Table 5-91. CPUE (number/collection) and water temperature for fishes collected with a seine at Station 220, July and August 2010-2013.

	2010		2011		2012		2013	
	July	August	July	August	July	August	July	August
Collection water temperature (°C)	29.2	28	28.1	27.8	30.8	29.1	28.6	24.8
Gizzard shad		**3**	**1**	**1**		**1**		**4**
Cutlips minnow						1		
Comely shiner		6				2		2
Spottail shiner	3	9				9	1	55
Spotfin shiner	**33**	**50**	**12**	**11**	**36**	**25**	**20**	**33**
Bluntnose minnow	**5**	**9**	**4**			**24**	**5**	**24**
Fallfish				7				
Quillback				1				
Northern hogsucker	2		5	2		5	1	2
Shorthead redhorse	1			2		1		1
Rock bass		1				4	4	
Green sunfish				3		1	2	
Bluegill	**2**	**13**		**6**		**21**	**1**	**1**
Smallmouth bass	**1**	**1**	**2**	**2**	**1**	**1**	**5**	**2**
Greenside darter		2						
Yellow perch							1	
Tessellated darter						1		
Chesapeake logperch	**9**	**2**		**2**		**3**		**19**
Total CPUE	56	96	24	37	37	99	40	143
Total species	8	10	5	10	2	14	9	10

Table 5-92. CPUE (number/collection) and water temperature for fishes collected with a seine at Station 221, July and August 2010-2013.

	2010		2011		2012		2013	
	July	August	July	August	July	August	July	August
Collection water temperature (°C)	30.2	25.1	31.2	20.8	26.1	30.2	21.2	21.6
Gizzard shad	**2**	**1**						
Comely shiner		1				4		3
Spottail shiner	1					38		28
Spotfin shiner	**19**	**5**	**6**	**10**	**1**	**1**	**2**	**1**
Bluntnose minnow		**1**	**4**	**6**		**18**	**1**	**19**
Quillback	2		7					
White sucker	**5**				**1**	**1**		**29**
Northern hogsucker	2	2	7	6		1		1
Shorthead redhorse	1		5				2	
Channel catfish								**2**
Banded killifish	1	1	5	1			1	13
Rock bass			1					
Bluegill					**1**			**1**
Smallmouth bass	**3**	**1**						**1**
Tessellated darter	3	12	1	2	6	6	2	5
Chesapeake logperch		**2**						**1**
Shield darter								1
Total CPUE	39	26	36	25	9	69	8	105
Total species	10	9	8	5	4	7	5	13

Table 5-93. CPUE (number/collection) and water temperature for fishes collected with a seine at Station 208, July and August 2010-2013.

	2010		2011		2012		2013	
	July	August	July	August	July	August	July	August
Collection water temperature (°C)	31.2	29.5	31.7	25.1	31.7	28.8	26.5	27.1
Comely shiner					1	1		
Spottail shiner				1		1		2
Spotfin shiner	**175**	**17**	**3**	**2**	**23**	**9**	**12**	**7**
Bluntnose minnow	**2**	**1**	**7**	**1**			**8**	**44**
Quillback	3		1					
White sucker								**1**
Northern hogsucker				1		1		
Banded killifish							2	7
Rock bass					1		1	
Green sunfish		1		4		3		12
Pumpkinseed		1						
Bluegill		**2**				**3**	**9**	**9**
Smallmouth bass				**2**			**6**	**1**
Largemouth bass	**2**							**1**
Greenside darter				1		1		2
Tessellated darter		1				7	2	2
Chesapeake logperch		**1**					**1**	**6**
Shield darter				1			1	3
Total CPUE	182	24	11	13	25	26	42	97
Total species	4	7	3	8	3	8	9	13

Table 5-94. CPUE (number/collection) and water temperature for fishes collected with a seine at Station 214, July and August 2010-2013.

	2010		2011		2012		2013	
	July	August	July	August	July	August	July	August
Collection water temperature (°C)	36.5	34.9	35.7	33.4	36.6	35.4	33.6	31.4
Gizzard shad	**3**			**7**			**2**	
Central stoneroller							4	1
Common carp				2				
Comely shiner						3		1
Spottail shiner	1							
Spotfin shiner		**9**		**21**	**62**	**107**	**62**	**10**
Bluntnose minnow				**4**		**13**	**6**	**2**
Blacknose dace								1
Channel catfish			**1**	**1**				
Banded killifish			2					
Green sunfish	2			1		3		
Bluegill	**7**	**1**		**2**		**6**		**1**
Smallmouth bass							**1**	
Largemouth bass				**1**				
Chesapeake logperch								**1**
Total CPUE	13	10	3	39	62	132	75	17
Total species	4	2	2	8	1	5	5	7

Table 5-95. CPUE (number/collection) and water temperature for fishes collected with a seine at Station 215, July and August 2010-2013.

	2010		2011		2012		2013	
	July	August	July	August	July	August	July	August
Collection water temperature (°C)	34.5	34.1	34.5	32.3	36.2	34.3	32.6	30.3
Gizzard shad	**4**			**4**				
Comely shiner							1	2
Spottail shiner								5
Spotfin shiner	**51**	**69**	**87**	**14**	**34**	**42**	**8**	**39**
Bluntnose minnow	**6**	**7**		**1**		**2**		**4**
Shorthead redhorse								1
Channel catfish							**1**	
Green sunfish	13	6				9		
Bluegill	**28**	**5**		**4**		**50**		**2**
Smallmouth bass				**1**	**1**		**4**	**2**
Largemouth bass	**1**							
Total CPUE	103	87	87	24	35	103	14	55
Total species	6	4	1	5	2	4	4	7

Length-Frequency Distribution

Length-frequency distributions of fish populations can provide an indication of rates of reproduction, recruitment, growth, and mortality of the age groups present. The length distributions and their changes over time can help in understanding population variations and identifying problems such as year-class failures or low recruitment, slow growth, or excessive annual mortality (Anderson and Neumann 1996). The presence of small-sized fish represents successful spawning and subsequent survival and multimodal distribution is indicative of several age classes. Note that interpretation of the data is dependent on the gear-related selectivity for certain sizes and numbers of fish. Data from the three sampling gears used in this study were combined where feasible to aid interpretation of the distributions. Only fish collected during the summer and fall (June to October) were included in this analysis to elucidate potential differences in distribution relative to the warmest times of the year.

For this analysis sampling sites were grouped into non-thermal and thermal stations based on their location in relation to the PBAPS thermal plume. Stations downstream of the discharge canal that experience elevated water temperatures above ambient water temperature for the entire collection period are considered to be thermally influenced. Stations that are upstream of the PBAPS thermal discharge that experience natural water temperature conditions are considered non-thermal (Figure 5-22 to Figure 5-24; Table 5-12 to Table 5-14). Electrofishing stations 161, 189, 190, and 217 are considered thermally influenced and stations 187, 164, and 165 are considered non-thermal. Seine stations 214 and 215 are considered thermal influenced

and stations 203, 202, 220, 221, and 208 are considered non-thermal. As previously discussed in Section 5.2, Station 208 does experience elevated water temperatures during a portion of the year resulting from thermal plume movement upstream during low flow conditions; however, this station is considered non-thermal because it does not experience a prolonged year-round thermal influence. Trawl transects 370, 380, 330, and 340 are considered to be thermally influenced and transect 320 is considered non-thermally influenced.

Bluegill

The length frequencies of Bluegill collected at the thermal and non-thermal stations exhibit similar multimodal distributions for the separate years 2010, 2011, 2012, and 2013 with a preponderance of the fish smaller than 60 mm (Figure 5-63 through Figure 5-66). In each year the number of small individuals (<60 mm) collected at the thermal stations was high, suggesting spawning activity in areas affected by the thermal plume (Table 5-96 through Table 5-98). The annual mode of small (20 to 60-mm) Bluegill for the thermal stations tends to be within the 45 to 60-mm intervals, whereas the mode for the non-thermal stations is slightly larger, within the 60 to 75–mm intervals. This slight difference appears to be due to collection of more small (<50 mm) Bluegill earlier in the year at the thermal stations. Additionally, other modes were present, indicating multiple age classes were present at both thermal and non-thermal stations. The overall similarity of the length frequency distributions indicates substantially similar successful reproduction, recruitment and growth of Bluegill in and near the thermally affected and non-thermally affected habitats represented by the sampling stations.

Bluntnose Minnow

Although the sample sizes were small, comparisons of the length frequencies of Bluntnose Minnow between the thermal and non-thermal stations exhibit similar multimodal distributions for the separate years 2010, 2011, and 2012 (Figure 5-67 through Figure 5-69). In 2013 with a larger sample size, Bluntnose Minnow exhibited a similar multimodal distribution between thermal and non-thermal stations (Figure 5-70). Each mode roughly corresponds to a separate year class. Like Bluegill, smaller (<50 mm) Bluntnose Minnow were collected in similar numbers at the thermal stations and the non-thermal stations, although in 2013 greater numbers of fish <45 mm were collected at the non-thermal stations. The presence of fish <50 mm suggests spawning activity in the thermally affected areas (Table 5-96 through Table 5-99).

Channel Catfish

Comparisons of the length frequencies of Channel Catfish between the thermal and non-thermal stations exhibit similar multimodal distributions for the separate years 2010, 2011, 2012, and 2013 (Figure 5-71 through Figure 5-73). Each mode roughly corresponds to a separate year class. Like the other species, small (<100 mm) Channel Catfish were collected in large numbers at the thermal stations suggesting spawning activity in the thermally affected areas (Table 5-96 through Table 5-99).

Gizzard Shad

Comparisons of the length frequencies of Gizzard Shad between the thermal and non-thermal stations exhibit similar multimodal distributions for the separate years 2010 through 2012, with a preponderance of the fish being smaller than 100 mm (Figure 5-75 through Figure 5-77). In 2013 the distribution of Gizzard Shad shifted with a preponderance of the fish between 100 and 140 mm at both the thermal and non-thermal stations (Figure 5-78.) Each mode roughly corresponds to a separate year class. Gizzard Shad were collected in greater numbers at the thermal stations than the non-thermal stations, including large numbers of individuals less than 100 mm, suggesting spawning activity in the thermally affected areas (Table 5-96 through Table 5-99).

Largemouth Bass

Due to the extremely small numbers of Largemouth Bass that were collected from the non-thermal stations, comparisons of the length frequencies of between the thermal and non-thermal stations were not deemed meaningful. Over the course of the last four years, few Largemouth Bass were collected from the non-thermal stations compared to several hundred that were collected at the thermal stations (Table 5-96 through Table 5-99). The length frequency distribution at the thermal stations exhibited a multimodal distribution for the separate years 2010, 2011, 2012, and 2013 (Figure 5-79 through Figure 5-82). Each mode roughly corresponds to a separate year class, indicating that multiple year classes were present at the thermal stations.

Chesapeake Logperch

Although over the course of the first three years of study reasonably similar totals of Chesapeake Logperch were collected from thermal and non-thermal stations, much between-year and station variability was observed (Table 5-96 through Table 5-99). In a given year, greater numbers of logperch came from either one type of station or the other. However, the very limited numbers collected each year indicated similar length distributions (Figure 5-83 through Figure 5-85). In 2013 greater numbers of Chesapeake Logperch were collected at both thermal and non-thermal stations with similar length distributions observed (Figure 5-86).

Smallmouth Bass

Similar numbers of Smallmouth Bass collected from the thermal and non-thermal stations (Table 5-96 -Table 5-99) allow valid comparison of length distributions in each of the four years. Length frequencies of Smallmouth Bass at the thermal and non-thermal stations exhibit similar multimodal distributions for the separate years 2010, 2011, 2012, and 2013 (Figure 5-87 through Figure 5-90). Each mode roughly corresponds to a separate year class. In 2010 larger Smallmouth Bass were collected from the thermal stations (Figure 5-87). During 2011 very similar distributions were observed (Figure 5-88). In 2012 the distributions were similar except for larger numbers of 70 to 90-mm Smallmouth Bass that were collected from the thermal stations (Figure 5-89). This slight difference appears to be due to collection of more Smallmouth Bass earlier in the year at the thermal stations, rather than any difference in growth rates or

attraction or repelling of fish in response to the thermal plume. In 2013 the distributions were similar except greater numbers of 60 to 100-mm Smallmouth Bass were collected at the thermal stations (Figure 5-90).

Spotfin Shiner

Similar numbers of Spotfin Shiner collected from the thermal and non-thermal stations (Table 5-96 through Table 5-99) allow valid comparison of length distributions in each of the 4 years. The numbers collected each year indicated similar multimodal distributions, suggesting the presence of multiple year classes and spawning activity (Figure 5-91 through Figure 5-94).

Walleye

Similar numbers of Walleye were collected from the thermal and non-thermal stations (Table 5-96 through Table 5-99). Although sample size was relatively small compared to most other RIS species, a sufficient number was collected to allow valid comparison of length distributions in each of the 4 years. Distributions in 2010, 2012, and 2013 were similar, especially in 2012. A greater range of lengths was collected in 2011 at the thermal stations than the non-thermal stations, indicating multiple year classes present at the thermal stations (Figure 5-96). In 2013 fewer Walleye were collected from thermal stations with many more fish <200 mm observed at non-thermal stations.

White Crappie

Figures of length distributions for White Crappie were not generated, as only nine individuals were collected from the non-thermal stations and 32 individuals from the thermal stations from June to October over the course of the 4 years (Table 5-96 through Table 5-99). Due to the extremely small numbers of White Crappie that were collected from all stations, comparisons of the length frequencies of between the thermal and non-thermal stations would not have been meaningful.

White Sucker

Figures of length distributions for White Sucker were not generated, as only seven individuals were collected from the non-thermal stations and 13 individuals from the thermal stations from June to October over the course of the 4 years (Table 5-96 through Table 5-99). Due to the extremely small numbers of White Sucker that were collected from all stations, comparisons of the length frequencies of between the thermal and non-thermal stations would not have been meaningful.

Conclusions

For most of the RIS that were evaluated (excluding White Crappie and White Sucker), multimodal length distributions indicated multiple year classes present at both the thermal and non-thermal stations. Differences in length frequency distributions between thermal and non-thermal stations were few and not directly attributable to the thermal plume. Differences in length distributions among species are likely due to habitat differences between stations and the

selection of preferred habitat (e.g. amount of SAV or woody debris) at an individual station. For most RIS, small individuals (young-of-the-year) were collected at the thermal stations, suggesting reproduction by the species near the collection location. Young of the year fishes tend to disperse gradually from spawning areas and their presence at a given location suggests reproduction in the vicinity of the collection site. However, the data provided herein provides no direct mechanism to verify that successful spawning occurred at any of the collection stations. Comparison of length frequency distributions did not indicate distorted distributions (e.g., absence of young-of-the-year or presence of only one year-class), and for most species many year-classes were present including young individuals and several age classes of mature fish. This analysis indicates that the RIS are able to reproduce, grow, and recruit to the fish community within Conowingo Pond.

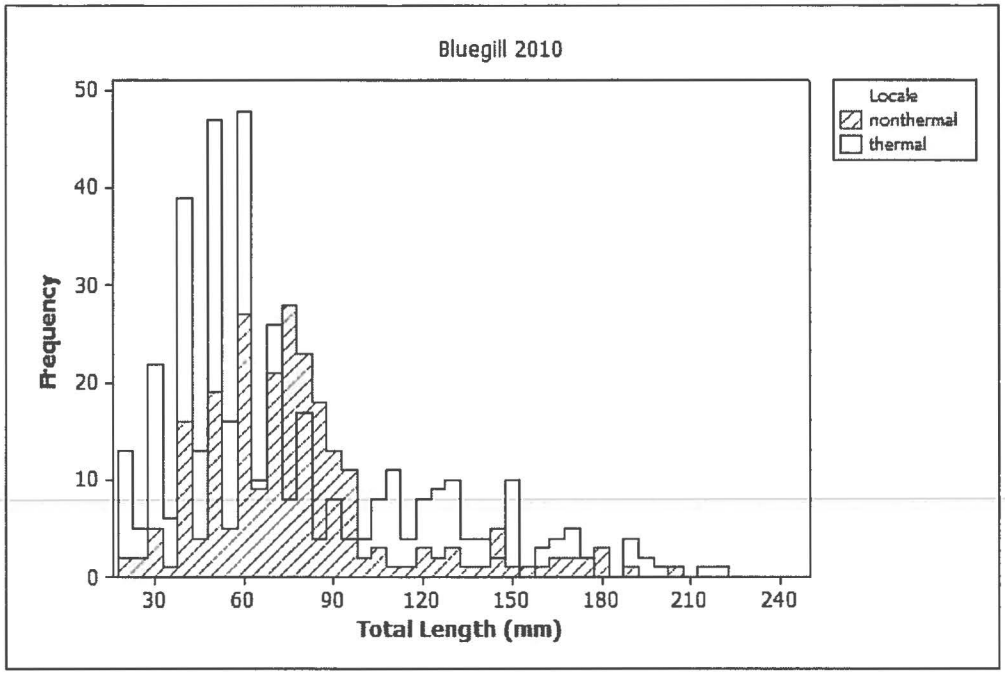


Figure 5-63. Length-frequency distribution of Bluegill collected in Conowingo Pond using all gear types for sample stations upstream (non-thermal) and within the PBAPS thermal plume (thermal), July to October 2010.

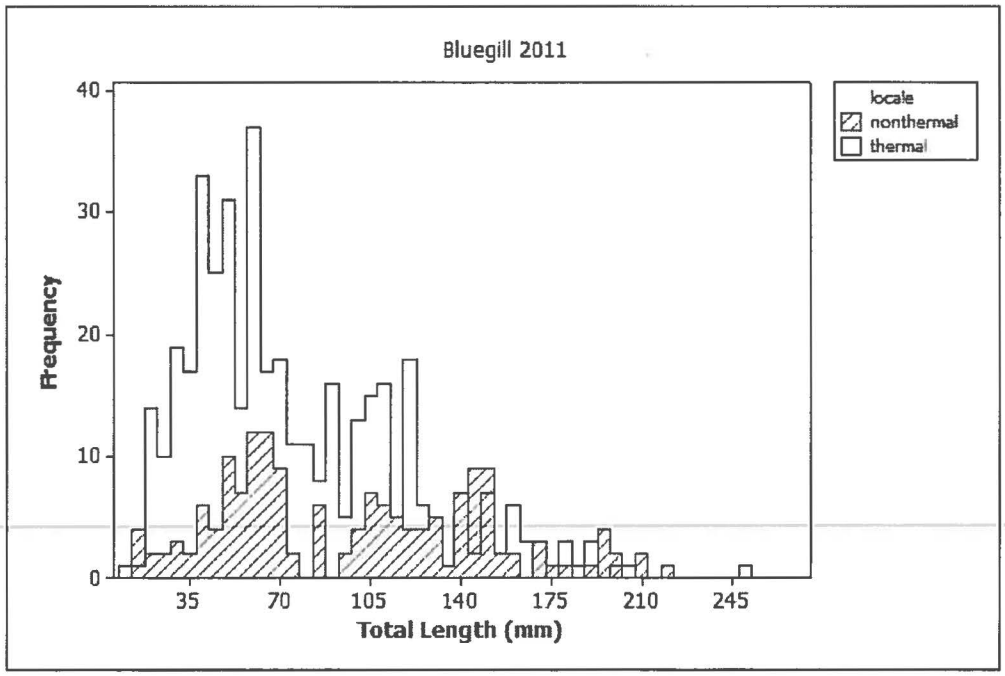


Figure 5-64. Length-frequency distribution of Bluegill collected in Conowingo Pond using all gear types for sample stations upstream (non-thermal) and within the PBAPS thermal plume (thermal), June to October 2011.

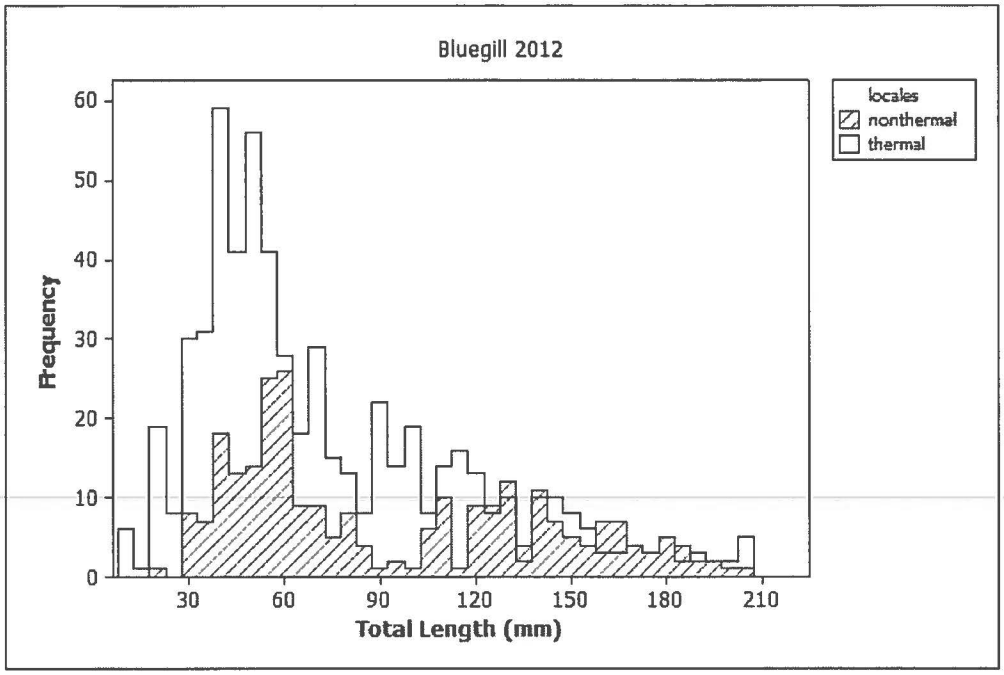


Figure 5-65. Length-frequency distribution of Bluegill collected in Conowingo Pond using all gear types for sample stations upstream (non-thermal) and within the PBAPS thermal plume (thermal), June to October 2012.

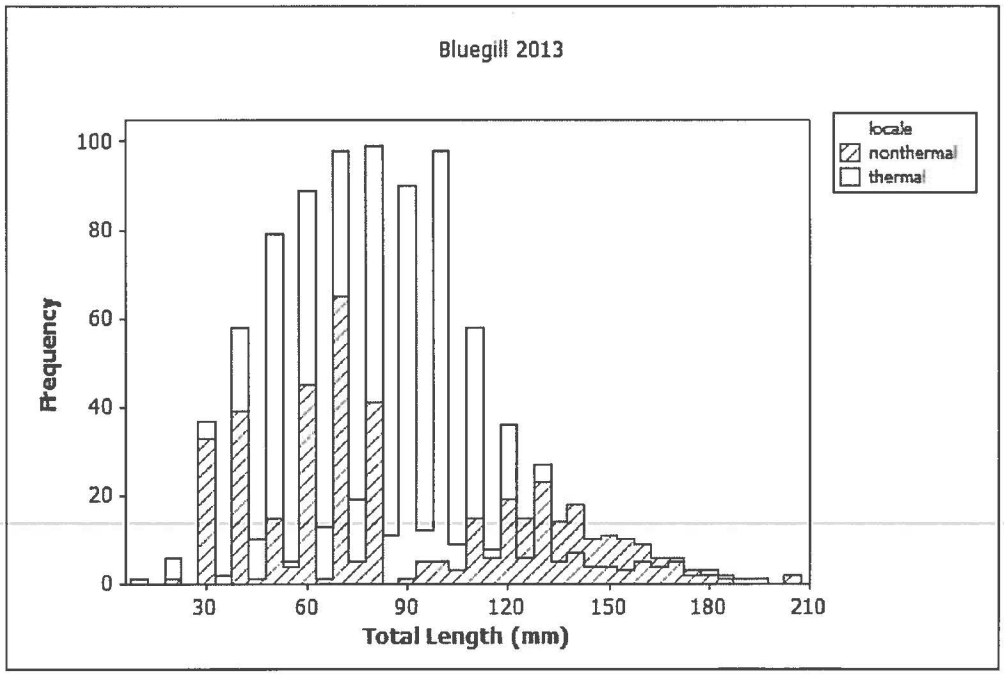


Figure 5-66. Length-frequency distribution of Bluegill collected in Conowingo Pond using all gear types for sample stations upstream (non-thermal) and within the PBAPS thermal plume (thermal), June to October 2013.

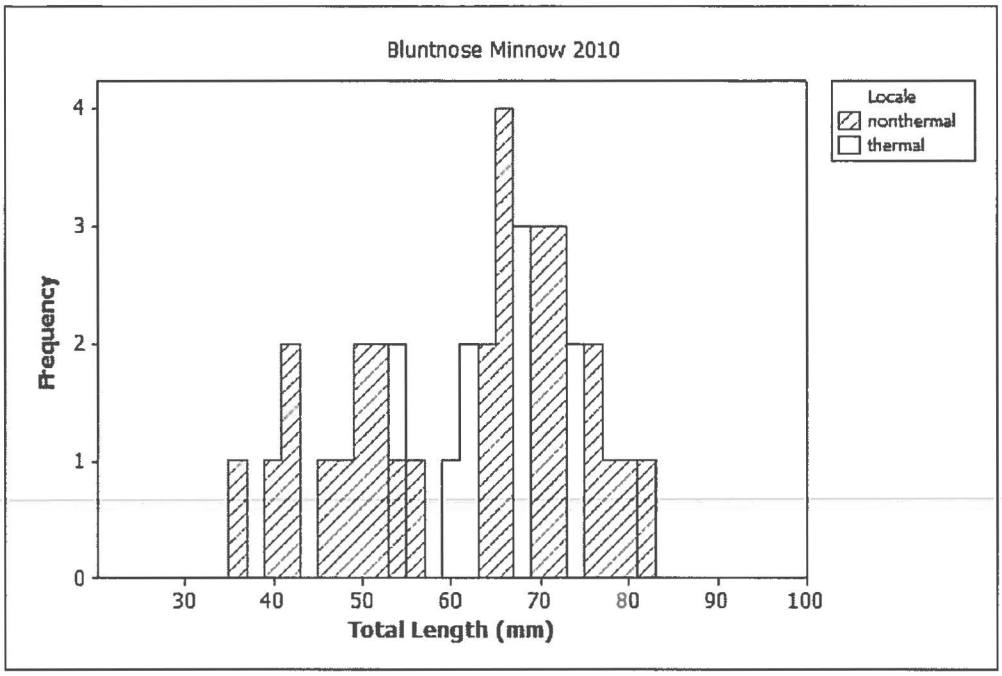


Figure 5-67. Length-frequency distribution of Bluntnose Minnow collected in Conowingo Pond using all gear types for sample stations upstream (non-thermal) and within the PBAPS thermal plume (thermal), July to October 2010.

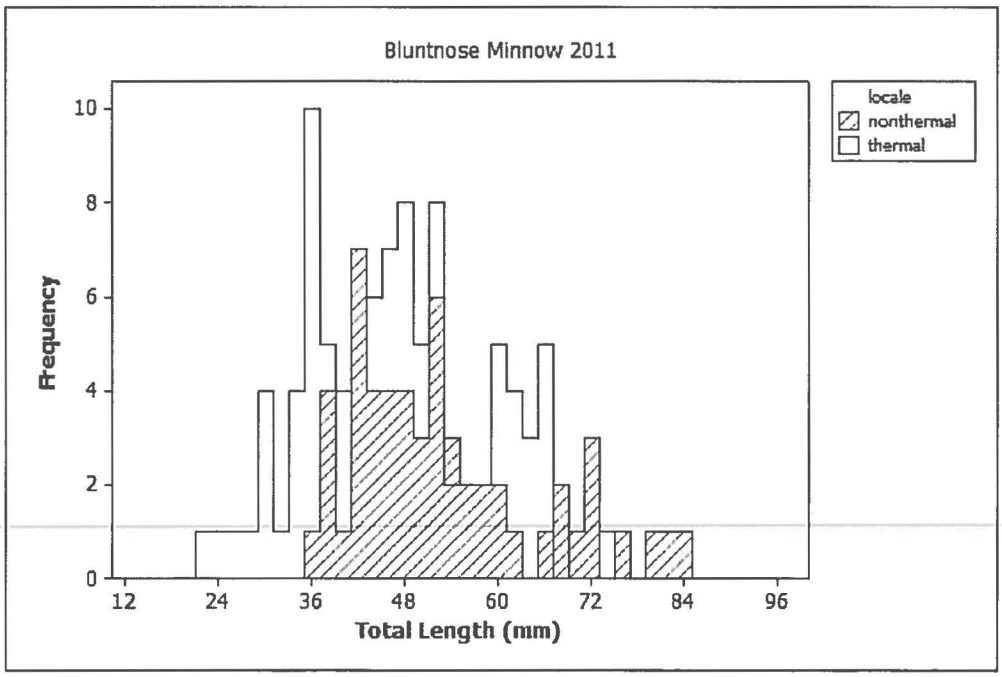


Figure 5-68. Length-frequency distribution of Bluntnose Minnow collected in Conowingo Pond using all gear types for sample stations upstream (non-thermal) and within the PBAPS thermal plume (thermal), June to October 2011.

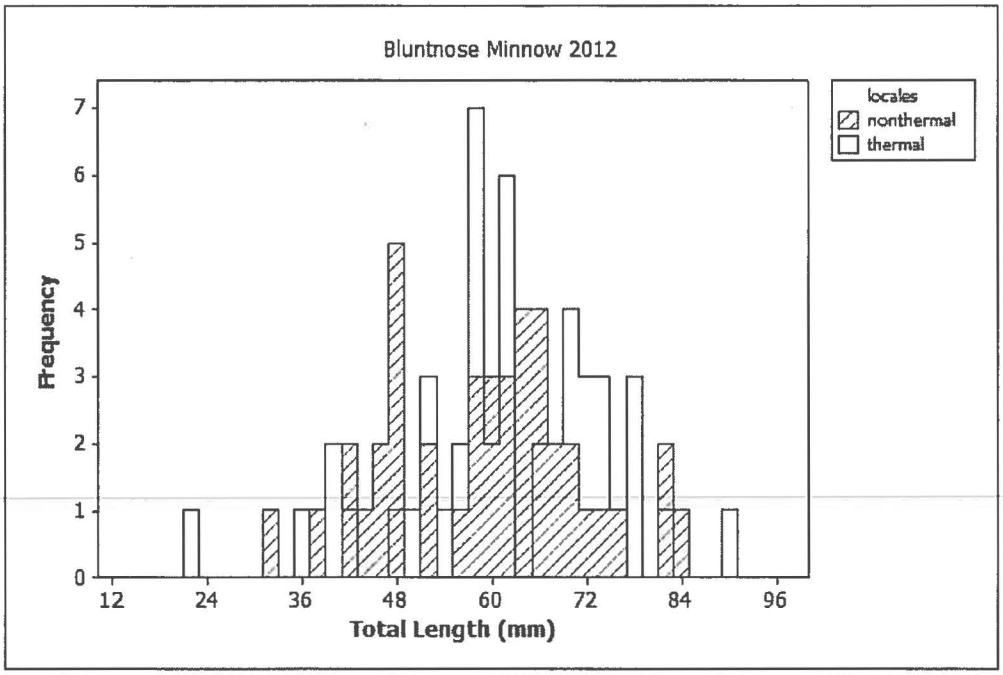


Figure 5-69. Length-frequency distribution of Bluntnose Minnow collected in Conowingo Pond using all gear types for sample stations upstream (non-thermal) and within the PBAPS thermal plume (thermal), June to October 2012.

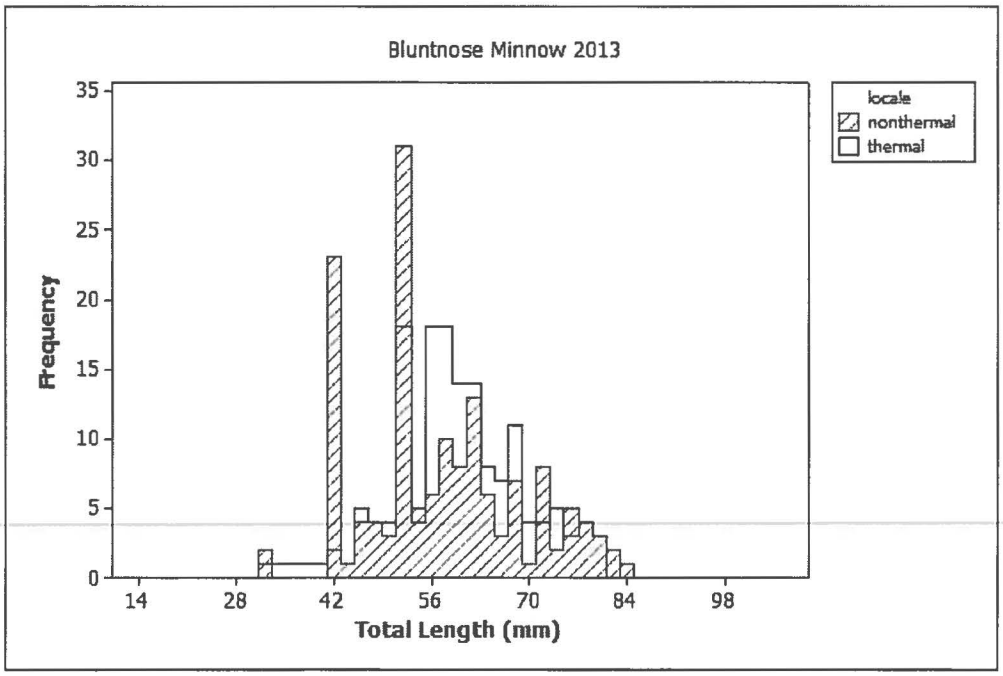


Figure 5-70. Length-frequency distribution of Bluntnose Minnow collected in Conowingo Pond using all gear types for sample stations upstream (non-thermal) and within the PBAPS thermal plume (thermal), June to October 2013.

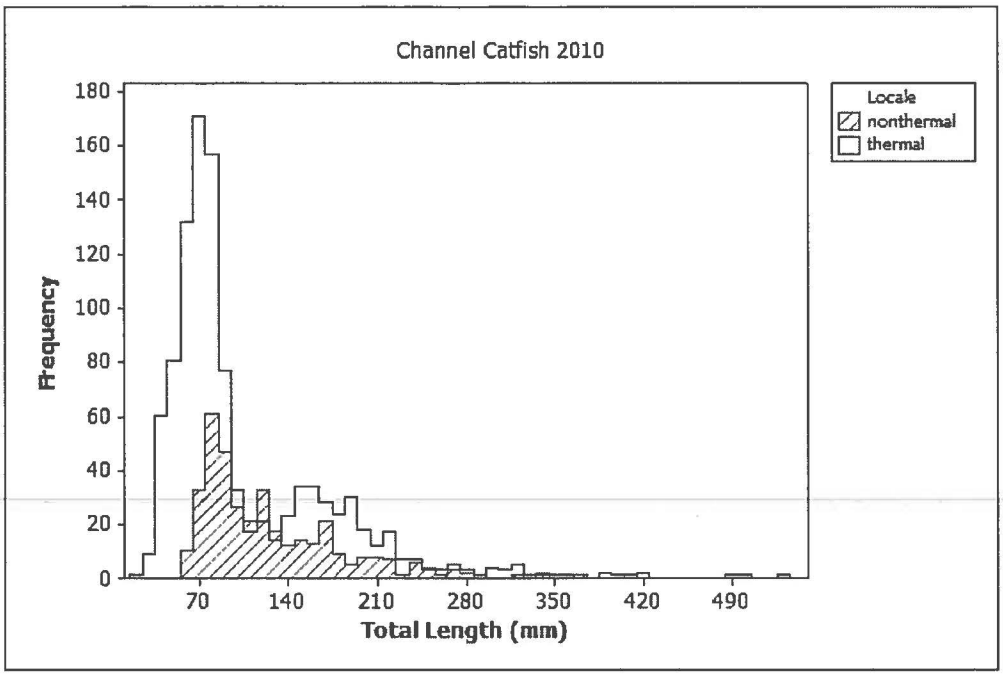


Figure 5-71. Length-frequency distribution of Channel Catfish collected in Conowingo Pond using all gear types for sample stations upstream (non-thermal) and within the PBAPS thermal plume (thermal), July to October 2010.

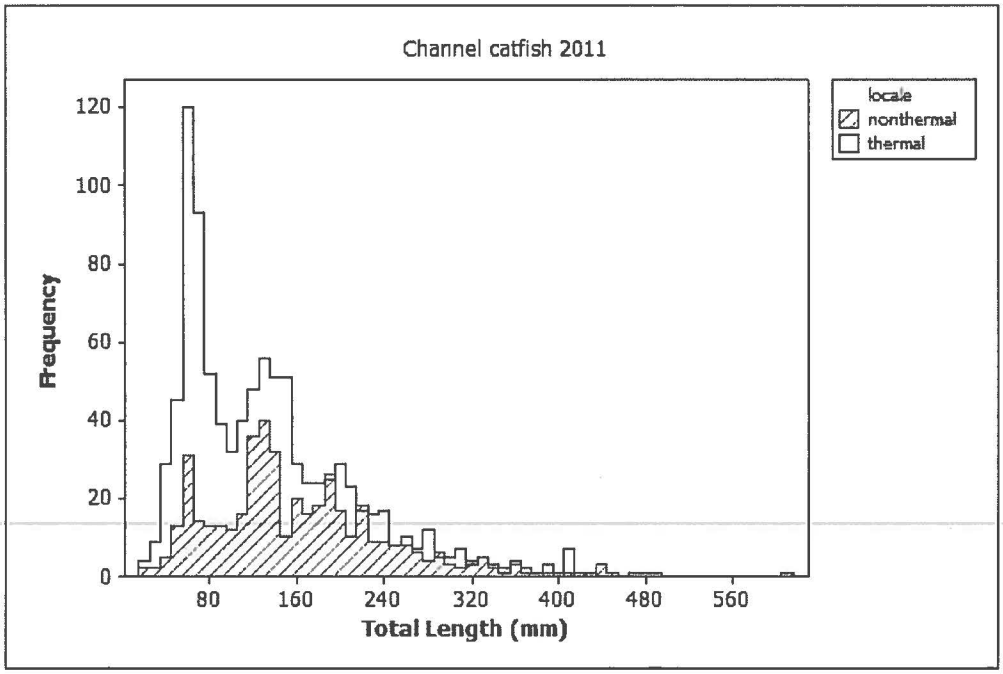


Figure 5-72. Length-frequency distribution of Channel Catfish collected in Conowingo Pond using all gear types for sample stations upstream (non-thermal) and within the PBAPS thermal plume (thermal), June to October 2011.

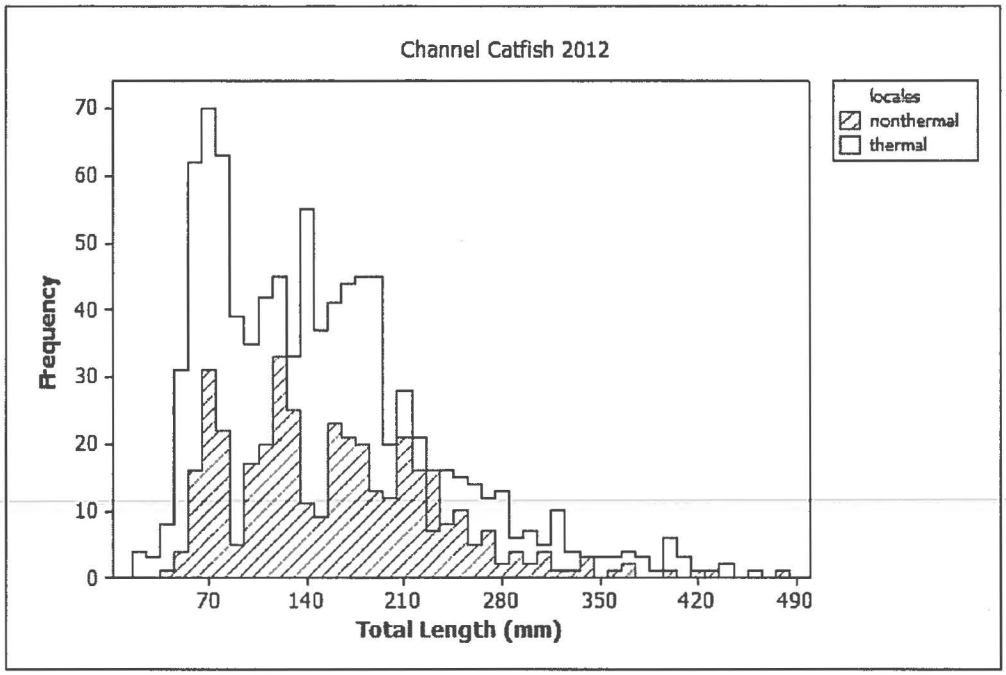


Figure 5-73. Length-frequency distribution of Channel Catfish collected in Conowingo Pond using all gear types for sample stations upstream (non-thermal) and within the PBAPS thermal plume (thermal), June to October 2012.

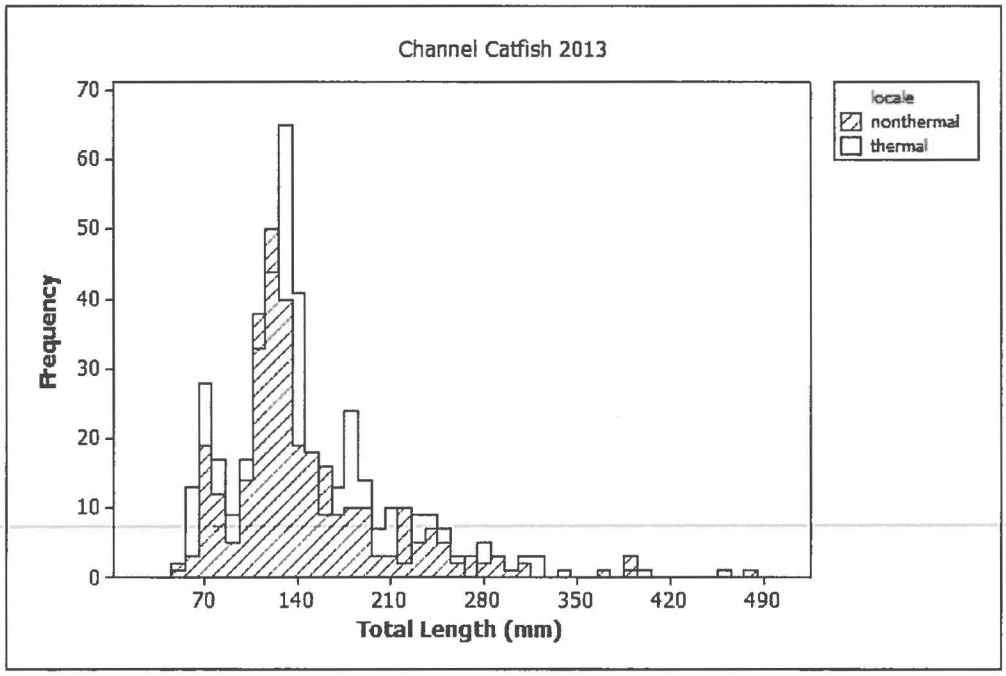


Figure 5-74. Length-frequency distribution of Channel Catfish collected in Conowingo Pond using all gear types for sample stations upstream (non-thermal) and within the PBAPS thermal plume (thermal), June to October 2013.

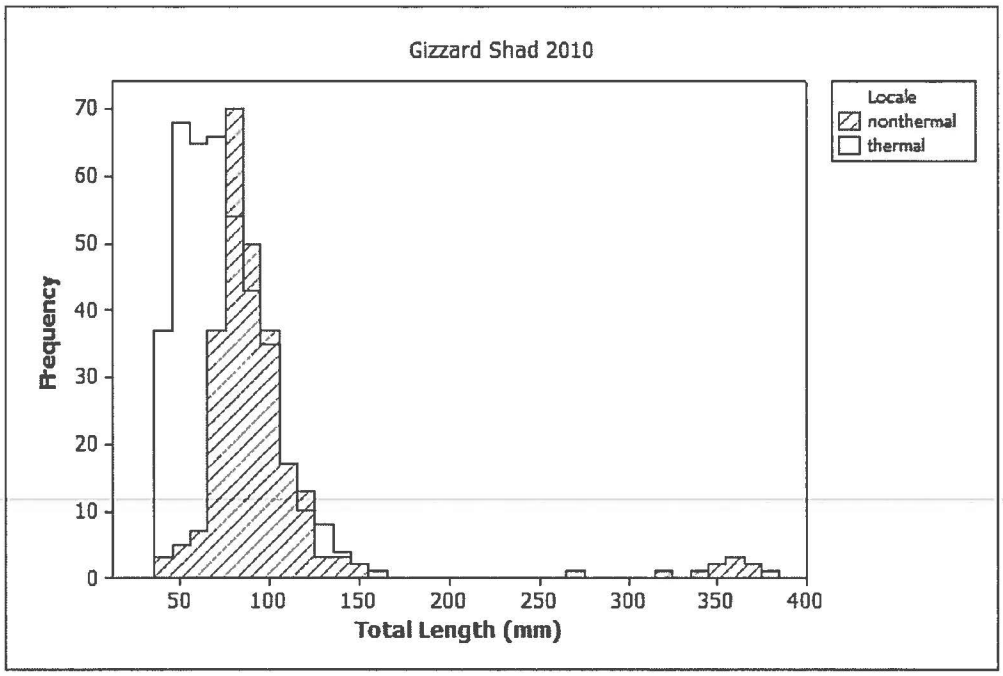


Figure 5-75. Length-frequency distribution of Gizzard Shad collected in Conowingo Pond using all gear types for sample stations upstream (non-thermal) and within the PBAPS thermal plume (thermal), July to October 2010.

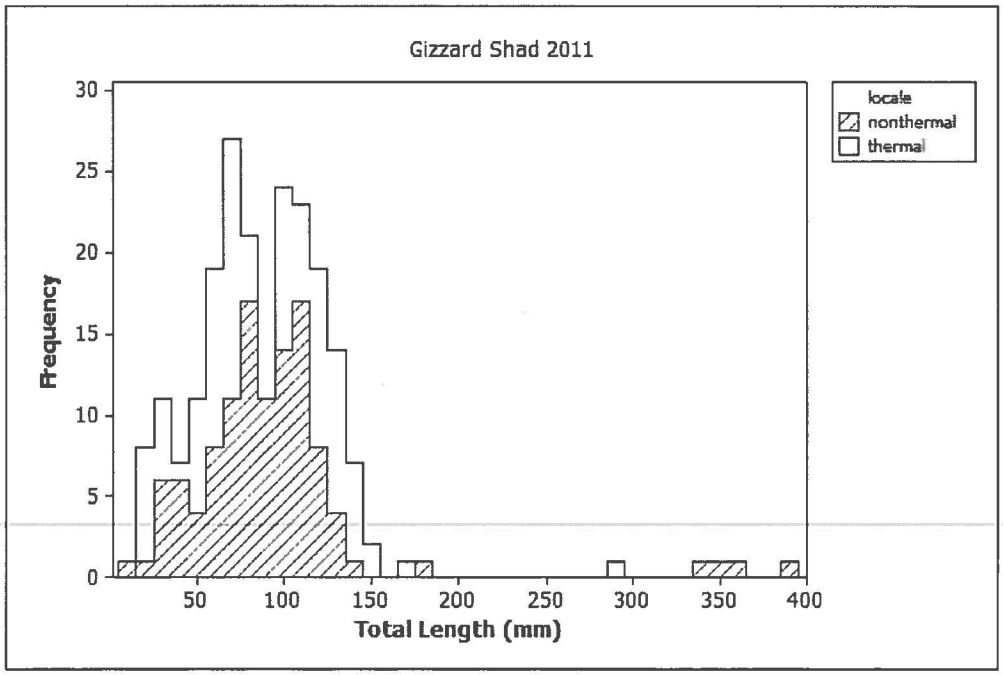


Figure 5-76. Length-frequency distribution of Gizzard Shad collected in Conowingo Pond using all gear types for sample stations upstream (non-thermal) and within the PBAPS thermal plume (thermal), June to October 2011.

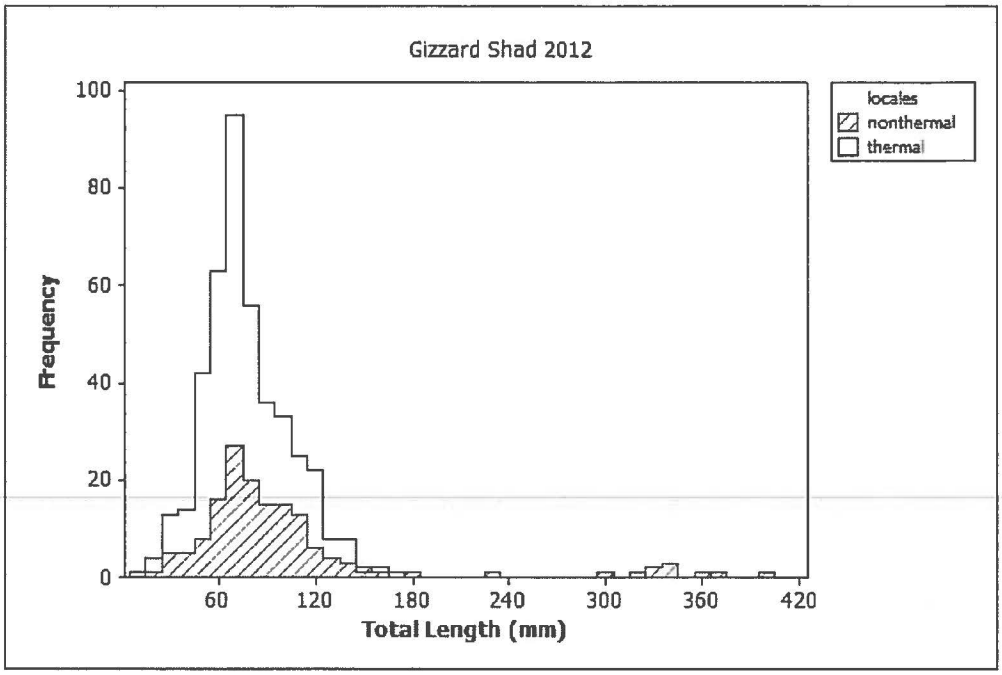


Figure 5-77. Length-frequency distribution of Gizzard Shad collected in Conowingo Pond using all gear types for sample stations upstream (non-thermal) and within the PBAPS thermal plume (thermal), June to October 2012.

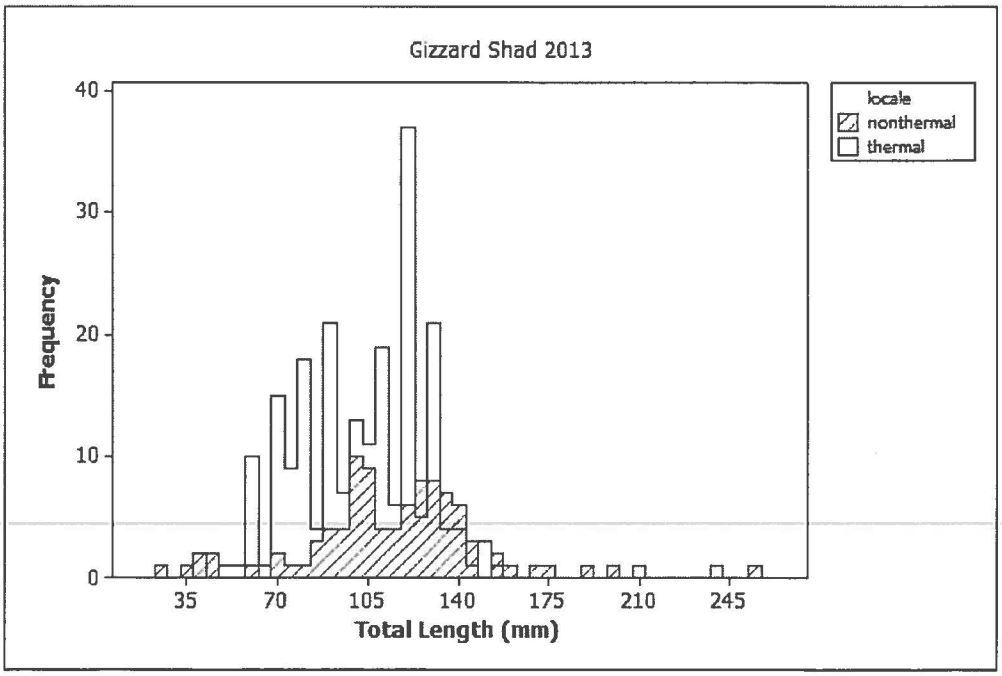


Figure 5-78. Length-frequency distribution of Gizzard Shad collected in Conowingo Pond using all gear types for sample stations upstream (non-thermal) and within the PBAPS thermal plume (thermal), June to October 2013.

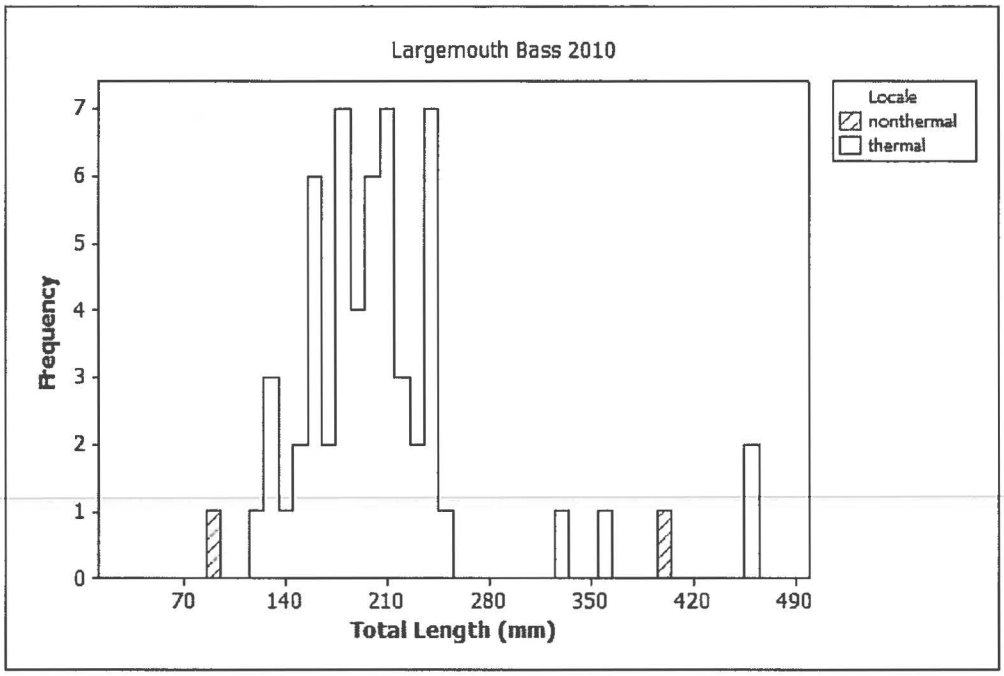


Figure 5-79. Length-frequency distribution of Largemouth Bass collected in Conowingo Pond using all gear types for sample stations upstream (non-thermal) and within the PBAPS thermal plume (thermal), July to October 2010.

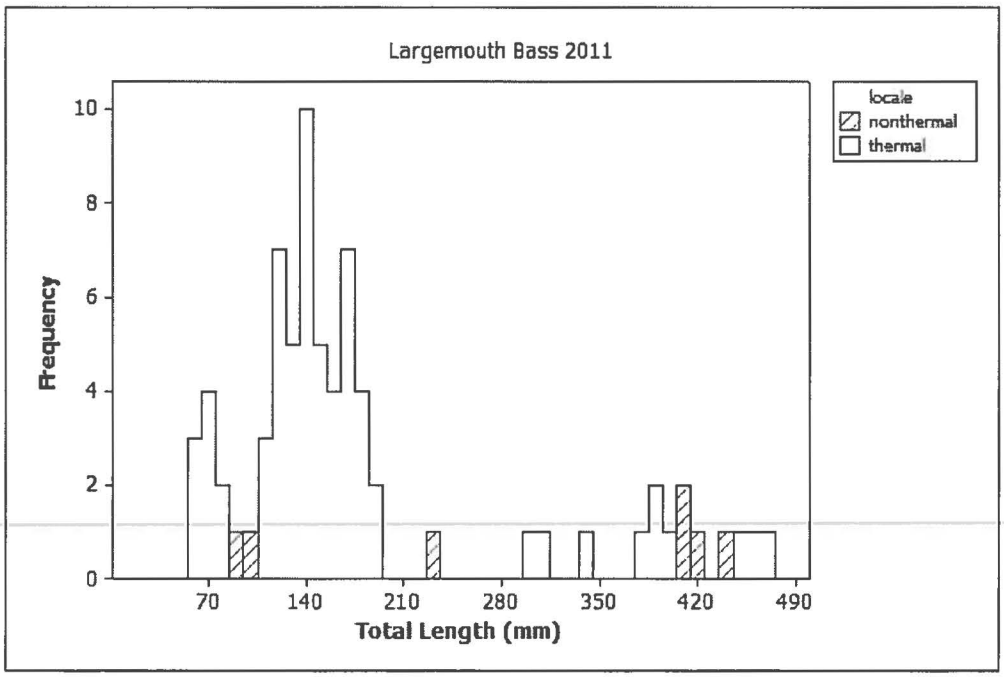


Figure 5-80. Length-frequency distribution of Largemouth Bass collected in Conowingo Pond using all gear types for sample stations upstream (non-thermal) and within the PBAPS thermal plume (thermal), June to October 2011.

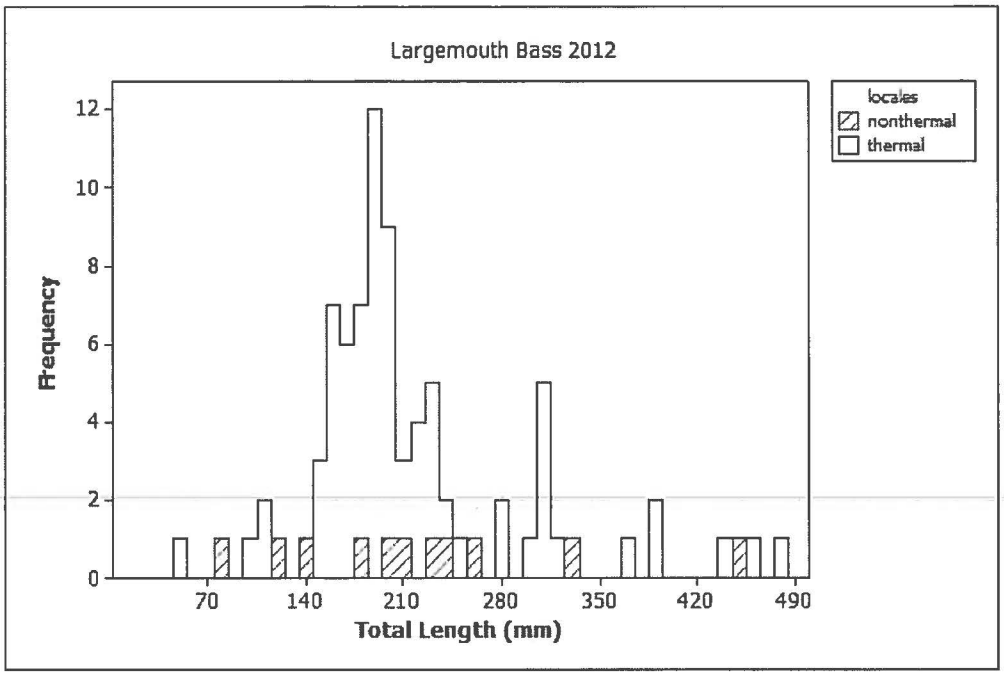


Figure 5-81. Length-frequency distribution of Largemouth Bass collected in Conowingo Pond using all gear types for sample stations upstream (non-thermal) and within the PBAPS thermal plume (thermal), June to October 2012.

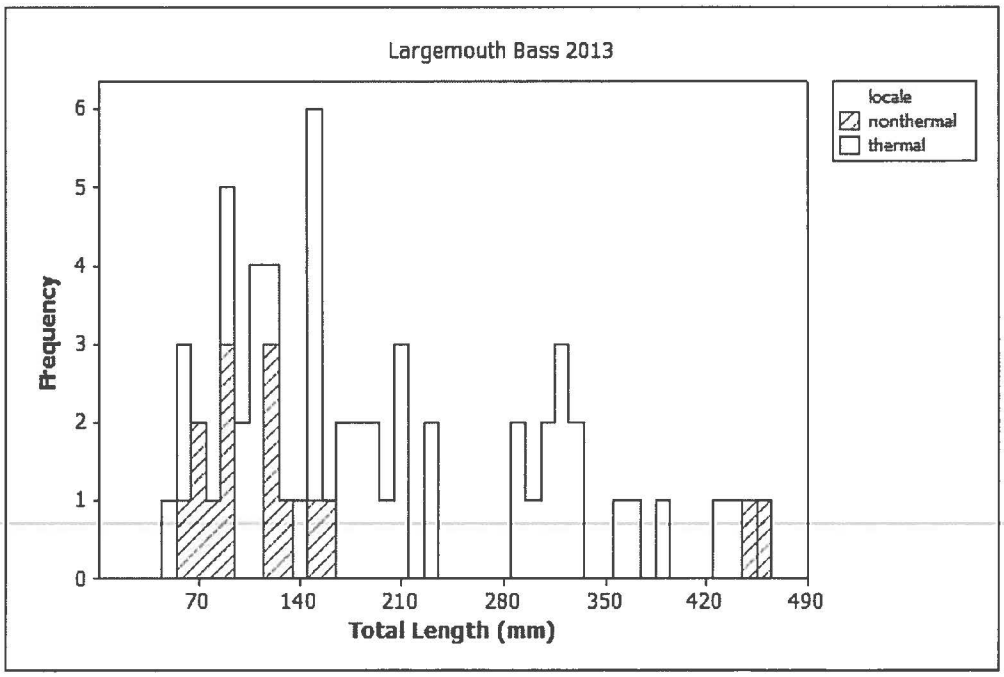


Figure 5-82. Length-frequency distribution of Largemouth Bass collected in Conowingo Pond using all gear types for sample stations upstream (non-thermal) and within the PBAPS thermal plume (thermal), June to October 2013.

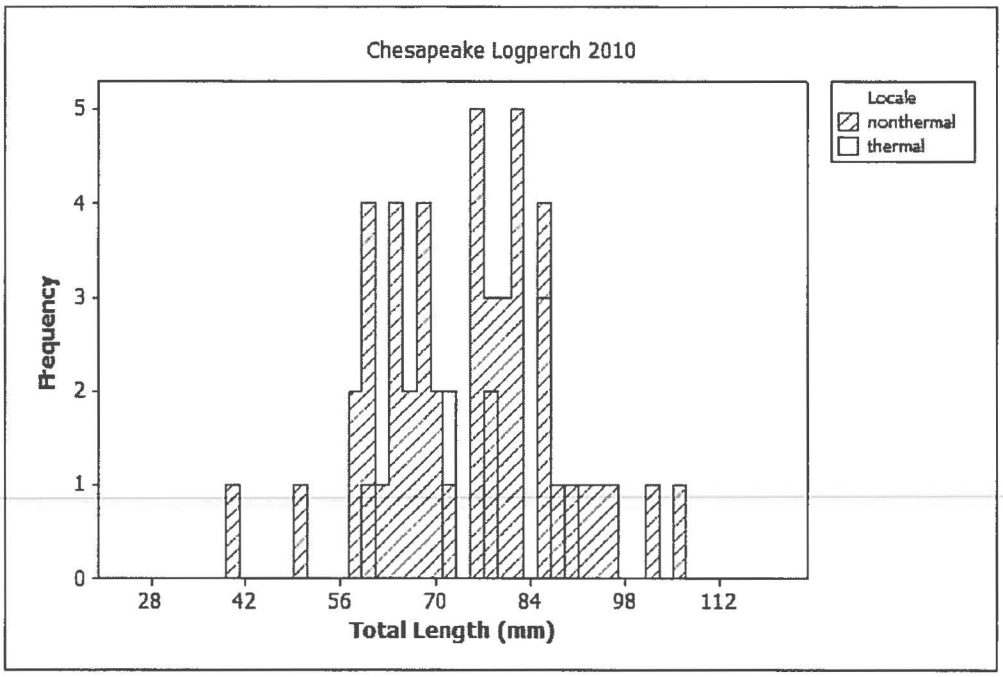


Figure 5-83. Length-frequency distribution of Chesapeake Logperch collected in Conowingo Pond using all gear types for sample stations upstream (non-thermal) and within the PBAPS thermal plume (thermal), July to October 2010.

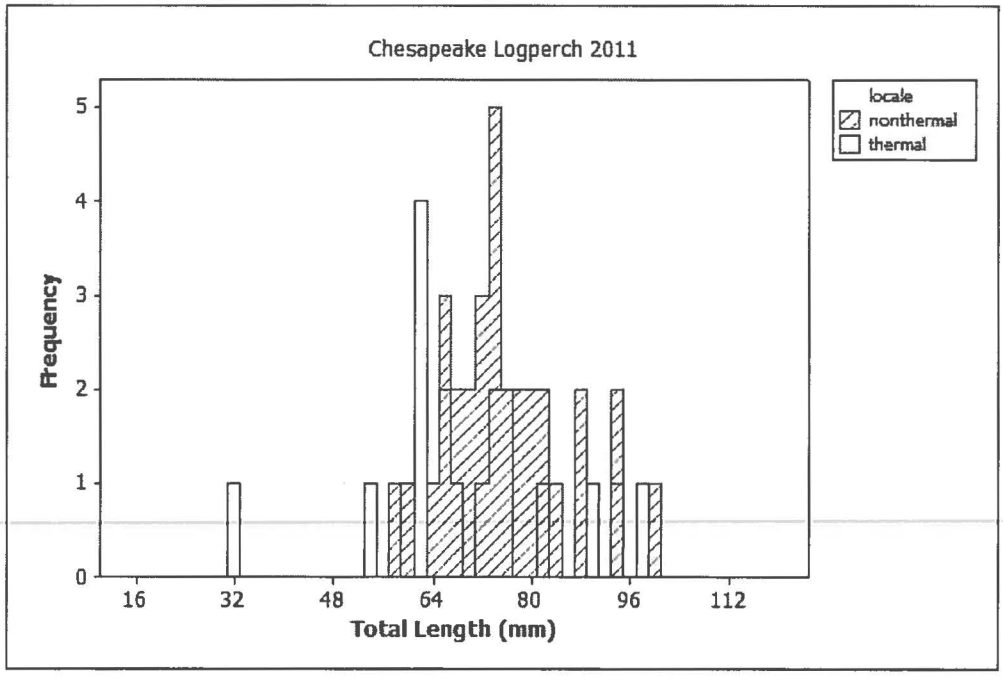


Figure 5-84. Length-frequency distribution of Chesapeake Logperch collected in Conowingo Pond using all gear types for sample stations upstream (non-thermal) and within the PBAPS thermal plume (thermal), June to October 2011.

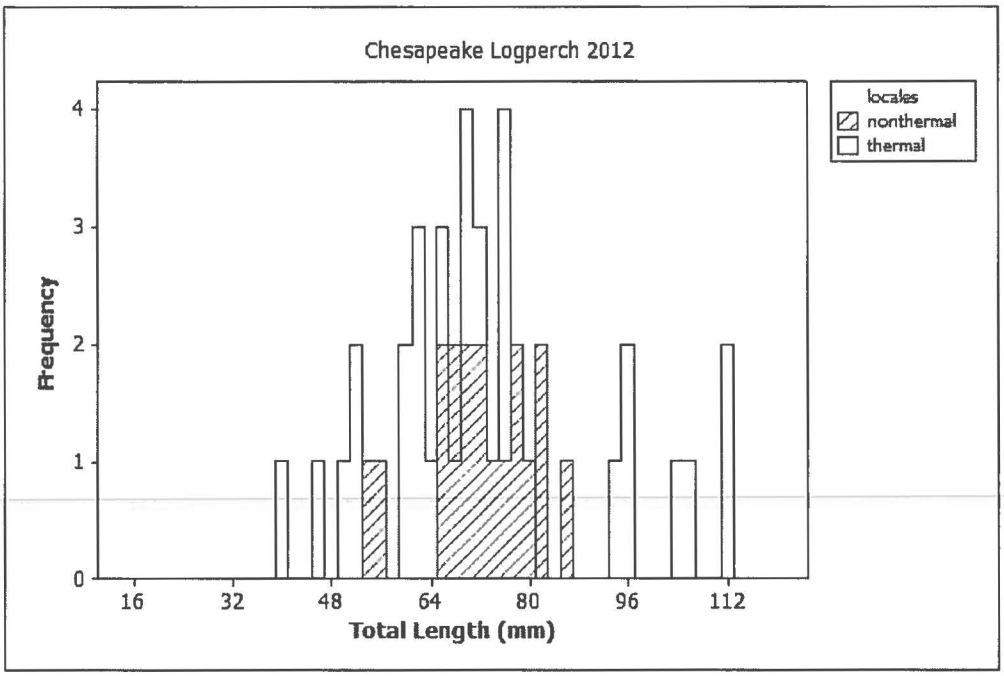


Figure 5-85. Length-frequency distribution of Chesapeake Logperch collected in Conowingo Pond using all gear types for sample stations upstream (non-thermal) and within the PBAPS thermal plume (thermal), June to October 2012.

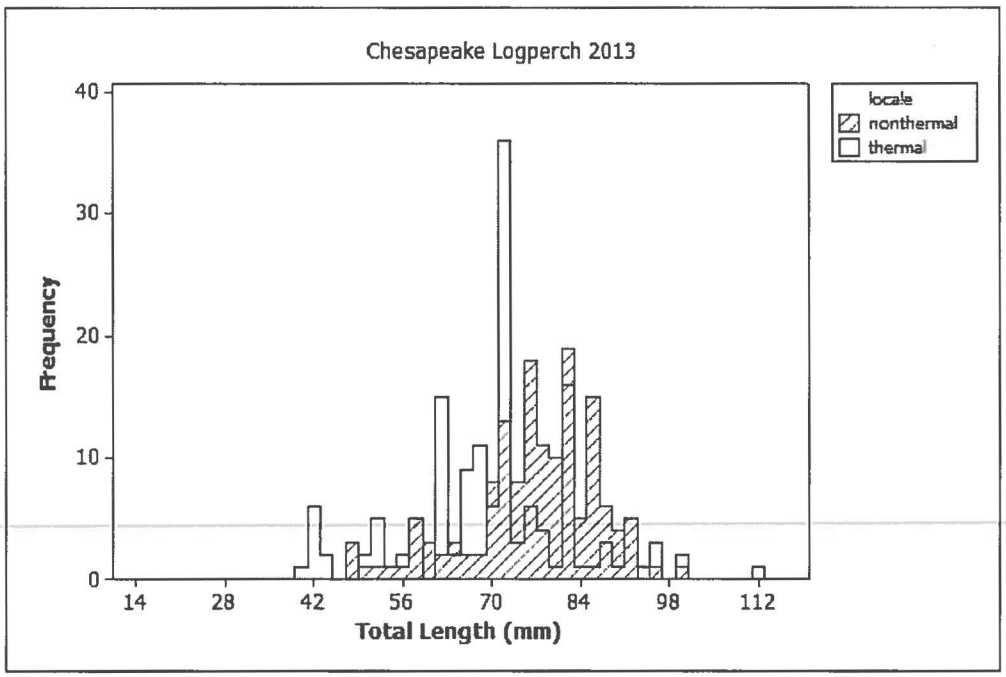


Figure 5-86. Length-frequency distribution of Chesapeake Logperch collected in Conowingo Pond using all gear types for sample stations upstream (non-thermal) and within the PBAPS thermal plume (thermal), June to October 2013.

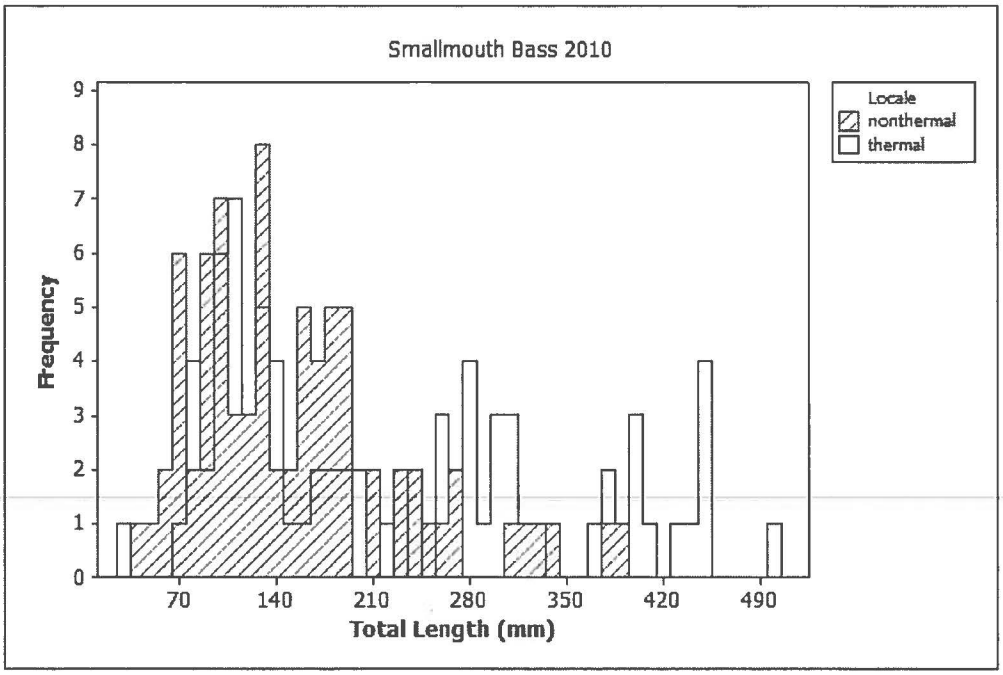


Figure 5-87. Length-frequency distribution of Smallmouth Bass collected in Conowingo Pond using all gear types for sample stations upstream (non-thermal) and within the PBAPS thermal plume (thermal), July to October 2010.

