ATTACHMENTS

Prepared for

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THERMAL MIXING ZONE EVALUATION VIRGIL C. SUMMER NUCLEAR STATION NPDES PERMIT FAIRFIELD COUNTY, SOUTH CAROLINA

ADDENDUM:

ADDITIONAL MODELING CASES FOR REVISED RESERVOIR AMBIENT AND DISCHARGE TEMPERATURES

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1. INTRODUCTION

South Carolina Electric and Gas Company (SCE&G, a subsidiary of SCANA Corporation) is making an application to the South Carolina Department of Health and Environmental Control (SCDHEC) for a renewal of its National Pollutant Discharge Elimination System (NPDES) permit for Unit 1 of the Virgil C. Summer Nuclear Station (VCSNS). VCSNS is located in Fairfield County near Jenkinsville, South Carolina.

Geosyntec Consultants (Geosyntec), and its wholly-owned subsidiary MMI Engineering (MMI), have supported SCE&G in the permit application process by providing modeling studies to determine the size of thermal mixing zones in Monticello Reservoir due to cooling water discharges from VCSNS Unit 1. This was reported in Geosyntec report *Thermal Mixing Zone Evaluation Virgil C. Summer Nuclear Station NPDES Permit* (Geosyntec Project reference GR4796; date January 9, 2012).

SCDHEC has since reviewed the report on the thermal plume sizes and has requested further information from SCE&G. This has included a request for additional modeling to determine the thermal plume sizes under the discharge conditions stated on the NPDES permit application and with revised ambient temperatures representing the highest and lowest ambient temperatures recorded over a longer period than used in the earlier modeling work.

This report is an addendum to the earlier thermal mixing zone report to provide the results of the additional models. As far as possible, the same model set ups have been used as in the original reported work with changes made only to the boundary and initial conditions in Monticello Reservoir to meet SCDHEC's request. This report is focused to provide principally the results of the additional modeling scenarios and does not include the full background to the work and computational model detail. As such, it should be read in conjunction with the original report.

2. MODELED TEMPERATURES

2.1 Reservoir Ambient Temperature

The preceding work used ambient temperatures in Monticello Reservoir which were based on Discharge Monitoring Report (DMR) temperature data for VCSNS unit 1 for 2010, the most recent complete year of temperature monitoring data at the time. These ambient reservoir temperatures were:

- Summer Condition: 86.4°F – this was the highest monthly-averaged temperature measured at the Unit 1 intakes in 2010.
- Winter Condition: 66.6°F – this was the reservoir temperature when the highest monthly-averaged change in temperature (ΔT) was recorded in 2010 between the reservoir ambient conditions and the Unit 1 cooling water discharge.

To address SCDHEC questions about the original model runs, SCE&G compiled DMR temperature data for VCSNS Unit 1 for a 10-year period from 2003 through 2012. Inspection of the 10-year data set revealed that the monthly average intake temperature of 86.4°F recorded in August 2010, which was used in the modeling of summer critical conditions, was the highest monthly average intake temperature in the 10-year data set.

Based on review of the longer-term data and SCE&G's proposal to maintain 113°F as a daily maximum discharge limit year-round, SCDHEC requested additional modeling runs using the highest and lowest ambient temperatures from the 10-year temperature data set. Specifically, SCDHEC requested that the additional model scenarios use the highest possible discharge temperature of 113°F for summer and winter model runs and these ambient reservoir temperatures:

- Summer Condition: 87.9°F – this was the highest daily maximum Unit 1 intake temperature recorded from 2003 through 2012 (July 2010).
- Winter Condition: 46.4°F – this was a low monthly-averaged Unit 1 intake temperature recorded from 2003 through 2012 (January 2010).

2.2 Nuclear Station Cooling Water Discharge Temperature

In the preceding work, the VCSNS Unit 1 cooling water discharge temperatures were set to 113°F (summer) and 98.7°F (winter).

For the current calculations, the cooling water discharge temperature has been set to 113°F for both summer and winter conditions to match the NPDES permit application and as requested by SCDHEC.

