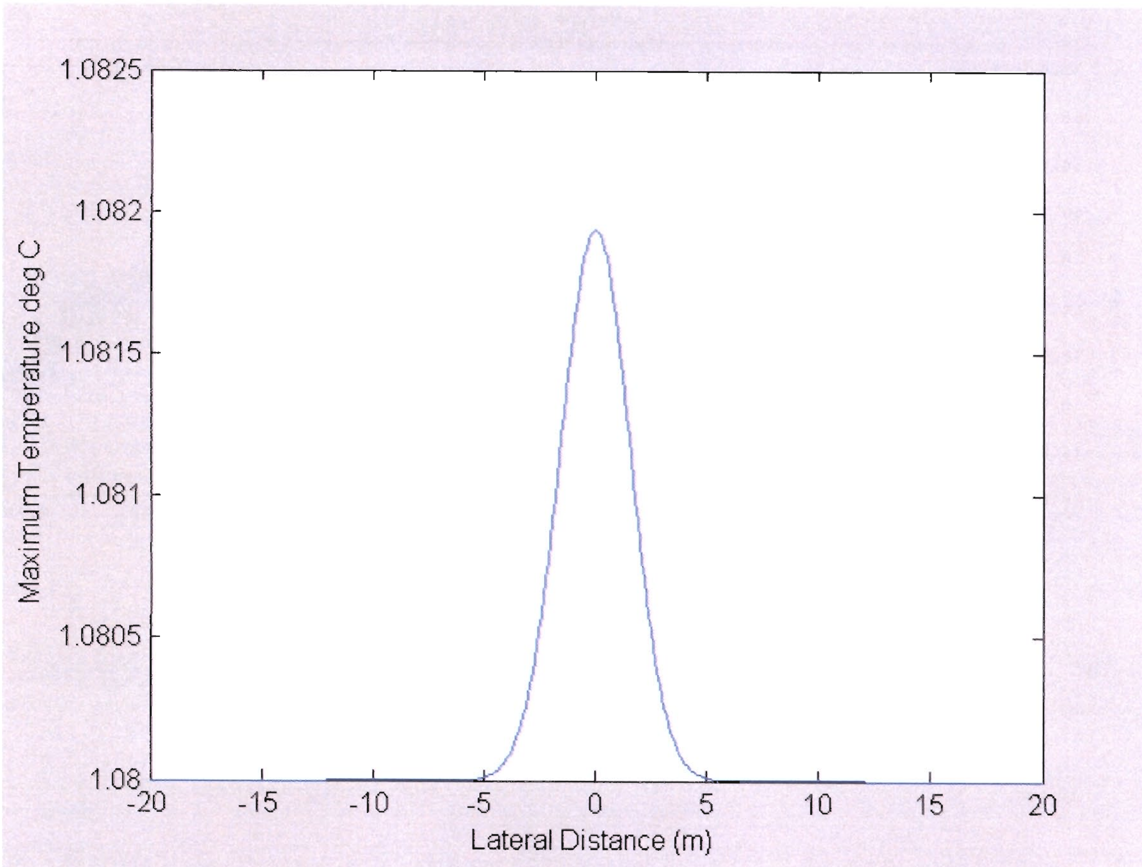

Figure 3. Winter Condition Example. Downstream water temperature distribution at a distance of 100 m for discharge of 100 ºC effluent into ambient water at 1.08 ºC (μ=0.1 m/s , ξ_t =0.12 m^2/s). Maximum temperature differential at 100 m is ~0.002 ºC.

