Cooling Water Blowdown Thermal Discharge Analysis for Plant Vogtle Early Site Permit Facility

As reflected in the supporting document:

TEMPERATURE DISTRIBUTION IN THE SAVANNAH RIVER AT VOGTLE AS A RESULT OF BLOWDOWN FROM PROPOSED 2-UNIT AP1000 OPERATION

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The Plant Vogtle Early Site Permit proposes that natural draft towers be used for circulating water cooling. The blowdown from this system would be to the Savannah River through a single port discharge pipe. The calculations which support the predicted effects of this discharge on the temperature distribution in the river are documented here. The blowdown characteristics (flow rate, temperature) were simulated for each hour of a five-year period of record; cases of interest (e.g., maximum hourly blowdown temperature, average conditions) were then selected for detailed analysis of the resulting temperature distribution in the river. River characteristics (flow rate, surface level, temperature) were defined; extreme river low flow (7-day 10-year low flow) conditions were assigned to the extreme discharge conditions to assure conservatism of results. River temperatures were calculated for each day of the year and assigned to the blowdown characteristics for that day. The analysis includes the contribution from the existing Vogtle plant blowdown discharge.

The thermal discharge analysis can be broken up into the following sub-analyses:

- Meteorological Data (Wet Bulb Temperature and Relative Humidity)
- Cooling Tower Operating Characteristics (Blowdown Flow and Temperature)
- Ambient River Temperature (upstream of existing discharge)
- River Flow Rate
- River Stage (Surface Level)
- Bathymetry (River Bottom Contour)
- Existing Discharge (contribution to river temperature)
- Temperature Distribution from Proposed Discharge

Meteorological Data

Hourly onsite data for the years 1998-2002 were used. This data set is the same as used for the cooling tower atmospheric discharge effects (salt deposition, icing) and for the accident analysis. The files V98 (99,00,01 and 02).DAT contain the hourly dry bulb and dew point values for each year of the 5-year data period. The fortran program DAT2MET (source and executable included) was used to convert those hourly values to a single 5-year text file, 5YRMET.TXT, with hourly relative humidity and wet bulb temperatures. The algorithms used for the psychrometry conversions were tested against the psychrometric charts (PSYCHROMETRIC CHART.MHT) and found to be excellent matches. The data for 1/31/2002, hour 15:00 (subsequently to be shown as the maximum heat discharge, maximum ΔT hour) is presented as an example. The dry bulb and dew point temperatures from V02.DAT (written also in 5YRMET.TXT) are 78.1 and 64.2°F, respectively. The calculated relative humidity and wet bulb temperature (given in 5YRMET.TXT) are 63.29% and 68.96°F. PSYCHROMETRIC CHART.MHT shows that these values are consistent. All computer files (filenames in capital letters) described above are contained on the accompanying CD under the \MET directory (folder).

Cooling Tower Operating Characteristics

The cooling tower operating characteristics are defined as a function of relative humidity and wet bulb temperature by the proposed manufacturer in the design curves contained in the three pdf files, PROPOSED TOWER SET 1 (2 and 3). Set 1 contains cooling tower evaporation rate (used to determine blowdown flow) for relative humidity up to 40% and wet bulb greater than 66°F, cold water (blowdown) temperatures for relative humidity up to 100% and wet bulb less than 55°F, and cold water (blowdown) temperatures for relative humidity up to 100% and wet bulb greater than 55°F . Set 2 contains evaporation rate for relative humidity greater than 60% and wet bulb greater than 66°F. Set 3 contains evaporation rates for relative humidity up to 100% and wet bulb less than 65°F. EXISTING TOWER.PDF contains the cold water design curves for the existing unit 1 operation. The existing discharge blowdown flow rate was taken explicitly from existing documentation (see subsequent discussion of existing discharge).

The design curves were digitized and fortran subroutines written to interpolate evaporation rates and cold water temperatures for the relative humidities and wet bulbs contained in the met data (described previously). 3-point interpolation, assuming functional relationships of the form $y = ax^b + c$ were used to interpolate the dependent variable (cold water temperature or evaporation rate) in terms of the independent variables (relative humidity and wet bulb) in turn. For example, the cold water temperature was calculated by first determining its value for the given wet bulb for each of three constant relative humidity values (surrounding the given relative humidity). These three cold water temperatures (functions of relative humidity for the given wet bulb) are then interpolated based on the given relative humidity. The spreadsheet, BLOWDOWN TEMPERATURE INTERPOLATION EXAMPLE.XLS, follows the interpolation of cold water temperature from the proposed tower design curves for 1/31/2002, hour 15:00; that example is further followed below. The fortran program MET2TOWR (source and executable included) calculates, for each hour of met data, the corresponding cold water temperature for the existing and proposed towers and the evaporation rate (E) and blowdown flow (Q) from the latter. Blowdown flows are given for 2 and 4 cycles of concentration (CC) and are calculated from Q = E / (CC – 1). The output files from MET2TOWR are 5YRTOWR.TXT and 5YRSTATS.TXT.

5YRTOWR.TXT contains, for each hour of the 5-year met data period, the met data, cold water (blowdown) temperature from the existing and proposed towers, and the proposed tower blowdown flow for 2 and 4 cycles of concentration. The corresponding ambient river temperature (and temperature excess of the proposed blowdown) is also in the file; river temperature calculations are described subsequently. The file 5YRSTATS.TXT summarizes the 5 years of hourly information, giving minimum, average and maximum monthly and annual values for each of the parameters.