3. MODELED SCENARIOS

There are four principal scenarios for Monticello Reservoir which were tested in the preceding work for both summer and winter temperature conditions:

1. **Scenario 1** – Thermal discharge under peak load and discharge flow with Monticello Reservoir elevation under high water-slack conditions (no flow through Fairfield Pumped Storage Facility [FPSF]).

2. **Scenario 2** – Thermal discharge under peak load and discharge flow with Monticello Reservoir elevation under low water-slack conditions (no flow through FPSF).

3. **Scenario 3** – Thermal discharge under peak load and discharge flow with Monticello Reservoir elevation under low water-rising conditions (FPSF pump-back); and

4. **Scenario 4** – Thermal discharge under peak load and discharge flow with Monticello Reservoir elevation under high water-falling conditions (FPSF generation).

All four scenarios were calculated in the preceding work, as it was not possible to determine *a priori* which scenario would provide the worst case in terms of the 90°F plume size (summer) and $\Delta T > 5$°F plume size (winter).

For the current work under summer conditions, it has been judged that there is only a small change in temperatures compared with the preceding work – the discharge temperature remains the same (113°F) and the ambient temperature has increased by only 1.5°F. It can be reasonably assumed that the worst scenario previously calculated would also be the worst case for the new temperature conditions. This was Scenario 4 (High water Level; FPSF generating), which is the only summer condition case to have been recalculated in the current work.

Under winter conditions, the current requirement for discharge and ambient temperatures has changed more considerably compared with the preceding calculations (discharge temperature has increased from 98.7°F to 113°F; ambient temperature has decreased from 66.6°F to 46.4°F). Given these large variations, it has not been possible reasonably to assume that the worst case will remain the same as previously calculated. Hence, all four winter scenarios have been re-calculated in the current work.

The cases which have been calculated in the current work are summarized in Table 1. Scenarios denoted with a "W" are the winter runs and the scenario denoted with an "S" is the summer run.

Table 1. Scenarios Calculated in the Current Work

Case	*Scenario*	*Water Level (feet)*	*FPSF (cfs)*	*Discharge Temp (° F)*	*Ambient Temp (° F)*	*Cooling Water Flow (gpm)*
1	1W	425.0	0	113	46.4	532,000
2	2W	420.5	0	113	46.4	532,000
3	3W	420.5	41800	113	46.4	532,000
4	4W	425.0	-50400	113	46.4	532,000
5	4S	425.0	-50400	113	87.9	532,000

4. COMPUTATIONAL MODEL

As far as was possible, the same modeling conditions were applied to the computational model in the current work as were used in the preceding work. This has been considered essential for direct comparison of cases. The changes that have been made and their potential effect on the results are noted in the following sub-sections.

4.1 Geometry and Mesh

The exact same geometry and mesh that were used in the preceding work have been used in the current work.

4.2 Boundary and Initial Conditions

All boundary and initial conditions have been applied in the same manner, with the only changes being to the specified values of ambient and cooling water discharge temperatures.

4.3 Computational Models

The thermodynamic model has retained the same dependence of water density on temperature only using the same tested polynomial relationship.

The same Shear Stress Transport (SST) turbulence model has been used for all calculations.

4.4 Numerical Models

The preceding work used the ANSYS-CFX v12.0 software to perform the calculations; this is a commercially available, general purpose Computational Fluid Dynamics (CFD) software package which is widely applied throughout a range of industries. The current work has used a later release of the same software ANSYS-CFX v14.0[1]. There are no changes to the solution method between these releases.

[1] ANSYS releases a new version of the code generally every 12 months; the new versions typically have new models for more esoteric calculations (combustion; 2-phase flow; reaction kinetics, etc.) and some bug fixes. However the underlying engine of the software has not changed since they released v5 in the mid 1990's. There have been no changes between v12 and v14 to the sub-set of models we are using in this analysis.

The preceding work used time-dependent ("transient") calculations to determine the plume sizes. Although there was no variation of the flow conditions with time, a time-dependent solution method is required to resolve the thermal buoyancy forces which are significant in large parts of the reservoir. The same approach has been used in the current work.