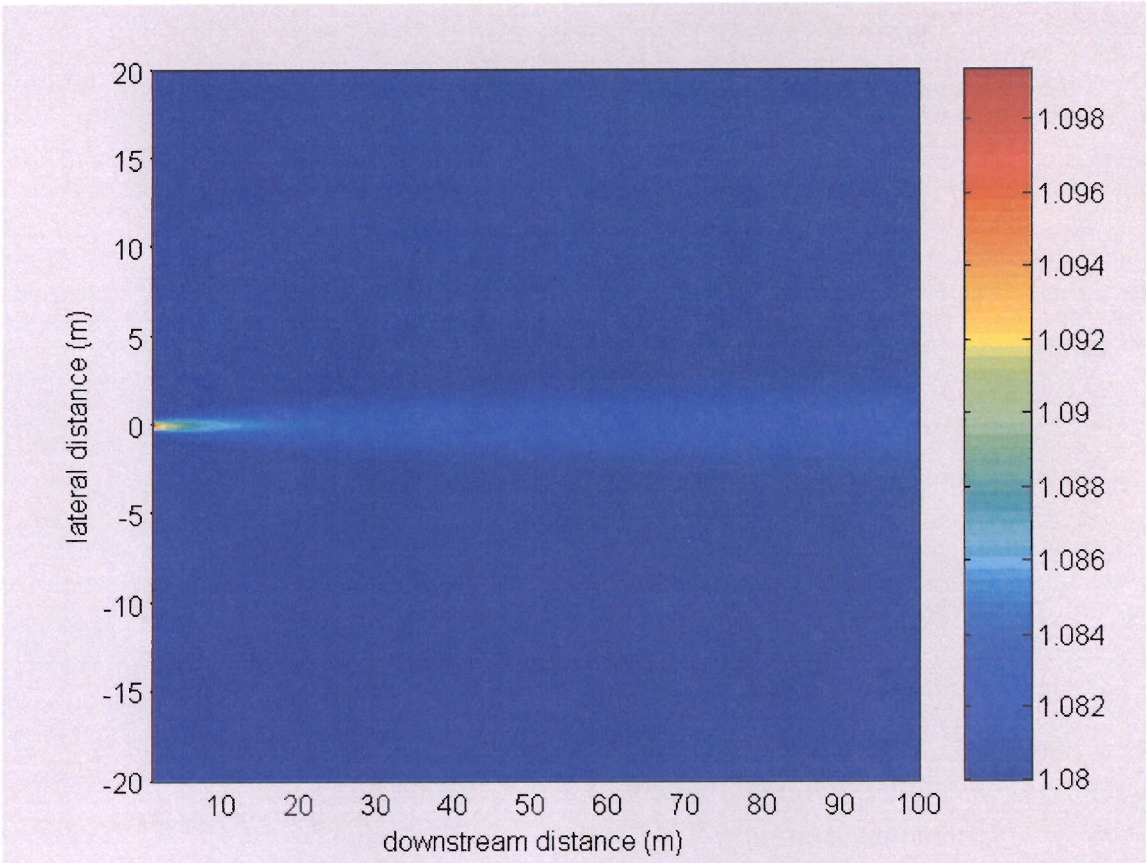

Figure 4. Winter Condition Example. Plan view (x,y) of ambient water temperature distribution after discharge of 100 °C effluent into ambient water of 1.08 °C (μ=0.1 m/s , ξ_t =0.12 m^2/s). The maximum temperature differential at 100 m is ~0.002 °C.

