



PPL Bell Bend Nuclear Power Plant

Luzerne County, Salem Township, Pennsylvania



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BINDER 3

Additional Reports and SRBC Applications
Items 34-38

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an AREVA and Siemens company

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Susquehanna River Thermal Plume and Dilution Modeling Bell Bend Nuclear Power Plant

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17 June 2008

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RESPONSIBLE STAFF

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UNITS

Conventional units are used in the analysis (foot-pound-seconds) rather than SI units (meters-kilograms-seconds). Conventional units were used because nearly all the data sources use those units and because Pennsylvania water quality standards are also written in conventional units. For significant results, SI units are noted in parentheses.

Temperatures are denoted in °F, as in "the maximum Susquehanna River was observed to be 86.5 °F." Temperature differences are denoted in °F, as in "the maximum temperature rise is 33.8 °F."

1. OBJECTIVE

ERM's Surfacewater Modeling Group has been contracted by AREVA NP Inc. (AREVA), to compute the size and configuration of the thermal plume from the cooling tower blowdown discharge at the proposed Bell Bend Nuclear Power Plant (BBNPP) and to compute the dilution rates for this same discharge for various locations of interest.

Specifically, the assignment included the following tasks:

- Assemble relevant information
- Review applicable agency standards for thermal discharges
- Perform CORMIX computations for centerline dilution and lateral distribution
- Compute 50 mile dilution
- Provide dilution and travel time estimates at additional locations, namely
 - the nearest shoreline,
 - the maximum impacted shoreline,
 - the point on the shoreline where the site property ends,
 - the nearest recreational shore (beach),
 - the nearest public water supply intake, and
 - the plant's cooling water intakes for all units.
 - 50 ft from the discharge

2. METHODOLOGY

To compute the size and configuration of the thermal plume and provide the dilution rates at the specified locations identified by AREVA, two types of models were used. These models are CORMIX for the near-field and GEMSS for the far-field. To show the cumulative thermal effects of the BBNPP, the size and configuration of the thermal plume from the existing cooling tower blowdown discharge from the Susquehanna Steam Electric Station (SSES) was also computed.

Descriptions of the two models are presented in the following sections. Table 1 summarizes their characteristics (U.S. Atomic Energy Commission, 1974).

Table 1 Characteristics of the models

CORMIX		GEMSS
Field	(1) Near-field	(4) Complete-field
Dimension	Longitudinal	Yes
	Lateral	Yes
	Vertical	Yes
Mathematical approach	(1) Phenomenological	(3) Finite difference
Approximations	(not strictly applicable for phenomenological models)	(2) Boussinesq (3) Hydrostatic pressure
Model verification	Yes	Yes
Computer program	(1) Proprietary (must be purchased, source code unavailable)	(2) Available on request (open source but requires user registration to obtain)

2.1. CORMIX

The Cornell Mixing Zone Expert System (CORMIX) is primarily a design tool that has also been used by regulatory agencies to estimate the size and configuration of proposed and existing mixing zones resulting from wastewater discharges. CORMIX is a near-field model, i.e., it applies to the region adjacent to the discharge structure in which the wastewater plume is recognizable as separate from the ambient water and its trajectory is dominated by the discharge rate, effluent density, and geometry of the discharge structure. The CORMIX calculation is based on defining the various hydraulic zones an effluent plume traverses when introduced into a receiving water body, then applying an analytical solution or empirical relationship to compute the plume trajectory and dilution rate in each zone. Each of these analytical solutions and empirical relationships has been validated by the developers and other researchers against laboratory and field studies. CORMIX has been applied to many cases and is recognized by the USEPA as an appropriate model.

CORMIX v5.0GT (the latest version) was used for the BBNPP calculations (MixZon Inc. 2007).

CORMIX has several limitations. It assumes steady-state conditions and unidirectional, uniform flow in the receiving water body. Secondly, CORMIX has simplified geometric capabilities. It assumes an idealized water body with straight sides and a single, positive bottom slope or no slope at all. CORMIX cannot consider multiple discharge structures with overlapping plumes.

Because CORMIX does not apply to the far-field, which is the region in the receiving water body in which the ambient flow fields dominate the transport of wastewater, a three-dimensional hydrodynamic, transport, and fate model is generally used to compute the trajectory and dilution of the wastewater plume in the far-field.

2.2. GEMSS

The hydrodynamic model chosen to assess the far-field characteristics of the thermal plume and dilution is the Generalized Environmental Modeling System for Surface Waters (GEMSS[®]). GEMSS is an integrated system of 3-D hydrodynamic and transport modules embedded in a geographic information and environmental data system. GEMSS is in the public domain and has been used for similar studies throughout the USA and worldwide. ERM's Surfacewater Modeling Group has special expertise with the model in that ERM staff contributes to the source code and has completed many applications with the model.

GEMSS[®] includes a grid generator and editor, control file generator, 2-D and 3-D post processing viewers, and an animation tool. It uses a database approach to store and access model results. The database approach is also used for field data; as a result, the GEMSS viewers can be used to display model results, field data or both, a capability useful for understanding the behavior of the prototype as well as for calibrating the model. The field data analysis features can be used independently using GEMSS modeling capability.

GEMSS[®] was developed in the mid-1980's as a hydrodynamic platform for transport and fate modeling. The hydrodynamic platform (kernel) provides 3-D flow fields from which the distribution of various constituents can be computed. The constituent transport and fate computations are grouped into modules. GEMSS modules include thermal analysis, water quality, sediment transport, particle tracking, oil and chemical spills, entrainment, and toxics.

The theoretical basis of the hydrodynamic kernel of GEMSS is the three-dimensional Generalized, Longitudinal-Lateral-Vertical Hydrodynamic and Transport (GLLVHT) model which was first presented in Edinger and Buchak (1980) and subsequently in Edinger and Buchak (1985). The GLLVHT computation has been peer reviewed and published (Edinger and Buchak, 1995; Edinger, et al., 1994). The kernel is an extension of the well known longitudinal-vertical transport model that forms the hydrodynamic and transport basis of the Corps of Engineers' water quality model CE-QUAL-W2. Improvements to the transport scheme, construction of the constituent modules, incorporation of supporting software tools, GIS interoperability, visualization tools, graphical user interface (GUI), and post-processors have been developed by Kolluru et al. (1998; 1999; 2003a; 2003).

Applications of GEMSS[®] and its individual component modules have been accepted by regulatory agencies in the U.S. and Canada. GEMSS-based studies have been accepted by the U.S. Environmental Protection Agency (EPA), and state agencies including those of California, Massachusetts, Pennsylvania, Louisiana, Texas, New York, and Delaware. Washington State's Department of Ecology has adopted GEMSS as a tool for estuarine and water quality modeling. Most recently GEMSS has been published as a recommended three-dimensional hydrodynamic

and water quality model in studies funded by EPA and by the Water Environment Research Foundation (WERF).

GEMSS[®] has been used for ultimate heat sink analyses at Comanche Peak, Farley, and Arkansas Nuclear One. In Pennsylvania, it has been applied at PPL's Brunner Island Steam Electric Station on the lower Susquehanna River, Exelon's Cromby and Limerick Generating Stations on the Schuylkill River, and at several other electric power facilities. River applications for electric power facilities have been made on the Susquehanna (Brunner Island), the Missouri (LaGradie), the Delaware (Mercer and Gilbert), the Connecticut (Connecticut Yankee), and others.

A GEMSS[®] application requires two types of data: (1) spatial data, primarily the waterbody shoreline and bathymetry, but also the locations, elevations, and configurations of man-made structures and (2) temporal data, that is, time-varying boundary condition data defining tidal elevation, inflow rate and temperature, inflow constituent concentration, outflow rate, and meteorological data. All deterministic models, including GEMSS, require uninterrupted time-varying boundary condition data. There can be no long gaps in the datasets and all required datasets must be available during the span of the proposed simulation period.

For input to the model, the spatial data is encoded primarily in two input files: the control and bathymetry files. These files are geo-referenced. The temporal data is encoded in many files, each file representing a set of time-varying boundary conditions, for example, meteorological data for surface heat exchange and wind shear, or inflow rates for a tributary stream. Each record in the boundary condition files is stamped with a year-month-day-hour-minute address. The data can be subjected to quality assurance procedures by using GEMSS to plot, then to visually inspect individual data points, trends and outliers. The set of input files and the GEMSS[®] executable constitute the model application.

The theory, assumptions, and basis for applicability of GEMSS are presented in Appendix A: GEMSS Theory, Assumptions and Applicability. Inasmuch as the BBNPP is a proposed facility, the model has not been verified for this application by comparing computed and observed values.

3. DATASETS

The datasets used to apply CORMIX and GEMSS to the BBNPP site are described below.

3.1. SPATIAL DATA

The spatial data required for the near- and far-field models (CORMIX and GEMSS, respectively) are the Susquehanna River depths and widths (the bathymetry) and the location of the shoreline. For use in GEMSS, the spatial data are required to be geo-referenced to Pennsylvania State Plane North, ft.

The bathymetry and shoreline datasets were obtained from the US Army Corps of Engineers, Philadelphia District (USACE), who provided digital terrain maps (TINs), shoreline data in ARC/INFO interchange file format (e00), and cross-section data from their FEMA HEC-RAS model (Arañatzis, 2008). The transmittal letter contains a qualifier that "this data may not be suitable for other engineering design purposes." The data coverage was from River Mile 205 (Scranton) to River Mile 104 (Millersburg, halfway between Sunbury and Harrisburg). The BBNPP site is at River Mile 165. The cross-section data were converted to a point bathymetry file with an approximate spacing of 500 ft longitudinally. More spatially-detailed bathymetric contours in the immediate vicinity of the SSES intake and discharge were obtained from Pennsylvania Power and Light Company (1978), FIGURE 2.4-3.

The contours were digitized and geo-referenced and combined with the data obtained from the USACE. The combined dataset was used to create the GEMSS finite difference grid, shown in Figure 1. The grid extends from 4,500 ft upstream of the SSES intake to 15 miles downstream, with decreasing detail in the downstream direction. Typical horizontal resolution near the BBNPP site is 30 ft by 50 ft, and 85 ft by 5500 ft at the downstream end. The vertical layers (not shown) are 1 ft thick so that there are typically 8-12 layers representing the depth of the Susquehanna River near the BBNPP site.

Values of the depth and width for CORMIX's simpler representation of the Susquehanna in the vicinity of the BBNPP were also derived from the USACE and the Pennsylvania Power and Light Company (1978) FIGURE 2.4-3. The elevation of the bottom of the Susquehanna River at the BBNPP discharge was found to be at 476 ft. The CORMIX parameter values are shown in Table 2—the scenarios are introduced and discussed in Section 4.

Table 2 CORMIX bathymetric-related parameter values

Parameter	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Average depth, ft	11.5	10	13.8	10.8	13.8
Depth at the discharge, ft	11.5	10	13.8	10.8	13.8
Width, ft	750	680	790	720	790

3.2. BOUNDARY CONDITION DATA

Boundary condition data are used to estimate surface heat exchange at the water surface and to compute the flow of mass and energy entering and leaving the model domain. All simulations used steady values of the boundary condition data.

All values for the boundary conditions discussed in the following sections are summarized in Table 4.

To capture the seasonal behavior of the thermal plume, a summer and a winter period were chosen for simulation. Inasmuch as the boundary condition datasets are cataloged monthly, this approach required choosing a single month to represent these periods and obtaining the corresponding boundary condition data. The representative summer and winter months were chosen on the basis of the observed occurrences of the maximum and minimum temperature, described below.

Susquehanna River temperature and solids data

Ecology III has measured water temperatures 1620 ft upstream of the SSES intake structure on the west bank of the Susquehanna River daily beginning in 1974 (Ecology III, Inc., 2008). Maximum and minimum temperatures occur in August and January and these months were selected to be representative of summer and winter conditions. The maximum water temperature of 86.5 F was recorded on 15 Aug 1988 and 4 Aug 2007. A minimum water temperature of 32.0 F was recorded numerous times in January.

Total mineral solids (TMS) values for the Susquehanna River were obtained from Sargent & Lundy (2008), Att. 3, Table 4, using the SSES values for 2/23/2006 for winter and 8/16/2006 for summer.

Susquehanna River flow and water surface elevation data

Flow rates in the Susquehanna River are measured at United States Geological Survey (USGS) sites upstream of the BBNPP site at Wilkes-Barre (Station No. 01536500) and downstream of the site at Danville (Station No. 01540500). In addition there are several statistical summaries of low and mean flows at these stations. These summaries are discussed below.

USGS flow data and statistics for the stream gauges at Wilkes-Barre and at Danville are found at the USGS website http://waterdata.usgs.gov/pa/nwis/inventory/?site_no=01536500& and http://waterdata.usgs.gov/pa/nwis/inventory/?site_no=01540500&, respectively.

Screenshots of both are provided as Figure 2 and Figure 3. For the selected January and August simulations, mean and low flows at the site are required to show the extremes of the computed size of the thermal plume and the downstream dilution values. Data and statistics for the Wilkes-Barre gauge, upstream of the site, were used in this analysis.

Low flow frequency statistics generated by Pennsylvania Department of Environmental Protection (PA DEP) for the Wilkes-Barre gauge can be found at the PA DEP website

<http://pa.water.usgs.gov/pc38/flowstats/lowflow.ASP?WCI=stats&WCUID=2415>. A screenshot of the website is provided as Figure 4. This website provides a value of 890 cfs for the annual 7-day, 10-year low flow (7Q10) rate over the post-regulation period in the Susquehanna River, 1980 to 1996. This annual 7Q10 value was multiplied by the PA DEP's default multiplier to convert the annual 7Q10 to a monthly 7Q10 rate. The default multiplier for January is 3.2, and the default multiplier for August is 1.4 (PA DEP, 2003).

The monthly mean flows used in the simulations for January and August were derived from the historical record at the Wilkes-Barre stream gauge for the period 1980 to 1996. These data were retrieved from the USGS website referenced above for Wilkes-Barre. The monthly data are provided in Figure 5.

For each selected flow, the corresponding water surface elevation was obtained from the rating table presented as Attachment 7 in Ecology III (1991).

Meteorological data

To compute surface heat exchange, the coefficient of surface heat exchange (K) and equilibrium temperature (E) method was used. Monthly average and extreme values of K and E for National Weather Service sites in the USA are cataloged by the Environmental Protection Agency (Environmental Protection Agency, 1971). The nearest cataloged site to BBNPP is Avoca, Pennsylvania (WBAN 14777), 27 miles to the northeast. Other candidate sites considered for this study were located at Williamsport-Lycoming County Airport (WBAN 14778), which is 43 miles WNW of the site and at Penn Valley Airport, Selinsgrove (WBAN 14770) which is 43 miles WSW of the site. Values from the Avoca site were chosen because of its nearness to the BBNPP site.

For these simulations, the extreme values shown in FIGURE 104 (Environmental Protection Agency, 1971) were used.

Susquehanna Steam Electric Station (SSES) data

The location of the SSES intake and discharge structures was obtained from PP&L Drawing No. E105151. This drawing was scanned, digitized and geo-referenced to Pennsylvania State Plane North, ft. The general configuration and dimensions of the SSES discharge structure were obtained from Bechtel DRAWING No. C-95. The SSES intake structure was assumed to draw from the bottom of the Susquehanna River.

For implementation in CORMIX, the discharge structure-related parameter values are shown in Table 3.

Table 3 CORMIX discharge structure-related parameter values

CORMIX parameter	Value
Surface, single- or multi-port	Multi-port with 72 individual ports
Opening diameter, in	4
Horizontal angle, degrees	0
Vertical angle, degrees	45
Height, ft	0 (at river bottom)

The CORMIX variable height is the distance of the ports above the waterbody bottom. Bechtel DRAWING No. C-95 indicates rocks placed nearly to the height of the ports (15 in above the nominal bottom). For this calculation, it was assumed the ports are located at the bottom.

The SSES intake and discharge rates and temperature rise were obtained from PPL Susquehanna, LLC (2006) Page 4.1-1 and 4.1-2.

Total mineral solids (TMS) values for the SSES discharge were obtained from Sargent & Lundy (2008), Att. 3, Table 4, using the BLOW DOWN values for 2/23/2006 for winter and 8/16/2006 for summer. These values represent a concentration factor of about four times.

Bell Bend Nuclear Power Plant (BBNPP) data

The location of the BBNPP intake and discharge structures was obtained from Sargent & Lundy DRAWING NO. CSK-014, REV 1. The drawing contained the site utilization plan for BBNPP overlaid on the existing SSES site. The BBNPP discharge structure was assumed to be identical to the SSES discharge structure. The BBNPP intake structure was assumed to draw from the bottom of the Susquehanna River.

Maximum and average intake and discharge rates for the BBNPP were obtained from Sargent & Lundy (2008), Page 4 of 33.

Discharge temperature rises for BBNPP were derived as follows:

The discharge temperature rise for the summer (August) scenario was calculated by subtracting the maximum observed summer ambient temperature of 86.5 F from the 90 F discharge temperature provided by Sargent & Lundy (2008a). The 90 F discharge temperature represents Option 1, i.e., no auxiliary heat exchanger (Page 4), yielding a discharge temperature rise of 3.5 F.

The temperature rise for the winter (January) scenario was calculated as follows. First the discharge temperature was estimated by assuming the MDT1 option (conservative in that the approach temperature is higher than for the other options), then by choosing the January average wet bulb temperature of 23.8 F (Page 9, Sargent & Lundy, 2008a) and an approach temperature of 30 F (Fig. 6-1 of that same report), and finally by incrementing the latter by 6 F, as noted on Page 24 of that same report for the 90 F approach curve. The resulting discharge temperature for the January scenario is 65.8 F. The January ambient temperature was

subtracted from the January discharge temperature to obtain the discharge temperature rise of 33.8°F.

Total mineral solids (TMS) values for BBNPP discharge were assumed to be equal to the SSES values.

Table 4 Parameter values for the simulations

Parameter	Units	Winter	Source	Summer	Source
Month		January		August	
Extreme ambient temperature	F	32.0	Ecology III, Inc., 2008	86.5	Ecology III, Inc., 2008
Discharge temperature	F	65.8	Sargent & Lundy, 2008a	90.0	Sargent & Lundy, 2008
Temperature rise	°F	33.8	calculated	3.5	calculated
Discharge TMS	mg/l	556	Sargent & Lundy, 2008	642	Sargent & Lundy, 2008
Average intake rate	gpm	27,850	Sargent & Lundy, 2008	27,850	Sargent & Lundy, 2008
Maximum intake rate	gpm	34,460	Sargent & Lundy, 2008	34,460	Sargent & Lundy, 2008
Average discharge rate	gpm	9,290	Sargent & Lundy, 2008	9,290	Sargent & Lundy, 2008
Maximum discharge rate	gpm	11,170	Sargent & Lundy, 2008	11,170	Sargent & Lundy, 2008
Low Susquehanna River flow	cfs	2,848	PA DEP, 2003 / USGS website	1,246	PA DEP, 2003 / USGS website
Low Susquehanna River elevation	ft	486.8	Ecology III, Inc., 1991	486.0	Ecology III, Inc., 1991
Mean Susquehanna River flow	cfs	12,482	USGS website	4,473	USGS website
Mean Susquehanna River elevation	ft	489.8	Ecology III, Inc., 1991	487.5	Ecology III, Inc., 1991
Susquehanna river TMS	mg/l	134	Sargent & Lundy, 2008	196	Sargent & Lundy, 2008
Heat exchange coefficient (K)	BTU ft ² day ⁻¹ °F ⁻¹	58	Environmental Protection Agency, 1971	104	Environmental Protection Agency, 1971
Equilibrium Temperature (E)	F	34	Environmental Protection Agency, 1971	85	Environmental Protection Agency, 1971

4. SIMULATIONS AND RESULTS

Five scenarios were simulated with both CORMIX and GEMSS². The scenarios are summarized in Table 5 and consist of combinations of summer and winter mean and low Susquehanna River flow conditions. For each scenario, design values of the SSES and BBNPP intake and discharge rates, temperatures, and total dissolved minerals were used as shown in Table 5. Parameters common to all scenarios are shown in Table 4.

For both models, the term "excess temperature" is used. Excess temperature is the increase in temperature over background temperature (ambient or natural) due to a heated water discharge.

To show both the incremental impact of the BBNPP thermal plume as well as the cumulative impact of the combined SSES and BBNPP thermal plumes, two sets of simulations were made with GEMSS for each scenario. In the first set of simulations a single excess temperature was included in the model, the sources of which were the temperature rises for the SSES discharge and for the BBNPP discharge. This set of simulations showed the combined thermal plume for two discharges, i.e., the cumulative plume. The second set of simulations included only the BBNPP discharge as the source of excess temperature, but did include the SSES discharge to correctly model its effect on the ambient temperature. This set of simulations showed the thermal plume due solely to the BBNPP discharge, i.e., the incremental plume.

Including both discharges in a single CORMIX simulation is not possible because CORMIX is incapable of modeling two plumes simultaneously. For the near-field, only the BBNPP was modeled. This approach is satisfactory because in the near-field, the plumes do not overlap due to the 380 ft separation of the SSES and BBNPP discharges.

Table 5 Simulation summary with scenario descriptions

Parameter	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Description	Summer mean flow (August)	Summer low flow (August)	Winter mean flow (January)	Winter low flow (January)	Annual mean flow (January)
Susquehanna River flow, cfs	4,473	1,246	12,482	2,848	12,800
Water surface elevation, ft	487.5	486.0	489.8	486.8	489.8
Susquehanna River Temperature, F	86.5	86.5	32.0	32.0	32.0
SSES					
Temperature rise, deg F	12.5	12.5	31.0	31.0	31.0
Intake rate, gpm	42,300	42,300	42,300	42,300	42,300
Discharge rate, gpm	11,200	11,200	11,200	11,200	11,200
BBNPP					
Temperature rise, deg F	3.5	3.5	33.8	33.8	33.8
Intake rate, gpm	34,458	34,458	34,458	34,458	34,458
Discharge rate, gpm	11,172	11,172	11,172	11,172	11,172

4.1. THERMAL PLUME CONFIGURATION AND SIZE

The thermal plume was first modeled using CORMIX for the near-field region and then using GEMSS² for the far-field region. Use of these two models provides a detailed near-field plume configuration along with the far-field plume behavior for non-uniform channel geometry.