For spatial discretization[2], the preceding work used a specified blend factor between first and second order schemes for all transported variables, with a blend factor of 0.5. In the current work a hybrid differencing scheme has been used, which applies second-order differencing as widely as possible in the domain, only reverting to first-order differencing in regions of high gradients in the transported variables. This was largely a change in style, rather than substance. The hybrid scheme has the potential to be marginally more accurate, but with perhaps slightly less stability.

For temporal discretization[3], the preceding work used a second-order implicit Euler scheme. In the current work, a first-order implicit Euler scheme was used as the second-order scheme is only considered essential where there are true transient conditions, rather than using a transient scheme to reach a steady solution.

Convergence in the preceding work was judged to be achieved by three metrics: (i) when the Root-Mean-Square (RMS) residuals were reduced below 1.0e-4 for all transport equations solved at each time step in the time-dependent solution; (ii) when the variable imbalances for all conserved variables were less than 1 percent; (iii) when the thermal plume sizes were observed not to vary in time. The same approach has been used in the current work with the exception that RMS residuals were reduced to 1.0e-5. This was largely a change in style, rather than substance.

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[2] *Discretization* describes a numerical technique which is used in computational models. The flow domain – in this case the reservoir – is split into a very large number of grid cells, typically $10^5 - 10^6$ and the flow details (velocity, pressure, temperature, turbulence) are calculated in each grid cell. The numerical method must have some means of passing information between neighbouring cells and other near-neighbours – this is the spatial discretization scheme.

[3] Similarly the flow data must be passed between time steps – this requires the temporal discretization scheme

5. RESULTS

5.1 Preceding Work

The principal results for plume sizes which were calculated in the preceding work are repeated here for comparison. Only the results for the cases which have been re-run in the current work are shown in Table 2. The average depths have been updated to be somewhat greater, as they were not presented correctly in the preceding report[4]; the plume volume, area, and average depth are the same.

The following thermal conditions were used in the preceding work:

- Winter: ambient temperature: 66.6°F; discharge temperature: 98.7°F.
- Summer: ambient temperature: 86.4°F; discharge temperature: 113°F.

Table 2. Calculated Plume Sizes Repeated from the Preceding Work

Case	*Scenario*	*Volume (acre-ft)*	*Surface Area (acre)*	*Average Depth (ft)*	*Maximum Depth (ft)*
		Winter Conditions $\Delta T = 5°F$			
1	1W	799	77	10.4	40
2	2W	1,005	107	9.4	36
3	3W	1,148	120	9.6	36
4	4W	1,043	110	9.5	40
		Summer Conditions $T = 90°F$			
5	4S	1,790	163	6.1	40

[4] The results from the preceding analysis were originally provided in the tables in Section 7 "Results Summary – T = 90°F Plume" and Section 8 "Results Summary – ΔT = 5°F Plume" of report: *Thermal Mixing Zone Evaluation Virgil C. Summer Nuclear Station NPDES Permit* (Geosyntec Project reference GR4796; date January 9, 2012).

5.2 Current Work

The equivalent results for the plume sizes calculated in the current work are shown in Table 3.

The following thermal conditions were used in the current work:

- Winter: ambient temperature: 46.4°F; discharge temperature: 113°F.
- Summer: ambient temperature: 87.9°F; discharge temperature: 113°F.

Table 3. Calculated Plume Sizes from the Current Work

Case	*Scenario*	*Volume (acre-ft)*	*Surface Area (acre)*	*Average Depth (ft)*	*Maximum Depth (ft)*
		Winter Conditions $\Delta T = 5°F$			
1	1W	1,031	125	8.2	40
2	2W	1,109	388	2.9	36
3	3W	1,246	130	9.6	36
4	4W	1,503	218	6.9	40
		Summer Conditions $T = 90°F$			
5	4S	4,841	378	12.8	40

Contour plots showing the extent of the thermal plumes at the surface of the reservoir for each case are presented in Figures 1 through 5. The results for plume volume are considered to be accurate to around 5 percent.