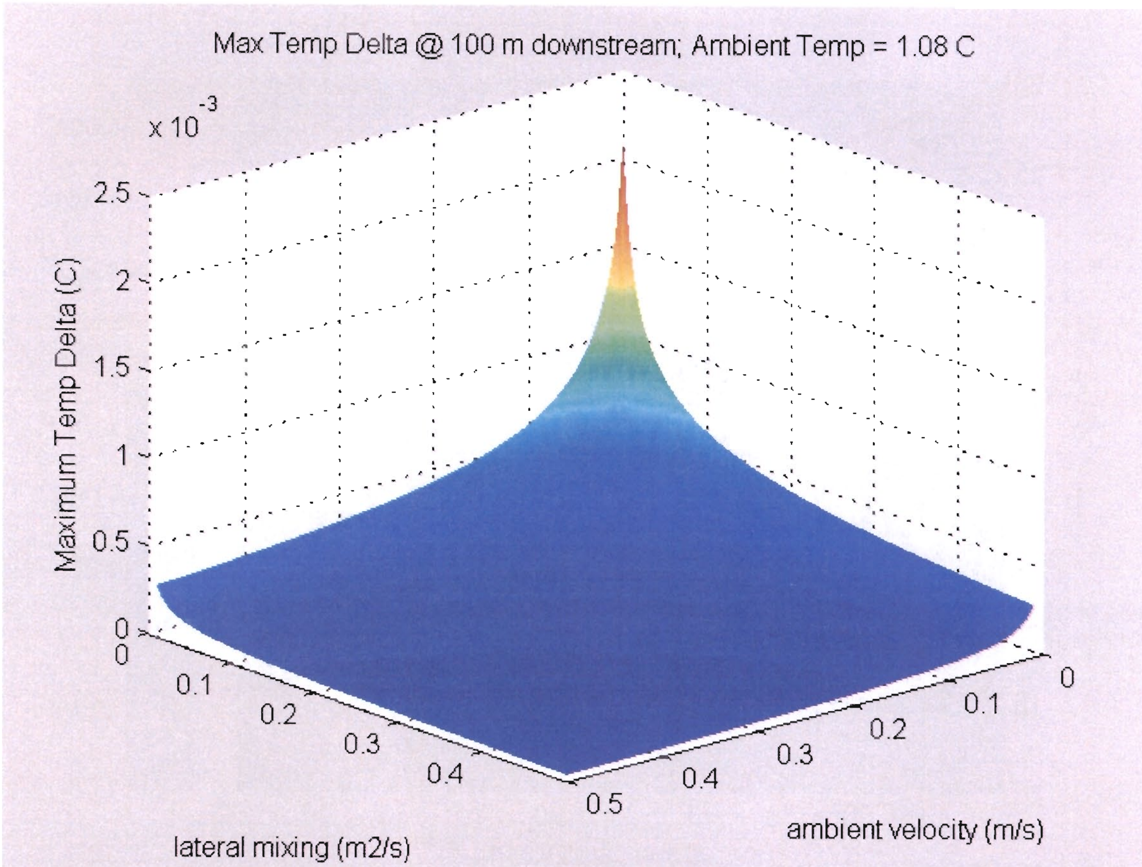

Figure 5. Winter Condition. Maximum temperature difference (above ambient of 1.08 °C) predicted at 100 m downstream location as a function of changes in both ambient current velocity (0.01 to 0.5 m/s) and lateral mixing coefficients (0.01to 0.5 m^2/s). Maximum temperature difference was less than 0.0022 °C under all tested conditions.