Near-field

CORMIX was used for near-field modeling of the thermal plume. The winter scenarios (Scenarios 3, 4 and 5) used an ambient river temperature of 32 F (0 C). CORMIX has an inherent limitation that requires that the ambient temperature be at least 39.2 F (4 C). In CORMIX, the ambient temperature is used to compute density and to establish the buoyancy differential between the effluent and ambient water. Since water has its maximum density at 4 C which decreases with both increasing and decreasing temperature, there are temperatures above 39.2 F with densities identical to temperatures below this value. In this case 46 F (7.8 C) has a density identical to the density of water at 32 F. This temperature was used in the winter CORMIX simulations.

The BBNPP discharge structure was assumed to be identical in configuration to the SSES diffuser. The ambient and effluent characteristics were taken directly from Table 2 through Table 5 and the discharge was modeled in CORMIX as a heated discharge using the heat loss coefficients listed in Table 5. The near-field plumes from the five scenarios are shown in Figure 6 for Scenario 1, Figure 7 for Scenario 2, Figure 8 for Scenario 3, Figure 9 for Scenario 4, and Figure 10 for Scenario 5. Note that CORMIX automatically sets the spatial scaling and thus the scales varies from one diagram to the next. The wide discharge line passing through the origin (0,0,0) along the y-axis depicts the diffuser of length 108 ft in all these diagrams.

Scenario 2 with the smallest Susquehanna River flow has the largest near-field plume as there is limited mixing near the diffuser, resulting in an expanded near-field region. Scenario 4 has the plume with the highest peak temperature due to the largest temperature rise (33.8°F) combined with the lowest Susquehanna River flow. During the summer period, Scenario 2 has the plume with the higher peak temperature due to lower Susquehanna River flow compared to Scenario 1. The excess temperature values in the near-field along the downstream distance for all five scenarios are shown in Figure 11.

In the near-field, the excess temperature decreases to small values due to rapid mixing. During the summer period, the discharge has an excess temperature of 3.5°F (1.9°C) which decreases to 0.13°F (0.07°C) and to 0.29°F (0.16°C) within 50 ft of the discharge for Scenarios 1 and 2, respectively. The winter period shows excess temperatures decreasing to 0.5°F (0.3°C), 1.75°F (0.97°C) and 0.5°F (0.3°C) for Scenarios 3, 4 and 5, respectively at 50 ft.

It is also desirable to compute the surface area and volume of the plume at different temperature rise isotherms. These areas and volumes provide an estimate of how much of the waterbody is affected by the thermal discharge. Figure 12 shows the area of the plume and Figure 13 shows the volume of the plume for the five scenarios against the temperature rise on the x-axis. A larger area (and volume) of the waterbody is impacted at lower temperature rise levels. These areas and volumes decrease with increasing temperature rise levels. A summary of these plots is shown in Table 6 which lists the areas and volumes for preset temperature rise levels.

Table 6 Near-field plume area (ft²) and volume (ft³)

Excess, °F	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5	
	Area	Volume	Area	Volume	Area	Volume	Area	Volume	Area	Volume
10	-	-	-	-	98	12.8	118	15.4	91	12.0
5	-	-	-	-	118	15.5	569	305.7	110	14.4
3	21	2.8	26	3.4	152	27.6	1739	2851.5	133	21.9
2	67	8.8	83	10.9	352	136.8	4034	15759.5	314	118.3
1	113	14.8	296	89.8	1462	2358.6	Not achieved in near-field	Not achieved in near-field	1285	1960.4

Table 7 Near-field plume area (m²) and volume (m³)

Excess, °C	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5	
	Area	Volume	Area	Volume	Area	Volume	Area	Volume	Area	Volume
5.6	-	-	-	-	9	1.2	11	1.4	8	1.1
2.8	-	-	-	-	11	1.4	53	28.4	10	1.4
1.7	2	0.3	2	0.3	14	2.6	162	264.9	12	2.0
1.1	6	0.8	8	1.0	33	12.7	375	1464.1	29	11.0
0.6	10	1.4	28	8.4	136	219.1	Not achieved in near-field	Not achieved in near-field	119	182

Far-field

GEMSS[®] was set up to model the far-field thermal plume emerging from the BBNPP discharge for the five scenarios. All five scenarios were run under two different setups to capture both the

cumulative and incremental thermal plume. The first setup included both the SSES and BBNPP discharges as excess temperature sources while the second setup included only the BBNPP discharge as an excess temperature source. This approach facilitated studying the thermal plume from BBNPP combined with the SSES thermal plume as well as studying it separately.

Scenarios 2 and 4 represent the low flow conditions during summer and winter periods, respectively. In general, during these conditions, the thermal plume is able to spread out due to decreased ambient velocities. The diffuser is closer to the western shore and thus Scenarios 1 and 3, which represent the mean flow conditions for summer and winter respectively, show that the thermal plume is pushed towards the western shore due to higher ambient velocities. Scenario 5, which is similar to Scenario 3, exhibits similar plume characteristics. This process, however, does not decrease the overall mixing of the discharge because during the high flow periods there is more water available to mix and the river surface elevations are higher.

The cumulative impacts of the SSES and the BBNPP for the surface and bottom thermal plumes are shown in Figure 14 and Figure 15 for Scenario 1, Figure 18 and Figure 19 for Scenario 2, Figure 22 and Figure 23 for Scenario 3, Figure 26 and Figure 27 for Scenario 4, and finally in Figure 30 and Figure 31 for Scenario 5. During the summer period, the excess temperature from BBNPP is small (3.46°F). However, the thermal plume at the bottom shows excess temperatures greater than the BBNPP temperature rise because the temperature rise from the SSES discharge is large (12.5°F). The extent of this combined thermal plume, however, is very small. The surface excess temperatures are less than 0.2°F (0.1°C) for Scenario 1, less than 0.8°F (0.4°C) for Scenario 2, less than 0.6°F (0.3°C) for Scenario 3, less than 0.6°F (0.3°C) for Scenario 4 and less than 0.6°F (0.3°C) for Scenario 5. Since the discharge is located near the river bottom, the combined thermal plume near the bottom shows a slightly increased maximum excess temperature with less than 2.7°F (1.5°C) for Scenario 1, less than 3.0°F (1.7°C) for Scenario 2, less than 13.5°F (7.5°C) for Scenario 3, less than 25.0°F (13.9°C) for Scenario 4 and less than 13.5°F (7.5°C) for Scenario 5. The extent of these plumes at the bottom are, however, very small (2.7°F contour for Scenario 1 near BBNPP discharge is only 75 ft). Both mean flow simulations (Scenario 1 and Scenario 3) have lower maximum excess temperature compared to their respective low flow counterparts for the period (Scenario 2 and Scenario 4). The plumes for Scenario 1, Scenario 3 and Scenario 5 are pushed against the western shoreline while the plumes for Scenario 2 and Scenario 4 are more spread out laterally. Scenario 5 (also Scenario 3 which is very similar) has the highest river flow which pushes the plume further towards the western shoreline compared to the other scenarios and, when combined with the shallow, near-shore bathymetry produces a small recirculation eddy that helps replace the water withdrawn from the intakes. This phenomenon results in the thermal plume extending upstream as seen in Figure 30 and Figure 31.

The second setup shows the thermal plume attributable only to the BBNPP discharge, i.e., the incremental impact. Under this setup the thermal plumes for the summer period are considerably smaller (Figure 16 and Figure 17 for Scenario 1 and Figure 20 and Figure 21 for Scenario 2) as the BBNPP discharge has a small excess temperature (3.5°F). During the winter period, the BBNPP excess temperature from the discharge is higher at 33.8°F (18.8°C). The maximum excess temperature seen at the surface are at less than 0.04°F (0.02°C) for Scenario 1, less than 0.3°F (0.2°C) for Scenario 2, less than 0.35°F (0.20°C) for Scenario 3, less than

0.3°F (0.2°C) for Scenario 4 and less than 0.35°F (0.20°C) for Scenario 5. The bottom excess temperatures are, however, in the same range as the combined thermal plume with maximum values at less than 2.5°F (1.4°C) for Scenario 1, less than 3.0°F (1.7°C) for Scenario 2, less than 13.0°F (7.2°C) for Scenario 3, less than 25.0°F (13.9°C) for Scenario 4 and less than 13.0°F (7.2°C) for Scenario 5. The plumes are shown in Figure 24 and Figure 25 for Scenario 3, Figure 28 and Figure 29 for Scenario 4, and Figure 32 and Figure 33 for Scenario 5. The extent of the bottom plume is very small (the 0.25°F contour is only 400 ft from the discharge for Scenario 1, 0.30°F is only 300 ft from the discharge for Scenario 2, 1.3°F is only 600 ft from the discharge for Scenario 3, 2.5°F is only 650 ft from the discharge for Scenario 4 and 1.3°F is only 580 ft from the discharge for Scenario 5).

4.2. PENNSYLVANIA STANDARDS

Pennsylvania provides the following criteria for temperature (Pa. Code, Chapter 93. Water Quality Standards, §93.7. Specific water quality criteria):

Maximum temperatures in the receiving water body resulting from heated waste sources are regulated under Chapters 92, 96 and other sources where temperature limits are necessary to protect designated and existing uses. Additionally, these wastes may not result in a change of more than 2°F during a 1-hour period.

The protected water use for the Susquehanna River adjacent to BBNPP is Warm Water Fishery (WWF), as shown in Pa. Code, Chapter 93. Water Quality Standards, §93.9k. Drainage List K as WWF (Warm Water Fishes Maintenance and propagation of fish species and additional flora and fauna which are indigenous to a warm water habitat) for the reach from the Lackawanna River to West Branch Susquehanna River. The WWF temperatures and temperatures for two other protected uses are presented in Table 8. These values represent the maximum allowable water temperatures at an unspecified distance downstream of the discharge where fully-mixed conditions occur.

Table 8 Protected use receiving water body temperatures, F

CWF=Cold Water Fishes WWF=Warm Water Fishes TSF=Trout Stocking

SYMBOL:	TEMP ₁	TEMP ₂	TEMP ₃
CRITICAL USE:	CWF	WWF	TSF
PERIOD			
January 1-31	38	40	40
February 1-29	38	40	40
March 1-31	42	46	46
April 1-15	48	52	52
April 16-30	52	58	58
May 1-15	54	64	64
May 16-31	58	72	68
June 1-15	60	80	70
June 16-30	64	84	72
July 1-31	66	87	74
August 1-15	66	87	80
August 16-30	66	87	87
September 1-15	64	84	84
September 16-30	60	78	78
October 1-15	54	72	72
October 16-31	50	66	66
November 1-15	46	58	58
November 16-30	42	50	50
December 1-31	40	42	42

The SSES NPDES permit does not contain specific discharge temperature limits (PPL Susquehanna, LLC, 2006a), although the station is required to meet WWF water temperatures (Table 8) and to limit temperature changes to 2°F per hour.

Experience with other sites and an examination of the language in the PA DEP guidance document (PA DEP, 2003) indicates PA DEP may include in the NPDES permit for BBNPP an end-of-pipe limit of 110 F and a heat load limit based on the difference between ambient temperature and the critical use temperatures shown in Table 8. Because actual limits are set when the NPDES permit is issued, no definitive statement can be made regarding the thermal discharge limits that will be set for the BBNPP, except to note that SSES does not have either the 110 F or the heat load limit. In developing the NPDES permit conditions for BBNPP, PA DEP may choose to consider the cumulative effects of the combined SSES and BBNPP thermal.

Because the WWF temperature limits vary by season as shown in Table 8, limiting slowdown temperatures to less than the maximum WWF temperature of 87 F does not guarantee that the system will be in compliance with WWF temperatures at other times. To assess compliance at seasonal extremes, additional near-field simulations were made to determine the size of the thermal plume under conditions when slowdown temperatures are at a maximum and Susquehanna River temperatures are at a minimum, yielding the maximum temperature rise in the River. These simulations utilized average Susquehanna River flows to represent a severe, but not extreme, case. The comparison metric is the distance along the centerline downstream of the BBNPP discharge where WWF temperatures are attained. These distances are shown in Table 9. In this table, the slowdown temperature rise is the difference between the slowdown temperature and the WWF ambient stream temperature (PPL Susquehanna, LLC, 2006a). The

WWF ambient stream temperature is an assumed natural temperature typically used by the PA DEP in computing waste heat load allocations. The target excess temperature in Table 9 is the difference between the WWF ambient temperature and the WWF temperature limit; this difference represents the excess temperature isotherm at which the WWF temperature limit is attained.

Table 9 Extreme period analysis of plume size

Period	WWF, F	WWF ambient, F	Blowdown temperature, F	Blowdown temperature rise, °F	Target excess temperature for compliance, °F	Centerline distance to WWF, ft
January 1-31	40	35	65.8	30.8	5.0	1.0
July 1-31	87	75	90	15.0	12.0	0.3
August 1-15	87	74	90	16.0	13.0	0.3
August 16-30	87	74	90	16.0	13.0	0.3

Centerline distances are very small and none of the target excess temperature contours reach the water surface. The results of this calculation indicate that BBNPP blowdown plume will be in compliance with WWF temperatures during other WWF periods.

4.3. DILUTION RESULTS

Using the near-field and far-field models, dilution of a numerical, non-decaying dye representing only the BBNPP discharge was computed along with the thermal plume. The dye was released at a nominal concentration of 100 mg/l. The results are reported as "dilution" defined as in Equation 1 where $C_{Discharge}$ is the concentration of dye released from the discharge (100 mg/l) and C is the concentration at a particular location of interest. To obtain the concentration of any other constituent at a location at which dilution is available, Equation 2 can be used.

Equation 1

$$Dilution = \frac{C_{Discharge}}{C}$$

Equation 2

$$C = \frac{C_{Discharge}}{Dilution}$$

Near-field

CORMIX simulations for thermal plume provided near-field dilution values. These dilution values are shown in Figure 34 and in Table 10 for all five scenarios. Note that Scenario 2 has the lowest dilution as this is the scenario with the lowest Susquehanna River flow while Scenario 3 has the highest dilution due to high Susquehanna River flow. The dilution values range from 11 to 70 near the end of the near-field region. Any subsequent dilution occurs in the far-field region and was modeled using GEMSS.

Table 10. Near-field dilution values

Scenario	Dilution (50) from BBNPP Discharge
Scenario 1	26.9
Scenario 2	11.8
Scenario 3	67
Scenario 4	19.2
Scenario 5	68.7

Far-field

The far-field dilution values obtained from GEMSS[®] at different locations of interest (shown in Figure 35) are listed in Table 15, shown in Section 7 Landscape-formatted tables and figures. The model was run for a period of 21 days which was sufficient to achieve a steady state. The numerical dye used to compute dilution values eventually spreads across the entire cross-section of the river resulting in fully-mixed conditions. The distance at which these fully-mixed conditions are achieved varies with different scenarios and is also listed in Table 11. All locations beyond this fully-mixed region will have same fully-mixed concentration that can be computed using Equation 3. Figure 36 shows the fully-mixed concentrations obtained from GEMSS[®] for the five scenarios. The italicized numbers on the plots show values computed from Equation 3 for these scenarios. Equation 4 shows an example calculation for Scenario 1.

Equation 3

$$C_{FullyMixed} = \frac{C_{River} \cdot Q_{River} + C_{BBNPP} \cdot Q_{BBNPP}}{Q_{River} + Q_{BBNPP}}$$

Equation 4

$$C_{FullyMixed} = \frac{0.000000000 + 0.000000000}{0.000000000 + 0.000000000} = 0.000 \text{ mg/l}$$

Scenario 2 again has the highest fully-mixed concentration and the lowest dilution while Scenario 3 has the lowest fully-mixed concentration and the highest dilution.

Table 11 Distance from BBNPP discharge

Location	Distance from the BBNPP discharge (ft)	Distance from the BBNPP discharge (m)
SSES cooling water intake	1050	320
BBNPP cooling water intake	650	198
Nearest Shoreline	300	91
Maximum impacted shoreline	Scenario dependent (see Table 15)	Scenario dependent (see Table 15)
Property boundary	330	101
S Hicks Ferry Rd	3250	991
Fully-mixed	Scenario dependent (see Table 15)	Scenario dependent (see Table 15)
Public water supply intake (Danville)	158,400	48,280
Recreational shore (Sunbury)	264,000	80,467

4.4. TRAVEL TIMES

For the near-field, CORMIX provided the travel time for the peak to reach a distance 50 ft from the discharge. For the far-field, travel times were computed by releasing a numerical dye from the BBNPP discharge structure, then determining its arrival time at the locations of interest with GEMSS. The dye was released over a 1-hour duration at a concentration of 100 mg/l. The concentrations of the dye were then studied at the locations listed in Table 11 to obtain the time of arrival of the peak concentration. The arrival time was used to compute the travel time from the BBNPP discharge.

Near-field

As stated, CORMIX provided the travel times for the spill to reach a distance 50 ft from the discharge. Travel times for the five scenarios in the near-field are listed in Table 12. Scenario 3 with the highest Susquehanna River flow rate has the shortest travel time of 45 seconds, while Scenario 2 with the lowest Susquehanna River flow rate has the longest travel time of 110 seconds.

Table 12 Near-field travel times obtained from CORMIX simulations

Scenario	Travel Time (minutes)	Travel Time (seconds)
Scenario 1	1.38	83
Scenario 2	1.83	110
Scenario 3	0.75	45
Scenario 4	1.63	98
Scenario 5	0.74	44

Far-field

The 1-hour dye release from the BBNPP discharge was simulated and then the concentrations at various locations were studied to detect the passage of the peak concentration. The

difference in times between the release and the peak at these locations was used to estimate the travel time to these locations. Locations downstream of the GEMSS grid were also beyond the fully-mixed location as seen in Table 11. Thus, the travel times to these locations were computed by adding the time needed to travel to these locations from fully-mixed location using the average flow velocity and the time taken to reach the fully-mixed location as shown in Equation 5 and Equation 6. The travel times to these locations are listed in Table 13 in hours and in Table 14 in minutes.

As was the case for the near-field times, the travel times are usually shortest for Scenario 3 and longest for Scenario 2. However, there are two locations (nearest the shoreline and nearest the property boundary) where Scenario 4 has the longest travel time. This result is due to the plume configuration and the location of interest relative to the discharge. Scenario 4 has a higher Susquehanna River flow rate than Scenario 2. The higher rate pushes the plume further downstream. The near-shore and property boundary locations are close to the discharge and thus the plume takes longer to get to these locations once it has been pushed away from the BBNPP discharge.

Equation 5

$$TravelTime_{Loc} = Time_{FullyMixed} + \frac{D_{Loc} - D_{FullyMixed}}{u_{avg}}$$

Equation 6

$$u_{avg} = \frac{Q_{Riv}}{CSArea_{Riv}}$$

$TravelTime_{Loc}$ = travel time to the location of interest

$Time_{FullyMixed}$ = travel time to the fully-mixed location

D_{Loc} and $D_{FullyMixed}$ = distance to the location of interest and fully-mixed location

$CSArea_{Riv}$ and Q_{Riv} = cross-sectional area and flow rate for Susquehanna River

Table 13 Travel times (hours) for various locations of interest

Location		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
SSES cooling water intake	Surface	2.92	6.67	2.08	5.58	2.00
	Bottom	3.08	7.00	2.08	5.42	2.00
BBNPP cooling water intake	Surface	2.33	3.58	1.67	4.83	1.58
	Bottom	2.33	3.83	1.58	4.83	1.50
Nearest Shoreline	Surface	1.92	1.33	1.17	2.58	1.17
	Bottom	1.92	1.42	1.08	2.25	1.08
Property Boundary	Surface	1.67	1.17	1.08	2.25	1.08
	Bottom	1.67	1.17	1.00	1.92	1.00
Maximum impacted shoreline	Surface	2.08	5.50	1.25	3.50	1.25
	Bottom	2.17	5.75	1.33	2.83	1.25
S Hicks Ferry Rd	Surface	2.08	3.08	1.42	2.50	1.42
	Bottom	2.08	3.58	1.42	2.67	1.42
Public water supply intake (Danville)	Surface	154	480	64	220	63
	Bottom	154	480	64	220	63
Recreational shore (Sunbury)	Surface	290	925	119	420	117
	Bottom	290	925	119	420	117

Table 14 Travel times (minutes) for various locations of interest

Location		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
SSES cooling water intake	Surface	175	400	125	335	120
	Bottom	185	420	125	325	120
BBNPP cooling water intake	Surface	140	215	100	290	95
	Bottom	140	230	95	290	90
Nearest Shoreline	Surface	115	80	70	155	70
	Bottom	115	85	65	135	65
Property Boundary	Surface	100	70	65	135	65
	Bottom	100	70	60	115	60
Maximum impacted shoreline	Surface	125	330	75	210	75
	Bottom	130	345	80	170	75
S Hicks Ferry Rd	Surface	125	185	85	150	85
	Bottom	125	215	85	160	85
Public water supply intake (Danville)	Surface	9240	28800	3840	13200	3780
	Bottom	9240	28800	3840	13200	3780
Recreational shore (Sunbury)	Surface	17400	55500	7140	25200	7020
	Bottom	17400	55500	7140	25200	7020

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6. PORTRAIT-FORMATTED FIGURES

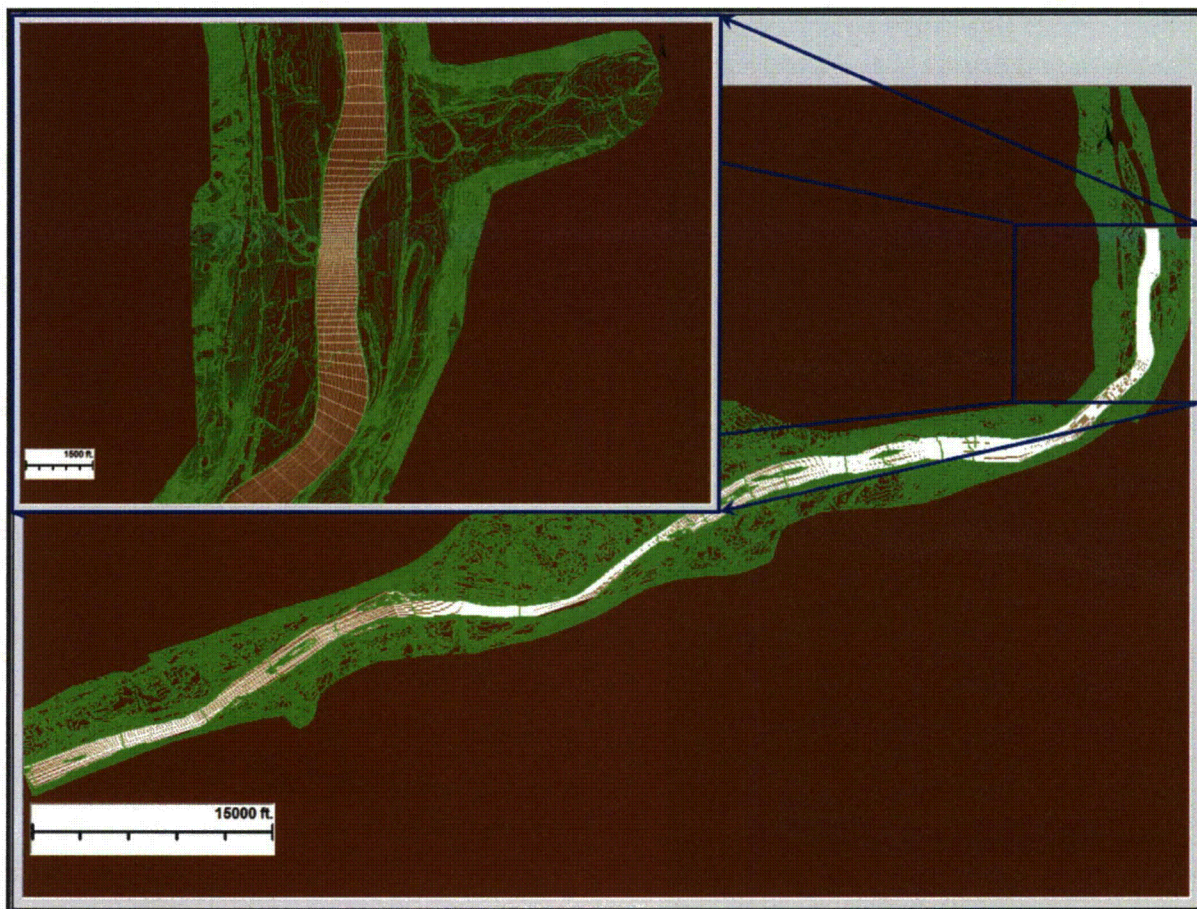



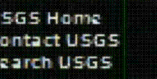


Figure 1 GEMSS finite difference grid

The green lines are surface contours.