The data for 1/31/2002, hour 15:00 is followed as an example. The relative humidity and wet bulb for this hour was shown previously (see METEOROLOGICAL DATA) to be 63.29% and 68.96°F. The blowdown temperatures for the proposed and existing towers are given in 5YRTOWR.TXT as 81.47 (also calculated in BLOWDOWN TEMPERATURE INTERPOLATION EXAMPLE.XLS) and 81.97°F, respectively. The 2-cycle and 4-cycle proposed tower discharge flow rate is 12281.2 and 4093.7 gpm per tower, respectively. The proposed tower blowdown temperature is seen to be consistent with the cold water design curve in PROPOSED TOWER SET 1.PDF (page 3) for the given meteorological conditions. The proposed tower blowdown rates, which correspond to an evaporation rate of 12281.2 gpm, are consistent with the evaporation design curve of PROPOSED TOWER SET 2.PDF. The existing tower blowdown temperature is consistent with EXISTING TOWER.PDF (page 2) as given in 5YRTOWR.TXT. The cold water design curve on page 2 reflects the existing tower cooling range as given in the OLSER; the design curve on page 1 is an earlier (construction phase) iteration.

All computer files (filenames in capital letters) described above are contained on the accompanying CD under the \TOWERS directory (folder).

Ambient River Temperature

Annual ambient river temperatures in Georgia were studied by Dyar and Alhadeff {included as pdf file WRIR96-4203 (TEMPERATURES)}. They described the annual cycle of temperatures for the Savannah River upstream and downstream from the plant's location. As related in the report (Toblin, 2006) being supported by this calculation package, the functional relationship between day of year and river temperature was determined for Shell Bluff Landing (near Vogtle) for the period subsequent to 1984, after the construction of Richard B. Russell Reservoir. Dyar and Alhadeff's results reflected river temperatures prior to the reservoir's construction.

The grab sampled river temperatures at Shell Bluff Landing, as supplied by Georgia DNR, are given in RIVRTEMP.XLS AND RIVR TEMP STATIONS.XLS. The fortran program TEMPCORR (source and executable included) calculates the coefficients for the day of year-river temperature functional relationship described in Toblin, 2006. The input file to this program, RIVRTEMP.CSV, is saved from RIVRTEMP.XLS (for the river location of interest). The output (coefficients of functional relationship) is given in TEMPCORR.OUT.

The river temperature for 1/31/2002, hour 15:00 is followed as an example. The river temperature is given in 5YRTOWR.TXT (see previous section, Cooling Tower Operating Characteristics) as 50.57°F (10.32°C). This is within the range of temperatures measured for dates within two weeks of 1/31 (1/25-2/13, after 1984 no measurements were taken between the dates of 1/17 and 1/25) at the location of interest (as given in RIVRTEMP.CSV), 5.8-14°C, and is a close match to the average of the latter measurements, 10.0°C. The calculated river temperature of 10.3°C can be manually calculated from the equations given in Toblin, 2006. The discharge temperature (proposed cooling tower blowdown) excess over ambient, 81.47 – 50.57 = 30.9°F, is given in 5YRTOWR.TXT. 5YRSTATS.TXT (see previous section, Cooling Tower Operating Characteristics) *shows that this is the maximum temperature excess for the 5-year meteorological* period analyzed (see previous section, METEOROLOGICAL DATA); this can be easily verified by reading 5YRTOWR.TXT into a spreadsheet and querying the spreadsheet for the maximum DT (temperature excess) and H (heat discharge, DT * Q).

All computer files (filenames in capital letters) described above are contained on the accompanying CD under the \RIVER directory (folder).

River Flow Rate

Daily river flow rates were measured by USGS at the Vogtle site (Waynesboro Gaging Station) during the period 1/22/05-9/30/05. Concurrent USGS measurements upstream (Augusta Gaging Station) and downstream (Millhaven Gaging Station) were available. Daily measurements at Augusta were available from 1925 and at Millhaven from 1939. AUGUSTA-WAYNESBORO-MILLHAVEN FLOW DATA.XLS (work sheet = Daily and 7-Day Flows) contains all of this data. 7-day rolling average flows were calculated for each of the three stations for the time period of concurrent data availability in the aforementioned spreadsheet and worksheet. Those values were cut and pasted into the work sheet = A-V-M Correlation, and saved as text file, VAM.IN.

The fortran program VAM (source and executable included) correlated the 7-day flows at the three stations as described in Toblin, 2006, with VAM.IN being the input data file. VAM.OUT shows the resulting correlations.

Monthly and annual minimum 7-day flows for each water year (October-September) since the construction of Richard B. Russell Dam, 1985-2005, were calculated in the last mentioned spreadsheet (work sheet = Monthly and 7-Day Flows) from Augusta and Millhaven daily data. Corresponding flow rates at Vogtle were simulated using the correlation described above and are given in that same work sheet (beginning in row 7697); 2004 flow rates for Vogtle were not included because corresponding measurements were not available at Millhaven. The minimum 7-day flow at Vogtle for the 20-year period is seen to be 3966 cfs (in November 1987). The next smallest value, 3967 cfs (in September 2002), is identified as the 7Q10 flow at the Vogtle site.