5.3 Results Discussion – Winter Condition

The preceding work showed that the worst case in winter was Scenario 3 (low water; pump-back operation at FPSF). This was the worst case for both the $\Delta T = 5°F$ plume volume and area on the reservoir surface.

In the current work, the worst case for $\Delta T > 5°F$ plume volume is Scenario 4 (high water; generation at FPSF) and the worst case for area on the surface of the reservoir is Scenario 2 (low water; no flow through FPSF) (Table 3). The $\Delta T > 5°F$ plume remains to the east of the island at the end of the jetty (Figures 1, 3, and 4) for all cases except Scenario 2, where it just passes around the northernmost extent of the island (Figure 2).

In general, the plumes calculated with the ambient temperature 46.4°F and discharge temperature 113°F (Table 3) have greater volume and greater extent on the surface of the reservoir than the equivalent plumes in the preceding work with ambient temperature 66.6°F and discharge temperature 98.7°F (Table 2). There are a number of effects which influence this. Firstly, the higher discharge temperature results in a greater body of water with $\Delta T > 5°F$; the lower ambient temperature also acts to increase this plume size. However, counter to that, the lower ambient temperature also provides a greater cooling effect and has the potential to reduce the thermal plume size. Overall, it appears that the increased discharge temperature and lower ambient temperature act to increase the size of the winter thermal plume, as defined by $\Delta T > 5°F$, to a greater extent than the lower ambient temperature provides cooling.

Scenario 2 is also slightly unusual in that the average plume depth (or thickness) is shallow; this increases its area on the surface of the reservoir relative to the other scenarios. This is most likely due to the low water level used in Scenario 2, which is set at 420.5 ft mean sea level (msl), compared with the high water level cases using 425 ft msl. Scenario 3 also has the low water level, but there is increased mixing in the reservoir due to pump-back operations at FPSF.

5.4 Results Discussion – Summer Condition

The T = 90°F thermal plume for Scenario 4 (high water; generation at FPSF) is considerably larger for the current conditions than in the preceding work. The increase is evident in the volume, extent on the surface area, and depth of the thermal plume (Tables 2 and 3).

The only change in the conditions for this scenario was the increase in the ambient temperature from 86.4°F to 87.9°F. Although this is a small increase, it is significantly closer to the T = 90°F limit that defines the thermal plume, and thus less able to cool the discharged water.

As shown in Figure 5, the thermal plume remains to the east of the island and does not extend towards the FPSF or the VCSNS Unit 1 cooling water intake structure.

6. CONCLUSIONS

Additional calculations have been carried out for cooling water discharges from VCSNS Unit 1 into Monticello Reservoir. The additional calculations have been made at the request of SCDHEC to investigate a number of effects: lower ambient temperature in the winter; higher ambient temperature in the summer; and cooling water discharge of 113°F in the winter.

In winter, reducing the ambient temperature in the reservoir and increasing the cooling water discharge temperature has the effect of increasing slightly the $\Delta T > 5°F$ thermal plume size. The worst case for plume volume is Scenario 4 (high water; FPSF pumping back to Monticello Reservoir) and worst case for plume area on the reservoir surface is Scenario 2 (low water; no flow through FPSF). The $\Delta T > 5°F$ plume remains to the east of the island at the end of the jetty (located between the VCSNS cooling water intake structure and the discharge point) for all cases except Scenario 2, where it just passes around the northernmost extent of the island.

In summer, increasing the ambient temperature in the reservoir to 87.9°F has a large effect on the $T = 90°F$ thermal plume. This is because there is little cooling potential in the reservoir when the ambient temperature is already close to the thermal plume limit. However, the thermal plume remains to the east of the island.

The accuracy of the CFD calculations used to produce these results is estimated to be around 5 percent on the volume of the thermal plumes.

Both winter and summer cases show larger thermal plumes than were calculated in the preceding work, due to the revised ambient and discharge temperatures specified by SCDHEC. However, it is significant that in all cases calculated, the thermal plumes due to the cooling water discharge remain entirely or predominantly to the east of the island that separates the VCSNS cooling water intake structure and discharge. The thermal plumes do not approach the FPSF intake, the VCSNS Unit 1 cooling water intake structure, or the northern reach of Monticello Reservoir.