National Water Information System: Web Interface

USGS Water Resources

Data Category:
Site Information

Geographic Area:
Pennsylvania

GO

New! Subscribe to [NWISWeb notifications](#)

USGS 01536500 Susquehanna River at Wilkes-Barre, PA

Available data for this site

SUMMARY OF ALL AVAILABLE DATA

GO

Stream/River Site

LOCATION
Latitude 41°15'03", Longitude 75°52'52" NAD27
Luzerne County, Pennsylvania , Hydrologic Unit 02050107

DESCRIPTION
Drainage area: 9,960 square miles
Datum of gage: 510.86 feet above sea level NAVD88.

AVAILABLE DATA:


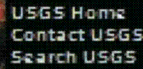
Data Type	Begin Date	End Date	Count
Real-time	This is a real-time site		
Daily Data			
Discharge, cubic feet per second	1899-04-01	2008-04-27	39838
Daily Statistics			
Discharge, cubic feet per second	1899-04-01	2007-09-30	39629
Monthly Statistics			
Discharge, cubic feet per second	1899-04	2007-09	
Annual Statistics			
Discharge, cubic feet per second	1899	2007	
Peak streamflow	1786-10-05	2007-03-16	122
Field measurements	1899-03-30	2008-04-11	752
Field/Lab water-quality samples	1963-10-17	2007-03-19	10

OPERATION:
Record for this site is maintained by the USGS Pennsylvania Water Science Center
Email questions about this site to [Pennsylvania Water-Data Inquiries](#)

ADDITIONAL INFORMATION

STATION.--01536500 SUSQUEHANNA RIVER AT WILKES-BARRE,
PA

Figure 2 USGS Station No. 01536500 (Susquehanna River at Wilkes-Barre) information sheet

National Water Information System: Web Interface

[USGS Water Data](#)
Data Category:
Geographic Area:

New! [Subscribe to NWISWeb notifications](#)

USGS 01540500 Susquehanna River at Danville, PA

Available data for this site:

Stream/River Site

LOCATION
Latitude 40°57'29", Longitude 76°37'10" NAD27
Montour County, Pennsylvania , Hydrologic Unit 02050107

DESCRIPTION
Drainage area: 11,220 square miles
Datum of gage: 431.29 feet above sea level NGVD29.

AVAILABLE DATA:

Data Type	Begin Date	End Date	Count
<u>Real-time</u>	This is a real-time site		
<u>Daily Data</u>			
Temperature, water, degrees Celsius	1945-10-01	1976-09-30	7126
Discharge, cubic feet per second	1905-04-01	2008-04-27	37648
Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius	1945-10-01	1976-09-30	6164
Suspended sediment concentration, milligrams per liter	1962-03-13	1976-09-30	932
Suspended sediment discharge, tons per day	1962-03-13	1976-09-30	932
<u>Daily Statistics</u>			
Discharge, cubic feet per second	1905-04-01	2007-09-30	37438
Suspended sediment concentration, milligrams per liter	1962-03-14	1976-09-30	931
Suspended sediment discharge, tons per day	1962-03-14	1976-09-30	931
<u>Monthly Statistics</u>			
Discharge, cubic feet per second	1905-04	2007-09	
Suspended sediment concentration, milligrams per liter	1962-03	1976-09	
Suspended sediment discharge, tons per day	1962-03	1976-09	
<u>Annual Statistics</u>			
Discharge, cubic feet per second	1905	2007	
Suspended sediment concentration, milligrams per	1962	1976	

Figure 3 USGS Station No. 01540500 (Susquehanna River at Danville) information sheet



Low-Flow Statistics for Pennsylvania Streams

Developed by the U.S. Geological Survey for the Pennsylvania Department of Environmental Protection



Pennsylvania Low-Flow Statistics - Query Results

LOW-FLOW STATISTICS

[All flow statistics in cubic feet per second (ft³/s)]

Mouse over or click on table headings to view definition of statistic

STREAM NAME: Susquehanna River
GAGE OR BRIDGE SITE: bridge
REFERENCE GAGE: 01536500

COUNTY: Luzerne
USGS QUAD: Wilkes-Barre West

LATITUDE: 411456
LONGITUDE: 755307
DRAINAGE AREA (sq. mi.): 9960

Entire Period of Record ²	<u>Q₁₋₁₀</u>	<u>Q₂₋₁₀</u>	<u>Q₅₋₁₀</u>	<u>MEAN</u>	<u>MEDIAN</u>	<u>HARMONIC MEAN</u>
1980-96	841	890	1070	12800	8820	4520

FLOW DURATION TABLE (Probability of Exceedance)									
P5	P10	P20	P30	P40	P50	P60	P70	P80	P90
40800	34110	21040	15610	11830	8820	6870	5220	3580	2300

¹ Reference Gage indicates which USGS gage was used in the computation of lowflow statistics for the specified locations

² Period of Record for climatic year, April 1 through March 31

³ Period of record refers to pre-regulation conditions

⁴ Period of record refers to post-regulation conditions

** Statistic not computed due to insufficient data

[RETURN TO PREVIOUS PAGE](#)

[RETURN TO START PAGE](#)

This system designed and developed by the U.S. Geological Survey, Water Resources Division, New Cumberland, Pa. © 2002.

Figure 4 Low flow statistics at Wilkes-Barre

USGS Surface-Water Monthly Statistics for the Nation

The statistics generated from this site are based on approved daily-mean data and may not match those published by the USGS in official publications. The user is responsible for assessment and use of statistics from this site. For more details on why the statistics may not match, [click here](#).

USGS 01536500 Susquehanna River at Wilkes-Barre, PA

Available data for this site: Time-series: Monthly statistics

Luzerne County, Pennsylvania
Hydrologic Unit Code 02050107
Latitude 41°15'03", Longitude 75°52'52" NAD27
Drainage area 9,960 square miles
Gage datum 510.86 feet above sea level NAVD88

Output formats

[HTML table of all data](#)
[Tab-separated data](#)
[Real-time output format](#)

00060, Discharge, cubic feet per second, Monthly mean in cfs (Calculation Period: 1980-01-01 -> 1996-12-30)												
YEAR	Period-of-record for statistical calculation restricted by user											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1980	7,779	3,326	31,090	37,530	11,500	3,701	4,497	1,975	1,152	1,762	4,645	7,363
1981	2,290	40,790	12,550	11,970	15,020	8,667	3,694	2,535	3,769	14,000	16,970	11,510
1982	10,240	16,870	32,180	30,600	7,935	20,780	7,588	2,458	1,339	1,267	3,487	8,053
1983	6,995	18,160	19,070	51,430	31,020	8,614	3,637	1,877	1,171	1,338	5,446	34,770
1984	5,548	36,800	15,660	50,110	31,200	14,800	10,800	7,481	3,254	1,995	4,493	19,310
1985	9,432	8,889	21,270	14,260	5,520	3,692	2,828	1,806	4,752	6,413	17,260	17,210
1986	12,160	18,620	42,820	21,230	10,770	11,930	6,083	8,627	2,581	6,454	21,960	20,430
1987	8,313	4,682	24,780	35,420	6,451	4,690	5,725	2,001	8,459	5,971	8,365	14,200
1988	6,334	16,060	19,730	13,220	19,150	4,155	2,357	1,985	3,293	2,888	12,090	5,955
1989	5,107	7,206	13,360	25,890	38,140	24,420	6,988	2,695	3,167	8,989	14,190	5,239
1990	14,550	37,320	17,650	22,600	21,320	6,815	5,823	3,874	2,957	24,180	22,160	28,540
1991	20,800	19,540	27,590	21,420	10,990	2,712	1,311	1,346	1,209	1,919	5,246	11,190
1992	12,460	8,367	24,330	26,780	14,270	10,660	6,203	10,040	7,683	9,541	22,580	15,820
1993	23,150	5,857	22,170	100,000	12,800	4,445	2,039	1,589	2,166	3,162	16,940	19,600
1994	6,917	17,430	43,670	61,030	11,450	11,680	9,344	19,560	7,105	5,358	10,760	18,080
1995	19,380	8,199	20,670	14,180	6,508	4,091	1,841	1,352	1,079	9,809	15,750	10,600
1996	40,740	19,470	21,020	32,350	36,730	8,321	8,785	4,846	4,778	13,040	29,540	44,610
Mean of monthly Discharge	12,500	16,900	24,100	33,500	17,100	9,070	5,270	4,470	3,520	6,950	13,600	17,200

** No Incomplete data have been used for statistical calculation

Figure 5 Monthly statistics at Wilkes-Barre

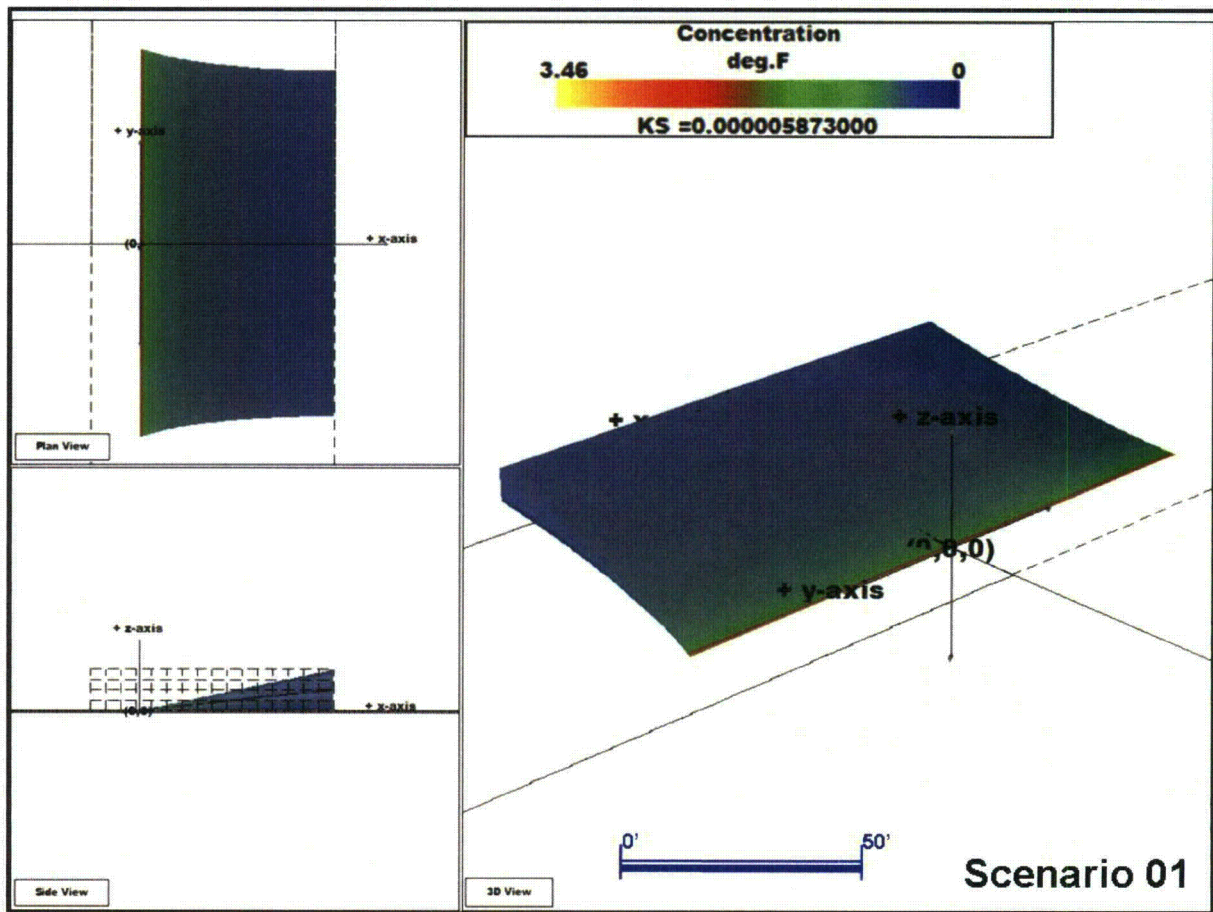


Figure 6 Near-field thermal plume orientation and size for Scenario 1

Scenario 1 is summer mean flow. The CORMIX graphical engine automatically scales diagrams—scales vary from one figure to the next.

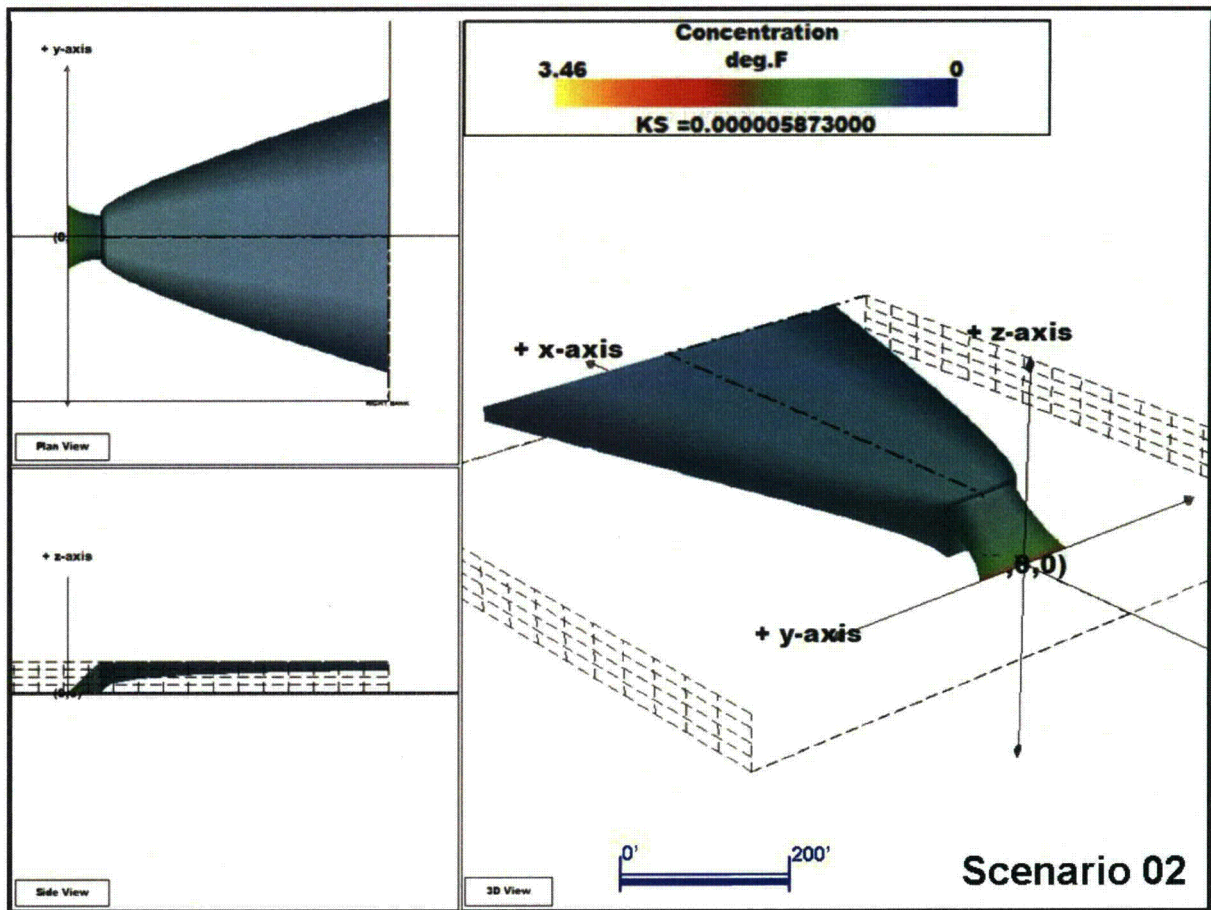


Figure 7 Near-field thermal plume orientation and size for Scenario 2

Scenario 2 is summer low flow.

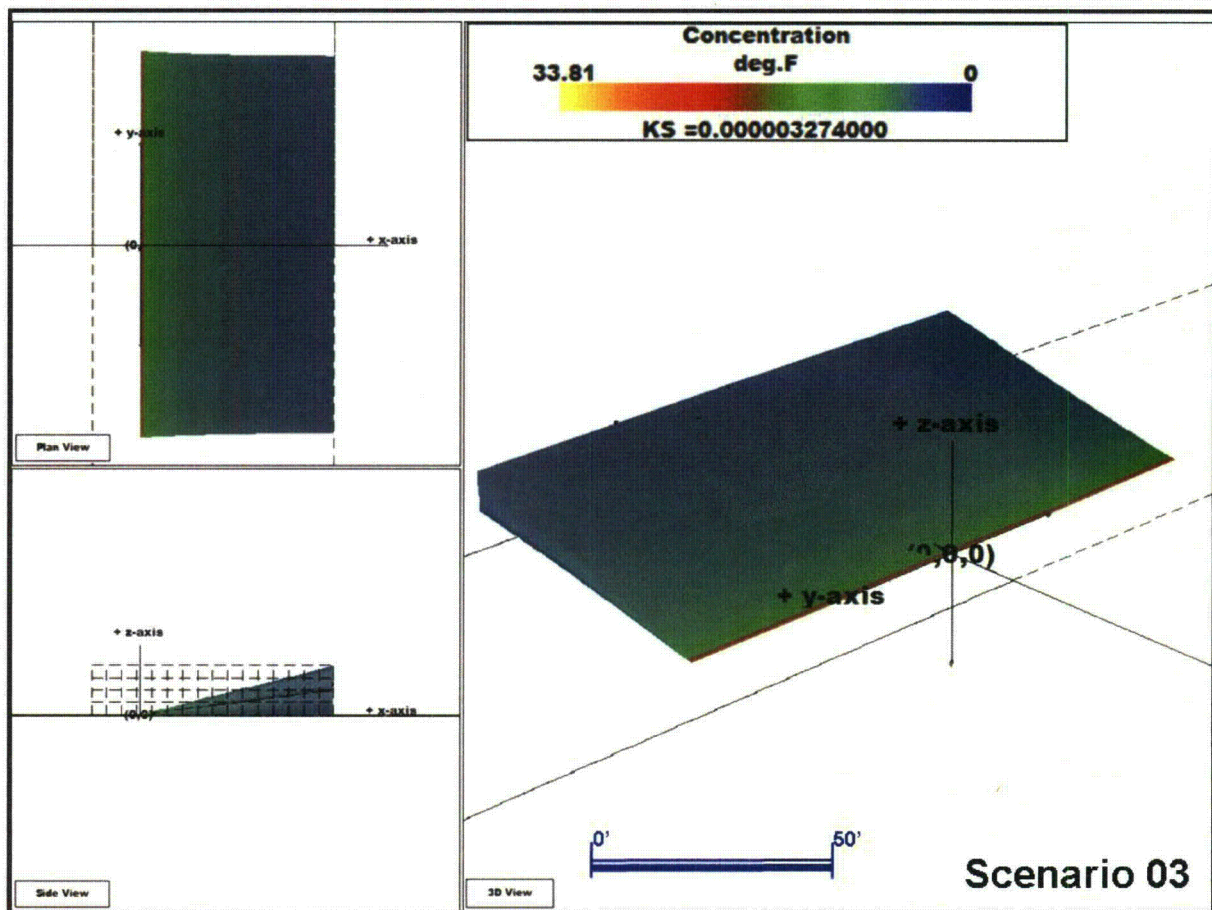


Figure 8 Near-field thermal plume orientation and size for Scenario 3

Scenario 3 is winter mean flow. The CORMIX graphical engine automatically scales diagrams—scales vary from one figure to the next.