The latter is followed as an example; all described flows are 7-day averages in cfs unless indicated otherwise. The September 2002 minimum flows at Augusta and Millhaven are 3874 and 4044 (cells V7691 and W7691 of work sheet = Monthly 7-Day Flows). These correspond with the 7-day periods ending on 9/12/2002 and 9/14/2002, respectively. The minimum monthly flow for each station is conservatively used to simulate the minimum flow at Vogtle, 3967 cfs (which can be confirmed manually applying the correlation equation in Toblin, 2006). If the concurrent flows for each date were used, the latter result would increase by 22 cfs (9/14/2002). The 9/12/2002 flow at Augusta is calculated in cell G28293 of work sheet = Daily And 7-Day Flows, and is composed of daily flows ranging from 3730 to 3980. The 9/14/2002 flow at Millhaven is calculated in cell I28295 of that same work sheet, and is composed of daily flows ranging from 3920 to 4140.

All computer files (filenames in capital letters) described above are contained on the accompanying CD under the \RIVER directory (folder).

River Stage

The Stage-Discharge relationship (river surface elevation-river flow rate) was obtained from the USGS internet site http://nwis.waterdata.usgs.gov/nwisweb/data/exsa_rat/021973269.rdb. The tabular values are in file STAG-DIS.TXT. The gage height datum is 70.75 feet MSL and is documented in file WAYNESBORO (VOGTLE) RIVER GAGE DATUM.EML.

The 7Q10 river elevation is followed as an example. The 7Q10 river flow, as determined above (see River Flow Rate), is 3967 cfs. The river stage corresponding to this flow is found in STAG-DIS.TXT as 6.79 feet. The river surface elevation at this flow is then 6.79 + 70.75 (datum) = 77.54 feet MSL.

All computer files (filenames in capital letters) described above are contained on the accompanying CD under the \RIVER directory (folder).

Bathymetry

River cross-sections were measured at various locations both upstream and downstream from the existing and proposed discharges. XSECT.XLS contains the measurements. Column A of that spreadsheet gives the generic cross-section location (relative to the proposed discharge location unless indicated otherwise). Column B is an approximate cross-stream station (location) for each elevation measurement. Column C contains the corresponding river bottom elevation in feet above MSL. Columns E and F give the measurement station coordinates. Columns J and K calculate each segment's length (J) and cross-sectional area perpendicular to flow direction (K). The segment areas are summed to give a total cross-sectional area in Column K at the concluding row of each segment's data. The average river velocity for each segment is calculated in Column L (adjacent to the total cross-sectional area) by dividing the flow rate (cell L2) by the area from the adjacent cell.

Cross-sectional areas and velocities are functions of the river flow. The river flow rate is input in cell L2. The corresponding gage height is read from work sheet = Stage-Discharge. The data in this work sheet is repeated from STAG-DIS.TXT (see River Stage above). A close approximation to the stage is also given based on a correlation equation relating stage to flow in cell H4. The latter is for checking purposes only and is not explicitly used in the calculations.

The river cross-section and related parameters are followed for 3967 cfs, the 7Q10 river flow at the proposed discharge location. The river flow is input in cell L2. The corresponding gage height is read from work sheet = Stage-Discharge as 6.79 feet (see also, River Stage above) and input into cell L3. The surface elevation, 77.54 ft MSL, is calculated in cell L4. The cross-sectional area at the proposed discharge is read from cell K95 as 2595 ft^2 and the river velocity is read as 1.53 ft/sec from cell L95. The minimum bottom elevation across the proposed discharge cross-section is 66.006 ft MSL at station 0+60 (cell C78). The maximum river depth for 7Q10 river flow at the proposed discharge cross-section is then 77.54 – 66.006 = 11.53 feet. A pictorial representation of this river cross-section is contained in Toblin, 2006. The river depth and conceptualized rectangular river cross-section (290 ft x 9 ft, necessary for thermal modeling) are discussed further in Toblin, 2006. The conceptualized river cross-sectional area, 290 * 9 = 2610 ft^2, closely approximates the 2595 ft^2 value determined in XSECT.XLS.

All computer files (filenames in capital letters) described above are contained on the accompanying CD under the \RIVER directory (folder).

Existing Discharge

The CORMIX model was used to simulate river temperatures downstream of the existing discharge. The computer text files, EDL.PRD, ETL.PRD, EML.PRD, and EAA.PRD are the model outputs for the Max-ΔT, Max-T, Min-ΔT, and average cases, respectively. These are the four cases analyzed in Toblin, 2006. The corresponding CORMIX input files have the extension .CMX and require the CORMIX model to interpret.

The existing discharge consists of a single 2-foot diameter port discharging 10,000 gpm into approximately 10 feet of water for 7Q10 river flow. Further details of the discharge are described in Toblin, 2006. The centerline plume temperature rise resulting from the existing discharge at the downstream location of the proposed discharge was conservatively chosen to represent the contribution of the former to the latter at all locations.

The existing discharge contribution for the Max-ΔT case is followed as an example. The CORMIX output for this case is file EDL.PRD. The downstream distance from the existing discharge to the proposed discharge is calculated in XSECT.XLS (see previous section, Bathymetry); that distance was conservatively chosen as the straight line distance from the transect 25 meters downstream of the existing discharge to the proposed discharge, 123.07 meters, and is calculated in cell A79 of the spreadsheet. The centerline temperature (as read from the .PRD file) at downstream distances (x) of 120.75 and 123.73 are .452 and .445°C above ambient, respectively; a value of 0.45°C = 0.81°F was chosen.