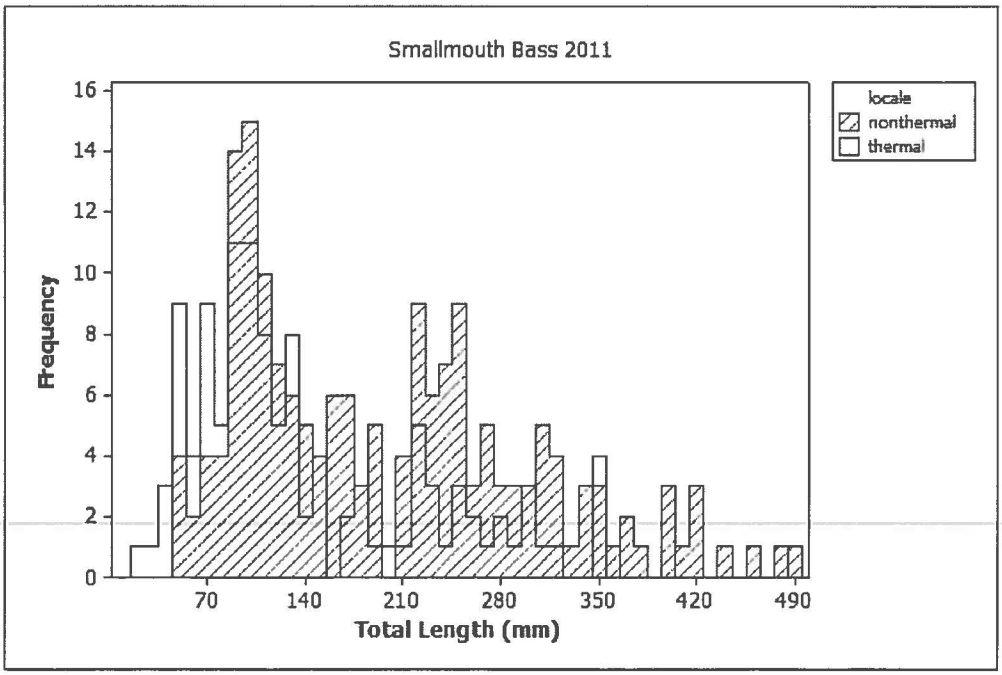


Figure 5-88. Length-frequency distribution of Smallmouth Bass collected in Conowingo Pond using all gear types for sample stations upstream (non-thermal) and within the PBAPS thermal plume (thermal), June to October 2011.

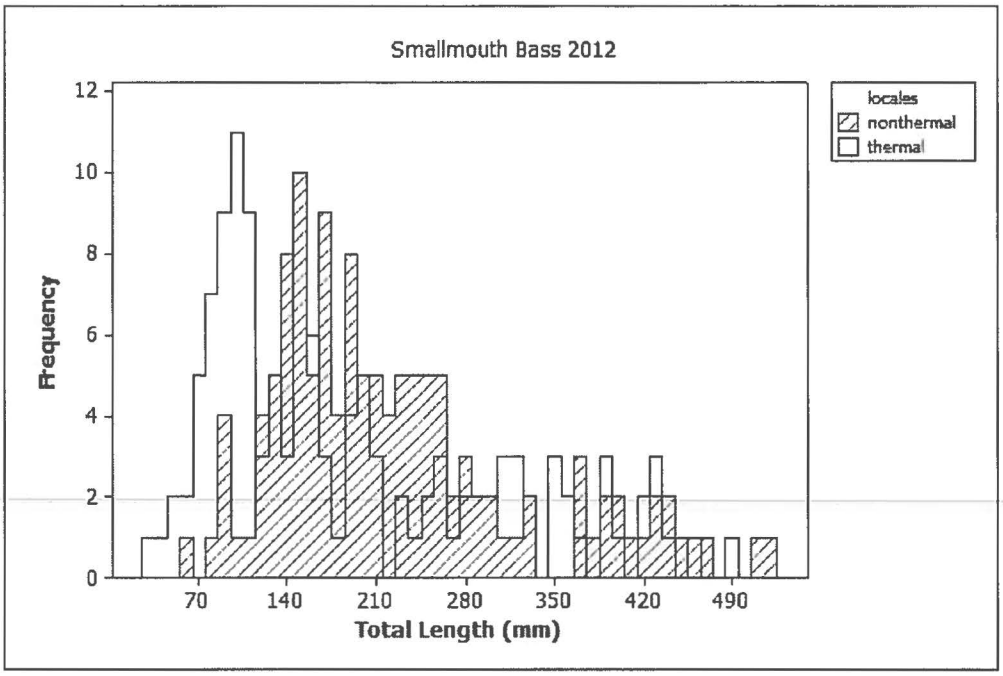


Figure 5-89. Length-frequency distribution of Smallmouth Bass collected in Conowingo Pond using all gear types for sample stations upstream (non-thermal) and within the PBAPS thermal plume (thermal), June to October 2012.

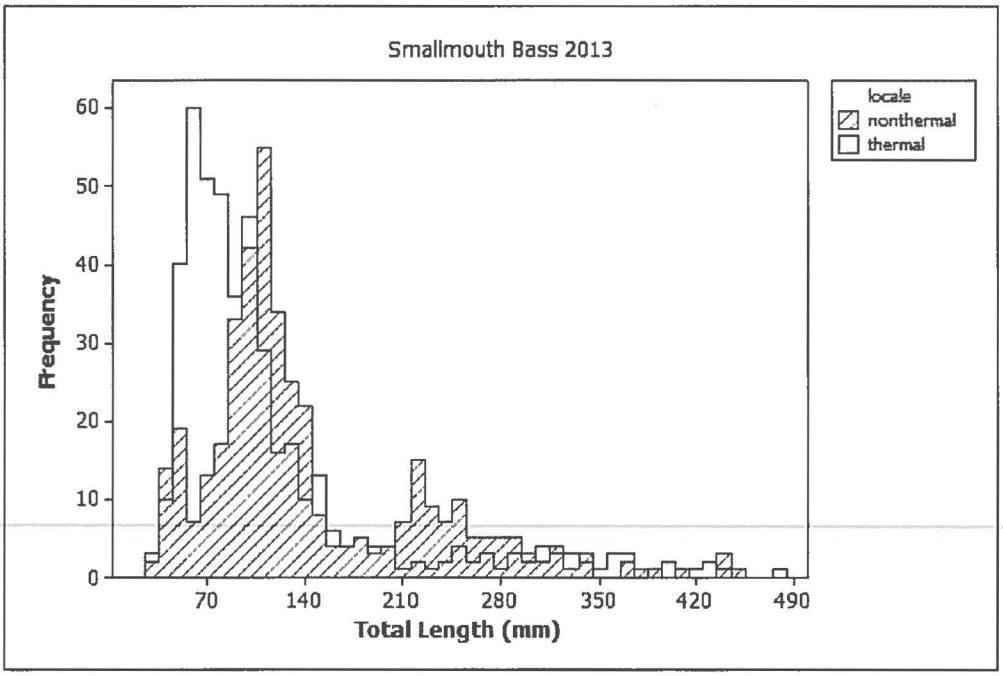


Figure 5-90. Length-frequency distribution of Smallmouth Bass collected in Conowingo Pond using all gear types for sample stations upstream (non-thermal) and within the PBAPS thermal plume (thermal), June to October 2013.

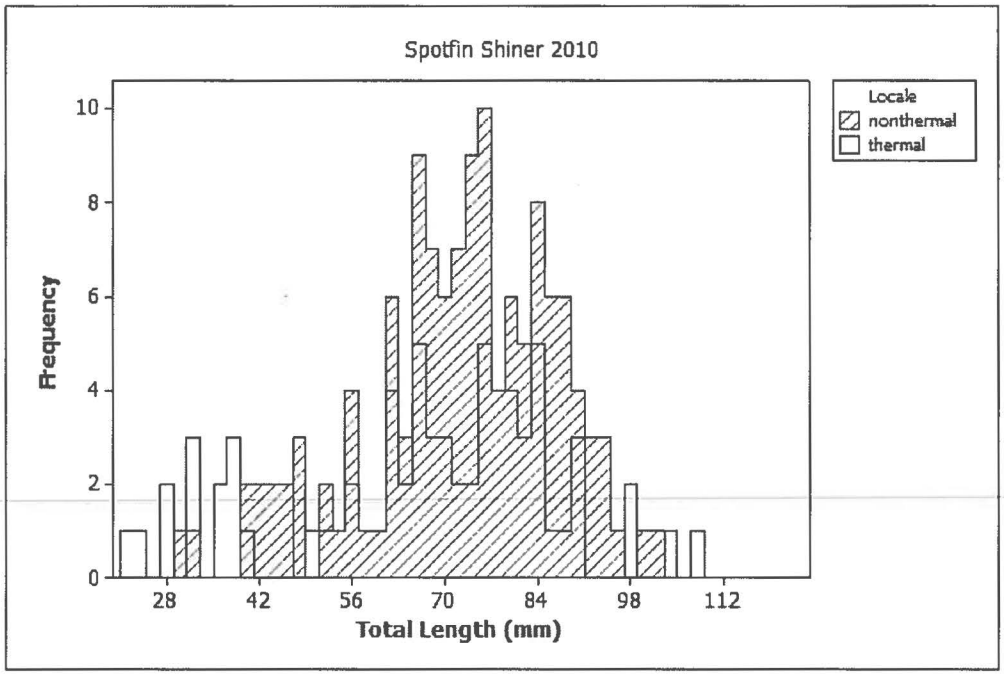


Figure 5-91. Length-frequency distribution of Spotfin Shiner collected in Conowingo Pond using all gear types for sample stations upstream (non-thermal) and within the PBAPS thermal plume (thermal), July to October 2010.

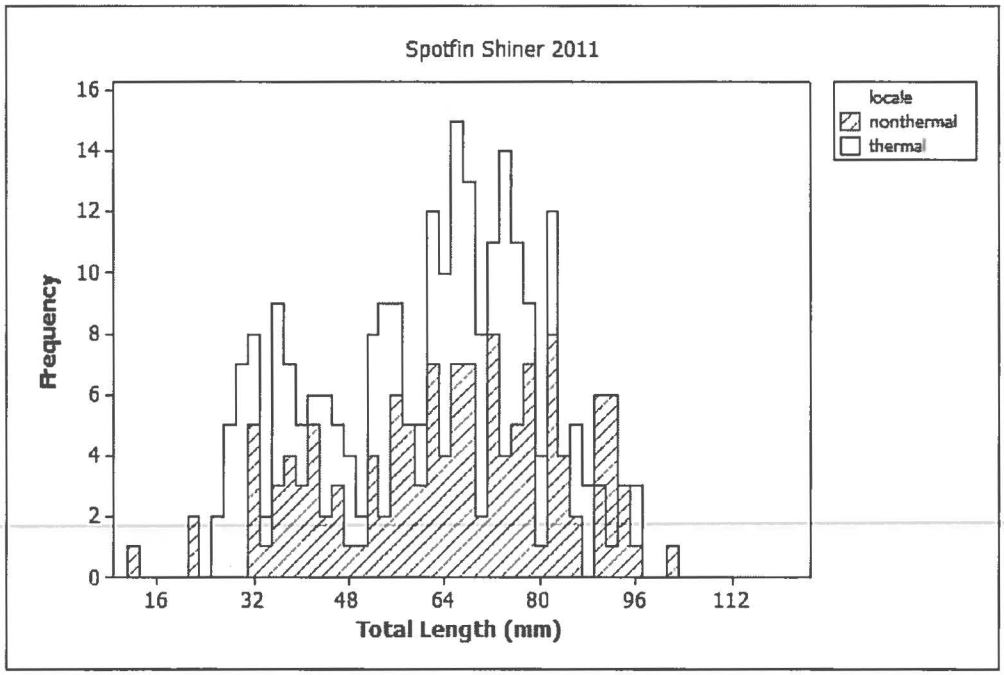


Figure 5-92. Length-frequency distribution of Spotfin Shiner collected in Conowingo Pond using all gear types for sample stations upstream (non-thermal) and within the PBAPS thermal plume (thermal), June to October 2011.

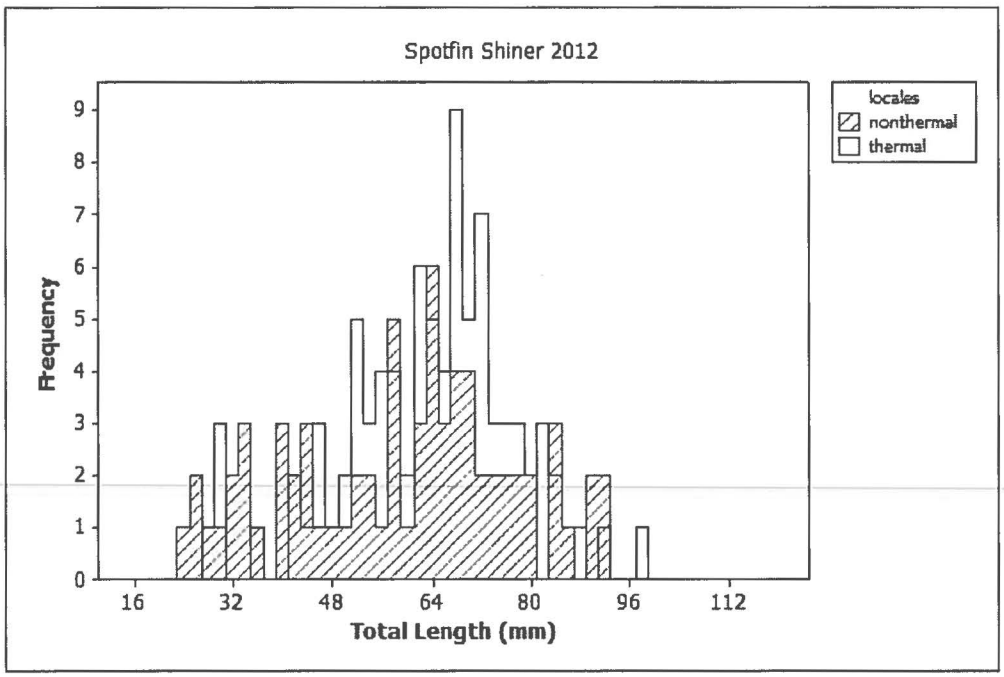


Figure 5-93. Length-frequency distribution of Spotfin Shiner collected in Conowingo Pond using all gear types for sample stations upstream (non-thermal) and within the PBAPS thermal plume (thermal), June to October 2012.

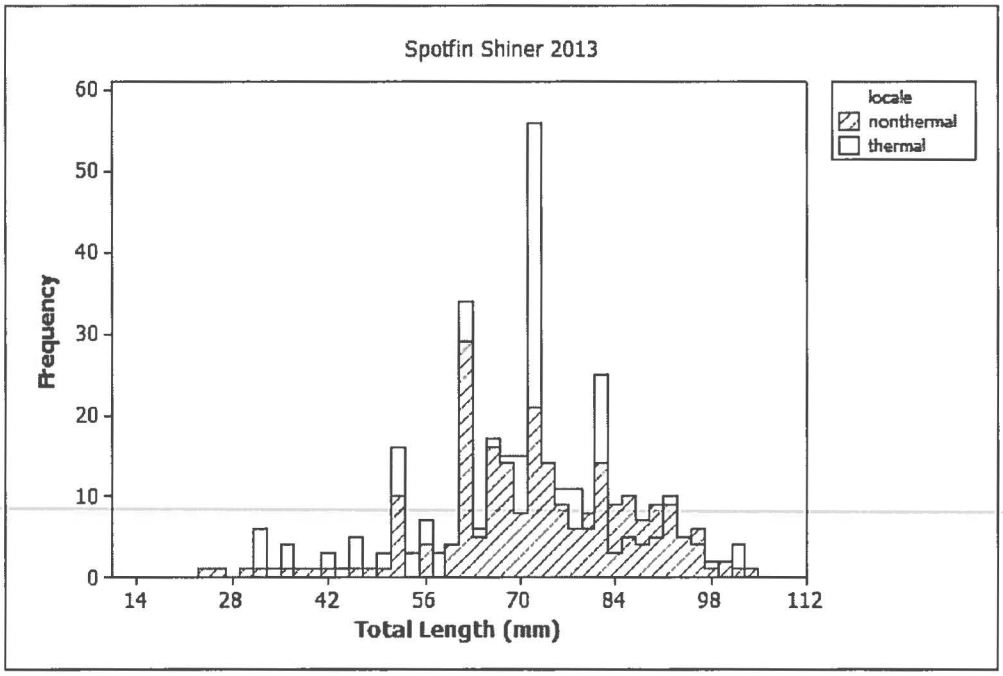


Figure 5-94. Length-frequency distribution of Spotfin Shiner collected in Conowingo Pond using all gear types for sample stations upstream (non-thermal) and within the PBAPS thermal plume (thermal), June to October 2013.

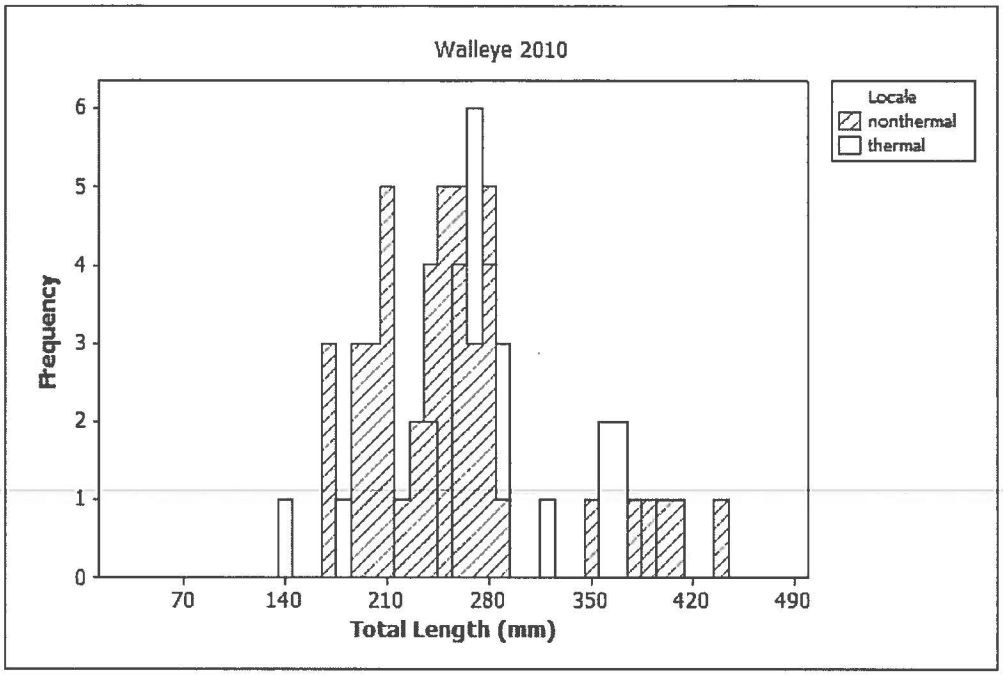


Figure 5-95. Length-frequency distribution of Walleye collected in Conowingo Pond using all gear types for sample stations upstream (non-thermal) and within the PBAPS thermal plume (thermal), July to October 2010.

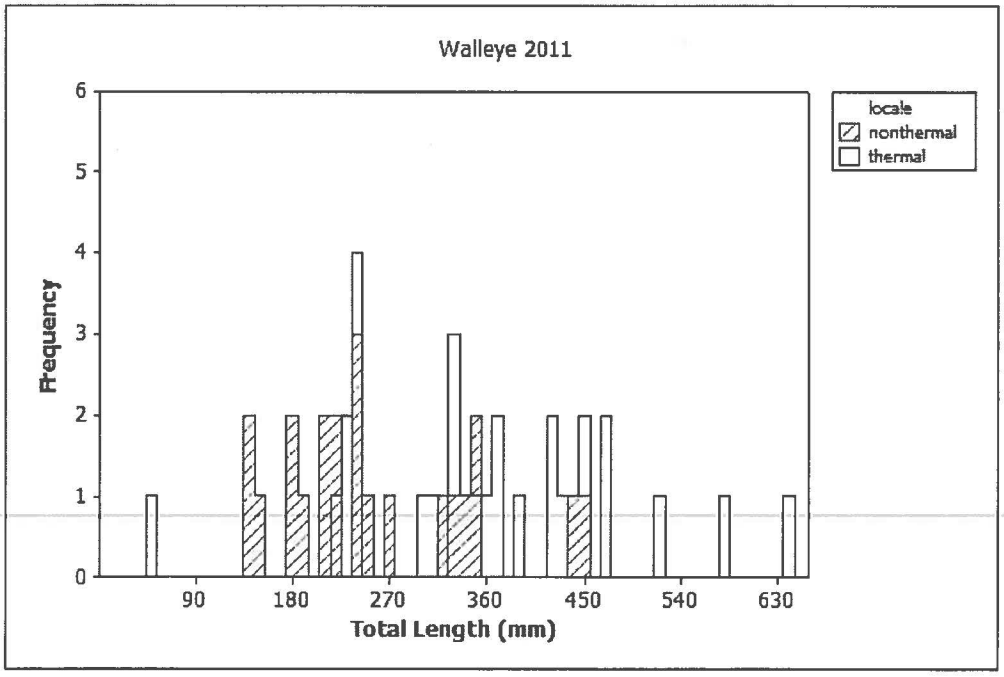


Figure 5-96. Length-frequency distribution of Walleye collected in Conowingo Pond using all gear types for sample stations upstream (non-thermal) and within the PBAPS thermal plume (thermal), June to October 2011.

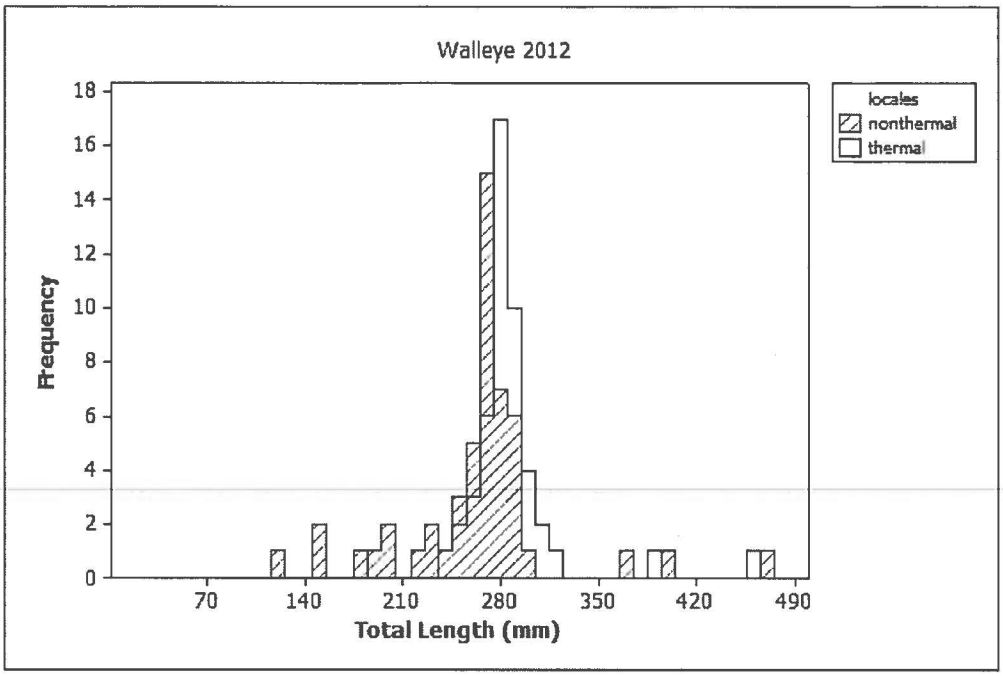


Figure 5-97. Length-frequency distribution of Walleye collected in Conowingo Pond using all gear types for sample stations upstream (non-thermal) and within the PBAPS thermal plume (thermal), June to October 2012.

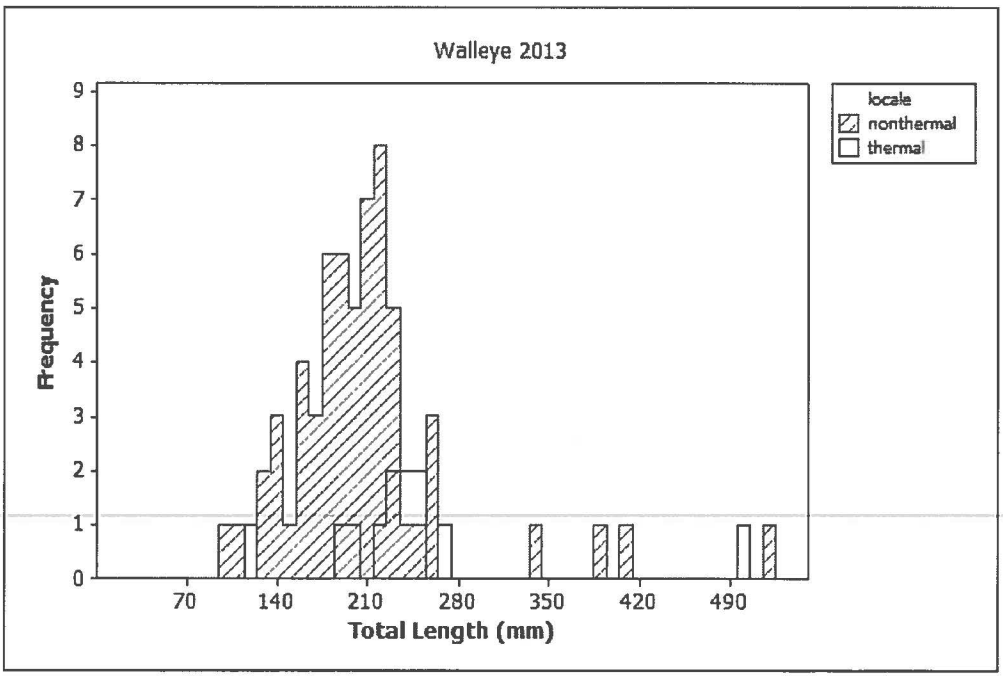


Figure 5-98. Length-frequency distribution of Walleye collected in Conowingo Pond using all gear types for sample stations upstream (non-thermal) and within the PBAPS thermal plume (thermal), June to October 2013.

Table 5-96. Descriptive statistics for total length of RIS, July to October 2010.

		Total Length (mm)				Number
Location	Species	Mean	Standard Deviation	Minimum	Maximum	Measured
nonthermal	Bluegill	83.7	35.4	21	206	240
thermal	Bluegill	83.1	45.8	21	218	384
nonthermal	Bluntnose minnow	60.9	13.4	36	82	29
thermal	Bluntnose minnow	65.6	8.8	53	82	11
nonthermal	Channel catfish	129.4	59.9	55	410	368
thermal	Channel catfish	121.3	76.6	21	526	1047
nonthermal	Gizzard shad	105.1	65.2	38	370	256
thermal	Gizzard shad	87.9	42.0	38	375	413
nonthermal	Largemouth bass	243.0	215.0	91	395	2
thermal	Largemouth bass	207.1	65.4	118	460	56
nonthermal	Logperch	74.1	13.5	40	105	49
thermal	Logperch	78.2	9.2	60	89	9
nonthermal	Smallmouth bass	155.4	77.3	43	387	78
thermal	Smallmouth bass	221.2	122.0	32	495	79
nonthermal	Spotfin shiner	71.9	14.7	30	101	127
thermal	Spotfin shiner	66.1	20.0	22	108	74
nonthermal	Walleye	255.3	64.4	166	438	46
thermal	Walleye	282.4	60.7	140	405	32
nonthermal	White crappie	127.0	*	127	127	1
thermal	White crappie	46.0	*	46	46	1
nonthermal	White sucker	127.0	*	127	127	1
thermal	White sucker	*	*	*	*	*

Table 5-97. Descriptive statistics for total length of RIS, June to October 2011.

		Total Length (mm)				Number
Location	Species	Mean	Standard Deviation	Minimum	Maximum	Measured
nonthermal	Bluegill	97.3	49.6	13	220	225
thermal	Bluegill	76.0	41.5	11	250	843
nonthermal	Bluntnose minnow	52.8	12.3	36	84	89
thermal	Bluntnose minnow	48.2	13.4	22	84	116
nonthermal	Channel catfish	162.2	84.0	21	606	582
thermal	Channel catfish	133.9	81.6	16	611	1746
nonthermal	Gizzard shad	94.2	58.7	14	392	256
thermal	Gizzard shad	85.9	35.4	19	290	497
nonthermal	Largemouth bass	298.0	156.0	85	438	7
thermal	Largemouth bass	177.9	105.9	57	465	69
nonthermal	Logperch	75.2	9.8	57	99	36
thermal	Logperch	69.3	14.6	32	97	22
nonthermal	Smallmouth bass	198.5	103.6	48	491	179
thermal	Smallmouth bass	154.2	102.3	22	494	123
nonthermal	Spotfin shiner	64.2	18.9	11	101	242
thermal	Spotfin shiner	60.8	18.2	12	102	288
nonthermal	Walleye	255.2	89.2	135	445	22
thermal	Walleye	358.0	120.5	54	635	30
nonthermal	White crappie	163.0	45.3	131	195	2
thermal	White crappie	113.5	47.4	47	240	13
nonthermal	White sucker	126.3	52.2	50	165	4
thermal	White sucker	160.0	*	160	160	1

Table 5-98. Descriptive statistics for total length of RIS, June to October 2012.

		Total Length (mm)				Number
Location	Species	Mean	Standard Deviation	Minimum	Maximum	Measured
nonthermal	Bluegill	93.6	48.2	22	204	356
thermal	Bluegill	74.3	42.8	11	205	1,338
nonthermal	Bluntnose minnow	59.0	12.0	32	84	51
thermal	Bluntnose minnow	60.7	13.4	21	89	49
nonthermal	Channel catfish	159.7	73.8	41	475	402
thermal	Channel catfish	149.7	80.5	16	460	1,311
nonthermal	Gizzard shad	100.0	68.9	21	398	624
thermal	Gizzard shad	79.2	35.4	11	400	1,126
nonthermal	Largemouth bass	220.5	102.0	75	445	11
thermal	Largemouth bass	218.6	81.8	52	483	80
nonthermal	Logperch	71.7	8.5	53	86	19
thermal	Logperch	72.7	17.5	39	112	41
nonthermal	Smallmouth bass	225.6	100.9	57	517	128
thermal	Smallmouth bass	188.8	112.1	31	493	133
nonthermal	Spotfin shiner	59.0	18.1	24	92	80
thermal	Spotfin shiner	63.3	14.2	27	98	148
nonthermal	Walleye	263.4	54.9	122	470	51
thermal	Walleye	286.4	39.5	182	457	50
nonthermal	White crappie	137.0	*	137	137	1
thermal	White crappie	147.6	21.9	113	168	7
nonthermal	White sucker	140.0	*	140	140	1
thermal	White sucker	111.5	112.8	31	324	10

Table 5-99. Descriptive statistics for total length of RIS, June to October 2013.

		Total Length (mm)				Number
Location	Species	Mean	Standard Deviation	Minimum	Maximum	Measured
nonthermal	Bluegill	118.7	38.4	21	205	434
thermal	Bluegill	91.6	37.2	11	197	917
nonthermal	Bluntnose minnow	61.0	11.1	31	83	152
thermal	Bluntnose minnow	59.3	10.0	32	83	157
nonthermal	Channel catfish	146.9	63.2	45	482	316
thermal	Channel catfish	147.4	64.6	52	535	414
nonthermal	Gizzard shad	116.0	37.6	25	255	95
thermal	Gizzard shad	105.4	31.6	38	240	217
nonthermal	Largemouth bass	151.5	127.8	64	461	15
thermal	Largemouth bass	193.1	109.4	45	456	59
nonthermal	Logperch	74.8	11.5	47	99	148
thermal	Logperch	68.7	15.8	40	112	151
nonthermal	Smallmouth bass	149.5	85.9	33	454	401
thermal	Smallmouth bass	125.0	87.0	33	482	452
nonthermal	Spotfin shiner	73.7	15.1	23	104	233
thermal	Spotfin shiner	70.6	15.6	31	102	308
nonthermal	Walleye	207.6	67.9	97	523	61
thermal	Walleye	244.6	87.7	121	495	12
nonthermal	White crappie	113.2	11.7	101	128	5
thermal	White crappie	129.3	68.9	56	263	11
nonthermal	White sucker	78.0	*	78	78	1
thermal	White sucker	267.5	133.6	173	362	2

Fish Condition

Introduction

Relative weight (W_r) is an index of condition or well-being for a fish. Relative weight and other condition assessments are commonly employed by fisheries personnel for evaluating fish populations and communities. This is a standard, widely accepted and used method for assessing fish body condition.

Methods

Relative weight is calculated with the following formula:

$$W_r = (W/W_s) \times 100$$

where:

W = actual fish weight and W_s = a standard weight for fish of the same length.

Standard weight is calculated with the following formula:

$$\text{Log}_{10} (W_s) = a' + b \log_{10} (L),$$

where:

a' is the intercept value,

b is the slope of the $\log_{10}$ (weight)-$\log_{10}$ (length) regression equation, and

L is the maximum total length of the fish species.

Standard weight equations for the species of interest were taken from Murphy and Willis (1996). The standard weight equation describes the inherent shape of a fish in good condition.

Relative weight is one indicator of overall fish condition and describes the relative plumpness of an individual fish. Plump fish may be indicators of favorable environmental conditions (e.g., habitat conditions, ample prey availability); whereas, thin fish may indicate less favorable environmental conditions. A relative weight of 100 for an individual fish would indicate that the weight is equal to the average weight of a fish with the identical length for the larger population that was used to develop the standard weight equation. Relative weight may be indicative of nutritional status (acquisition and storage of energy and nutrients). Values of W_r well below 100 may indicate feed or food condition problems for individual or species and a W_r well above 100, suggests that fish may not be making the best use of a surplus of prey (Murphy and Willis 1996). A W_r of 100 for a broad range of size-groups may reflect ecological and physiological optimality for populations.

Some difficulty exists in defining good condition for any species and some literature suggests that W_s, the reference weight in the W_r index, should be used as a benchmark for comparison among populations or samples, not as a reliable measure of optimality for a particular species

(Murphy *et al.* 1990). This approach will be used herein to compare W_r among the sample stations.

Relative weights were calculated for four of the RIS: Bluegill, Smallmouth Bass, Largemouth Bass, and Channel Catfish. These four RIS were selected for analysis because sufficient numbers of individuals and weight measurements were taken to enable valid comparisons of individuals collected at both thermal and non-thermal stations. In addition, W_s equations have been developed for these species. The purpose of this analysis is to determine whether W_r was different between the thermal and non-thermal locations. Conceptually, fishes living in elevated water temperatures may be affected by insufficient food availability, physiological stress associated with elevated temperatures, higher metabolic demands, and therefore, poorer body condition indicated by low W_r values. The non-parametric Kruskal-Wallis test was used to determine whether statistically significant differences in W_r values existed among the sample stations. Obvious erroneous W_r values were excluded from the analysis as determined by the range of species-specific length-weight values provided in Carlander (1969 and 1977). Additionally, the W_s equations require minimum lengths for each species (Bluegill TL=80mm, Smallmouth Bass TL=150mm, Largemouth Bass TL=150, and Channel Catfish TL=70) and all individuals below these minimum lengths were excluded from analysis.

Results

Relative weights were calculated for Bluegill, Smallmouth Bass, Largemouth Bass, and Channel Catfish collected from the electrofishing stations during 2010-2013. A total of seven stations were assessed (non-thermal: Station 187, 164, and 165; thermal: Station 161, 189, 190, and 217). Weight measurements were not taken for these four species collected using a seine or trawl because most were smaller, young individuals. Few individuals of these four species were collected with a seine.

Relative weights were calculated for a total of 1,056 Bluegill with mean W_r of 100 (Table 5-100). Mean W_r ranged from 81 at Station 190 (thermal) to 107 at Station 164 (non-thermal). The distribution of W_r among the sample stations was similar for non-thermal and thermal stations with mean W_r below 100 for all stations except Stations 161, 164, and 187 (Figure 5-99). Mean W_r values at Station 164 were statistically higher than Stations 190, 189, 217, and 165 ($p \leq 0.05$). Other statistically significant differences were observed between both thermal and non-thermal stations ($p \leq 0.05$).

Relative weights were calculated for a total of 318 Largemouth Bass with an overall mean W_r of 107 (Table 5-101). Mean W_r ranged from 94 at Station 165 (non-thermal) to 112.3at Station 161 (thermal). The distribution of W_r among the sample stations was higher for thermal stations, with median and mean W_r above 99 for all thermal stations (Figure 5-100). Note that W_r was calculated for only 40 individuals at the non-thermal stations. Relative weights were statistically different ($p \leq 0.05$) between several of the stations; however, median values were generally higher for the thermal stations.

Relative weights calculated for a total of 788 Channel Catfish resulted in an overall mean W_r of 112 (Table 5-102). Mean W_r ranged from 1169at Station 187 (non-thermal) to 110 at Stations

189 and 190 (thermal). The distribution of W_r among the sample stations was similar for non-thermal and thermal stations with median and mean W_r above 100 for all stations (Figure 5-101). Relative weights were statistically different ($p \leq 0.05$) between several of the stations (Table 5-102). However, no pattern was observed for median values between the non-thermal and thermal stations.

Relative weights calculated for 780 Smallmouth Bass resulted in a mean W_r of 98 (Table 5-103). Mean W_r ranged from 93 at Station 190 (thermal) to 101 at Station 161 (thermal). The distribution of W_r among the sample stations in reference to W_r of 100 was variable with only Station 161 having mean and median W_r above 100 (Figure 5-102). Relative weights for Station 161 were statistically different ($p \leq 0.05$) from both non-thermal (Stations 164 and 187) and thermal stations (Stations 189, 190, and 217) (Table 5-103). Significant differences ($p \leq 0.05$) were also observed between thermal Stations 217 and 189 and thermal Station 190 and non-thermal Station 187. No other statistically significant differences were observed among the other stations.

Discussion

Relative weights for all four species were similar between non-thermal and thermal stations. In theory, lower W_r values might be expected at those thermal stations (161 and 189) closest to the end of the PBAPS discharge canal because those stations experience the greatest temperature rise above ambient and the greatest duration of elevated water temperatures, assuming that fish are remaining in these areas for extended periods of time. Low W_r values are generally characteristic of fish in poor health, whereas high W_r values indicate fish in excellent health (Blackwell *et al.* 2000). Although mean and median W_r values showed some variation among the stations, the relative weight observations did not indicate low W_r values for the near-field or far-field thermal stations. Differences in W_r were likely due to seasonality, reproductive status (pre- or post-spawn), length distribution of individuals at a station, and differences between the sexes. The observations for these four species indicate no detrimental effect of the thermal plume on fish condition as measured by relative weight. The W_r evaluation confirms the visual observations of no emaciated fish and few fish in poor condition during the course of field studies.

Table 5-100. Descriptive statistics for Bluegill relative weight, 2010-2013.

Station	Relative Weight (Wr) Mean	Relative Weight (Wr) Median	Total Number
187	101	97	51
164	107	107[abcd]	197
165	99	101[dg]	131
161	101	100[ef]	302
189	94	92[bf]	138
190	91	86[aeg]	107
217	98	95[c]	130
Overall	100	98	1,056

Kruskal-Wallis test, p <0.001), values followed by same letter were signficantly different.

Table 5-101. Descriptive statistics for Largemouth Bass relative weight, 2010-2013.

Station	Relative Weight (Wr) Mean	Relative Weight (Wr) Median	Total Number
187	97	94	12
164	102	103[abd]	24
165	94	97	4
161	112	109[ce]	79
189	99	99[be]	39
190	110	108[ac]	71
217	108	106[d]	89
Overall	107	106	318

Kruskal-Wallis test, p <0.001), values followed by same letter were signficantly different. Station 165 excluded from analysis

Table 5-102. Descriptive statistics for Channel Catfish relative weight, 2010-2013.

Station	Relative Weight (Wr) Mean	Relative Weight (Wr) Median	Total Number
187	116	113[ab]	116
164	112	109	112
165	112	105	112
161	114	108	114
189	110	107[b]	110
190	110	103[a]	110
217	114	111	114
Overall	112	108	788

Kruskal-Wallis test, p <0.03), values followed by same letter were signficantly different.

Table 5-103. Descriptive statistics for Smallmouth Bass relative weight, 2010-2013.

Station	Relative Weight (Wr) Mean	Relative Weight (Wr) Median	Total Number
187	97	95[fh]	99
164	96	94[c]	247
165	99	96	110
161	101	101[acefg]	218
189	95	92[bgd]	31
190	93	94[edh]	38
217	94	93[ab]	37
Overall	98	96	780

Kruskal-Wallis test, p<0.001), values followed by same letter were signficantly different.

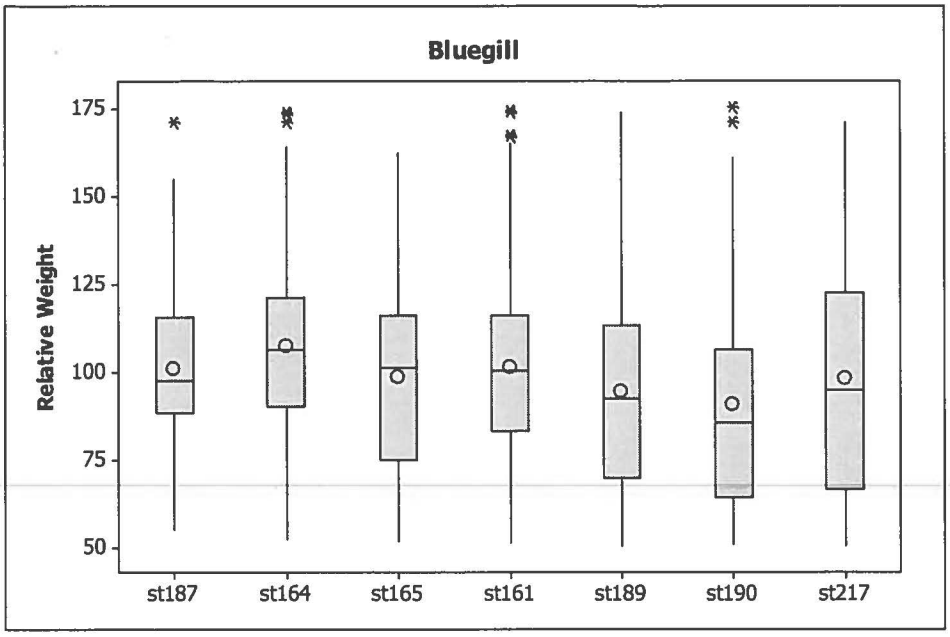


Figure 5-99. Box plot of Bluegill relative weight relative to station, 2010-2013. (boxes = interquartile range containing 50% of the values, the line across the box = median value, circle = mean, and the vertical lines extending from the box = highest and lowest values, asterisk = outlier)

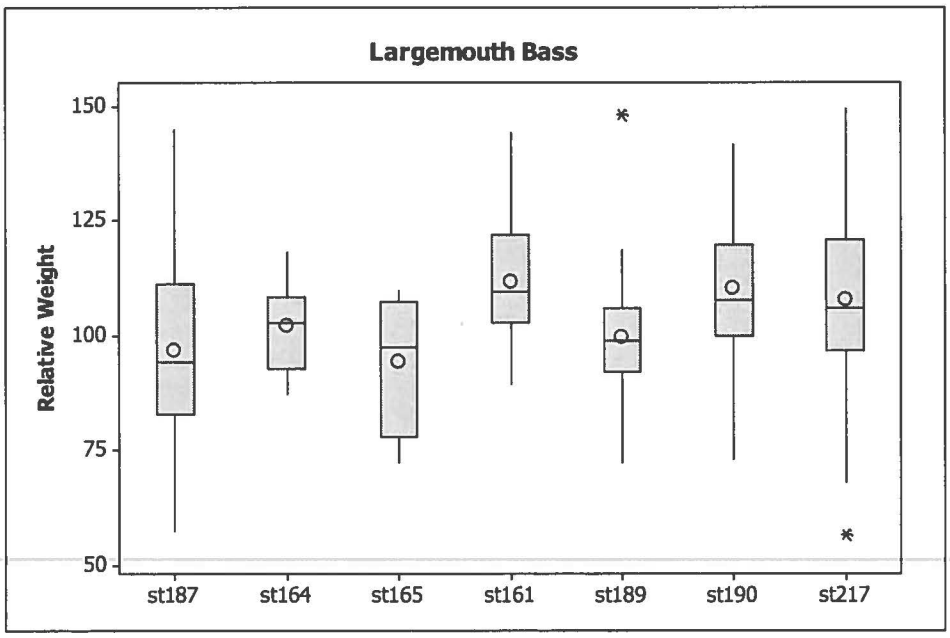


Figure 5-100. Box plot of Largemouth Bass relative weight relative to station, 2010-2013. (boxes = interquartile range containing 50% of the values, the line across the box = median value, circle = mean, and the vertical lines extending from the box = highest and lowest values, asterisk = outlier)

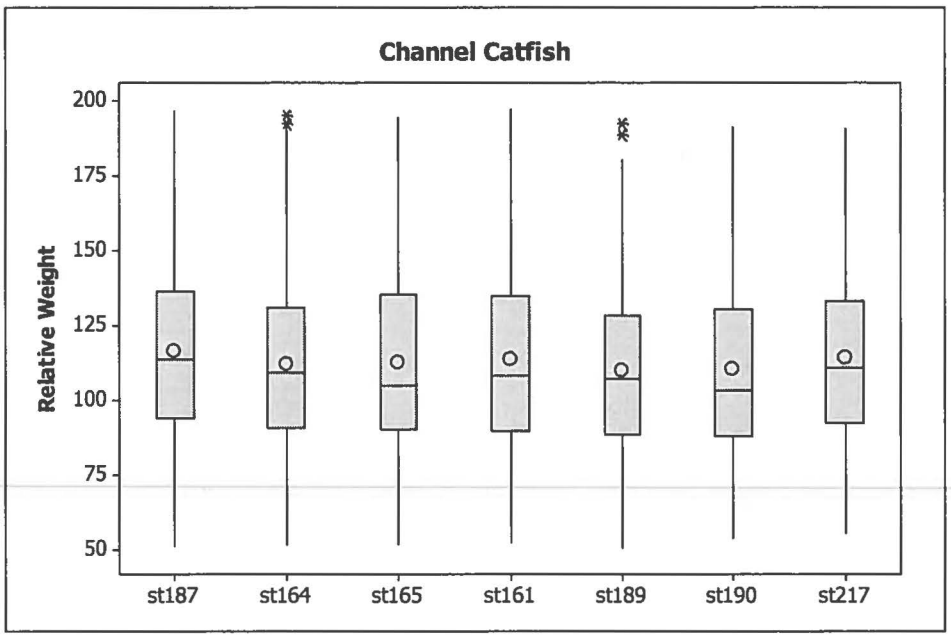


Figure 5-101. Box plot of Channel Catfish relative weight relative to station, 2010-2013. (boxes = interquartile range containing 50% of the values, the line across the box = median value, circle = mean, and the vertical lines extending from the box = highest and lowest values, asterisk = outlier)

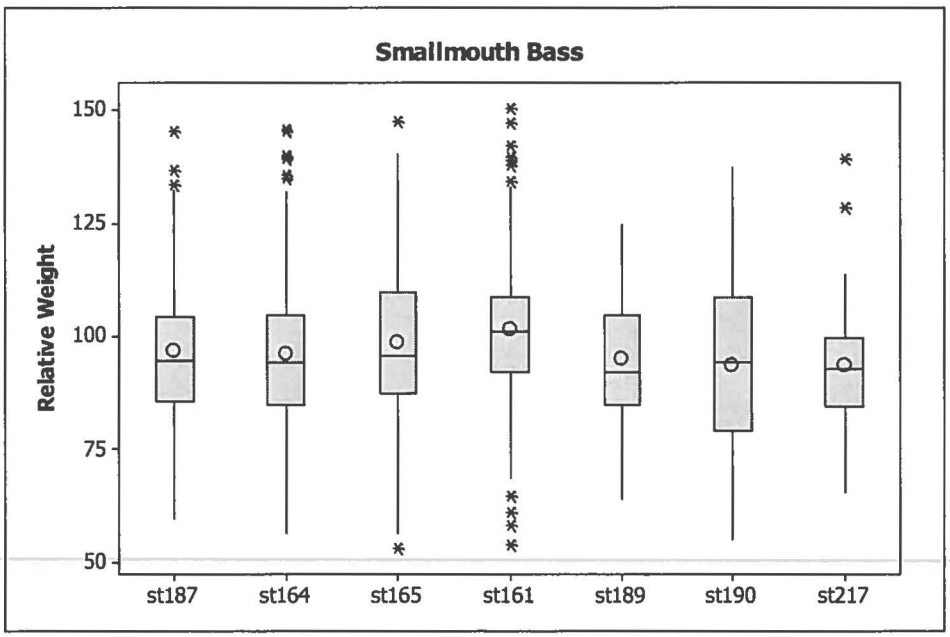


Figure 5-102. Box plot of Smallmouth Bass relative weight relative to station, 2010-2013. (boxes = interquartile range containing 50% of the values, the line across the box = median value, circle = mean, and the vertical lines extending from the box = highest and lowest values, asterisk = outlier)

External Anomalies (DELTs)

During the course of fish processing in the field, they were examined for external anomalies or DELTs. The term DELTs refers to deformities, erosions, lesions, and tumors. This examination is a visual assessment completed with the naked eye that is commonly used during fisheries investigations to document the external condition of captured fish. Types of external anomalies that were determined during the course of study included deformities, eroded fins, lesions, tumors, anchor worm, black spot, leeches, and fungal infections. No examination of gills or internal structures was completed. All fish that were measured for length were evaluated for external anomalies. For collection events where large numbers of individuals were collected, only a subsample of individuals was evaluated for DELTs. While the remaining individuals were counted, the occurrence of external anomalies was not determined for these specimens.

This metric is an indicator of the health and condition of an individual fish. The proportion of fish with DELTs is generally small in minimally impaired waterbodies, but tends to be higher among fish living in areas where toxic chemicals or other stressful water quality conditions exist.

The effects of elevated water temperatures downstream of PBAPS could potentially result in increased stress for fish within the thermally influenced regions of Conowingo Pond. The potential stress induced by the thermal plume would likely be a function of the magnitude and duration of exposure to elevated water temperatures. Previous studies have shown that when fish crowd into a thermal discharge the potential exists for increased incidence of disease. For example, Petty and Magnuson (1974) found the incidence of viral lymphocystis disease in young Bluegill to be greater in those living in a thermal discharge than in those living in unheated reference areas. Similarly, Khan (1998) found parasite loads to be higher for flounder living in a thermal discharge compared to outside of the discharge.

The occurrence of DELTs was tabulated for both non-thermally influenced and thermally influenced stations. The incidence of DELTs in the Conowingo Pond fish community was low during each of the 4 years of field investigations. DELTs were observed on 103 individuals of 18 species. The highest incidence of DELTs for any species or year occurred in 2013 with 10 Smallmouth Bass observed with DELTs; a proportion of 1.2% of the Smallmouth Bass examined during the year. The occurrence of DELTS was similar at non-thermal and thermally influenced stations (Table 5-104 through Table 5-107). Appendix 11.2 provides a list of DELTs for each individual fish observed during the study.

Overall, fish with DELTs comprised approximately 0.5% of all individuals that were collected and examined. The incidence of DELTs was not greater for those stations closest to the end of the PBAPS discharge canal (Stations 161, 214, 189, and 190), where the greatest temperature rise above ambient occurs. The low proportion of fishes with DELTs indicates an aquatic environment where stressful water quality conditions are minimal or such that conditions did not result in significant occurrence of DELTs. It is important to note that we do not know for certain where fishes lived prior to being collected at individual stations, thus, the thermal history is assumed to be that of the collection station.

Table 5-104. Total number of each species with DELTS for all gear types and all sample locations in Conowingo Pond, July to October 2010.

	Non-thermal Stations						Thermal Stations			
Species	164	165	187	220	221	Total	190	331	383	Total
Bluegill	1					1				0
Channel Catfish			1			1		1	1	2
Comely Shiner					1	1				0
Largemouth Bass			1			1				0
Rock Bass			2			2				0
Smallmouth Bass		1				1	1			1
Spotfin Shiner				1		1				0
Total	1	1	4	1	1	8	1	1	1	3

Table 5-105. Total number of each species with DELTS for all gear types and all sample locations in Conowingo Pond, February to October 2011.

	Non-thermal Stations				Thermal Stations				
Species	164	165	187	Total	161	189	190	217	Total
Bluegill	1	1		2			3		3
Channel Catfish	1			1		1	1	1	3
Common Carp				0		1			1
Green Sunfish	1			1			3		3
Largemouth Bass	1		1	2			1		1
Rock Bass				0			1		1
Smallmouth Bass		2		2	1			1	2
Walleye				0	1				1
Total	4	3	1	8	2	2	9	2	15

Table 5-106. Total number of each species with DELTs for all gear types and all sample locations in Conowingo Pond, January to October 2012.

	Non-thermal Stations					Thermal Stations						
Species	164	165	187	321	Total	161	189	190	217	333	341	Total
Bluegill	1				1			2				2
Channel Catfish	2			1	3	1	2			1		4
Flathead Catfish			1		1		1					1
Green Sunfish			1		1			1				1
Largemouth Bass	1		1		2	1			2			3
Pumpkinseed					0				1			1
Rock Bass		3	1		4							0
Shorthead Redhorse					0		1					1
Smallmouth Bass	2	1			3	3					1	4
White Sucker					0		1					1
Total	6	4	4	1	15	5	5	3	3	1	1	18

Table 5-107. Total number of each species with DELTs for all gear types and all sample locations in Conowingo Pond, January to October 2013.

	Non-thermal Stations							Thermal Stations				
Species	164	165	187	203	220	221	Total	161	189	190	217	Total
Bluegill	1	1					2		3	1		4
Bluntnose Minnow						1	1					0
Channel Catfish	1	1	1				3	1				1
Comely Shiner							0			1		1
Green Sunfish	1				1		2					0
Largemouth Bass							0	3		1	1	5
Rock Bass			1				1		1		2	3
Smallmouth Bass	2	3	2				7	2	1			3
Spottail Shiner				1		1	2					0
White Crappie		1					1					0
	5	6	4	1	1	2		6	5	3	3	
Total							19					17

Relative Abundance and Retrospective Analysis of RIS

Knowledge of the abundance of fish populations is an important component in management of fisheries. The most common indices of relative abundance are computed from catch per unit effort (CPUE) data for samples from a fish population. A common application in fisheries management is using CPUE to evaluate temporal patterns in relative abundance. Here, relative abundance is illustrated with time series plots for select RIS in Conowingo Pond. CPUE is a standardized approach useful for comparing gear-specific catch data over time.

Temporal patterns in CPUE are illustrated for both seine and electrofishing gears. A long-term data set for select RIS is available for the Pond for the period 1966 to 2013. This period covers fish collections at many locations throughout Conowingo Pond prior to operation of PBAPS

(1966-1973) and after PBAPS became operational (1974-2013). Electrofishing surveys were not initiated until 1974, thus no pre-operational relative abundance data for this sampling gear are available. The data set for 1993 includes only October sampling and the 1996 data set includes multiple samples each month. This data set includes several time intervals associated with prior PBAPS 316(a) demonstration studies (PECO 1975, and 1979; Normandeau Associates 1996-2000a).

Relative abundance data provided in each figure includes fish collections throughout the entire Conowingo Pond, thus evaluating the relative abundance of a species within the entire Pond. Sampling station locations varied throughout the course of study within the Pond, thus not all stations sampled previously are the same as the present study. However, the long-term data set provides useful information regarding abundance trends in the Pond. Additionally, although station locations differed over time, the collections occurred in similar habitats (i.e., shallow shoreline areas suitable for the sampling gear). The data reflect collections from June-October. A square root transformation of the mean CPUE data was used to decrease the effects of single year extreme CPUE values.

Seine

Relative abundance data from all stations surveyed in the Pond using a seine are provided for Bluegill, Smallmouth Bass, Spotfin Shiner, Bluntnose Minnow, and Chesapeake Logperch. This subset of RIS represents species that are commonly collected using a seine.

For the period 2010-2013 relative abundance for each species was similar among years. No discernible pattern in RIS relative abundance in relation to cooling tower operation was observed. Annual CPUE values during 2010-2013 were within or above the historical range for all species except Spotfin Shiner (Figure 5-103 through Figure 5-107) No long-term temporal trends in CPUE were observed for Bluegill, Bluntnose Minnow, or Smallmouth Bass. Short-term trends were observed for Spotfin Shiner and Bluntnose Minnow during mid-1990s with a general increase in CPUE each year except 1999. Bluntnose Minnow CPUE was lower during 2010-2013 as compared to 1990's, but higher than most values during 1960-1970s. Spotfin Shiner CPUE was lower in 2010-2013 as compared to historic collections which varied widely from year to year and over the short-term relative abundance appears to be declining in the Pond. Chesapeake Logperch relative abundance was higher during the 1996-2013 period compared to prior years indicating a longer-term trend of increasing abundance.

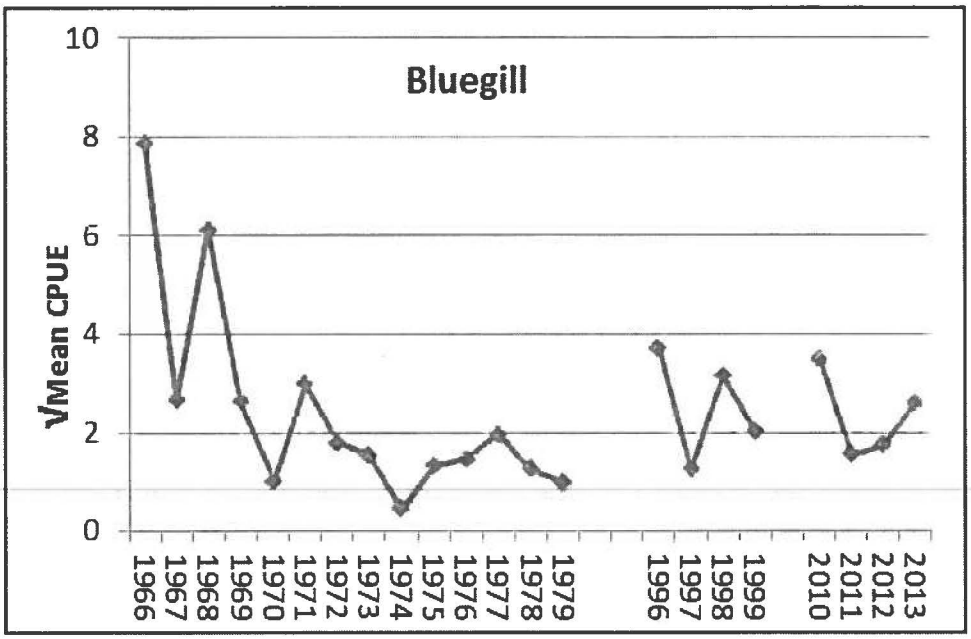


Figure 5-103. Square root transformed mean CPUE for Bluegill collected using a seine in Conowingo Pond, June-October 1966-2013.

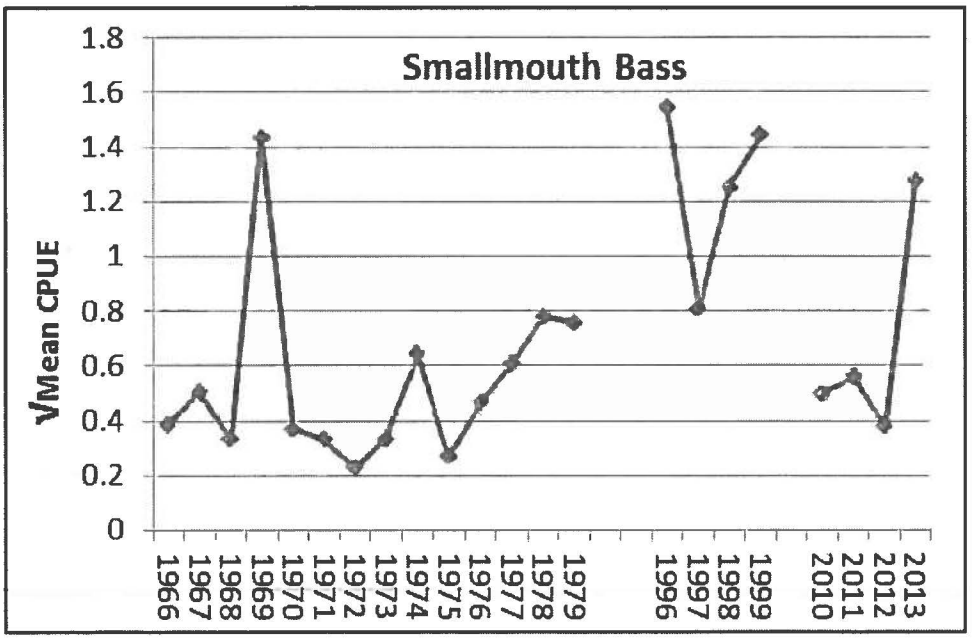


Figure 5-104. Square root transforme mean CPUE for Smallmouth Bass collected using a seine in Conowingo Pond, June-October 1966-2013.

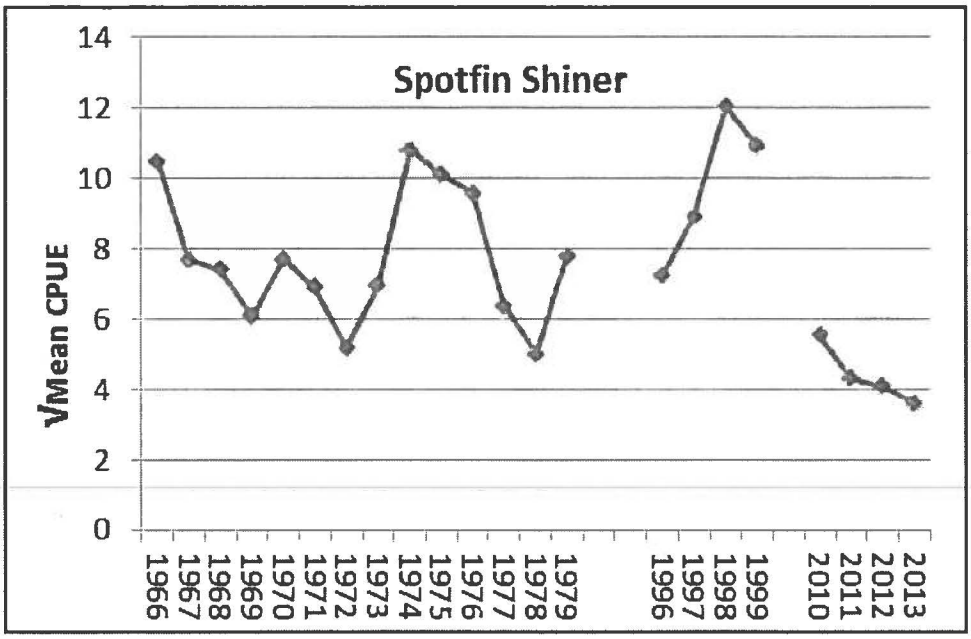


Figure 5-105. Square root transformed mean CPUE for Spotfin Shiner collected using a seine in Conowingo Pond, June-October 1966-2013.

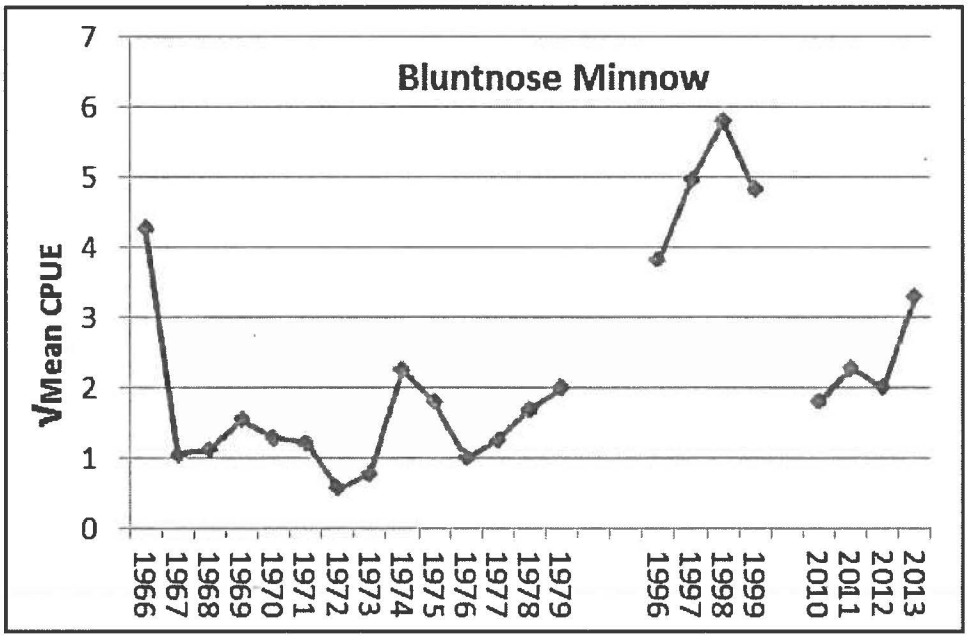


Figure 5-106. Square root transformed mean CPUE for Bluntnose Minnow collected using a seine in Conowingo Pond, June-October 1966-2013.

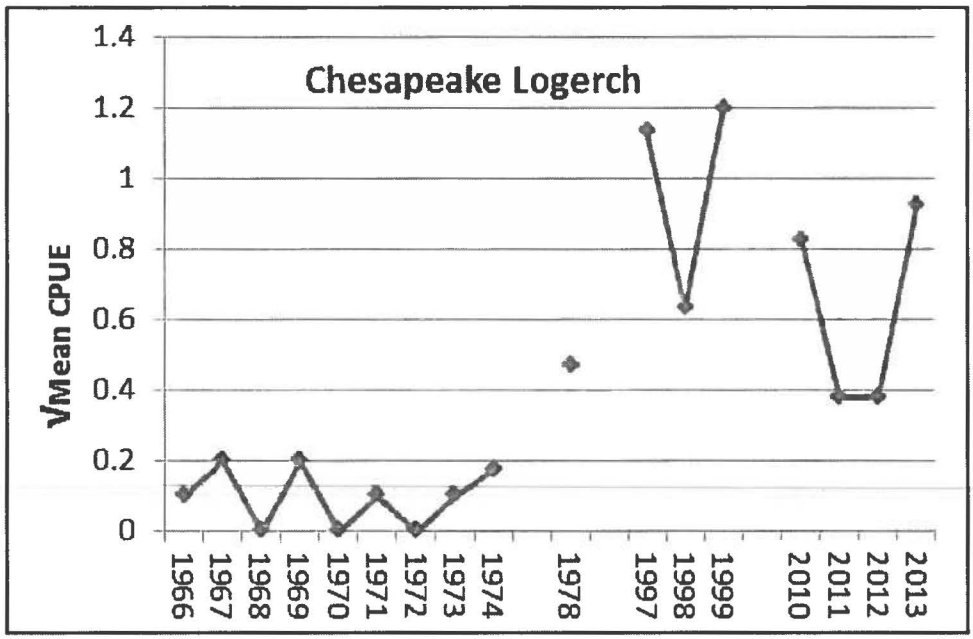


Figure 5-107. Square root transformed mean CPUE for Chesapeake Logperch collected using a seine in Conowingo Pond, June-October 1966-2013.

Electrofishing

Relative abundance data from all stations surveyed in the Pond using boat electrofisher are provided for Bluegill, Smallmouth Bass, Gizzard Shad, White Crappie, Channel Catfish, Walleye, and Chesapeake Logperch. Figure 5-108 through Figure 5-114 compare the annual mean CPUE for each species during the period of available electrofishing data from 1975-2013. This subset of RIS represent species that are commonly collected using a boat electrofisher in the Pond.

Relative abundance was similar for the period 2010 to 2013 for all species except Bluegill and Gizzard Shad (Figure 5-108 through Figure 5-114). No pattern in relative abundance was evident related to cooling tower operation. Bluegill relative abundance was higher in 2012 as compared to 2010, 2011 or 2013. Gizzard Shad relative abundance declined dramatically in 2013 and was comparable to values observed during the 1980's and 1990's. The highest relative abundance during the current study period was observed for Gizzard Shad and Bluegill. Annual CPUE values during 2010-2013 were within or above the historical range for all species except Smallmouth Bass. Fewer Smallmouth Bass were collected during 2010-2012 as compared to historic collections. Catch of Smallmouth increased in 2013 and was comparable to values observed in the 1990's. Long-term trends were evident for White Crappie and Gizzard Shad. White Crappie relative abundance showed a long-term decline over time and Gizzard Shad relative abundance indicated a long-term increase over time. Walleye CPUE also indicated a slight increasing trend over time.

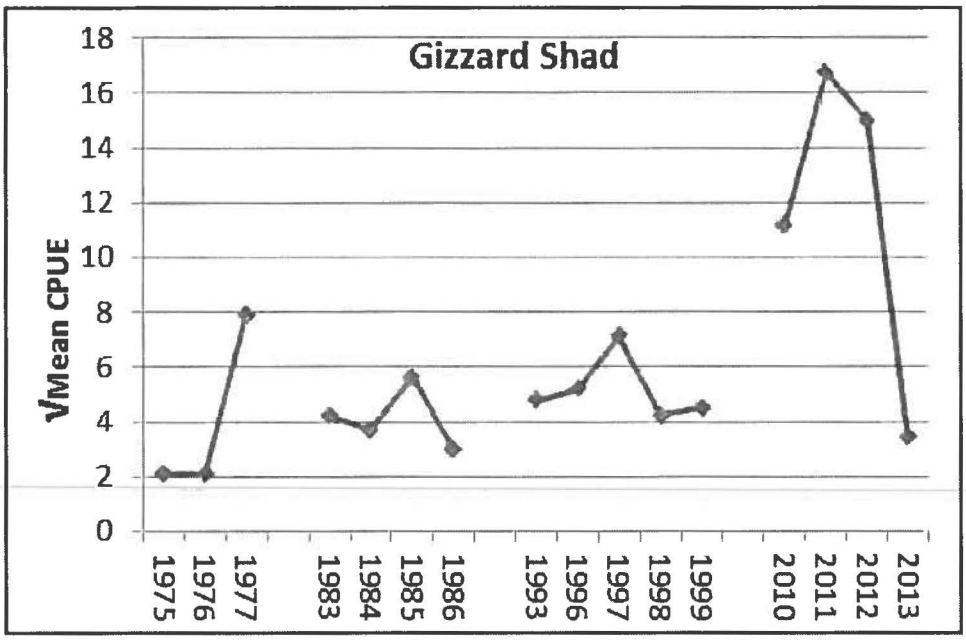


Figure 5-108. Square root transformed mean CPUE(no/0.5hr) for Gizzard Shad collected using a boat electrofisher in Conowingo Pond, June-October 1975-2013.

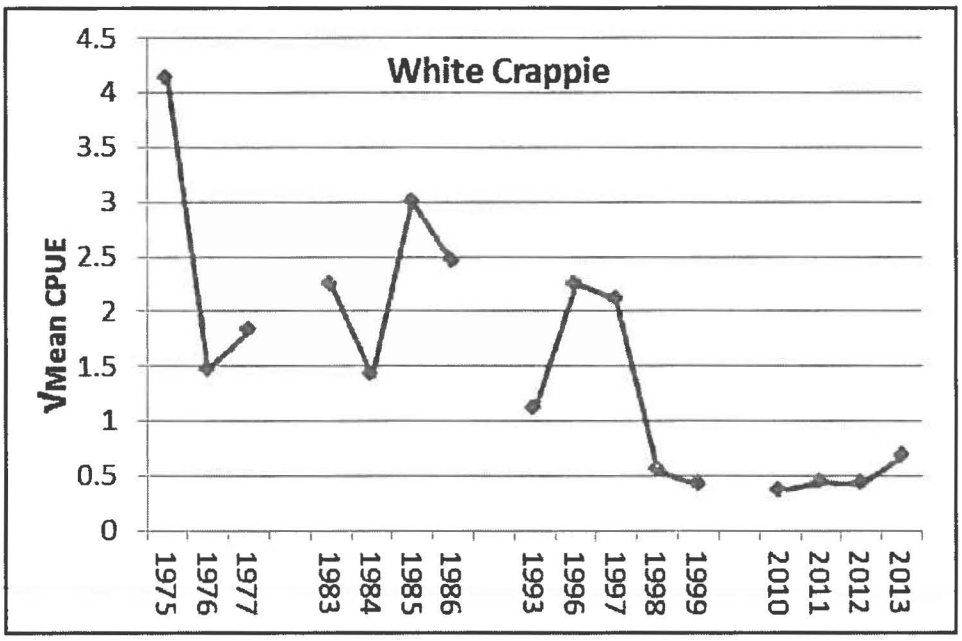


Figure 5-109. Square root transformed mean CPUE(no/0.5hr) for White Crappie collected using a boat electrofisher in Conowingo Pond, June-October 1975-2013.

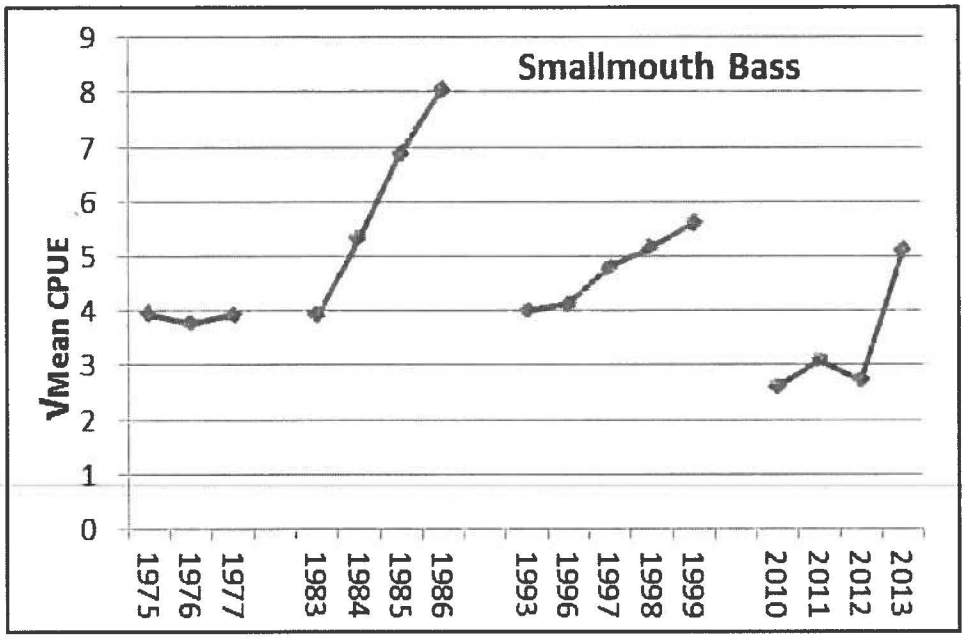


Figure 5-110. Square root transformed mean CPUE(no/0.5hr) for Smallmouth Bass collected using a boat electrofisher in Conowingo Pond, June-October 1975-2013.