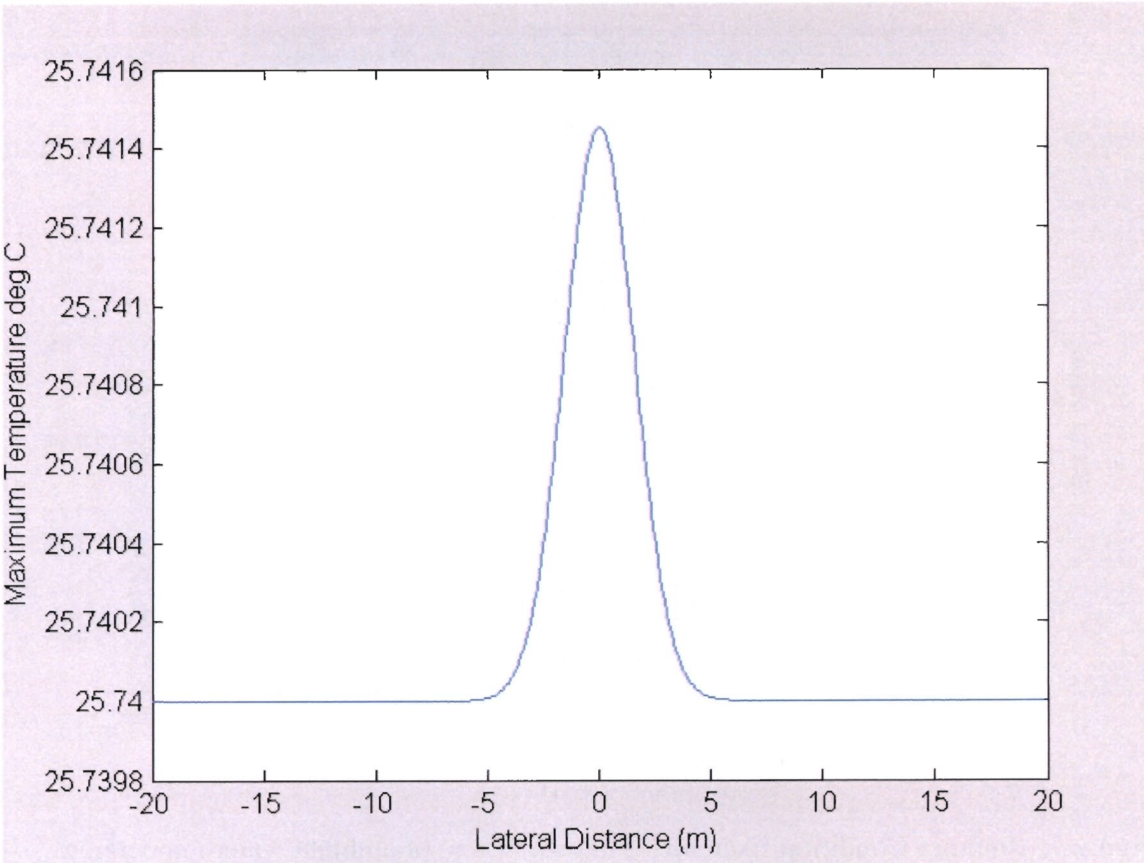

Figure 6. Summer Condition Example. Downstream water temperature distribution at a distance of 100 m for discharge of 100 °C effluent into ambient water at 25.74 °C (μ=0.1 m/s , ξ_t =0.12 m^2/s). Maximum temperature differential at 100 m is ~0.0015 °C.