Note that the discharge temperature for the hours of interest, 1/31/2002 hour 15:00, exceeds ambient by 81.97°F (see previous section, Cooling Tower Operating Characteristics) – 50.57°F (see prvious section, Ambient River Temperature) = 31.40°F = 17.44°C. The latter value is found at the top of EDL.PRD (parameter C0). Other of the input variables listed at the top of this file and described previously include river flow (QA = 112.33 m^3/sec = 3967 ft^3/sec), river depth at the discharge (HD = 3.05 m = 10 ft), discharge diameter (D0 = .610 m = 2 ft), and discharge flow rate (Q0 = 0.63 m^3/sec = 10,000 gpm).

The .PRD and .CMX files described above are contained on the accompanying CD under the \EXISTING directory (folder).

Temperature Distribution from Proposed Discharge

The CORMIX input and output files (extensions .CMX and .PRD, respectively) for the four proposed discharge cases analyzed in Toblin, 2006 have the filenames PDLa237-, PTLa237-, PMLa237-, and PAAa237-, where a is the number of cycles of concentration (2 or 4). These files correspond to the Max-ΔT, Max-T, Min-ΔT, and average cases, respectively.

The proposed discharge, like the existing discharge, is a single 2-foot diameter port. The discharge centerline is 3-feet above bottom and is oriented 70° from the river flow. The discharge is pointed 5° downwards from horizontal. Further details of the design and discharge parameters are given in Toblin, 2006.

The thermal distributions from the CORMIX outputs were pasted into spreadsheets (.XLS extension) with the same filenames as the output files. The spreadsheet, then calculated, at each downstream plume centerline location listed in the output, the 5°F excess temperature isotherm (mixing zone) coordinates based on the CORMIX distribution parameters. The spreadsheet also calculates the total surface area, cross-sectional area (perpendicular to flow), and volume of that isotherm.

The 2-cycle Max-ΔT case is followed as an example. The CORMIX output file for this case is PDL2237-.PRD. The top of that file contains the model input values. Some of those input variables which have been discussed previously include river width (BS = 88.39 m = 290 ft), river depth (HA = 2.74 m = 9 ft), river flow (QA = 112.33 m^3/sec = 3967 ft^3/sec), discharge diameter (D0 = .610 m = 2 ft), angle with horizontal (THETA = -5°), angle with river flow (SIGMA = 70°) and discharge flow rate (Q0 = 1.55 m^3/sec = 24,562 gpm). Note that the blowdown flow is twice that described in the previous section, Cooling Tower Operating Characteristics. The previous section described the characteristics from a single cooling tower; the total proposed blowdown is from two towers.

The excess temperature of the discharge (above the river temperature) for 1/31/2002 hour 15:00 is input as C0 = 81.47°F (see Cooling Tower Operating Characteristics) – [50.57°F (see Ambient River Temperature) + 0.81°F (see Existing Discharge)] = 30.09°F = 16.72°C. The mixing zone temperature of interest is then 5°F – 0.81°F (existing discharge component) = 4.19°F = 2.33°C. The furthest downstream extent of that temperature is seen from PDL2237-.PRD to be (2.37°C at x = 9.68 m, 2.32°C at x = 9.95 m) 9.9 m = 32.5 ft. The surface area, cross-sectional area and volume of the river enclosed by the mixing zone isotherm are found in PDL2237-.XLS, cells X56, V56 and W56, respectively.

The .PRD, .CMX, and .XLS files described above are contained on the accompanying CD under the \PROPOSED directory (folder).

TEMPERATURE DISTRIBUTION IN THE SAVANNAH RIVER AT VOGTLE AS A RESULT OF BLOWDOWN FROM PROPOSED 2-UNIT AP1000 OPERATION

Meteorological Data (Wet Bulb Temperature and Relative Humidity)

Onsite hourly meteorological data for the five years 1998-2002 was used as input to simulate the cooling tower blowdown temperature from the existing and proposed units at Vogtle. The data was first examined and missing hours of data filled in with either the preceding available hour's data or, if closer in time, the subsequent available hour's data. No more than 4 hours of consecutive data was missing. The data parameters of interest for cooling tower cold end temperature performance, dry bulb and dew point temperatures, were extracted from the data base and converted to the explicit parameters in which cooling tower performance is expressed, relative humidity and wet bulb temperature.

2.53% of the 5 years of hourly dry bulb/dew point data is either missing (2.44%) or physically unreasonable (0.09%). Dew point temperatures should never be greater than dry bulb temperatures. Allowance was made for differences in measurement calibration between the two parameters by considering physically unreasonable data as dew point temperatures minus dry bulb temperatures greater than 2°F; the relative humidity was set to 100% for the 0.28% of the data for which measured dew points were greater than dry bulbs but within the tolerance of 2°F. This is a conservative use of the data in that high relative humidity leads to high blowdown temperatures.

Tower Operation/ Discharge Parameters (Temperature and Flow)

Tower operating design curves were supplied by the tower manufacturer for the proposed natural draft towers. These curves relate tower cold-end (equivalent to blowdown) temperature to atmospheric wet bulb temperature and relative humidity. A similar set of curves were supplied which relate tower evaporation rate to the atmospheric wet bulb temperature and relative humidity. These curves were digitized and cold-end temperatures and evaporation rates simulated for each hour of the 5-year meteorological data base described previously. The river temperatures for each day of the year were calculated as subsequently described (see **Ambient River Temperatures**).