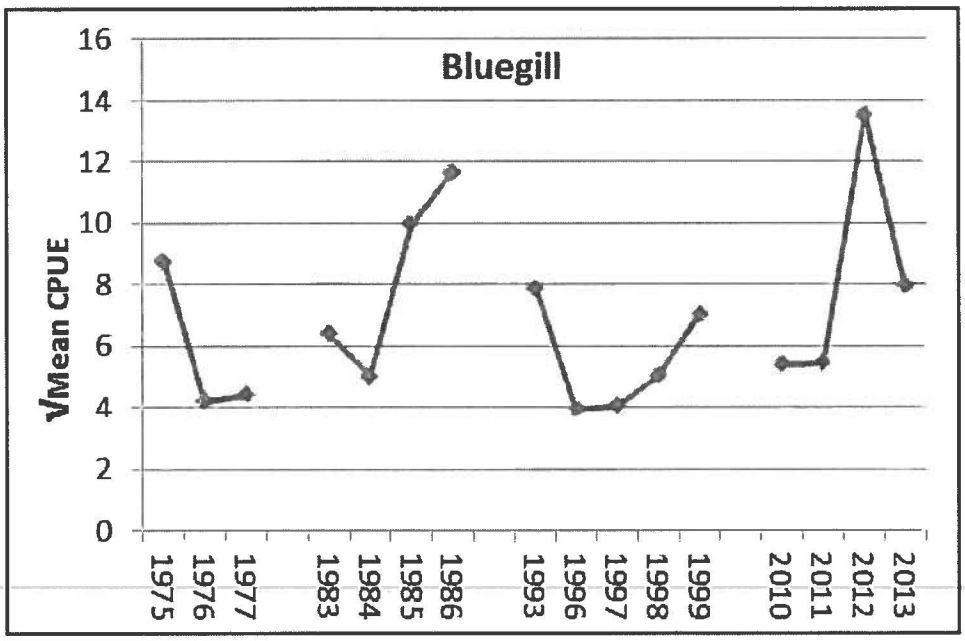


Figure 5-111. Square root transformed mean CPUE(no/0.5hr) for Bluegill collected using a boat electrofisher in Conowingo Pond, June-October 1975-2013.

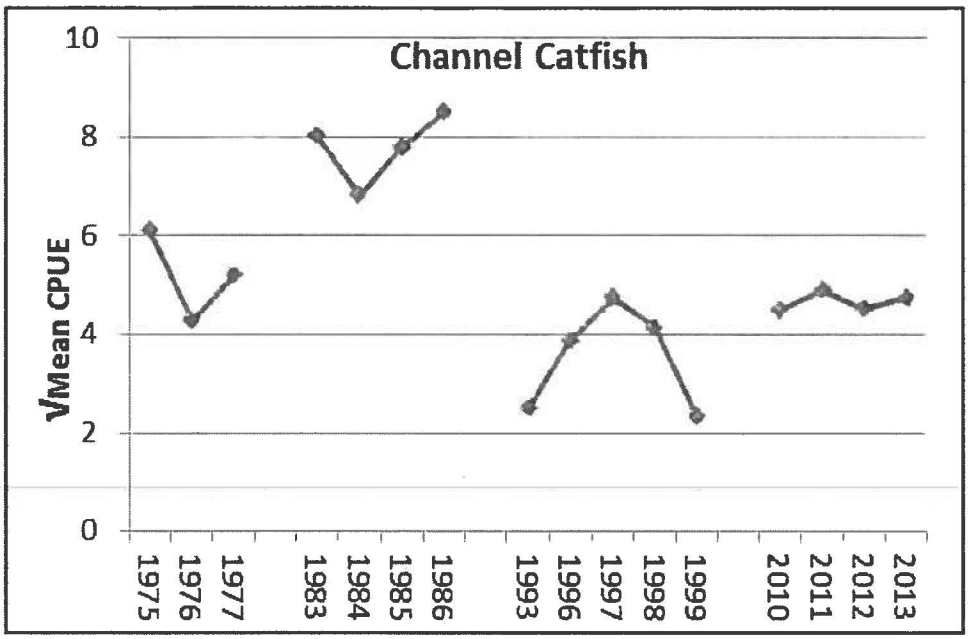


Figure 5-112. Square root transformed mean CPUE(no/0.5hr) for Channel Catfish collected using a boat electrofisher in Conowingo Pond, June-October 1975-2013.

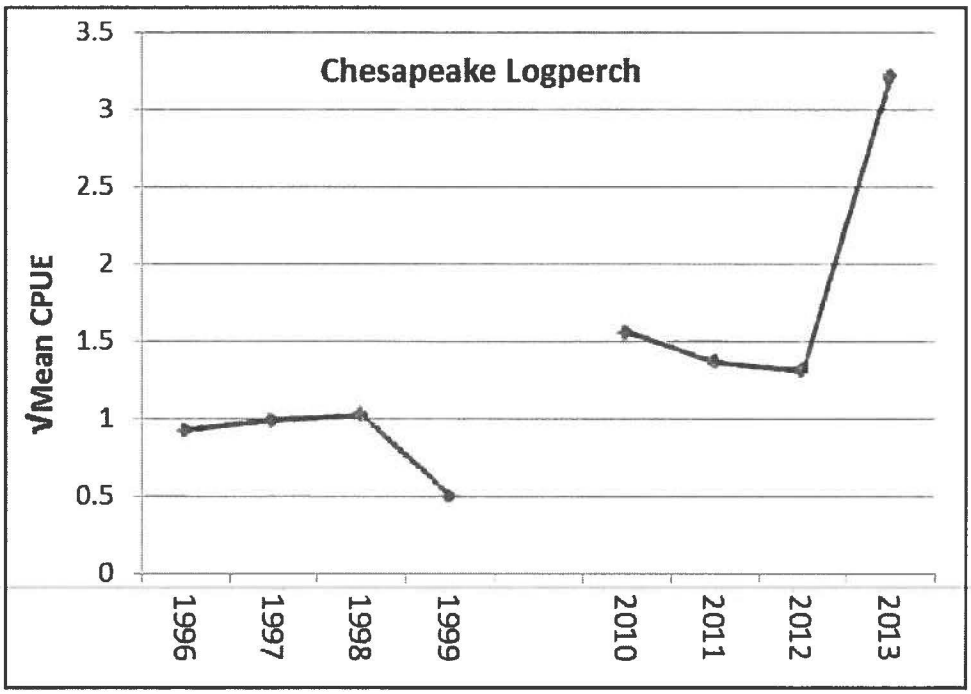


Figure 5-113. Square root transformed mean CPUE(no/0.5hr) for Chesapeake Logperch collected using a boat electrofisher in Conowingo Pond, June-October 1996-2013.

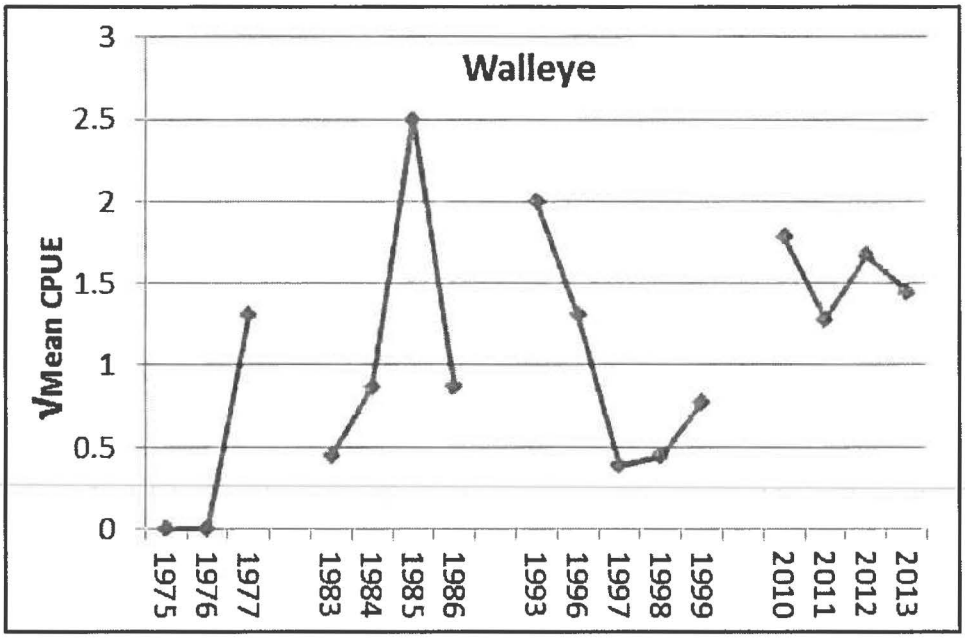


Figure 5-114. Square root transformed mean CPUE(no/0.5hr) for Walleye collected using a boat electrofisher in Conowingo Pond, June-October 1975-2013.

Discussion

Temporal differences in CPUE were evident for several species and reflect variations in the fish community associated with year-class strength and changes in species composition. CPUE during 2010 through 2013 was similar for most species except Bluegill, Gizzard Shad, and Smallmouth Bass. Greater numbers of young Bluegill were collected while electrofishing in 2012 as compared to 2010, 2011 or 2013. Fewer Gizzard Shad were collected while electrofishing in 2013 as compared to the previous 3 years. Smallmouth Bass catch was much higher in 2013 compared to 2010 through 2012. Long-term trends in electrofishing CPUE were observed for Gizzard Shad and White Crappie. No long-term trends in the seine collections were evident for the selected RIS.

Many confounding factors affect fish population dynamics in Conowingo Pond, including changes in water quality, year-to-year differences in River flow, species introductions, and immigration from Conowingo East Fish Lift and emigration through the Holtwood Fish Lift. Fish populations are not static and differences in relative abundance reflect these changes. The complex interaction of multiple variables makes pinpointing a single variable as causative of a change in relative abundance difficult. Many environmental factors including floods, droughts, and water quality changes (e.g. phosphorous loading from upper basin) can affect relative abundance. For example, large flood events can virtually eliminate year-classes of some species depending on timing of the event. This has been observed in recruitment of young of the year Smallmouth Bass in riverine systems (Smith *et al.* 2005).

The increase in Gizzard Shad relative abundance potentially affects early life stages of many fishes. Strong populations of Gizzard Shad, bolstered by introductions from the Conowingo Dam East fish lift, may out-compete other species for available food during critical juvenile stages, as occurred with White Crappie after the introduction of Gizzard Shad in the 1970s. Other potential differences in CPUE may be related to changes in the location of sampling stations and habitat changes at some of the stations that have occurred over the years.

Long-term trends reflecting changes in relative abundance within the Pond were observed for Gizzard Shad and White Crappie. Short-term trends were also observed for several species but short-term trends may or may not be representative of long-term dynamics. The observations of considerable variation in CPUE is typical of fish data. Abundance and percent composition are influenced greatly by year-class strength. No pattern in CPUE could be attributed directly to differences in water temperature observed during 2010-2013.

Conclusions

Based on the comparison of relative abundance results of this study and the available historic data we can conclude:

- Differences in relative abundance during the current study did not appear to be related to differences in water temperature resulting from cooling tower operation,
- Relative abundance of most RIS in 2010-2013 was within their historic ranges,
- Considerable variation in relative abundance occurred over time,
- Variable year-class strength for some species resulted in a wide range of relative abundance, and
- Changes in fish populations are expected due to naturally variable environmental conditions and species introductions.

5.7 Summary and Conclusions

The evaluation and analyses presented previously in Section 5 provide information about the fish and benthic macroinvertebrate communities in the Pond and comparisons between the thermal and non-thermal stations. These analyses aid in interpreting whether a BIC exists within the Pond. Several key characteristics of a BIC, as defined in the 316(a) rule, have been determined with these analyses.

A BIC is typically characterized by a diverse aquatic assemblage. The Pond community is comprised of over 50 fish species and over 100 benthic macroinvertebrate taxa and species composition was similar for both groups among the study years. Part of the basis for evaluating a BIC for this study was to evaluate spatial and temporal distribution of the 11 RIS. The 11 RIS occur in similar abundance throughout the Pond with CPUE and community metrics being similar among the collection locations. The capacity of an aquatic community to sustain itself through cyclic seasonal changes is a characteristic of a BIC. The Pond aquatic community continues to thrive within and outside of the thermal plume.

Benthic macroinvertebrate community sampling during the current study marked the first study of the shallow shore zone benthos assemblage in Conowingo Pond. Benthos sampling

associated with the previous 316(a) thermal variance studies focused on deeper, open water areas which are the predominant benthic habitat in the Pond. This study determined that the shore zone benthic community both within and outside of the thermal plume was characterized by limited diversity. Benthic community impacts resulting from the thermal plume were localized and temporary and limited to a small proportion of the available shallow shoreline habitat within the Pond. These impacts were determined based on evaluation of IBI scores and metric values. Lower IBI scores and metric values were observed at Stations 214 and 215, which are the stations closest to the end of the discharge canal. The lower IBI scores occurred after a sustained period of high water temperatures for a portion of July and August and, thereafter, recovery took place. There was no observed impact to the benthic community at the three thermally-influenced Stations (189, 216 and 217) that are farthest downstream from the discharge canal. The benthic community was able to sustain itself through cyclical seasonal changes both within and outside of the thermal plume. A balanced indigenous benthic community was observed within Conowingo Pond.

The primary factors that structure fish populations are recruitment, growth, and mortality. High rates of mortality, poor recruitment, or a reduction in growth can lead to a decline in relative abundance of a population and loss of a BIC. Fishes in Conowingo Pond are able to reproduce, recruit to the population, and grow to maturity. Likewise, the benthic community in the shallow, nearshore habitat continues to persist throughout the Pond, including in those near-field locations where the temporary and localized influence of the thermal plume is greatest. Both fish and benthic communities represent many different levels of the aquatic food chain, both as necessary forage species as well as top level predators. The diverse aquatic community is not dominated by pollution tolerant species. Several RIS are numerically dominant throughout the Pond and their presence is not a result of the thermal discharge. This predominance is most evident for Gizzard Shad which is the most numerically dominant RIS. This species was inadvertently introduced in 1972 and nearly 1 million adult Gizzard Shad are introduced annually from the Conowingo Dam fish lift.

An important component of evaluating a BIC is whether appreciable harm occurs to the aquatic community from the thermal discharge. Key components, as contained in the 316(a) rule, to evaluating damage resulting from a thermal discharge include:

- Substantial increase in abundance or distribution of any nuisance species or heat tolerant community not representative of the highest community development achievable in receiving waters of comparable quality,
- Substantial decrease in formerly indigenous species, other than nuisance species,
- Changes in community structure to resemble a simpler successional stage than is natural for the locality and season in question,
- Unaesthetic appearance, odor or taste of the waters,
- Elimination of an established or potential economic or recreational use of the waters,
- Reduction in completion of life cycles of indigenous species, including migratory species, and
- Substantial reduction in community heterogeneity or trophic structure.

None of these components describe the conditions observed within the Pond or within the thermal plume.

A primary variable in this field study and experiment was the effect of operation of cooling towers on the Pond's aquatic community. Overall, operation of variable numbers of cooling towers during the study had no detectable effect on the integrity of the BIC in Conowingo Pond. Fish community composition and relative abundance was similar among years. No spatial or temporal patterns were evident in the fish community that can be related to the number of cooling towers that were operating.

Findings of no obvious biological effects of zero cooling tower operation on fish relative abundance are not surprising and, indeed, are consistent with results reported in thermal discharge studies in other waters as well as in prior studies in Conowingo Pond (Bennett and Gibbons 1974; Coutant 1972, 1974; Raney *et al.* 1973; Romberg *et al.* 1943; PECO 1975; Stauffer *et al.* 1975; Thorpe and Gibbons 1977; Normandeau 2000b). A major contributing factor for this conclusion is that fish exhibit behavioral responses (preference or avoidance) to thermal discharges that ensure continued propagation of a balanced, indigenous community. Fishes present in Conowingo Pond are no exception. They are not trapped and thus they freely exercise their preference/avoidance behavior relative to the PBAPS discharge. Because the configuration and size of the PBAPS thermal plume and its associated temperature profiles vary with the prevailing hydrological conditions, fish are not consistently exposed to a specific temperature rise for a long period of time. The temperature regime created as a result of not operating cooling towers was within the tolerance limits of fishes. No direct mortality associated with the thermal plume or stressed fish were observed during this study or during the previous studies in Conowingo Pond.

Fishes can and will follow a temperature gradient. They normally follow this gradient to or toward their preferred temperature. The behavior of a given species often depends on the magnitude of change of temperature to which it may be exposed. It may be attracted to a higher or lower temperature, or it may avoid higher or lower temperature, or it may not react.

The preference and avoidance behavior of fish is an important factor which governs their distribution in relation to heated discharges. Lethal temperatures are avoided by motile aquatic organisms. Thus, fishes generally avoid the highest plume temperatures during the summer. Conversely, fishes will be attracted to the warmer plume temperatures during the winter months. This was evident for the winter electrofishing collections where species richness was the highest at Station 161, the thermally influenced station closest to the end of the discharge canal. Observations at power stations discharging relatively large volumes of heated water into rivers and lakes confirm the absence or rarity of thermal fish kills where fish can avoid lethal conditions. Upper temperature tolerance limits are not applicable unless fish are trapped and have no escape routes; fish at PBAPS are not trapped.

The fish community in Conowingo Pond shows great seasonal and annual fluctuations in abundance under natural conditions and is governed by the fundamental processes of reproduction, growth, and mortality. Fish populations within this community exhibit cyclical abundance patterns that interact with these processes. Fish species abundance during the

study was no different, as strong year classes were evident for several species (i.e., Comely Shiner, Channel Catfish, Bluegill, and Gizzard Shad). The fish species present in Conowingo Pond are naturally adapted to a wide range of temperatures.

This demonstration study provides evidence that a BIC is maintained in Conowingo Pond. The previous 316(a) thermal variance issued in 2000 is appropriate and achieves the goal of protecting and maintaining the BIC. The 4 years of this study provide confirmation of the conclusions that were drawn from the most recent previous thermal discharge demonstration study completed in Conowingo Pond (Normandeau 1996-2000). The previous study focused on the effects of the operation of a variable number of cooling towers at PBAPS on potential fish habitat and evaluated the potential effects on the operation of variable number of cooling towers on the existing fish communities. The study concluded that a thriving, balanced fish community can and does exist in Conowingo Pond without cooling towers in operation. That is, operation of PBAPS without cooling towers is compatible with the existence of a balanced, thriving, indigenous Conowingo Pond fish community. Several other important conclusions resulting from the prior study were reaffirmed by similar findings from the present demonstration study:

- The areas of preferred habitats with water temperatures that exceed avoidance temperatures for most RIS are relatively small compared to the size of Conowingo Pond;
- Fish are free to swim about and avoid the areas with temperatures not in their preferred range;
- Little or no habitat avoidance occurred in May and early June, a peak spawning period for most fishes in Conowingo Pond;
- The observed fish avoidance for select species occurred mostly in July and August when either the species naturally move out of the area or the important spawning activity does not occur;
- Naturally occurring hydrological events, such as Hurricane Agnes in 1972 and Hurricane Eloise in 1975, and biological events (i.e., introduction of Gizzard Shad) have had much more substantial and longer lasting effects on fish populations than the PBAPS thermal discharge;
- No long-term trends in declining CPUE for the RIS (with the exception White Crappie) or loss of important species were evident within Conowingo Pond;
- The 3 years of monitoring without cooling tower operation in 1997-1999 and the 4 years of monitoring in 2010-2013 at zero to three cooling tower operation over a wide range of hydrological conditions did not reveal obvious changes in the Conowingo Pond fish community due to the thermal discharge from PBAPS; and
- In 1999 the fish community was exposed to near worst-case summer temperature conditions and in 2010 and 2012 the fish community was exposed to below normal flows and above average temperatures in July and August, yet it appeared to have thrived, with no thermally-induced fish stress or mortality observed.
- Observations of the aquatic community during the current study support the thermal variance that PBAPS has operated under since 2000.

6 Hydrothermal and Avoidance Modeling

As noted in the Study Plan, the primary objectives of the hydrothermal modeling program were to:

- Provide a framework for a quantitative description of the Conowingo Pond-Holtwood-Muddy Run-Peach Bottom-Conowingo system; and,
- Quantify overall flow and heat balances in Conowingo Pond.

To meet these objectives and others, a time-varying, spatially detailed hydrodynamic and thermal model (the "hydrothermal model") was applied to Conowingo Pond, and calibrated for data collected in 2010 and 2011. The calibrated model was then used to estimate the size and configuration of the thermal plume for post-EPU heat loads, for extreme combinations of low flow and high temperature, and for zero to three cooling towers. Modeled estimates of the thermal plume dimensions were used to support an evaluation of the potential effects of the thermal plume on the fish and benthic communities under those conditions. The model also considered the effects of operations at Muddy Run Pumped Storage Facility on the thermal plume.

A key feature of the chosen hydrothermal model was its ability to calculate temperature increases in Conowingo Pond due to the PBAPS heat loads separately from the overall temperature computations. This feature allowed the hydrothermal model to be coupled to a second model that calculates fish temperature avoidance areas and volumes. This second model will be referred to as the avoidance model. Avoidance temperatures are species-specific temperatures shown in laboratory experiments to be avoided by fish.

6.1 Choice of Hydrothermal Model

To reproduce the dynamic interactions of facilities located on Conowingo Pond as well as the effects of forcing functions (solar heating, wind, Susquehanna River flows and temperatures), the hydrothermal model must be time-varying, three-dimensional and capable of including all significant heat sources, sinks, and considering all governing processes; capable of simulating other-than-observed conditions; and, shareable with PADEP.

GEMSS® (the Generalized Environmental Modeling System for Surface waters) meets these requirements. This model has been used in applications to determine the distribution of temperature and temperature rises due to the discharge of heat in the regulatory context. Locally, this model has been used successfully on the Susquehanna River (Brunner Island Steam Electric Station, Susquehanna Steam Electric Station) and on the Schuylkill and Delaware Rivers (Cromby, Eddystone and Edge Moor Generating Stations).

Features of GEMSS significant to application to Conowingo Pond include:

- The capability to calculate temperature rises over time, as well as overall temperatures, which allows for separation of natural- and induced-temperature changes;
- Bathymetry-handling functions, which allow islands, intake and discharge structures, canals, cooling towers, tributaries, weirs and dams to be represented;
- The ability to quantify plume dimensions and volumes within specific isotherms; and

- GIS-interoperability, which allows presentation of modeling results on habitat maps and other summaries of biological data.

GEMSS is an integrated system of three-dimensional hydrodynamic and transport modules embedded in a geographic information and environmental data system. GEMSS is in the public domain and has been used for hydrodynamic and water quality studies in 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 of the model.

GEMSS was developed in the mid-1980s as a hydrodynamic platform for transport and fate modeling of many types of introduced constituents. The hydrodynamic platform ("kernel") provides three-dimensional 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 those used for 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 that 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 and 1997; Edinger and Kolluru, 1999). The kernel is an extension of the well-known longitudinal-vertical transport model written by Buchak and Edinger (1984) that forms the hydrodynamic and transport basis of the Corps of Engineers' water quality model CE-QUAL-W2 (U. S. Army Engineer Waterways Experiment Station, 1986). 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; 2003b) and by Prakash and Kolluru (2006).

GEMSS capabilities have been evaluated by professional organizations, e.g., HGL and Aqua Terra (1999) and Water Environment Federation (2001).

GEMSS development continues as additional applications are completed. A second hydrodynamic kernel, the Princeton Ocean Model (POM), has been added as an alternative to GLLVHT for deep ocean systems. In addition, new constituent modules have been developed and tested, including source water protection (Kolluru and Prakash, 2012), watershed nutrient load allocation (Kolluru et al., 2009), chlorine and chlorine by-products fate and transport (Kolluru et al. 2012); mine pit lake analysis (Vandenberg, et al., 2011; Prakash, et al., 2012); debris fouling at cooling water intakes (Prakash et al., 2012); coliform fate and transport (Tryland et al., 2012); thermal avoidance calculations (Buchak, et. al., 2012); impact assessment (Fichera et al., 2013); and contaminated sediment transport (Kolluru et al., 2006.)

GEMSS applications to estuarine and coastal waterbodies have been validated by comparisons to extensive, field-collected datasets. These include currents, temperature and chlorine and chlorine by-products offshore Qatar (Kolluru et al., 2005; Adenekan et al., 2009; Febbo et al., 2012; Kolluru et al., 2003; Kolluru et al., 2012); currents, temperatures and nutrient water quality

in Puget Sound (Albertson et al., 2009); nutrients in coastal Delaware (Kolluru and Fichera, 2003), and the Vistula River in Poland (Kruk et al., 2011); currents and temperatures in the New York Harbor area (Edinger et al., 1997); larval populations in coastal Alaska (Edinger et al.,1994); and, mine tailings ponds (Prakash et al., 2011).

For inland waterbodies, GEMSS has been validated for temperatures in cooling lakes (Buchak et al., 2012 and Long et al., 2011); temperatures and nutrients in the Han River and Lake Paldang, Korea (Kim and Park, 2012a and 2012b; Na and Park, 2005 and 2006, respectively); temperature and fecal coliforms in Norwegian water supply reservoirs (Tryland et al., 2012). Many other inland, estuarine and coastal waterbody validations have been completed and published as client reports.

6.2 Data Needed to Support the Application of the Model

There are three types of data needed to apply GEMSS to Conowingo Pond:

- Spatial data that define the size and extent of Conowingo Pond and the locations and features of the facilities that use the Pond's water resources;
- Time-varying data (e.g., hourly Susquehanna River inflow rates) that quantify the forcing functions that govern diurnal and seasonal changes in the Pond during the study period; and,
- Observations of temperature that can be used to show that the model reproduces the characteristics of Conowingo Pond consistent with the intended modeling objective (i.e., estimates for extreme conditions and EPU).

The latter can be demonstrated by comparing computed flow patterns and temperatures to observed flow patterns and temperatures.

Sources and descriptions of each of these types of data are discussed in the following sections.

Spatial Data

A high resolution, three-dimensional grid for use with the hydrothermal model was developed using geo-referenced bathymetric data and engineering drawings of the intake and discharge structures for all facilities that use Conowingo Pond's water resources. The spatial features that were incorporated into the model grid (Figure 6-1) are as follows:

- Conowingo Pond bathymetry (i.e., elevations of the Pond bottom) and shoreline location;
- Holtwood Hydroelectric Plant dam and discharge structures;
- Muddy Run pumpback and generation structures;
- PBAPS intake and discharge structures; and
- Conowingo Hydroelectric Station discharge structures.

Conowingo Pond

To assure that the extent of the thermal plume is represented under all conditions, the model domain needed to encompass Conowingo Pond in its entirety from Holtwood Dam to Conowingo Dam. Shoreline location and bathymetric information for the entire Pond are

therefore required to develop and geo-reference the model's spatial grid. Design elevation-area-volume curves were used to verify that the model grid was consistent with this storage data (Gomez and Sullivan Engineers, P.C. 2010).

A bathymetric survey performed by USGS in 1996 was initially obtained from the USACE and used with digitized shoreline location data. In 2011, exceptionally detailed bathymetric data for Conowingo Pond became available. Gomez and Sullivan performed a depth survey of Conowingo Pond in 2011 spanning Hennery Island to Conowingo Hydroelectric Station (Gomez and Sullivan Engineers, P.C. 2011). The new bathymetric survey dataset consisted of 104,663 measurements and replaced 1996 USGS dataset used in earlier versions of the hydrothermal model. The availability of this dataset provided an opportunity to provide a better-resolved model grid downstream of the PBAPS discharge structure.

The shoreline polygon and additional shoreline bathymetric information was obtained from URS.

The model domain extends from the base of Holtwood Dam to Conowingo Dam. The three-dimensional grid includes lateral resolution ranging from 40 ft to 1250 ft, longitudinal resolution of 300 ft to 2500 ft, and vertical resolution of 1 ft. The grid incorporates 1191 cells. The grid is more highly resolved in the region immediately downstream of the discharge canal and adjacent to the western shore. Consistent with the known structure of Conowingo Pond, the grid shows increased depth at the lower end of the Pond and is shallow at the upper end, the region above Muddy Run being more tailrace and river than pond.

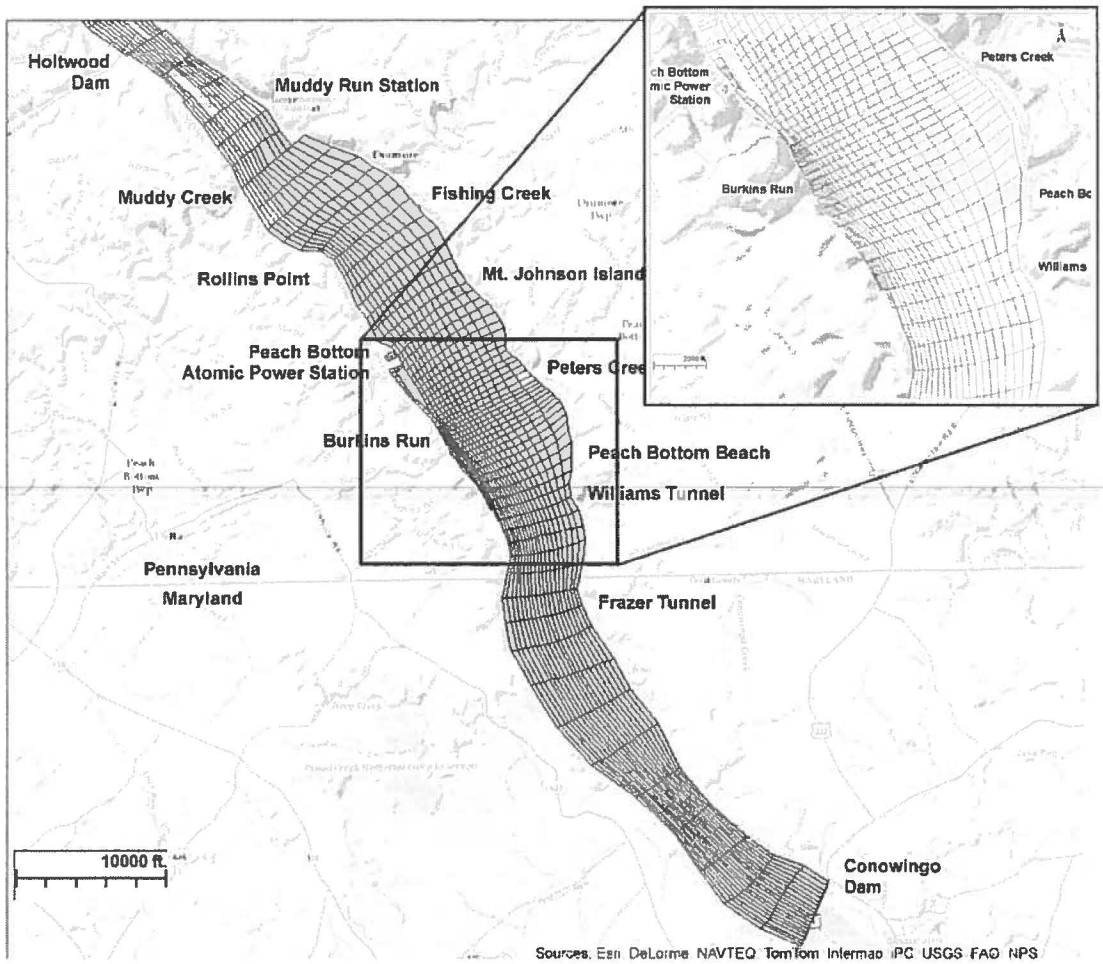


Figure 6-1. Model grid.

Holtwood Hydroelectric Plant

Information on the Holtwood Dam and discharge structure was available from the environmental report submitted to FERC in support of the proposed generating capacity addition (Kleinschmidt 2007).

Muddy Run Pumped Storage Station

Muddy Run Reservoir is not part of the model domain, but its effects on Conowingo Pond are an important boundary condition. Flows into and from Muddy Run Reservoir are an important part of the overall volume balance of Conowingo Pond. The storage curve for Muddy Run was obtained from Gomez and Sullivan Engineers, P.C. (2011). Intake and discharge structure drawings for Muddy Run were available from staff at Conowingo Hydroelectric Station. A storage curve based on a recent survey of Muddy Run was also obtained from Gomez and Sullivan. The pumpback and generation flows for Muddy Run were calculated from hourly water surface elevations and the storage curve obtained from Exelon. This calculation is described later in this report.

Peach Bottom Atomic Power Station

PBAPS outer screen drawings, depths in the intake basins, inner screen drawings, depths in the discharge canal, and drawings of the PBAPS canal discharge structure were obtained from Exelon. For the canal discharge structure, gate positions based on field observations were used in the model setup.

Cooling tower computations were also added to the model in 2011, which required extension of the grid into the discharge canal to accommodate the location of the individual intakes and discharges for each of the three cooling towers.

Conowingo Hydroelectric Station

Conowingo Dam release and spillway structure drawings were obtained from Exelon.

Time-varying Data

The model requires time-varying data to quantify the forcing functions that establish current patterns and temperatures within Conowingo Pond. The forcing functions consist of Susquehanna River flows and temperatures, flows and temperatures of other facilities on the Pond, and meteorological data. Taken together, these data quantify the water and heat balances for Conowingo Pond on a daily, or for certain datasets, hourly basis.

The time-varying data used by the model consist of:

- Susquehanna River inflows at Holtwood and outflows at Conowingo Hydroelectric Station;
- Muddy Run surface elevations from which to compute pumpback and generation flows;
- PBAPS discharge rate and temperature rise; and,
- meteorological data to calculate surface heat exchange, wind stress at the water surface, and cooling tower performance.

Susquehanna River inflows at Holtwood Hydroelectric Plant

Susquehanna River flows are measured by the USGS at Marietta (01576000) and immediately downstream of Conowingo Dam (01578310). Between Marietta and Holtwood the Conestoga and Pequea Creeks are also gaged by the USGS (01576754 and 01576787); these measurements are incorporated into PPL's records for Holtwood Dam as hourly values of total flow as well as corresponding values of flow through the turbines, with the difference being spillage over the dam, if any.

PPL records forebay temperatures six times a day. The combination of measured flows and temperatures serve as the upstream boundary conditions for the hydrothermal model.

Susquehanna River outflows at Conowingo Hydroelectric Station

Time-varying flow rates at the USGS Station 01578310 downstream of the Conowingo Dam are available from USGS website. These datasets have been downloaded and included in the model as the downstream flow boundary condition.

Muddy Run Pumped Storage Station

Pumpback and release rates were not measured. However, Muddy Run hourly water surface elevations were available which, when combined with the Muddy Run storage curve, can be used to obtain pumpback and release rates based on a volume balance for Muddy Run Reservoir.

Assuming the only inflows and outflows to and from Muddy Run Reservoir are the exchanges between Muddy Run Reservoir and Conowingo Pond and that evaporation from the reservoir surface can be neglected, the volume balance equation for the reservoir can be written as:

$$\frac{dS}{dt} = I - O \qquad \text{Equation 1}$$

where

dS	=	change in storage (a volume)
I	=	inflow rate
O	=	outflow rate
t	=	time

Equation 1 can be simplified to:

$$\frac{dS}{dt} = Q \qquad \text{Equation 2}$$

where

Q	=	I (+) or O (-)

Water in storage (S) for a given elevation in the reservoir at a given time was obtained from the storage-elevation curve and the change in storage, ΔS, over any time period can subsequently be calculated. The ΔS was used to estimate Q, which can be applied as either an inflow (release) or outflow (pumpback). Because hourly values of elevation are available the daily release and pumpback cycle can be calculated.

Peach Bottom Atomic Power Station

To incorporate PBAPS's intake and discharge flows, including heat from power production and service water needs, Exelon provided hourly values of

- Unit 2 and Unit 3 core thermal power (MWt);
- Unit 2 and Unit 3 electrical generation (MWe);
- Status of each of three Unit 2 circulating water pumps (i.e., on or off); and,
- Status of each of three Unit 3 circulating water pumps (i.e., on or off).

The total circulating water rate was calculated based on the number of pumps operating multiplied by the capacity of each pump (250,000 gpm, 557 cfs). Six pumps ordinarily run during the summer, for a total circulating water flow rate of 3342 cfs. The service water flow rate is 14,000 gpm for each of six pumps, a total of 187.2 cfs. The design value for the service water temperature rise of 10.7°F was used for all simulations.

Meteorological data

Meteorological data were used to quantify surface heat exchange, wind stress and to calculate heat loss through each cooling tower. Hourly data were available from three different sources. A local solar radiation measuring instrument was installed at Normandeau's office in Drumore, PA, adjacent to Muddy Run. Wind speed, direction, air temperature and dew point temperature were available from the PBAPS meteorological tower. The remaining meteorological parameters (wet bulb, relative humidity) were obtained from the nearest NOAA/NCDC meteorological station located at Lancaster, PA.

The model uses the term-by-term approach to calculating surface heat exchange and the Brady, Graves and Geyer evaporative windspeed function, an appropriate choice for heated waterbodies.

York Energy Center, City of Baltimore and Chester Water Authority

Intake and discharge rates and heat loads for the York Energy Center were not included in the model because these makeup and blowdown flows and heat loads are small relative to PBAPS flows and heat loads and because the York Energy Center intake and discharge are located well upstream of the PBAPS intake structure. The two public water supply withdrawals, City of Baltimore and Chester Water Authority, were similarly small and far removed from the region of interest and therefore not included explicitly in the model.

Calibration Data

The calibration data available to confirm model performance consist of the following:

- Temperature monitoring data; and,
- Water surface elevation at Conowingo Hydroelectric Station.

Model calibration (comparison observations and subsequent adjustment of model input parameters) was initially performed for 2010 based on comparisons between modeled and observed temperatures in Conowingo Pond. Model validation was completed with the comparison to 2011 observations without adjustment of model input parameters; model performance was essentially the same as that for the calibration year. A second model validation, i.e., comparisons to observations taken in 2012, was subsequently performed. All observations were used in the calibration and validation exercises, including

- Conowingo Pond elevations;
- Transects;
- Seining stations;

- Electrofishing stations; and,
- Cooling water stations.

6.3 Model Calibration

Model calibration refers to the comparison of model results to observations and the subsequent adjustment of model input parameters to better reproduce those observations. For the Conowingo Pond hydrothermal model, calibration was initially performed using data obtained in 2010. As noted earlier, updated Conowingo Pond and Muddy Run bathymetric data became available for the 2011 simulations. Because these datasets are important determinants of flow fields in Conowingo Pond, the model was re-calibrated using 2011 data and then validated by a second comparison to 2010 observations.

The model was first calibrated to observed water surface elevations and further calibrated to observed water temperatures. Comparisons of observed, time-varying water surface elevations with predicted values measure the model's ability to account for flows into and out of the Pond and of the model's representation of the elevation-area-volume curve. Comparisons to temperature, especially during low flow periods, evaluated the model's ability to estimate temperatures at extreme conditions.

Muddy Run Reservoir water surface elevations in conjunction with the reservoir storage curve were used to calculate flows entering and leaving Conowingo Pond from Muddy Run Reservoir. These flow rates, in addition to the USGS-provided Susquehanna flows (the sum of flows from the Susquehanna River, Conestoga and Pequea Creeks) and Conowingo Dam releases, provided the basis for calculating the changes in volume in Conowingo Pond over time (the "volume balance"). Changes in volume can be assessed simply by comparing computed and observed water surface elevations.

Computed water surface elevations in the Pond compared to model-predicted water surface elevations for 2010 and 2011 are shown in Figure 6-2 and Figure 6-3. The average difference between modeled and measured elevations (the mean error) is one-hundredth of a foot (0.01 ft). The standard deviation is one-third of a foot (0.35 ft). The small mean error confirms that the model accurately incorporates the dynamic inflows and outflows characteristic of Conowingo Pond averaged over the daily and seasonal cycles. The standard deviation shows that agreement at the hourly time scale is somewhat degraded. Discrepancies at the hourly time scale may be due in large part to uncertainties in the Muddy Run inflow and outflow rates, but with respect to estimating the size and configuration of the thermal plume for steady, low flow events, the model volume balance is quite good.

In addition to the volume balance, accurate reproduction of temperatures at the extreme low flows at which the model will be run is an important indicator of the model's predictive ability for the extreme condition EPU simulations. Measurements from temperature monitoring stations were compared with model-predicted temperatures and statistical summaries of these comparisons were developed. These goodness-of-fit summaries were then assessed against literature-based norms.

Comparisons of predicted and observed temperatures were made for groups of stations:

- Upstream stations (203, 102, and 151) that represent ambient temperatures
- Near-field stations (214, 201, 215) located immediately downstream of the discharge structure
- Far-field stations (202, 189, 301, 302) located further downstream and across the Pond
- Downstream stations (402, 403, 611) nearer the Pennsylvania – Maryland border.

September 2010 was the month with the lowest flows during the study period (see Table 3-2), during which the average Susquehanna River flow at Holtwood was 6,142 cfs and therefore the best period to assess model performance for the model's intended use. Values of goodness-of-fit statistics for this period are shown in Table 6-1.

Table 6-1. Mean errors (computed minus observed) by station group for September 2010.

Location	Mean error (°F)
Upstream stations	
All depths	-0.81
Surface	-1.44
Bottom	-0.18
Near-field stations	
All depths	0.19
Surface	0.44
Bottom	-0.58
Far-field stations	
All depths	-0.32
Surface	-0.15
Bottom	-0.55
Downstream stations	
All depths	0.38
Surface	0.44
Bottom	0.31

The mean error values show that the model is predicting lower than observed temperatures by about 0.8°F at upstream stations; higher temperatures at the near-field stations (by about 0.2°F); lower than observed temperatures by about the same magnitude at the far-field stations; and, higher at the downstream stations, but also by a small amount. The goodness-of-fit for the near-field, far-field, and downstream stations is more than adequate for the model's intended use: predicting temperatures at these stations for low flow events during warm periods. With respect to model – data comparison norms, Cole and Wells (2011, p. 36) show mean errors for 70 reservoirs modeled with CE-QUAL-W2, the two-dimensional companion to GEMSS. These published model applications showed mean errors between 0.3 and 0.9°C (0.5 to 1.6°F).

Additional goodness-of-fit guidance can be found in EPA (Ambrose *et al.*, 2006) in which relative mean error, error coefficient of variation, and the squared correlation coefficient are the recommended metrics and for which acceptable values are listed. The metrics shown in Table 6-2 were developed for all of 2010. The model performance substantially exceeds the goodness-of-fit metrics cited in the EPA guidance.

Table 6-2. Error statistics and EPA guidance by station group for September 2010.

Metric	Guidance Value	EPA Technical Guidance 2006, Table 5-15 (Transport)	Station Set	2010
Relative Mean Error	25%	25%	Upstream	0.43%
			Near-Field	0.06%
			Far-Field	0.37%
			Downstream	0.74%
Error Coefficient of Variation	45%	45%	Upstream	2.00%
			Near-Field	2.13%
			Far-Field	2.04%
			Downstream	1.69%
Squared Correlation Coefficient	0.71	0.71	Upstream	0.89
			Near-Field	0.92
			Far-Field	0.90
			Downstream	0.93

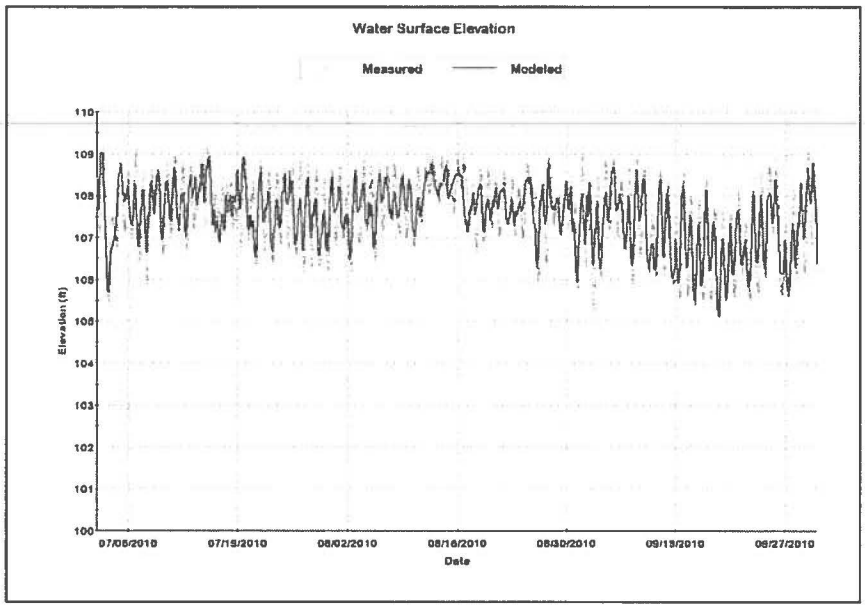


Figure 6-2. Model to data comparison of water surface elevations in Conowingo Pond for 2010.

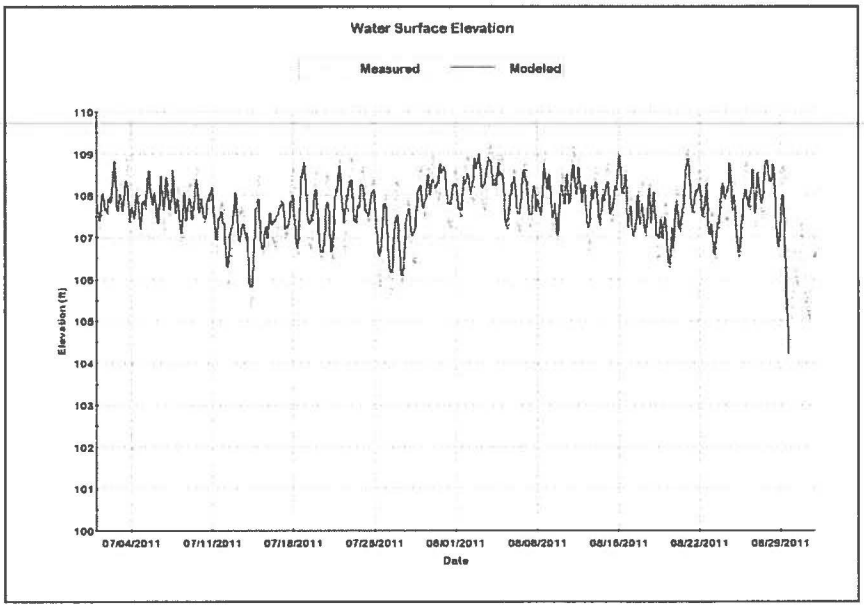


Figure 6-3. Model to data comparison of water surface elevations in Conowingo Pond for 2011.

6.4 Conclusions: Hydrothermal Modeling

Each of the objectives of the hydrothermal modeling program was met:

- The chosen model provided a quantitative framework for assessing changes in the thermal plume under various conditions; and,
- Effects on the thermal plume of pumpback and generation at Muddy Run, diurnal heating and cooling, and other dynamic input parameters were quantified.

The model calibration covered a useful range of Susquehanna River flows and temperatures during which PBAPS was operating at rated capacity and circulating water rate. An assessment of the hydrothermal model performance indicated:

- The model's ability to reproduce the observed thermal behavior is consistent with literature-based norms for model applications;
- The model reproduces the hydrodynamics and thermal structure of the Pond relative to the PBAPS thermal plume and other dynamic input parameters;
- The agreement of computed and observed temperatures during low flows allows the model to predict the thermal structure in the pond for extreme conditions; and
- The model provides detailed information for the Peach Bottom thermal plume that can be used to quantify areas of higher temperature that are potentially avoided by fish in the Conowingo Pond.

The combination of extensive thermal monitoring and modeling programs is a valuable tool in understanding the behavior of Conowingo Pond under varying flow rates and temperatures. While the thermal monitoring program provides direct information on the existing conditions and helps to validate the thermal model, the model provides a tool that can be used to simulate unobserved or unobservable conditions, including combinations of low flows, high temperatures and the EPU.

6.5 Avoidance Model

Output from the Conowingo Pond hydrothermal model was used to obtain information relevant to fish habitat, specifically to delineate areas above temperature tolerances for various species. Experimental data in the literature provides avoidance temperature information. This avoidance temperature is a function of the background temperature ("acclimation temperature"); fish can acclimate to a wide range of temperatures. Tolerance to warmer temperatures increases, within limits, as the acclimation temperature increases.

Avoidance temperature curves for species of interest have been provided by Normandeau Associates, Inc. Because the hydrothermal model also calculates temperature rise, thermal plume sizes can be directly mapped to avoidance areas and volumes.

Evaluation of RIS avoidance is presented in Section 7. For illustrative purposes, avoidance areas for Spotfin Shiner were calculated for hottest day of 2012, which occurred on July 18, 2012, and are shown in Figure 6-4. On this day, the PBAPS intake temperatures reached 86.3 F and the Susquehanna flow rate was 7,500 cfs. The corresponding avoidance temperature was 92.3 F. Two cooling towers were operational during 2012 resulting in a small avoidance area

(shown in blue in Figure 6-4). As will be described later, this combination of observed temperature and flow corresponds to the extreme case used in the model simulations.

However, Spotfin Shiner was found in mapped avoidance areas. As shown in Figure 6-4, numerous Spotfin Shiner were collected in the theoretical avoidance areas. This result indicates that the avoidance temperature model is very conservative (overestimates the behavioral impact).

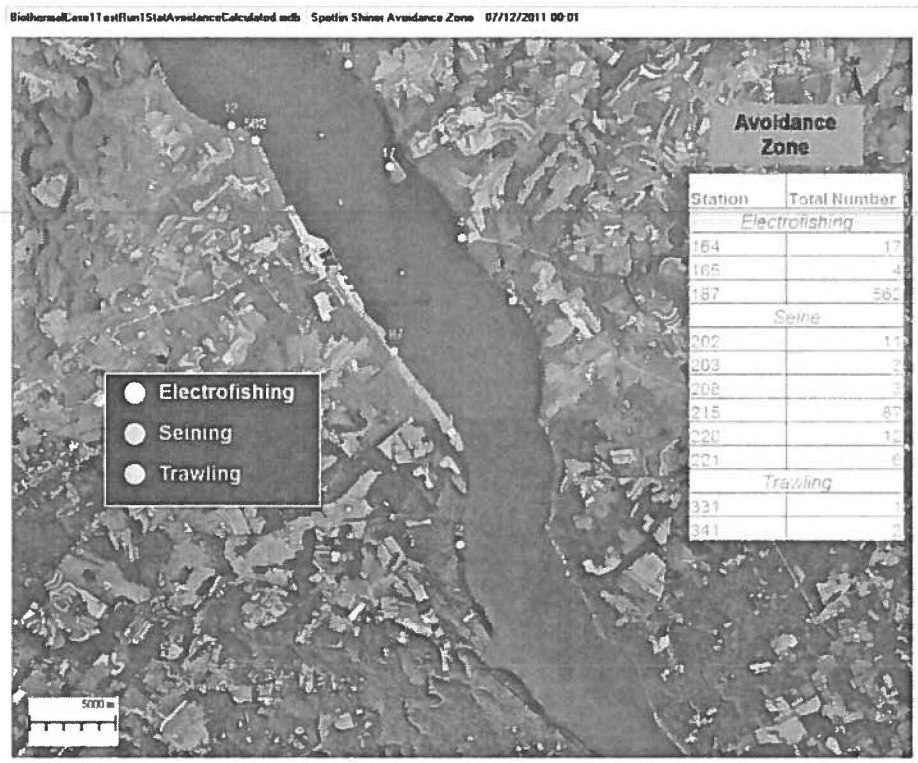


Figure 6-4. Calculated avoidance areas for Spotfin Shiner at the surface on July 10, 2012.

6.6 Modeling Scenarios

The hydrothermal model was run for two overall cases: Current Licensed Thermal Power (CLTP) and Extended Power Uprate (EPU). The EPU simulations are predictive because the EPU represents a planned increase in the heat load to Conowingo Pond. These predictions are presented in Chapter 7 and used for the post-EPU biological assessment. Similar simulations representing the existing CLTP heat load are presented in this section to characterize the thermal plume and to allow for direct comparison with the EPU simulations. The existence of the BIC for the CLTP has previously been demonstrated separately from the model results using an analysis of the biological data collected during the present study. Therefore, potential fish avoidance is not evaluated for CLTP.

Since thermal plume size and configuration are dependent primarily on the upstream temperature, Susquehanna River flow rate, and the amount of heat discharged by PBAPS, values for these parameters need to be selected such that realistic, but infrequent, combinations

of temperature and flow are also represented. To do so, a long record of simultaneous Susquehanna River temperatures and flows was obtained and analyzed. This record consisted of daily Holtwood Hydroelectric Facility temperatures and flows, 1956 to 2012. This record is longer than the individual flow and temperature datasets used to characterize the study years (Section 3.2) because it is sufficient for this analysis that pairs of flows and temperatures be available and not necessary that the records are continuous, as was required for the Section 3.2 analysis.

Table 6-3 shows the cumulative frequency distribution of these flow and temperature pairs. There were 2,027 occurrences of temperatures greater than 80°F (26.7°C) coinciding with Susquehanna River flows less than 13,000 cfs out of 20,299 pairs, or 10% of the total, equivalent to about 35 days each year. There were 203 occurrences of temperatures greater than 86°F (30°C) coinciding with Susquehanna River flows less than 7,000 cfs, or about 1% of the total, equivalent to 3 or 4 days a year. Such occurrences do not necessarily occur on consecutive days; the cumulative frequency distribution cannot be used to draw conclusions about the duration of these events.

Table 6-3. Numbers of Susquehanna River high temperature and low flow events; the annual probabilities of these events can be obtained by dividing by 20,299.

Flows (cfs)	Temperatures (F)												
	>80	>81	>82	>83	>84	>85	>86	>87	>88	>89	>90	>91	>92
<2000	8	7	5	5	3	3	3	3	0	0	0	0	0
<2500	24	20	17	15	11	10	9	8	3	0	0	0	0
<3000	65	58	49	41	27	24	20	18	7	2	1	1	0
<3500	146	136	120	93	65	50	36	29	12	4	2	1	0
<4000	260	235	206	163	121	80	54	39	15	7	5	3	0
<4500	366	323	279	227	171	116	77	58	26	15	11	6	2
<5000	508	430	363	287	218	146	99	[illegible]	[illegible]	[illegible]	[illegible]	8	3
<5500	647	544	457	358	272	183	127	[illegible]	[illegible]	[illegible]	[illegible]	8	3
<6000	766	641	536	422	325	222	154	[illegible]	[illegible]	[illegible]	[illegible]	9	3
<6500	880	741	625	496	378	263	181	128	70	36	15	9	3
<7000	989	832	700	553	425	299	203	141	77	38	17	10	4
<7500	1102	939	792	625	476	335	230	152	79	39	17	10	4
<8000	1220	1042	882	694	529	370	242	157	82	39	17	10	4
<8500	1318	1124	949	743	564	389	255	166	87	42	19	12	4
<9000	1428	1223	1031	803	601	413	269	174	89	43	20	12	4
<9500	1535	1313	1101	845	624	429	277	179	92	44	21	13	4
<10000	1624	1387	1158	886	651	446	286	185	96	47	24	14	5
<10500	1706	1449	1204	915	668	458	293	189	98	48	25	15	5
<11000	1779	1508	1244	946	688	468	297	191	100	48	25	15	5
<11500	1842	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	300	194	102	50	27	17	5
<12000	1906	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	304	196	103	51	28	18	5
<12500	1973	1658	1353	1017	732	488	308	199	104	52	29	18	5
<13000	2027	1700	1378	1036	744	492	309	199	104	52	29	18	5

Three or four days during the summer

About 35 days during the summer

The Current Licensed Thermal Power (CLTP) temperature rise (ΔT), defined as the average difference between temperatures measured at the head of the discharge canal and PBAPS intake temperature, is 19.4°F, and was computed using data from the monitoring program for the months of July and August, 2010 through 2012. The EPU is expected to increase the ΔT by up to 3°F. Thus, the post-EPU ΔT will be 19.4°F + 3°F = 22.4°F. The associated full capacity discharge rate (condenser cooling and service water flows) is 3,529 cfs.

Use of the Holtwood record allowed the frequency analysis to be developed from a very large number of measurements. However, based on a comparison of June 15 to September 15 data for 2010, 2011 and 2012, Holtwood temperatures are warmer than observed intake temperatures by 0.53°F. The implication for the hydrothermal model is that the selected conditions overestimate temperatures and thus the size of the avoidance zone, adding another level of conservatism to the avoidance evaluations in Section 7.

This method of developing conditions for analysis is similar to that used in the recent previous thermal effects reports (Normandeau Associates 1999, 2000a, 2000b) in that both methods focus on simultaneous occurrences of high temperatures and low flows.

The combination of flows less than 13,000 cfs and temperatures greater than 80°F will be referred to as the *typical summer condition*. This condition occurs approximately 30 days each summer. The *extreme summer condition* occurs no more than 1% of the time, or about 3 or 4 times each summer and consists of flows less than 7,000 cfs and water temperatures greater than 86°F. A hydrothermal and avoidance model simulation was made for each high temperature / low flow condition for each of four possible cooling tower configurations (a total of eight simulations). Table 6-4 summarizes these simulations. To account for heat rejected to the atmosphere by the cooling towers, heat is removed from the discharge canal at a rate equivalent to the 1.75°F discharge canal reduction observed for each operating tower (i.e., two towers show a 3.5°F reduction). These values were derived from 2011, 2012 and 2013 observations of cooling tower performance (Section 3.2).

Table 6-4. Modeling simulation identifiers and conditions.

Identifier	Susquehanna River flow at Holtwood and Conowingo, cfs	Susquehanna River temperature, °F	Number of cooling towers
Typical summer, 0 CT	13000	80	0
Typical summer, 1 CT	13000	80	1
Typical summer, 2 CT	13000	80	2
Typical summer, 3 CT	13000	80	3
Extreme summer, 0 CT	7000	86	0
Extreme summer, 1 CT	7000	86	1
Extreme summer, 2 CT	7000	86	2
Extreme summer, 3 CT	7000	86	3

During the 2010-2013 study period, there were few days of coincident high temperature and low flow (Table 6-5), which is consistent with the overall frequency statistics shown earlier. In 2010, the closest observed values to the *extreme summer condition* occurred on August 11, when

water temperature was 29.4°C (84.9°F) and flow was 5,100 cfs. During 2011, conditions near the *extreme summer condition* occurred on July 31 (30.5°C or 86.9°F and 6,900 cfs), with similar high temperature and low flow values observed on the days surrounding this event. In 2012, conditions near the *extreme summer condition* occurred on several consecutive days in mid-July (30.2°C or 86.4°F and 7,000 cfs on July 18). No coincident high water temperature and low flow conditions comparable to the *extreme summer condition* were observed in 2013.

Table 6-5. Observed temperature-discharge measurements at Holtwood similar to the *extreme summer condition* modeling scenario, 2010-2013.

Date	Discharge (cfs)	Temperature (°F)
7/12/2010	7100	83.8
8/6/2010	6300	83.4
8/7/2010	5400	83.1
8/8/2010	5600	82.5
8/9/2010	5000	82.5
8/10/2010	5800	83.8
8/11/2010	5100	84.9
8/12/2010	5100	83.7
7/30/2011	7600	86.7
7/31/2011	6900	86.9
8/1/2011	7700	86.9
8/2/2011	7500	85.8
7/13/2012	6200	86.2
7/14/2012	6500	85.1
7/15/2012	5900	85.4
7/16/2012	7600	85.8
7/17/2012	6900	85.9
7/18/2012	7000	86.4
7/19/2012	7000	86.2

The upstream temperature, Susquehanna River flow rate, and the amount of heat discharged by PBAPS were held constant throughout each simulation. One feature of the Conowingo Pond system was varied on a diurnal cycle: the Muddy Run Pumped Storage Station, as noted earlier, regularly removes a large volume of water from Conowingo Pond during nighttime pumpback operations and returns that volume during daytime generation. Typical generation and pumpback flow rates are shown below in Figure 6-5.

The behavior of the thermal plume with respect to Muddy Run operations was studied with the model. Figure 6-5 is marked to show four key times during the pumpback and generation cycle: maximum pumpback, end of pumpback, maximum generation, end of generation. These times are not evenly spaced, but were selected to show the impacts of these events on the thermal plume. Figure 6-6 shows the configuration of the plume at each of these times during extreme

low flows. Not shown is the location of the Muddy Run intake and discharge structure, which is further north than the diagram extends.

During extreme low flow events, the pumpback and generation flows exceed the Susquehanna River flow of 8,000 cfs by a factor of 4 and the PBAPS condenser cooling and service water flows by a factor of 8. An examination of the plume as defined by the 95°F isotherm shows upstream extension of the plume at the end of pumpback and downstream extension and elongation of the plume at the end of Muddy Run generation. Other isotherms show similar behavior. The 10 ft and bottom views of the plume during pumpback and generation show very little movement.

Hydrothermal model results were used to choose the end of pumpback as the standard time to show the plume configuration throughout this report.

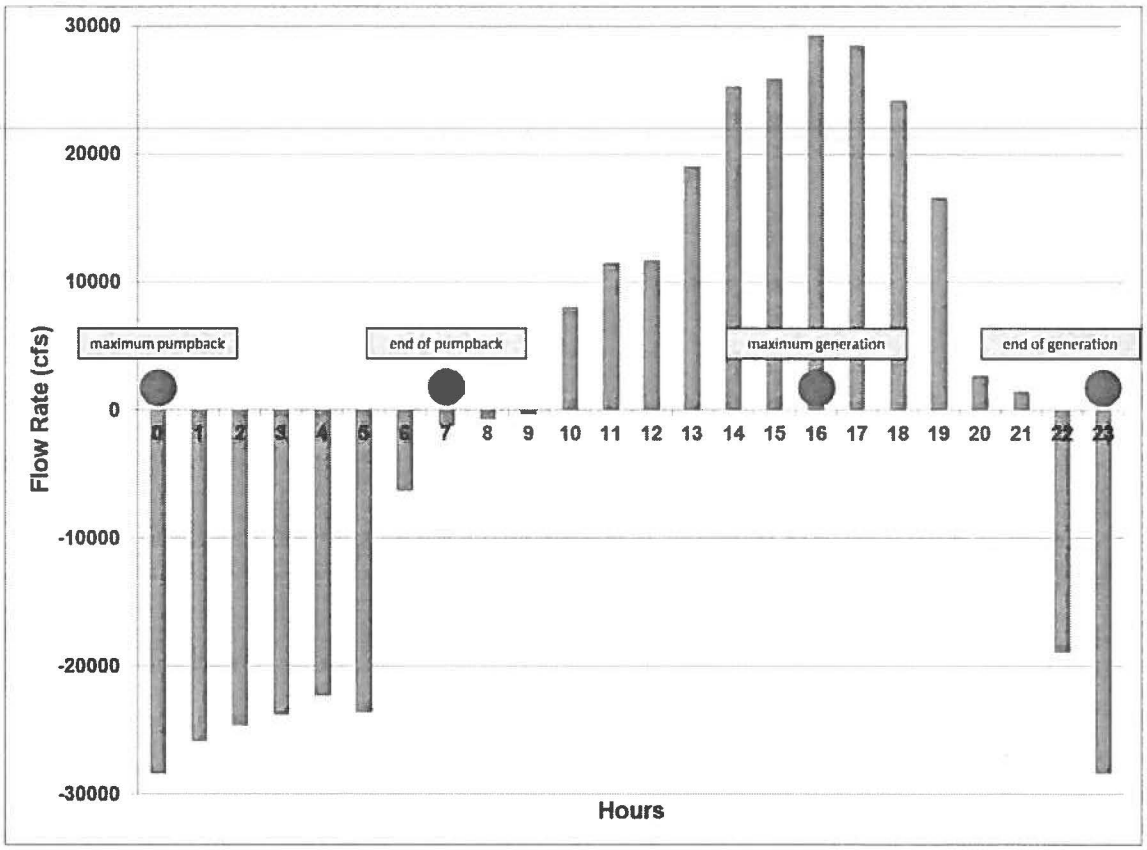


Figure 6-5. Muddy Run pumpback and generation cycle showing flow rates; positive values are into Conowingo Pond.

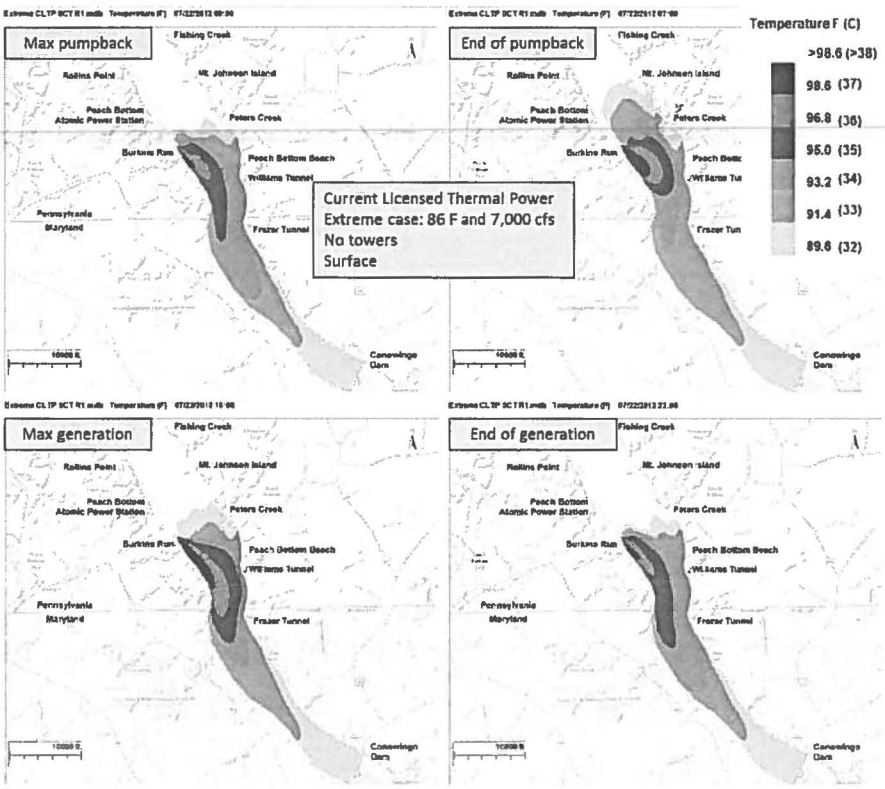


Figure 6-6. Behavior of the thermal plume at the four instances of the Muddy Run pumpback and generation cycle identified in the previous figure.

Heat loss from the surface of Conowingo Pond to the atmosphere was assumed to be limited. The approach developed by Edinger *et al.* (1974) was adopted. In that approach, the net rate of surface heat exchange is computed from a coefficient of surface heat exchange and an equilibrium temperature. The value of the equilibrium temperature was assumed to be identical to the Holtwood inflow temperature and the coefficient of surface heat exchange was taken to be 145 Btu ft^{-2} $°F^{-1}$ (35 W m^{-2} $°C^{-1}$). Under these conditions, heat is transferred to the atmosphere only when water temperatures exceed the assumed Susquehanna River temperature (80°F: *typical summer condition*; 86°F: *extreme summer condition*) and, overall, the equilibrium temperature approach forces all water temperatures towards the chosen temperature (either 80°F or 86°F). The value of the coefficient of surface heat exchange (Figure 2.4.2 in Edinger *et al.* 1974) corresponds to a surface water temperature of 86°F and a wind speed of 6 mph, which is the August average for Conowingo Pond (U. S. Department of Commerce 1968).

There are a number of assumptions in the method of calculating avoidance areas that individually and in combination overestimate avoidance:

- The simulations require running the present hydrothermal model for approximately 2 weeks until it reaches stationary state, during which time the selected temperature and flow conditions are constant. In fact, the Susquehanna River flow rate always increases from short-term lows and upstream temperatures always decrease from short-term highs. In reality, extreme summer conditions last just a few days, not several weeks. The simulations represent a substantial buildup of temperature that would not occur in reality. This buildup is further enhanced because the equilibrium temperature approach forces temperatures toward high values instead of the cooling that naturally occurs after a high temperature period.
- Intake temperatures are likely overestimated because Holtwood temperatures are taken as equivalent when in fact Holtwood temperatures are higher by 0.5°F during the summer.
- PBAPS operating units are assumed to be running at full capacity for the entire simulation. In fact, the pre-refueling power coast down occurs approximately 6 weeks prior to the refueling outage which occurred by mid-September in 2010 to 2013. To the extent that the selected *extreme summer conditions* occur in late August or September, the full capacity assumption is conservative.
- Field data show that fish were collected in areas with temperatures exceeding the avoidance temperature.
- Modeled avoidance areas do not account for preferred or actual habitat used by a species (i.e., they may include areas that the fish would not generally use absent a thermal effect).

6.7 Modeled Thermal Plume for Typical and Extreme Conditions

This section presents snapshots of the modeled thermal plume for the typical and extreme conditions, each with 0, 1, 2, and 3 cooling towers operating (2 conditions x 4 cooling tower configurations). For each of these combinations 6 views are shown: 2 longitudinal-vertical ("transect") views and 4 lateral-longitudinal ("planar") views. The latter are at the surface, 10 ft, and the bottom. There are two bottom views: the entire plume and, for benthic macroinvertebrate evaluation, the bottom plume where temperatures are greater than 94°F.

Figure 6-7 shows the locations of transects 1,000 and 5,000 ft downstream of the discharge structure. These transects were chosen to represent the evolution of vertical and lateral mixing downstream of the discharge. For reference, the locations of the transects are also shown on the planar views. Surface in this case means temperatures averaged over the top 1 ft and bottom is the true bottom, regardless of the depth. A total of 2 x 4 x 6 = 48 figures are shown on the following pages. The conditions, configurations and views are identified on the figures themselves.

Cross-sectional areas, expressed as a fraction of the total, are shown in Table 6-6 (*typical* and *extreme conditions*). Surface, 10-ft, and bottom areas in excess of specific temperatures use in the avoidance evaluations are shown in Table 6-7 (*typical* and *extreme conditions*).

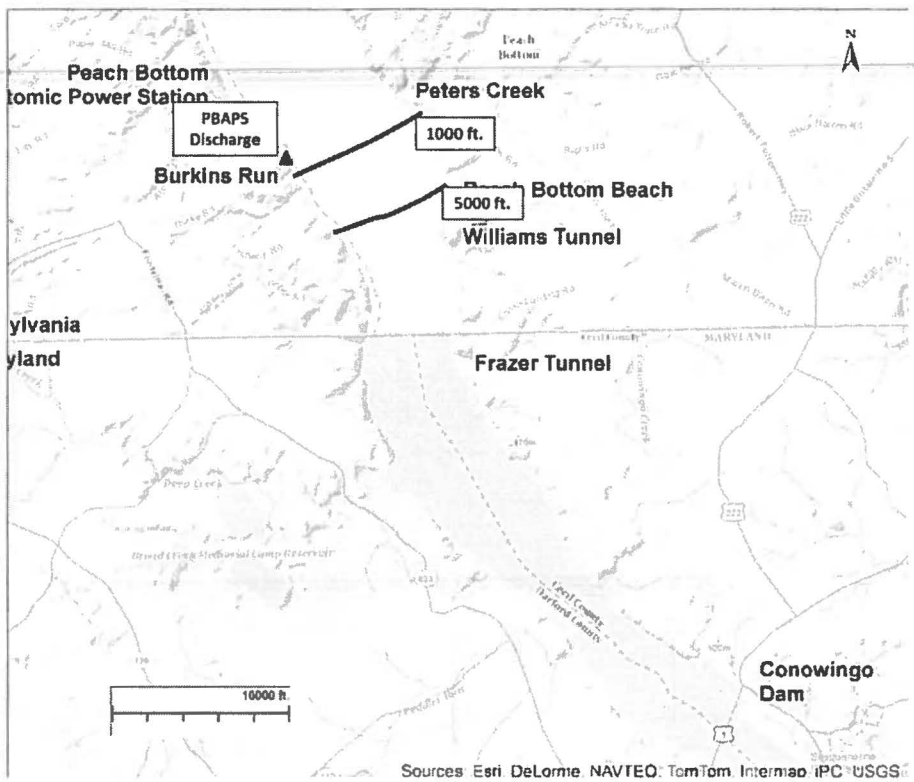


Figure 6-7. Location of transects for cross-sectional diagrams.