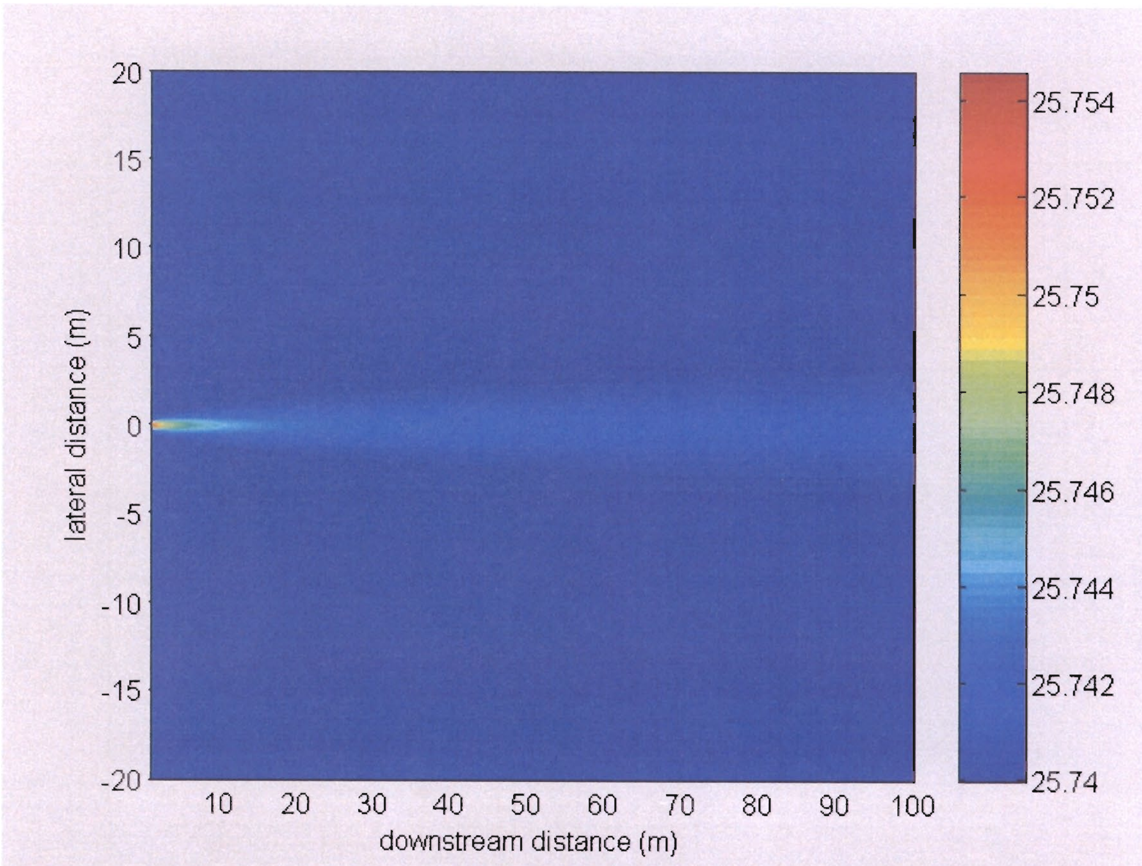

Figure 7. Summer Condition Example. Plan view (x,y) of ambient water temperature distribution after discharge of 100 °C effluent into ambient water of 25.74 °C (μ=0.1 m/s , ξ_t =0.12 m^2/s). The maximum temperature differential at 100 m is ~0.0015 °C.

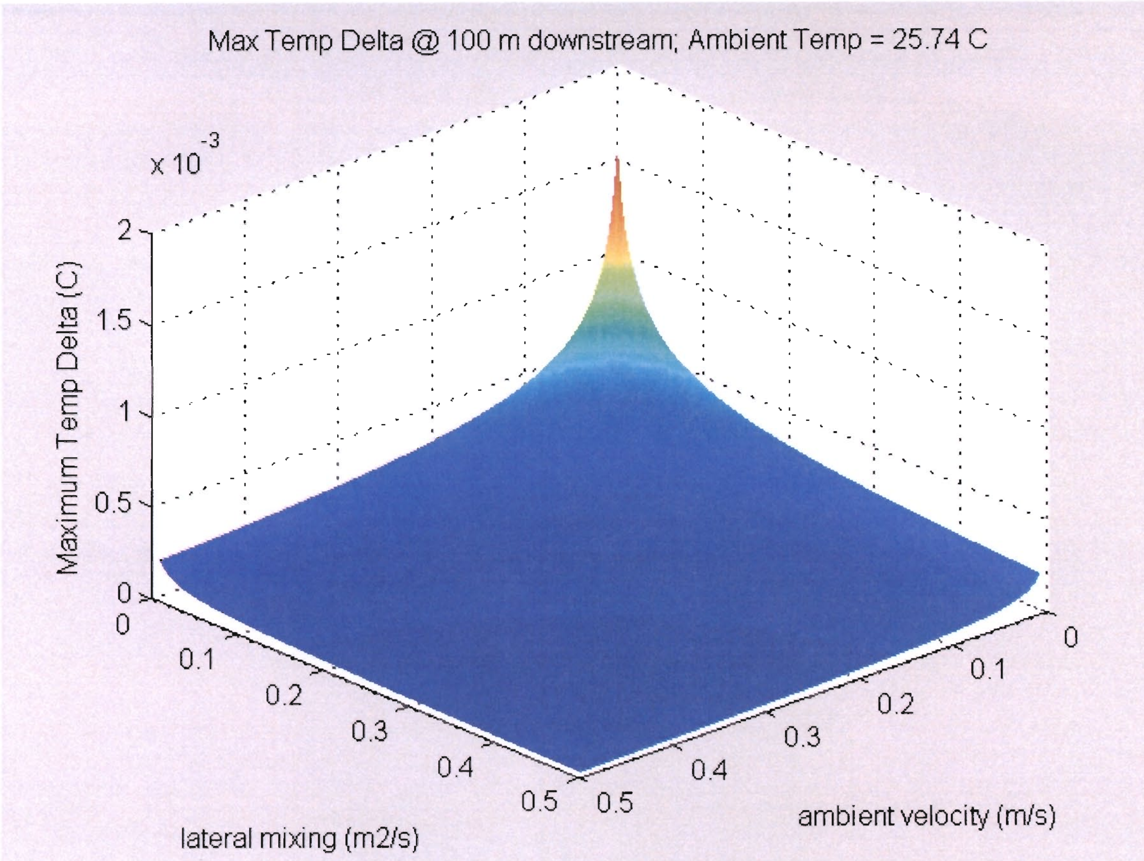

Figure 8. Summer Condition. Maximum temperature difference above ambient value of 25.74 °C predicted at 100 m downstream location as a function of changes in both ambient current velocity (0.01 to 0.5 m/s) and lateral mixing coefficients (0.01 to 0.5 m^2/s). Maximum temperature difference was ≤ 0.0015 °C under all tested conditions.