The normal intake/discharge operating mode will be 4 cycles of concentration. During periods of high river TDS, the plant may operate at 2 cycles of concentration in order to maintain circulating water concentrations within design bounds. Discharge (blowdown) flow rates were simulated for each hour of the data period for each of 2- and 4-cycle operation.

The following tables give the range of blowdown parameters for each month of the year, based on the 5-year hourly simulations. The right-most column shows the range for the entire data set.

Table 1 Monthly and Five-Year Blowdown Temperatures (°F)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	ALL
Min	42.4	44.0	46.1	52.8	60.7	67.9	69.5	65.5	62.2	53.9	49.6	42.6	42.4
Average	62.6	64.4	66.8	72.4	76.9	81.4	83.1	82.3	78.2	73.3	68.1	62.5	72.6
Max	81.5	80.3	83.0	85.4	88.3	90.4	91.5	91.1	88.4	86.3	81.3	81.0	91.5

Table 2 Monthly and Five-Year ΔT (Blowdown Temperature Excess Above Ambient River, °F)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	ALL
Min	-9.1	-8.5	-6.5	-8.9	-7.2	-5.1	-8.4	-10.9	-9.8	-14.0	-9.7	-10.8	-14.0
Average	11.6	13.1	11.8	11.1	8.7	7.2	5.7	5.2	4.9	6.2	8.1	8.4	8.5
Max	30.9	29.1	28.0	25.0	20.8	17.5	13.6	14.1	15.6	19.1	23.1	26.2	30.9

Table 3 Blowdown Flow for 4 Cycles of Concentration Operation (gpm per unit)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	ALL
Min	2208	2315	2448	2783	3168	3504	3657	3332	3198	2833	2684	2228	2208
Average	3302	3436	3566	3796	3994	4053	4098	4098	3982	3764	3592	3343	3751
Max	4160	4268	4346	4486	4570	4681	4601	4713	4614	4410	4264	4201	4713

Table 4 Blowdown Flow for 2 Cycles of Concentration Operation (gpm per unit)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	ALL
Min	6624	6945	7344	8348	9503	10513	10971	9995	9594	8498	8053	6685	6624
Average	9905	10308	10697	11389	11981	12158	12293	12293	11945	11291	10776	10029	11252
Max	12480	12804	13038	13458	13711	14043	13802	14138	13842	13230	12791	12602	14138

The maximum blowdown temperature is expected to be 91.5°F, occurring in July; the blowdown temperature during the 5-year period exceeds 90°F for less than 7 hours per year. The maximum ΔT (blowdown temperature – river temperature) is 30.9°F, occurring during the winter; ΔT of 20°F is exceeded 5% of the hours during the 5-year period. The maximum ΔT corresponds with the maximum heat discharge (discharge flow* ΔT). The minimum ΔT is -14.0°F, occurring in October. Negative ΔTs are seen 8% of the time; ΔTs less than -6.5°F are seen 0.5% of the time.

The cooling water discharge conditions for which thermal plume calculations were performed are maximum blowdown temperature (max-T), maximum blowdown ΔT (max-ΔT), minimum ΔT (min-ΔT), and 5-year average (average). The following table summarizes the discharge parameters modeled.

Table 5 Discharge Parameters For Blowdown Modeling

CASE	Discharge Temperature (°F)	Discharge ΔT (°F)	Discharge Flow (4 Cycles of Concentration, gpm per unit)	Discharge Flow (2 Cycles of Concentration, gpm per unit)
Max-T	91.5	13.6	4576	13728
Max-ΔT	81.5	30.9	4094	12281
Min-ΔT	54.4	-14.0	2869	8605
Average	72.6	8.5	3751	11252

Ambient River Temperatures

Dyar and Alhadeff, 1997 studied stream temperatures in Georgia. They correlated water temperature measurements versus time of year for a number of water bodies in the state, including the Savannah River, using an equation of the form of $T = HM + AMP [\sin (2 \pi t / 365+ PHC)]$, where T is the river temperature in °C, t is the time of year in water days (October 1 being day 1), HM is denoted as the harmonic mean coefficient, AMP the amplitude coefficient and PHC the phase coefficient. The result of their correlation for Millhaven in the Savannah River downstream from Vogtle, including the time period and number of measurements used and the standard deviation of the equation, is indicated in Table 6.

Dyar and Alhadeff note that, "After completion of Richard B. Russell Reservoir in 1983, some changes in downstream temperature characteristics are expected." Filling of the reservoir began in October 1983 and was completed in December 1984 (COE, 2006). Because the Dyar and Alhadeff correlation used data prior to completion of the reservoir, a new correlation was performed for this study using data subsequent to 1984. The data was gathered approximately monthly during the period of record at Shell Bluff Landing near Vogtle by the Georgia Department of Natural Resources (Frazier to Patterson, 2006).

Table 6 Savannah River Temperature Correlation Parameters Near Vogtle

Reference	Time Period	Number of measurements	HM	AMP	PHC	Standard Deviation (deg-C)
Dyar and Alhadeff,	8/57-6/79 (Millhaven)	81	16.8	8.2	2.64	1.82

1997						
Present Study	1/85-8/96 (Shell Bluff Landing)	129	17.9	7.6	2.66	2.13

Table Note: T (deg-C) = HM + AMP [sin($2\pi t$/ 365+ PHC)] ; t in days from October 1

River temperatures for this study were calculated using the correlation equation and parameters for the present study as indicated in Table 6. It is believed that this is conservative in the sense that river temperature trends will generally follow blowdown temperature trends, both following meteorology. For conditions of blowdown temperatures exceeding normally expected values, ambient river temperatures are also likely to exceed the normally expected values given by the equation. Specifying delta-t (blowdown temperature – ambient river temperature) using extreme meteorology and "normal" river temperatures, as in the Max-ΔT case of Table 5 is likely an overestimate.