The presentation sequence is a follows:

Typical condition

- 0 cooling towers
  - 1000 ft transect
  - 5000 ft transect
  - Surface plume

10 ft plume

Bottom plume

Bottom plume >94°F

1 cooling tower

(same six views)

2 cooling towers

(same six views)

3 cooling towers

(same six views)

Extreme condition

0 cooling towers

1000 ft transect

5000 ft transect

Surface plume

10 ft plume

Bottom plume

Bottom plume >94°F

1 cooling tower

(same six views)

2 cooling towers

(same six views)

3 cooling towers

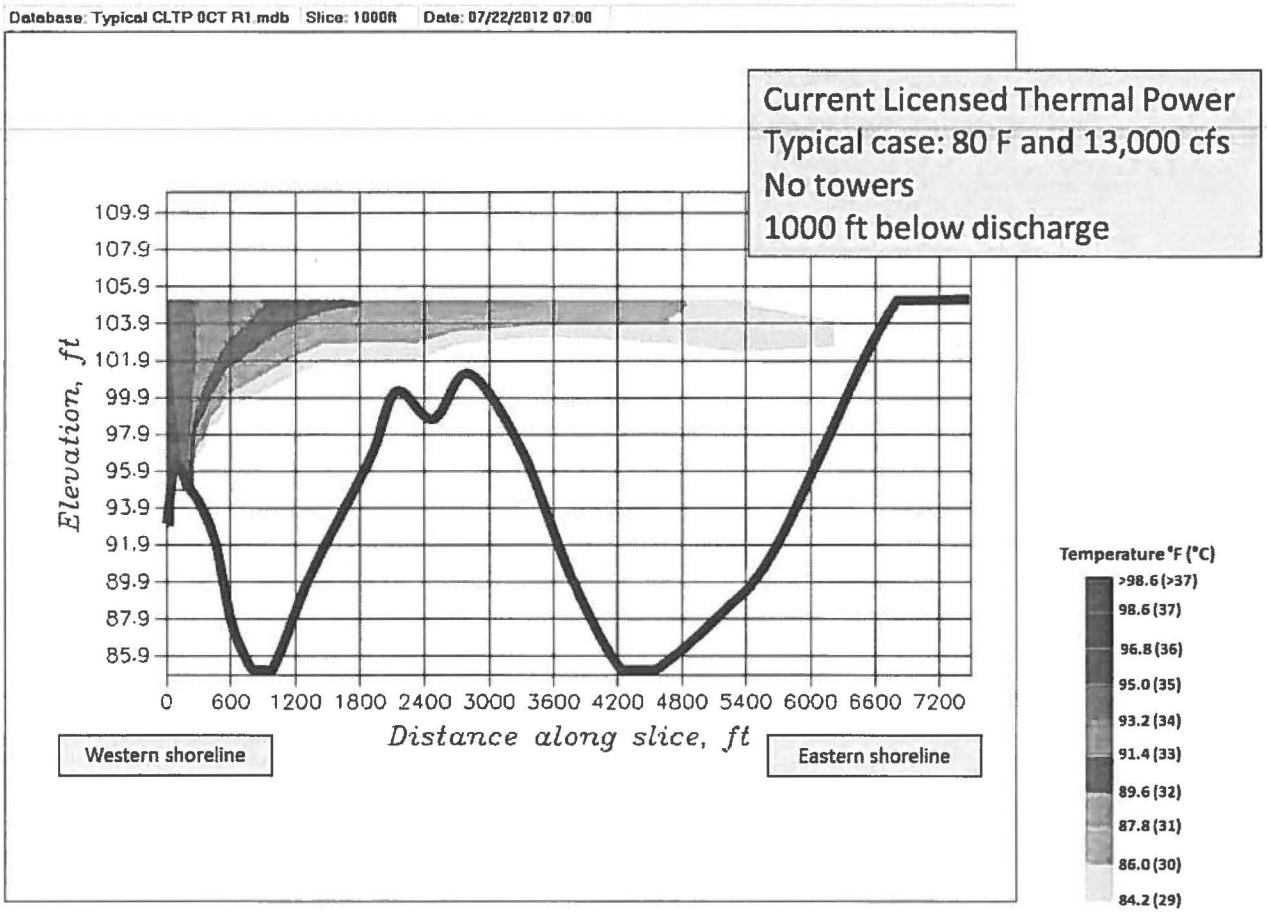
(same six views)

Table 6-6. Modeled cross-sectional areas (fraction of total, in per cent) exceeding various temperatures for the four cooling tower cases, typical and extreme summer conditions, CLTP

Load	Condition	CT	Location	>84.2°F	>86°F	>87.8°F	>89.6°F	>91.4°F	>93.2°F	>95°F	>96.8°F	>98.6°F
CLTP	Typical	0	1000ft	25.7%	16.2%	10.8%	7.3%	5.2%	2.9%	1.0%	0.2%	0.0%
			5000ft	35.9%	22.5%	14.6%	7.4%	1.7%	0.0%	0.0%	0.0%	0.0%
		1	1000ft	23.1%	14.7%	9.8%	6.5%	4.3%	1.7%	0.3%	0.0%	0.0%
			5000ft	32.9%	20.4%	12.4%	4.9%	0.0%	0.0%	0.0%	0.0%	0.0%
		2	1000ft	19.9%	13.2%	8.6%	5.7%	3.0%	0.4%	0.0%	0.0%	0.0%
			5000ft	29.5%	18.4%	9.7%	2.3%	0.0%	0.0%	0.0%	0.0%	0.0%
		3	1000ft	18.0%	11.5%	7.1%	4.5%	1.3%	0.0%	0.0%	0.0%	0.0%
			5000ft	25.6%	15.9%	6.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Extreme	0	1000ft	100.1%	100.1%	73.0%	57.9%	45.1%	30.7%	16.6%	8.9%	5.3%
			5000ft	100.0%	100.0%	96.2%	83.3%	60.1%	34.4%	20.4%	9.8%	0.0%
		1	1000ft	100.1%	100.1%	72.5%	56.8%	42.7%	23.5%	13.4%	7.1%	4.1%
			5000ft	100.0%	100.0%	95.5%	81.6%	56.3%	28.4%	16.2%	4.8%	0.0%
		2	1000ft	100.1%	100.1%	71.5%	55.0%	39.3%	20.4%	10.4%	5.5%	2.6%
			5000ft	100.0%	100.0%	95.0%	79.1%	51.2%	24.0%	11.1%	0.0%	0.0%
		3	1000ft	100.1%	100.1%	70.2%	52.2%	31.2%	16.0%	7.6%	3.8%	0.6%
			5000ft	100.0%	100.0%	94.6%	73.9%	35.5%	18.9%	4.7%	0.0%	0.0%

Table 6-7. Modeled areas (acres) exceeding various temperatures for the four cooling tower cases, typical and extreme summer conditions, EPU

Load	Condition	CT	Location	>84.2°F	>86°F	>87.8°F	>89.6°F	>91.4°F	>93.2°F	>95°F	>96.8°F	>98.6°F
CLTP	Typical	0	Surface	3,854	1,331	852	427	152	25	0	0	0
			10-ft	6	5	4	3	3	2	1	0	0
			Bottom	133	35	19	14	11	8	4	1	0
		1	Surface	3,297	1,178	694	288	69	4	0	0	0
			10-ft	6	5	4	3	3	2	0	0	0
			Bottom	107	29	19	14	11	7	2	0	0
		2	Surface	2,543	1,019	521	169	17	0	0	0	0
			10-ft	6	5	4	3	2	1	0	0	0
			Bottom	102	26	19	14	10	2	0	0	0
		3	Surface	1,525	846	340	69	0	0	0	0	0
			10-ft	6	5	4	3	1	0	0	0	0
			Bottom	54	25	19	13	6	1	0	0	0
	Extreme	0	Surface	7,400	7,294	5,828	5,509	4,000	1,561	769	395	141
			10-ft	5,829	5,460	3,859	3,534	642	5	4	3	3
			Bottom	7,412	6,942	4,322	2,502	530	58	20	14	11
		1	Surface	7,401	7,258	5,756	5,370	3,475	1,074	593	247	56
			10-ft	5,829	5,428	3,849	3,470	66	5	4	3	2
			Bottom	7,412	6,889	4,259	2,078	344	28	20	13	10
		2	Surface	7,401	7,212	5,669	5,162	2,908	845	415	122	10
			10-ft	5,829	5,396	3,836	3,312	6	5	4	3	2
			Bottom	7,413	6,851	4,184	1,471	201	23	19	13	9
		3	Surface	7,401	7,170	5,555	4,563	1,827	644	243	33	0
			10-ft	5,830	5,349	3,811	2,703	6	5	4	3	1
			Bottom	7,413	6,741	4,057	1,032	94	22	19	12	3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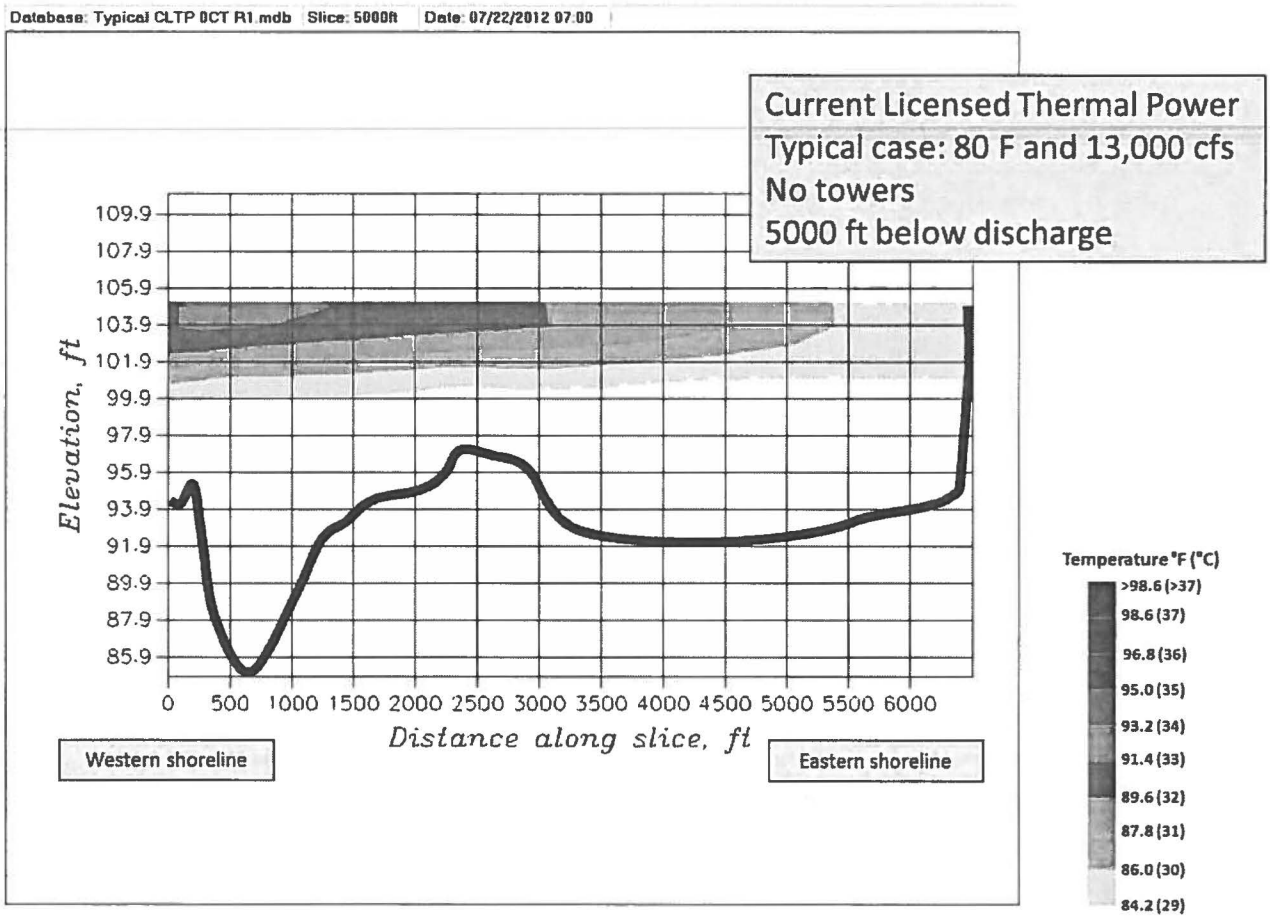
Current Licensed Thermal Power
Typical case: 80 F and 13,000 cfs
No towers
1000 ft below discharge
Elevation, ft
109.9
107.9
105.9
103.9
101.9
99.9
97.9
95.9
93.9
91.9
89.9
87.9
85.9
0 600 1200 1800 2400 3000 3600 4200 4800 5400 6000 6600 7200
Distance along slice, ft
Western shoreline
Eastern shoreline
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)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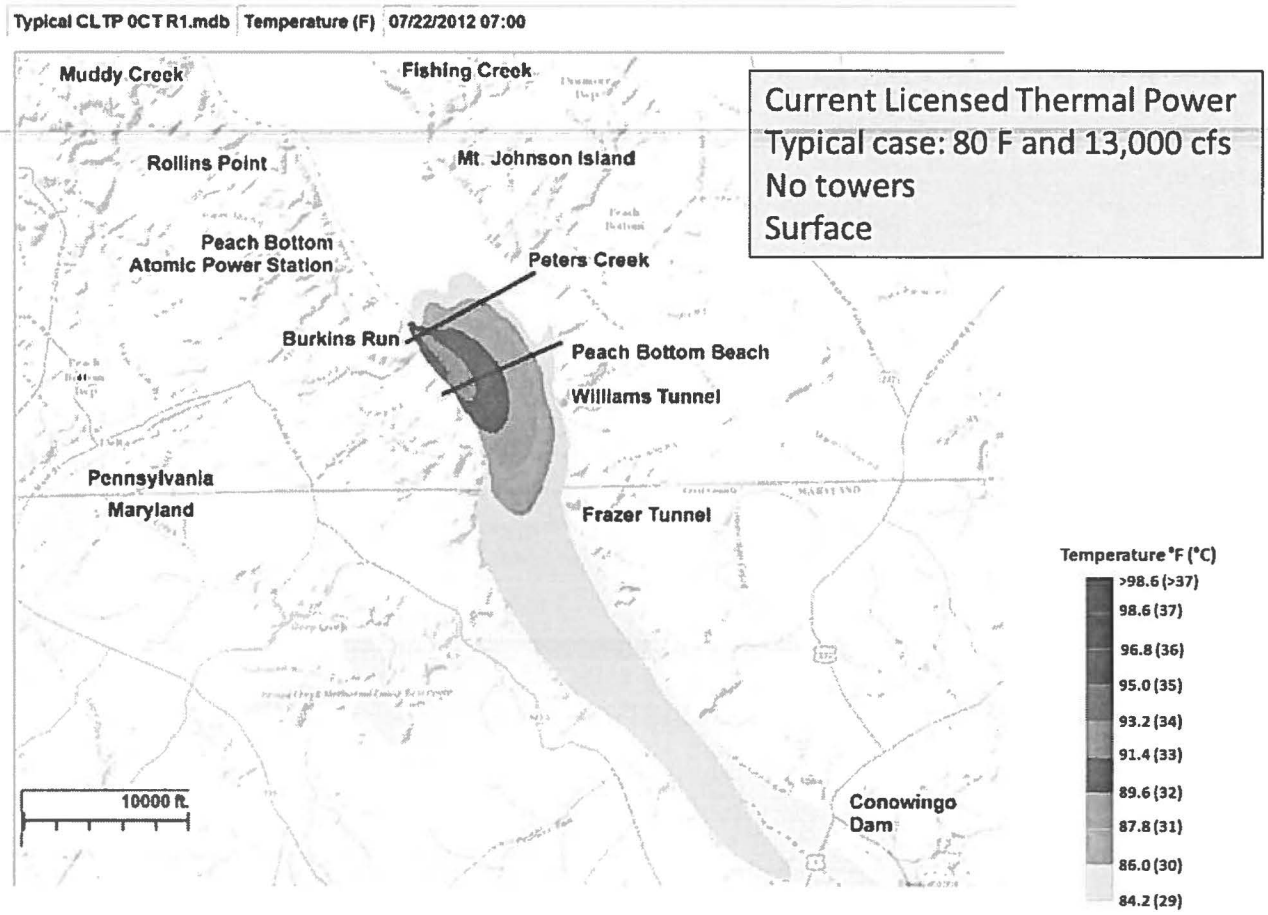
Current Licensed Thermal Power
Typical case: 80 F and 13,000 cfs
No towers
5000 ft below discharge
Elevation, ft
109.9
107.9
105.9
103.9
101.9
99.9
97.9
95.9
93.9
91.9
89.9
87.9
85.9
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 6000
Distance along slice, ft
Western shoreline
Eastern shoreline
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)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Temperature (F)
07/22/2012 07:00
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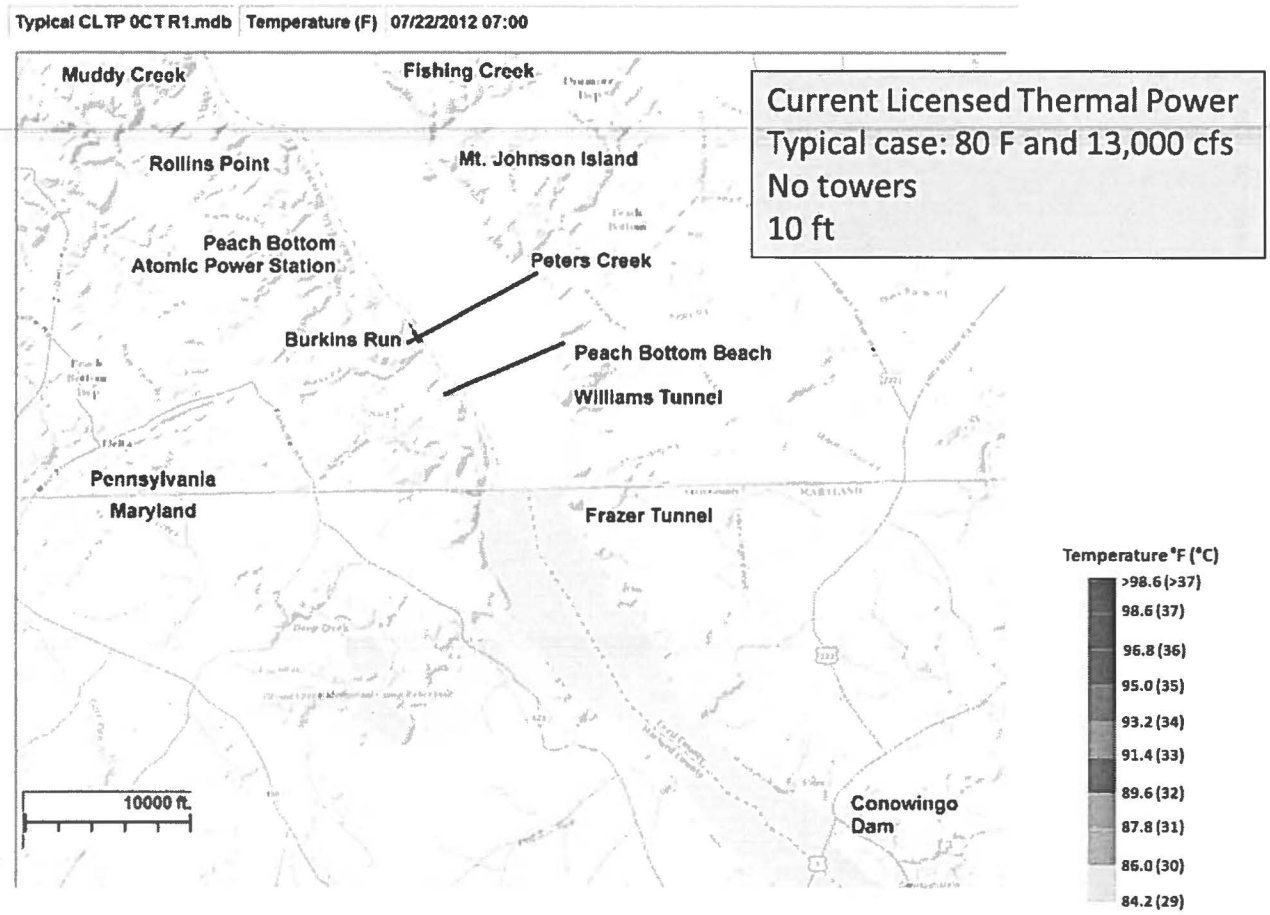
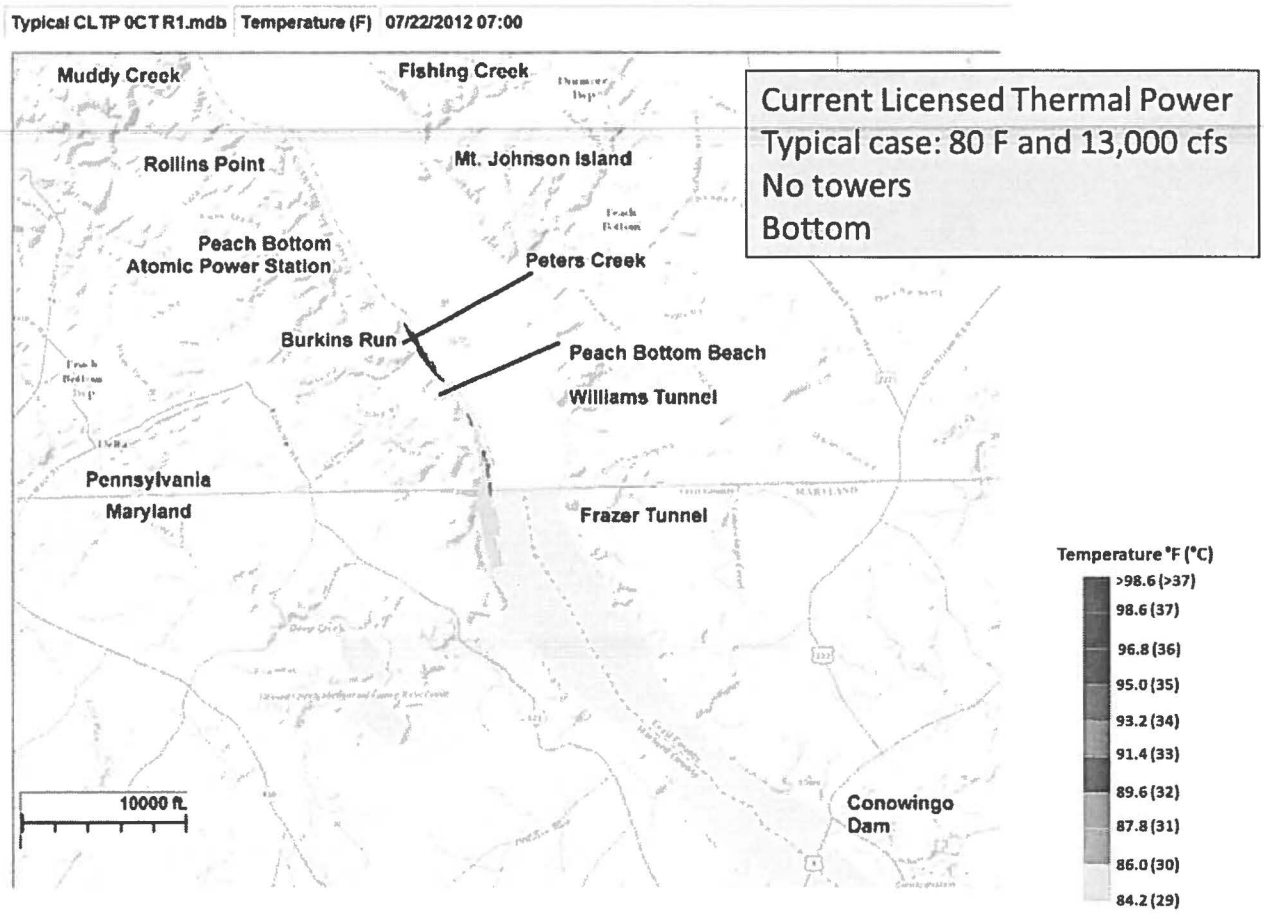
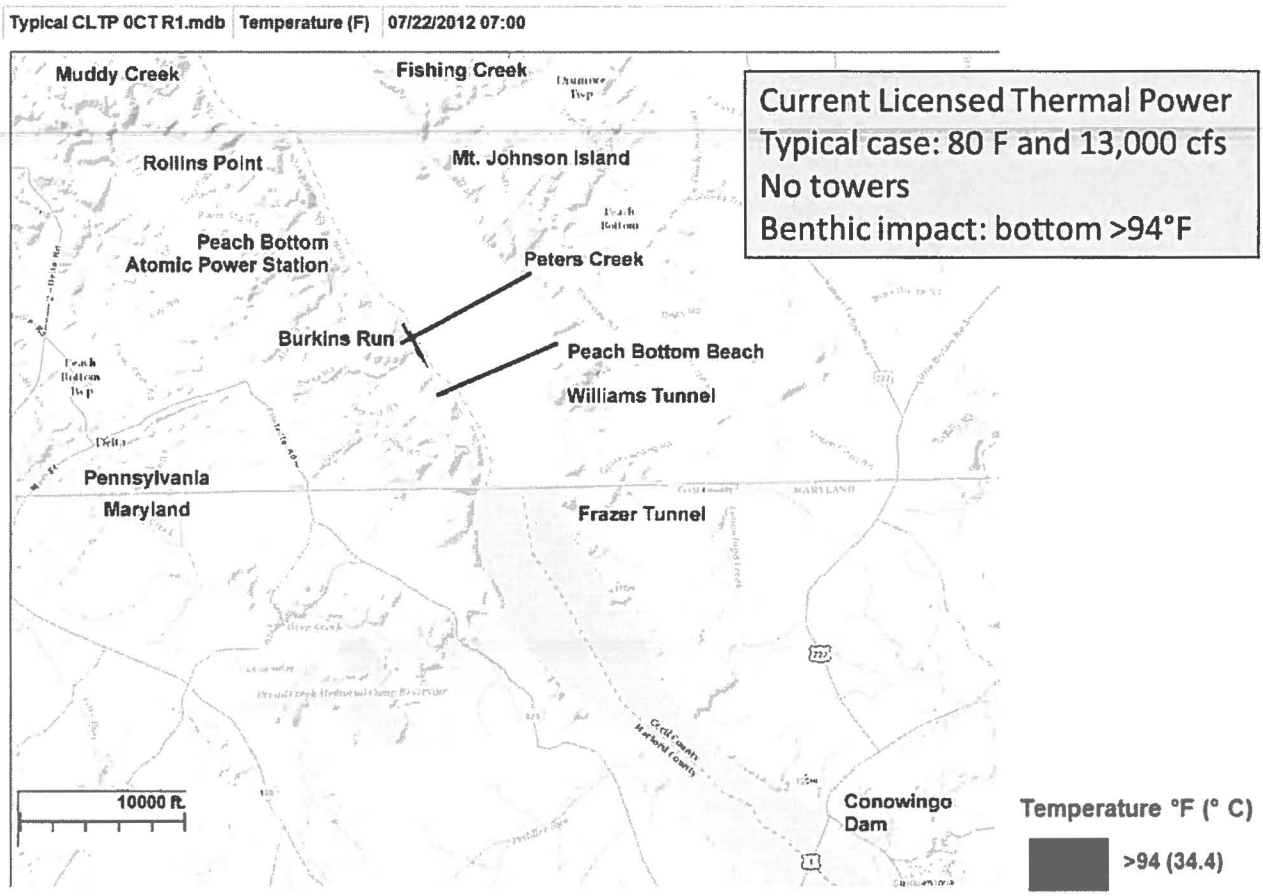
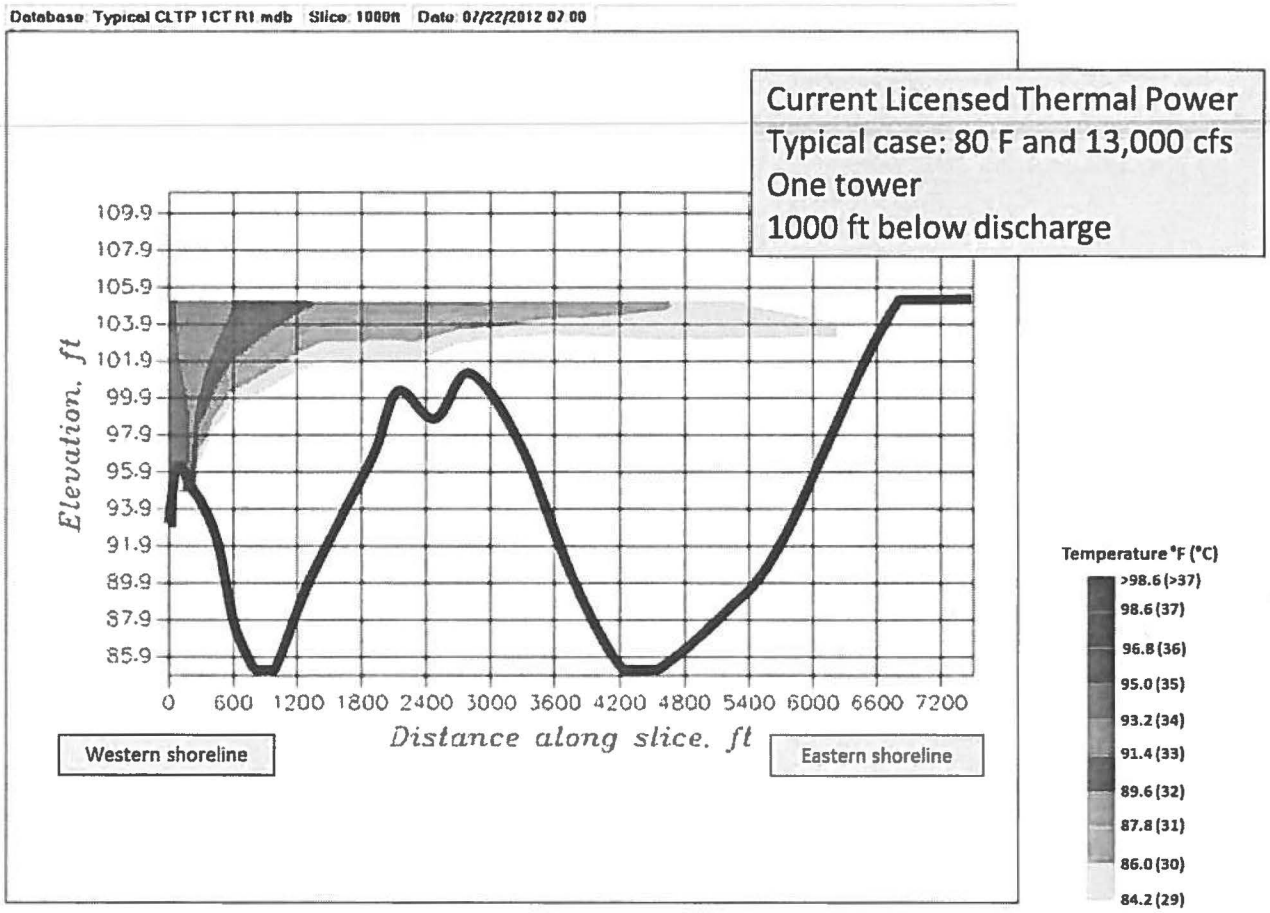
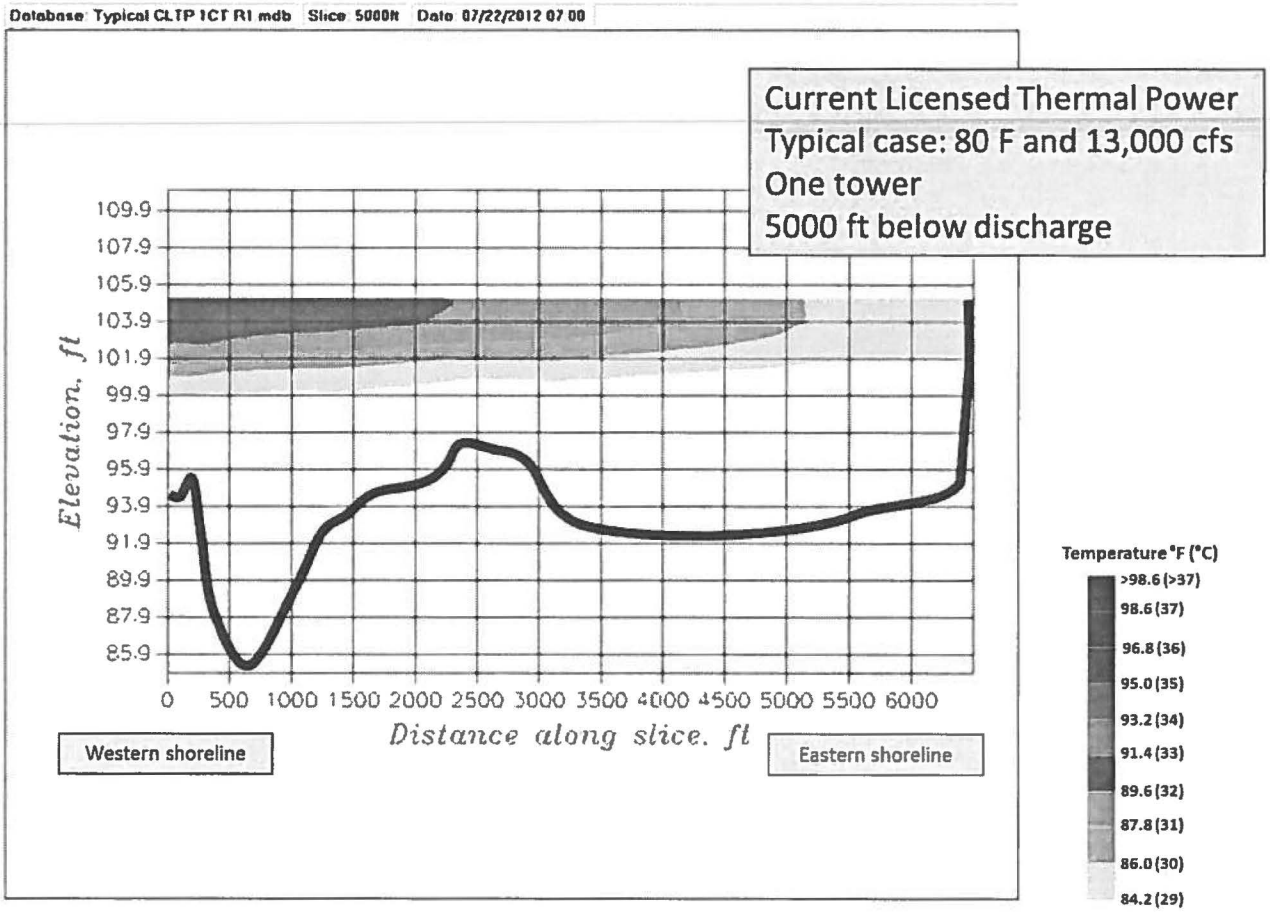
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
10000 ft.
Conowingo
Dam
Current Licensed Thermal Power
Typical case: 80 F and 13,000 cfs
No towers
Surface
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

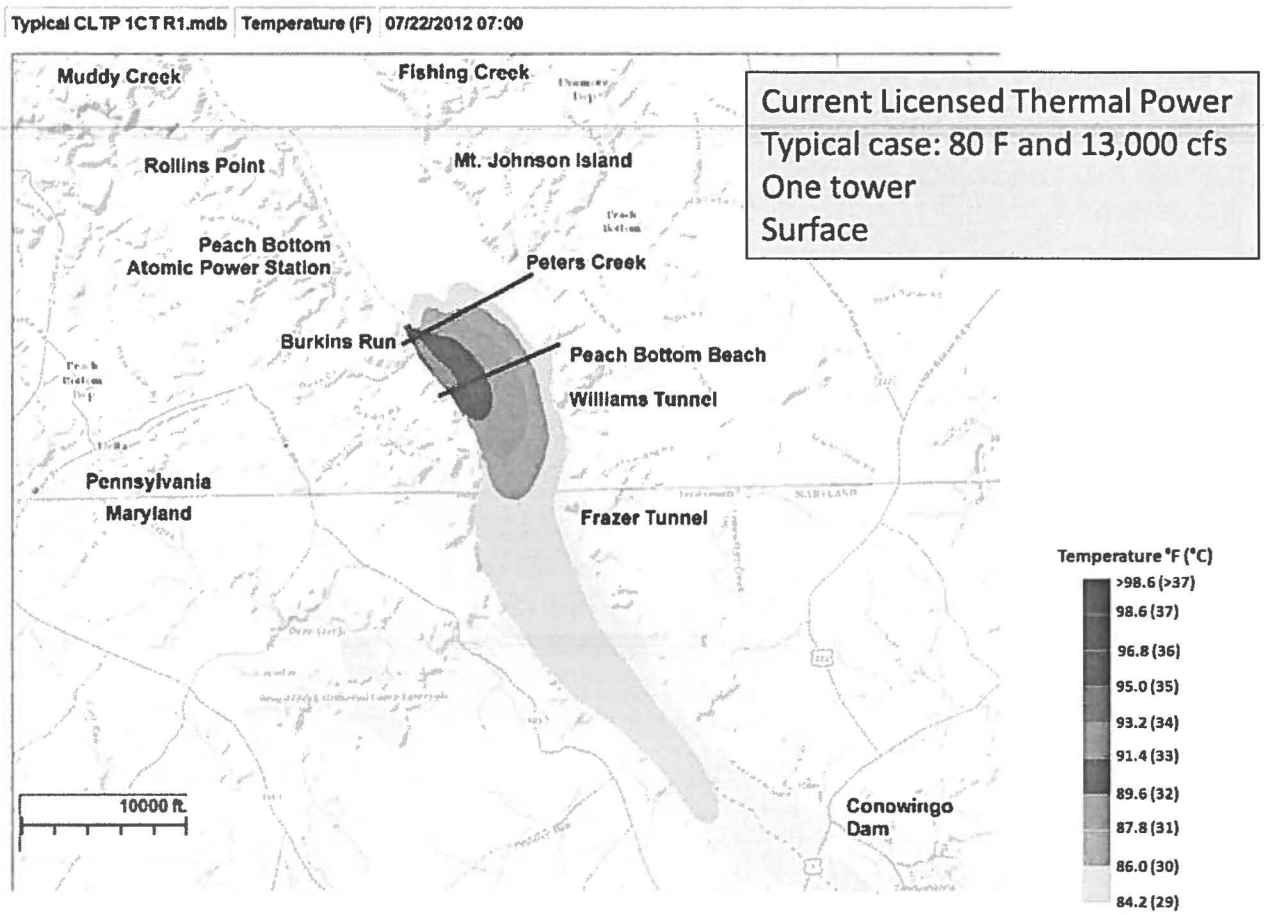

Typical CLTP 0CTR1.mdb
Temperature (F)
07/22/2012 07:00
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
Conowingo
Dam
10000 ft.
Current Licensed Thermal Power
Typical case: 80 F and 13,000 cfs
No towers
10 ft
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

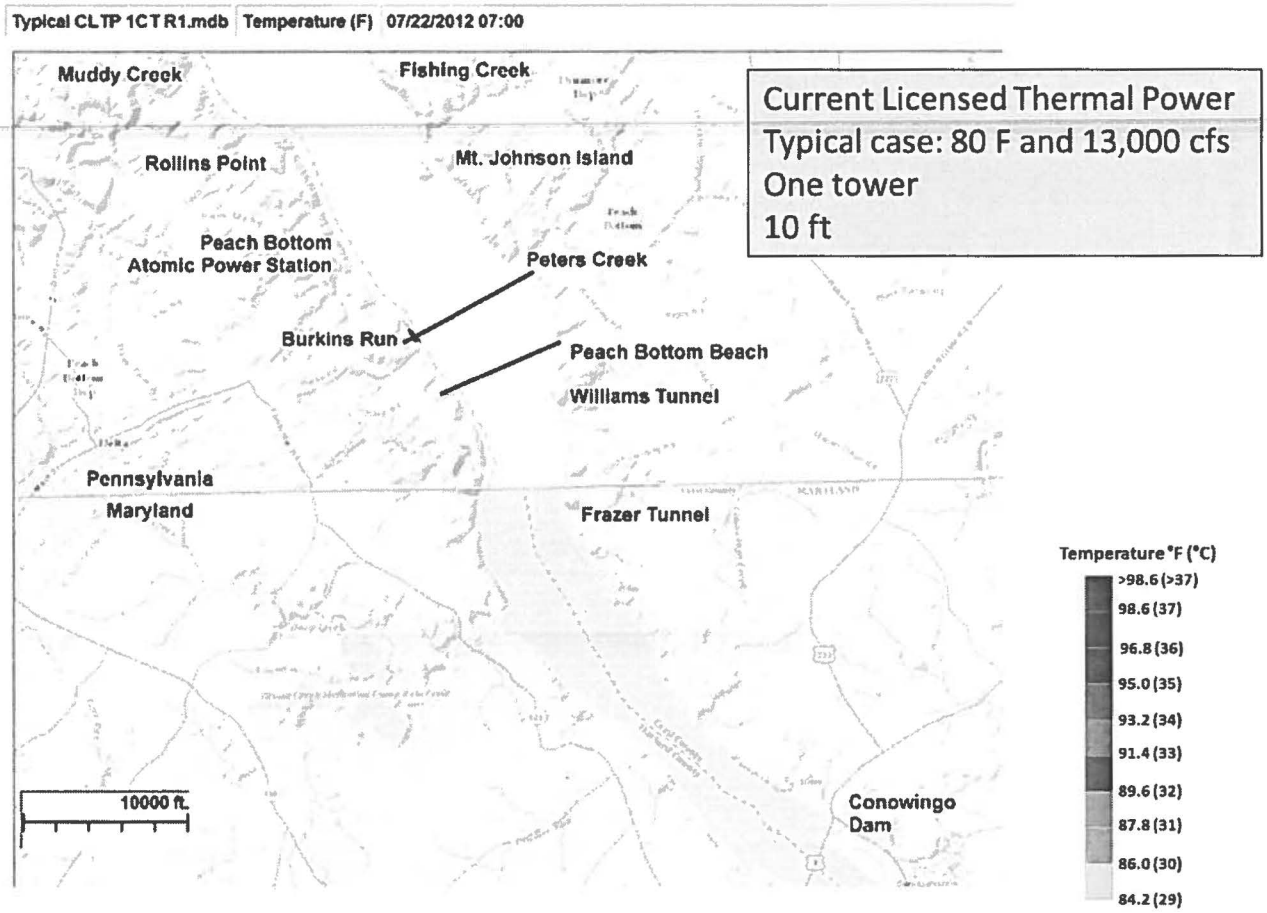

Typical CLTP 0CTR1.mdb
Temperature (F)
07/22/2012 07:00
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
Conowingo
Dam
10000 ft.
Current Licensed Thermal Power
Typical case: 80 F and 13,000 cfs
No towers
Bottom
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

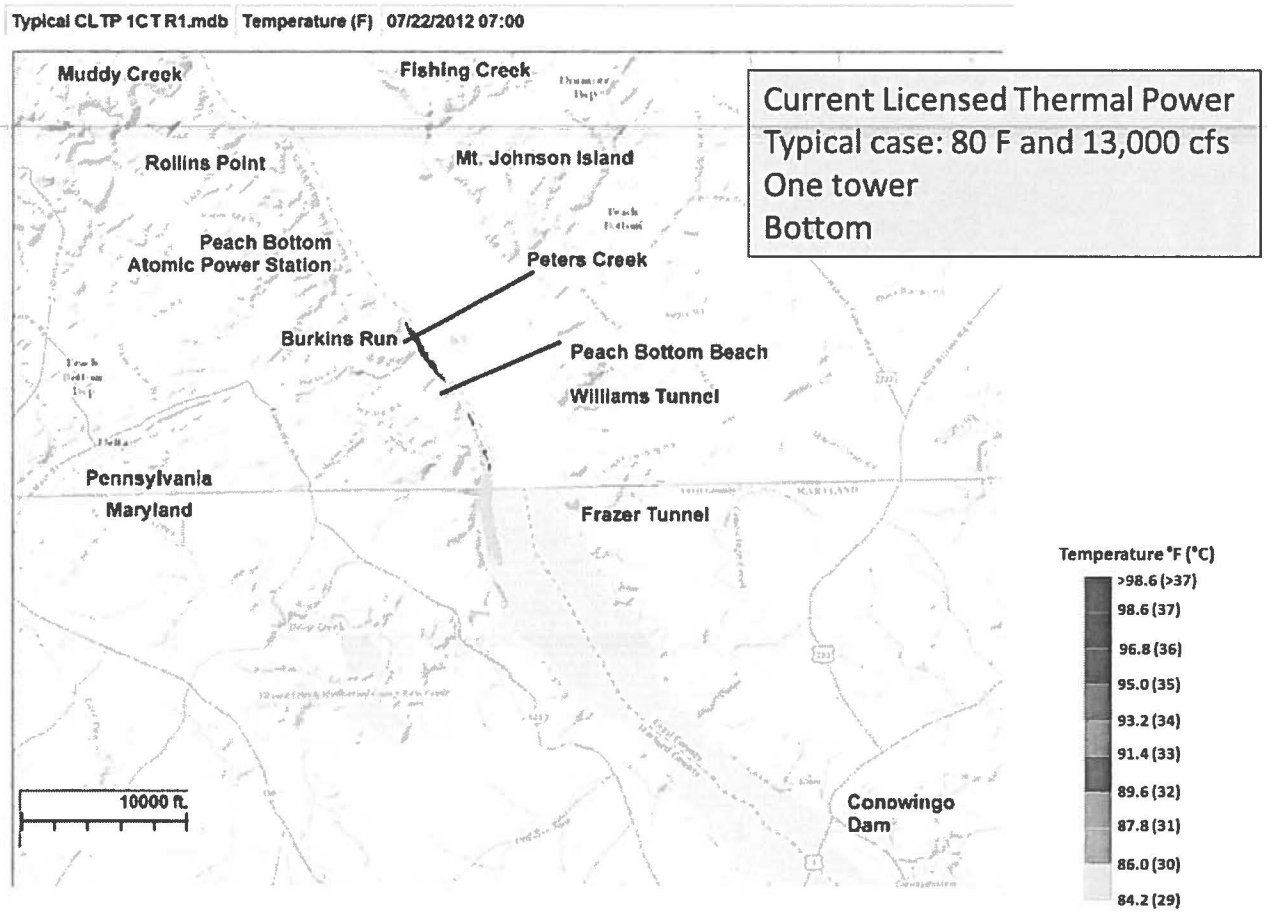

Typical CLTP 0CT R1.mdb
Temperature (F)
07/22/2012 07:00
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
Conowingo
Dam
10000 ft
Current Licensed Thermal Power
Typical case: 80 F and 13,000 cfs
No towers
Benthic impact: bottom >94°F
Temperature °F (° C)
>94 (34.4)

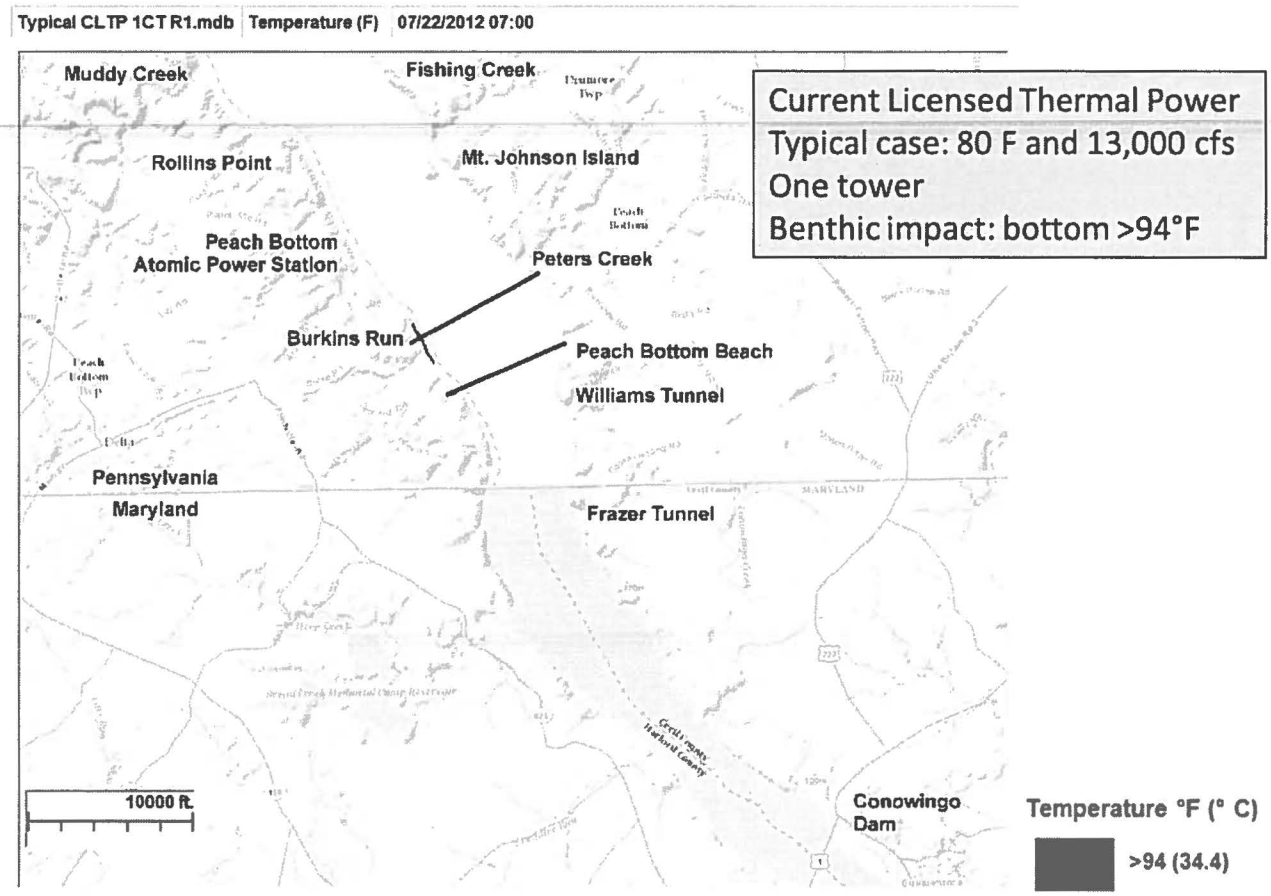

Database: Typical CLTP 1CT R1.mdb Slice: 1000ft Date: 07/22/2012 07:00
Current Licensed Thermal Power
Typical case: 80 F and 13,000 cfs
One tower
1000 ft below discharge
Elevation, ft
109.9
107.9
105.9
103.9
101.9
99.9
97.9
95.9
93.9
91.9
89.9
87.9
85.9
0 600 1200 1800 2400 3000 3600 4200 4800 5400 6000 6600 7200
Distance along slice, ft
Western shoreline
Eastern shoreline
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

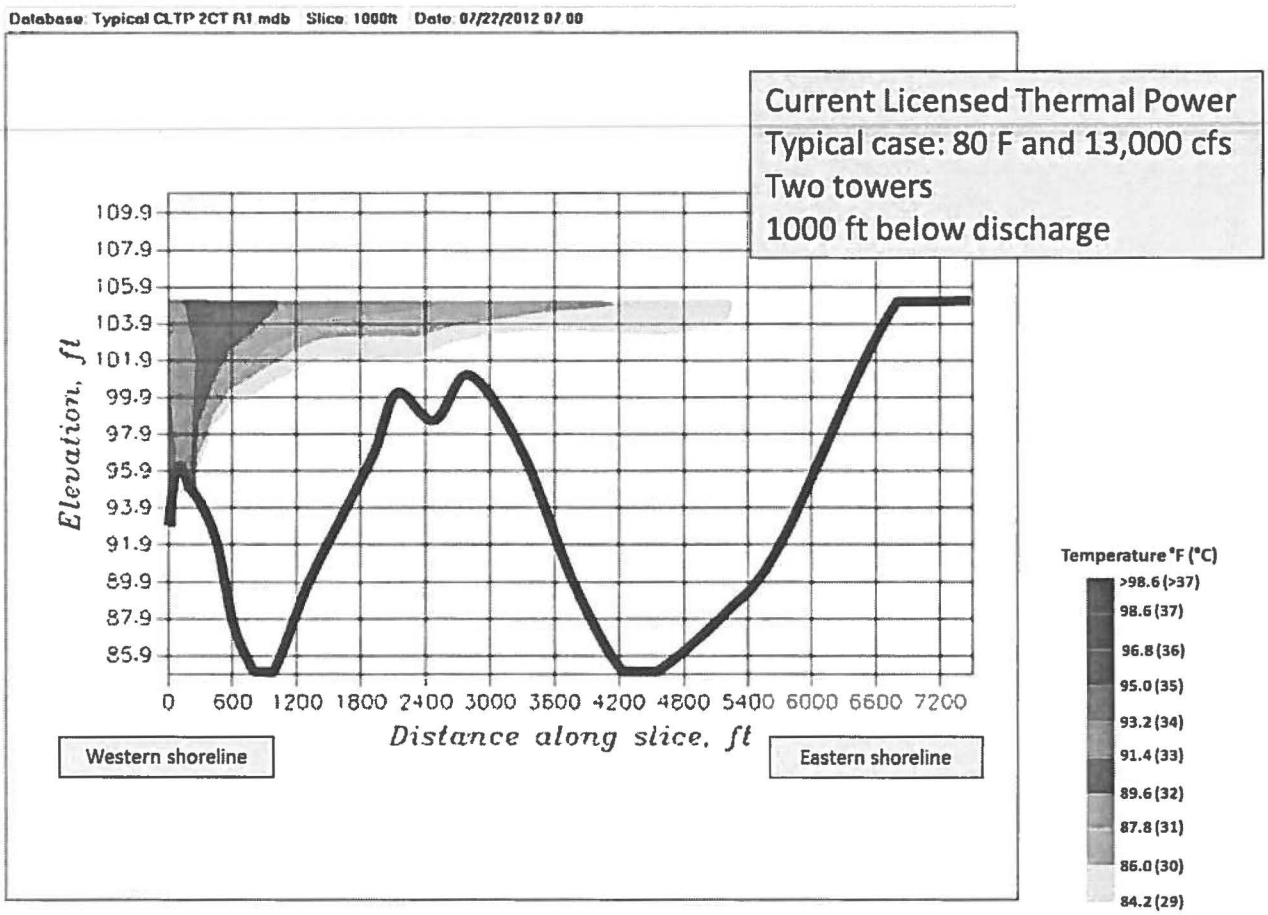

Database Typical CLTP 1CT R1 mdb Slice 5000ft Date 07/22/2012 07 00
Current Licensed Thermal Power
Typical case: 80 F and 13,000 cfs
One tower
5000 ft below discharge
Elevation, ft
109.9
107.9
105.9
103.9
101.9
99.9
97.9
95.9
93.9
91.9
89.9
87.9
85.9
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 6000
Distance along slice, ft
Western shoreline
Eastern shoreline
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

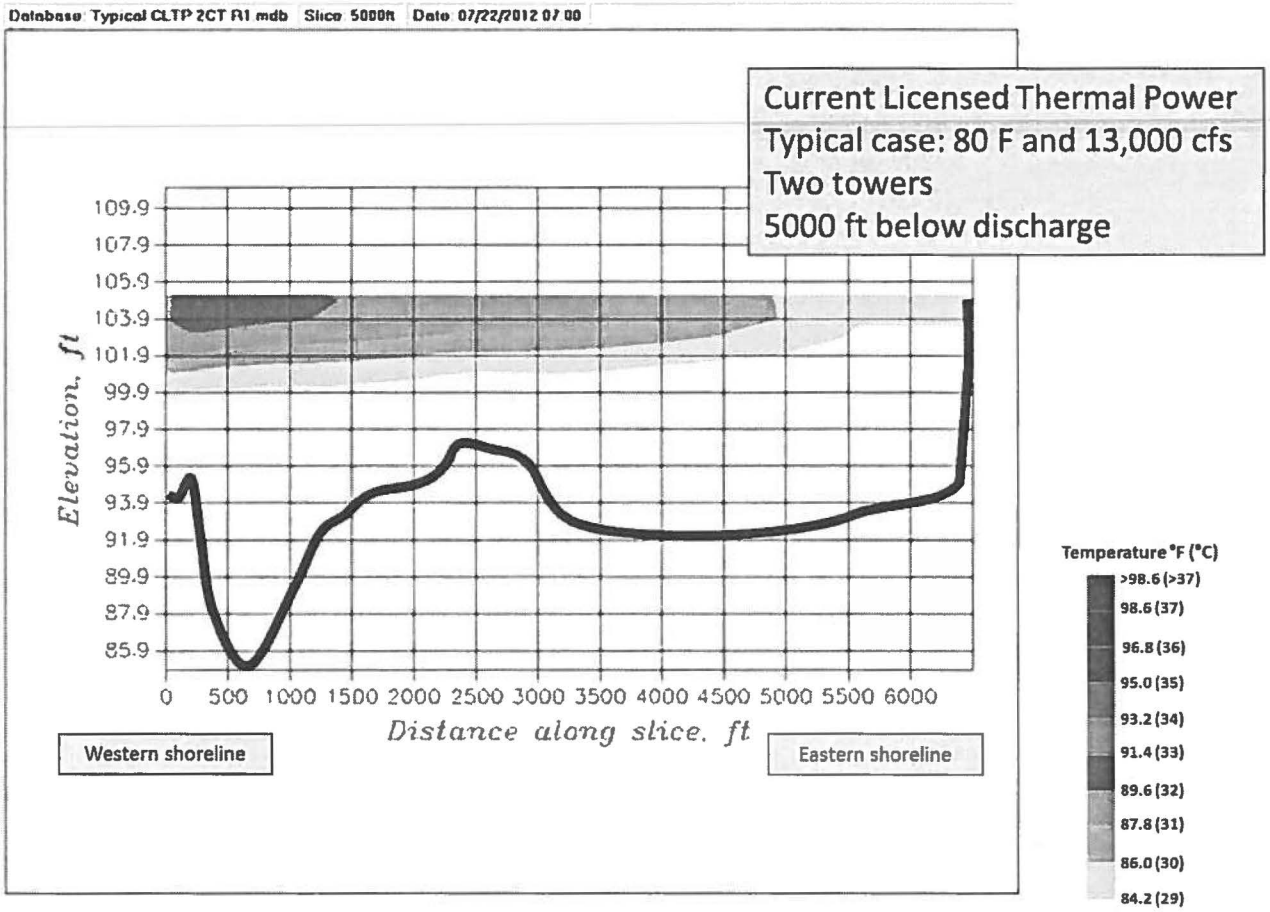

Typical CLTP 1CT R1.mdb
Temperature (F)
07/22/2012 07:00
Current Licensed Thermal Power
Typical case: 80 F and 13,000 cfs
One tower
Surface
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
Conowingo
Dam
10000 ft.
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

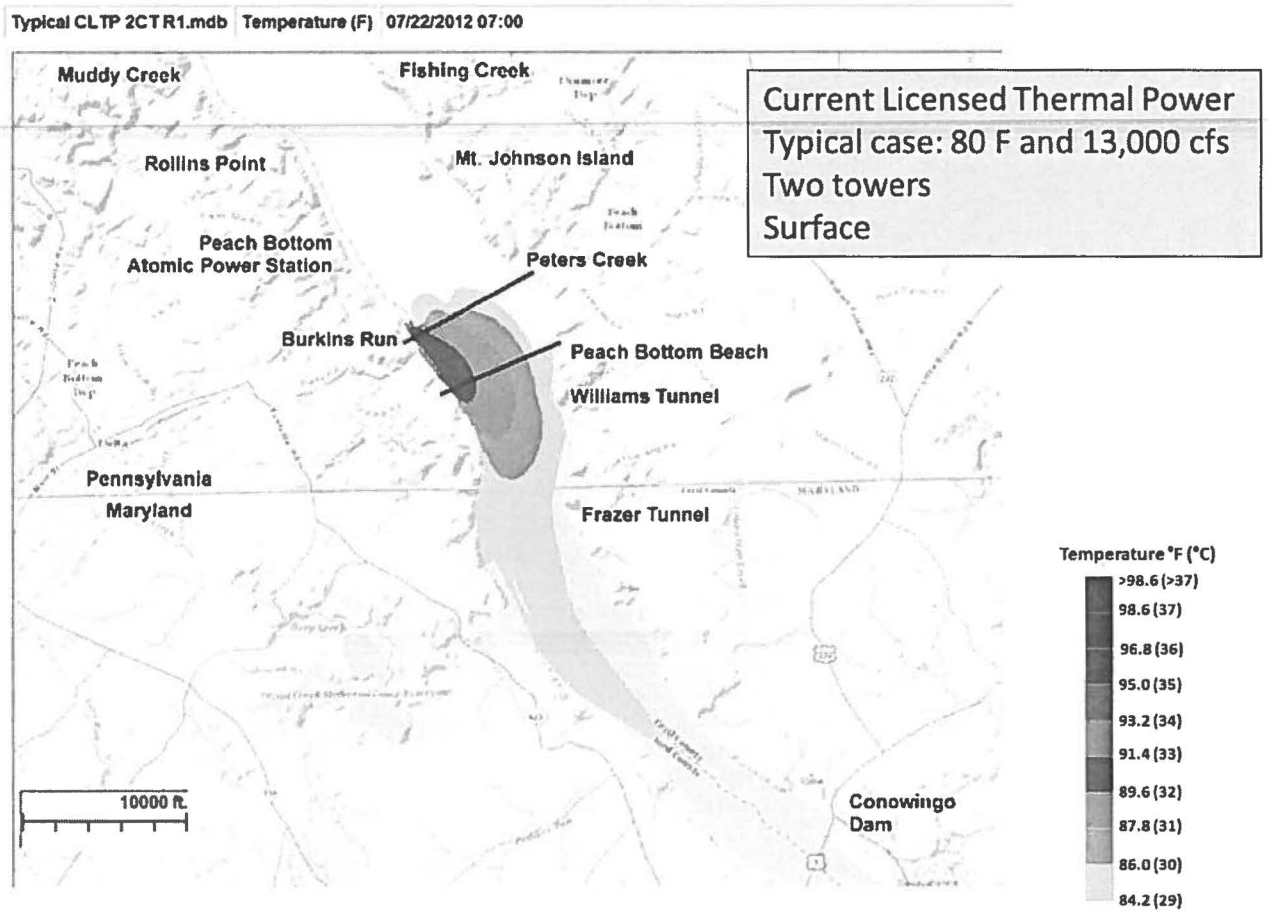

Typical CLTP 1CT R1.mdb
Temperature (F)
07/22/2012 07:00
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
Conowingo
Dam
10000 ft.
Current Licensed Thermal Power
Typical case: 80 F and 13,000 cfs
One tower
10 ft
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

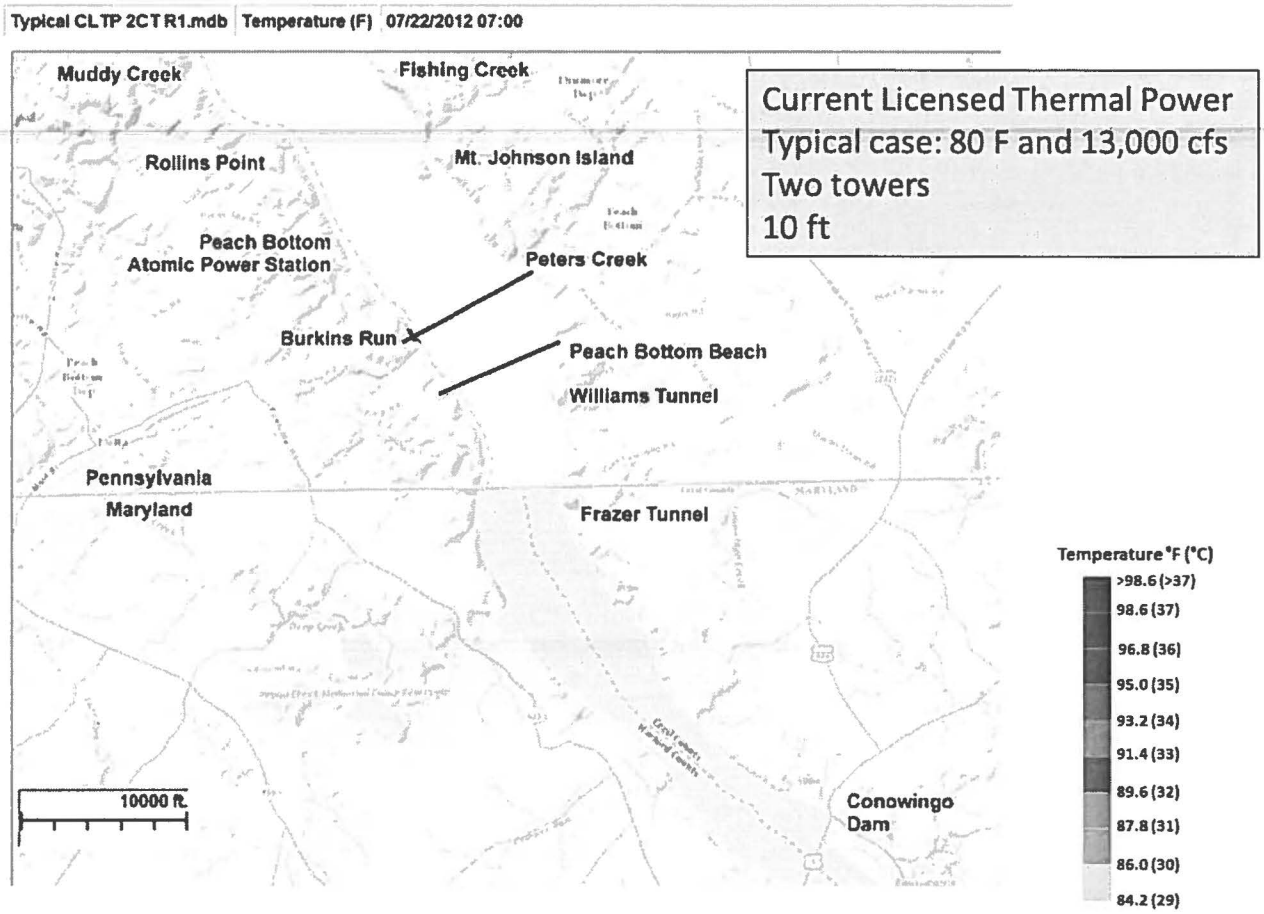

Typical CLTP 1CTR1.mdb Temperature (F) 07/22/2012 07:00
Current Licensed Thermal Power
Typical case: 80 F and 13,000 cfs
One tower
Bottom
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
Conowingo
Dam
10000 ft.
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

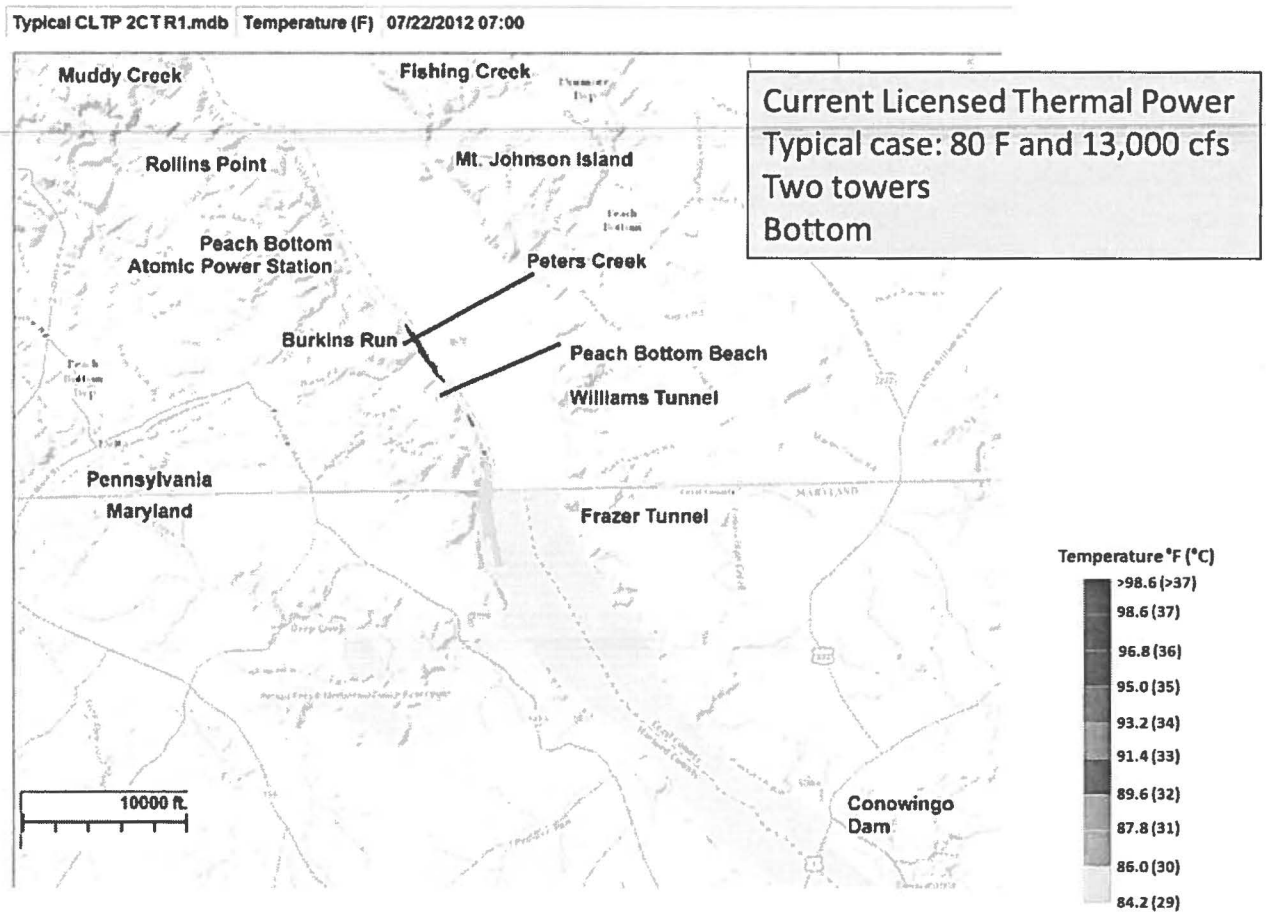

Typical CLTP 1CT R1.mdb
Temperature (F)
07/22/2012 07:00
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
10000 ft.
Conowingo
Dam
Current Licensed Thermal Power
Typical case: 80 F and 13,000 cfs
One tower
Benthic impact: bottom >94°F
Temperature °F (° C)
>94 (34.4)


Database: Typical CLTP 2CT R1.mdb Slice: 1000ft Date: 07/27/2012 07:00
Current Licensed Thermal Power
Typical case: 80 F and 13,000 cfs
Two towers
1000 ft below discharge
Elevation, ft
109.9
107.9
105.9
103.9
101.9
99.9
97.9
95.9
93.9
91.9
89.9
87.9
85.9
0 600 1200 1800 2400 3000 3600 4200 4800 5400 6000 6600 7200
Distance along slice, ft
Western shoreline
Eastern shoreline
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

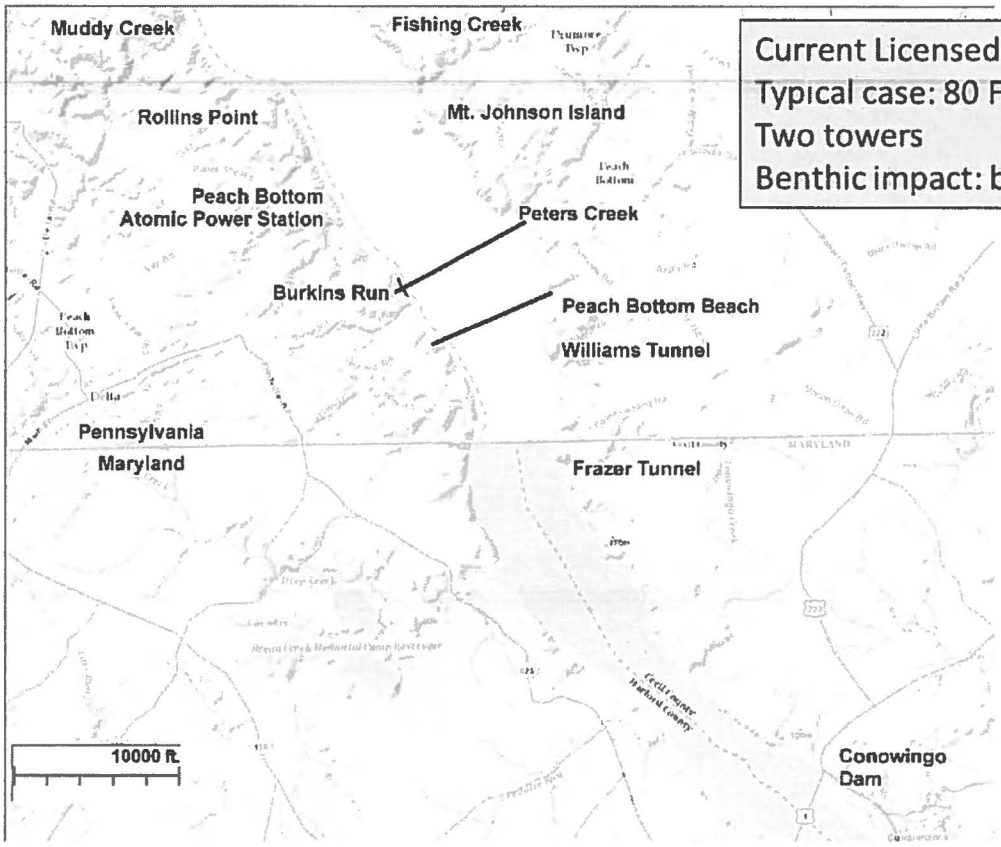

Database Typical CLTP 2CT R1 mdb Slice 5000ft Date 07/22/2012 07 00
Current Licensed Thermal Power
Typical case: 80 F and 13,000 cfs
Two towers
5000 ft below discharge
Elevation, ft
109.9
107.9
105.9
103.9
101.9
99.9
97.9
95.9
93.9
91.9
89.9
87.9
85.9
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 6000
Distance along slice, ft
Western shoreline
Eastern shoreline
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)


Typical CLTP 2CT R1.mdb Temperature (F) 07/22/2012 07:00
Current Licensed Thermal Power
Typical case: 80 F and 13,000 cfs
Two towers
Surface
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
Conowingo
Dam
10000 ft.
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)


Typical CLTP 2CT R1.mdb
Temperature (F)
07/22/2012 07:00
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
Conowingo
Dam
10000 ft
Current Licensed Thermal Power
Typical case: 80 F and 13,000 cfs
Two towers
10 ft
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)


Typical CLTP 2CT R1.mdb
Temperature (F)
07/22/2012 07:00
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
10000 ft.
Conowingo
Dam
Current Licensed Thermal Power
Typical case: 80 F and 13,000 cfs
Two towers
Bottom
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

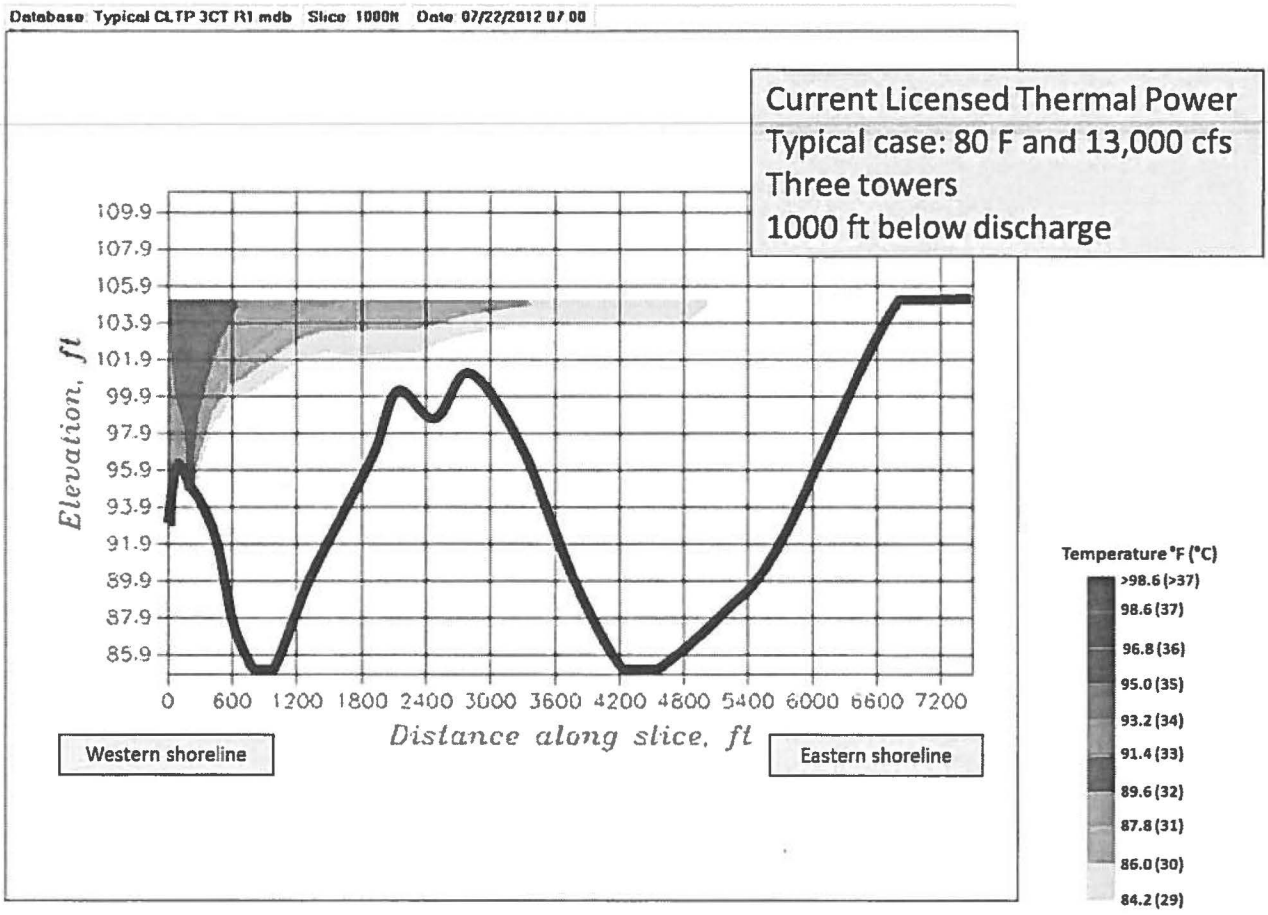
Typical CLTP 2CT R1.mdb | Temperature (F) | 07/22/2012 07:00