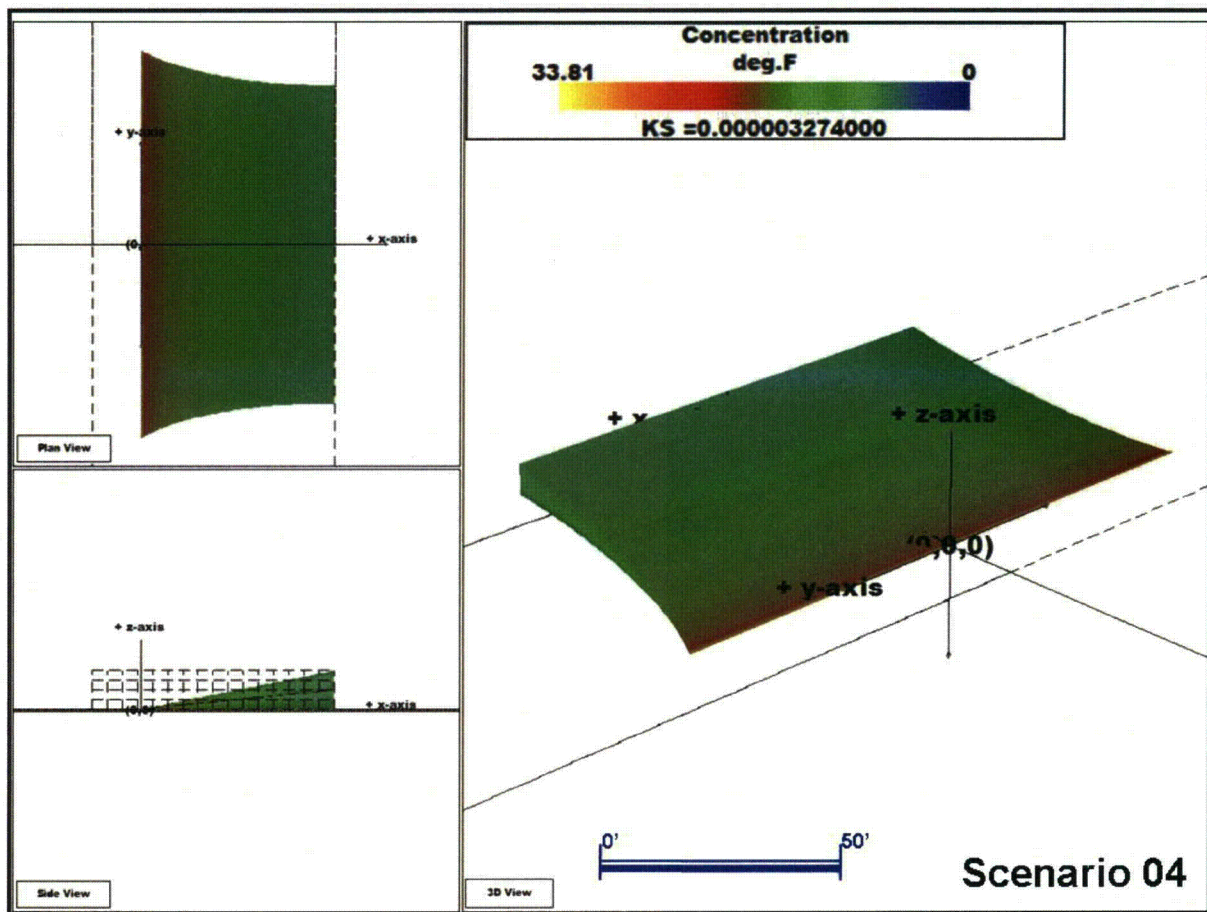


Figure 9 Near-field thermal plume orientation and size for Scenario 4

Scenario 4 is winter low flow.

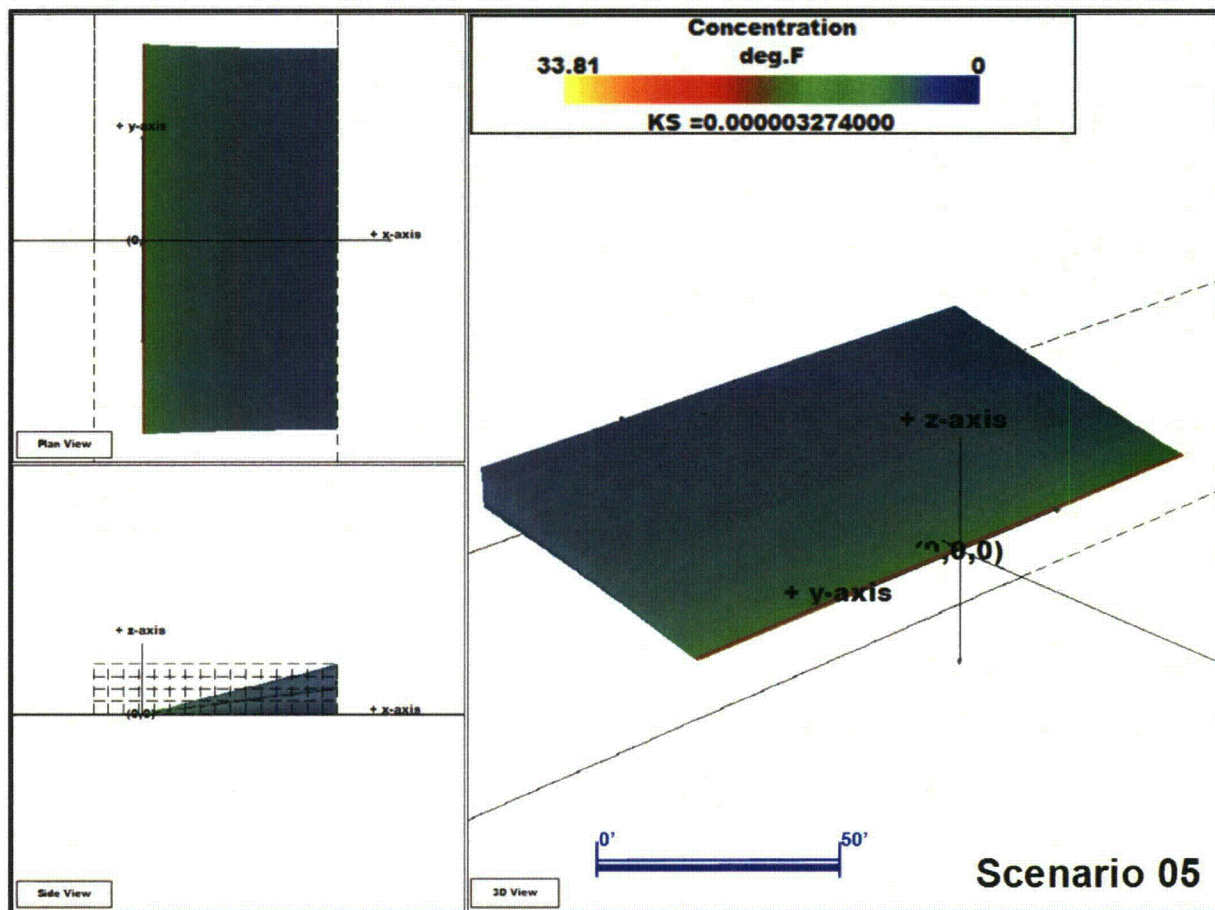


Figure 10 Near-field thermal plume orientation and size for Scenario 5

Scenario 5 is average annual flow.

7. LANDSCAPE-FORMATTED TABLES AND FIGURES

Table 15 Dilution values and related distances for various locations of interest

The location of the property boundary was taken from PETERS CONSULTANTS, INC. (2008).

Dilution at	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5	
SSES cooling water intake	2598	2623	Does not reach	Does not reach	289	167	Does not reach	Does not reach	287	166
BBNPP cooling water intake	936	918	Does not reach	Does not reach	285	179	Does not reach	Does not reach	279	176
Nearest Shoreline	623	623	Does not reach	Does not reach	208	138	Does not reach	Does not reach	200	134
Maximum impacted shoreline	101	90	44	44	108	85	106	106	108	86
Distance of maximum impacted shoreline from BBNPP Discharge (ft)	3000	2275	8000	8000	1750	1975	8000	4450	1750	1975
Property boundary	620	620	9265	13233	224	132	Does not reach	5850	216	128
S Hicks Ferry Rd	101	101	57	53	109	102	Does not reach	5850	216	128
Fully-mixed	175	175	46	46	500	500	111	111	500	500
Distance to fully-mixed (ft)	41300		53000		66300		26150		66300	
Locations Beyond Fully-mixed Region										
Public water supply intake (Danville)	175	175	46	46	500	500	111	111	500	500
Recreational shore (Sunbury)	175	175	46	46	500	500	111	111	500	500

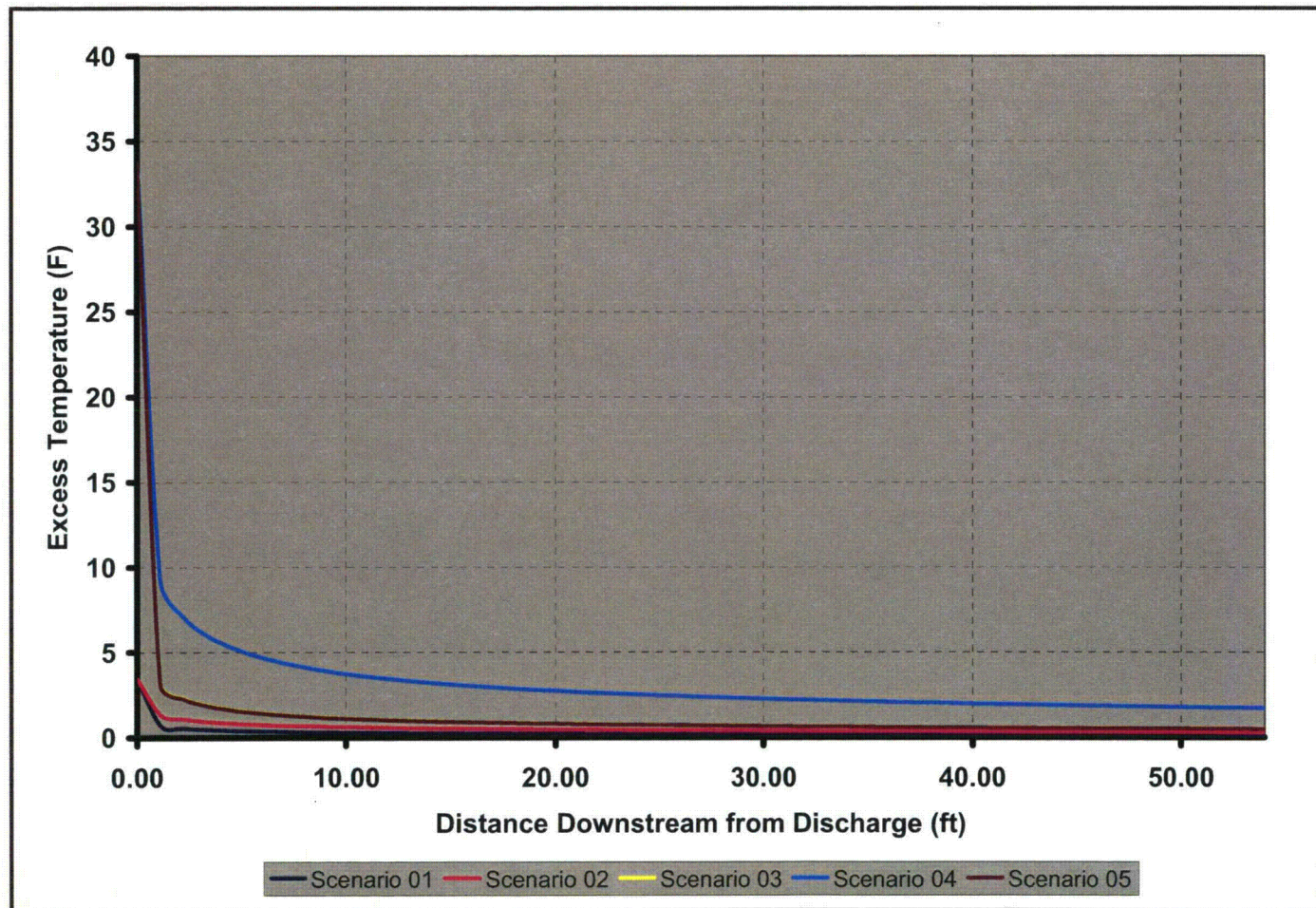


Figure 11 Excess temperature versus downstream distance for all five scenarios

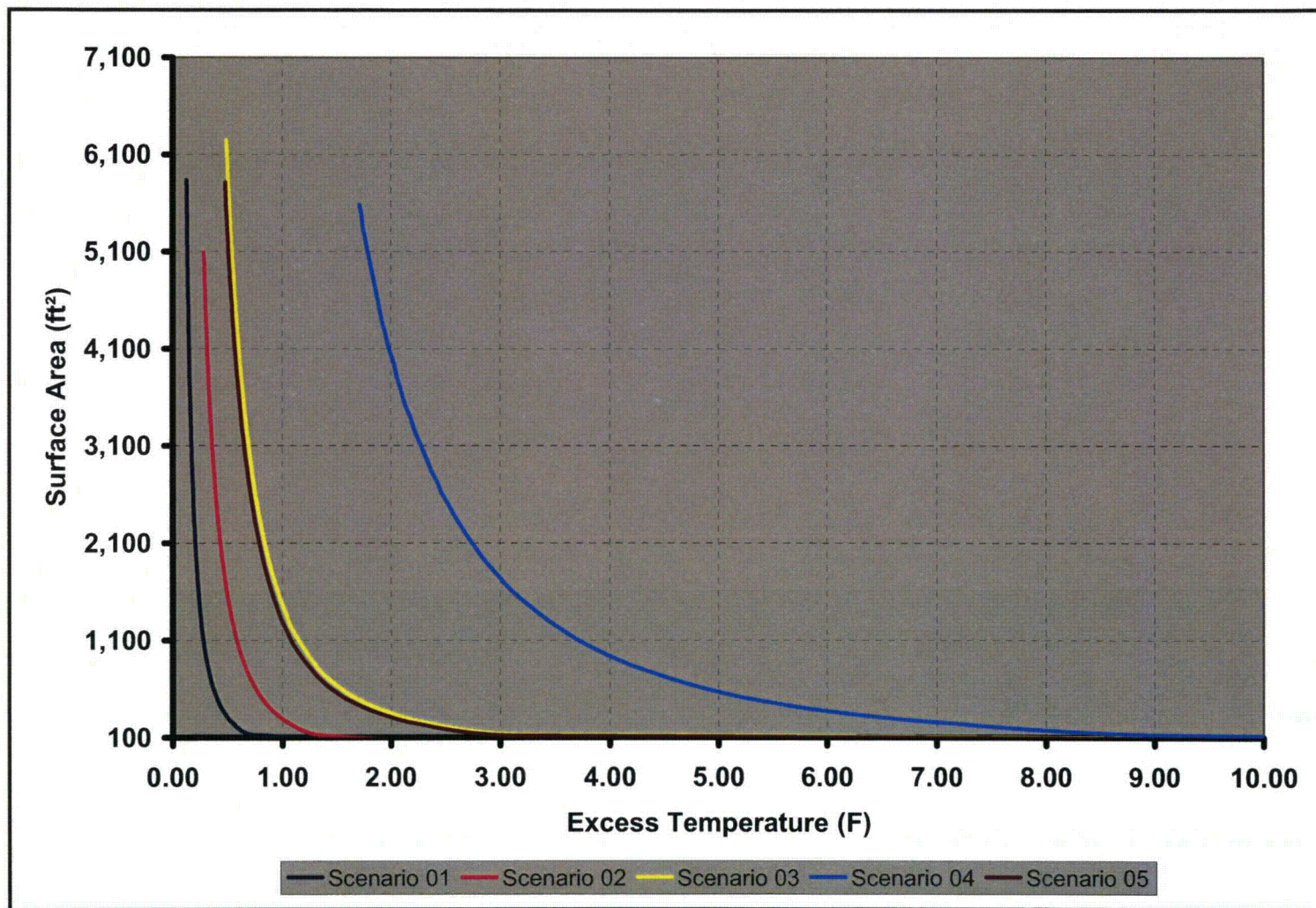


Figure 12 Near-field plume surface area versus temperature rise isotherms for all five scenarios

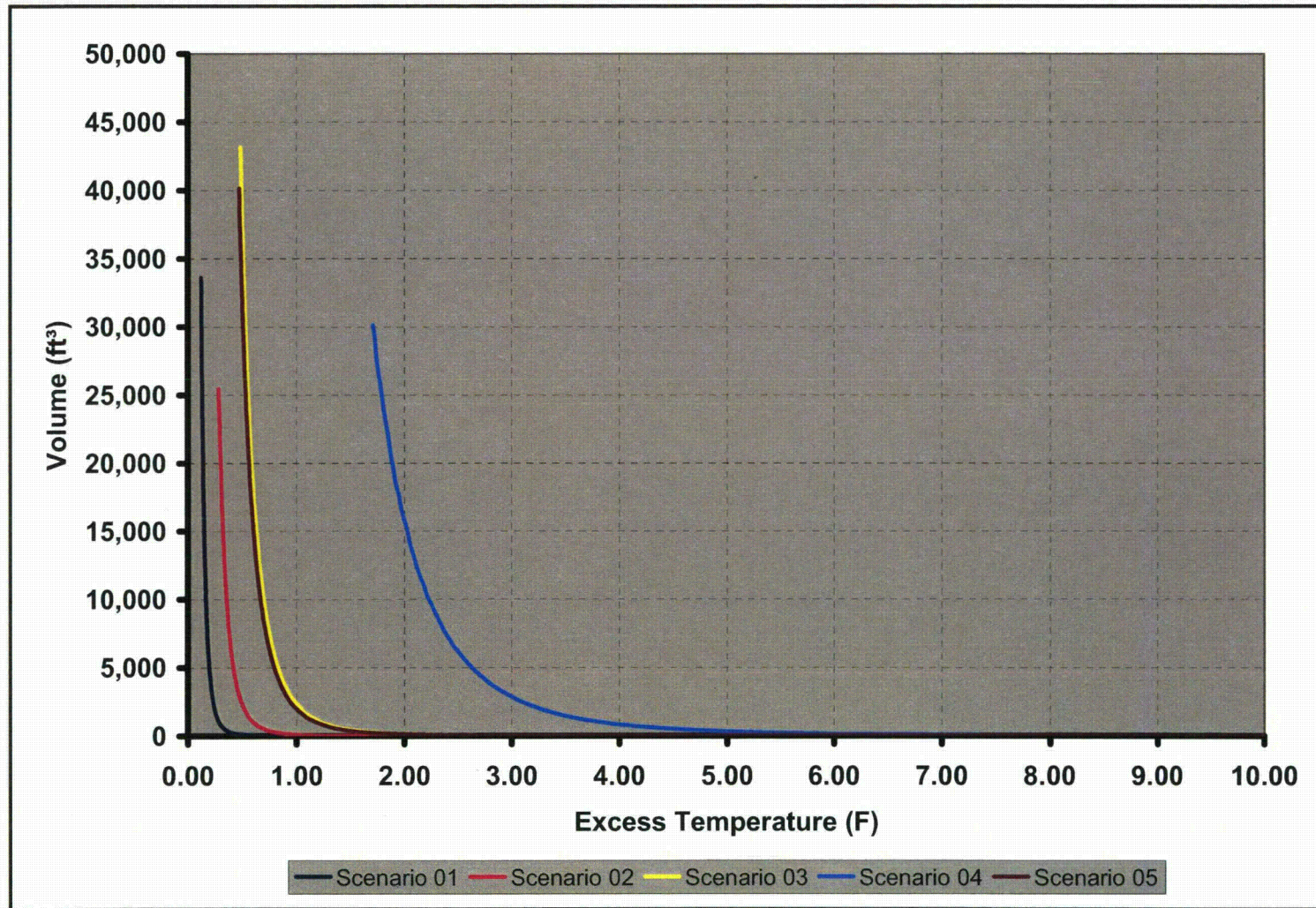


Figure 13 Near-field plume volume versus temperature rise isotherms for all five scenarios

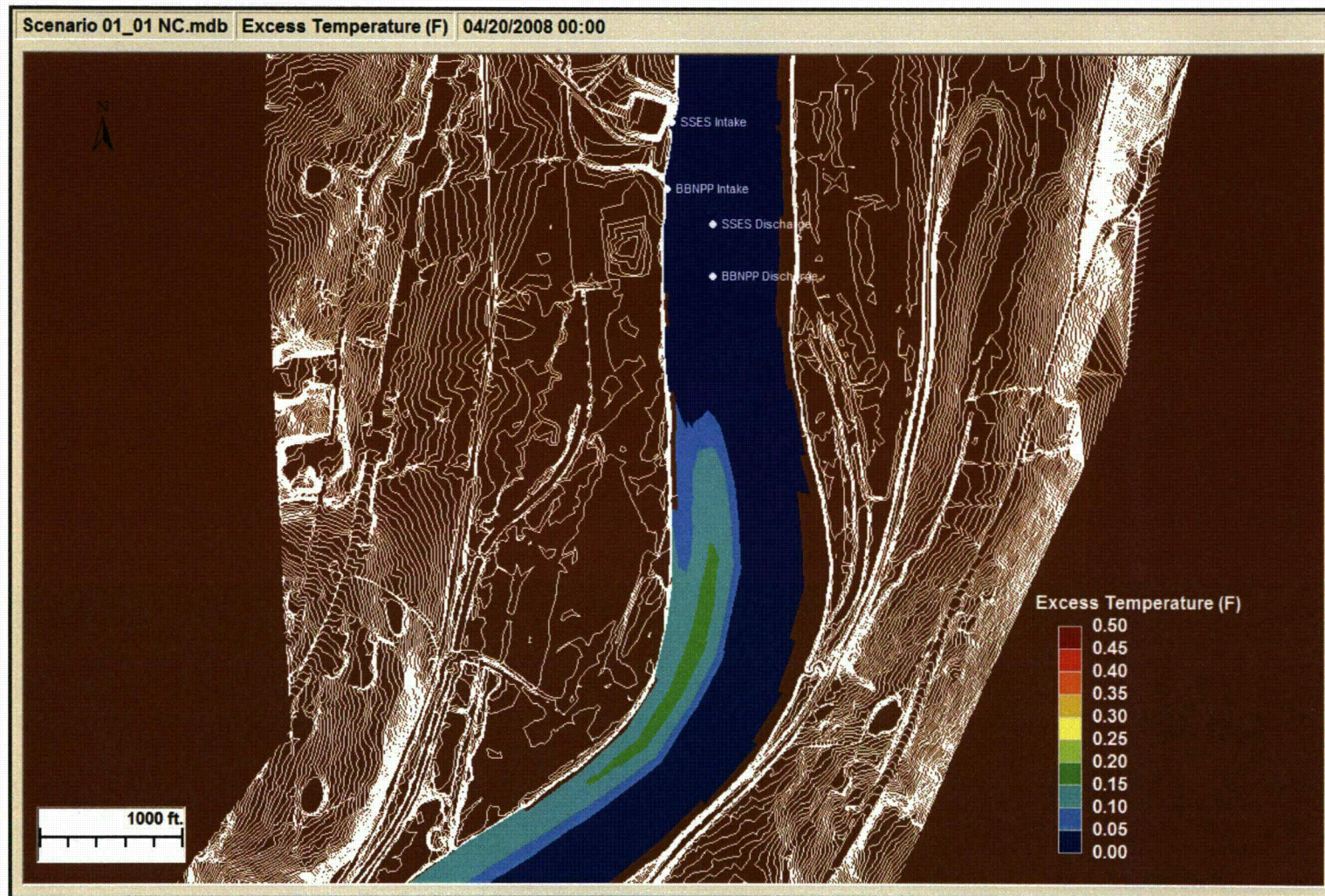


Figure 14 Excess temperature at the surface for cumulative SSES and BBNPP impacts for Scenario 1

Scenario 1 is summer mean flow—note that the temperature scale varies from diagram to diagram.