Ambient River Flow

Long term daily river flow records in the Savannah River were available from USGS gaging stations upstream (Augusta) and downstream (Millhaven) of the Vogtle location. Concurrent daily river flow information was available for these two stations plus the recently installed Waynesboro (at Vogtle) gaging station for the period 1/22/05 through 9/30/05.

A relationship among the flow at these three locations was hypothesized which conceptually expresses the flow (Q) at Vogtle as the upstream Augusta flow incremented by a fraction (c) of the increase in flow between the Augusta and Millhaven locations. That is, Q(Vogtle) = Q(Augusta) + c * [Q(Millhaven) – Q(Augusta)]. Rolling 7-day average flows at these three locations were regressed for the concurrent data period. The value of c was determined for the entire range of flows (5060 to 23,600 cfs at Augusta) seen during this data period (246 data points) and for low flows only (34 data points with 7-day flows < 7000 cfs – only 12 data points were available for 7-day flows < 6000 cfs). The values of c and the corresponding standard deviation of the flows calculated with that constant in the equation above were found to be (0.592, 977 cfs) for all conditions and (0.543, 336 cfs) for low flow conditions. The similarity of the "c" values for the two conditions lends credence to the chosen relationship.

A 20-year record of flows at Vogtle was synthesized by applying the above relationship to the rolling 7-day average flows at Augusta and Millhaven for water year 1985 (10/1/84-9/30/85), corresponding to filling of the Richard B. Russell reservoir (see **Ambient River Temperatures**), through the most recent water year, 2005. Water year 2004 was not simulated because Millhaven data was not available for that year. 7Q10 (7-day average low flow appearing once per ten years) flows were obtained by ordering the minimum 7-day flow for each of the twenty years (by month and annually) and reporting the second lowest value of the series. Table 7 shows the resulting monthly and annual 7Q10 and average Savannah River flows at Vogtle, applying the values of "c" described above for low (7Q10) and all (average) flows.

Table 7 Monthly and Annual Low and Average Savannah River Flows at Vogtle (cfs)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	ALL
7Q10	4557	4774	4815	4579	4305	4188	4249	4270	4387	4141	4215	4358	3967
Average	9859	12143	14217	10993	8660	7806	7868	8141	7340	7777	7034	8911	9229

The annual 7Q10 low flow is less than any of the monthly 7Q10 flows because the second lowest (of the twenty) annual 7-day flow (occurring in September 2002) corresponds to the lowest September 7-day flow. The lowest 7-day flow of the 20-year record is 3966 cfs, occurring in November, 1987.

River flow rates (both low and average) are greatest from January through April and lowest from June through November. The monthly low flow (7Q10) range is relatively small, with 16.3% difference from minimum (October) to maximum (March). The annual low flow was conservatively applied to all of the restrictive discharge cases (Max-T, Max-ΔT, and Min-ΔT as described in the **Tower Operation/Discharge Parameters** section). The annual average flow of 9229 cfs was applied to the Average discharge case.

Stage-Discharge

The USGS presented a rating curve table, describing river stage-discharge (river surface elevation vs. river flow) at the Waynesboro (Vogtle) gaging station (USGS, 2006). This table was directly used to define gage height for a given river flow in the Vogtle discharge analysis. The Waynesboro river gage datum is at 70.75 feet above mean sea level (msl) (Greene to Toblin, 2006). River elevation (in feet above msl) is then the gage height from the rating curve for a given flow + 70.75 feet.

The rating curve is defined for flows from 3230 cfs (81% of the annual 7Q10 flow) to 30,000 cfs (325% of the annual average flow). The relationship between gage height and flow, for the entire range of flows contained in the rating curve, is well represented (standard deviation of 0.10 feet) by:
$H = 0.0583\ Q^{0.583} - 0.640$, where H = gage height (feet above gage datum) and Q = river flow (cubic feet per second, cfs). This equation is presented for use if the USGS table is unavailable. The river surface elevations used in the Vogtle discharge analysis were taken directly from the USGS rating curve table.

Temperature Distribution as a Result of Blowdown Discharge

CORMIX Model

The CORMIX (Jirka, Doneker, and Hinton, 1996) Version 4.3 model was used to simulate the temperature distribution in the Savannah River resulting from discharge of Vogtle blowdown water. CORMIX is a U.S. EPA supported mixing zone model which emphasizes the role of boundary interactions to predict steady state mixing behavior and plume geometry. It is widely used and recognized as a state of the art tool for discharge mixing zone analyses. (CORMIX, 2006a) The model has been validated in numerous applications. (CORMIX, 2006b)

Georgia Mixing Zone Regulations

The Savannah River at Vogtle is classified for water use as "fishing." Temperatures of such waters cannot exceed 90°F nor can they be increased by more than 5°F above intake temperature. Specific sizes of mixing zones are not specified; "Use of a reasonable and limited mixing zone may be permitted on receipt of satisfactory evidence that such a zone is necessary and that it will not create an objectionable or damaging pollution condition." (DNR, 2004)

Discharge Design

Determination of the proposed 2-Unit AP1000 blowdown discharge design was based on the mixing zone necessary under worst case conditions: max-ΔT (see Table 5), 2 cycles of concentration (maximum discharge flow), and 7Q10 (minimum) river flow. A single submerged port was the conceptual discharge design. If the mixing zone resulting from such a design were unreasonably large, a more complex multi-port diffuser would then have been considered.