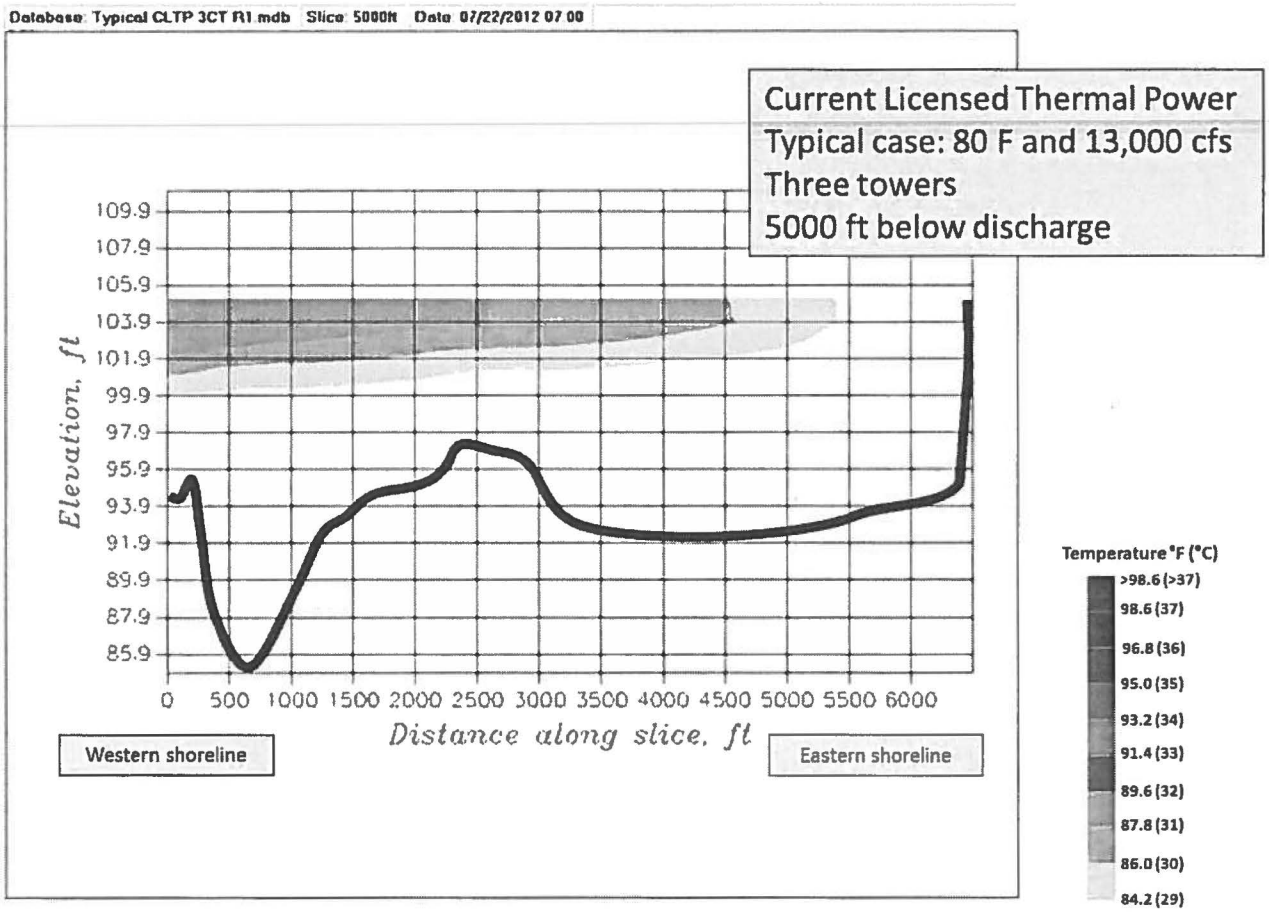


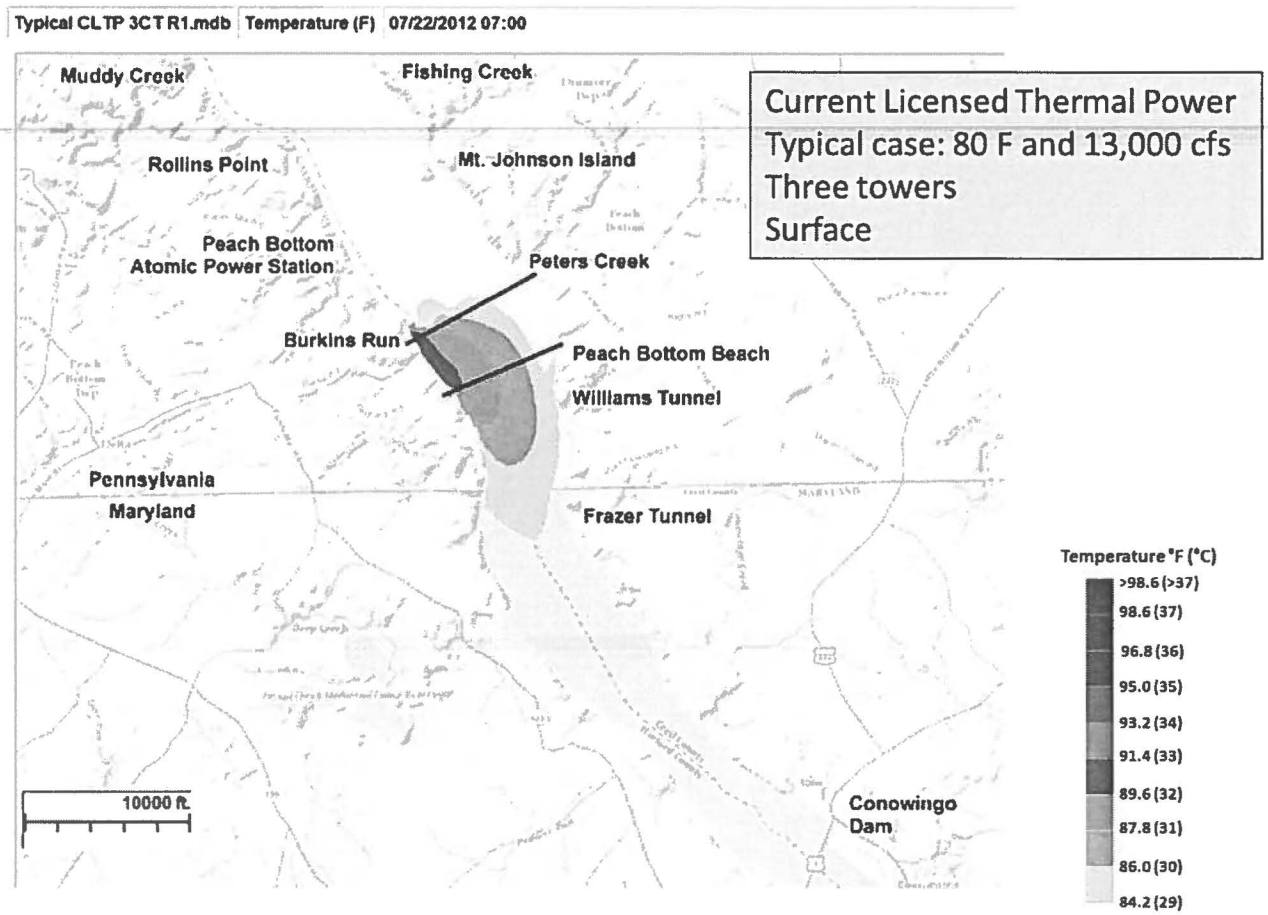
Current Licensed Thermal Power
Typical case: 80 F and 13,000 cfs
Two towers
Benthic impact: bottom >94°F

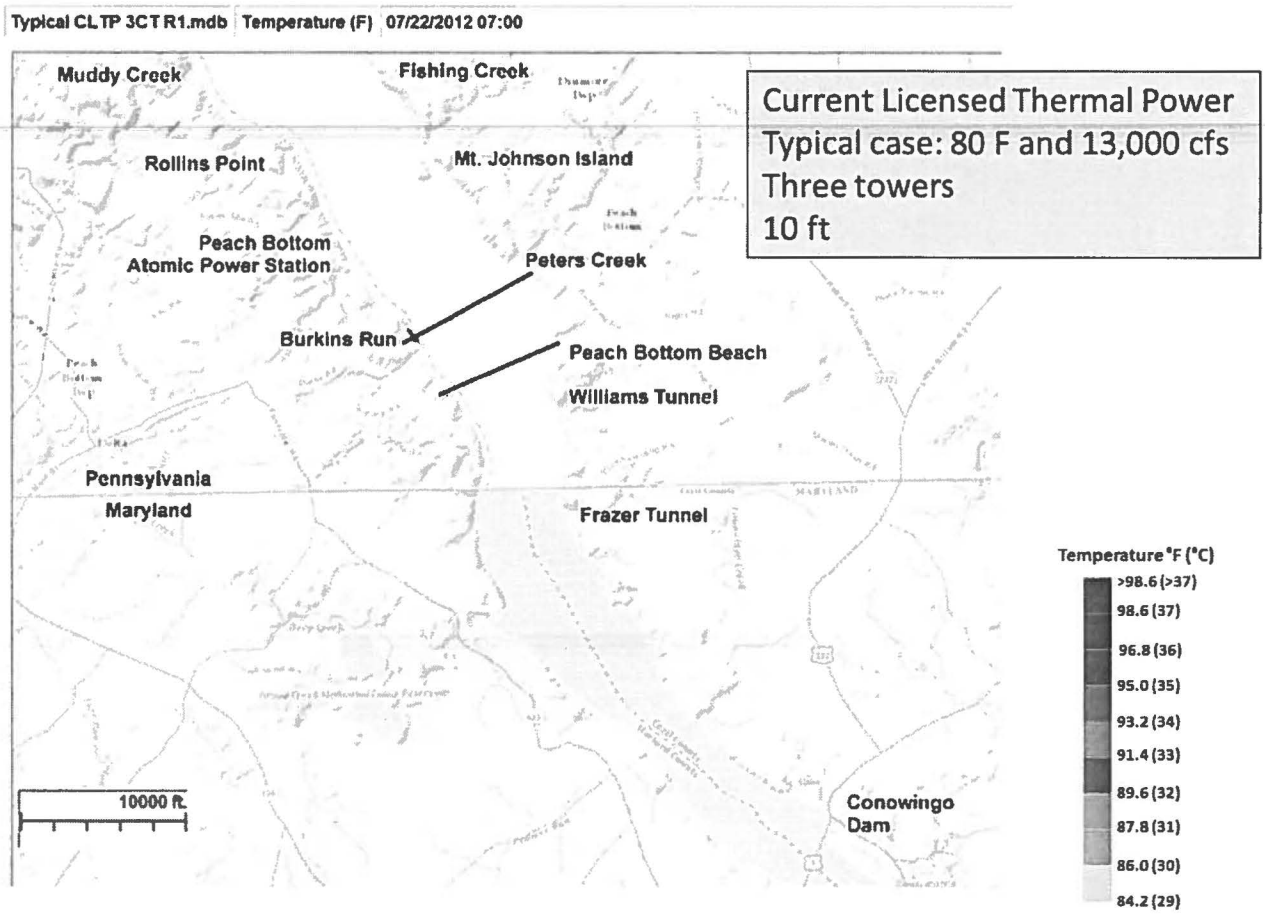
Temperature °F (° C)

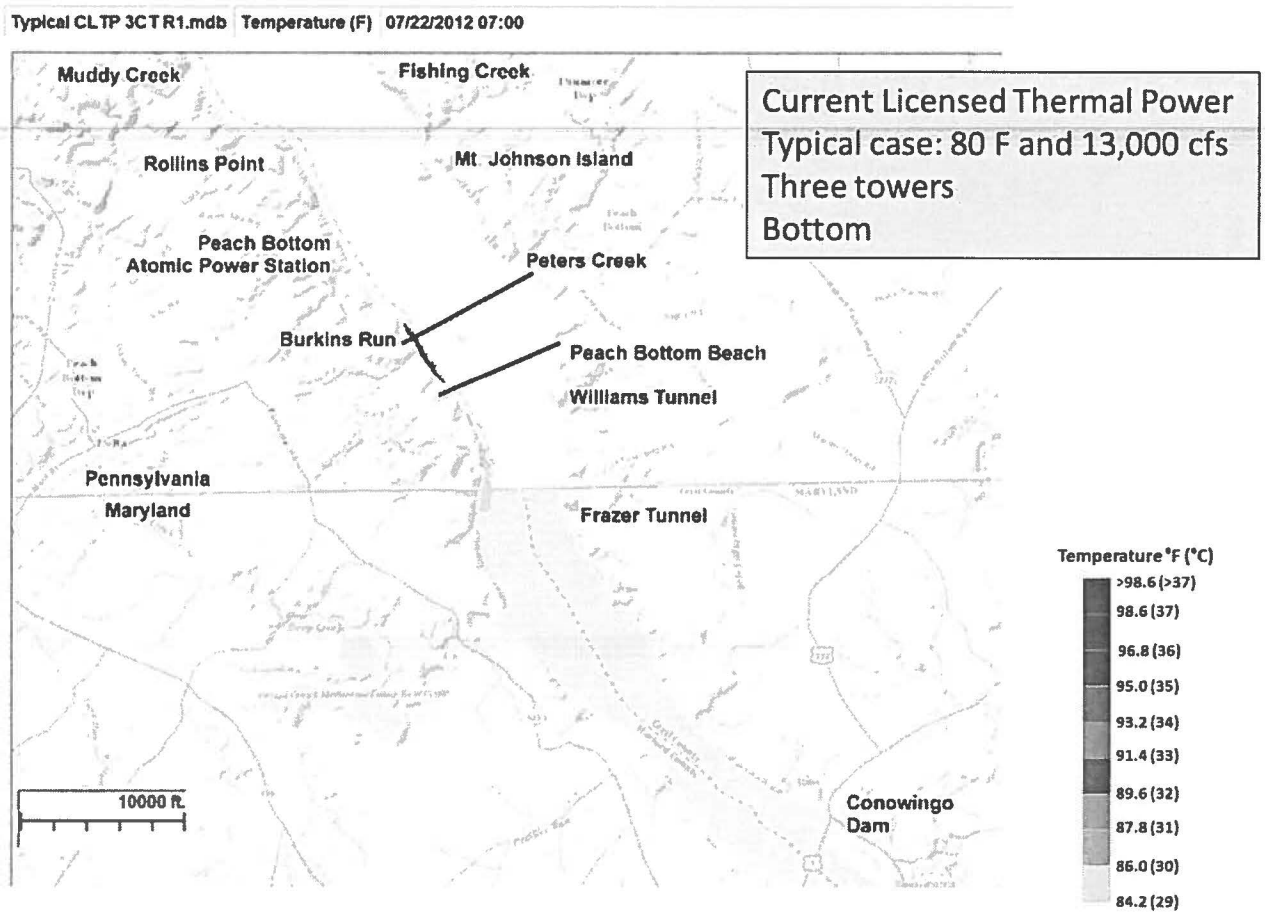
>94 (34.4)

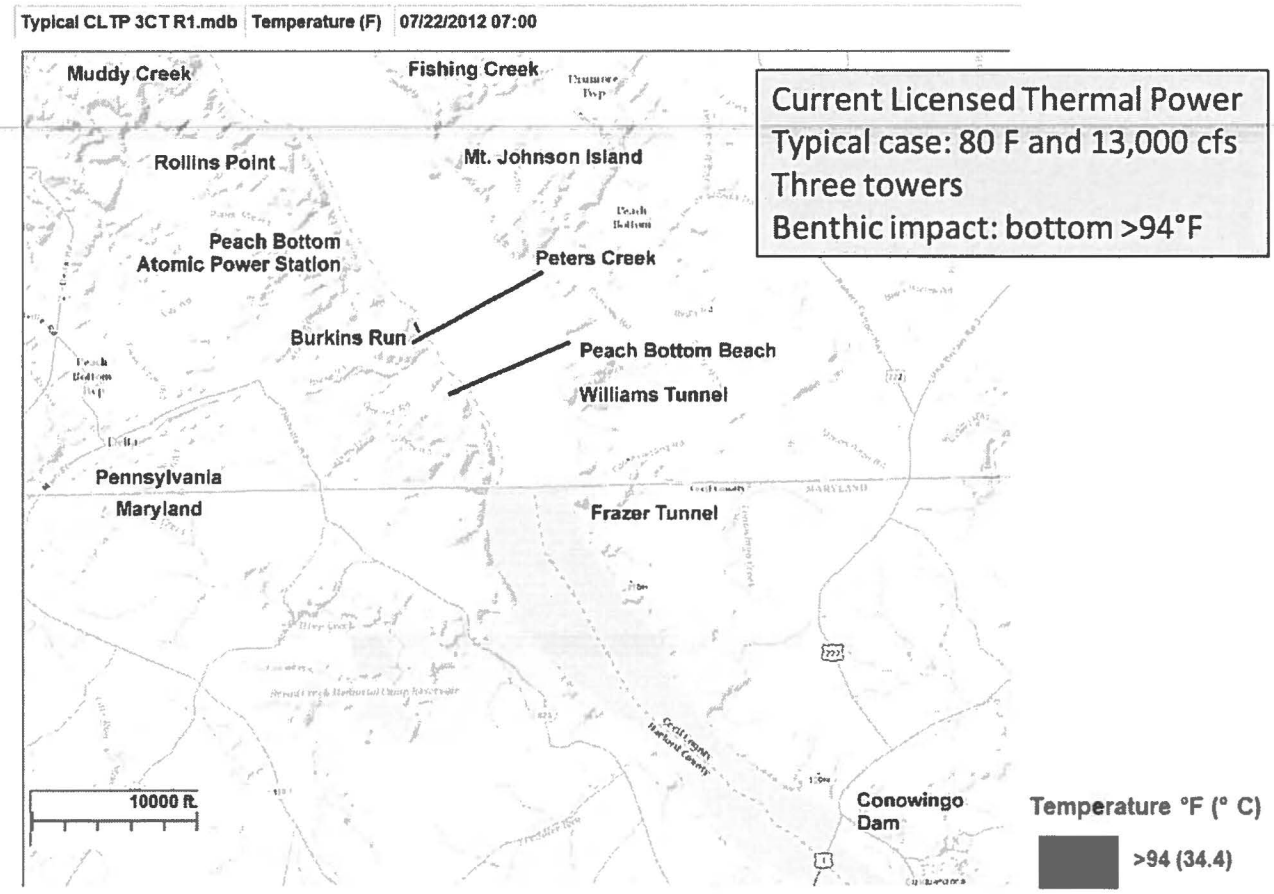

Database Typical CLTP 3CT R1 mdb Slice 1000ft Date 07/22/2012 07 00
Current Licensed Thermal Power
Typical case: 80 F and 13,000 cfs
Three towers
1000 ft below discharge
Elevation, ft
109.9
107.9
105.9
103.9
101.9
99.9
97.9
95.9
93.9
91.9
89.9
87.9
85.9
0 600 1200 1800 2400 3000 3600 4200 4800 5400 6000 6600 7200
Distance along slice, ft
Western shoreline
Eastern shoreline
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

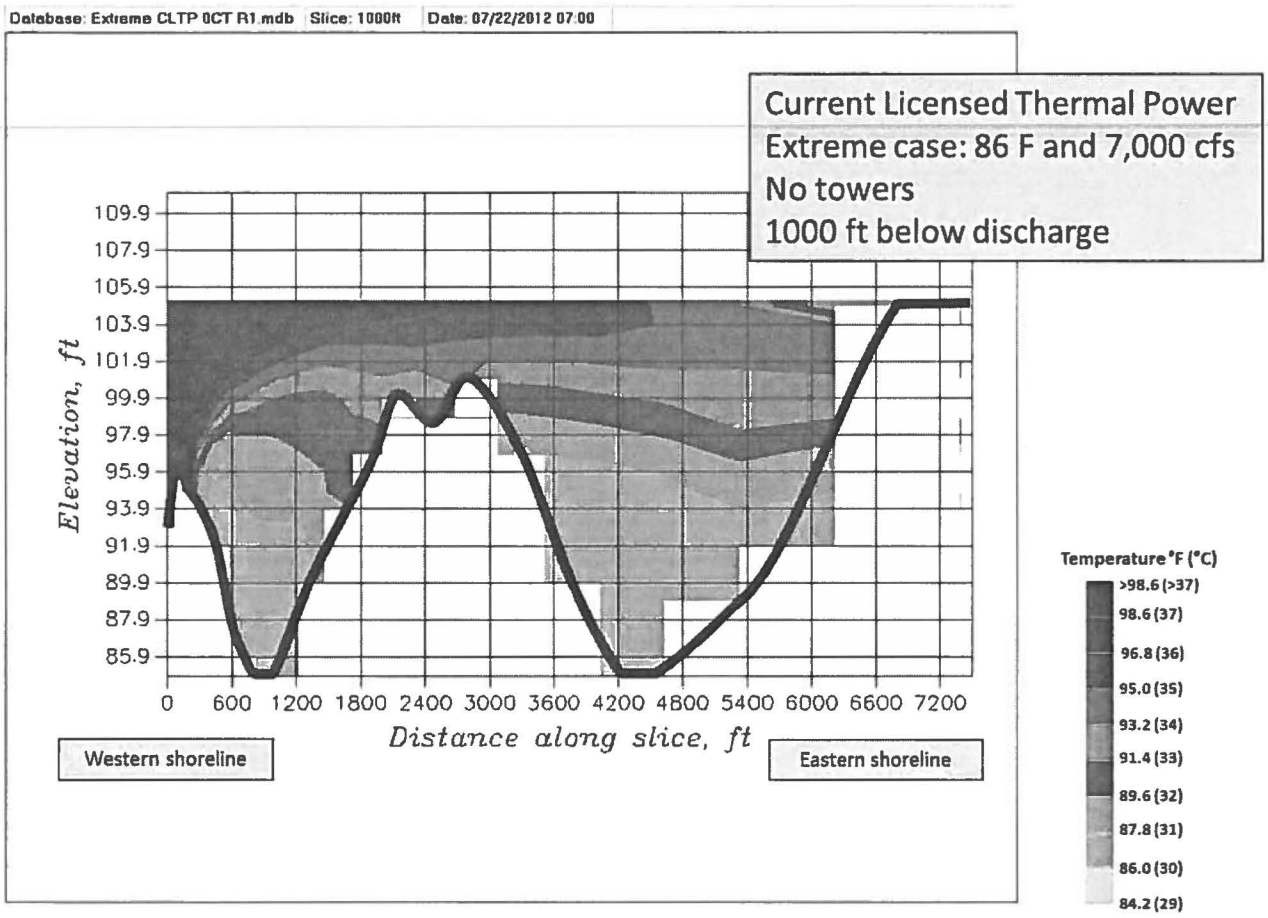

Database: Typical CLTP 3CT R1.mdb Slice: 5000ft Date: 07/22/2012 07:00
Current Licensed Thermal Power
Typical case: 80 F and 13,000 cfs
Three towers
5000 ft below discharge
Elevation, ft
109.9
107.9
105.9
103.9
101.9
99.9
97.9
95.9
93.9
91.9
89.9
87.9
85.9
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 6000
Distance along slice, ft
Western shoreline
Eastern shoreline
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

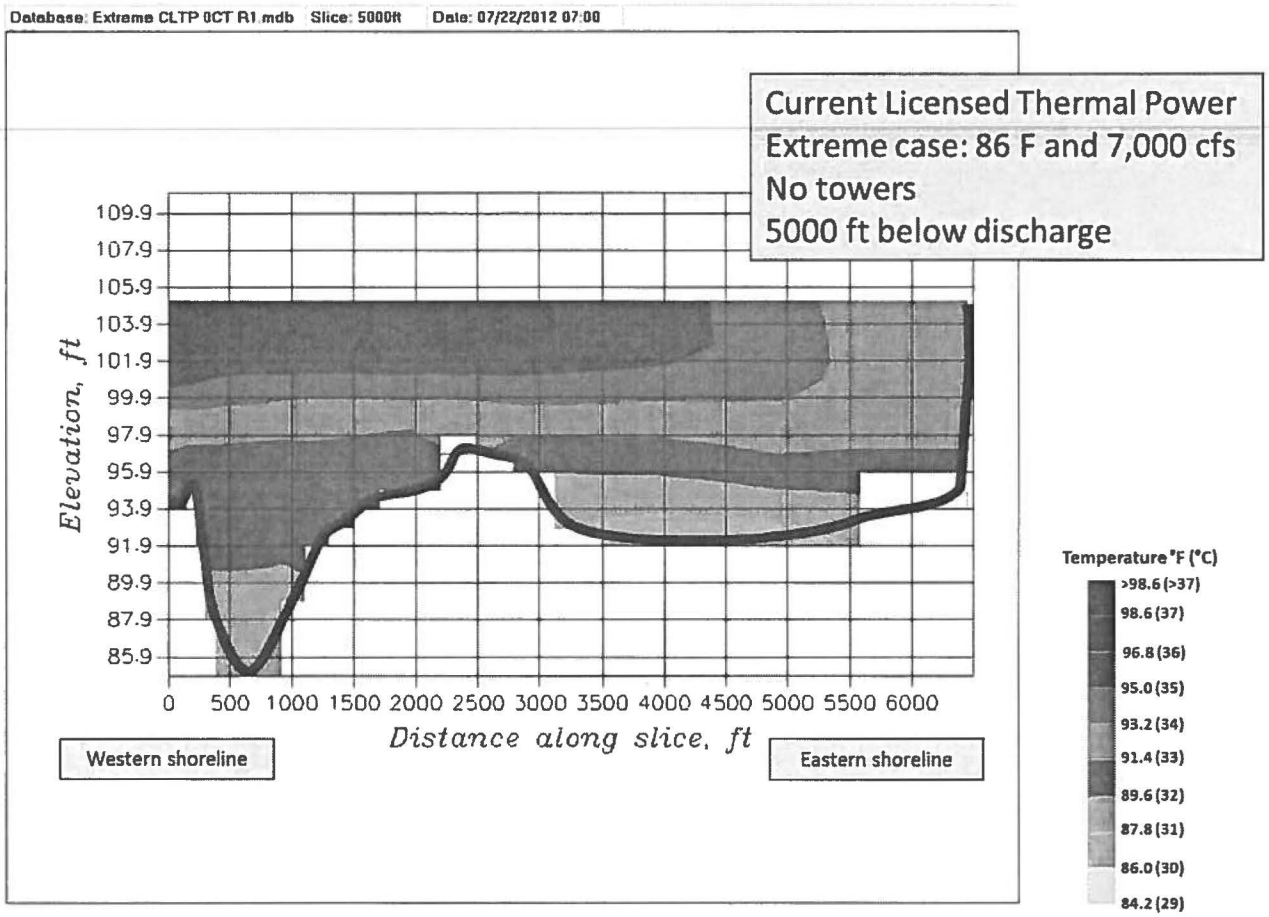

Typical CLTP 3CT R1.mdb
Temperature (F)
07/22/2012 07:00
Current Licensed Thermal Power
Typical case: 80 F and 13,000 cfs
Three towers
Surface
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
Conowingo
Dam
10000 ft.
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

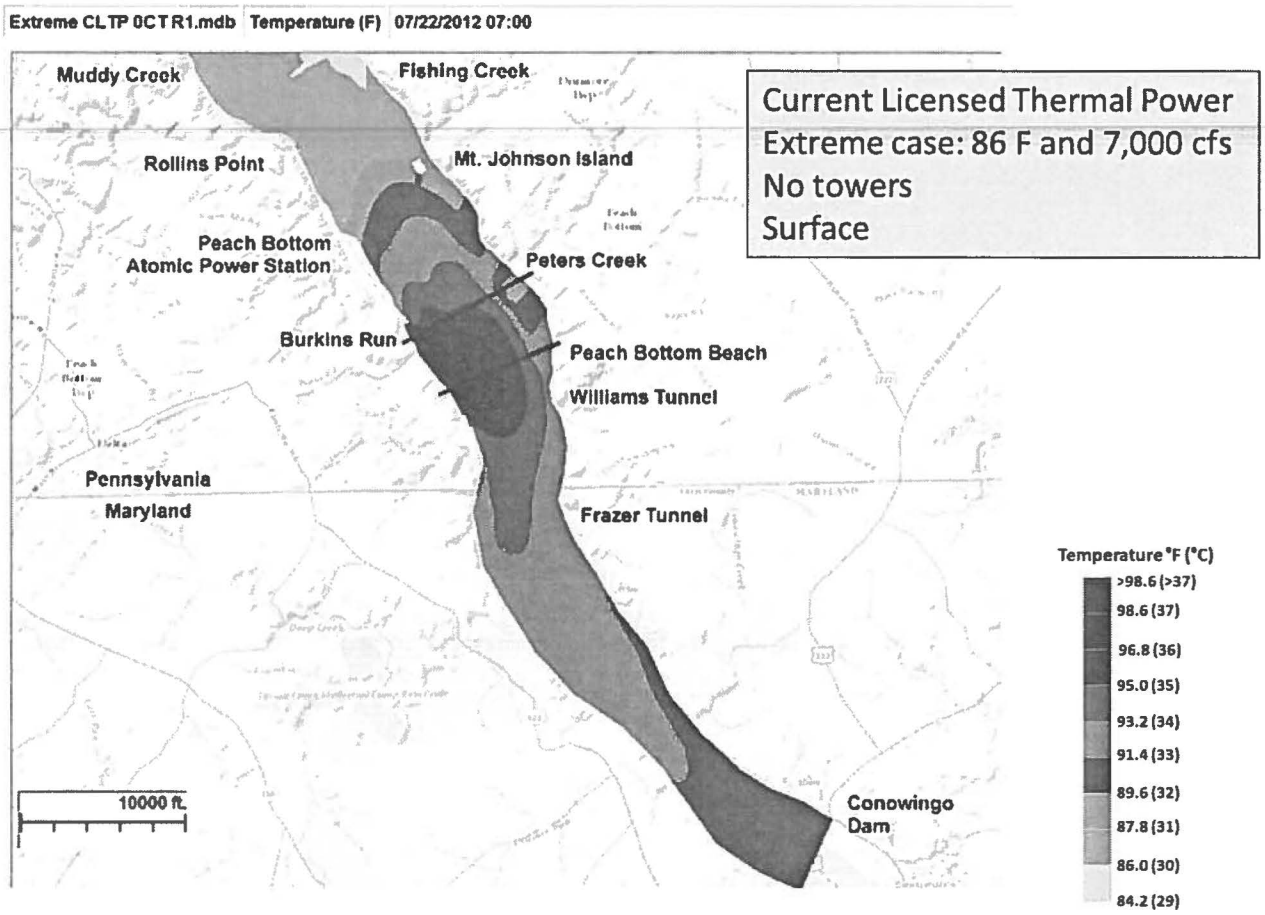

Typical CLTP 3CT R1.mdb
Temperature (F)
07/22/2012 07:00
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
10000 ft.
Conowingo
Dam
Current Licensed Thermal Power
Typical case: 80 F and 13,000 cfs
Three towers
10 ft
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

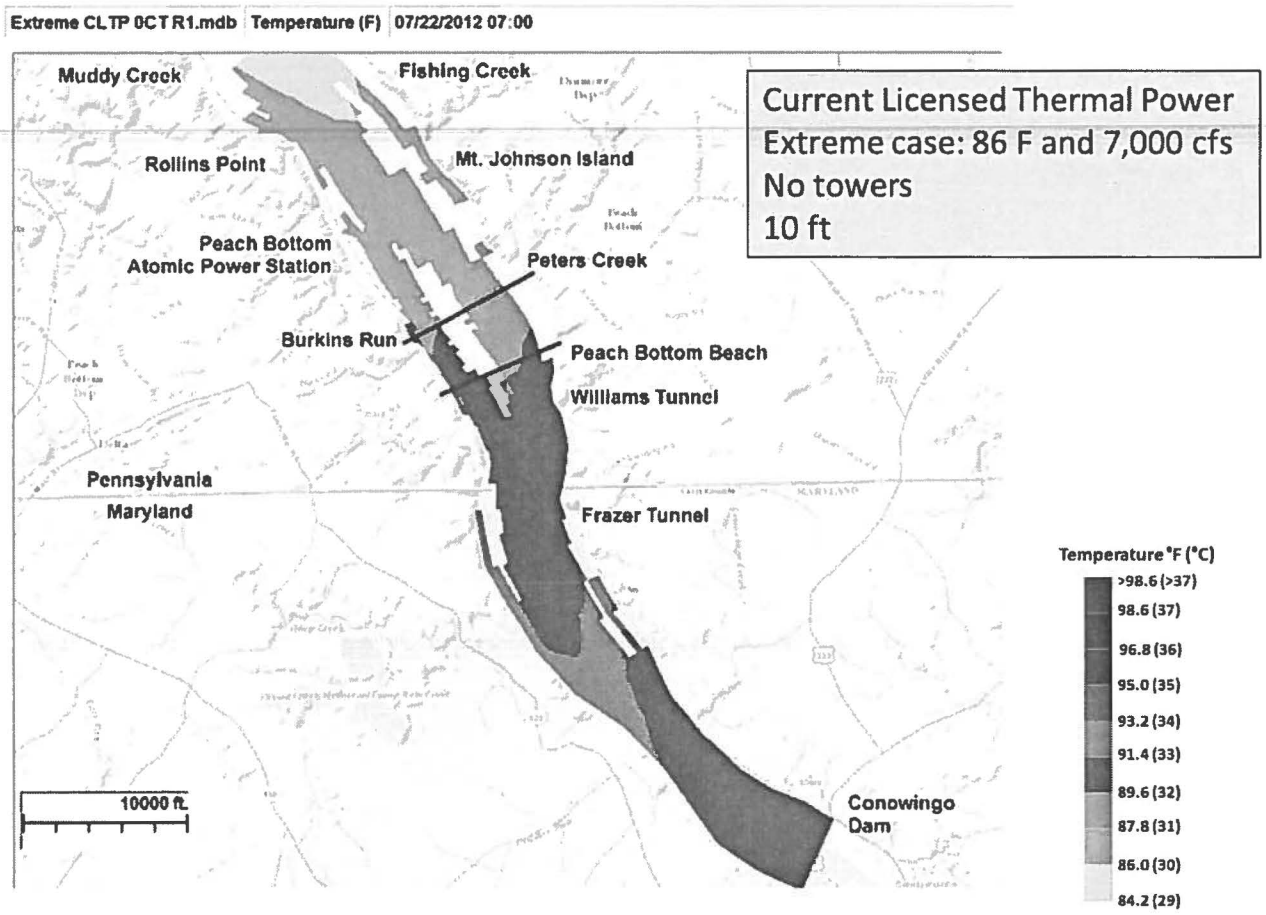

Typical CLTP 3CTR1.mdb Temperature (F) 07/22/2012 07:00
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
10000 ft.
Conowingo
Dam
Current Licensed Thermal Power
Typical case: 80 F and 13,000 cfs
Three towers
Bottom
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

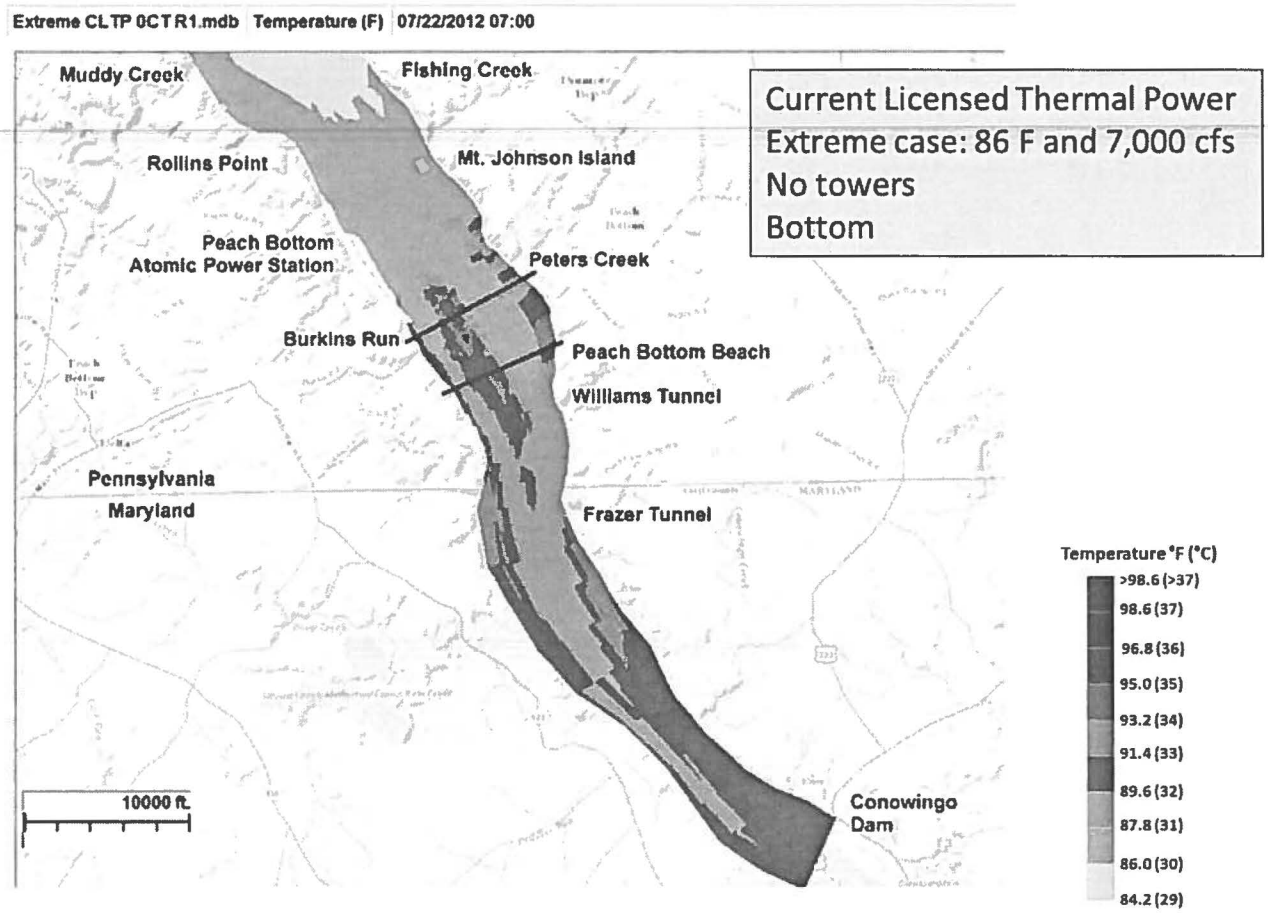

Typical CLTP 3CT R1.mdb
Temperature (F)
07/22/2012 07:00
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
10000 ft
Conowingo
Dam
Current Licensed Thermal Power
Typical case: 80 F and 13,000 cfs
Three towers
Benthic impact: bottom >94°F
Temperature °F (° C)
>94 (34.4)


Database: Extreme CLTP OCT R1.mdb
Slice: 1000ft
Date: 07/22/2012 07:00
Current Licensed Thermal Power
Extreme case: 86 F and 7,000 cfs
No towers
1000 ft below discharge
Elevation, ft
109.9
107.9
105.9
103.9
101.9
99.9
97.9
95.9
93.9
91.9
89.9
87.9
85.9
0 600 1200 1800 2400 3000 3600 4200 4800 5400 6000 6600 7200
Distance along slice, ft
Western shoreline
Eastern shoreline
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

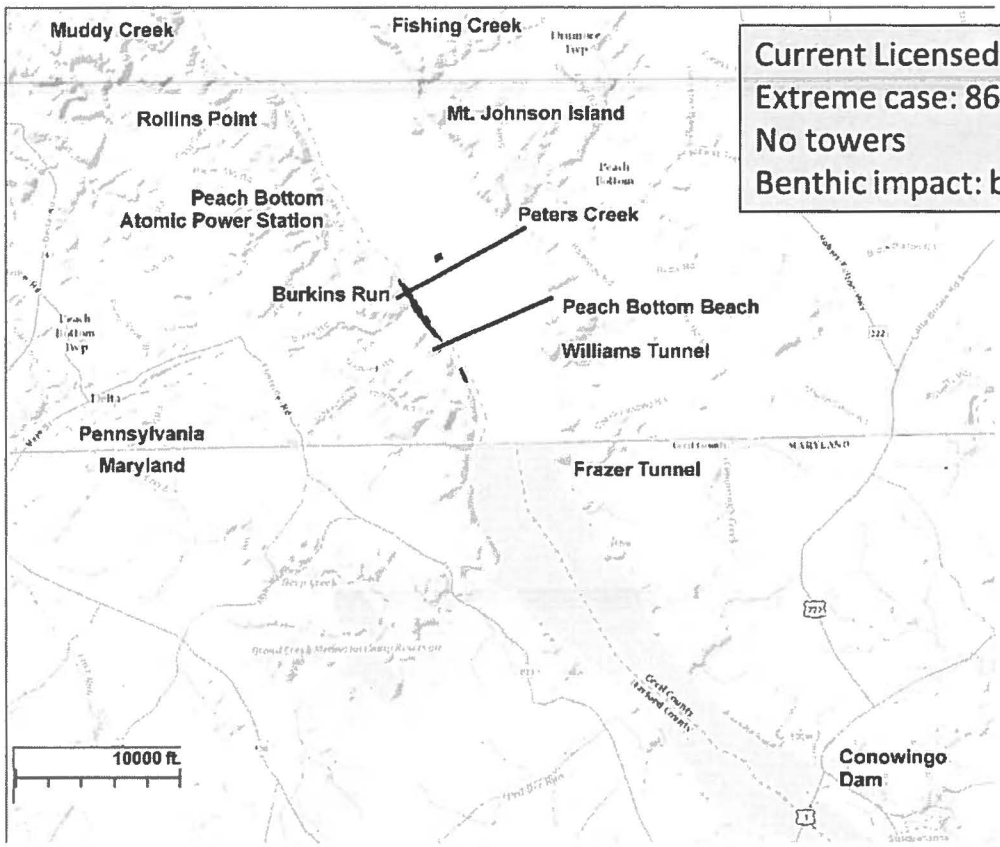

Database: Extreme CLTP OCT R1.mdb Slice: 5000ft Date: 07/22/2012 07:00
Current Licensed Thermal Power
Extreme case: 86 F and 7,000 cfs
No towers
5000 ft below discharge
Elevation, ft
109.9
107.9
105.9
103.9
101.9
99.9
97.9
95.9
93.9
91.9
89.9
87.9
85.9
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 6000
Distance along slice, ft
Western shoreline
Eastern shoreline
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)


Extreme CLTP OCT R1.mdb
Temperature (F)
07/22/2012 07:00
Current Licensed Thermal Power
Extreme case: 86 F and 7,000 cfs
No towers
Surface
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
Conowingo
Dam
10000 ft.
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)


Extreme CLTP OCT R1.mdb
Temperature (F)
07/22/2012 07:00
Current Licensed Thermal Power
Extreme case: 86 F and 7,000 cfs
No towers
10 ft
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
Conowingo
Dam
10000 ft
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)


Extreme CLTP OCTR1.mdb Temperature (F) 07/22/2012 07:00
Current Licensed Thermal Power
Extreme case: 86 F and 7,000 cfs
No towers
Bottom
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
Conowingo
Dam
10000 ft.
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

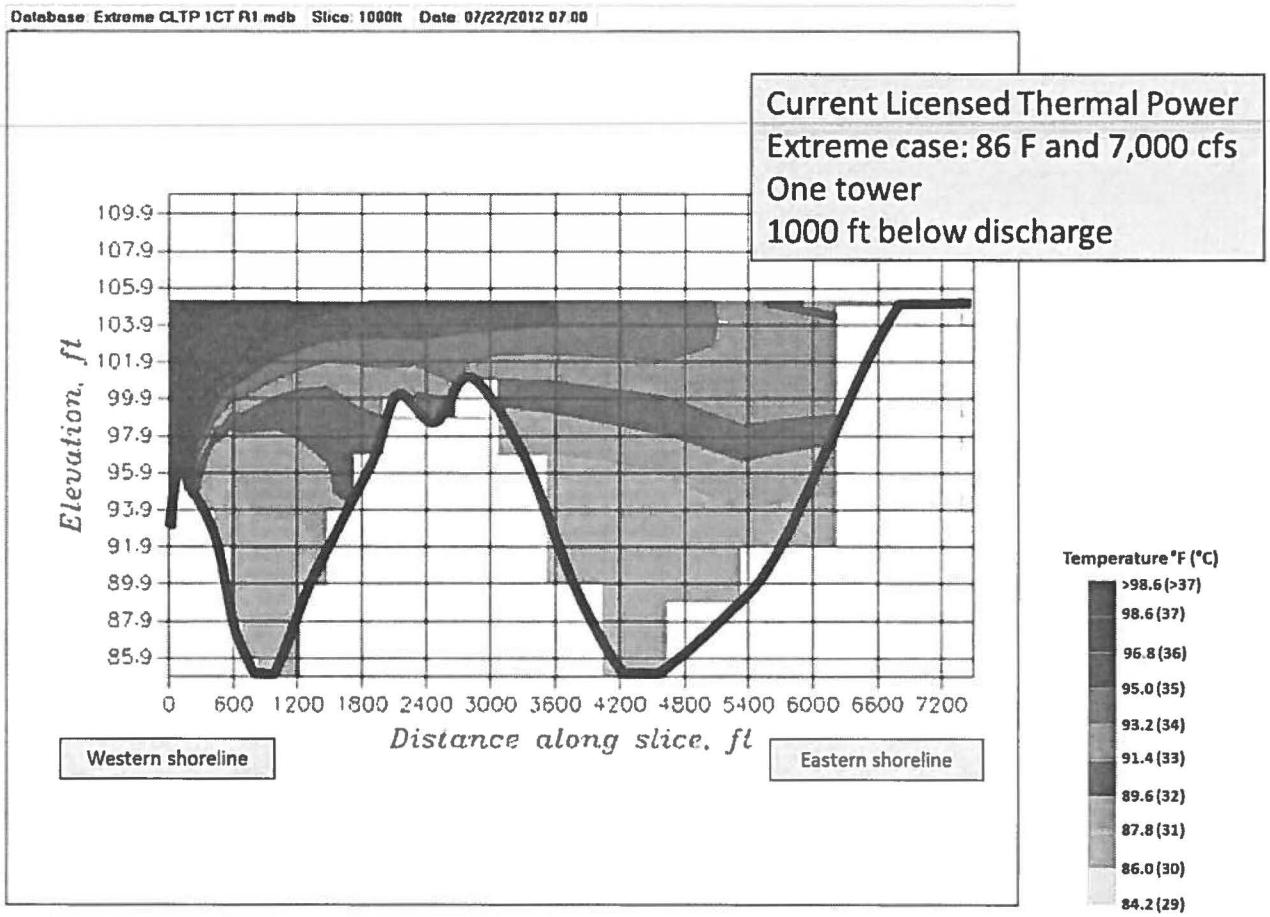
Extreme CLTP 0CT R1.mdb | Temperature (F) | 07/22/2012 07:00

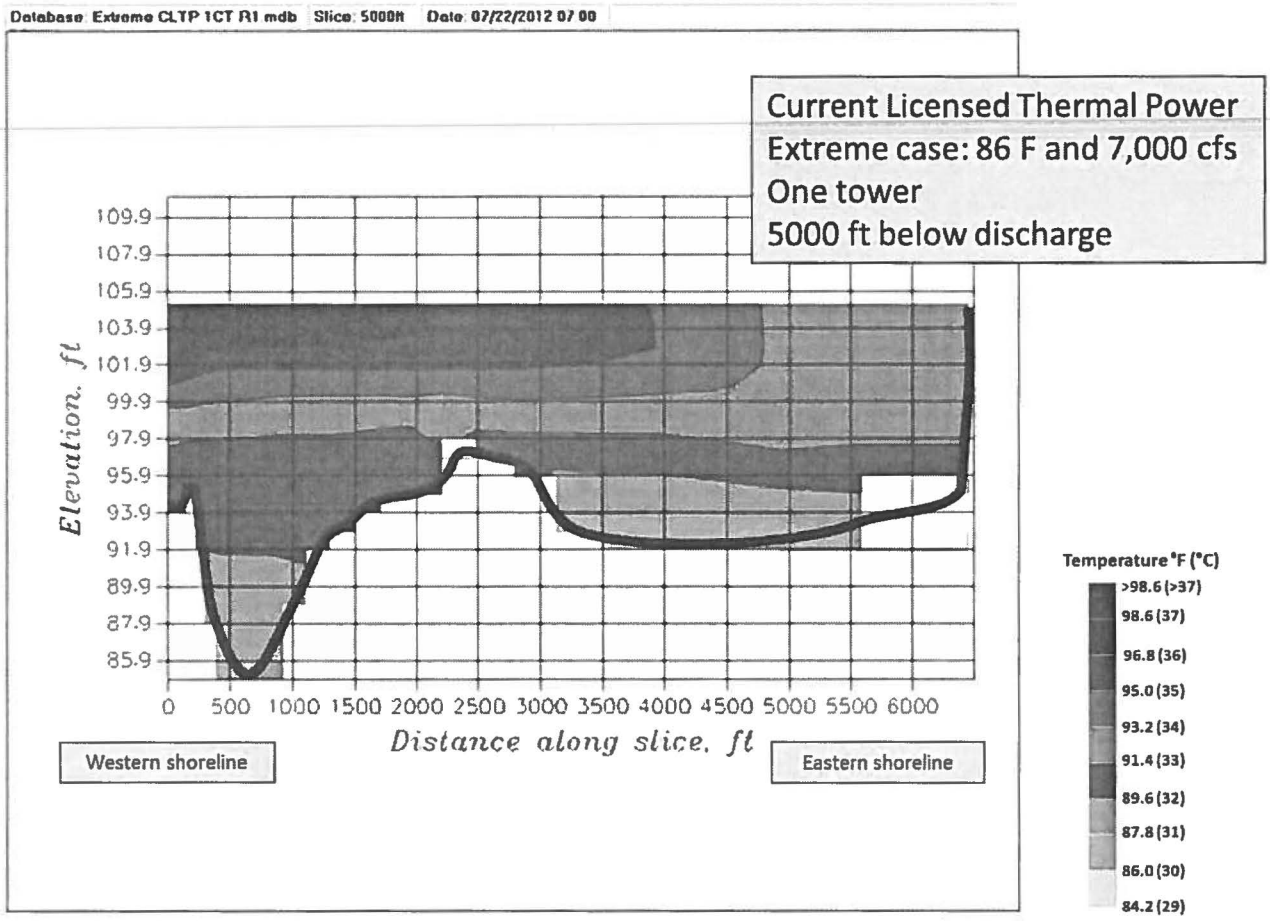


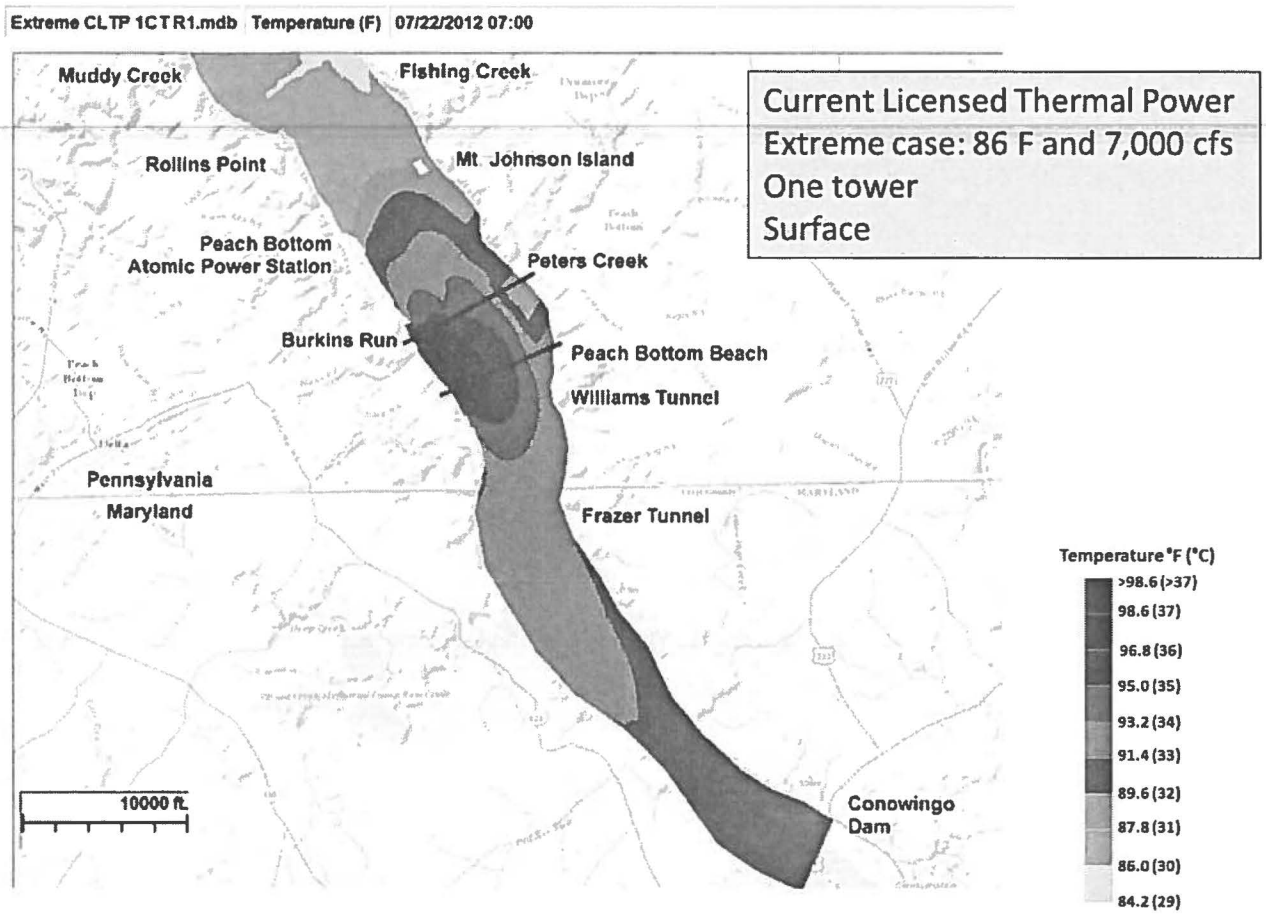
Current Licensed Thermal Power
Extreme case: 86 F and 7,000 cfs
No towers
Benthic impact: bottom >94°F

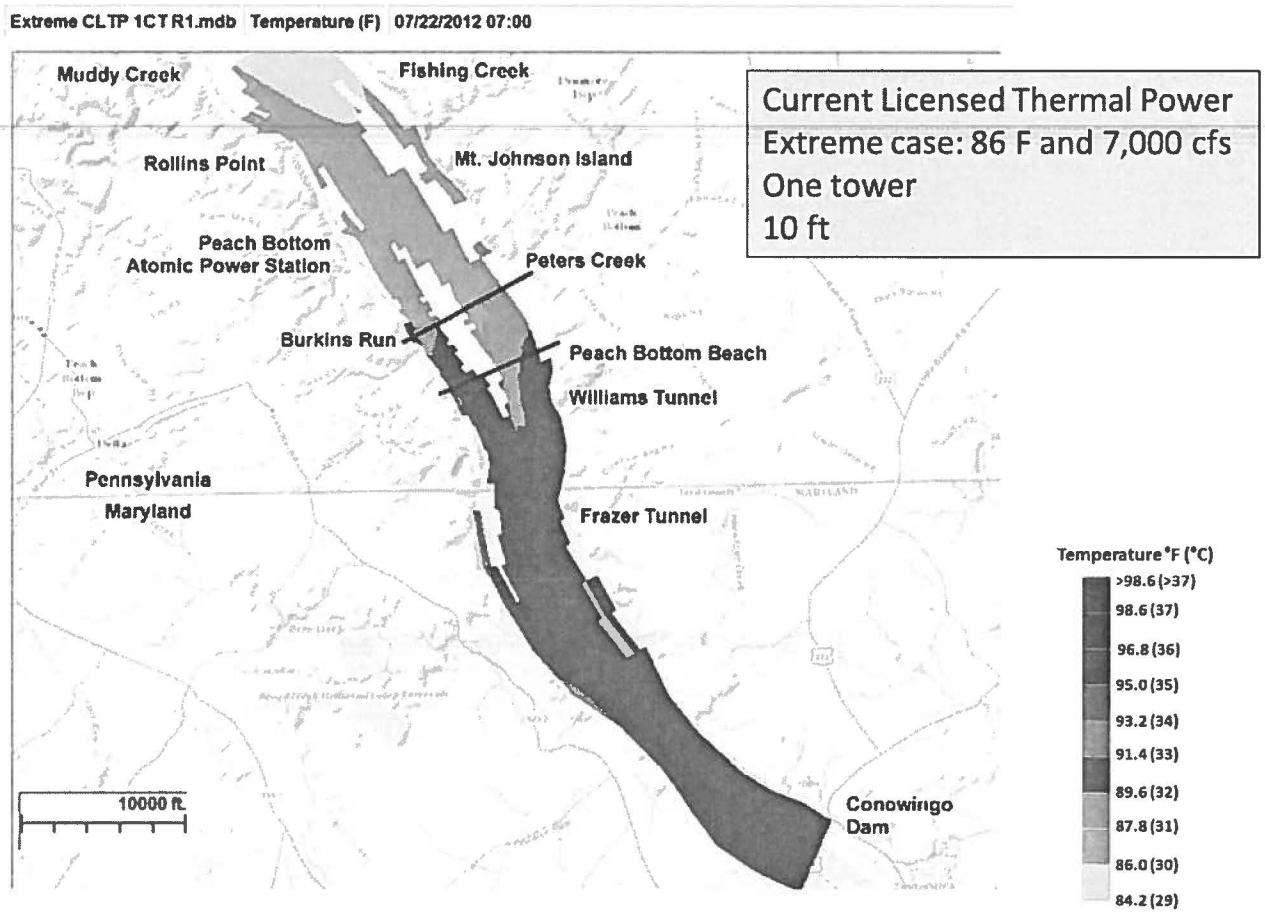
Temperature °F (° C)

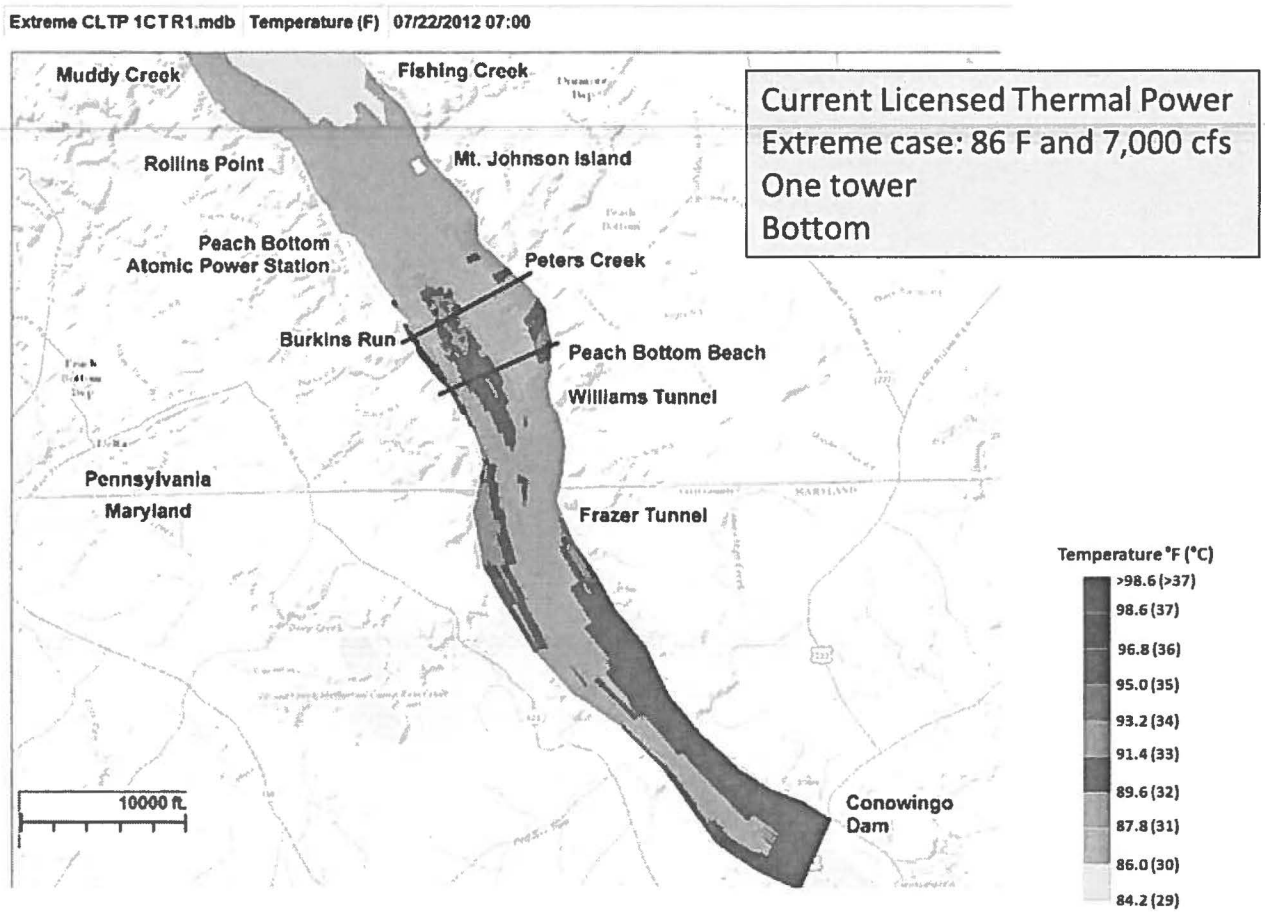
>94 (34.4)


Database Extreme CLTP 1CT R1 mdb Slice 1000ft Date 07/22/2012 07 00
Current Licensed Thermal Power
Extreme case: 86 F and 7,000 cfs
One tower
1000 ft below discharge
Elevation, ft
109.9
107.9
105.9
103.9
101.9
99.9
97.9
95.9
93.9
91.9
89.9
87.9
85.9
0 600 1200 1800 2400 3000 3600 4200 4800 5400 6000 6600 7200
Distance along slice, ft
Western shoreline
Eastern shoreline
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

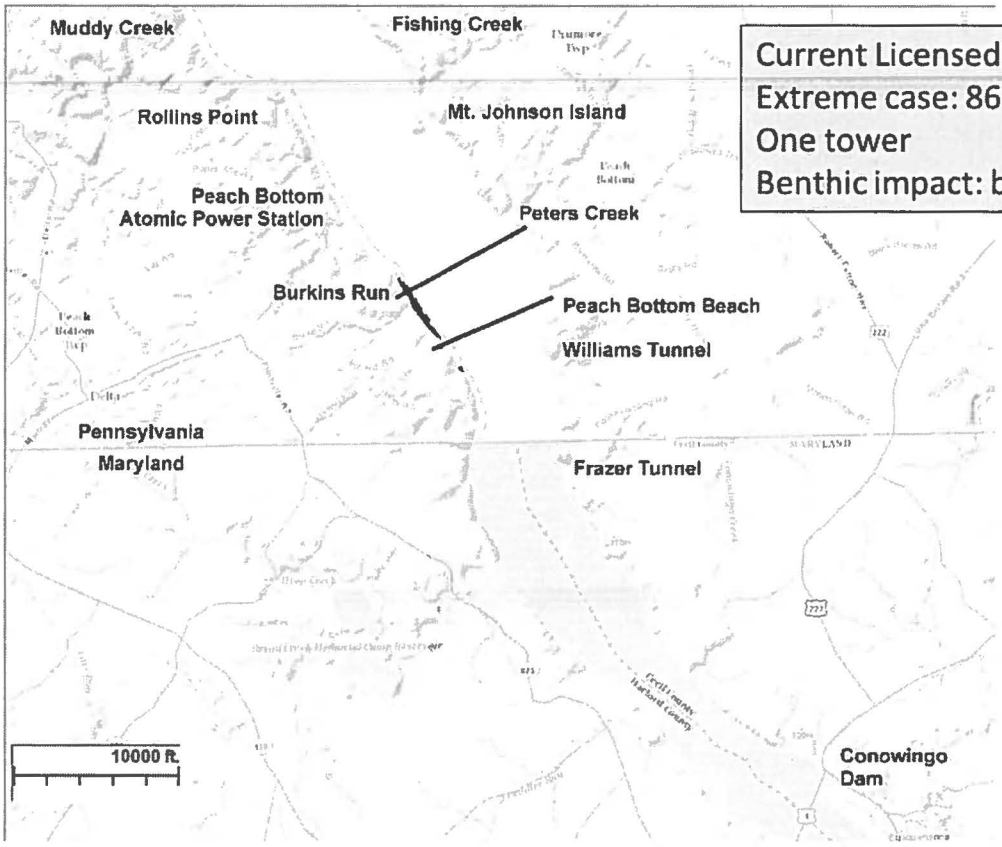

Database: Extreme CLTP 1CT R1.mdb Slice: 5000ft Date: 07/22/2012 07:00
Current Licensed Thermal Power
Extreme case: 86 F and 7,000 cfs
One tower
5000 ft below discharge
Elevation, ft
109.9
107.9
105.9
103.9
101.9
99.9
97.9
95.9
93.9
91.9
89.9
87.9
85.9
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 6000
Distance along slice, ft
Western shoreline
Eastern shoreline
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)


Extreme CLTP 1CTR1.mdb Temperature (F) 07/22/2012 07:00
Current Licensed Thermal Power
Extreme case: 86 F and 7,000 cfs
One tower
Surface
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
Conowingo
Dam
10000 ft
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)


Extreme CLTP 1CTR1.mdb Temperature (F) 07/22/2012 07:00
Current Licensed Thermal Power
Extreme case: 86 F and 7,000 cfs
One tower
10 ft
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
Conowingo
Dam
10000 ft
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)


Extreme CLTP 1CTR1.mdb Temperature (F) 07/22/2012 07:00
Current Licensed Thermal Power
Extreme case: 86 F and 7,000 cfs
One tower
Bottom
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
10000 ft.
Conowingo
Dam
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

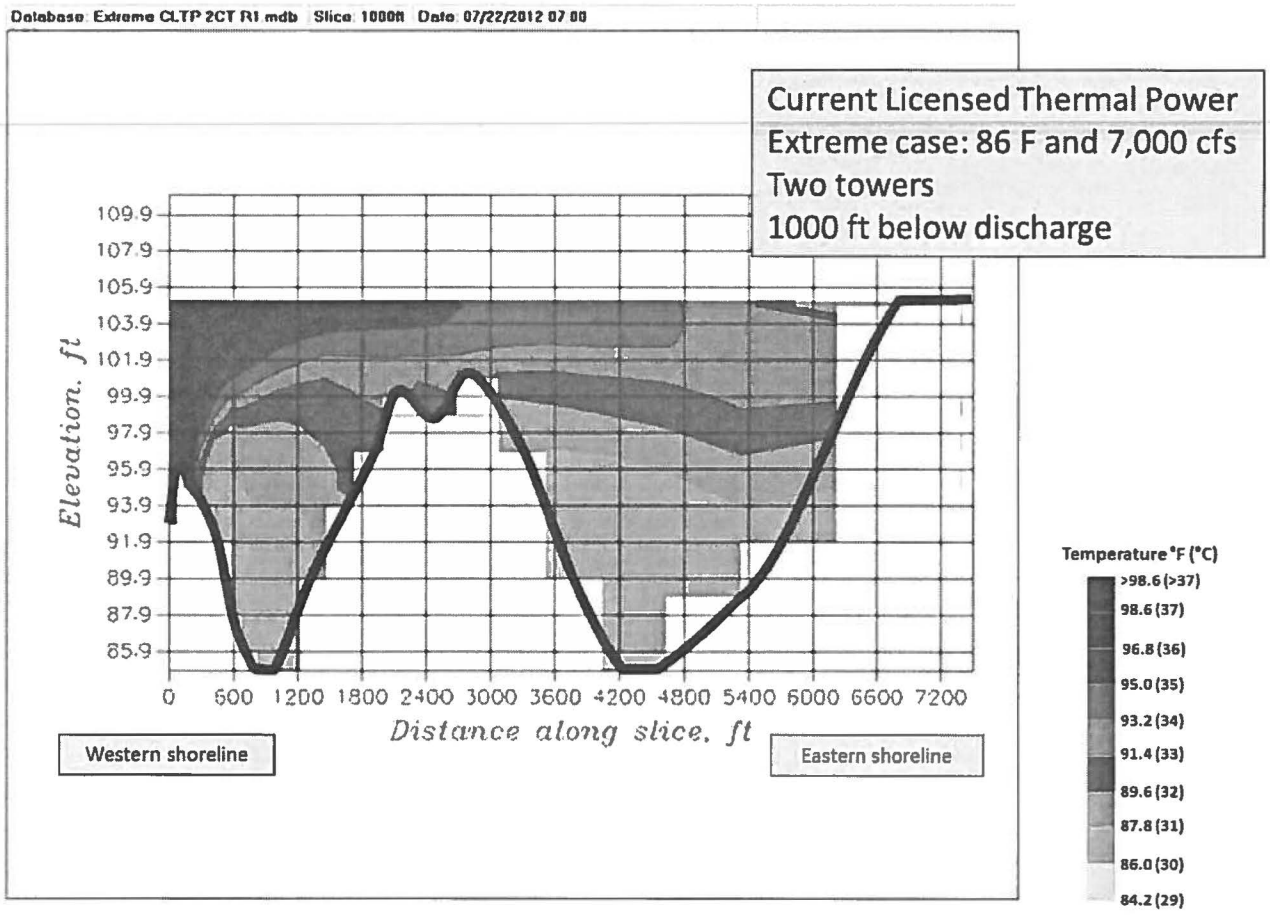
Extreme CLTP 1CT R1.mdb | Temperature (F) | 07/22/2012 07:00