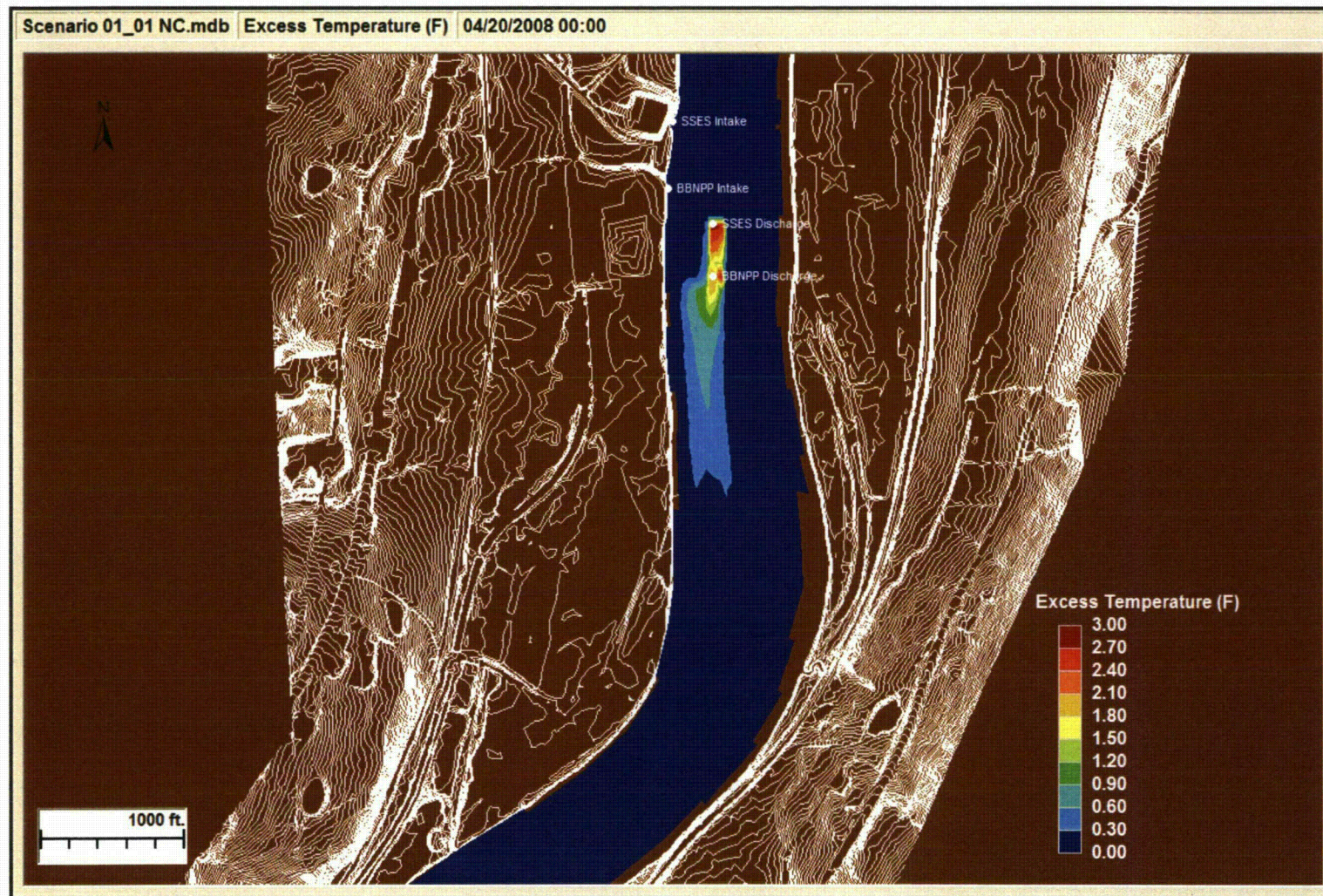


Figure 15 Excess temperature at the bottom for cumulative SSES and BBNPP impacts for Scenario 1

Scenario 1 is summer mean flow.

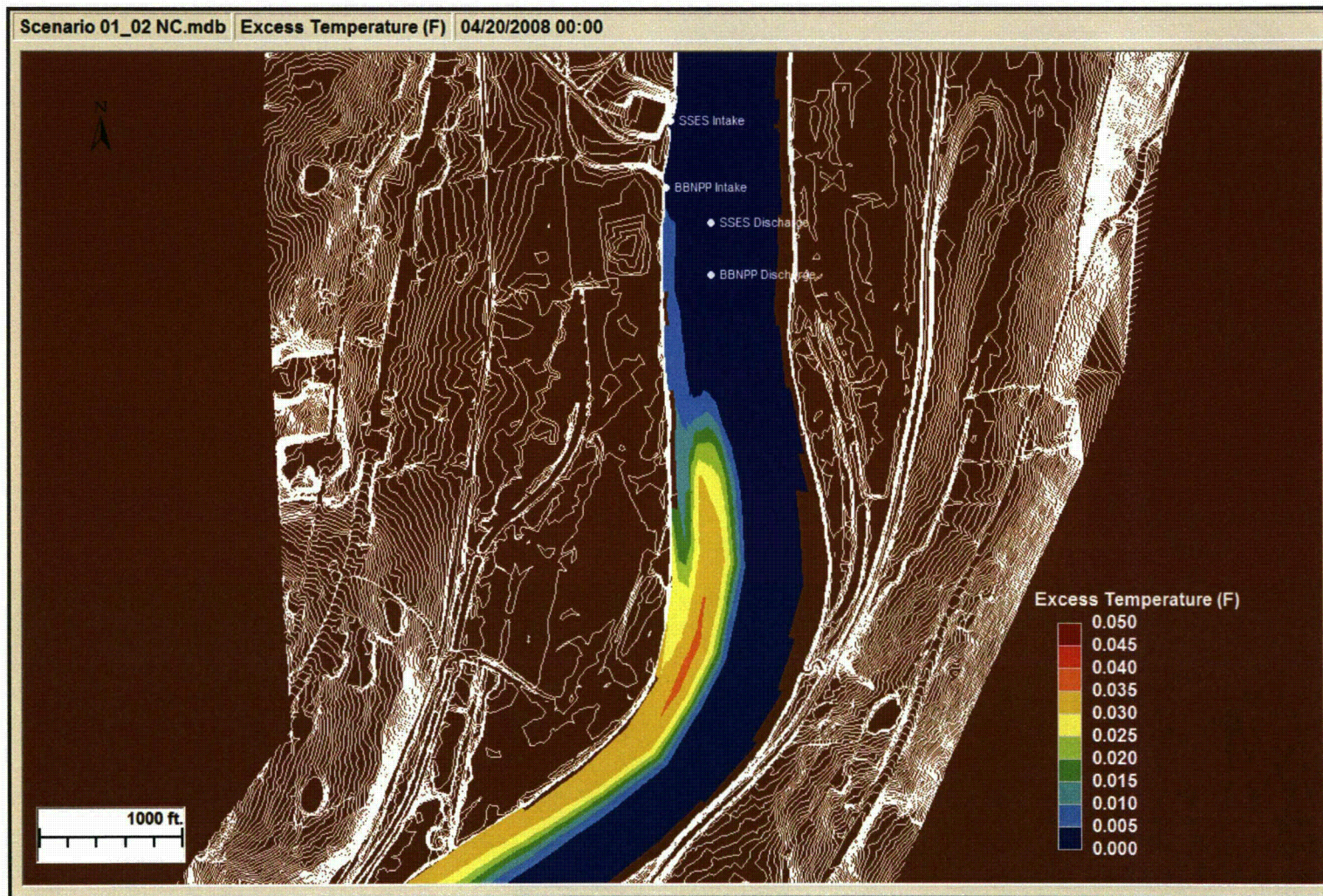


Figure 16 Excess temperature at the surface for incremental BBNPP impact for Scenario 1

Scenario 1 is summer mean flow.

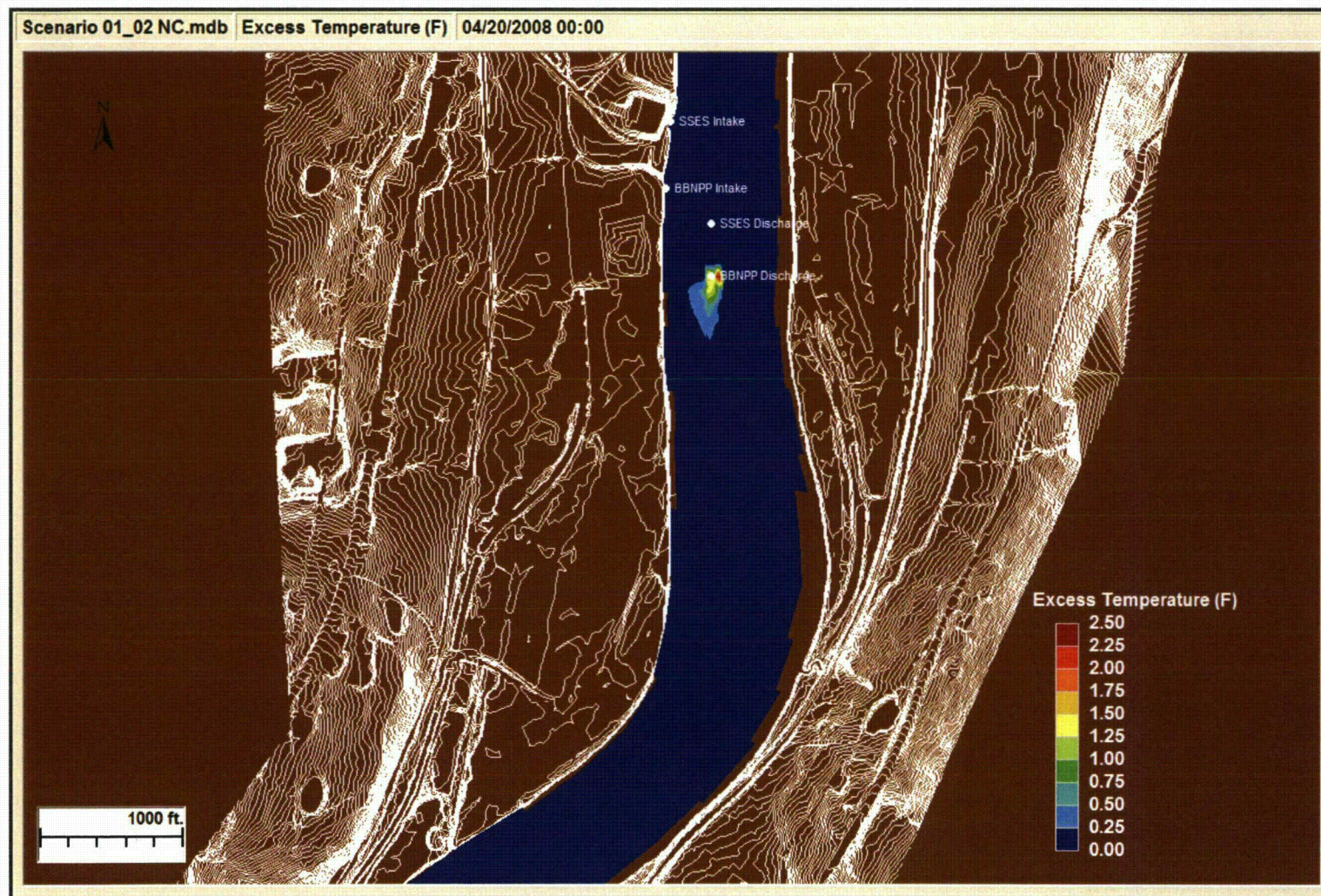


Figure 17 Excess temperature at the bottom for incremental BBNPP impact for Scenario 1

Scenario 1 is summer mean flow.

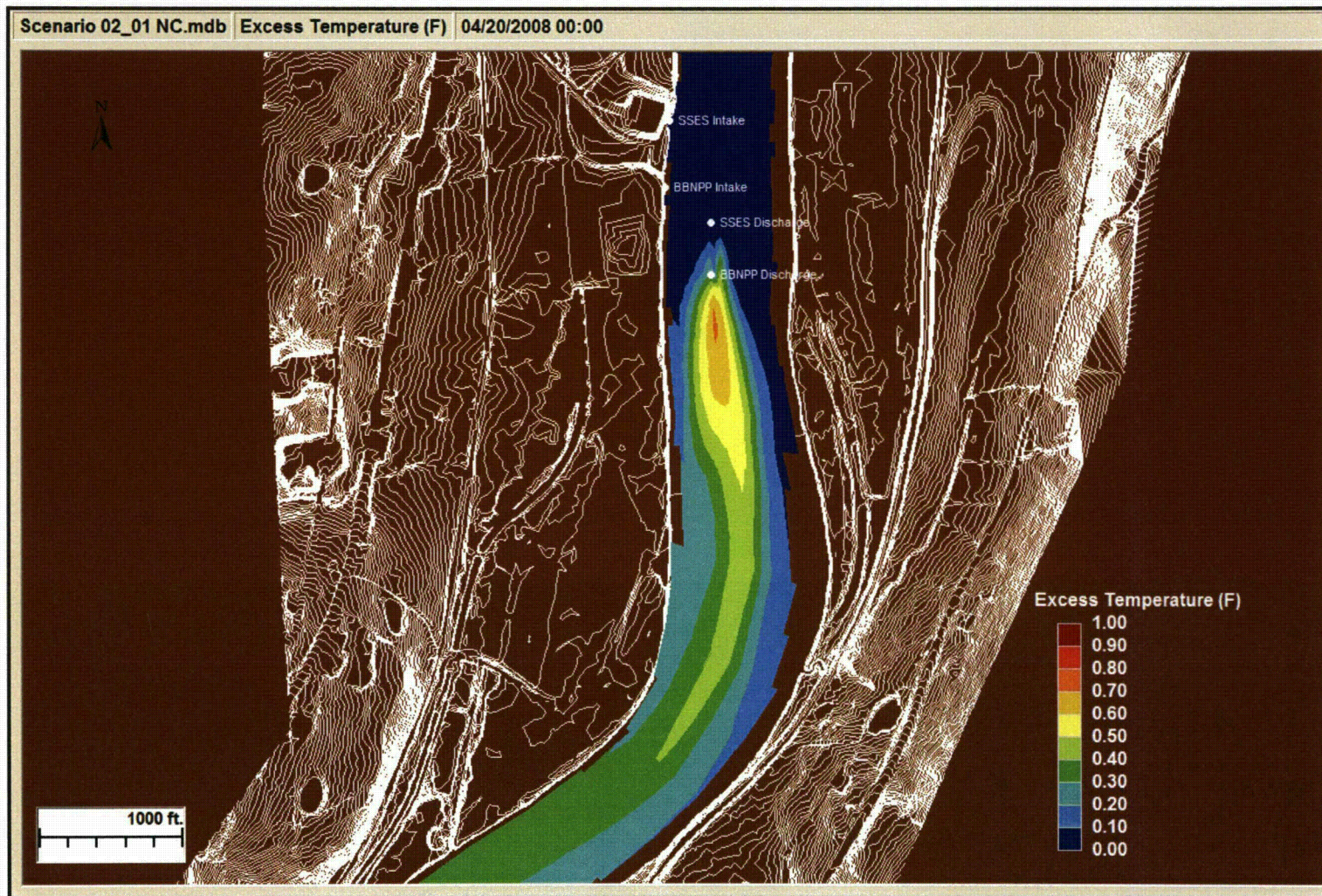


Figure 18 Excess temperature at the surface for cumulative SSES and BBNPP impacts for Scenario 2

Scenario 2 is summer low flow.

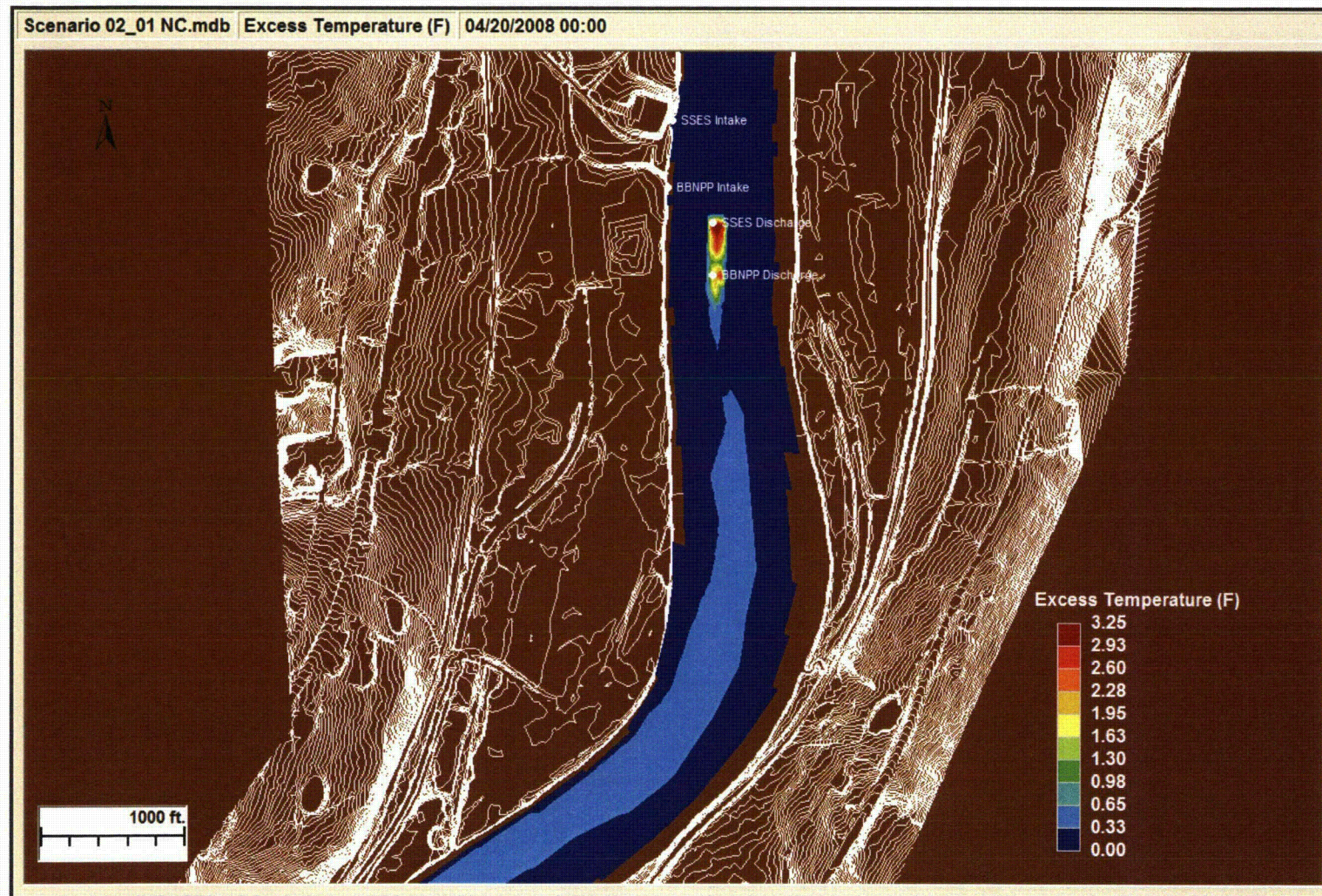


Figure 19 Excess temperature at the bottom for cumulative SSES and BBNPP impacts for Scenario 2

Scenario 2 is summer low flow.