It was found that the mixing zone size, shape and orientation were insensitive to the choice of vertical orientation of the port (i.e., angle in the vertical plane from horizontal) and height of the discharge above the river bottom. This was a result of the discharge plume quickly attaching to the river bottom as a result of low pressure effects due to effluent jet entrainment requirements and the proximity of the river bottom. A vertical angle of 5 degrees downward from horizontal and a height of the discharge (center of port) above the river bottom of 3 feet were arbitrarily chosen. They are both representative of the placement and orientation of the existing Vogtle blowdown discharge.

Changes in the horizontal port orientation (i.e., angle in the horizontal plane from downstream) were found to change the orientation of the mixing zone but only small changes were seen in the zone's extent as long as it were not pointed downstream. As this angle increased from 0 (downstream) to 90 degrees (cross-stream), the mixing zone changed from a downstream to cross-stream orientation. The existing Vogtle discharge is oriented 70 degrees counterclockwise from downstream (facing away from the near shoreline).

That discharge is successfully operating; the horizontal orientation of the proposed discharge was chosen to mimic that of the existing discharge.

The extent of the mixing zone decreases with decreasing port diameter. This is a result of the greater entrainment resulting from an increase in discharge velocity (the discharge velocity increases as the diameter decreases for the same flow). A design choice of port diameter is a compromise between mixing zone size (favored by smaller diameter) on one hand and pumping costs (possibly required to move the necessary flow through the discharge port at higher velocity) and river bed scour (caused by high jet velocity along the bed) on the other.

CORMIX results indicate that the mixing zone for a port diameter of 2 feet has less than half the extent as does one for a port diameter of 3 feet. Smaller proportional reductions in mixing zone extent per unit port area are seen for diameters less than 2 feet. Discharge velocities, on the other hand, increase dramatically (being inversely proportional to the square of the diameter). For discharge port diameters of 3, 2, and 1 foot, the discharge velocities for the worst case conditions considered are 8, 17, and 70 fps, respectively. A two-foot diameter port was chosen as a compromise between mixing zone and velocity considerations. It is noted that the existing Vogtle blowdown discharge is successfully operating with a single two-foot diameter port.

Bathymetry

In support of this analysis, river bottom elevations were surveyed from one bank to the other for locations from the existing discharge to well downstream of the proposed discharge location. Figure 1 shows the river cross-section at and 25 meters downstream from the proposed discharge. Note that the figure is drawn with a tenfold vertical scale exaggeration so that details are clearly delineated. As will be shown (see **Proposed Discharge Mixing Zone**), this river stretch encompasses the proposed mixing zone.

As depicted in Figure 1, the river reaches a maximum depth of approximately 11.5 feet in the immediate area of the proposed discharge for low river flow (7Q10) conditions. However, that depth decreases a foot within about 20 feet of the maximum in the cross-stream direction and decreases about 2.5 feet within the 25-meter river stretch downstream from the proposed discharge. The river depth at the blowdown discharge (an input parameter required by the CORMIX model) was chosen as 9 feet (for 7Q10 river flow). The choice of this parameter is not important for design conditions because of the discharge's attachment to the river bottom (see Discharge Design, above). However, it is a conservative choice for less severe conditions, such as 4-Cycles of Concentration operation with Average river flow. Note that, as shown in Figure 1, for average river flow the river surface is 4.5 feet higher than for 7Q10 river flow.

CORMIX requires that the river cross-section be represented by a rectangle of dimensions width x depth. Cross-sections for low and average river flow were chosen such that the river cross-sectional areas were equal to those depicted in Figure 1. The low river flow cross-section was chosen as 290 feet x 9 feet and the average river flow cross-section as 303 feet x 13.5 feet. The river velocity (river flow rate/ cross-sectional area) is approximately 1.5 and 2.3 fps for low and average river flow, respectively.

Existing Discharge

The mixing zone temperature excess of 5°F is based on the intake river temperature, which is located upstream from both the existing and proposed discharge. The temperature distribution from the proposed AP1000 blowdown discharge must then include a component representing the effect of the existing Vogtle blowdown discharge. The existing-tower design curves and 5-year meteorology were used to simulate the hourly blowdown temperatures from existing operations in the same manner as was described for the proposed towers (see **Tower Operation/Discharge Parameters**). The existing blowdown temperature was chosen as that calculated for the hour concurrent with that of each of the proposed blowdown discharge cases (see Table 5). The existing blowdown discharge flow rate was taken as 10,000 gpm. (Vogtle, 2004)

The river cross-section at the existing discharge (see Figure 4 in Proposed Discharge Mixing Zone) was represented by a cross-section of 310 feet x 8 feet for low flow and 327 feet x 12.5 feet for average flow, with an additional 2 feet below the discharge. As described previously (see Discharge Design), the existing single-port discharge has the same diameter and orientation as that chosen for the proposed AP1000 discharge.