FIGURES

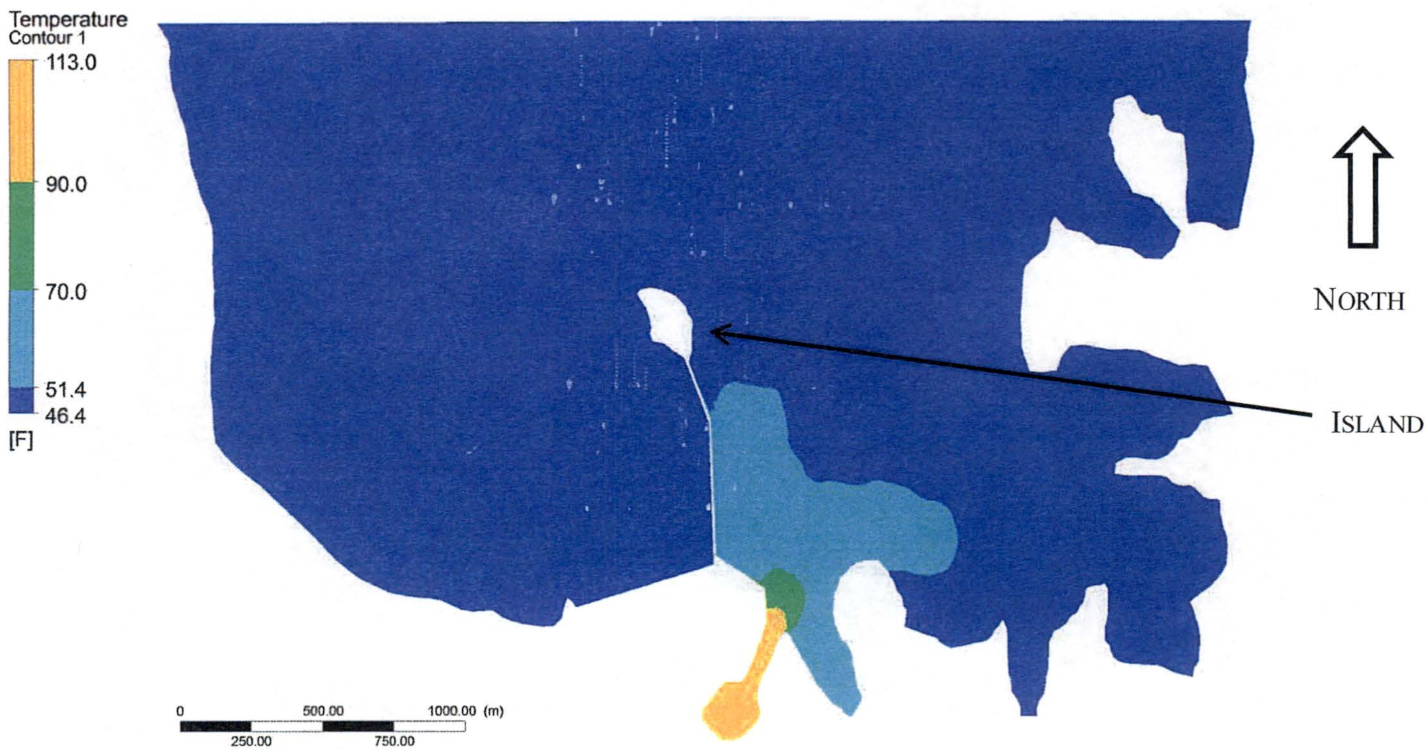

Figure 1. Scenario 1: Winter - High Water; No Flow through FPSF.