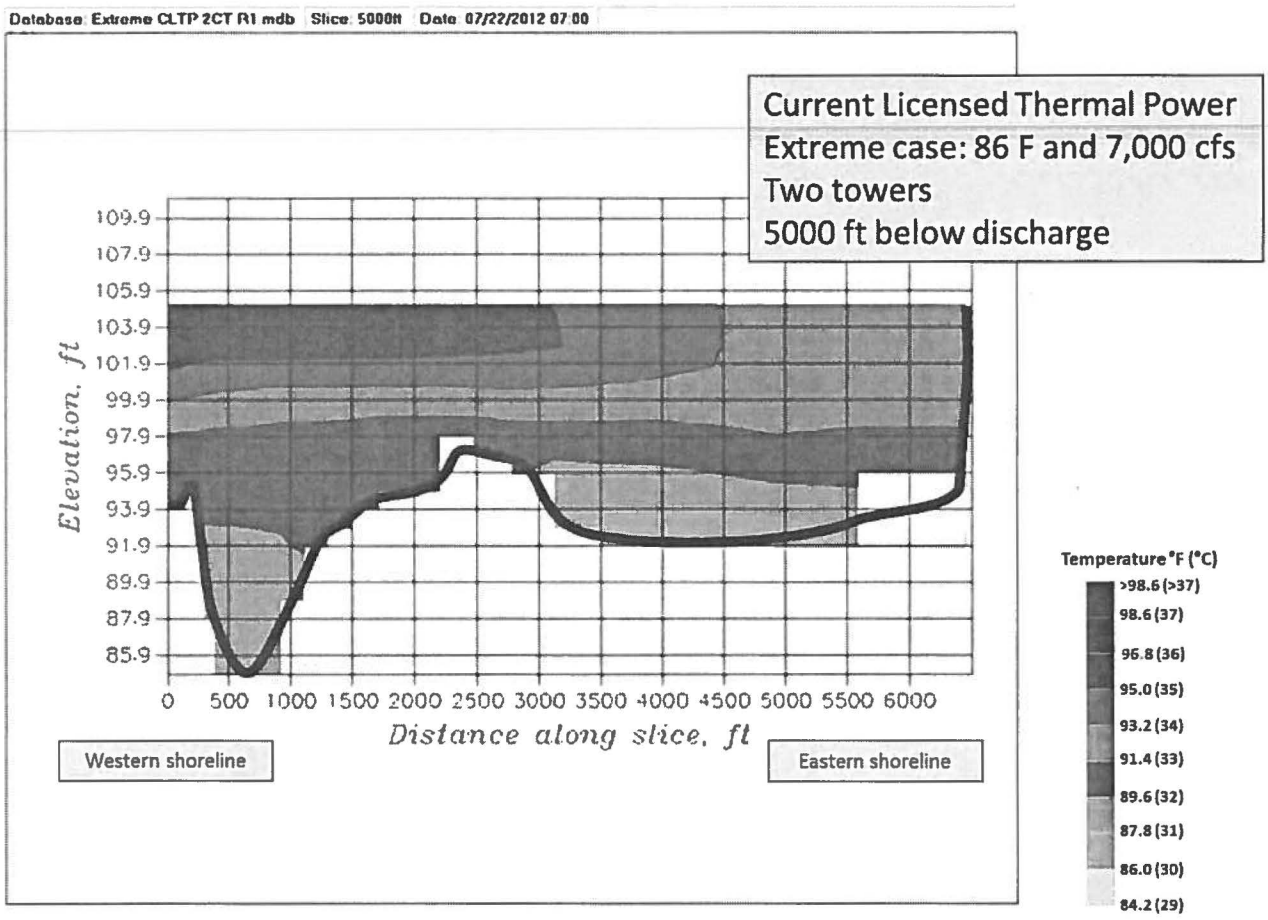


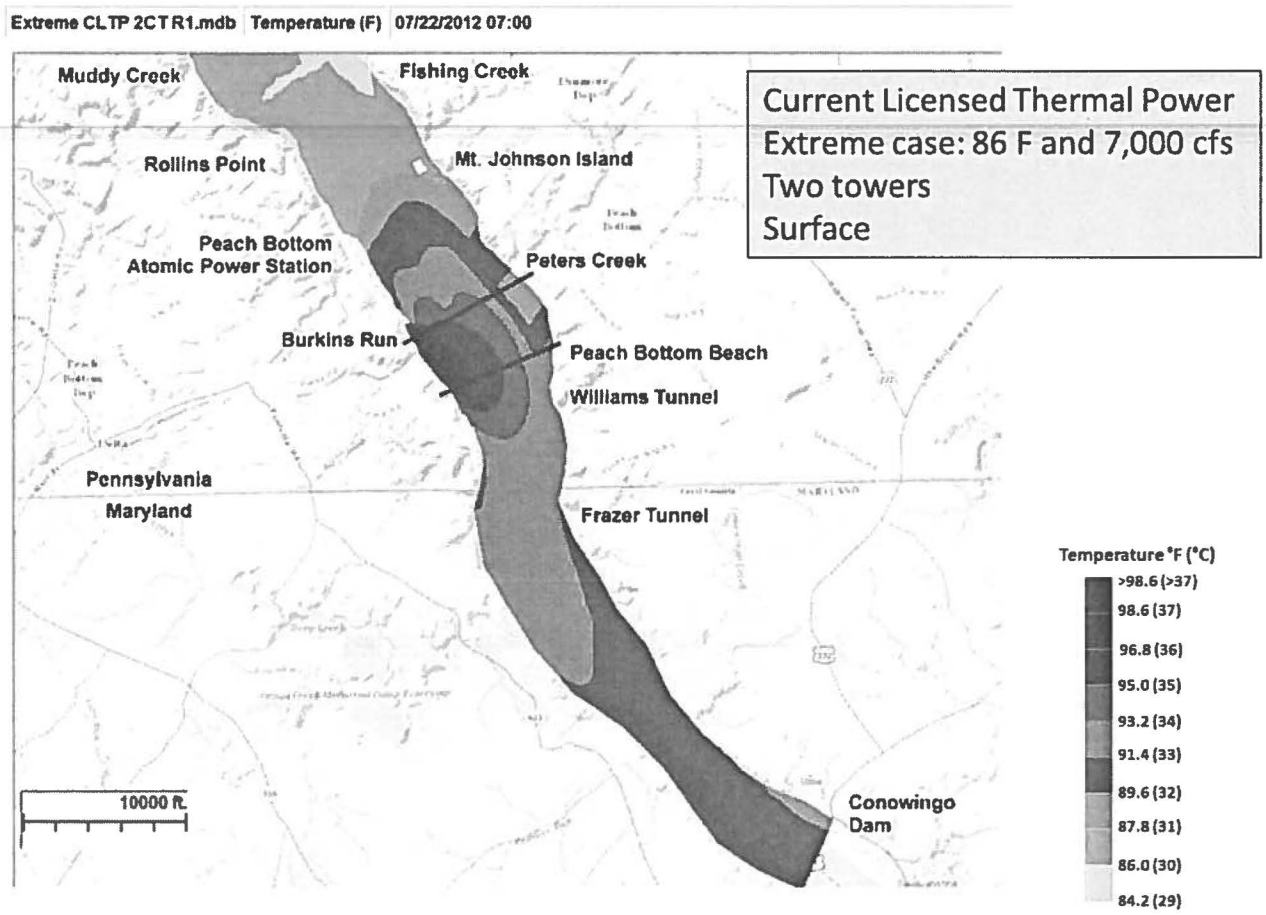
Current Licensed Thermal Power
Extreme case: 86 F and 7,000 cfs
One tower
Benthic impact: bottom >94°F

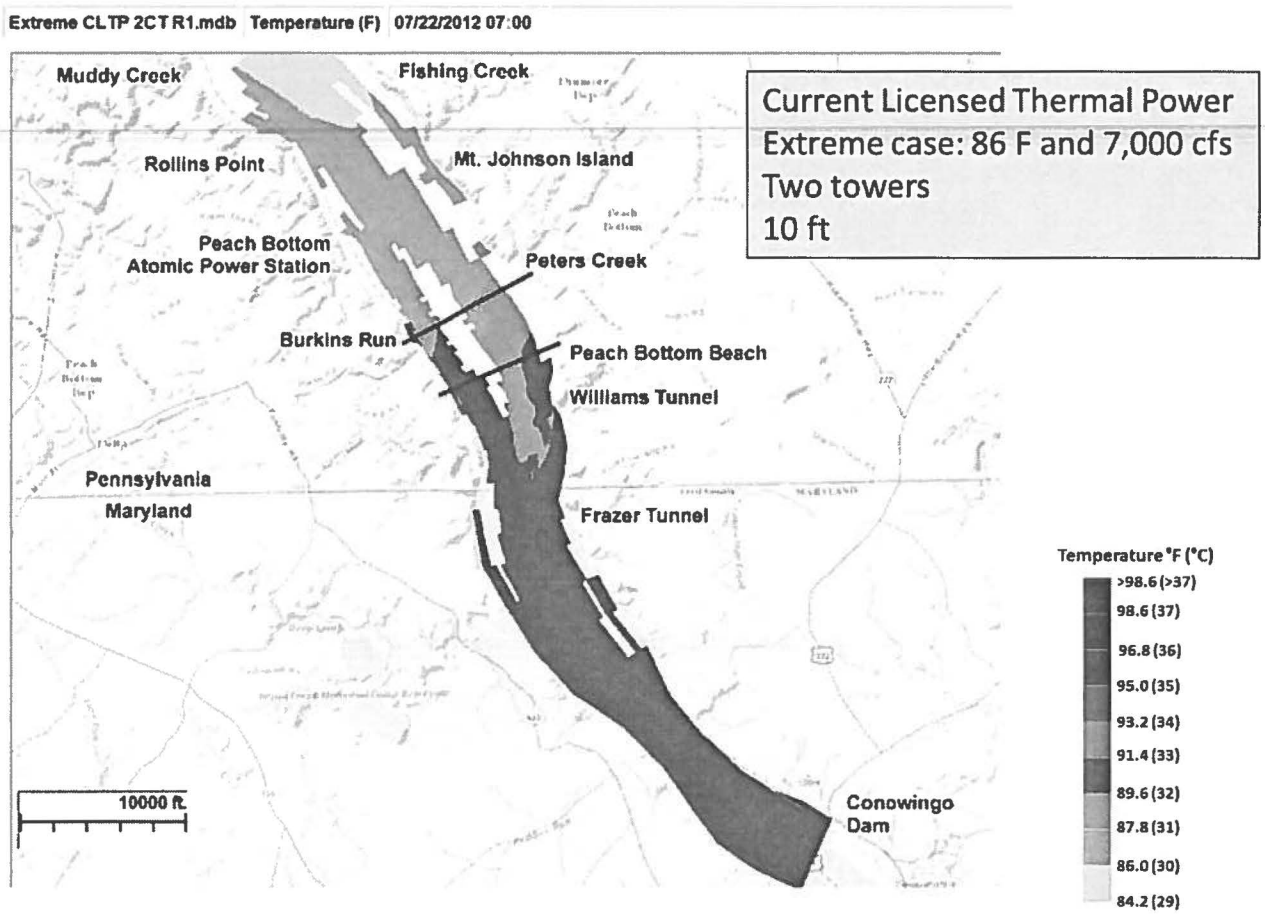
Temperature °F (° C)

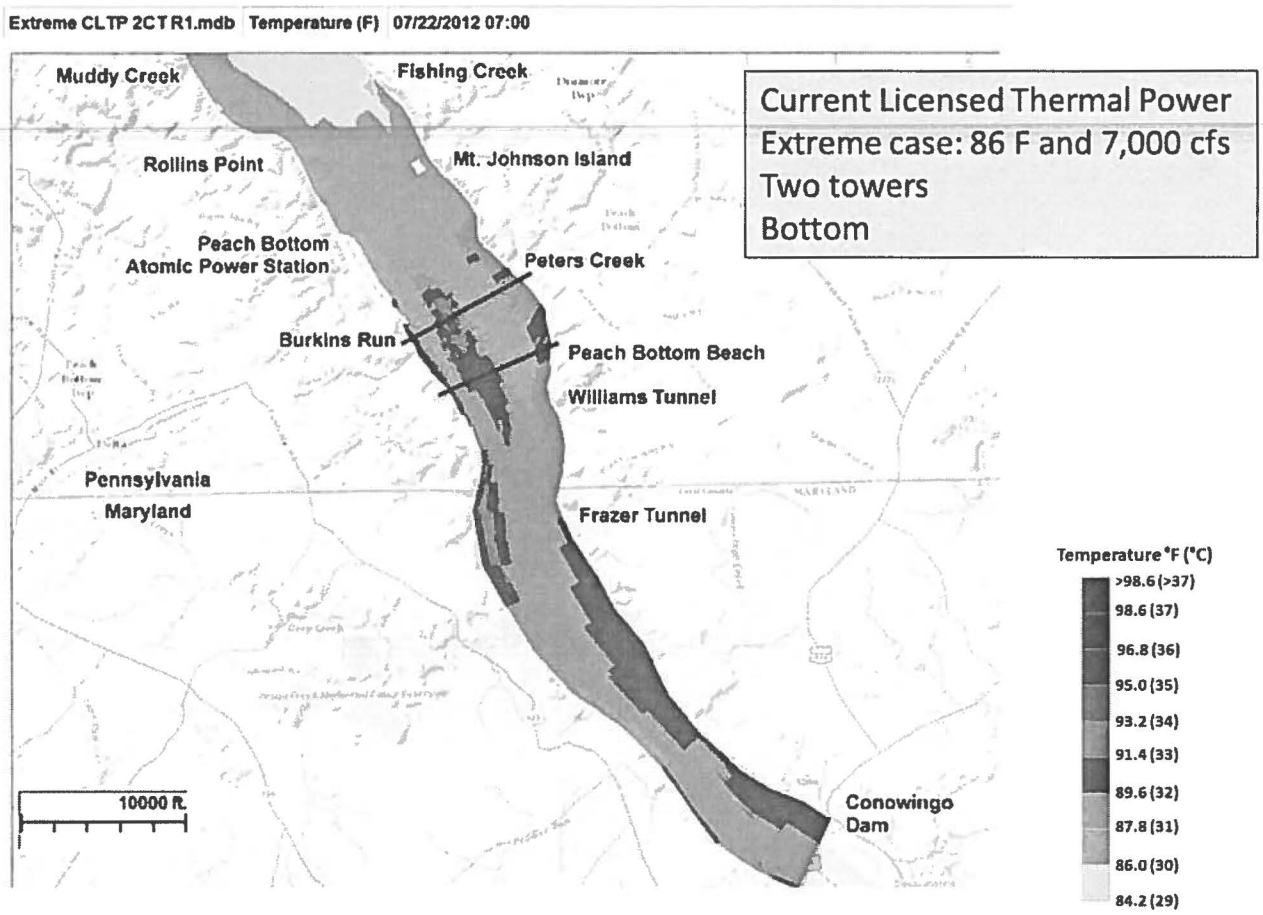
>94 (34.4)

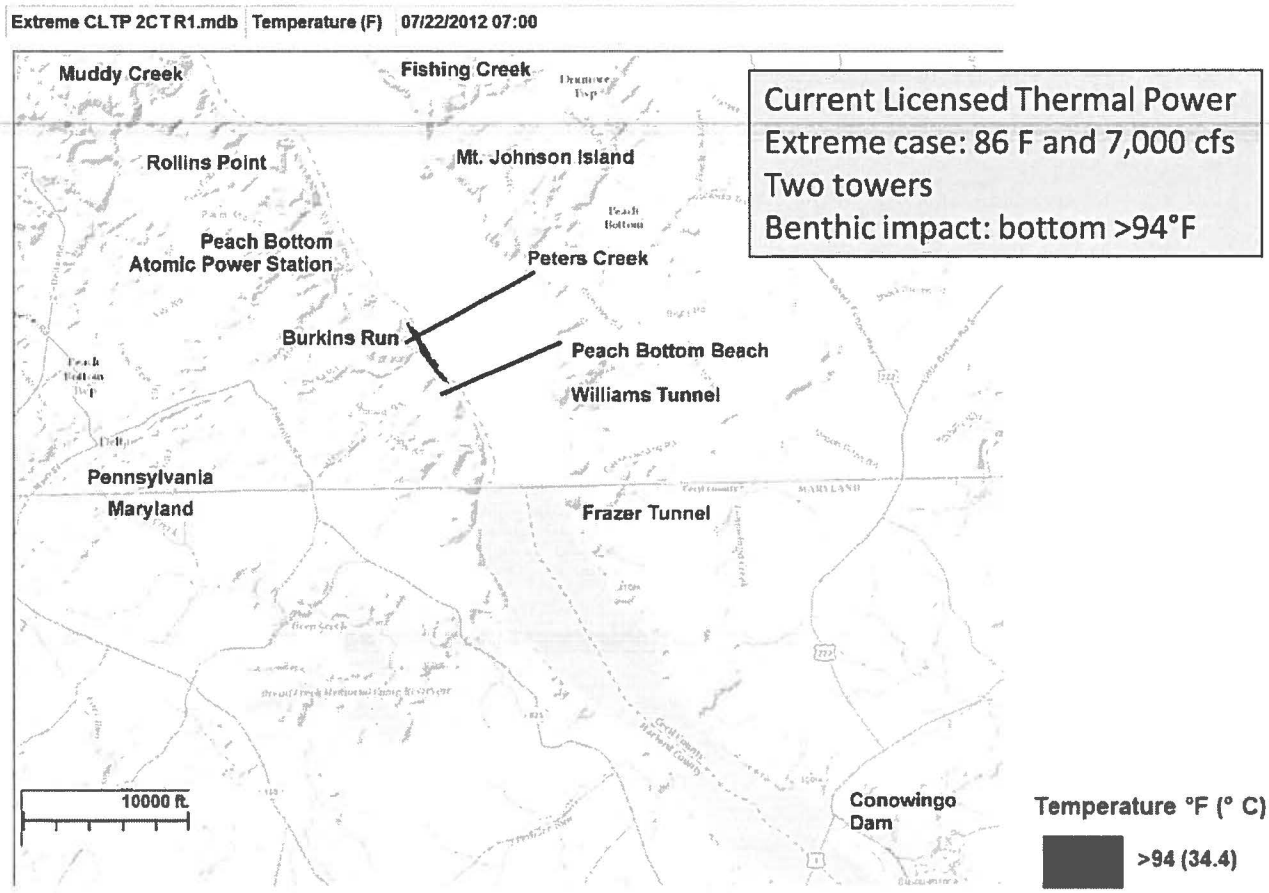

Database: Extreme CLTP 2CT R1.mdb Slice: 1000ft Date: 07/22/2012 07:00
Current Licensed Thermal Power
Extreme case: 86 F and 7,000 cfs
Two towers
1000 ft below discharge
Elevation, ft
109.9
107.9
105.9
103.9
101.9
99.9
97.9
95.9
93.9
91.9
89.9
87.9
85.9
0 600 1200 1800 2400 3000 3600 4200 4800 5400 6000 6600 7200
Distance along slice, ft
Western shoreline
Eastern shoreline
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

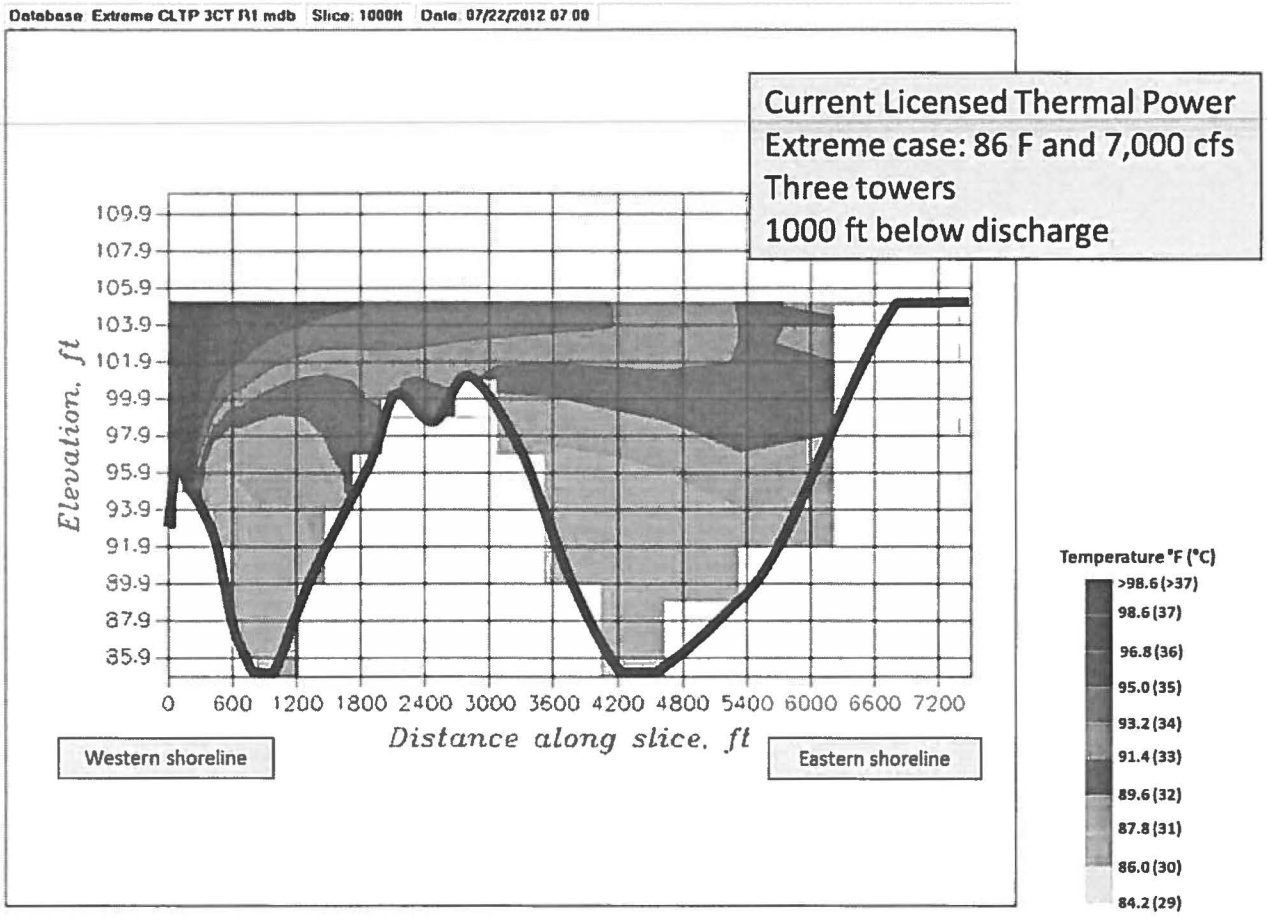

Database: Extreme CLTP 2CT R1.mdb Slice: 5000ft Date: 07/22/2012 07:00
Current Licensed Thermal Power
Extreme case: 86 F and 7,000 cfs
Two towers
5000 ft below discharge
Elevation, ft
109.9
107.9
105.9
103.9
101.9
99.9
97.9
95.9
93.9
91.9
89.9
87.9
85.9
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 6000
Distance along slice, ft
Western shoreline
Eastern shoreline
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

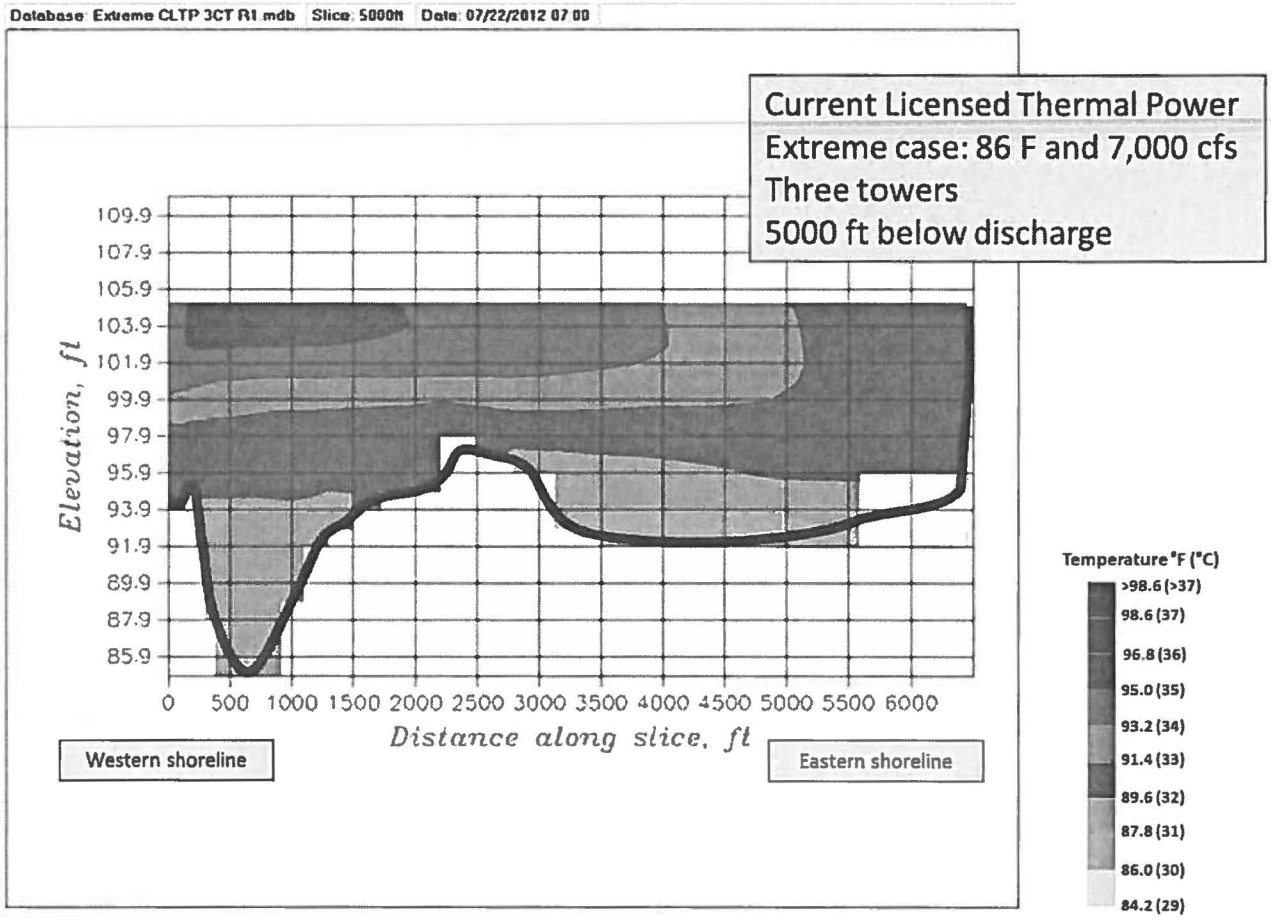

Extreme CLTP 2CT R1.mdb Temperature (F) 07/22/2012 07:00
Current Licensed Thermal Power
Extreme case: 86 F and 7,000 cfs
Two towers
Surface
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
Conowingo
Dam
10000 ft.
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

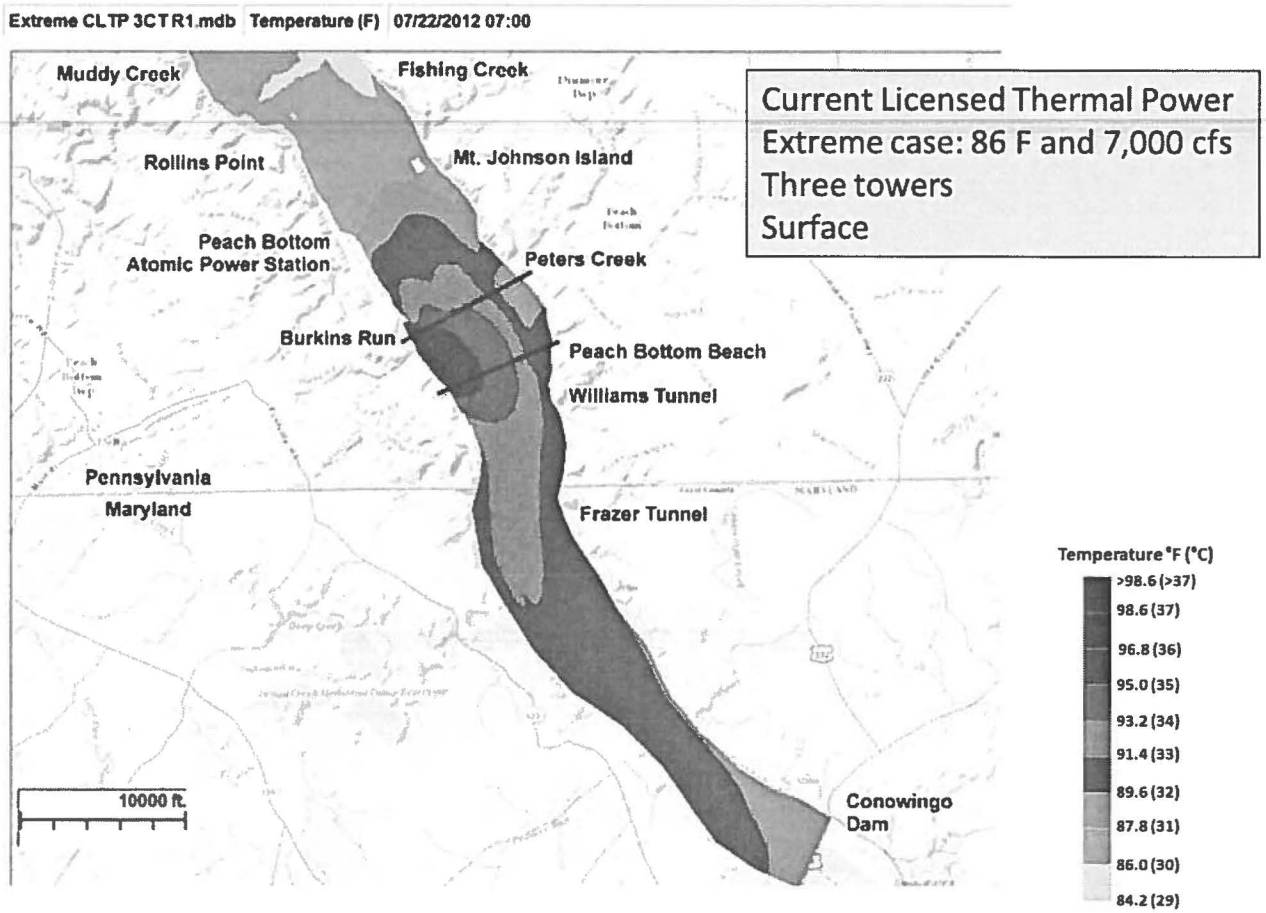

Extreme CLTP 2CT R1.mdb Temperature (F) 07/22/2012 07:00
Current Licensed Thermal Power
Extreme case: 86 F and 7,000 cfs
Two towers
10 ft
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
Conowingo
Dam
10000 ft
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

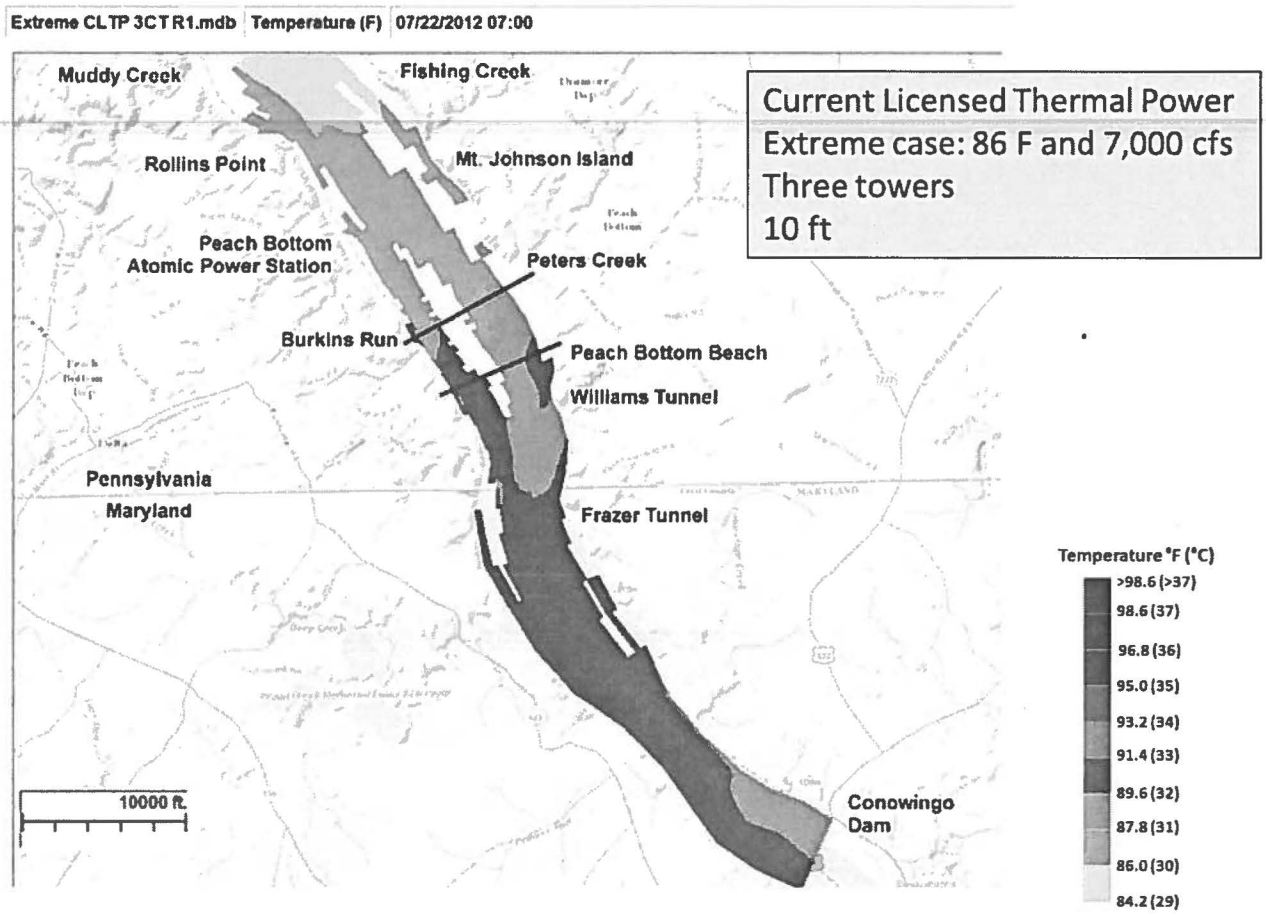

Extreme CLTP 2CT R1.mdb Temperature (F) 07/22/2012 07:00
Current Licensed Thermal Power
Extreme case: 86 F and 7,000 cfs
Two towers
Bottom
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
Conowingo
Dam
10000 ft.
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

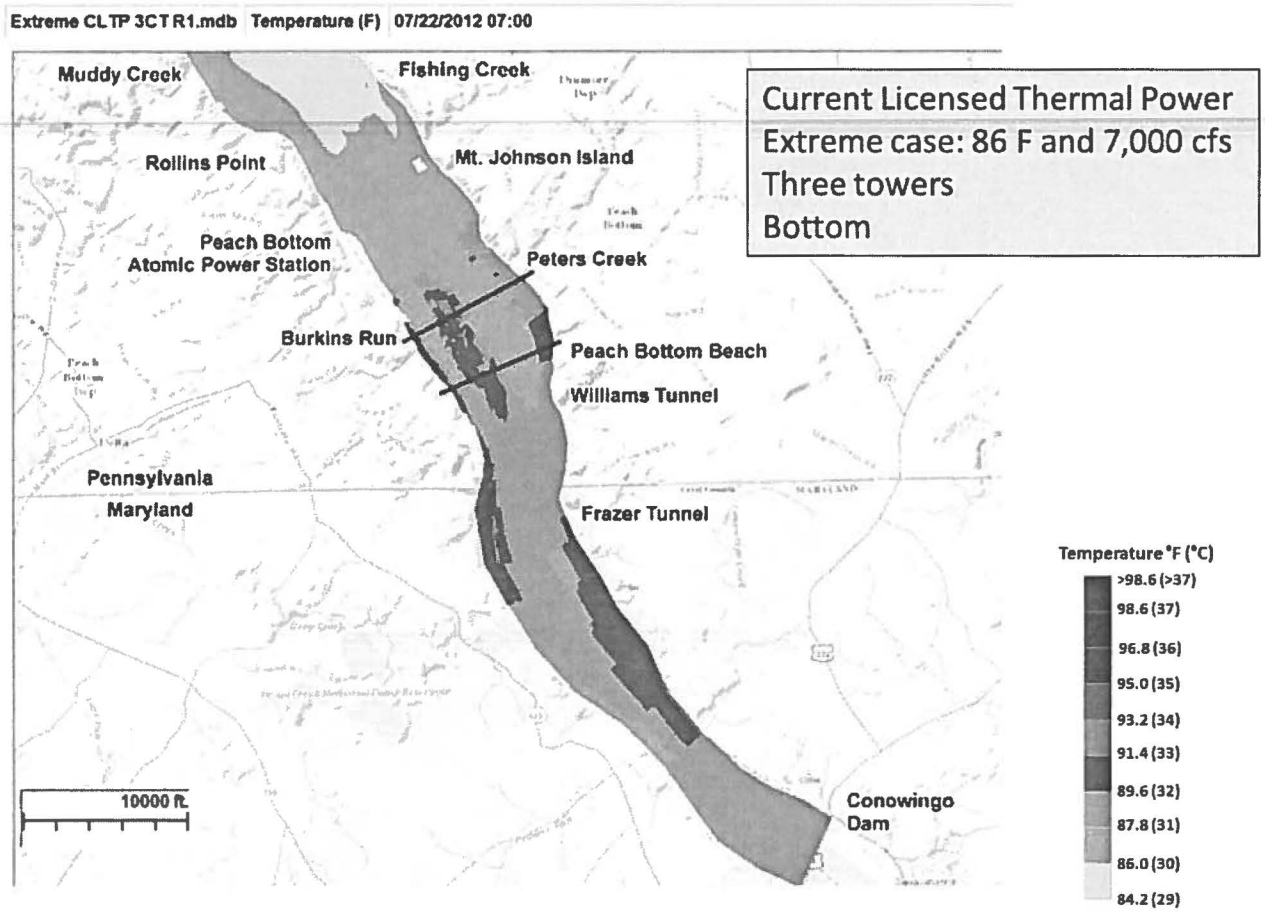

Extreme CLTP 2CT R1.mdb
Temperature (F)
07/22/2012 07:00
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
10000 ft.
Conowingo
Dam
Current Licensed Thermal Power
Extreme case: 86 F and 7,000 cfs
Two towers
Benthic impact: bottom >94°F
Temperature °F (° C)
>94 (34.4)


Database: Extreme CLTP 3CT R1.mdb Slice: 1000ft Date: 07/22/2012 07:00
Current Licensed Thermal Power
Extreme case: 86 F and 7,000 cfs
Three towers
1000 ft below discharge
Elevation, ft
109.9
107.9
105.9
103.9
101.9
99.9
97.9
95.9
93.9
91.9
89.9
87.9
85.9
0 600 1200 1800 2400 3000 3600 4200 4800 5400 6000 6600 7200
Distance along slice, ft
Western shoreline
Eastern shoreline
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

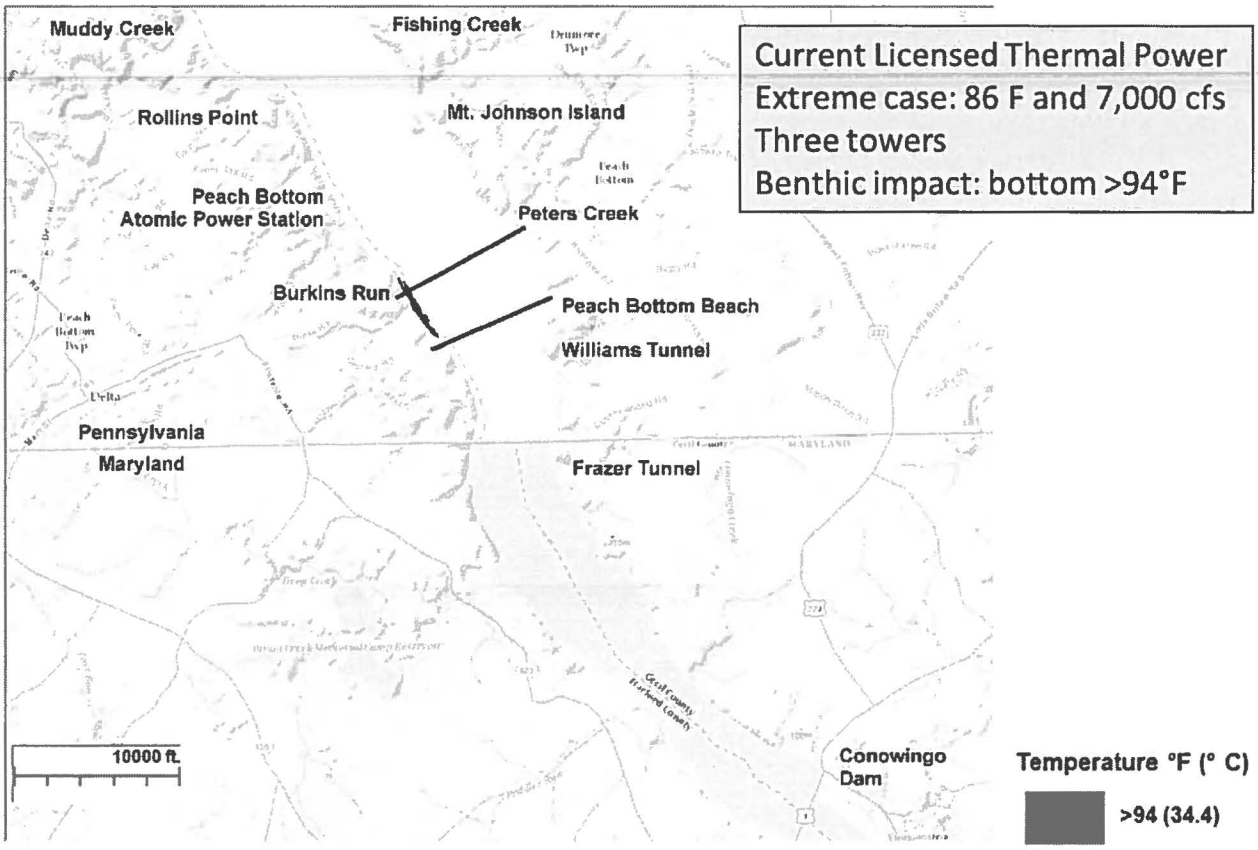

Database: Extreme CLTP 3CT R1.mdb Slice: 5000ft Date: 07/22/2012 07:00
Current Licensed Thermal Power
Extreme case: 86 F and 7,000 cfs
Three towers
5000 ft below discharge
Elevation, ft
109.9
107.9
105.9
103.9
101.9
99.9
97.9
95.9
93.9
91.9
89.9
87.9
85.9
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 6000
Distance along slice, ft
Western shoreline
Eastern shoreline
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)


Extreme CLTP 3CTR1.mdb Temperature (F) 07/22/2012 07:00
Current Licensed Thermal Power
Extreme case: 86 F and 7,000 cfs
Three towers
Surface
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
Conowingo
Dam
10000 ft.
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)


Extreme CLTP 3CTR1.mdb
Temperature (F)
07/22/2012 07:00
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
Conowingo
Dam
10000 ft.
Current Licensed Thermal Power
Extreme case: 86 F and 7,000 cfs
Three towers
10 ft
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)


Extreme CLTP 3CT R1.mdb Temperature (F) 07/22/2012 07:00
Current Licensed Thermal Power
Extreme case: 86 F and 7,000 cfs
Three towers
Bottom
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
Conowingo
Dam
10000 ft.
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

Extreme CLTP 3CTR1.mdb | Temperature (F) | 07/22/2012 07:00



7 Post-EPU Biological Assessment

The Extended Power Uprate (EPU) will increase licensed thermal power by approximately 12.4%, which allows PBAPS to produce more electricity, but with an increase in the heat load to Conowingo Pond. Increased heat results in a higher condenser temperature rise of approximately 3 °F because the circulating water flow rate will remain constant.

The intent of the hydrothermal modeling is to predict the dimensions of the thermal plume for low flow and high temperature conditions and the heat discharge rate associated with the EPU.

The combined hydrothermal and avoidance modeling evaluated potential thermal effects on fish by computing the extent of the thermal plume. Because fish can move to regions of cooler water, the BIC can be maintained if the thermal plume is "confined" such that cooler regions are large, connected, and always available.

7.1 Modeled RIS Avoidance and Benthos Impacts Areas

Modeled avoidance areas were used to assess potential avoidance zones for *typical summer* and *extreme summer conditions* post-EPU for the conditions defined earlier for the CLTP simulations. This section presents the same sequence of snapshots of the modeled thermal plume for *typical* and *extreme* conditions and cooling tower configurations (2 conditions x 4 cooling tower configurations). Six views are shown: 2 transect locations and 4 planar depths (surface, 10 ft, and the bottom for the entire plume and for the bottom plume greater than 94°F.

Figure 6-7 shows the locations of transects 1,000 and 5,000 ft downstream of the discharge structure. These transects were chosen to represent the evolution of vertical and lateral mixing downstream of the discharge. Transect locations are also shown on the planar views. Cross-sectional areas for the transects are summarized in Table 7-1 (*typical conditions*) and Table 7-2 (*extreme conditions*).

Although the operation of additional cooling towers decreases the extent of the plume, the model results show that zero tower operation also meets the BIC requirements for size, connectivity and availability. In particular, the plume is stratified such that cooler water is always available.

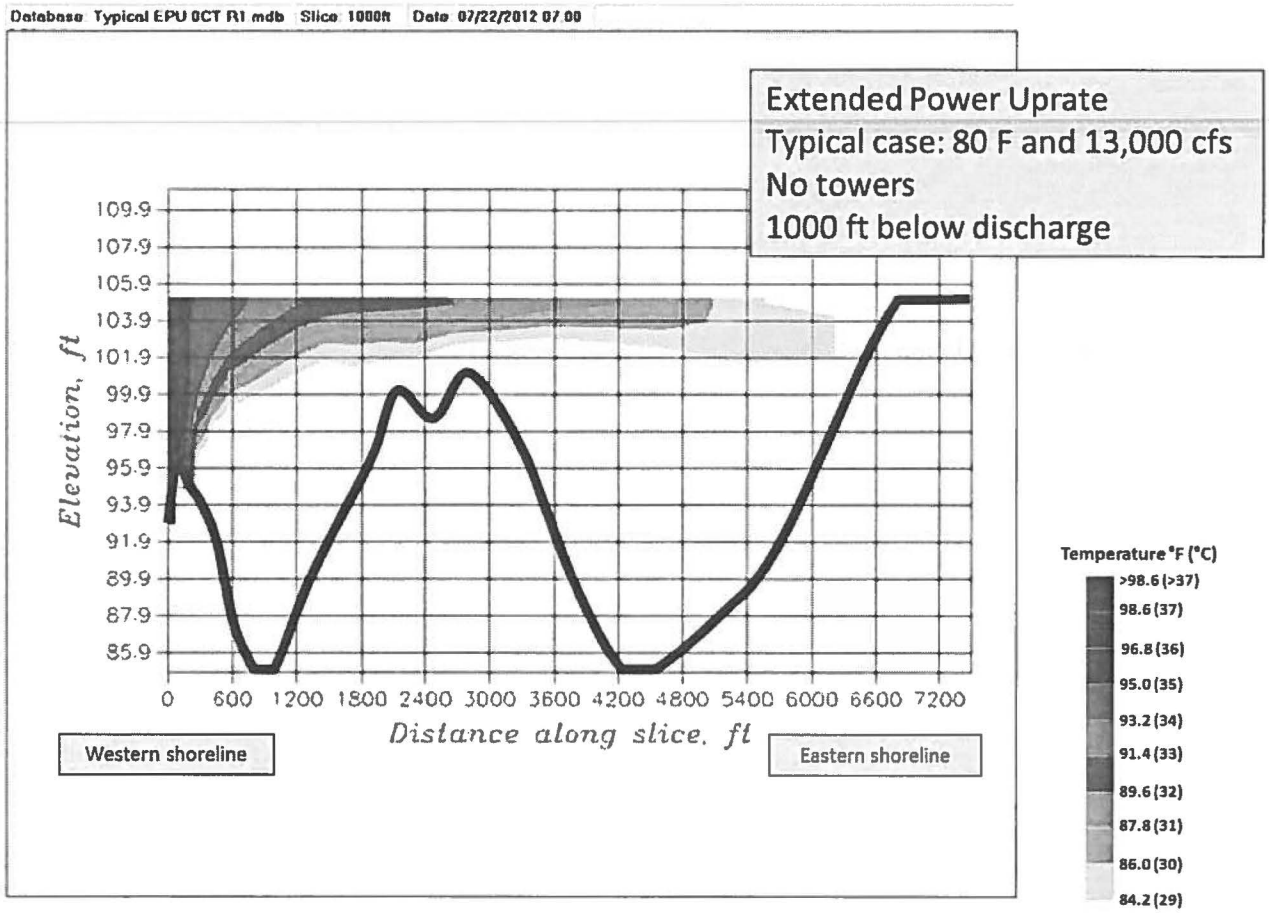
Cross-sectional areas, expressed as a fraction of the total, are shown in the plume diagrams for both *typical* and *extreme conditions*. Surface areas are shown in the plume diagrams for both the *typical* and *extreme conditions*.

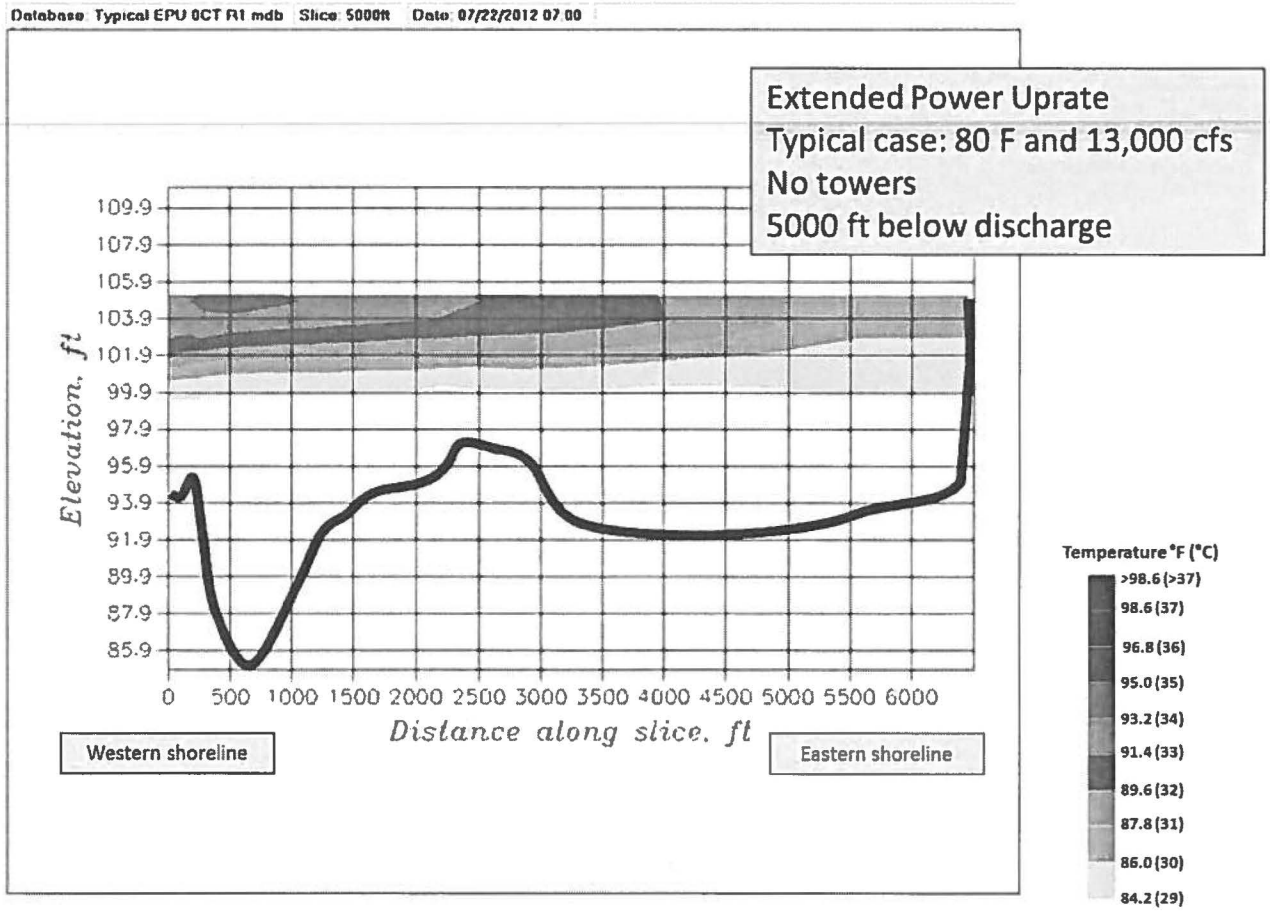
Table 7-1. Modeled cross-sectional areas (fraction of total, in per cent) exceeding various temperatures for the four cooling tower cases, *typical* and *extreme* summer conditions, EPU

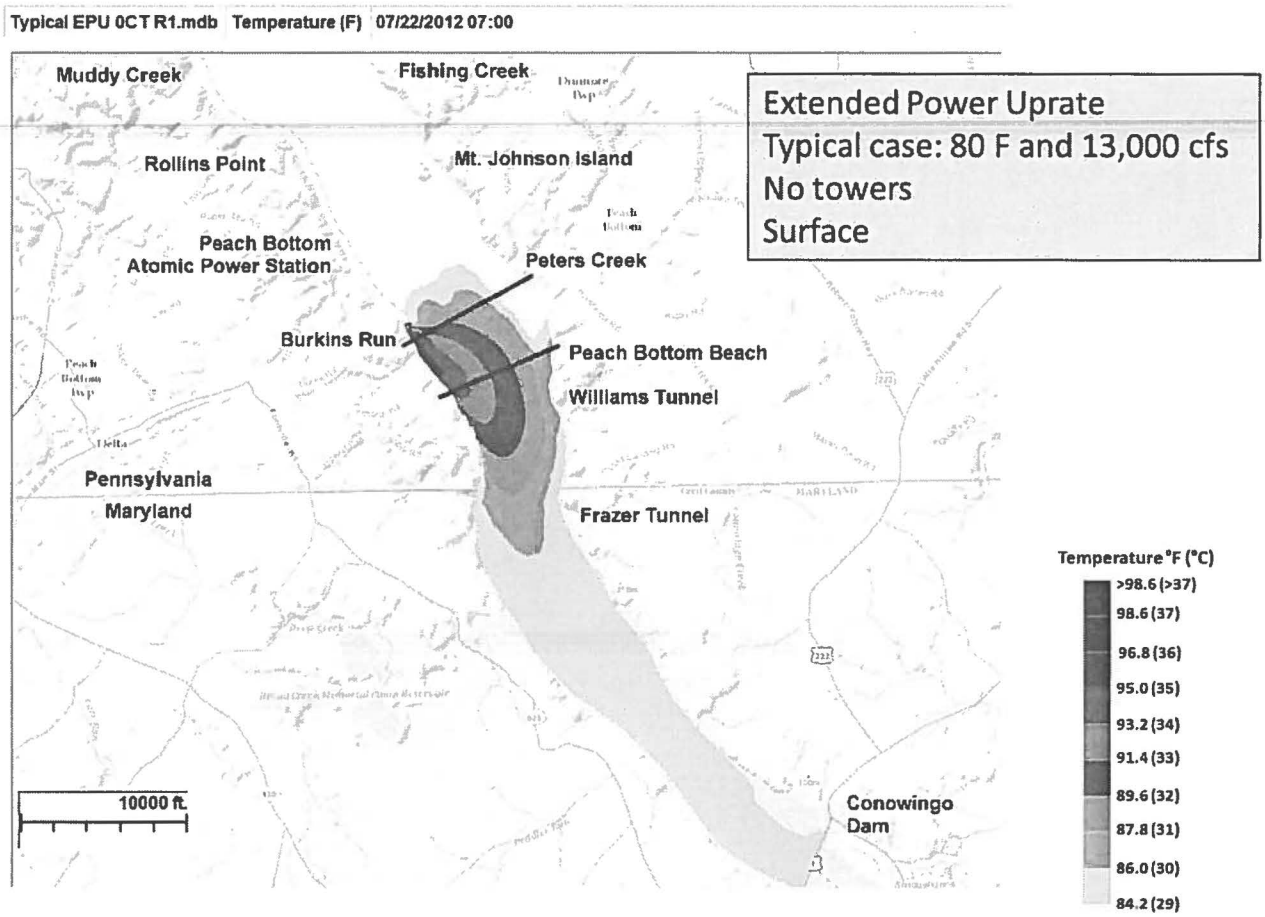
Load	Condition	CT	Location	>84.2°F	>86°F	>87.8°F	>89.6°F	>91.4°F	>93.2°F	>95°F	>96.8°F	>98.6°F
EPU	Typical	0	1000ft	28.2%	17.7%	12.4%	8.5%	6.1%	4.3%	2.5%	1.1%	0.3%
			5000ft	40.6%	28.0%	17.6%	10.9%	5.0%	0.6%	0.0%	0.0%	0.0%
		1	1000ft	26.7%	16.7%	11.4%	7.8%	5.6%	3.5%	1.6%	0.4%	0.0%
			5000ft	37.7%	23.8%	15.8%	8.8%	3.1%	0.0%	0.0%	0.0%	0.0%
		2	1000ft	25.0%	15.6%	10.5%	7.0%	4.9%	2.5%	0.6%	0.0%	0.0%
			5000ft	34.8%	21.8%	13.8%	6.4%	0.7%	0.0%	0.0%	0.0%	0.0%
		3	1000ft	21.7%	14.2%	9.4%	6.2%	3.8%	1.2%	0.2%	0.0%	0.0%
			5000ft	31.7%	19.7%	11.4%	4.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Extreme	0	1000ft	100.1%	100.1%	73.7%	59.5%	48.3%	36.2%	20.4%	12.1%	7.0%
			5000ft	100.0%	100.0%	97.1%	86.2%	66.5%	48.8%	26.0%	16.1%	7.3%
		1	1000ft	100.1%	100.1%	73.3%	58.5%	46.7%	33.7%	18.3%	10.0%	5.9%
			5000ft	100.0%	100.0%	96.7%	84.7%	62.2%	44.6%	22.5%	12.5%	3.3%
		2	1000ft	100.1%	100.1%	72.8%	57.5%	44.1%	25.5%	15.4%	8.2%	4.8%
			5000ft	100.0%	100.0%	96.0%	82.7%	58.6%	31.5%	18.9%	8.0%	0.0%
		3	1000ft	100.1%	100.1%	72.3%	56.1%	41.4%	22.3%	12.1%	6.5%	3.5%
			5000ft	100.1%	100.1%	95.3%	80.8%	54.7%	26.7%	14.3%	2.4%	0.0%

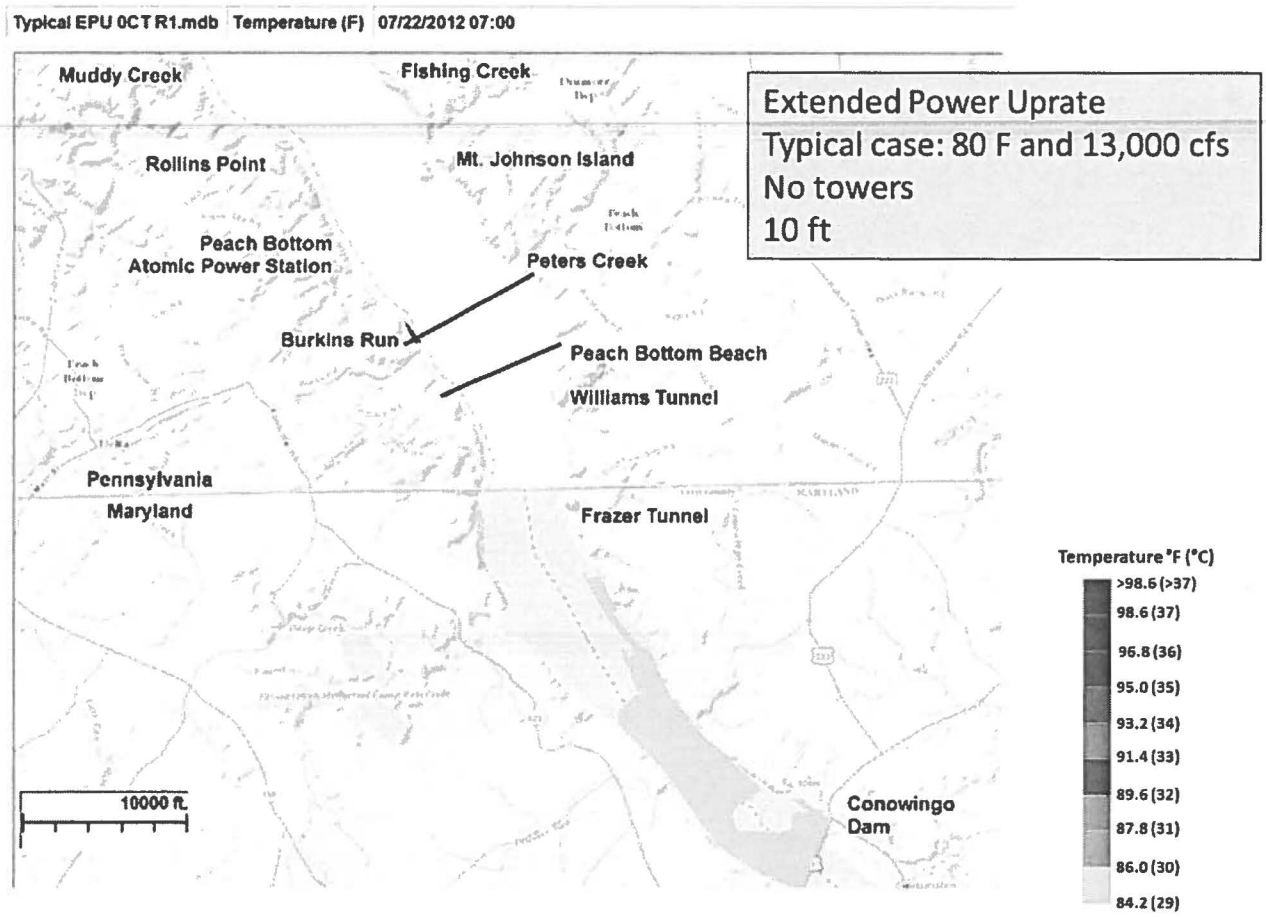
Table 7-2. Modeled areas (acres) exceeding various temperatures for the four cooling tower cases, typical and extreme summer conditions, EPU

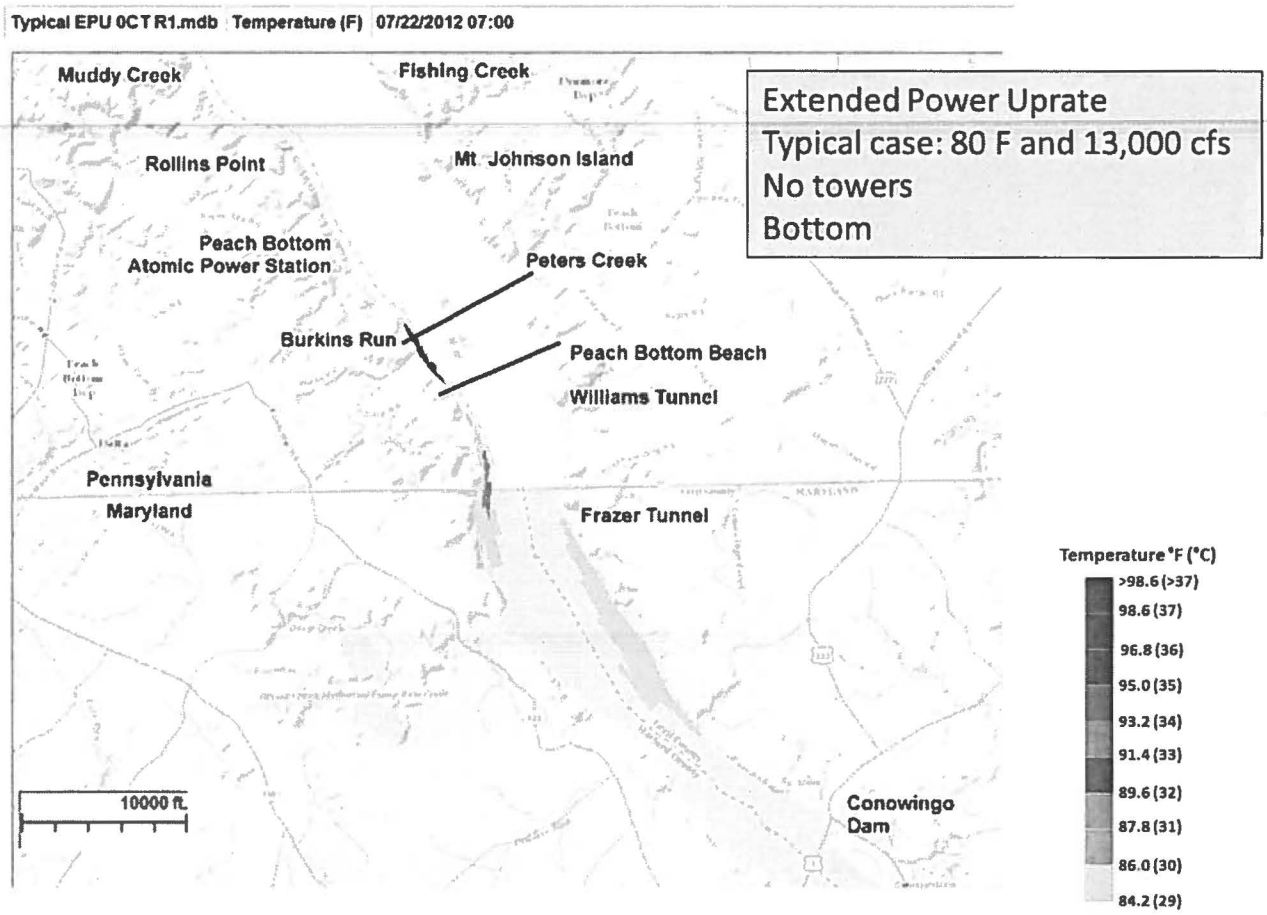
Load	Condition	CT	Location	>84.2°F	>86°F	>87.8°F	>89.6°F	>91.4°F	>93.2°F	>95°F	>96.8°F	>98.6°F
EPU	Typical	0	Surface	4,398	1,658	1,071	661	315	110	22	1	0
			10-ft	1,189	5	4	4	3	2	2	1	0
			Bottom	467	54	23	14	11	9	7	4	1
		1	Surface	4,139	1,453	938	517	210	51	6	0	0
			10-ft	108	5	4	3	3	2	1	0	0
			Bottom	243	41	21	14	11	9	6	2	0
		2	Surface	3,644	1,271	794	371	118	15	0	0	0
			10-ft	6	5	4	3	3	2	1	0	0
			Bottom	130	32	32	14	11	8	3	1	0
		3	Surface	3,076	1,118	629	240	45	1	0	0	0
			10-ft	6	5	4	3	3	1	0	0	0
			Bottom	105	28	19	14	10	5	1	0	0
	Extreme	0	Surface	7,392	7,331	7,331	5,681	4,762	3,008	1,058	649	333
			10-ft	5,829	5,507	3,879	3,572	1,902	5	4	4	3
			Bottom	7,407	7,022	4,394	2,967	863	176	22	14	11
		1	Surface	7,400	7,309	5,872	5,577	4,290	2,182	873	491	206
			10-ft	5,829	5,478	3,868	3,554	1,117	5	4	4	3
			Bottom	7,411	6,973	4,361	2,691	659	132	20	14	11
		2	Surface	7,400	7,282	5,800	5,452	3,795	1,277	702	337	105
			10-ft	5,829	5,448	3,855	3,512	246	5	4	3	3
			Bottom	7,412	6,918	4,301	2,408	437	38	20	14	10
		3	Surface	7,401	7,239	5,725	5,318	3,280	978	525	195	34
			10-ft	5,829	5,416	3,844	3,433	32	5	4	3	2
			Bottom	7,412	6,877	4,242	1,914	300	25	20	13	10

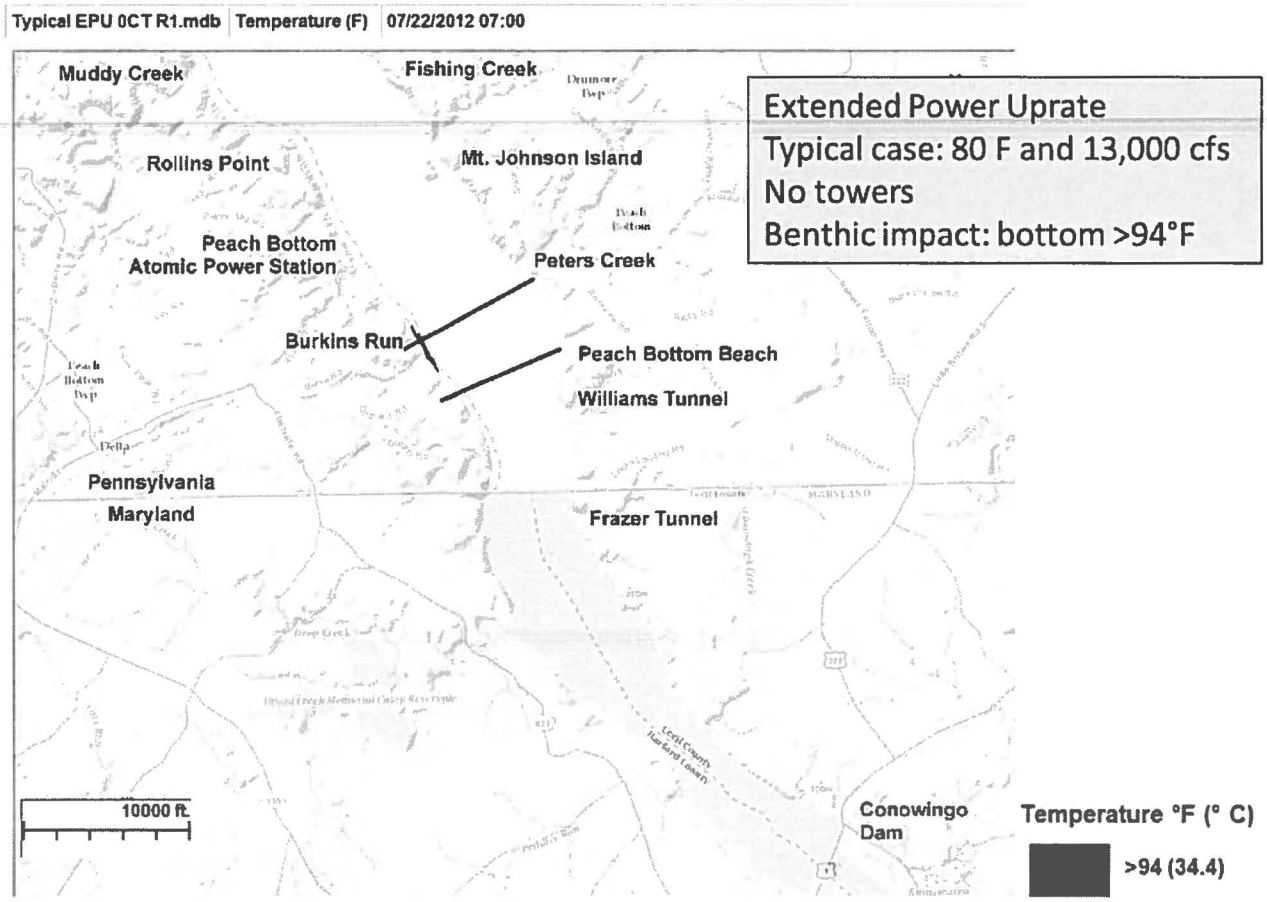

Database Typical EPU OCT R1 mdb Slice 1000ft Date 07/22/2012 07:00
Extended Power Uprate
Typical case: 80 F and 13,000 cfs
No towers
1000 ft below discharge
Elevation, ft
109.9
107.9
105.9
103.9
101.9
99.9
97.9
95.9
93.9
91.9
89.9
87.9
85.9
0 600 1200 1800 2400 3000 3600 4200 4800 5400 6000 6600 7200
Distance along slice, ft
Western shoreline
Eastern shoreline
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

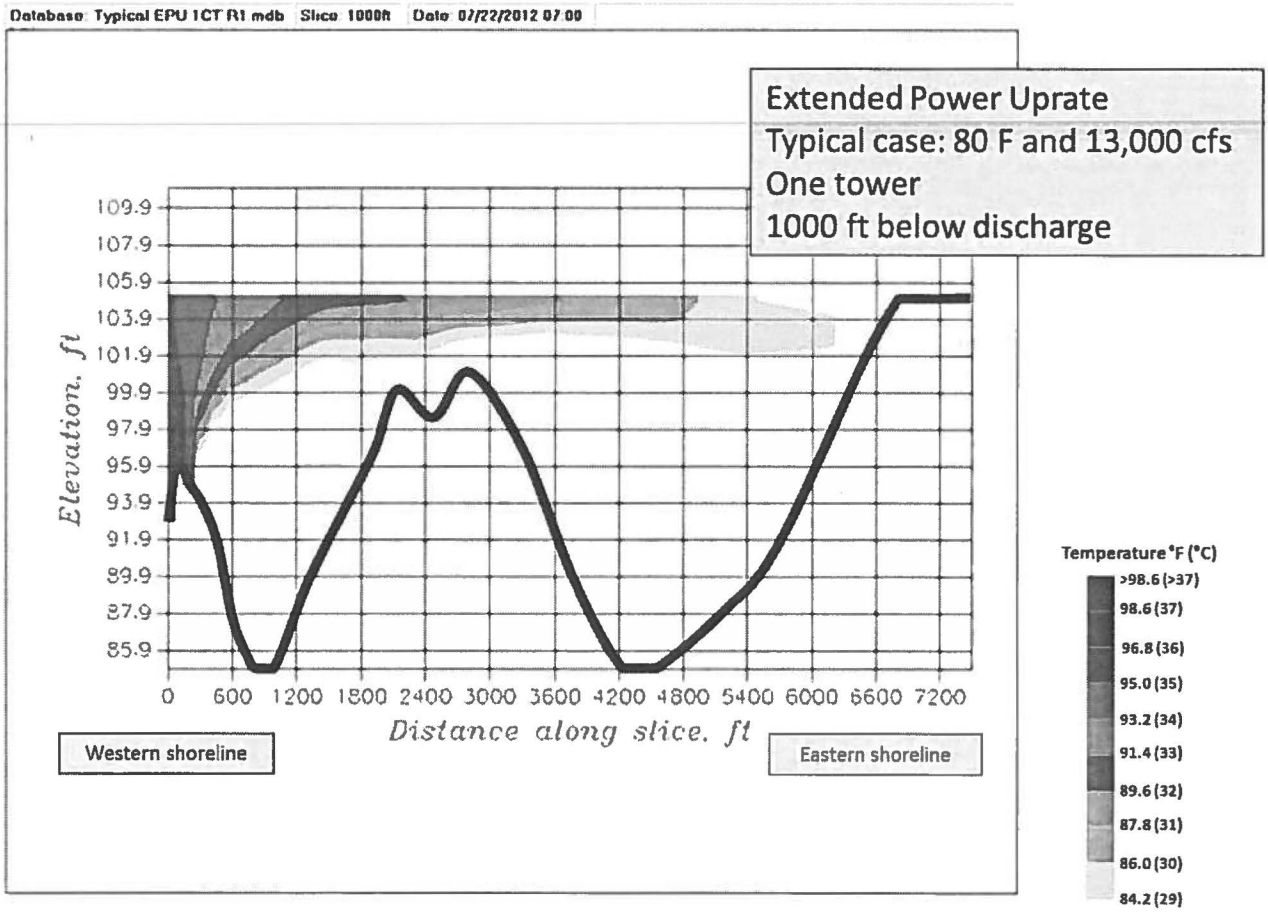

Database: Typical EPU OCT R1.mdb Slice: 5000ft Date: 07/22/2012 07:00
Extended Power Uprate
Typical case: 80 F and 13,000 cfs
No towers
5000 ft below discharge
Elevation, ft
109.9
107.9
105.9
103.9
101.9
99.9
97.9
95.9
93.9
91.9
89.9
87.9
85.9
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 6000
Distance along slice, ft
Western shoreline
Eastern shoreline
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