CORMIX was then used to calculate the temperature excess (above ambient) in the river resulting from the existing discharge at the proposed discharge location, 404 feet downstream. Table 8 gives the maximum (centerline) temperature excess at that location for each of the discharge cases analyzed.

Table 8 Centerline Temperature Excess (Above Ambient) at the Proposed Discharge Location as a Result of the Existing Vogtle Discharge

Discharge Case	River Temperature Increase 404 feet Downstream from Existing Discharge (°F)
Max-T	0.30
Max-ΔT	0.81
Min-ΔT	-0.32
Average	0.36

The existing discharge centerline temperature excess for the Average case exceeds that for the Max-T case. This reflects the temperature distribution of the former being narrower than that of the latter. If an average temperature excess over the width of the proposed plume were taken, the existing discharge component for the Max-T case would exceed that of the Average case. The use of centerline temperatures is conservative. Furthermore, as will be shown (see Table 9), the effects of the Average case are smaller than the others even with using the existing discharge centerline temperature excess.

Proposed Discharge Mixing Zone

As described previously (see Georgia Mixing Zone Regulations) the mixing zone is defined in terms of the 5°F temperature excess (increase above intake temperature or ambient) and 90°F river temperature. The centerline temperature increase from the existing discharge was added in each case to the ambient river temperature prior to simulating the proposed discharge effects. The mixing zone temperature excess for the proposed discharge was then defined by decrementing the required 5°F difference with the existing discharge component from Table 8; the proposed discharge 90°F isotherm (only applicable for the Max-T case) was defined based on the proposed discharge blowdown temperature and the ambient river temperature incremented as described.

Linear, areal, and volume characteristics of the mixing zone for the proposed discharge are given in Table 9.

Table 9 Proposed Discharge Mixing Zone Statistics

Case	Furthest downstream extent, ft from discharge	Furthest cross-stream extent, ft from discharge	Surface area (horizontal projection), ft^2	Cross-sectional area (vertical projection perpendicular to flow), ft^2	Volume, ft^3
5°F Temperature Increase Above Intake Temperature, 2 Cycles of Concentration					
Max-T	11.2	20.9	57.0	25.4	61.8
Max-ΔT	32.5	37.3	295.9	114.7	781.6
Min-ΔT	11.1	17.1	50.3	21.5	55.7
Average	5.4	10.0	13.4	6.0	7.4
5°F Temperature Increase Above Intake Temperature, 4 Cycles of Concentration					
Max-T	9.7	11.1	33.1	13.0	33.6
Max-ΔT	57.2	21.8	197.4	47.9	375.0
Min-ΔT	9.9	8.1	26.6	9.1	25.7
Average	2.1	2.2	2.2	1.7	0.8
90°F River Temperature					

Max-T (2 Cycles of Concentration)	2.6	6.3	2.0	0.9	0.2
Max-T (4 Cycles of Concentration)	2.2	4.3	1.3	0.6	0.2

The 2 Cycle, Max-ΔT case results in the largest mixing zone; this case corresponds to the maximum heat discharge to the river (see **Tower Operation/Discharge Parameters**). Even for this case, the mixing zone is demonstrably small. Allowing for approximately 20 feet between the river bank and the discharge port and adding the maximum cross-stream extent of 37 feet, less than 20% of the river width is impacted by the mixing zone and discharge structure. Approximately 11% of the bank to bank cross-sectional area of the river is impacted by the mixing zone and discharge structure (20 ft x 9 ft for the structure + 114.7 ft^2 for the heated water). The volume of water affected by the mixing zone, 782 ft^3, is less than 1% of the volume (290 ft x 9 ft, see Bathymetry, x 32.5 ft) in the river stretch from the discharge to its furthest downstream extent.

Figures 2 and 3 show the Max-ΔT mixing zone in the river for 2 and 4-Cycle operation, respectively. Note that the vertical axis is exaggerated in order to depict greater plume detail. The 4 Cycle mixing zone, although affecting less area and volume of water, extends further downstream than the 2 Cycle mixing zone. Although more heat is advected with the greater discharge flow of the latter, the lesser mechanical dispersion of the former caused by its lesser discharge velocity results in greater centerline temperatures.

The change in the 4-Cycle Max-ΔT mixing zone appearance approximately 40 to 50 feet along the plume trajectory reflects a flow regime change. In this region the plume is transitioning from a bottom attached near field jet (see Discharge Design) to a more quiescent plume that is lifting off the river bottom. As is evident in the plan view, the plume is nearly parallel to the river flow at this juncture.

Bottom Scour

The cooling water system will typically be operating at 4 Cycles of Concentration. The discharge velocity for such operation is in the range of 3.1 to 6.7 fps (minimum and maximum blowdown flow from Table 3 divided by the discharge port area). Such velocities are roughly comparable to normal river velocities. For example, the average river velocity is 2.3 fps. Because of these relatively low discharge velocities and rapid plume dilution, only minor scouring of the river bottom is expected.

During periods of 2 Cycle operation, discharge velocities will range from 9.4 to 20.1 fps (see Table 4 for blowdown flow range) and somewhat more scouring could be expected. In any case, such scouring will be localized, as exhibited in Figure 4. That figure depicts the stream cross-section at the existing discharge and 25 meters downstream from it. One can infer from that figure that scouring likely occurs right at the discharge; evidence of scouring is apparent neither 25 meters downstream nor about 10 meters across-stream from the discharge.

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