Contour plot showing the extent of the $\Delta T > 5°F$ plume which for $T_{ambient} = 46.4°F$ has the value $T_{plume} = 51.4°F$

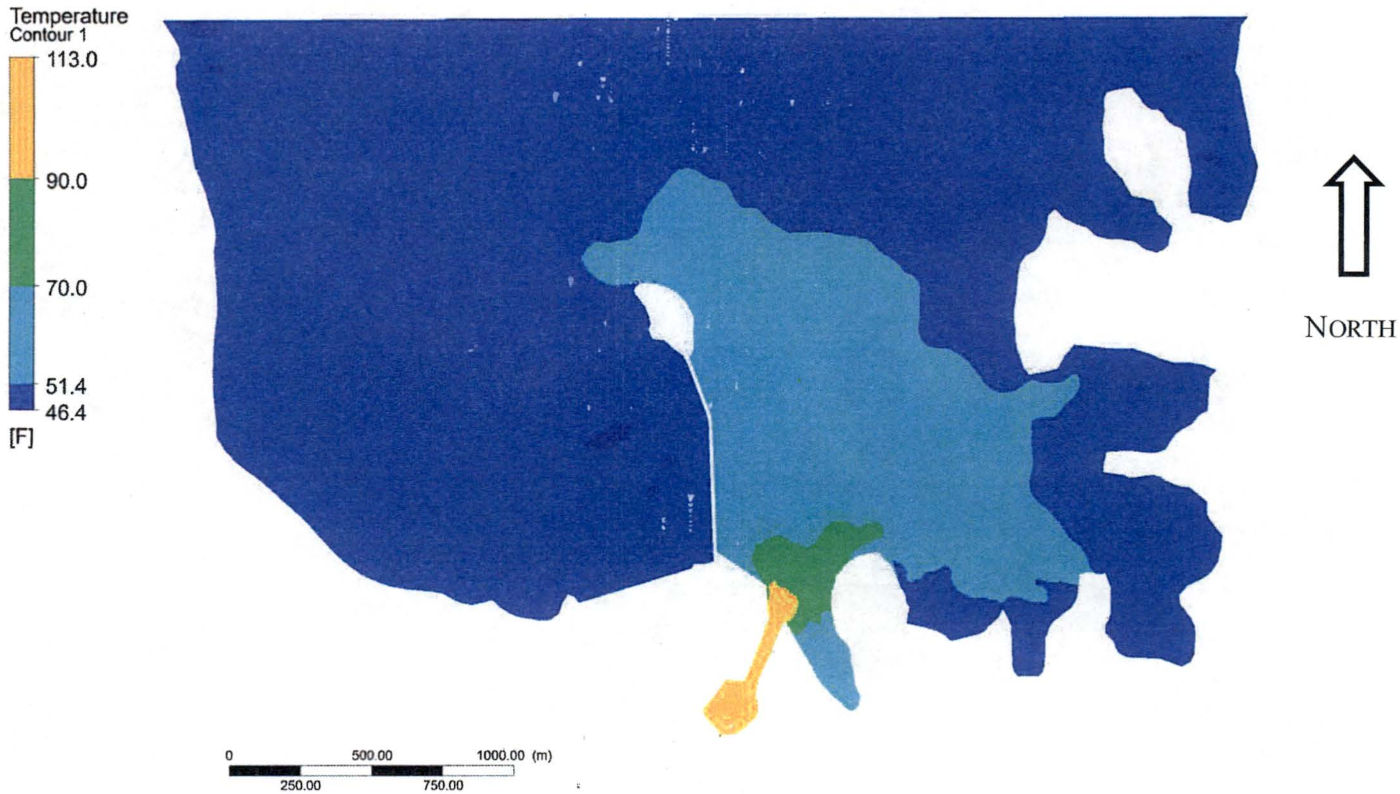

Figure 2. Scenario 2: Winter - Low Water; No Flow through FPSF.

Contour plot showing the extent of the $\Delta T > 5°F$ plume which for $T_{ambient} = 46.4°F$ has the value $T_{plume} = 51.4°F$