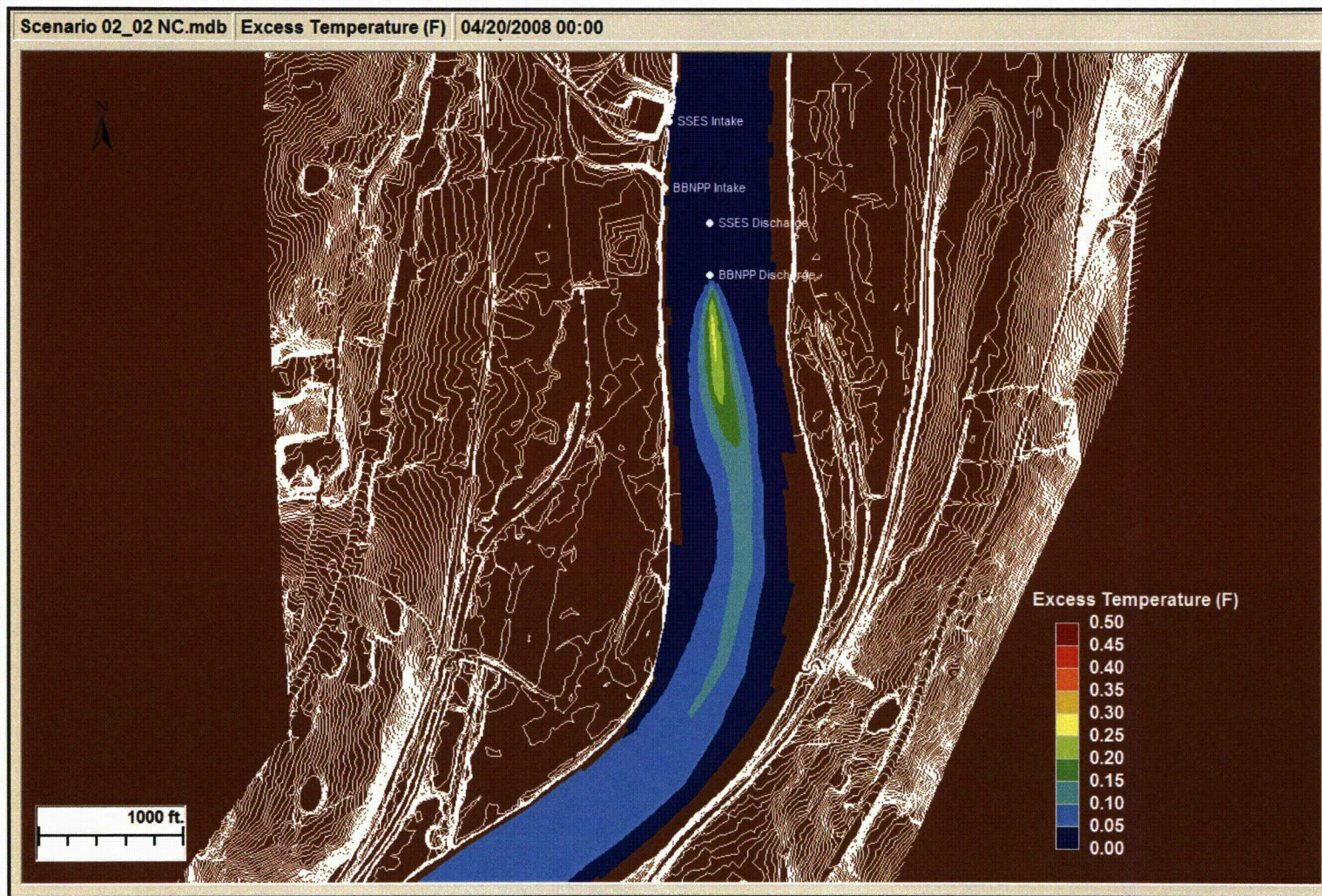


Figure 20 Excess temperature at the surface for incremental BBNPP impact for Scenario 2

Scenario 2 is summer low flow.

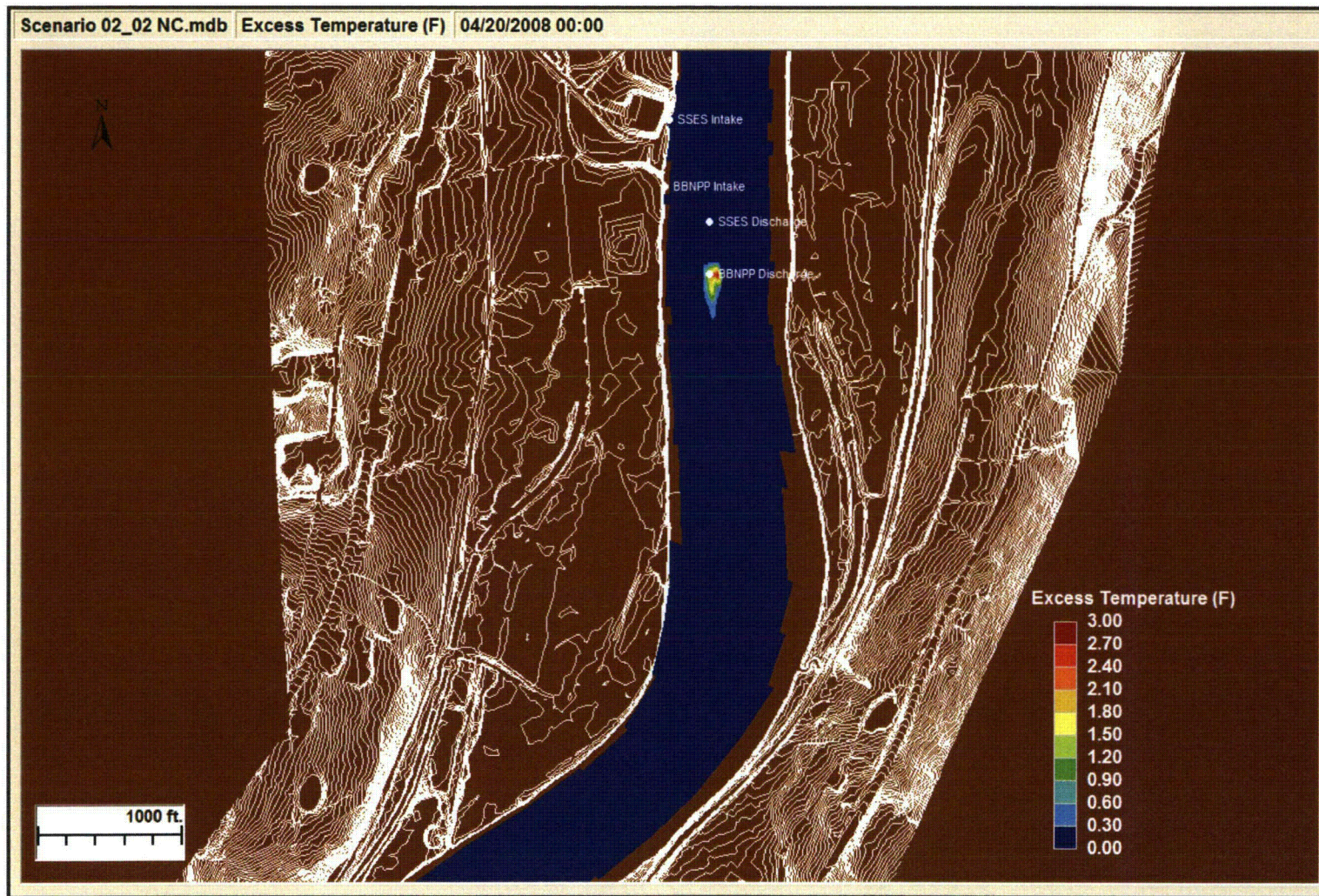


Figure 21 Excess temperature at the bottom for incremental BBNPP impact for Scenario 2

Scenario 2 is summer low flow.

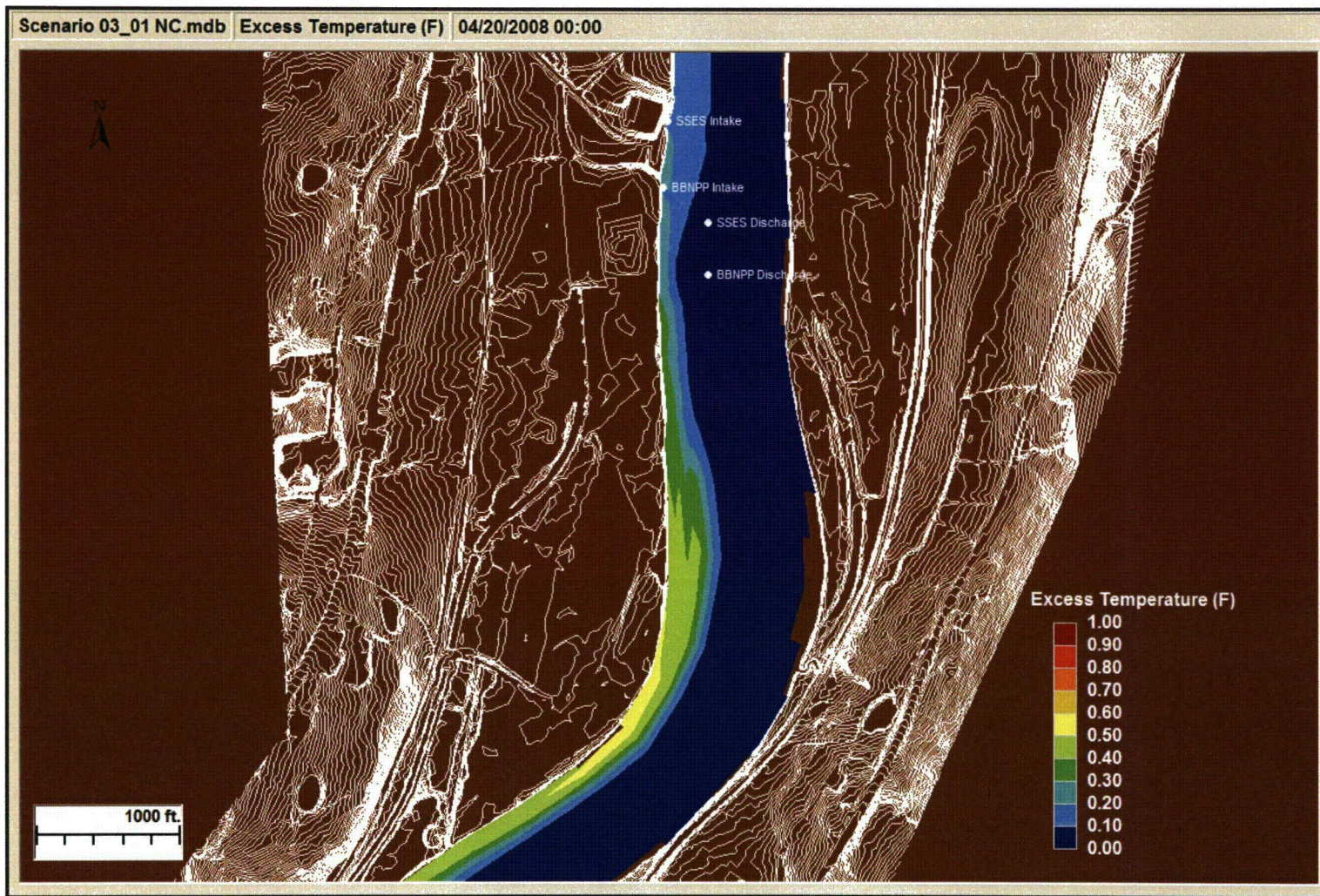


Figure 22 Excess temperature at the surface for cumulative SSES and BBNPP impacts for Scenario 3

Scenario 3 is winter mean flow.

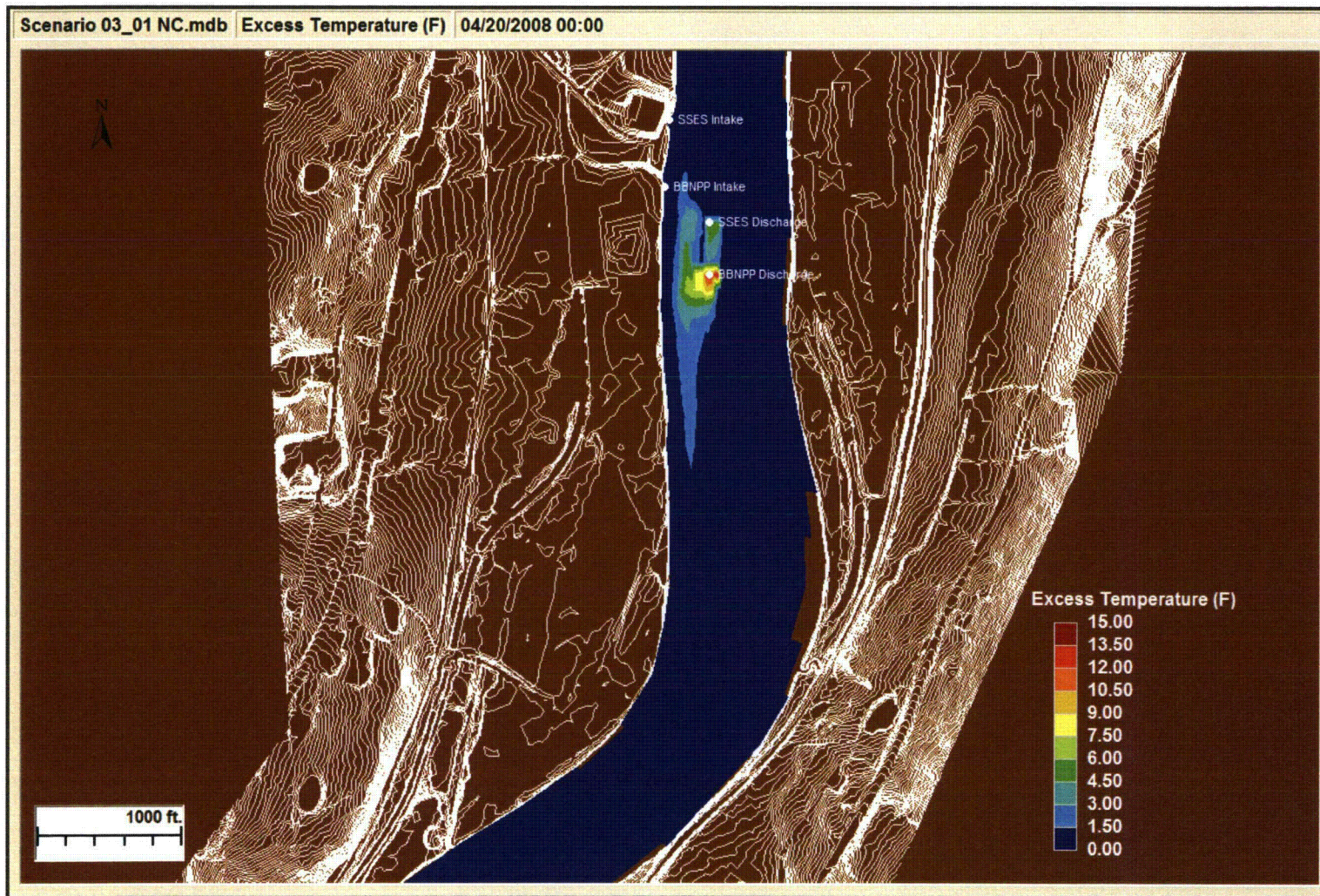


Figure 23 Excess temperature at the bottom for cumulative SSES and BBNPP impacts for Scenario 3

Scenario 3 is winter mean flow.

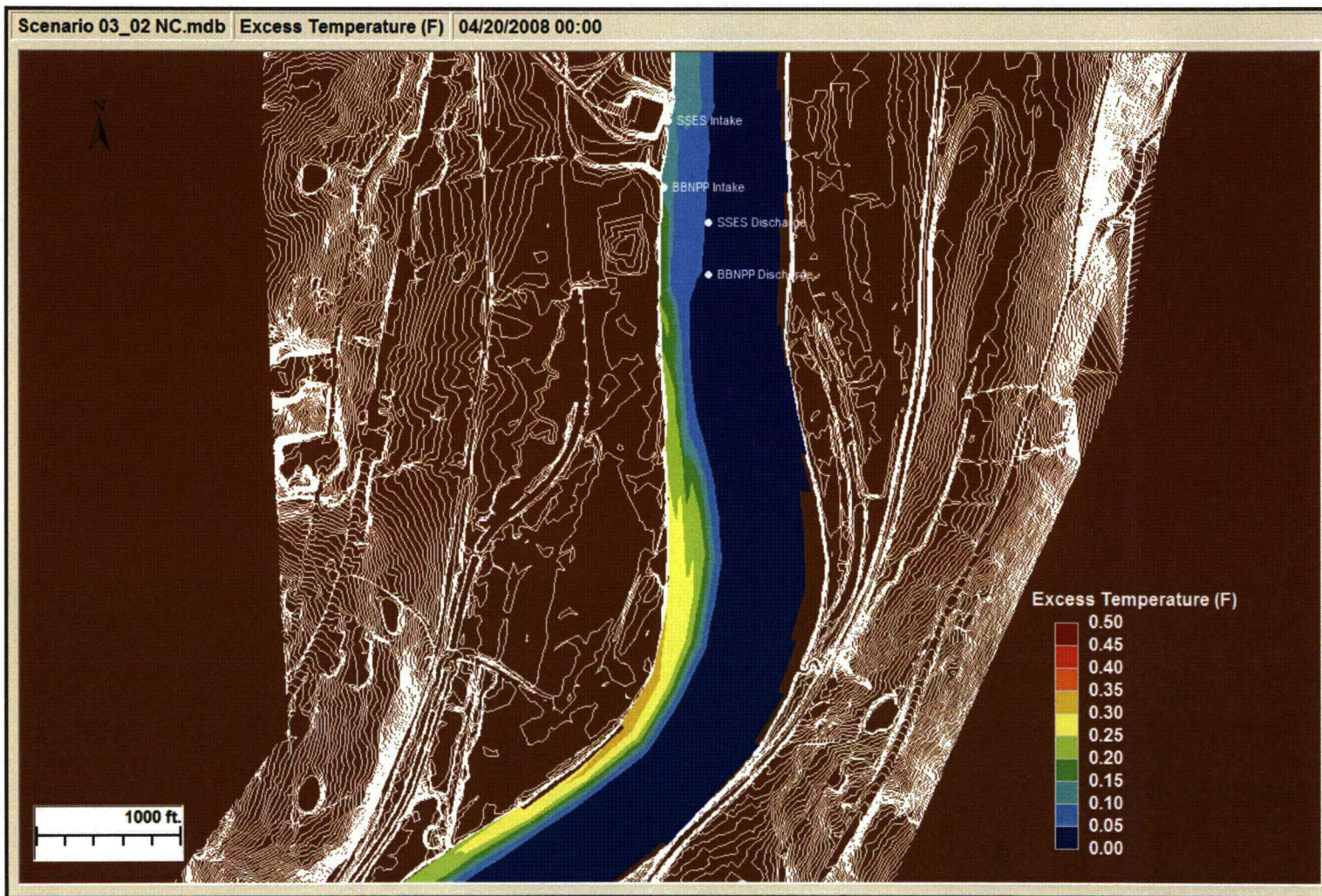


Figure 24 Excess temperature at the surface for incremental BBNPP impact for Scenario 3

Scenario 3 is winter mean flow.

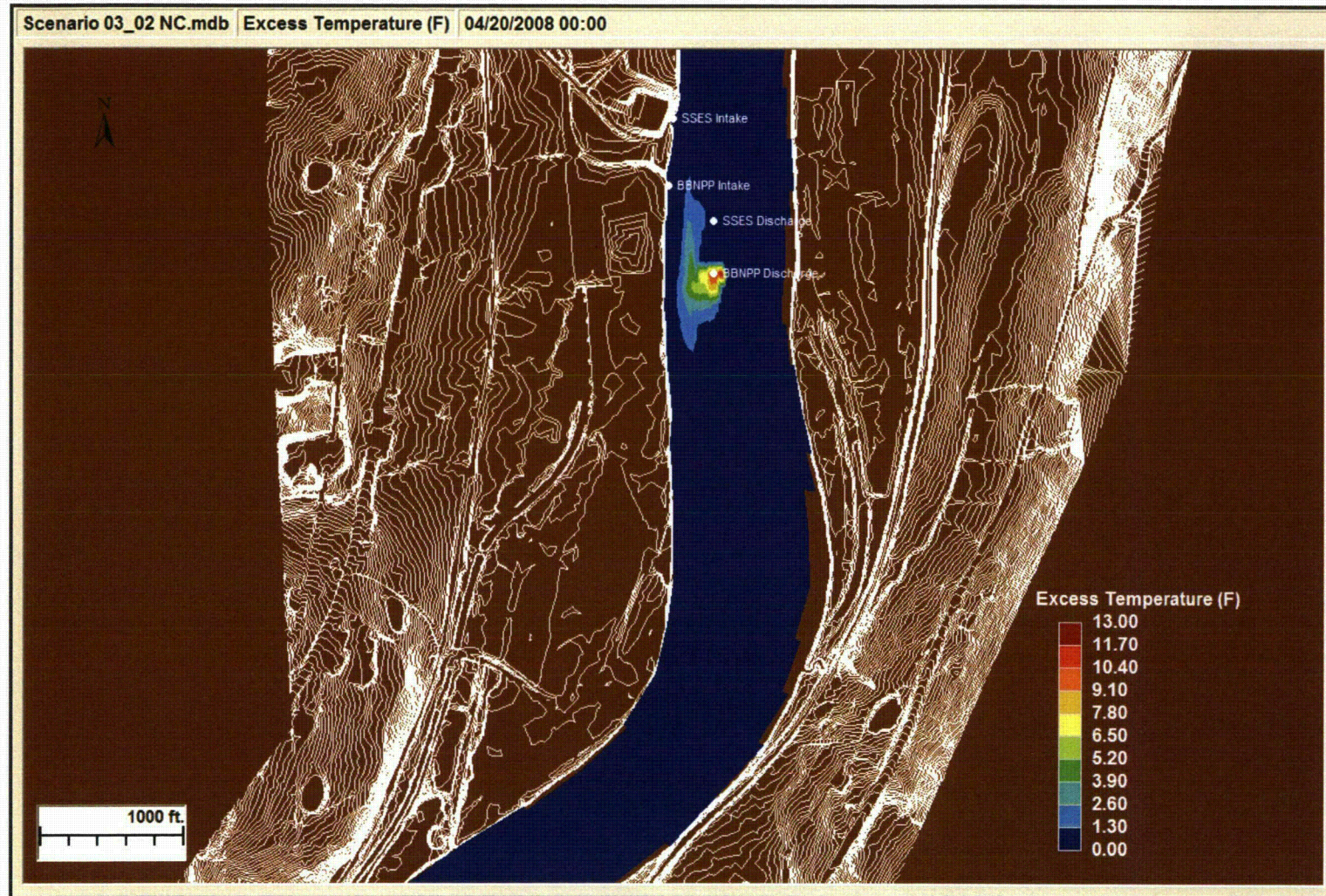


Figure 25 Excess temperature at the bottom for incremental BBNPP impact for Scenario 3

Scenario 3 is winter mean flow.