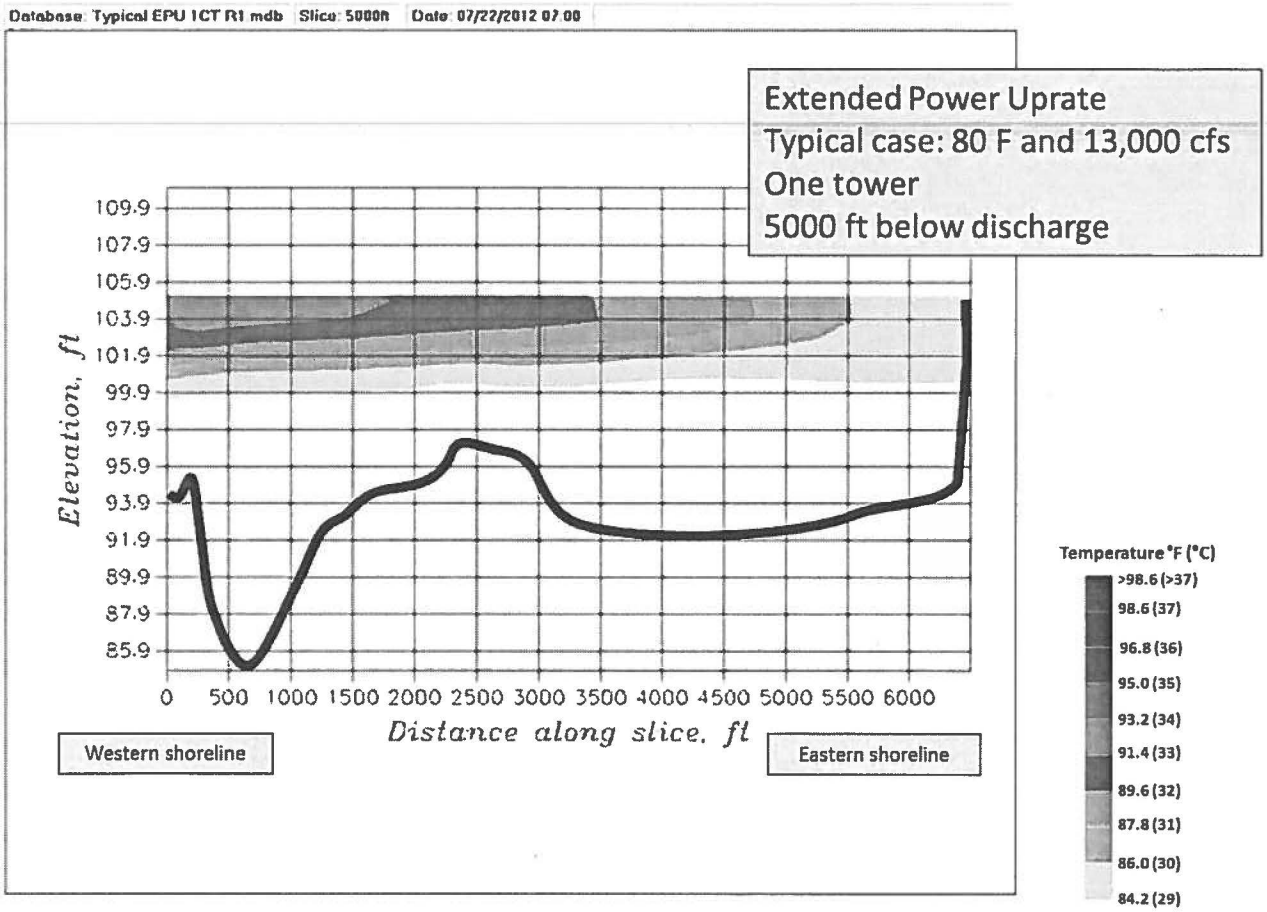

Typical EPU 0CT R1.mdb Temperature (F) 07/22/2012 07:00
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
Conowingo
Dam
10000 ft.
Extended Power Uprate
Typical case: 80 F and 13,000 cfs
No towers
Surface
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

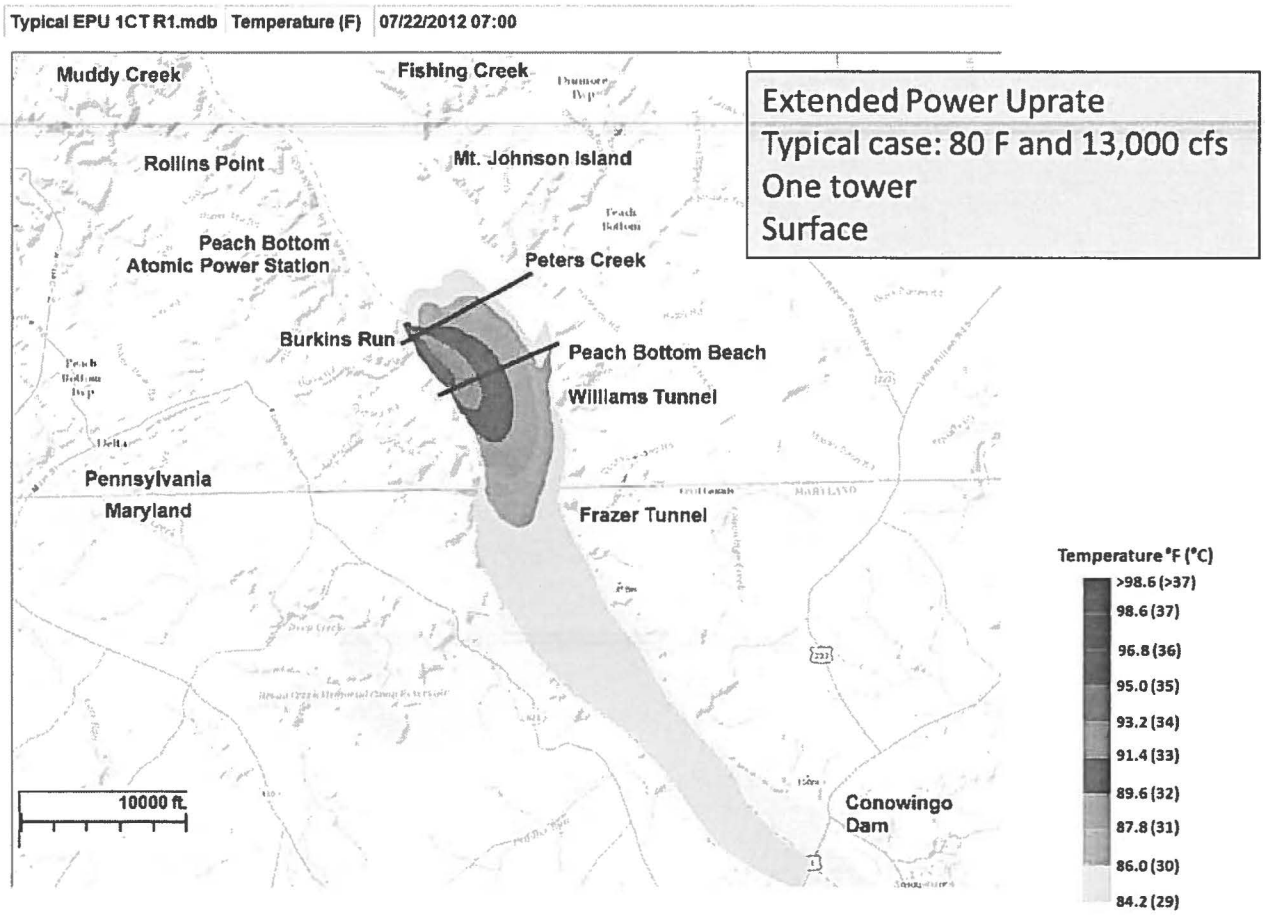

Typical EPU 0CT R1.mdb Temperature (F) 07/22/2012 07:00
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
Conowingo
Dam
10000 ft.
Extended Power Uprate
Typical case: 80 F and 13,000 cfs
No towers
10 ft
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

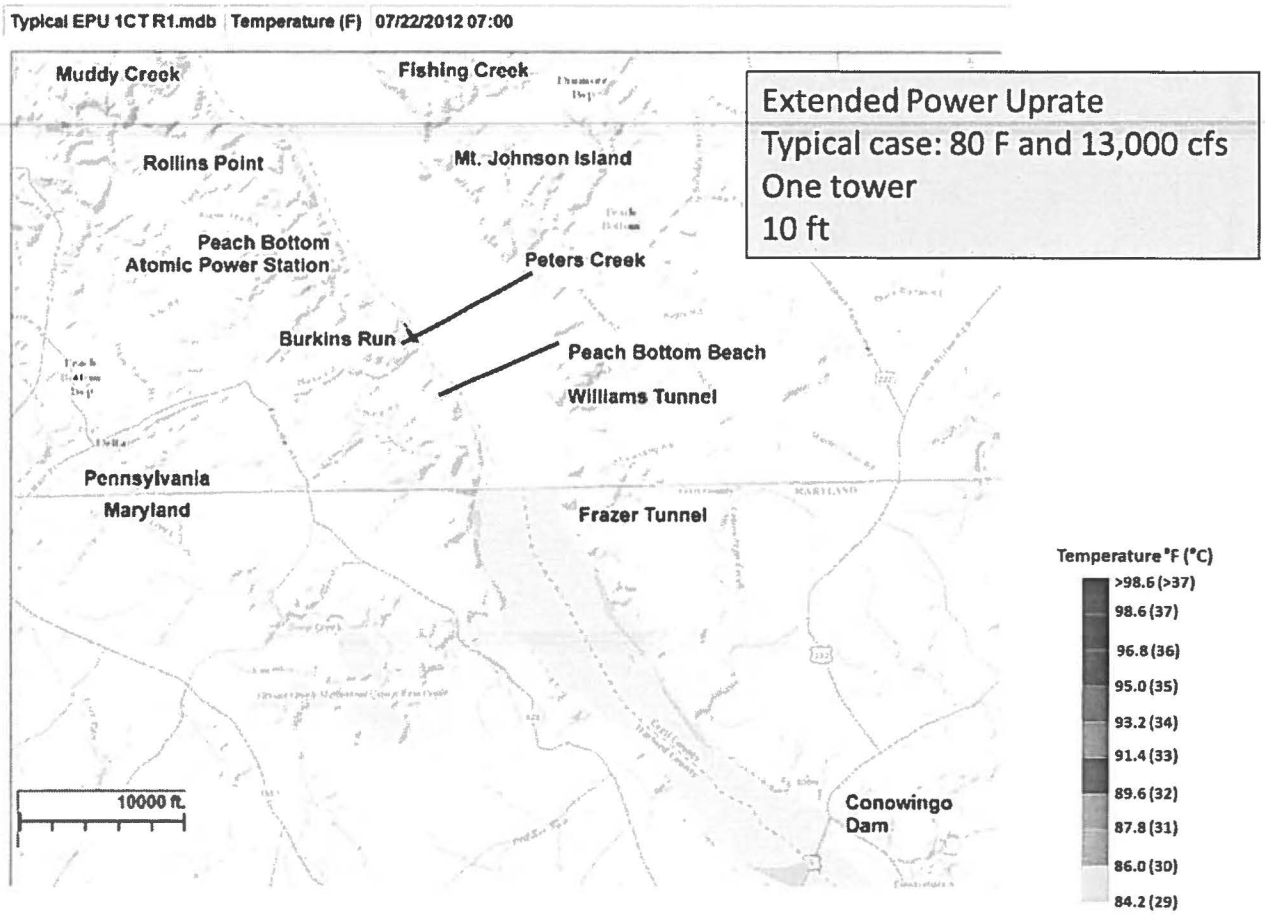

Typical EPU 0CT R1.mdb Temperature (F) 07/22/2012 07:00
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
10000 ft.
Conowingo
Dam
Extended Power Uprate
Typical case: 80 F and 13,000 cfs
No towers
Bottom
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

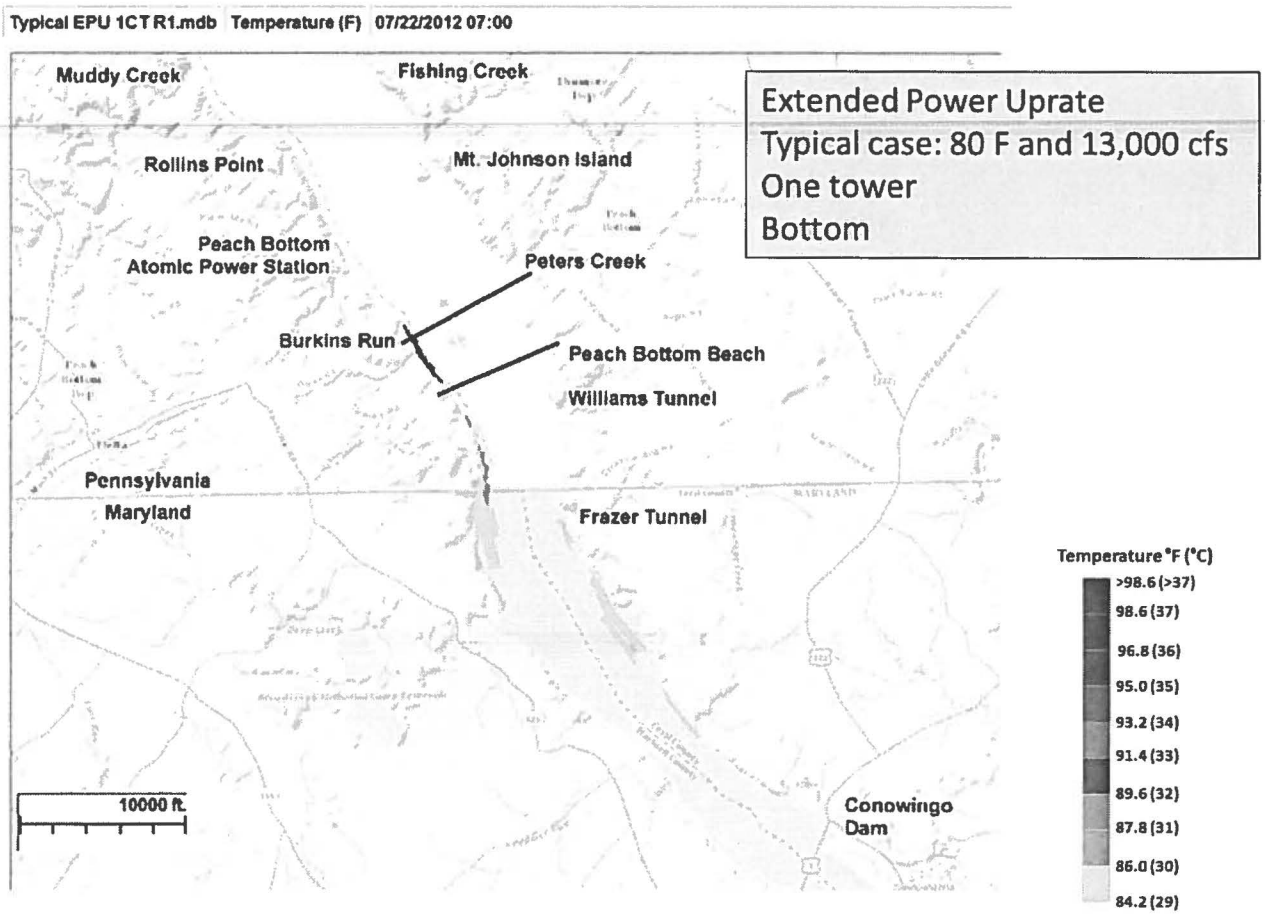

Typical EPU 0CT R1.mdb
Temperature (F)
07/22/2012 07:00
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
10000 ft
Conowingo
Dam
Extended Power Uprate
Typical case: 80 F and 13,000 cfs
No towers
Benthic impact: bottom >94°F
Temperature °F (° C)
>94 (34.4)


Database Typical EPU 1CT R1 mdb Slice 1000ft Date 07/22/2012 07:00
Extended Power Uprate
Typical case: 80 F and 13,000 cfs
One tower
1000 ft below discharge
Elevation, ft
109.9
107.9
105.9
103.9
101.9
99.9
97.9
95.9
93.9
91.9
89.9
87.9
85.9
0 600 1200 1800 2400 3000 3600 4200 4800 5400 6000 6600 7200
Distance along slice, ft
Western shoreline
Eastern shoreline
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

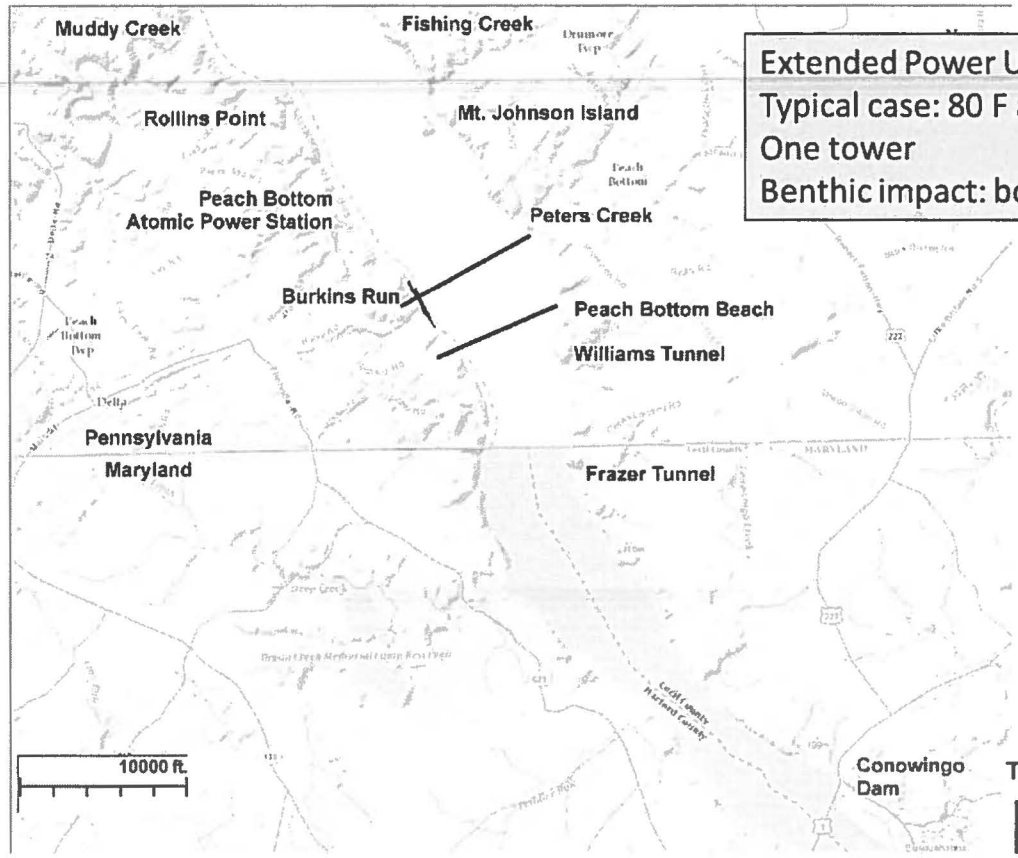

Database: Typical EPU 1CT R1.mdb Slice: 5000ft Date: 07/22/2012 07:00
Extended Power Uprate
Typical case: 80 F and 13,000 cfs
One tower
5000 ft below discharge
Elevation, ft
109.9
107.9
105.9
103.9
101.9
99.9
97.9
95.9
93.9
91.9
89.9
87.9
85.9
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 6000
Distance along slice, ft
Western shoreline
Eastern shoreline
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)


Typical EPU 1CT R1.mdb
Temperature (F)
07/22/2012 07:00
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
Conowingo
Dam
10000 ft.
Extended Power Uprate
Typical case: 80 F and 13,000 cfs
One tower
Surface
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)


Typical EPU 1CT R1.mdb Temperature (F) 07/22/2012 07:00
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
Conowingo
Dam
10000 ft.
Extended Power Uprate
Typical case: 80 F and 13,000 cfs
One tower
10 ft
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

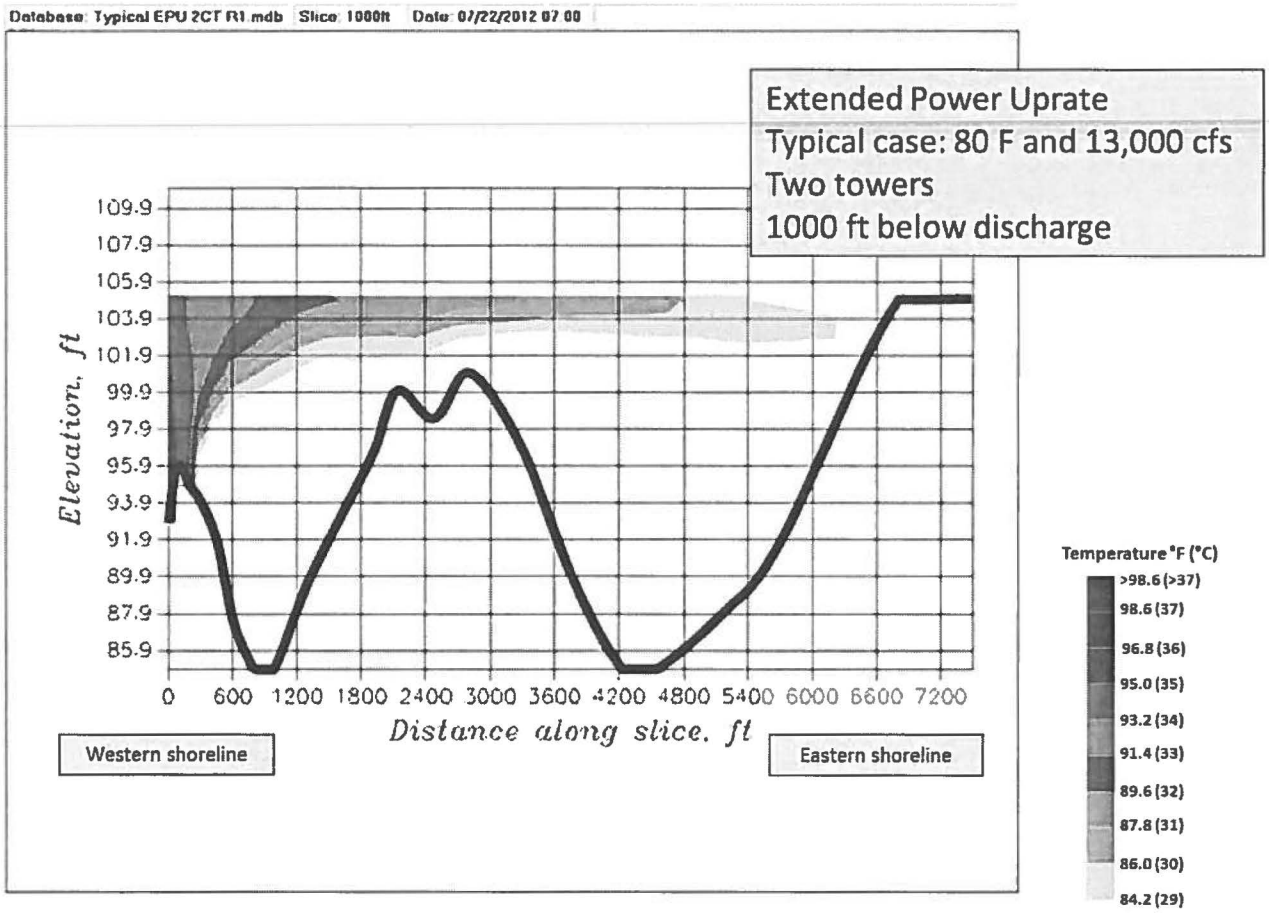

Typical EPU 1CT R1.mdb Temperature (F) 07/22/2012 07:00
Extended Power Uprate
Typical case: 80 F and 13,000 cfs
One tower
Bottom
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
Conowingo
Dam
10000 ft.
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

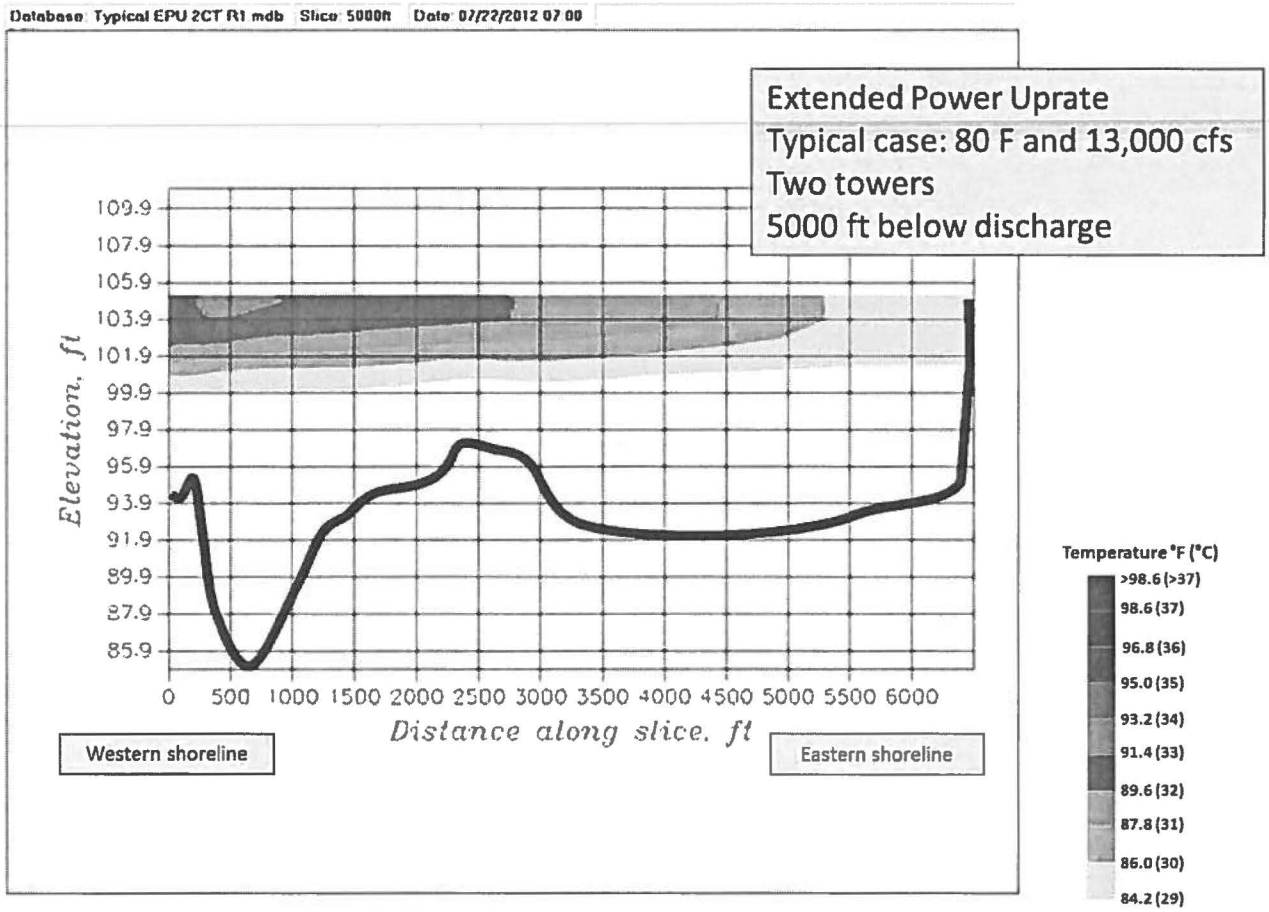
Typical EPU 1CT R1.mdb | Temperature (F) | 07/22/2012 07:00



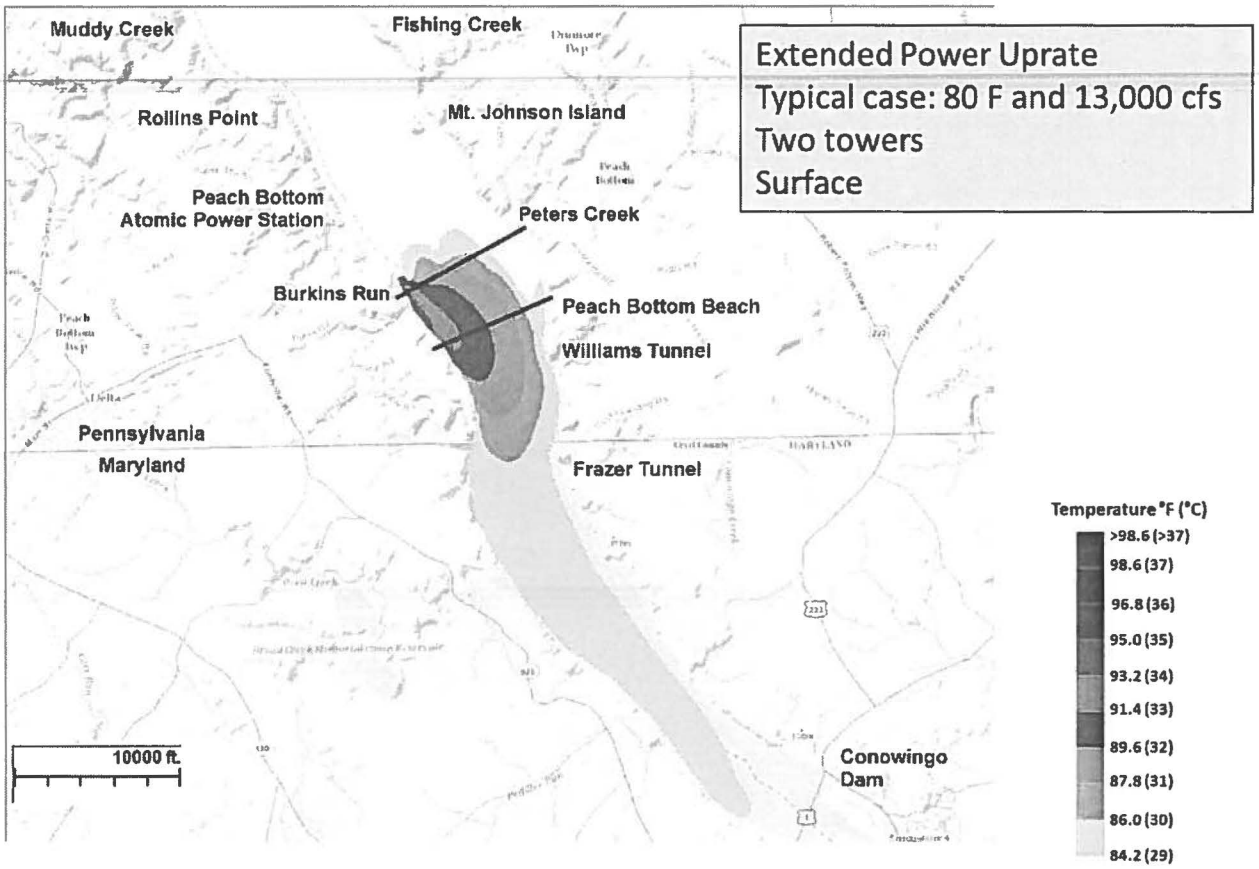
Extended Power Uprate
Typical case: 80 F and 13,000 cfs
One tower
Benthic impact: bottom >94°F

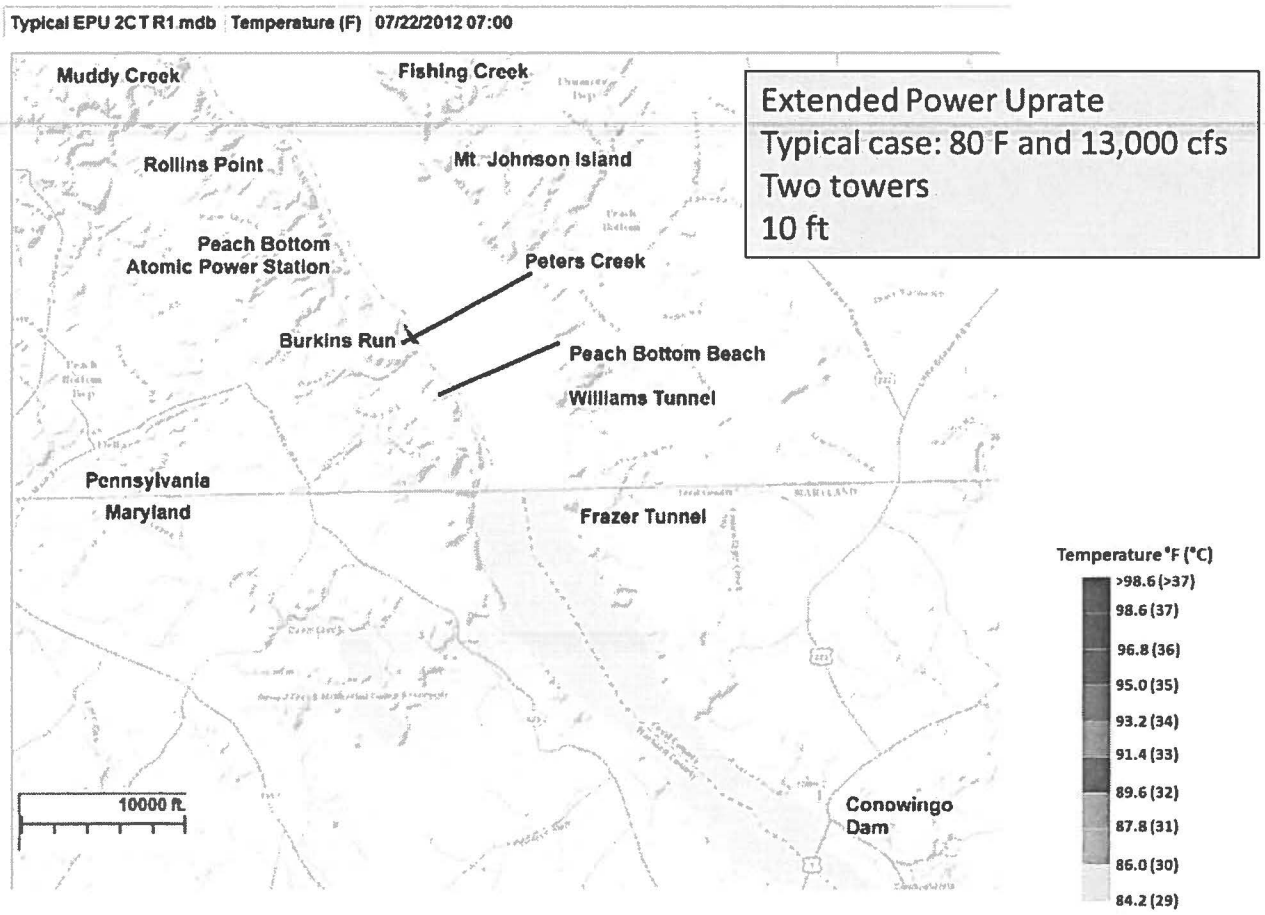
Temperature °F (° C)
>94 (34.4)

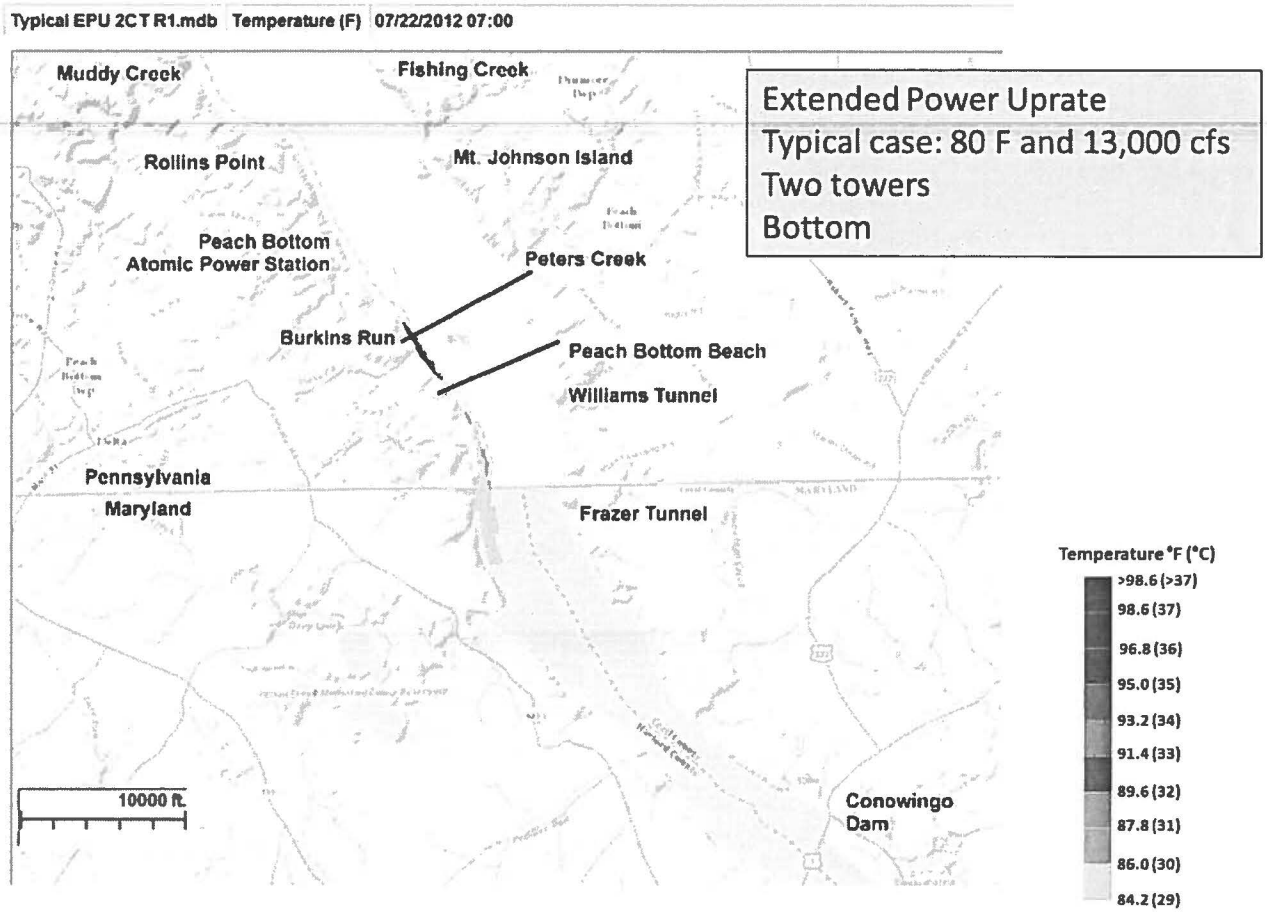

Database: Typical EPU 2CT R1.mdb Slice: 1000ft Date: 07/22/2012 07:00
Extended Power Uprate
Typical case: 80 F and 13,000 cfs
Two towers
1000 ft below discharge
Elevation, ft
109.9
107.9
105.9
103.9
101.9
99.9
97.9
95.9
93.9
91.9
89.9
87.9
85.9
0 600 1200 1800 2400 3000 3600 4200 4800 5400 6000 6600 7200
Distance along slice, ft
Western shoreline
Eastern shoreline
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)


Database Typical EPU 2CT R1 mdb Slice 5000ft Date 07/22/2012 07 00
Extended Power Uprate
Typical case: 80 F and 13,000 cfs
Two towers
5000 ft below discharge
Elevation, ft
109.9
107.9
105.9
103.9
101.9
99.9
97.9
95.9
93.9
91.9
89.9
87.9
85.9
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 6000
Distance along slice, ft
Western shoreline
Eastern shoreline
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

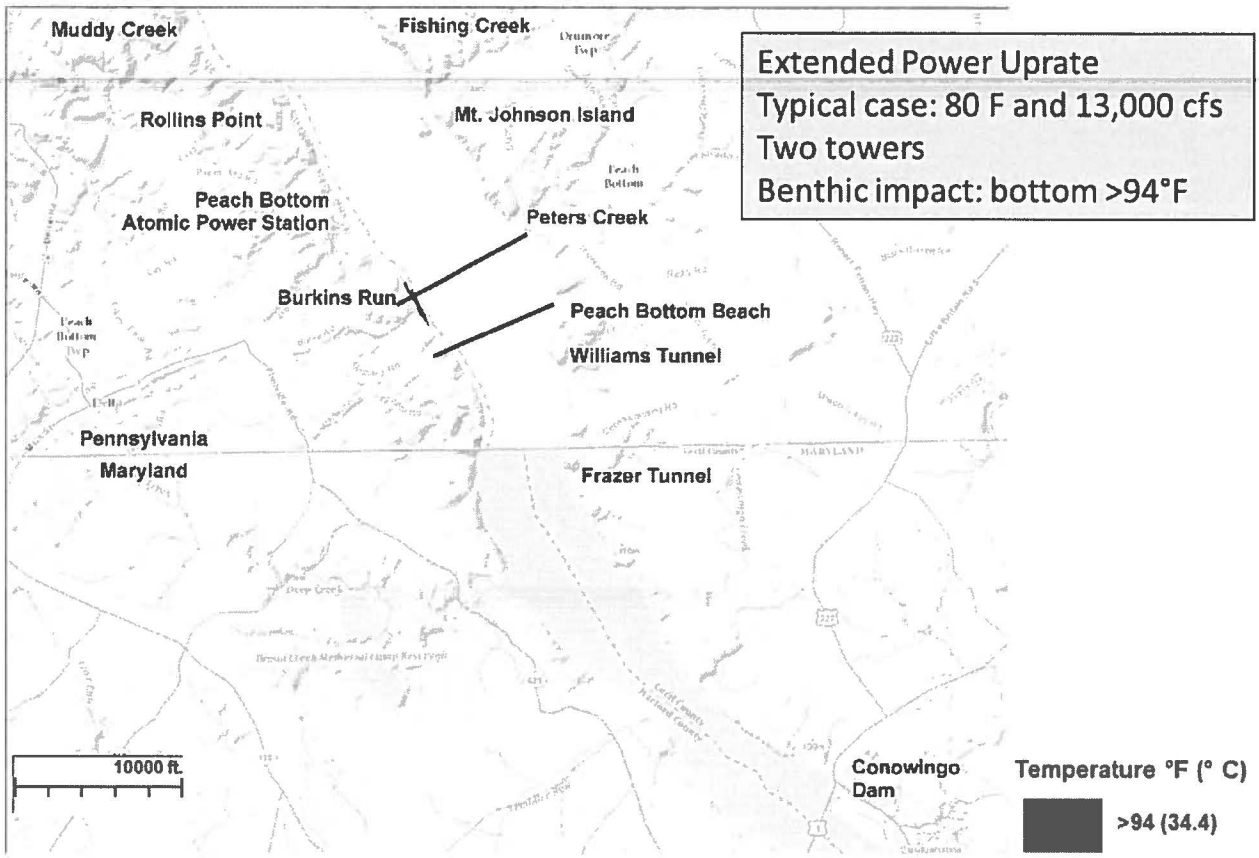
Typical EPU 2CT R1.mdb Temperature (F) 07/22/2012 07:00



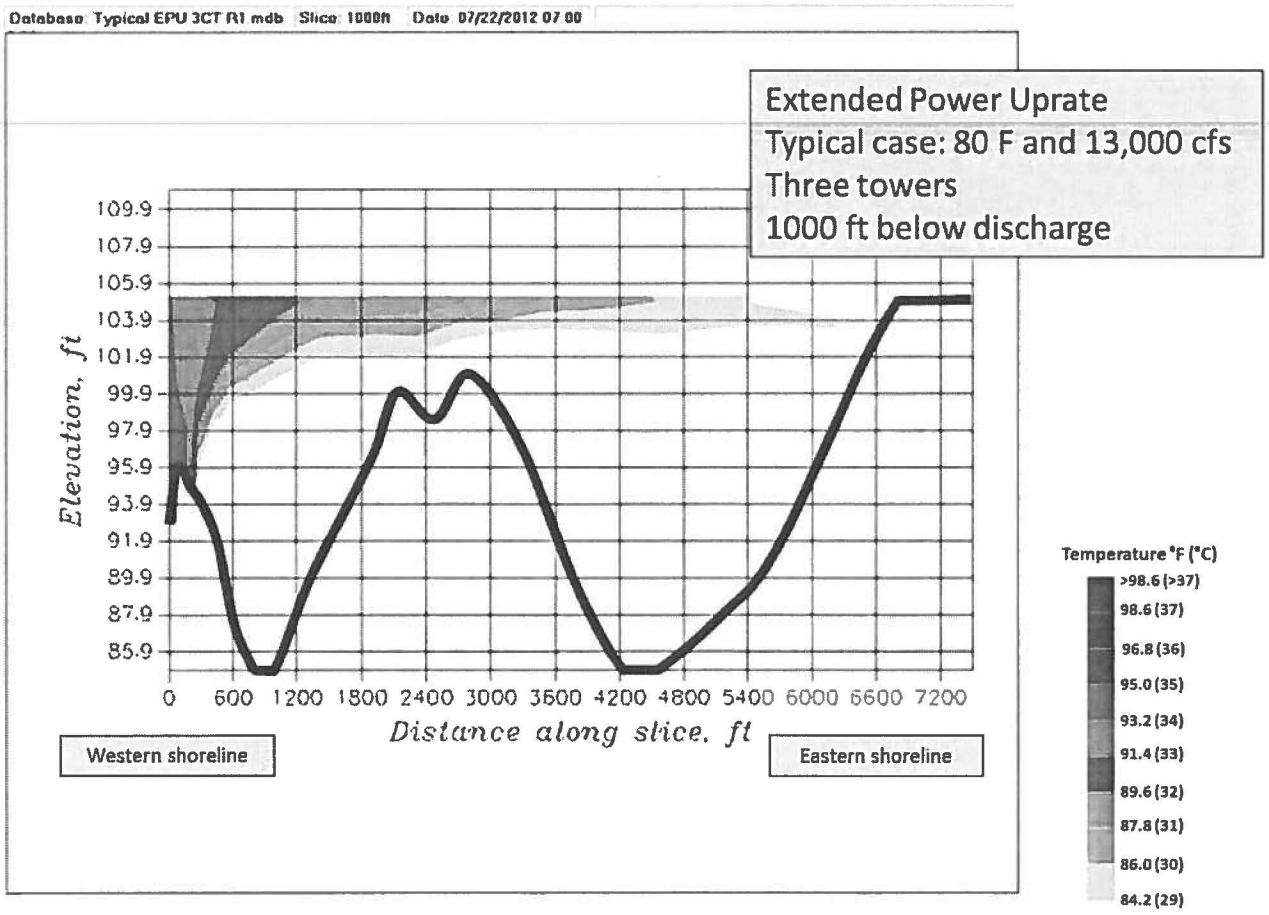

Typical EPU 2CTR1.mdb Temperature (F) 07/22/2012 07:00
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
Conowingo
Dam
10000 ft.
Extended Power Uprate
Typical case: 80 F and 13,000 cfs
Two towers
10 ft
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

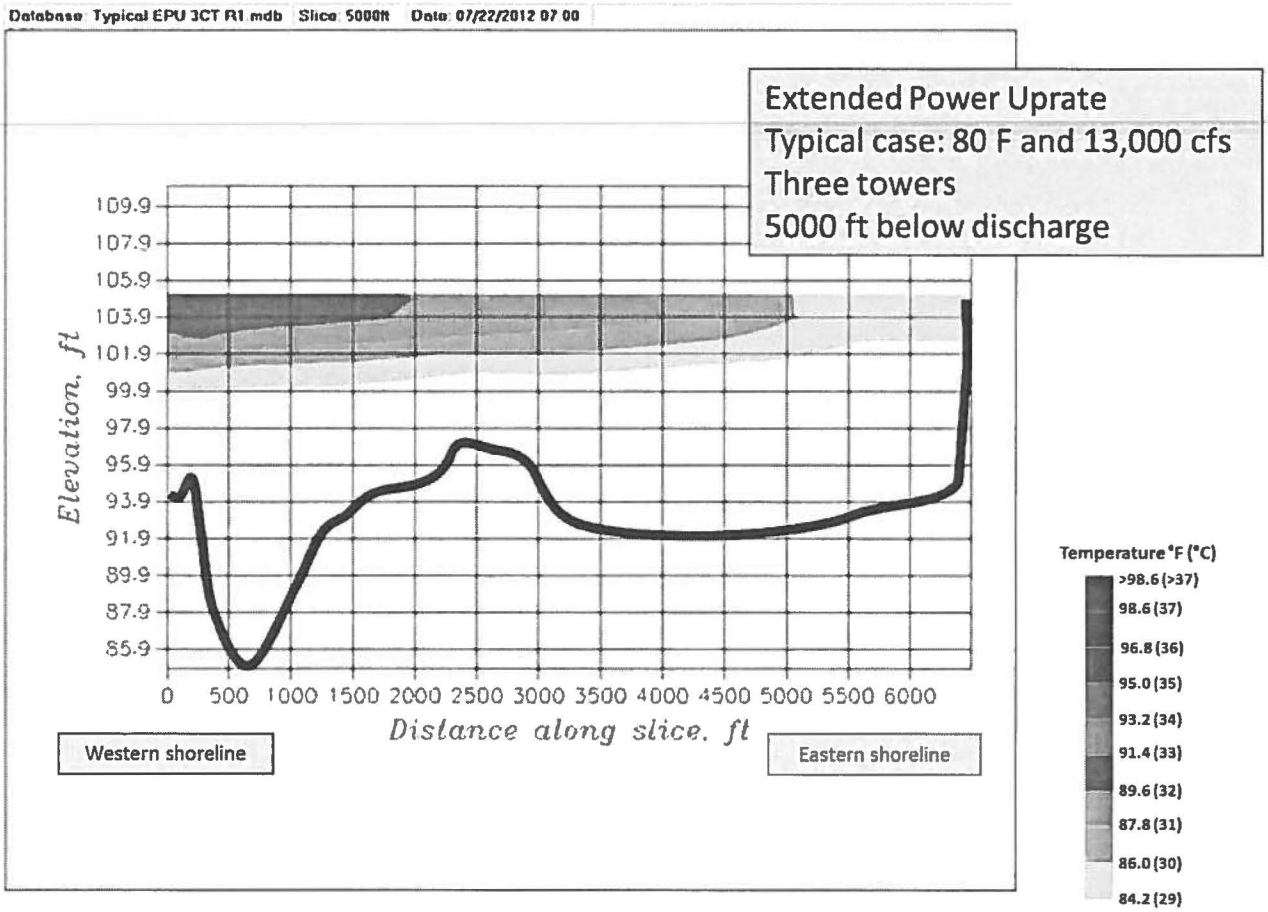

Typical EPU 2CT R1.mdb Temperature (F) 07/22/2012 07:00
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
10000 ft.
Conowingo
Dam
Extended Power Uprate
Typical case: 80 F and 13,000 cfs
Two towers
Bottom
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

Typical EPU 2CT R1.mdb | Temperature (F) | 07/22/2012 07:00

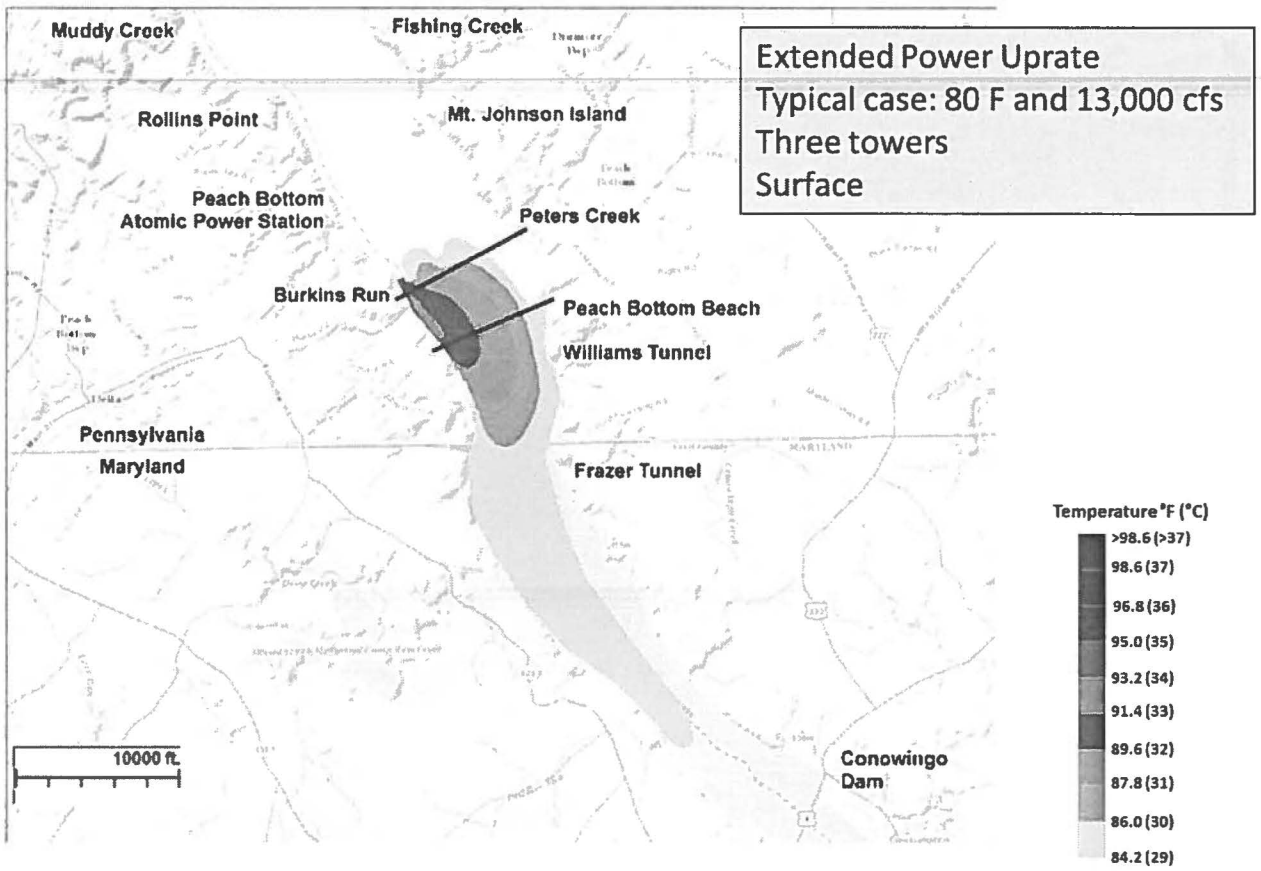


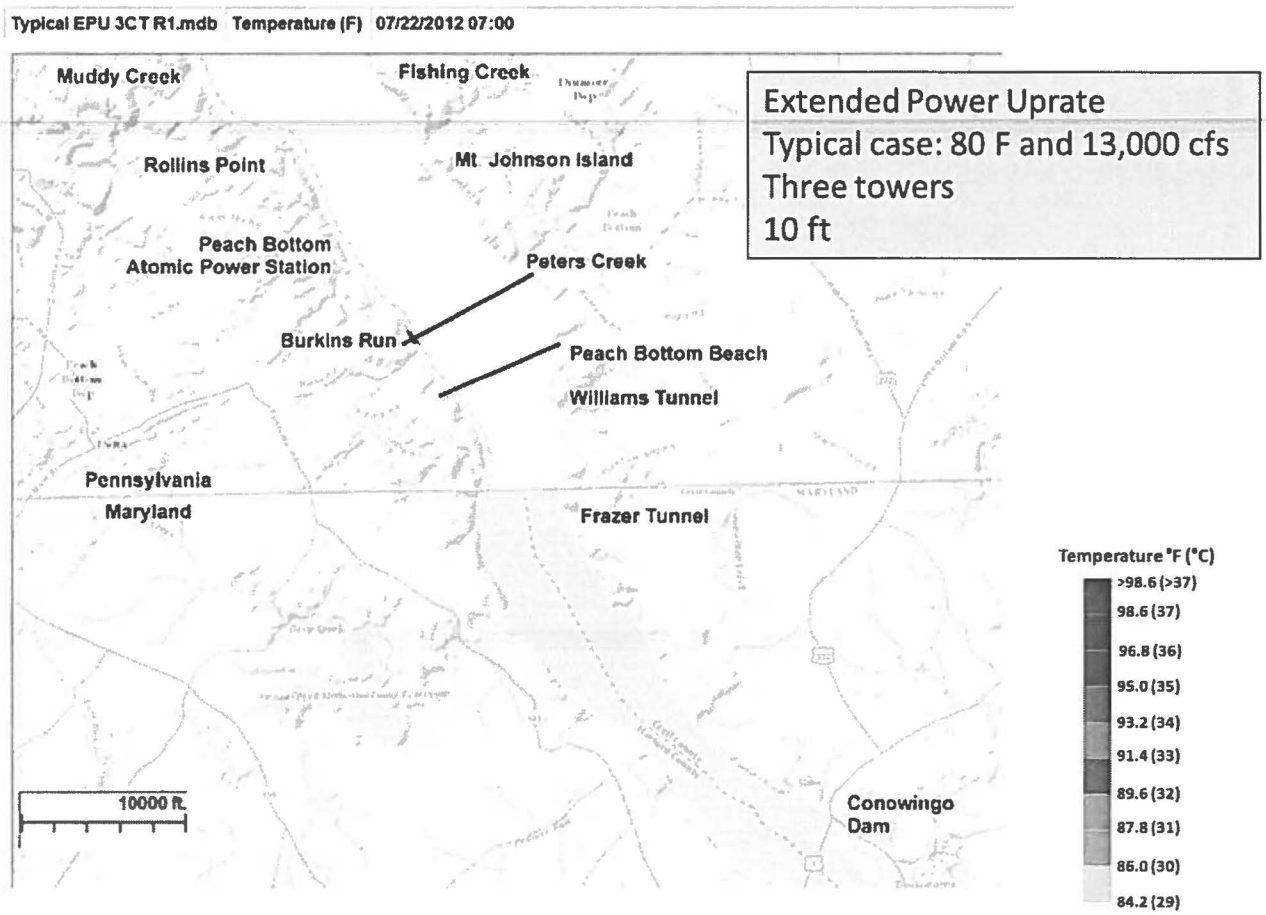
Extended Power Uprate
Typical case: 80 F and 13,000 cfs
Two towers
Benthic impact: bottom >94°F


Database: Typical EPU 3CT R1.mdb Slice: 1000ft Date: 07/22/2012 07:00
Extended Power Uprate
Typical case: 80 F and 13,000 cfs
Three towers
1000 ft below discharge
Elevation, ft
109.9
107.9
105.9
103.9
101.9
99.9
97.9
95.9
93.9
91.9
89.9
87.9
85.9
0 600 1200 1800 2400 3000 3600 4200 4800 5400 6000 6600 7200
Distance along slice, ft
Western shoreline
Eastern shoreline
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

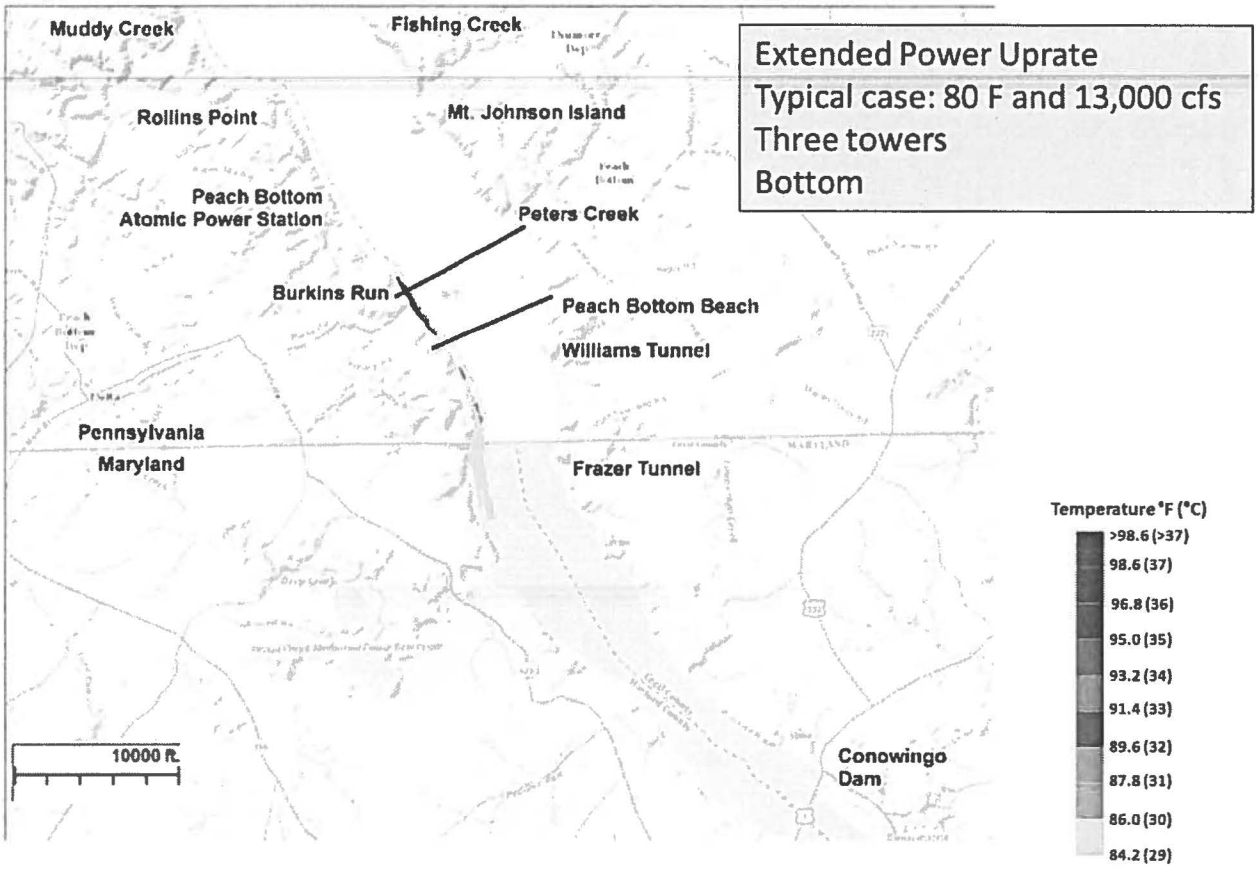

Database Typical EPU 3CT R1.mdb Slice 5000ft Date 07/22/2012 07:00
Extended Power Uprate
Typical case: 80 F and 13,000 cfs
Three towers
5000 ft below discharge
Elevation, ft
109.9
107.9
105.9
103.9
101.9
99.9
97.9
95.9
93.9
91.9
89.9
87.9
85.9
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 6000
Distance along slice, ft
Western shoreline
Eastern shoreline
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

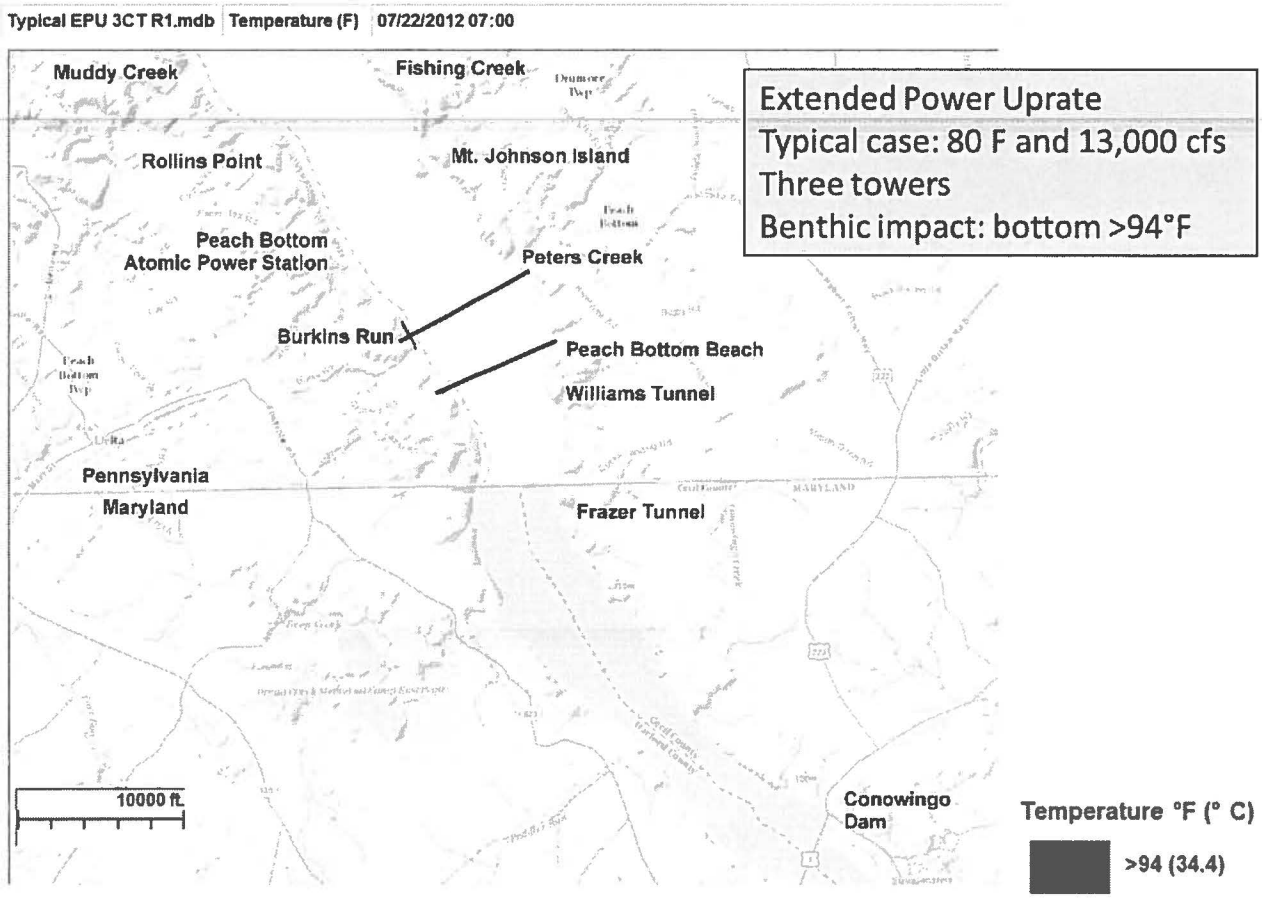
Typical EPU 3CT R1.mdb Temperature (F) 07/22/2012 07:00

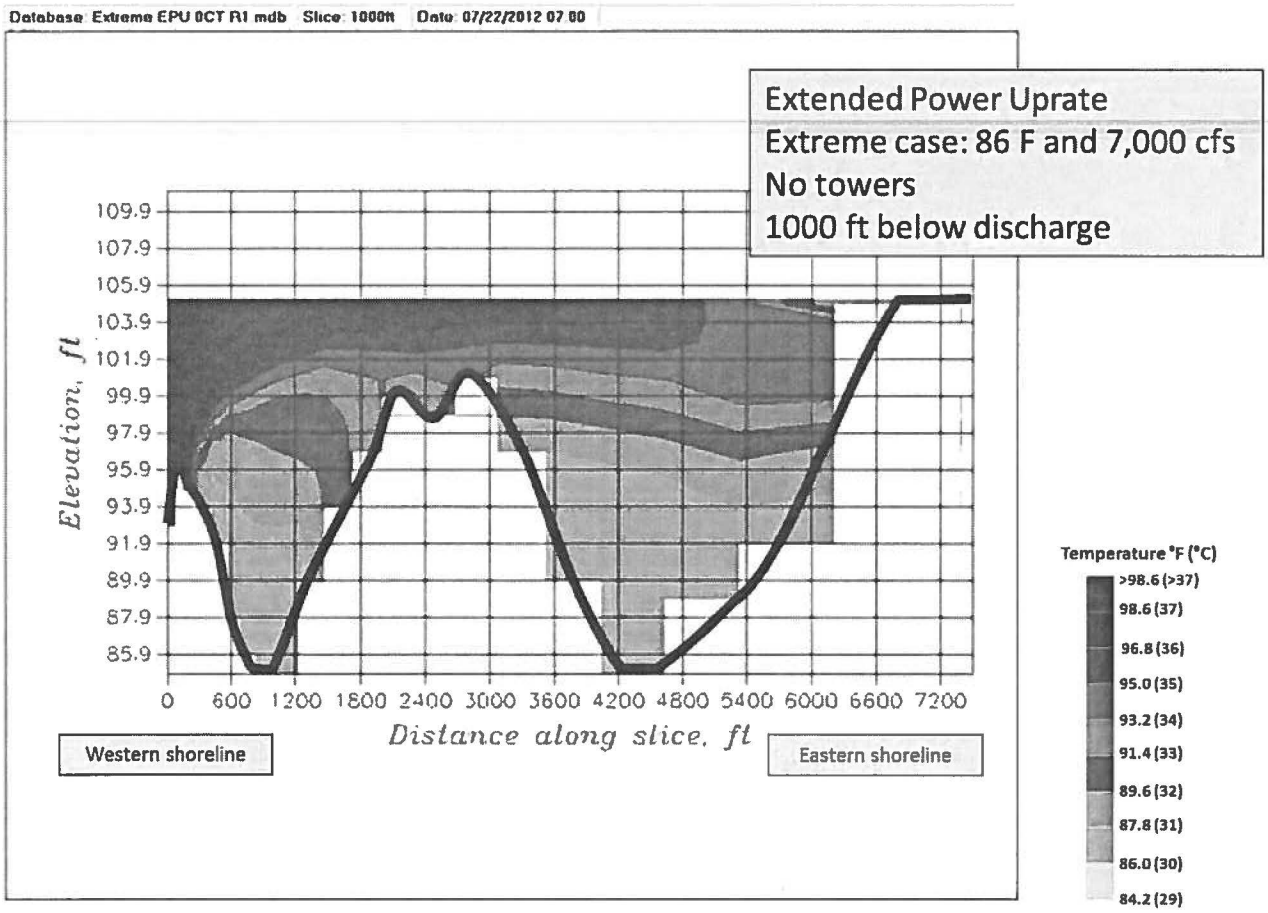


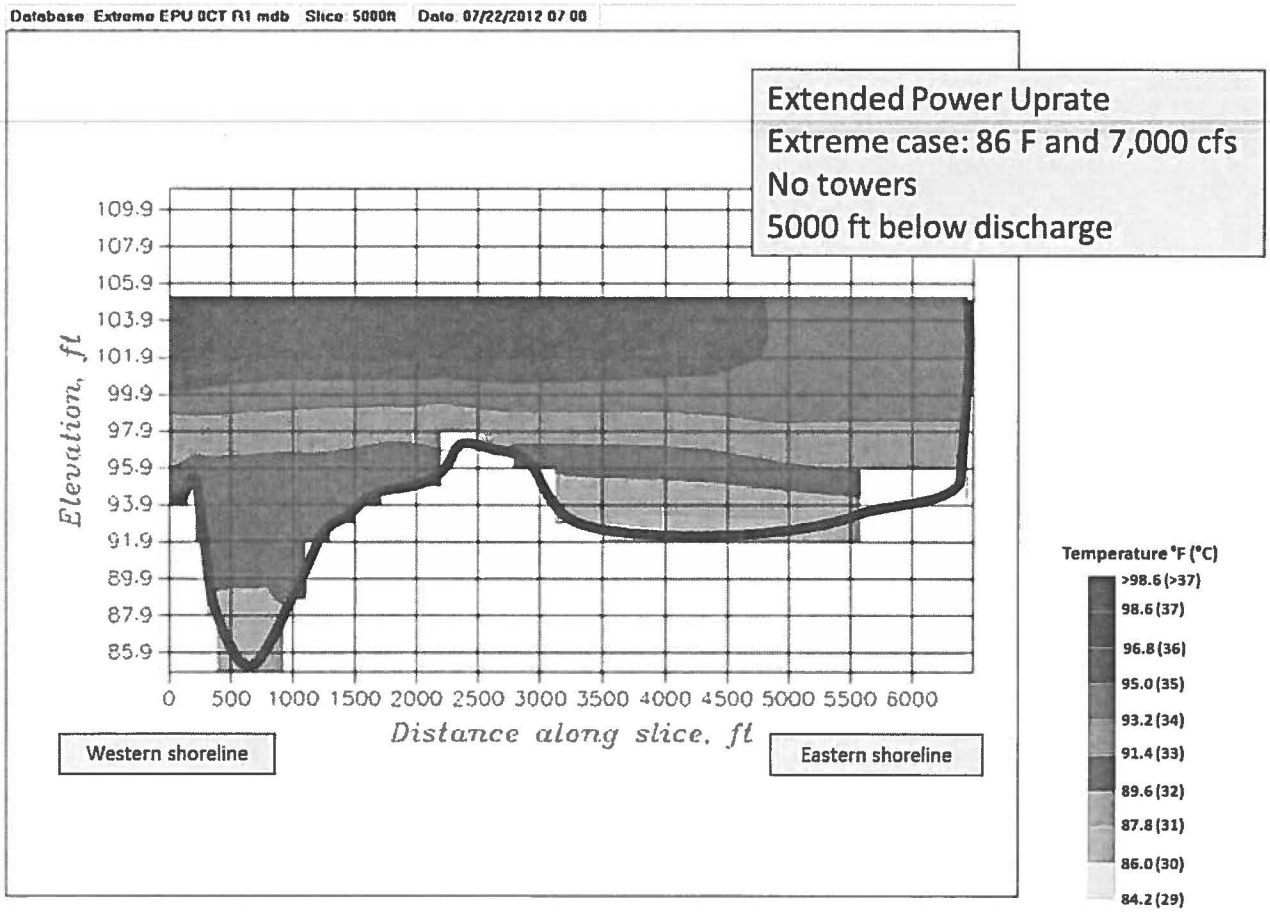

Typical EPU 3CT R1.mdb Temperature (F) 07/22/2012 07:00
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
Conowingo
Dam
10000 ft.
Extended Power Uprate
Typical case: 80 F and 13,000 cfs
Three towers
10 ft
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