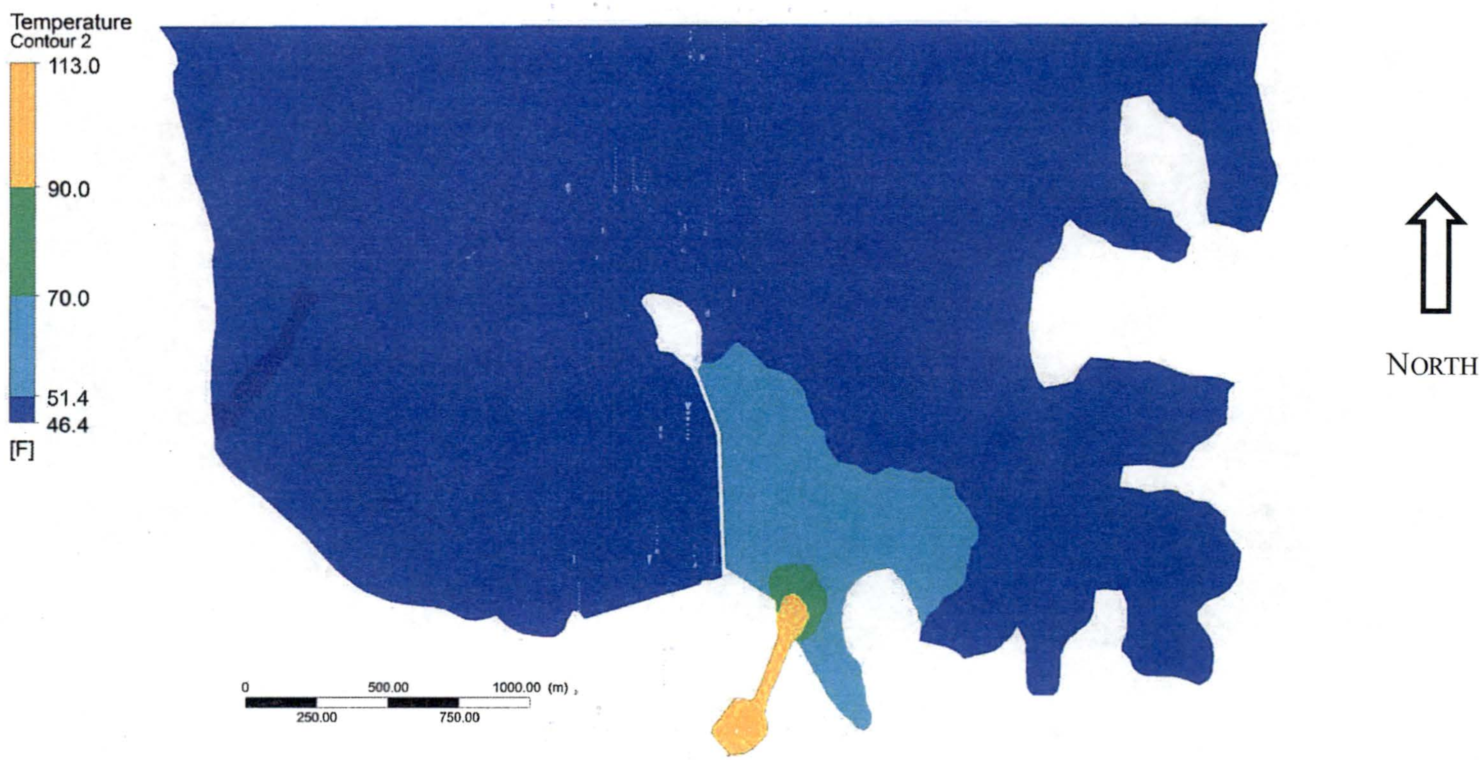

Figure 3. Scenario 3: Winter - Low Water; FPSF Pumping Back to Reservoir.

Contour plot showing the extent of the $\Delta T > 5°F$ plume which for $T_{ambient} = 46.4°F$ has the value $T_{plume} = 51.4°F$

Figure 4. Scenario 4: Winter - High Water; FPSF Generating (Discharging from Reservoir).

Contour plot showing the extent of the $\Delta T > 5°F$ plume which for $T_{ambient} = 46.4°F$ has the value $T_{plume} = 51.4°F$

Figure 5. Scenario 4: Summer - High Water; FPSF Generating (Discharging from Reservoir).

Contour plot showing the extent of the T = 90°F plume;
also shown is ΔT > 5°F plume which for $T_{ambient}$ = 87.9°F has the value T_{plume} = 92.9°F