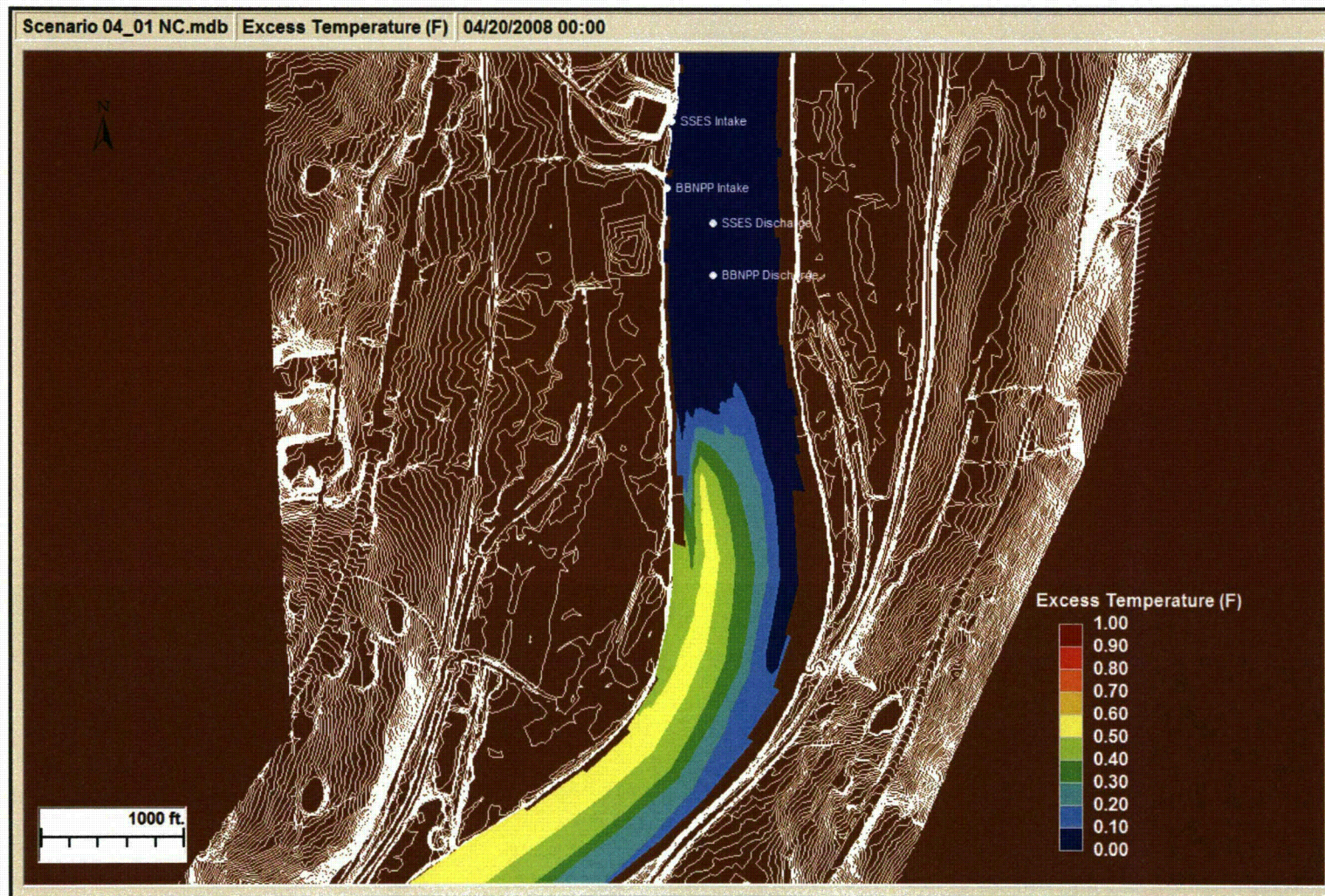


Figure 26 Excess temperature at the surface for cumulative SSES and BBNPP impacts for Scenario 4

Scenario 4 is winter low flow.

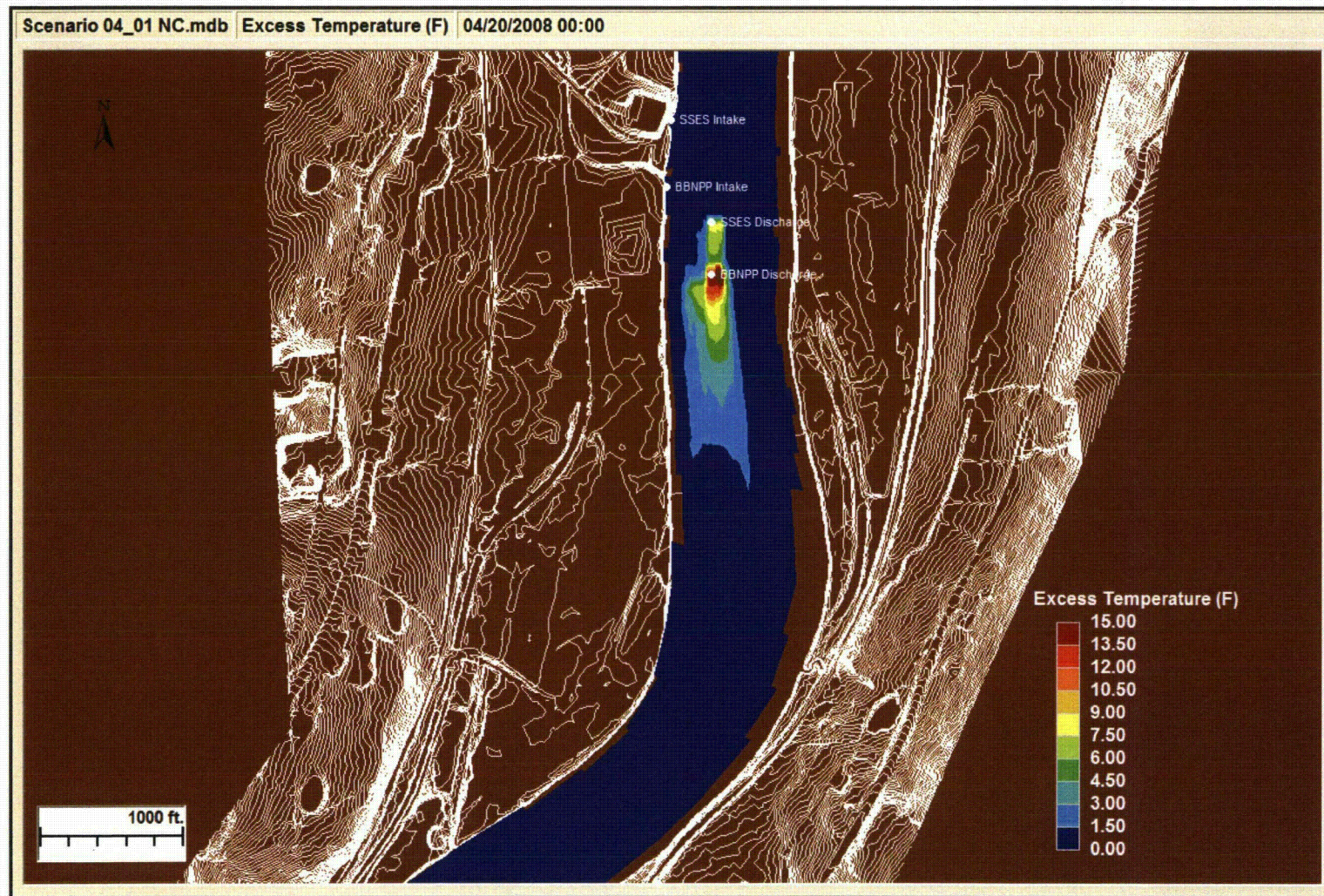


Figure 27 Excess temperature at the bottom for cumulative SSES and BBNPP impacts for Scenario 4

Scenario 4 is winter low flow.

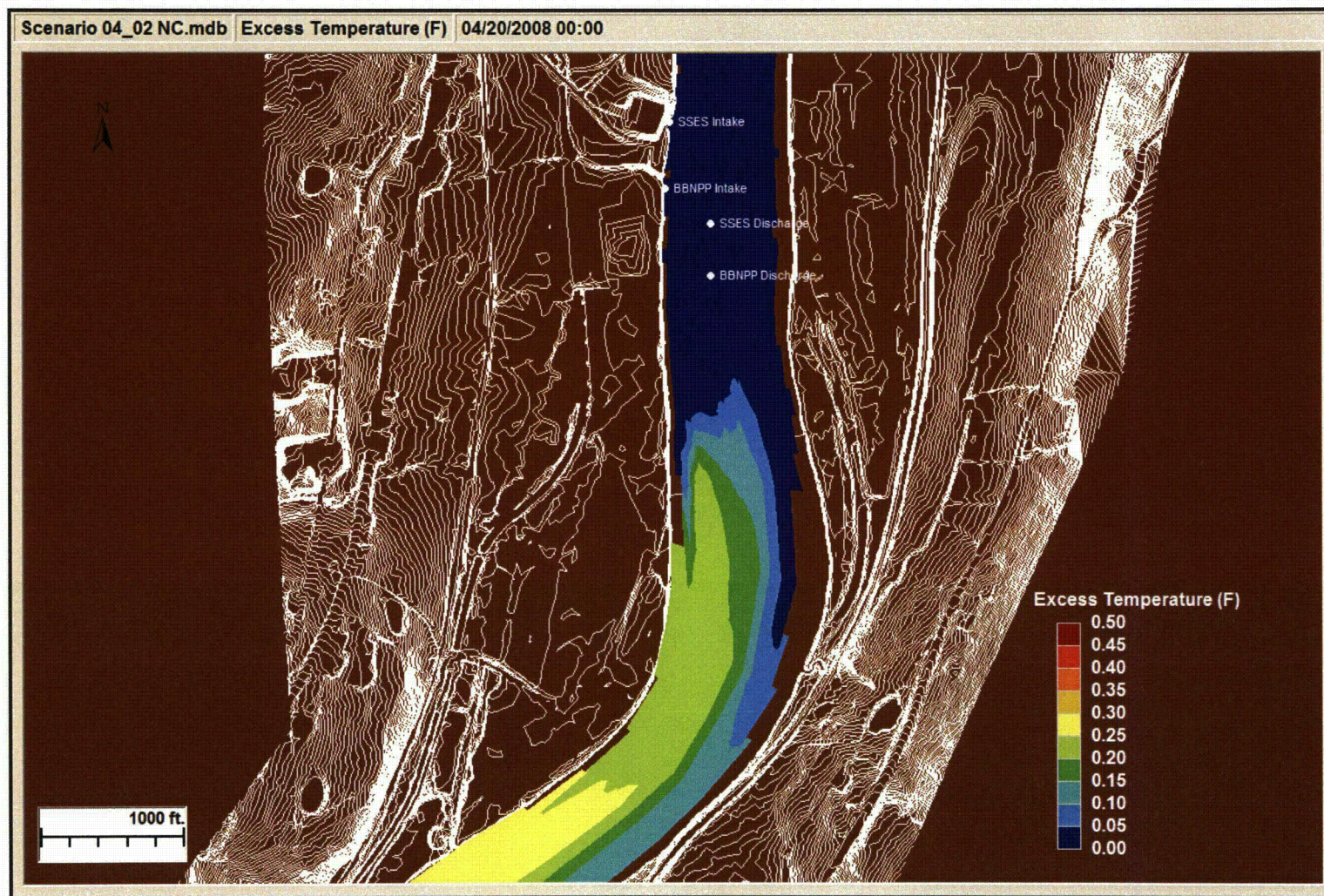


Figure 28 Excess temperature at the surface for incremental BBNPP impact for Scenario 4

Scenario 4 is winter low flow.

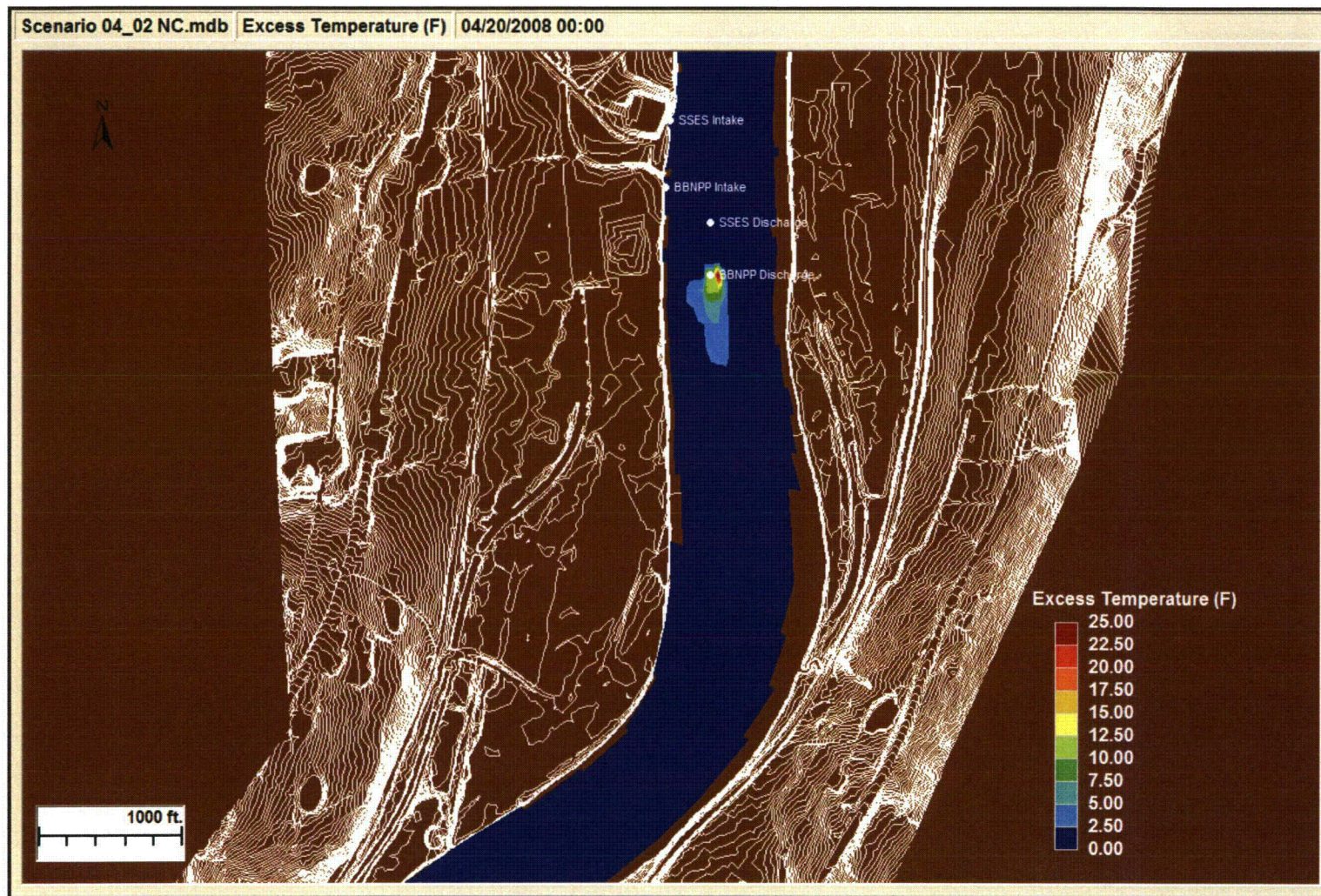


Figure 29 Excess temperature at the bottom for incremental BBNPP impact for Scenario 4

Scenario 4 is winter low flow.

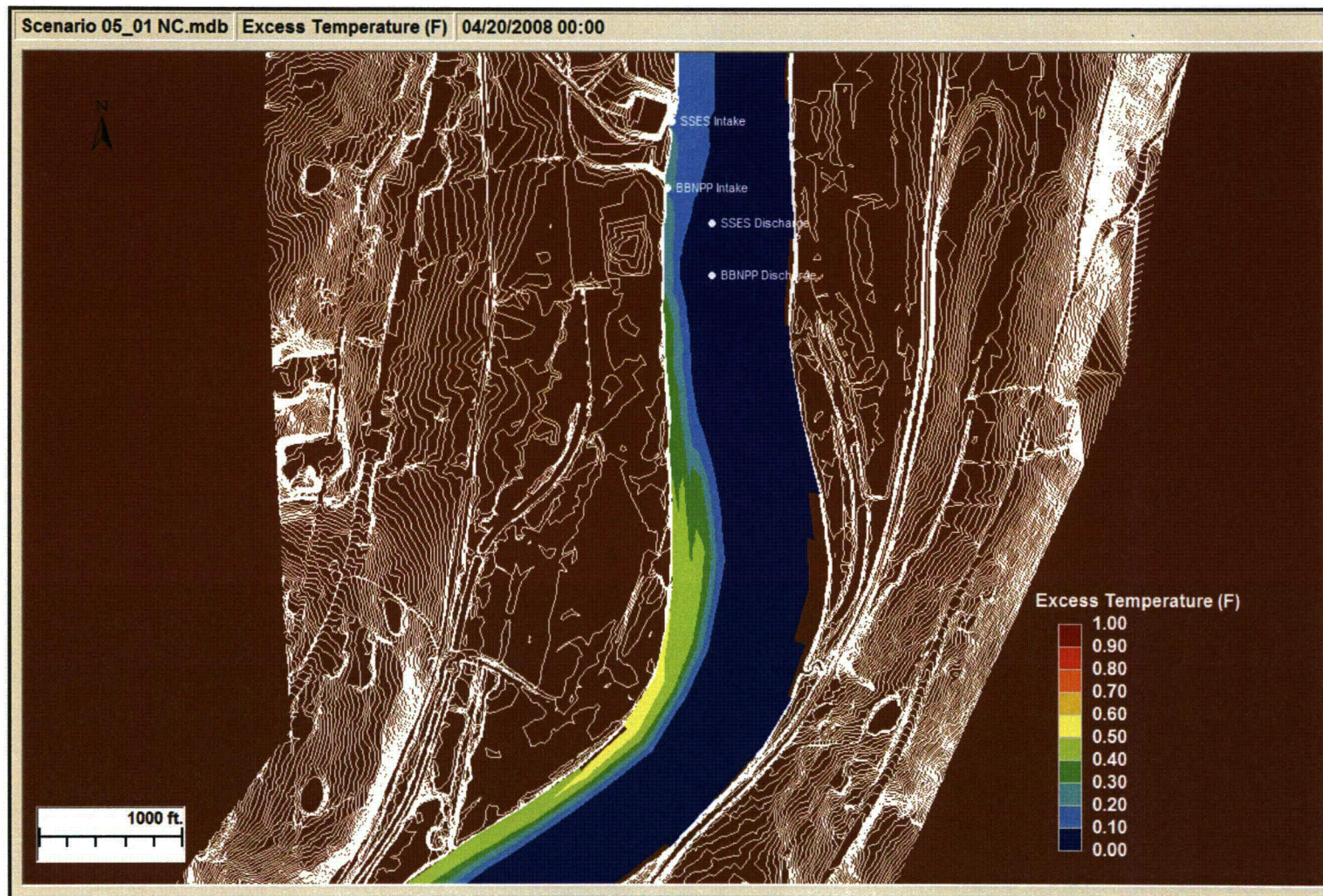


Figure 30 Excess temperature at the surface for cumulative SSES and BBNPP impact for Scenario 5

Scenario 5 is average annual flow.

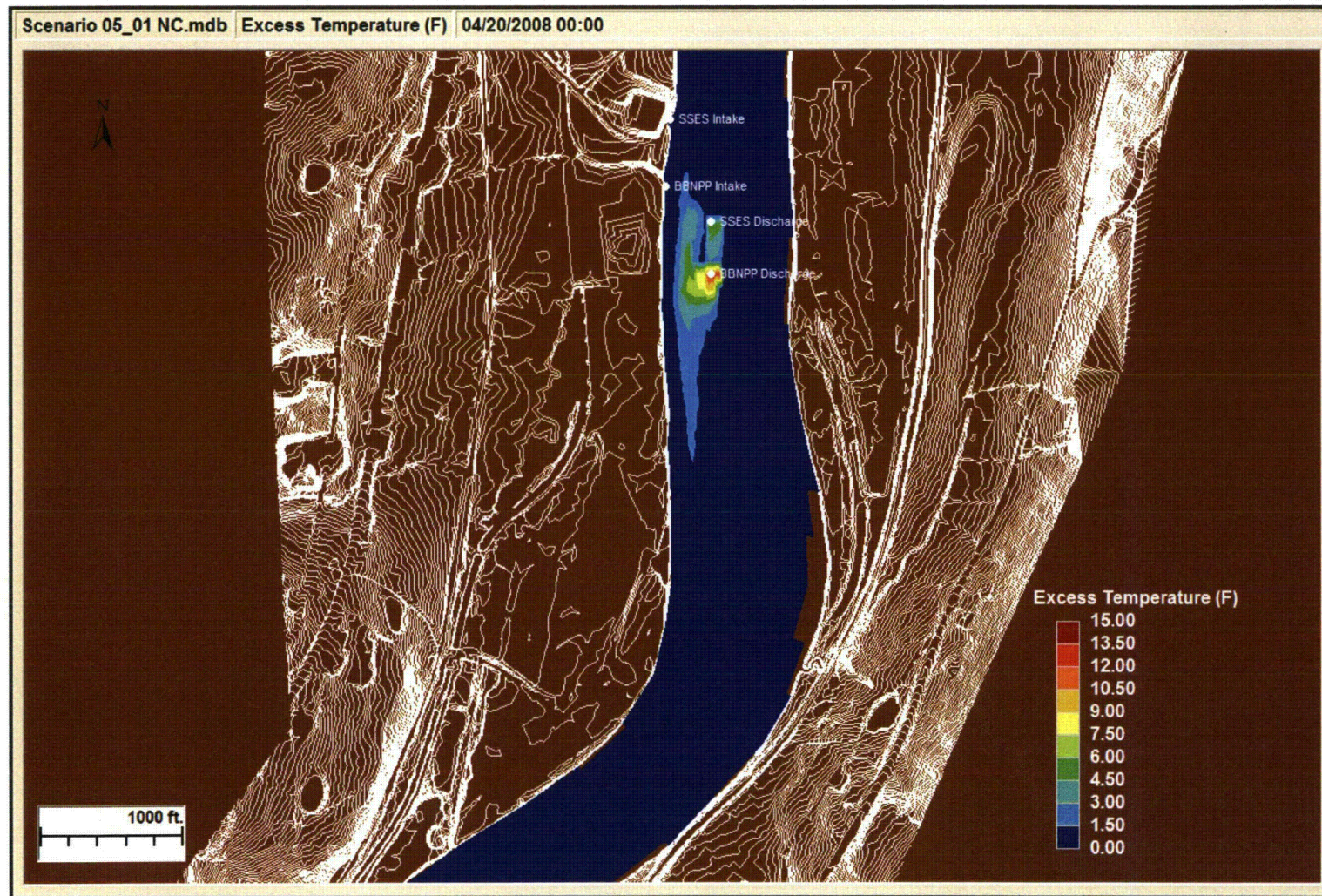


Figure 31 Excess temperature at the bottom for cumulative SSes and BBNPP impact for Scenario 5

Scenario 5 is average annual flow.

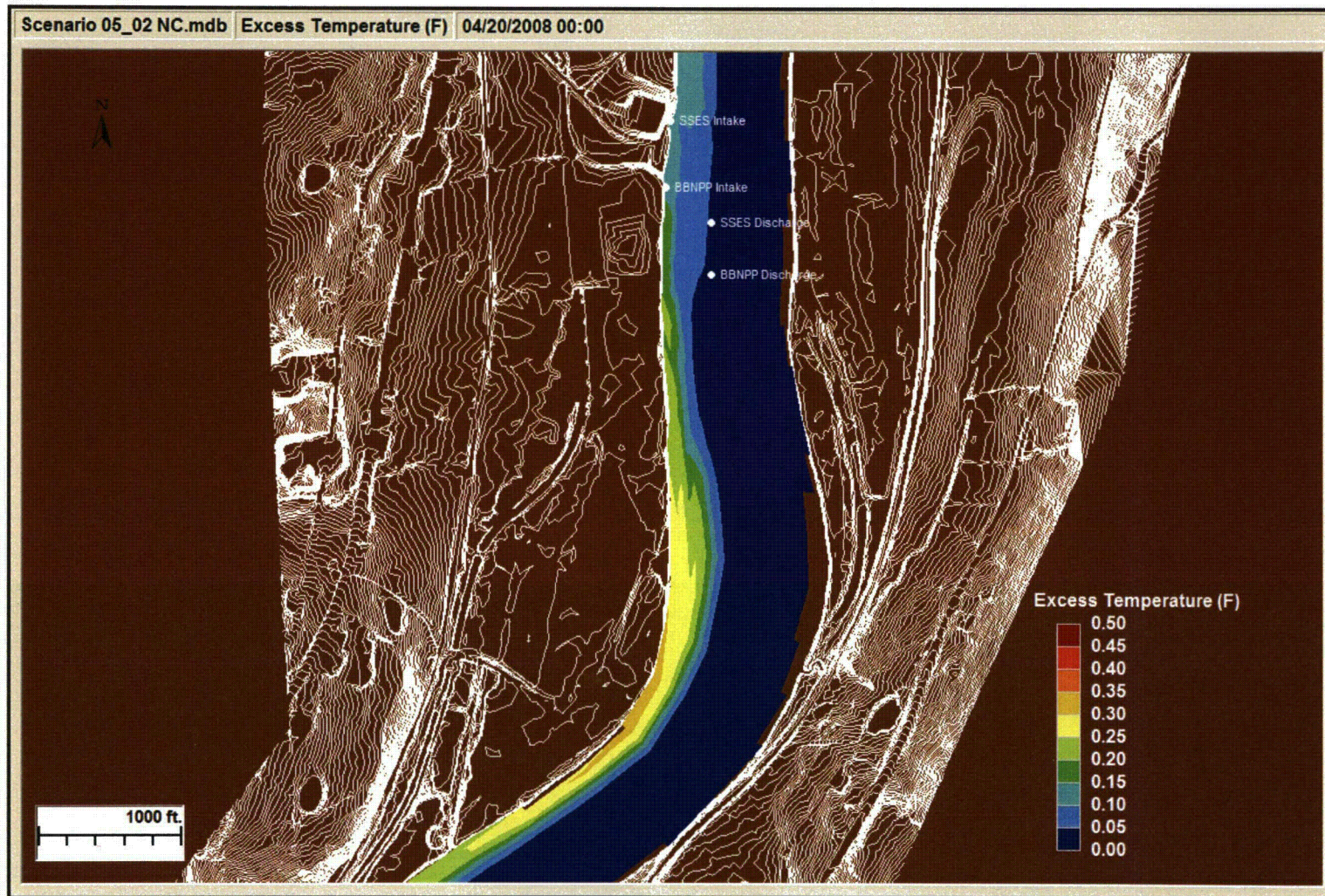


Figure 32 Excess temperature at the surface for incremental BBNPP impact for Scenario 5

Scenario 5 is average annual flow.

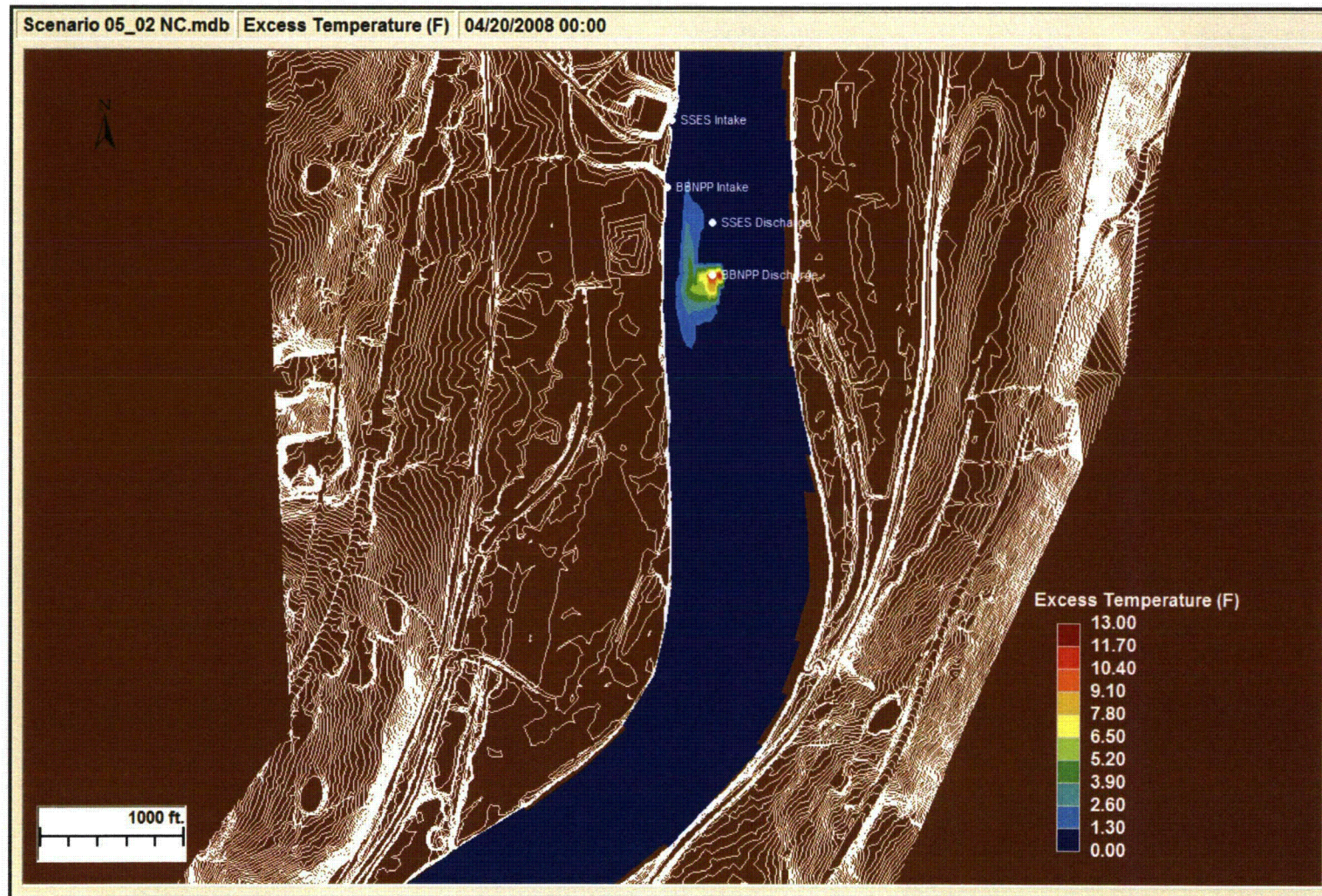


Figure 33 Excess temperature at the bottom for incremental BBNPP impact for Scenario 5

Scenario 5 is average annual flow.

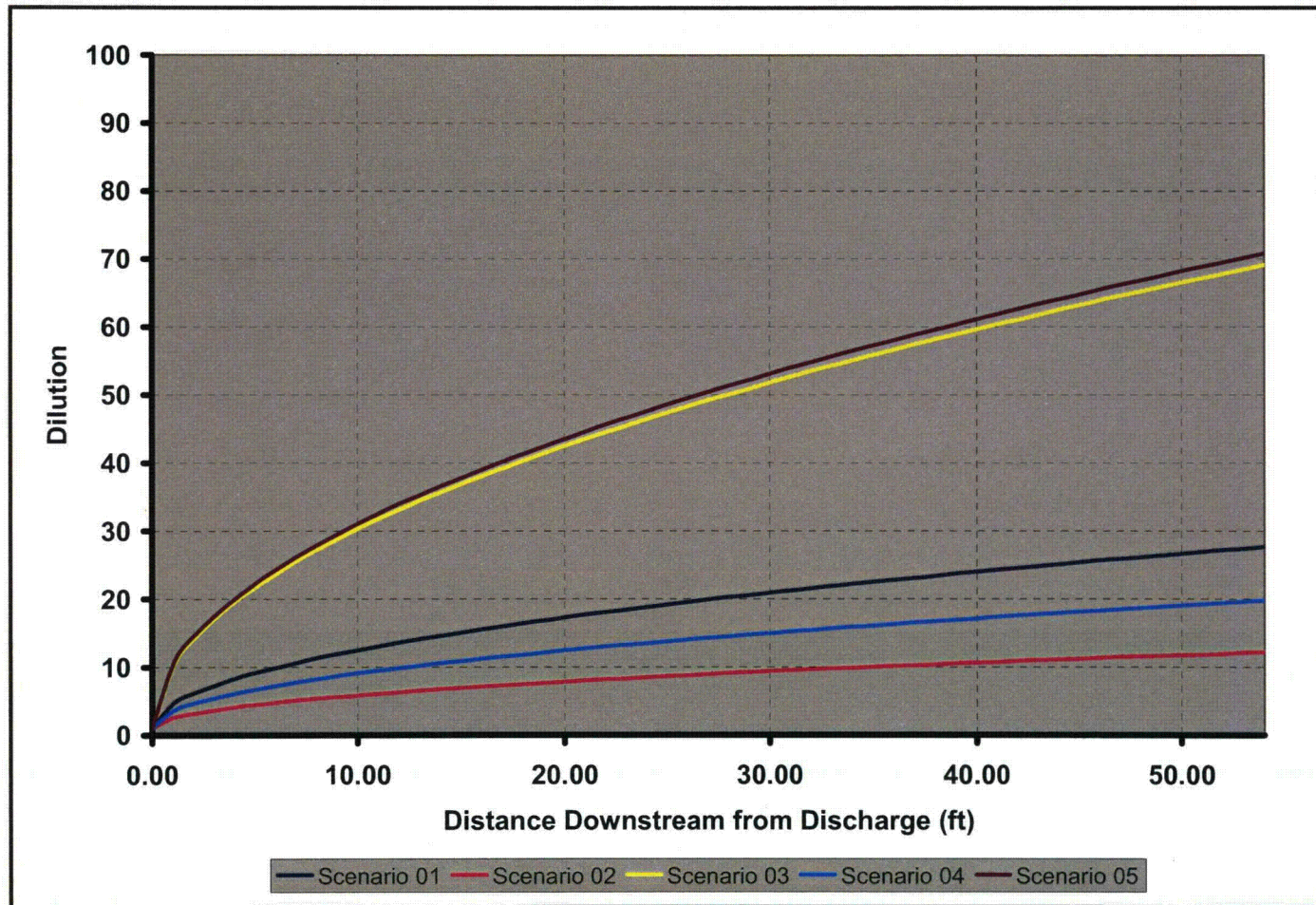


Figure 34 Near-field dilution versus downstream distance for all five scenarios

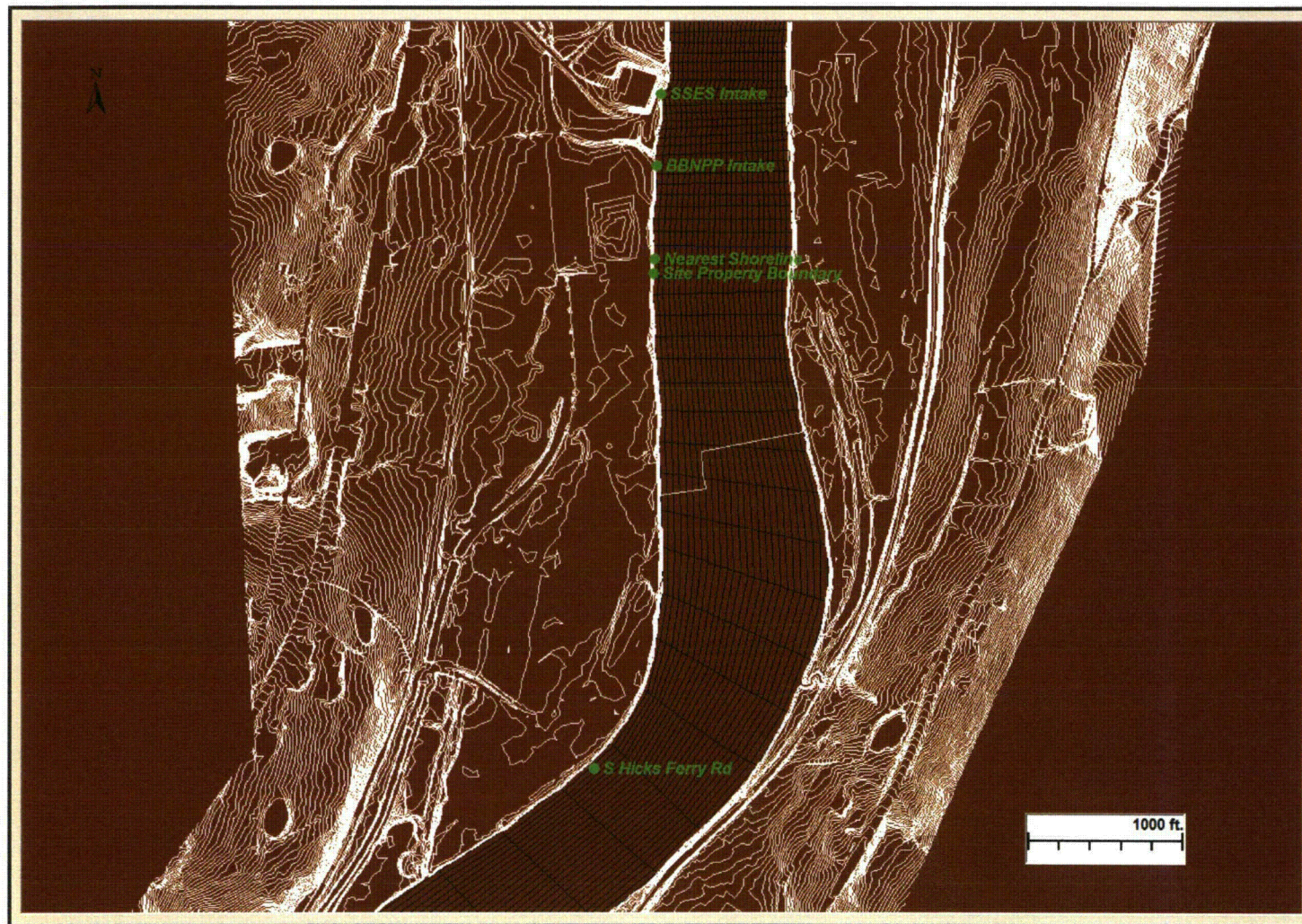


Figure 35 Dilution value locations

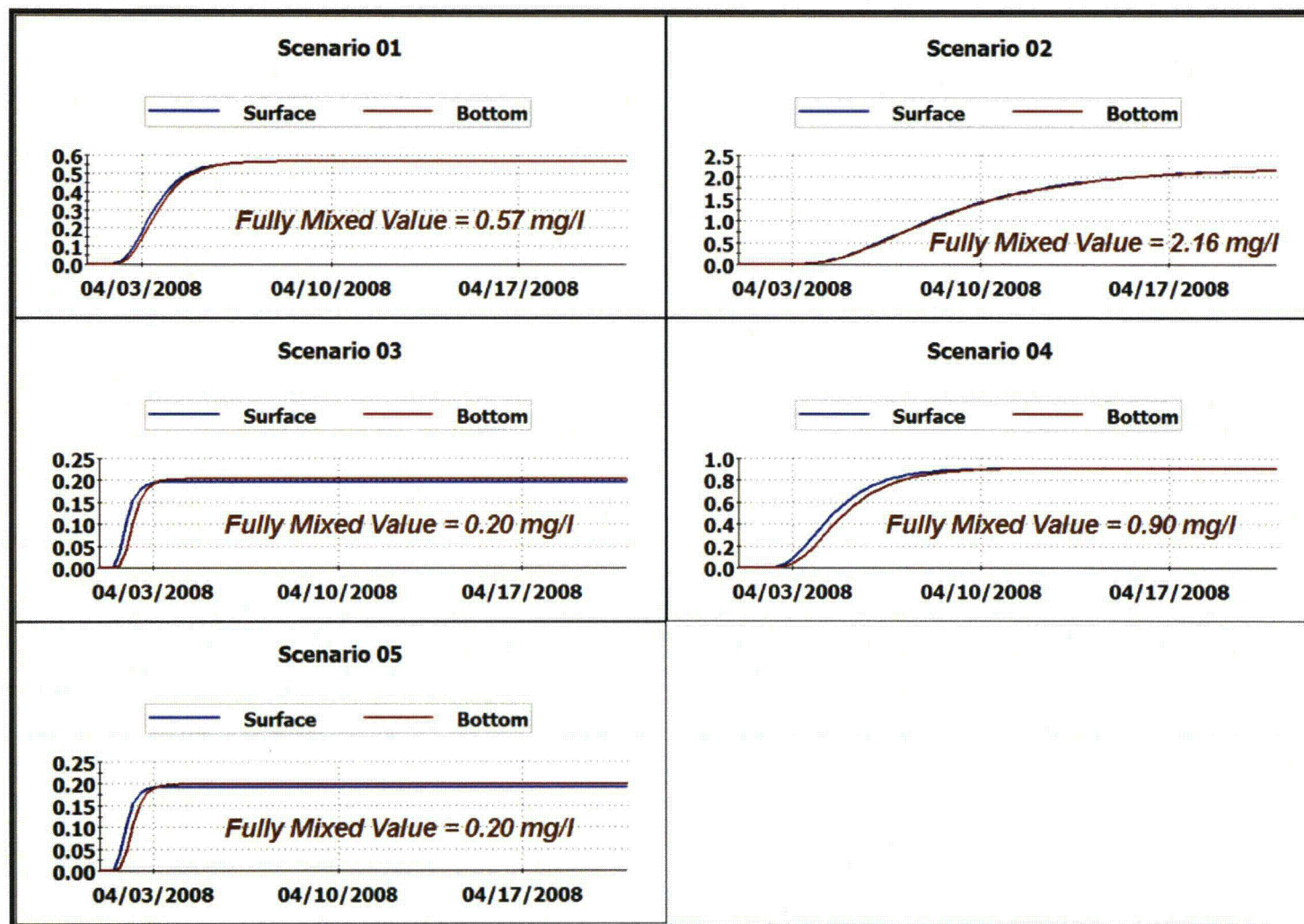


Figure 36 Fully-mixed concentrations for dilution study

Curves show values obtained from GEMSS simulations and the italicized text shows values obtained from fully-mixed analytical calculation (Equation 3).