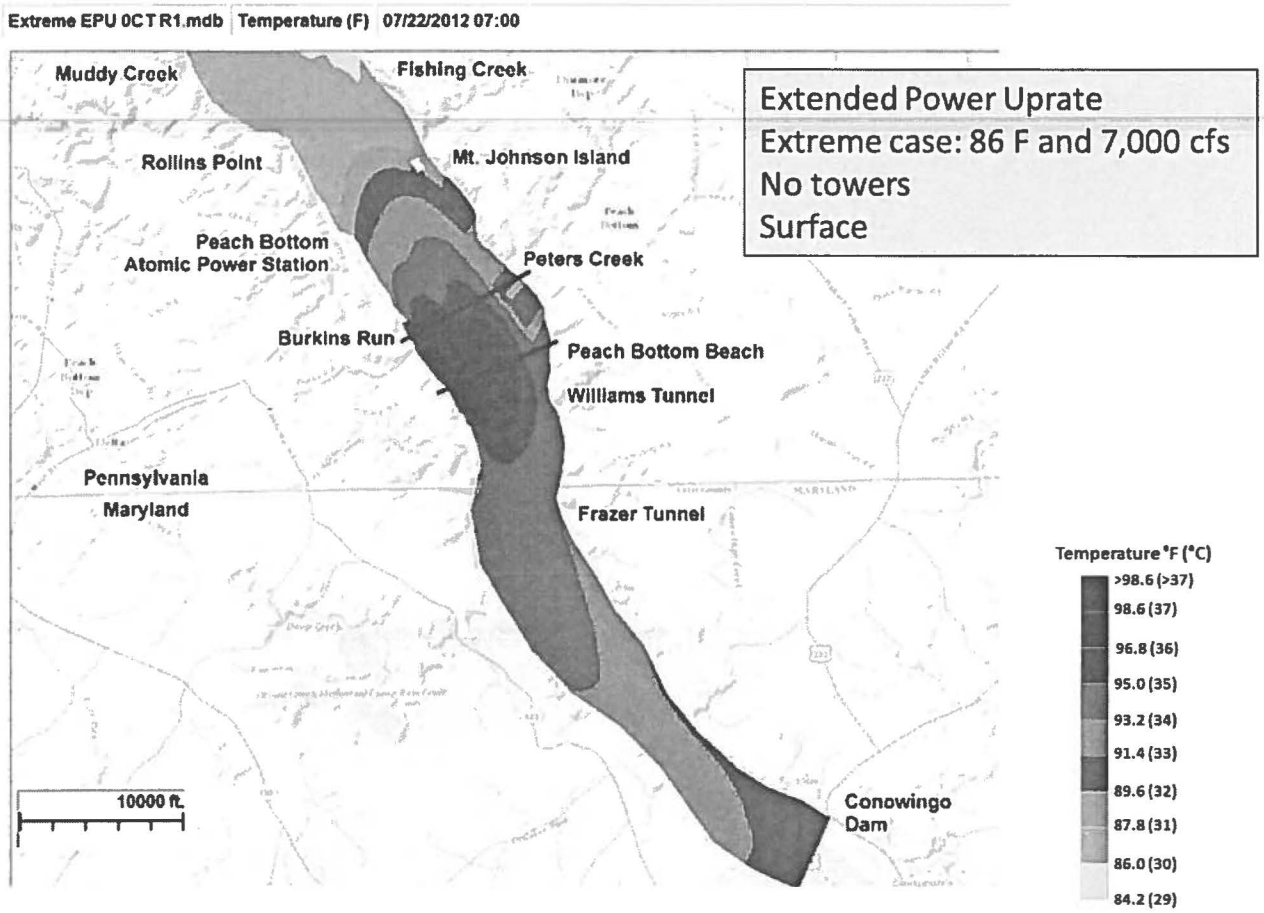
Typical EPU 3CT R1.mdb | Temperature (F) | 07/22/2012 07:00

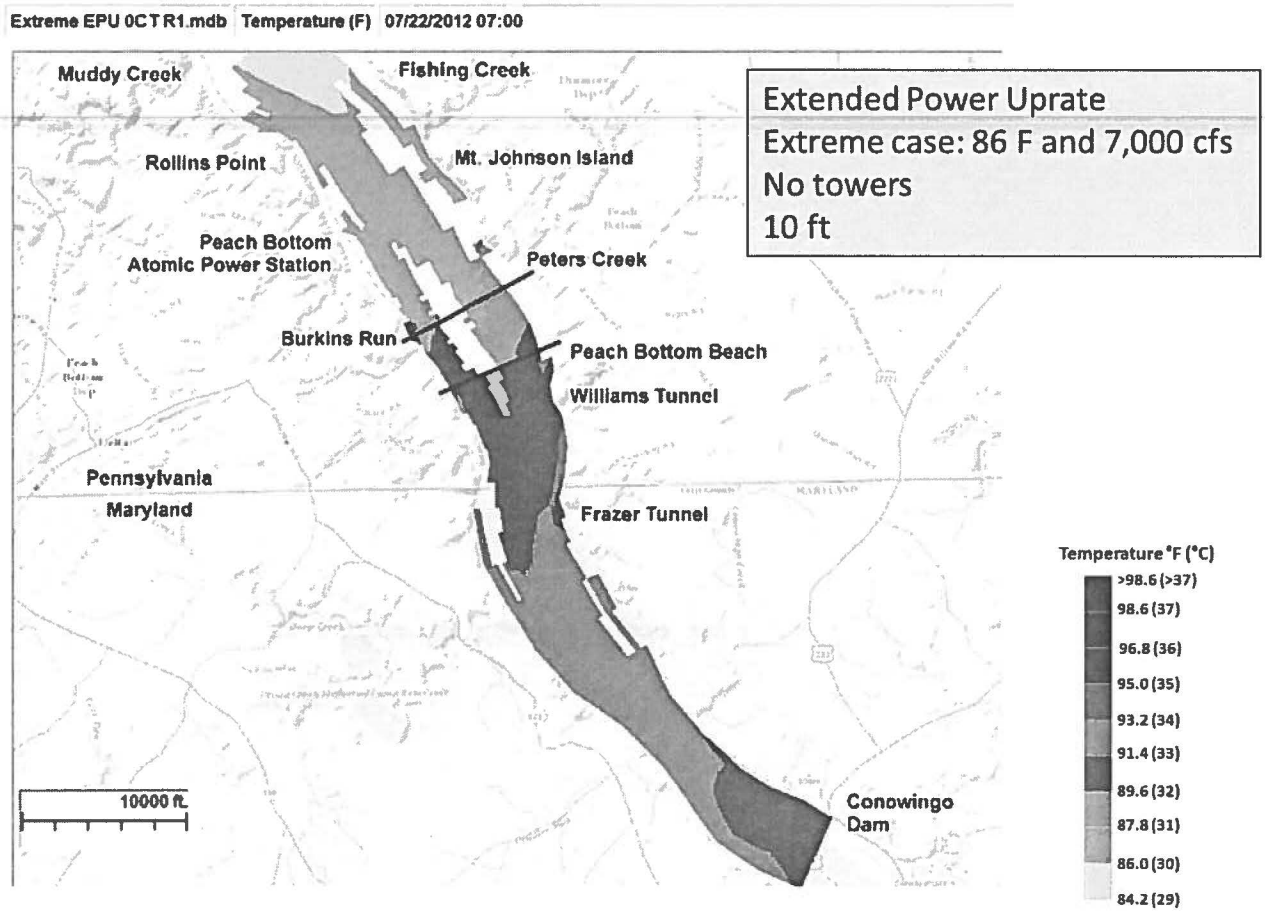


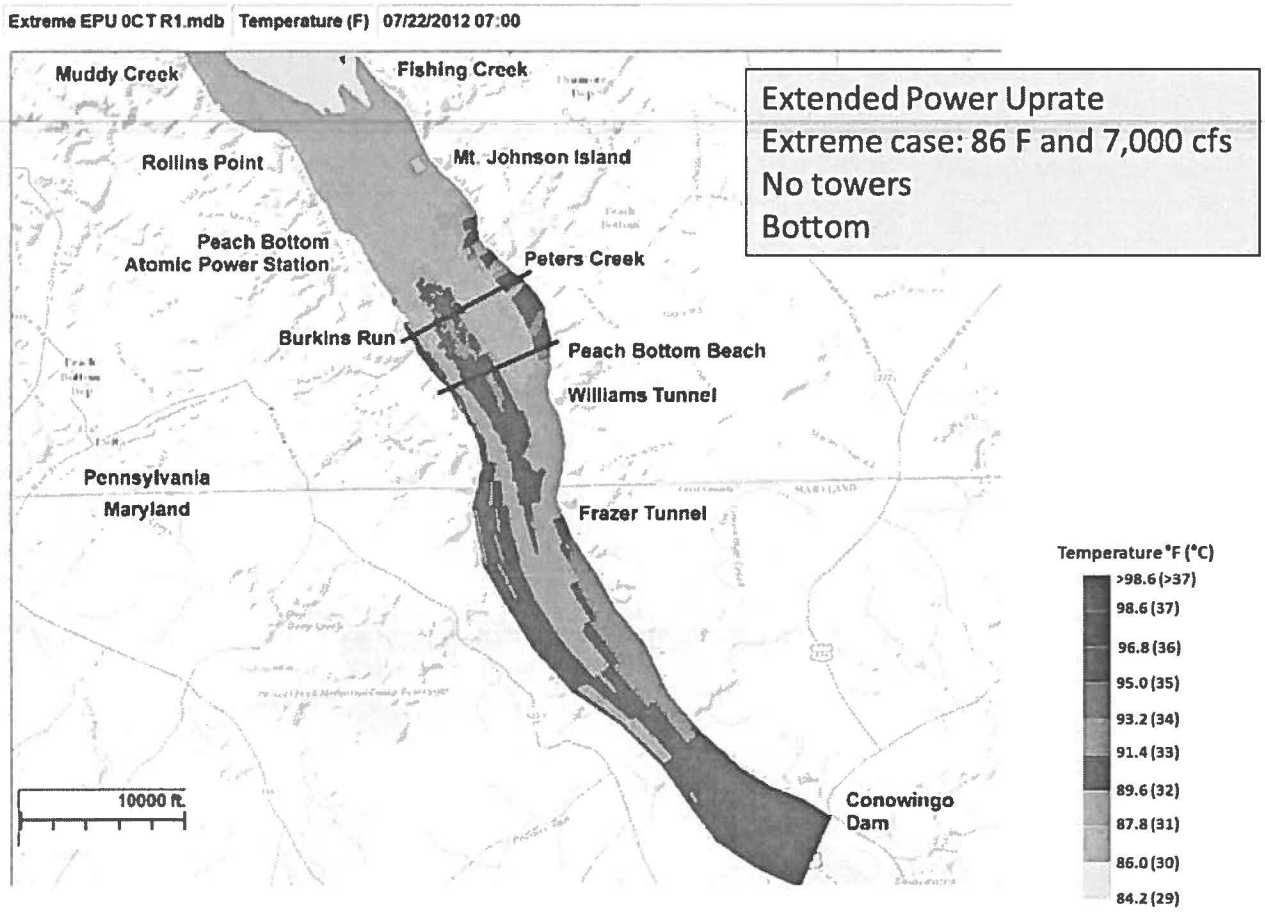

Typical EPU 3CT R1.mdb
Temperature (F)
07/22/2012 07:00
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
10000 ft.
Conowingo
Dam
Extended Power Uprate
Typical case: 80 F and 13,000 cfs
Three towers
Benthic impact: bottom >94°F
Temperature °F (° C)
>94 (34.4)

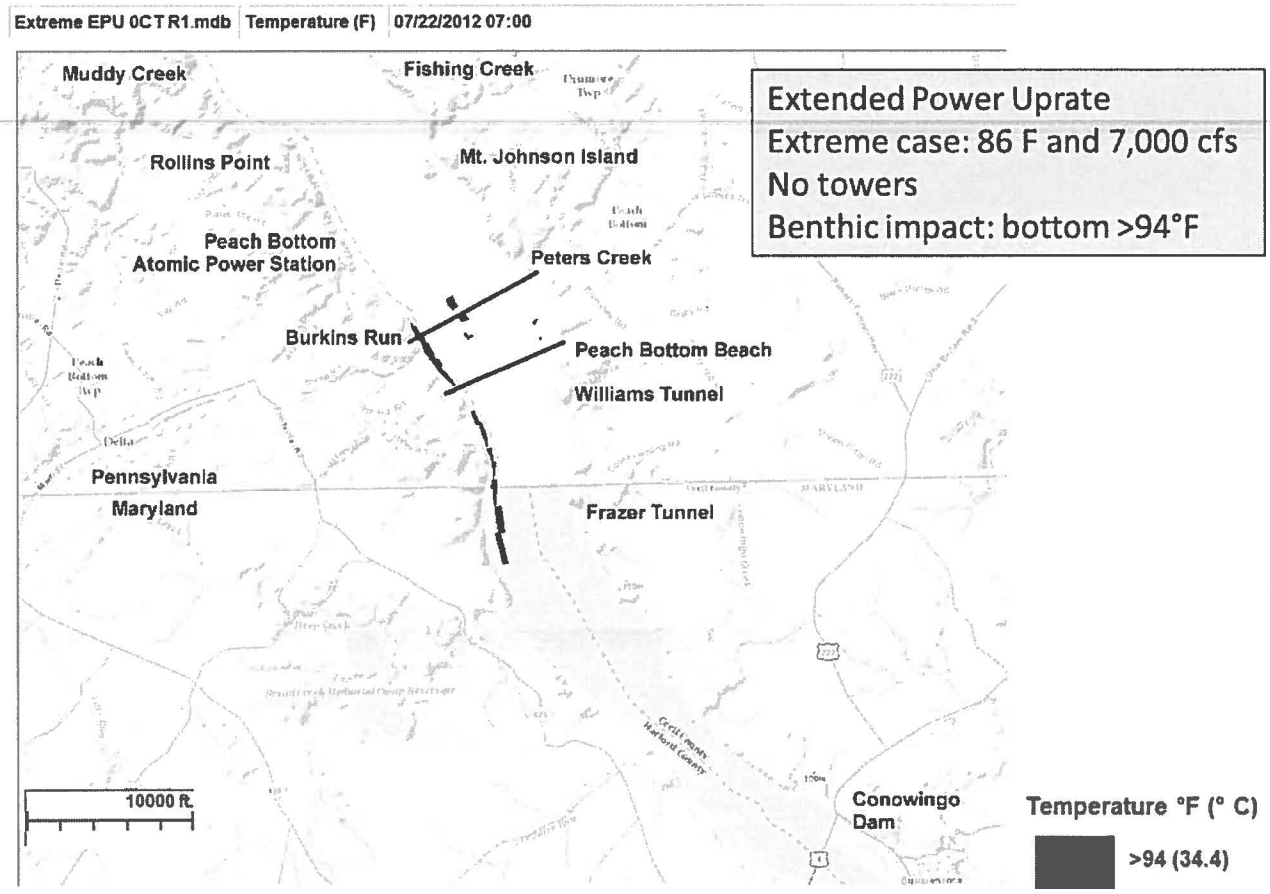

Database: Extreme EPU OCT R1.mdb Slice: 1000ft Date: 07/22/2012 07:00
Extended Power Uprate
Extreme case: 86 F and 7,000 cfs
No towers
1000 ft below discharge
Elevation, ft
109.9
107.9
105.9
103.9
101.9
99.9
97.9
95.9
93.9
91.9
89.9
87.9
85.9
0 600 1200 1800 2400 3000 3600 4200 4800 5400 6000 6600 7200
Distance along slice, ft
Western shoreline
Eastern shoreline
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

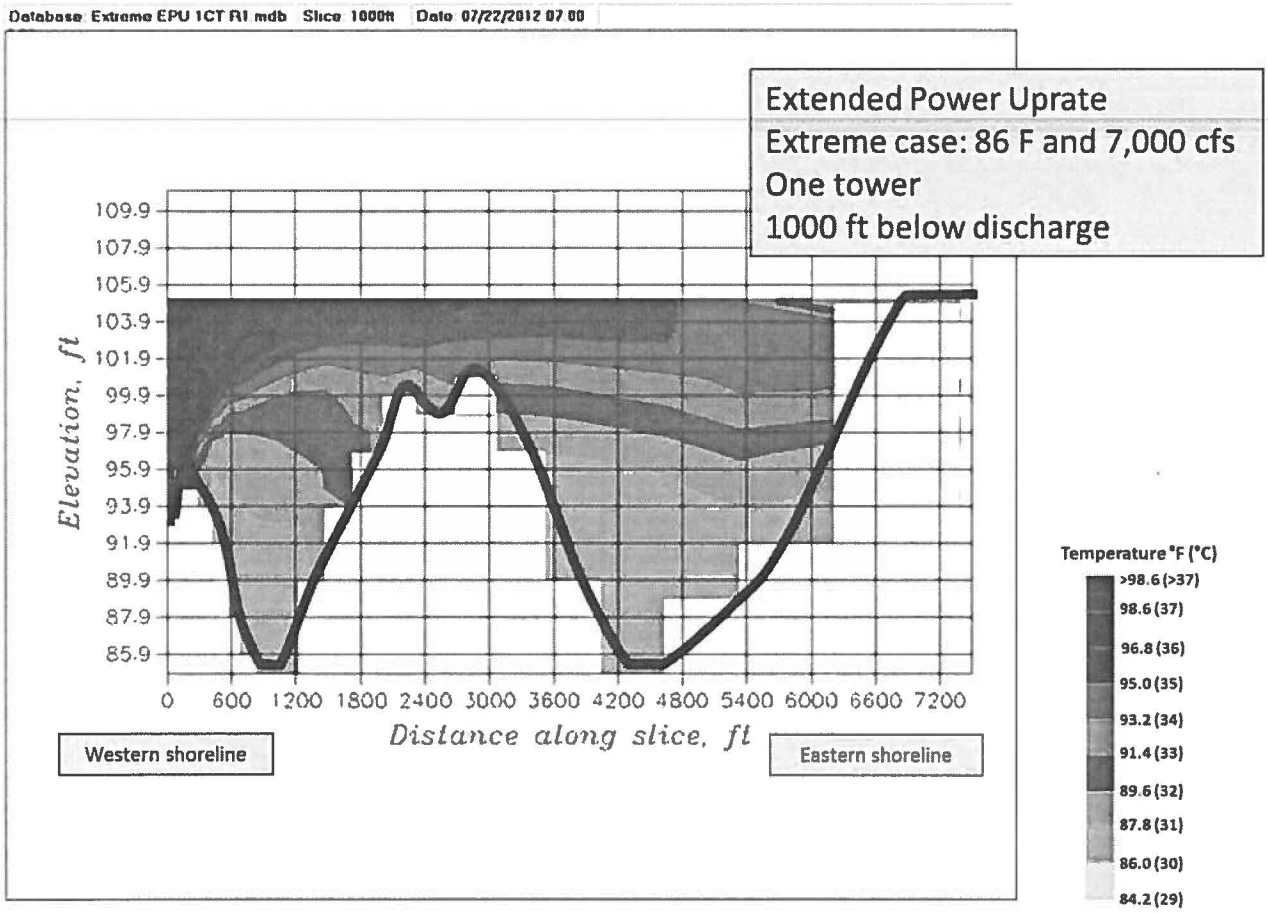

Database: Extreme EPU OCT R1.mdb Slice: 5000ft Date: 07/22/2012 07:00
Extended Power Uprate
Extreme case: 86 F and 7,000 cfs
No towers
5000 ft below discharge
Elevation, ft
109.9
107.9
105.9
103.9
101.9
99.9
97.9
95.9
93.9
91.9
89.9
87.9
85.9
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 6000
Distance along slice, ft
Western shoreline
Eastern shoreline
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

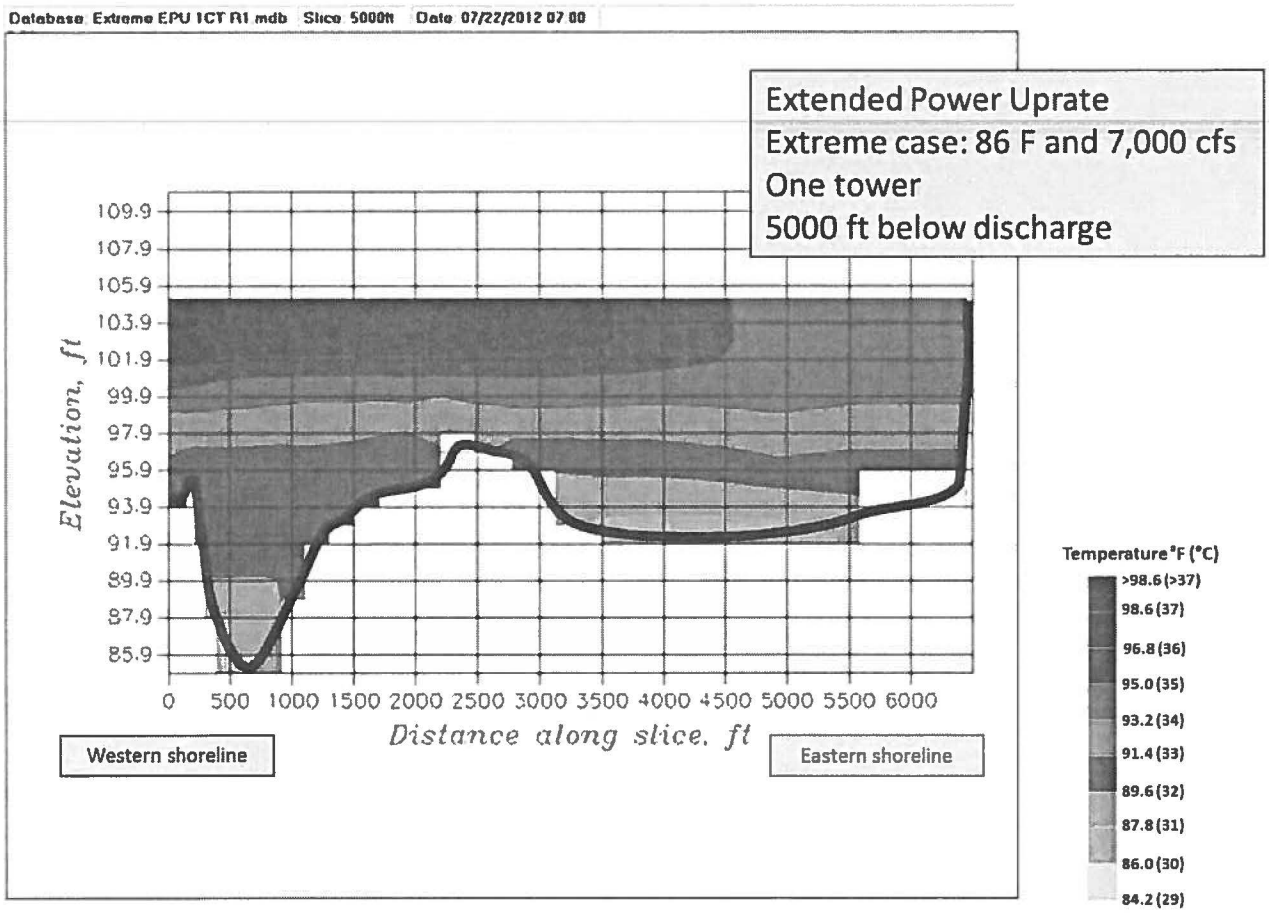

Extreme EPU OCT R1.mdb
Temperature (F)
07/22/2012 07:00
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
10000 ft.
Conowingo
Dam
Extended Power Uprate
Extreme case: 86 F and 7,000 cfs
No towers
Surface
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

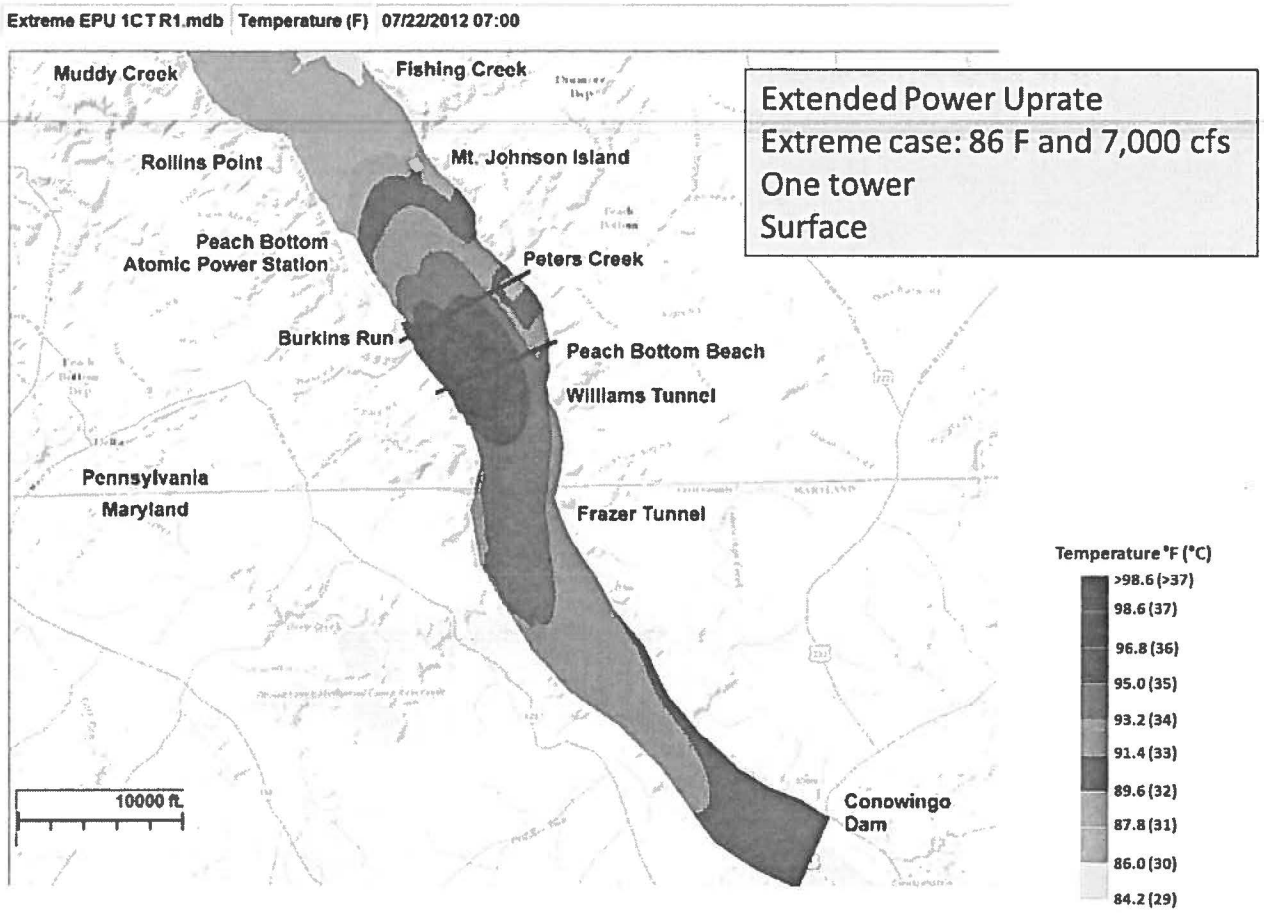

Extreme EPU 0CTR1.mdb Temperature (F) 07/22/2012 07:00
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
Conowingo
Dam
10000 ft
Extended Power Uprate
Extreme case: 86 F and 7,000 cfs
No towers
10 ft
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

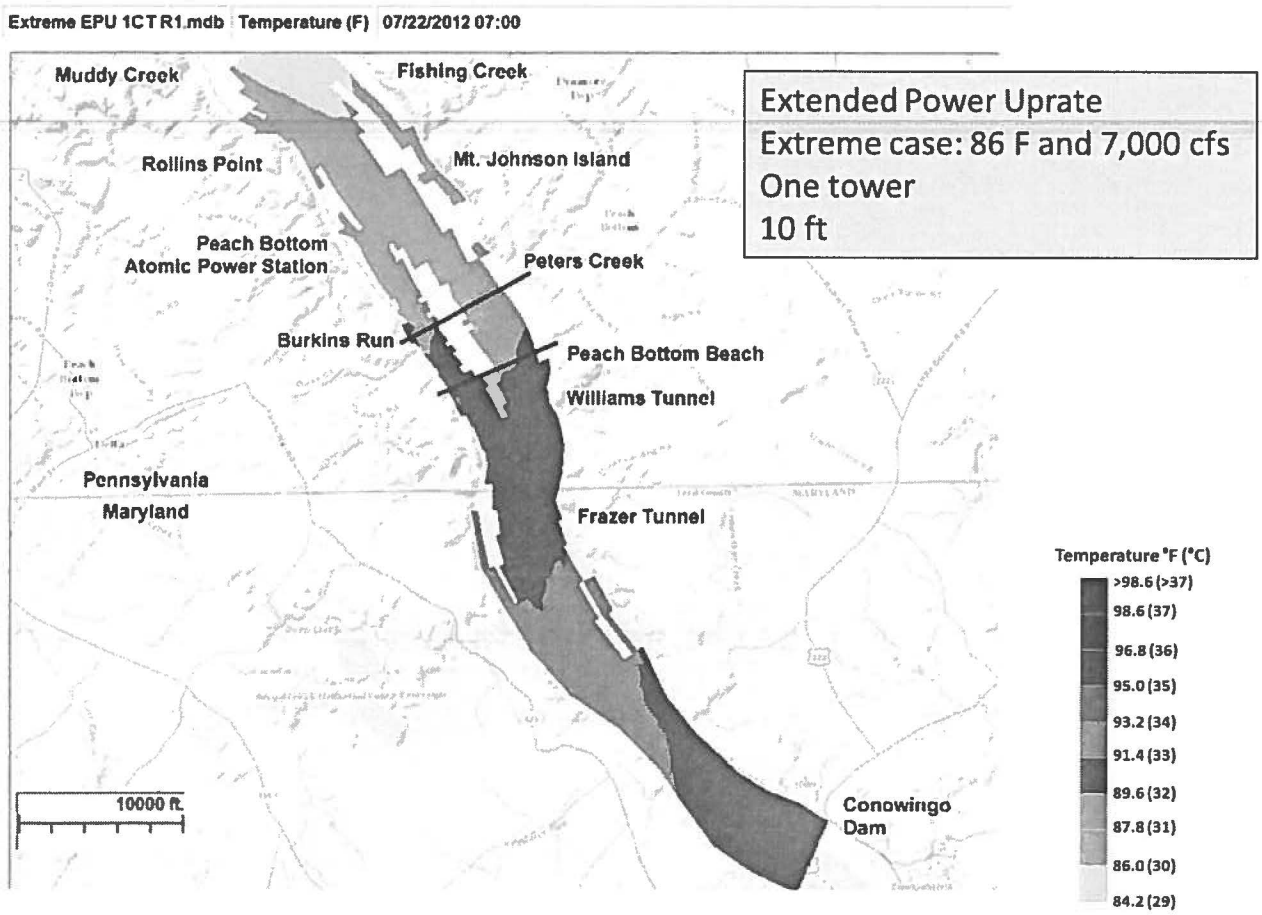

Extreme EPU OCT R1.mdb
Temperature (F)
07/22/2012 07:00
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
Conowingo
Dam
10000 ft.
Extended Power Uprate
Extreme case: 86 F and 7,000 cfs
No towers
Bottom
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

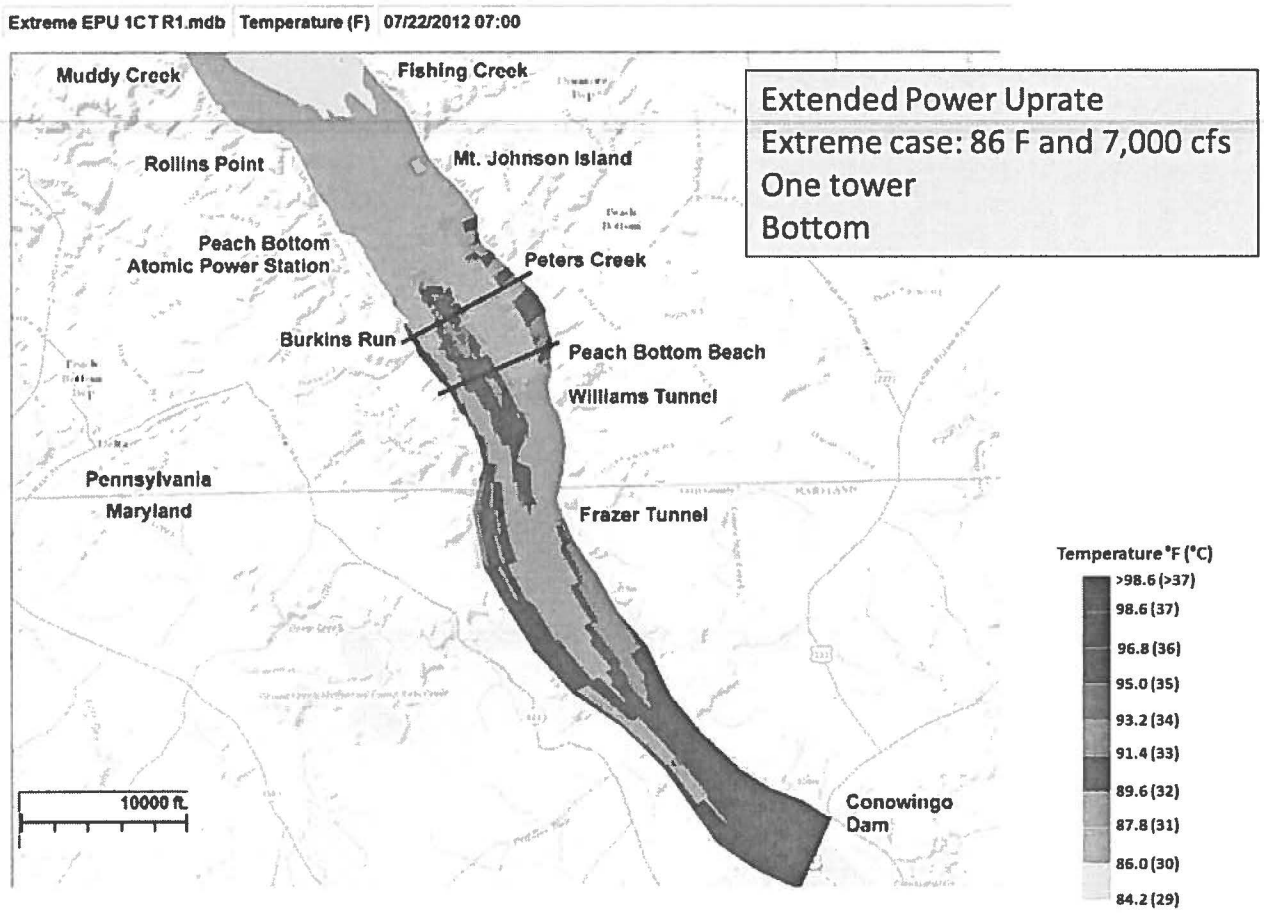

Extreme EPU 0CT R1.mdb
Temperature (F)
07/22/2012 07:00
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
10000 ft
Conowingo
Dam
Extended Power Uprate
Extreme case: 86 F and 7,000 cfs
No towers
Benthic impact: bottom >94°F
Temperature °F (° C)
>94 (34.4)

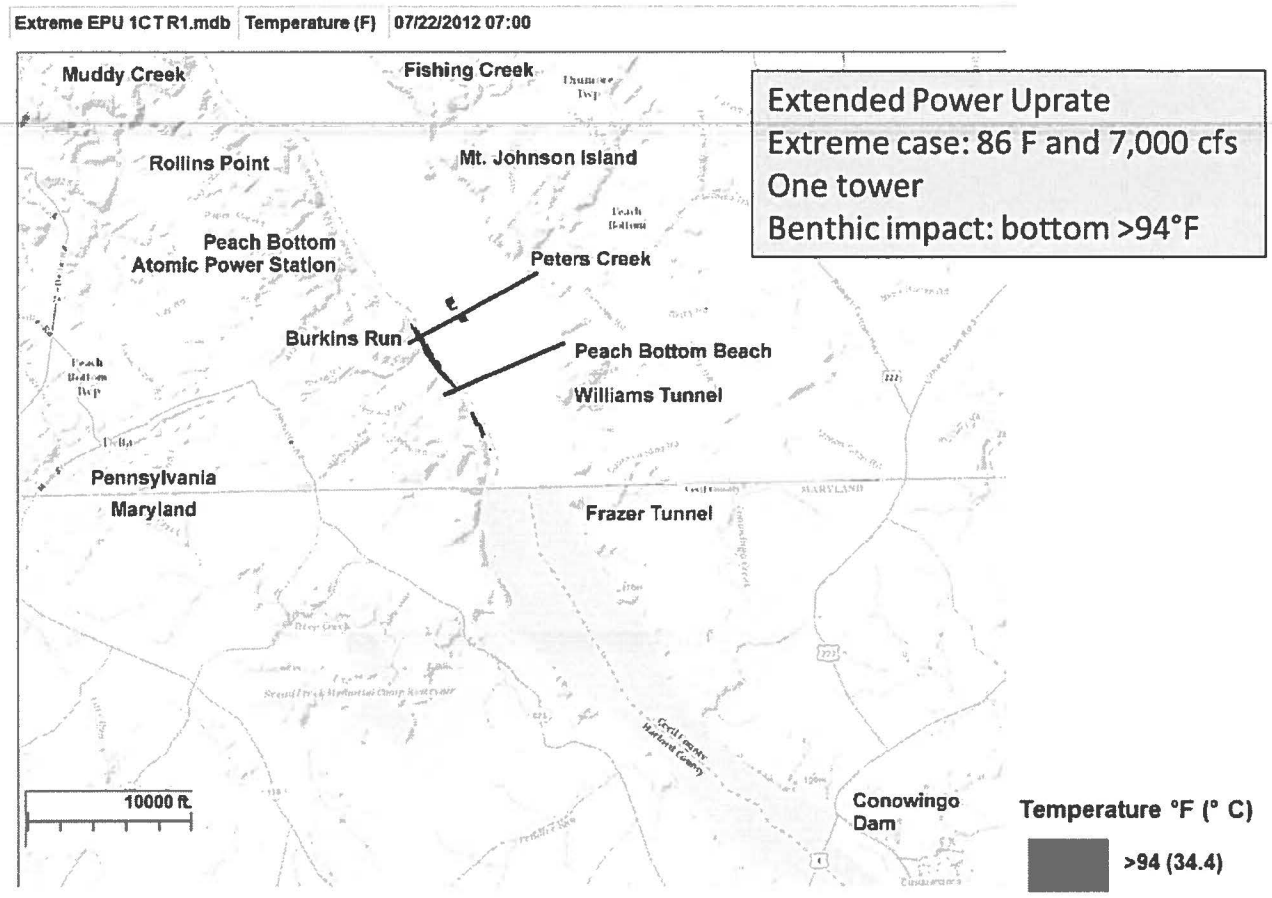

Database Extreme EPU 1CT R1 mdb Slice 1000ft Date 07/22/2012 07 00
Extended Power Uprate
Extreme case: 86 F and 7,000 cfs
One tower
1000 ft below discharge
Elevation, ft
109.9
107.9
105.9
103.9
101.9
99.9
97.9
95.9
93.9
91.9
89.9
87.9
85.9
0 600 1200 1800 2400 3000 3600 4200 4800 5400 6000 6600 7200
Distance along slice, ft
Western shoreline
Eastern shoreline
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

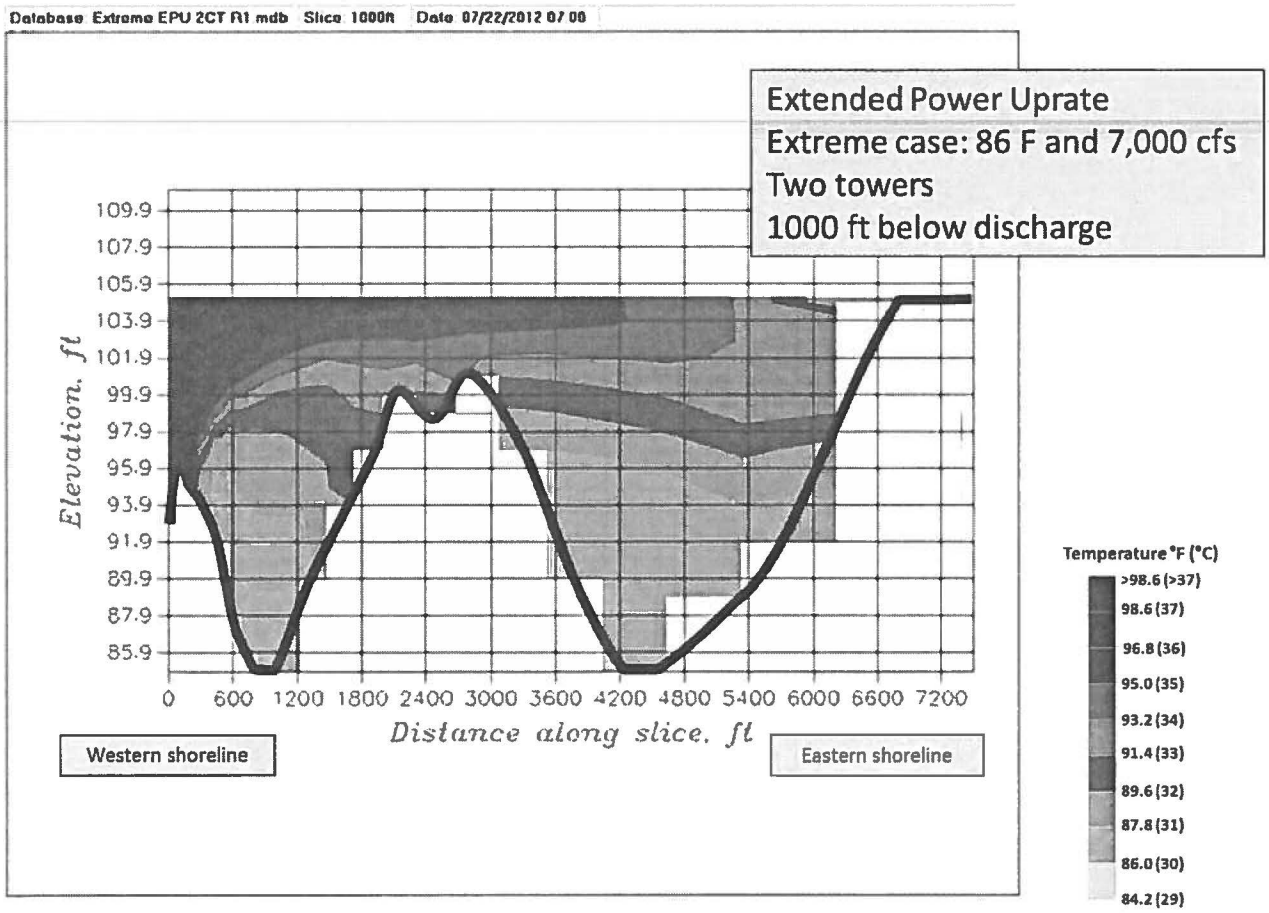

Database: Extreme EPU 1CT R1.mdb Slice: 5000ft Date: 07/22/2012 07:00
Extended Power Uprate
Extreme case: 86 F and 7,000 cfs
One tower
5000 ft below discharge
Elevation, ft
109.9
107.9
105.9
103.9
101.9
99.9
97.9
95.9
93.9
91.9
89.9
87.9
85.9
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 6000
Distance along slice, ft
Western shoreline
Eastern shoreline
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

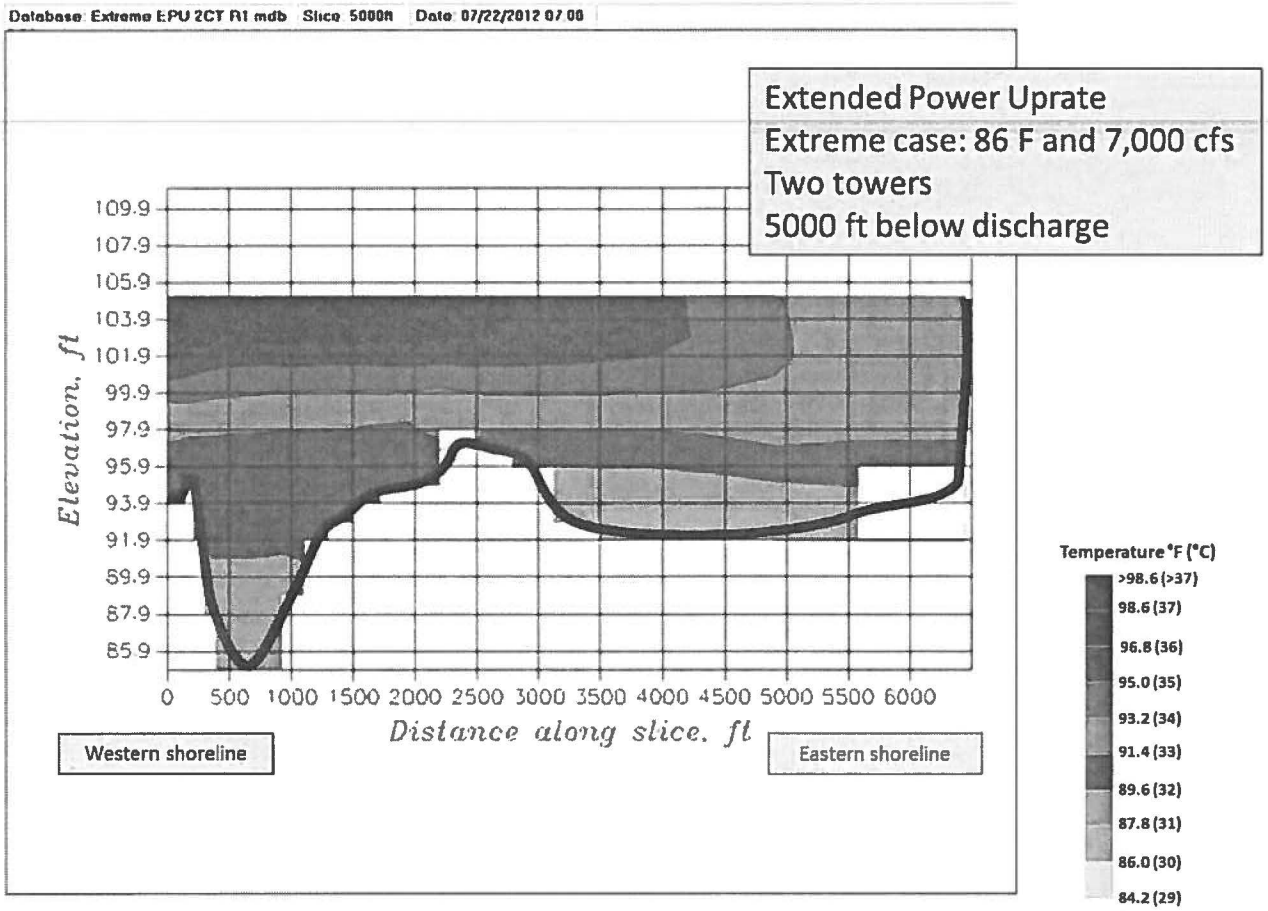

Extreme EPU 1CT R1.mdb
Temperature (F)
07/22/2012 07:00
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
Conowingo
Dam
10000 ft.
Extended Power Uprate
Extreme case: 86 F and 7,000 cfs
One tower
Surface
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

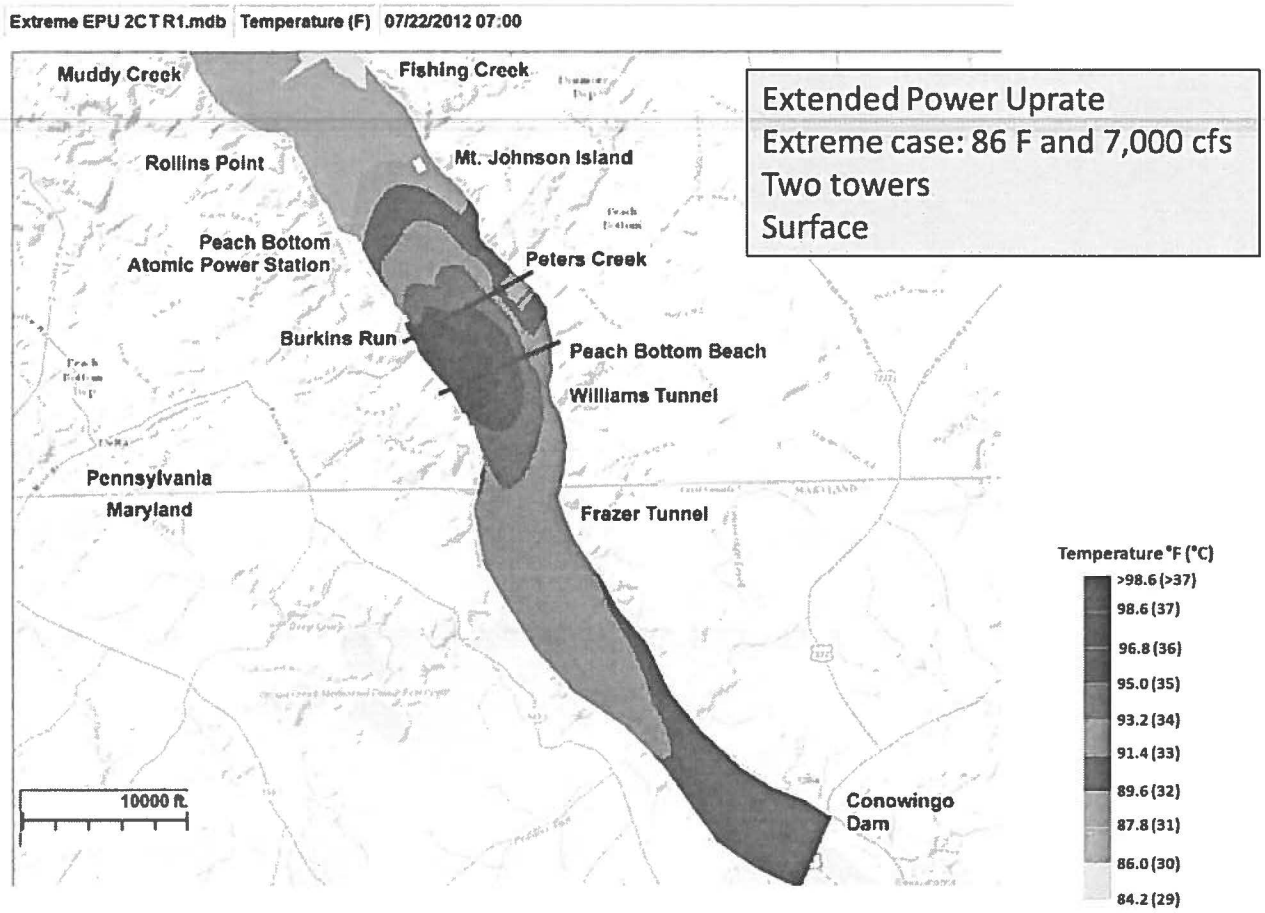

Extreme EPU 1CT R1.mdb Temperature (F) 07/22/2012 07:00
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
Conowingo
Dam
10000 ft.
Extended Power Uprate
Extreme case: 86 F and 7,000 cfs
One tower
10 ft
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

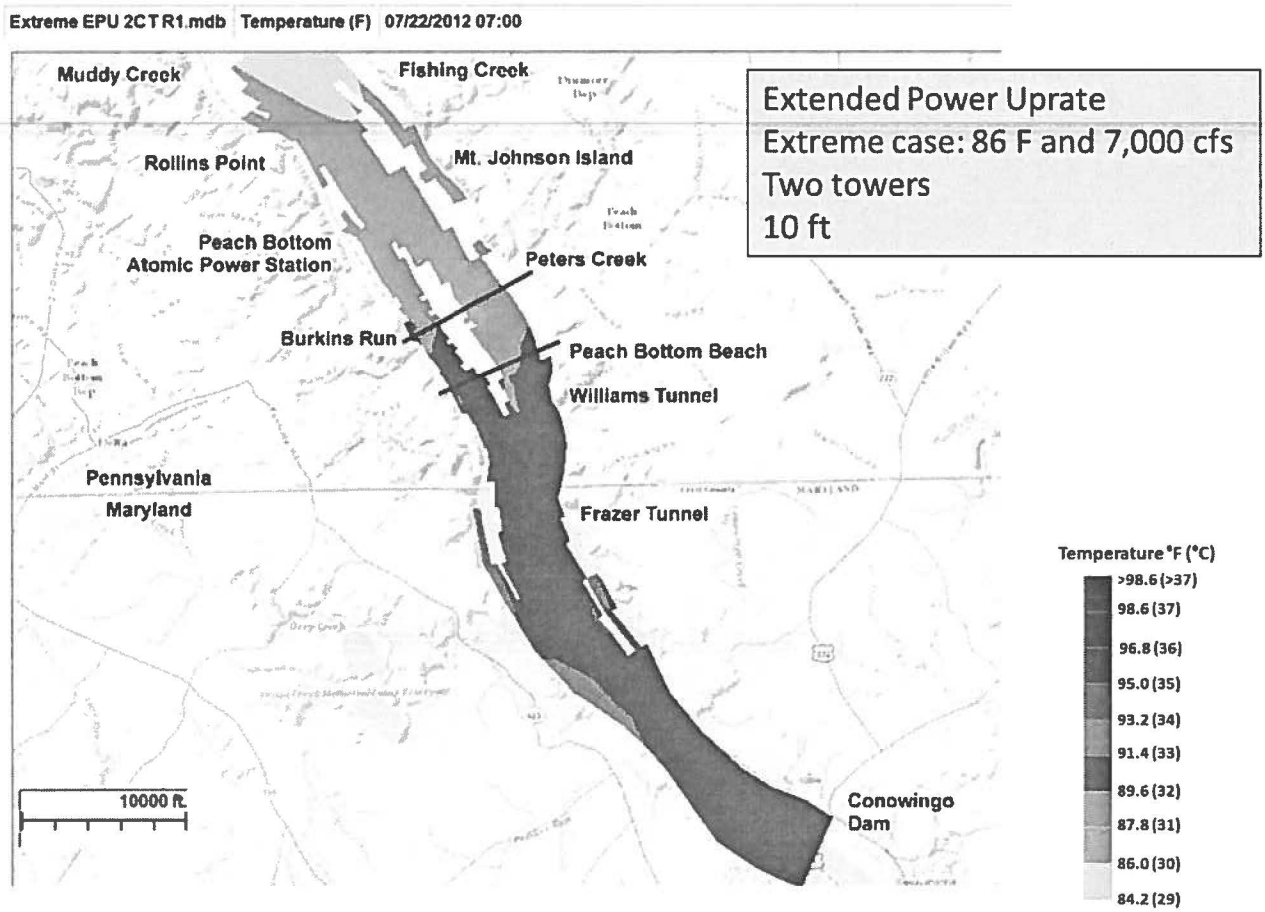

Extreme EPU 1CTR1.mdb Temperature (F) 07/22/2012 07:00
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
Conowingo
Dam
10000 ft.
Extended Power Uprate
Extreme case: 86 F and 7,000 cfs
One tower
Bottom
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

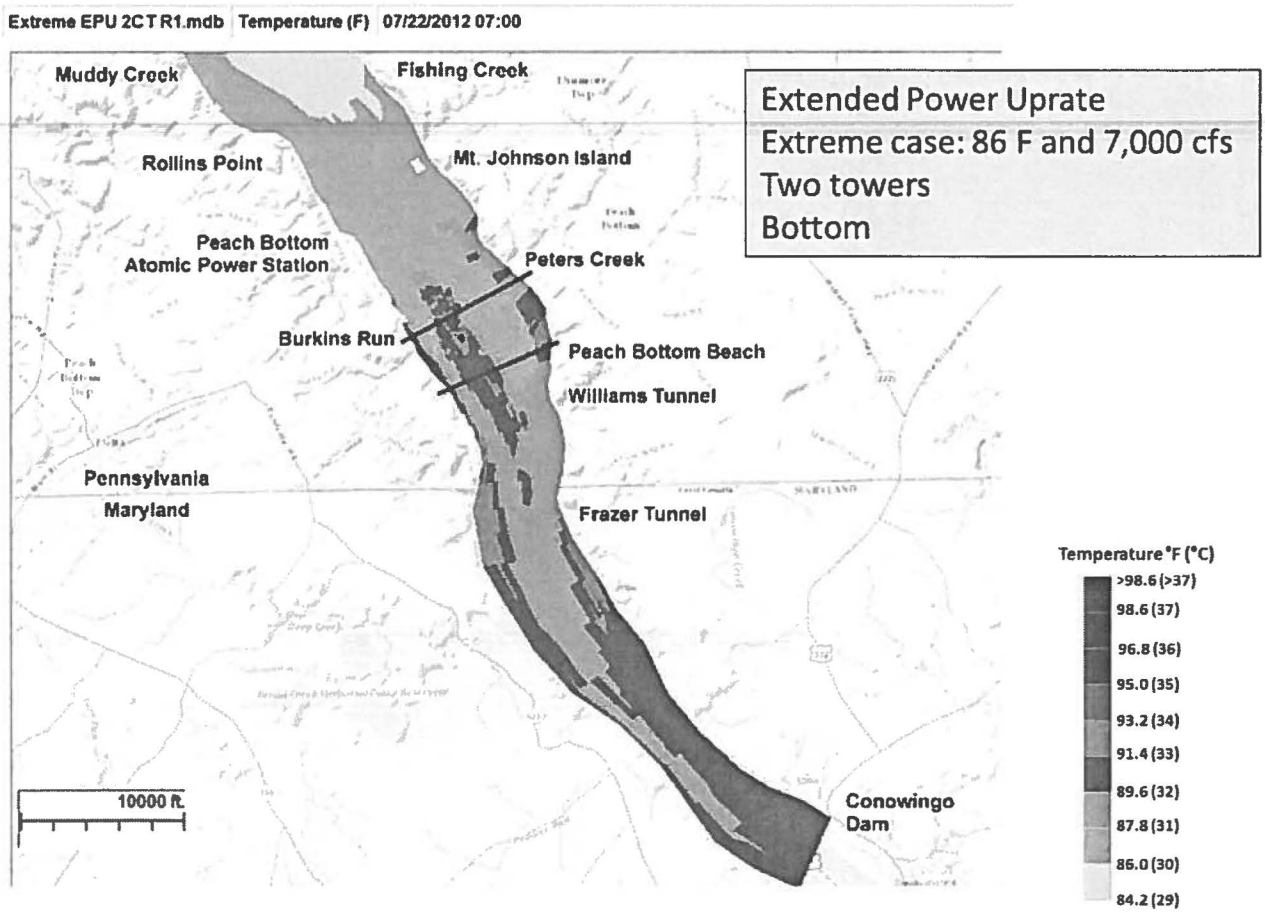

Extreme EPU 1CT R1.mdb
Temperature (F)
07/22/2012 07:00
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
10000 ft
Conowingo
Dam
Extended Power Uprate
Extreme case: 86 F and 7,000 cfs
One tower
Benthic impact: bottom >94°F
Temperature °F (° C)
>94 (34.4)

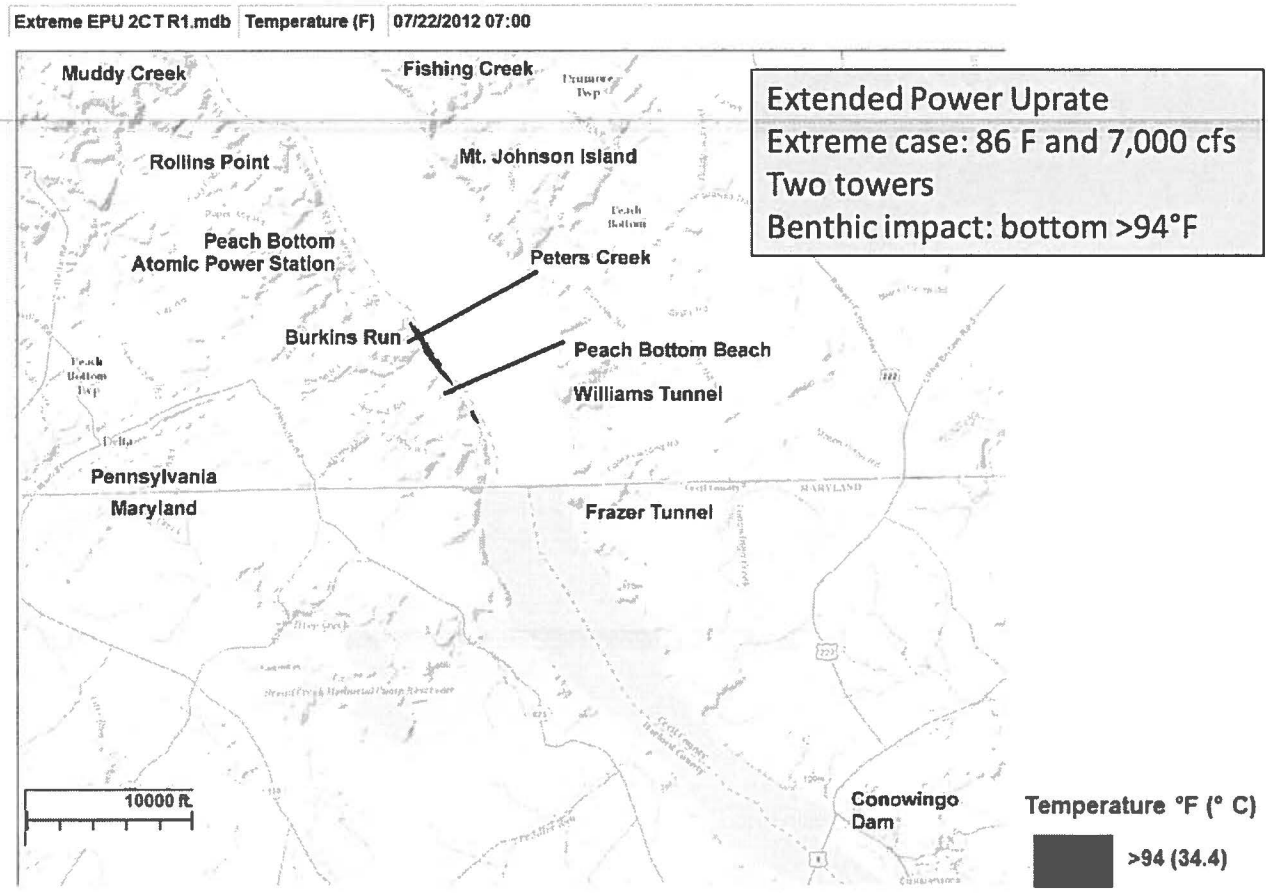

Database Extreme EPU 2CT R1 mdb Slice 1000ft Date 07/22/2012 07:00
Extended Power Uprate
Extreme case: 86 F and 7,000 cfs
Two towers
1000 ft below discharge
Elevation, ft
109.9
107.9
105.9
103.9
101.9
99.9
97.9
95.9
93.9
91.9
89.9
87.9
85.9
0 600 1200 1800 2400 3000 3600 4200 4800 5400 6000 6600 7200
Distance along slice, ft
Western shoreline
Eastern shoreline
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

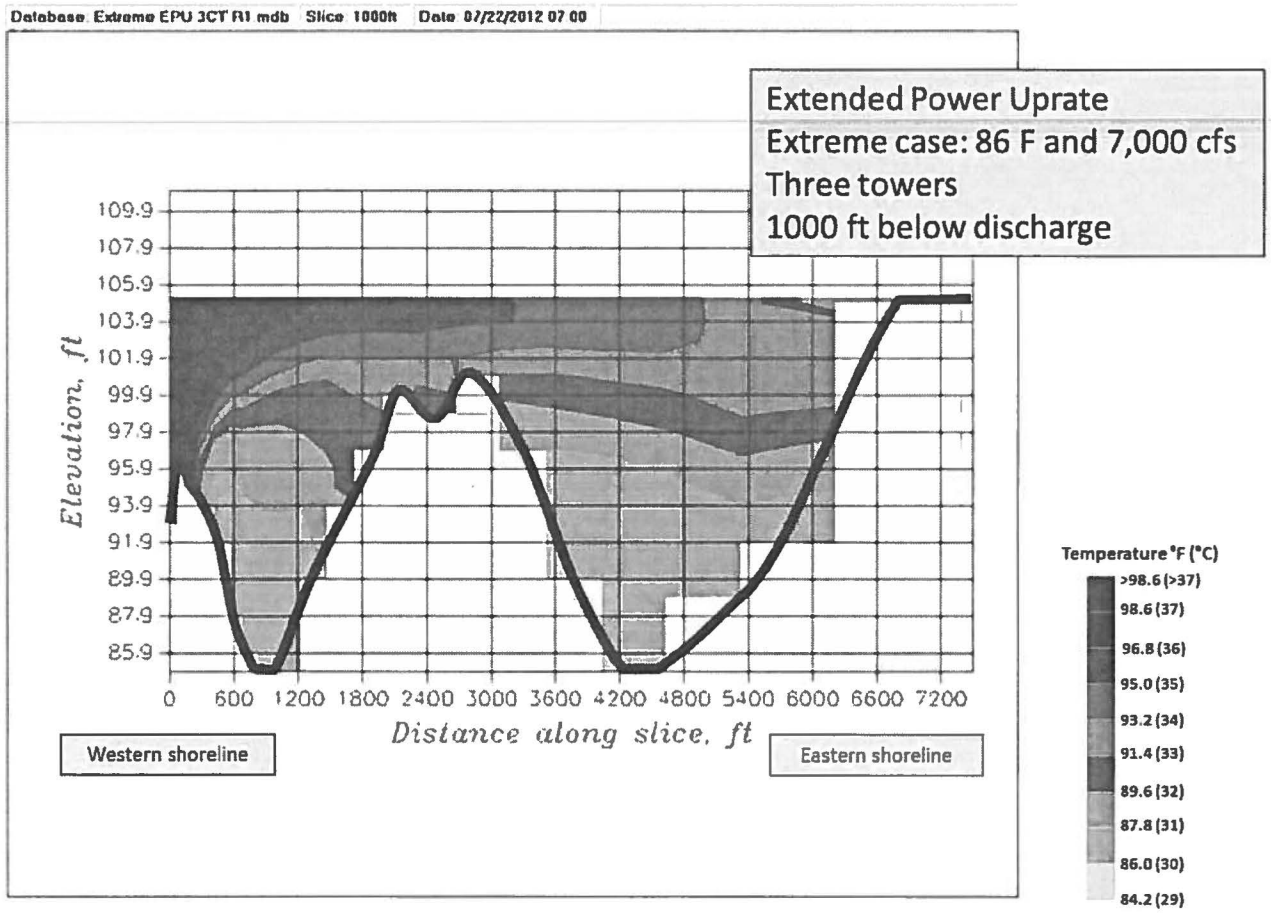

Database: Extreme EPU 2CT R1.mdb Slice: 5000ft Date: 07/22/2012 07:00
Extended Power Uprate
Extreme case: 86 F and 7,000 cfs
Two towers
5000 ft below discharge
Elevation, ft
109.9
107.9
105.9
103.9
101.9
99.9
97.9
95.9
93.9
91.9
89.9
87.9
85.9
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 6000
Distance along slice, ft
Western shoreline
Eastern shoreline
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)

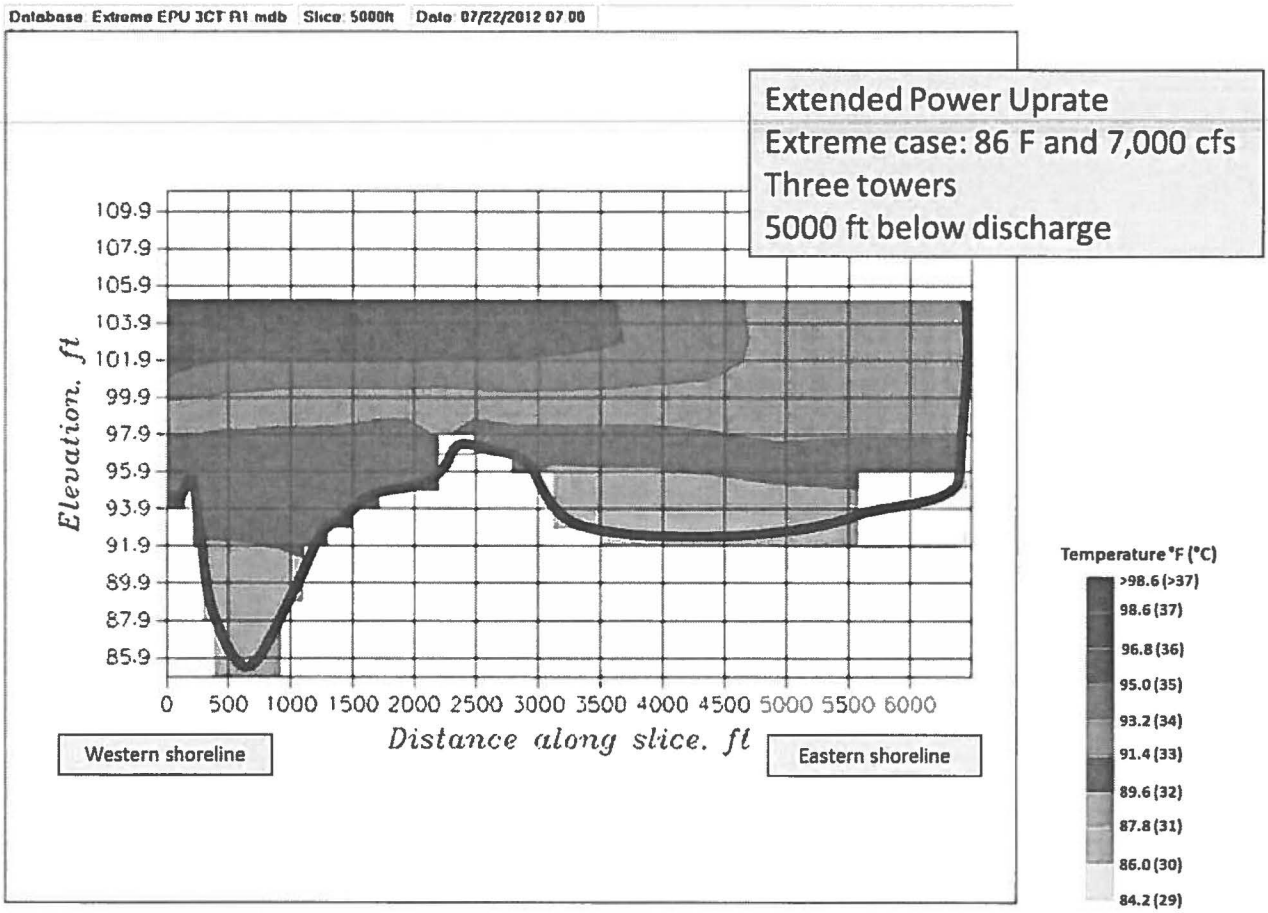

Extreme EPU 2CT R1.mdb
Temperature (F)
07/22/2012 07:00
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
Conowingo
Dam
10000 ft.
Extended Power Uprate
Extreme case: 86 F and 7,000 cfs
Two towers
Surface
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)


Extreme EPU 2CT R1.mdb
Temperature (F)
07/22/2012 07:00
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
Conowingo
Dam
10000 ft.
Extended Power Uprate
Extreme case: 86 F and 7,000 cfs
Two towers
10 ft
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)


Extreme EPU 2CT R1.mdb
Temperature (F)
07/22/2012 07:00
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
10000 ft.
Conowingo
Dam
Extended Power Uprate
Extreme case: 86 F and 7,000 cfs
Two towers
Bottom
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)


Extreme EPU 2CT R1.mdb
Temperature (F)
07/22/2012 07:00
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
10000 ft.
Conowingo
Dam
Extended Power Uprate
Extreme case: 86 F and 7,000 cfs
Two towers
Benthic impact: bottom >94°F
Temperature °F (° C)
>94 (34.4)


Database: Extreme EPU 3CT R1.mdb Slice: 1000ft Date: 07/22/2012 07:00
Extended Power Uprate
Extreme case: 86 F and 7,000 cfs
Three towers
1000 ft below discharge
Elevation, ft
109.9
107.9
105.9
103.9
101.9
99.9
97.9
95.9
93.9
91.9
89.9
87.9
85.9
0 600 1200 1800 2400 3000 3600 4200 4800 5400 6000 6600 7200
Distance along slice, ft
Western shoreline
Eastern shoreline
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)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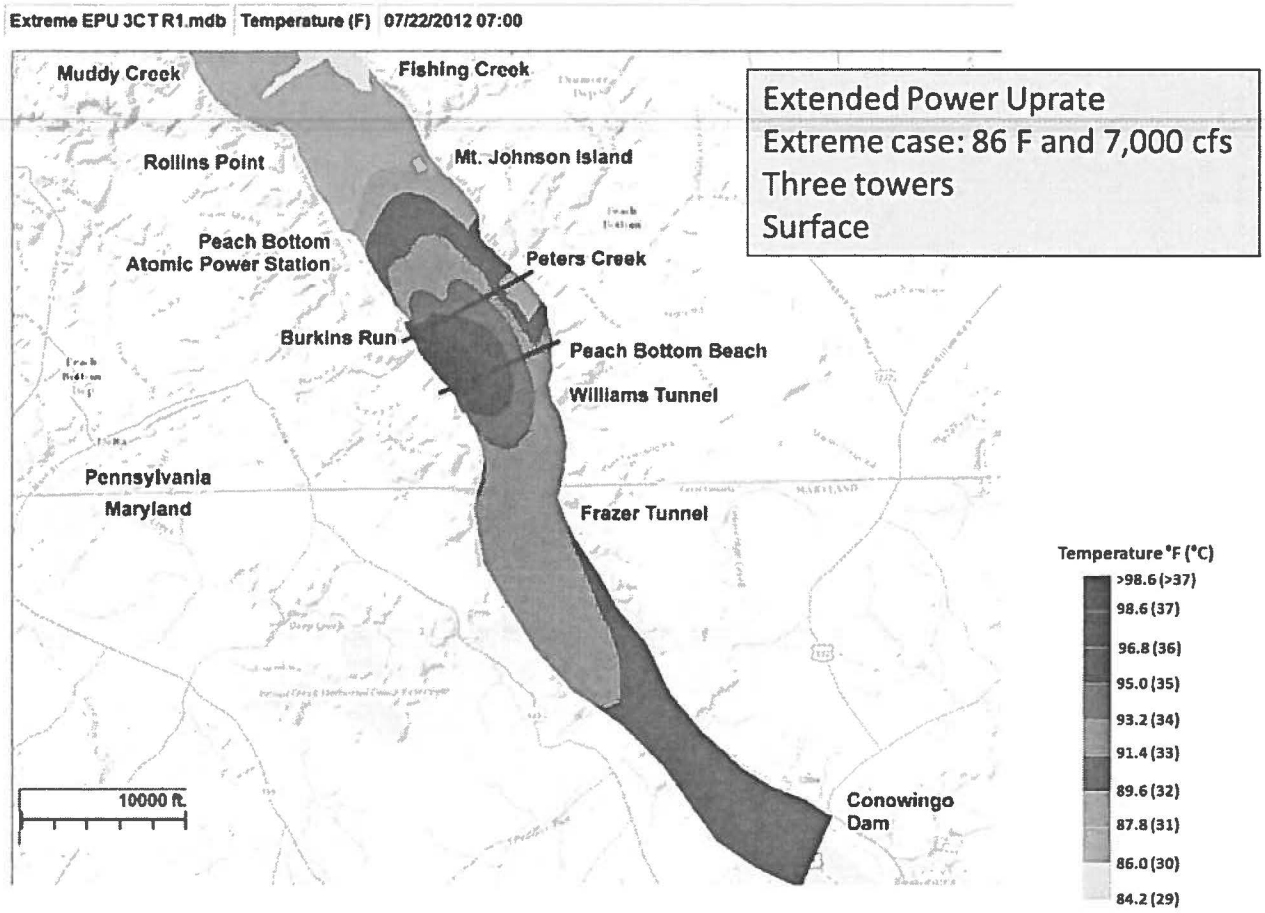
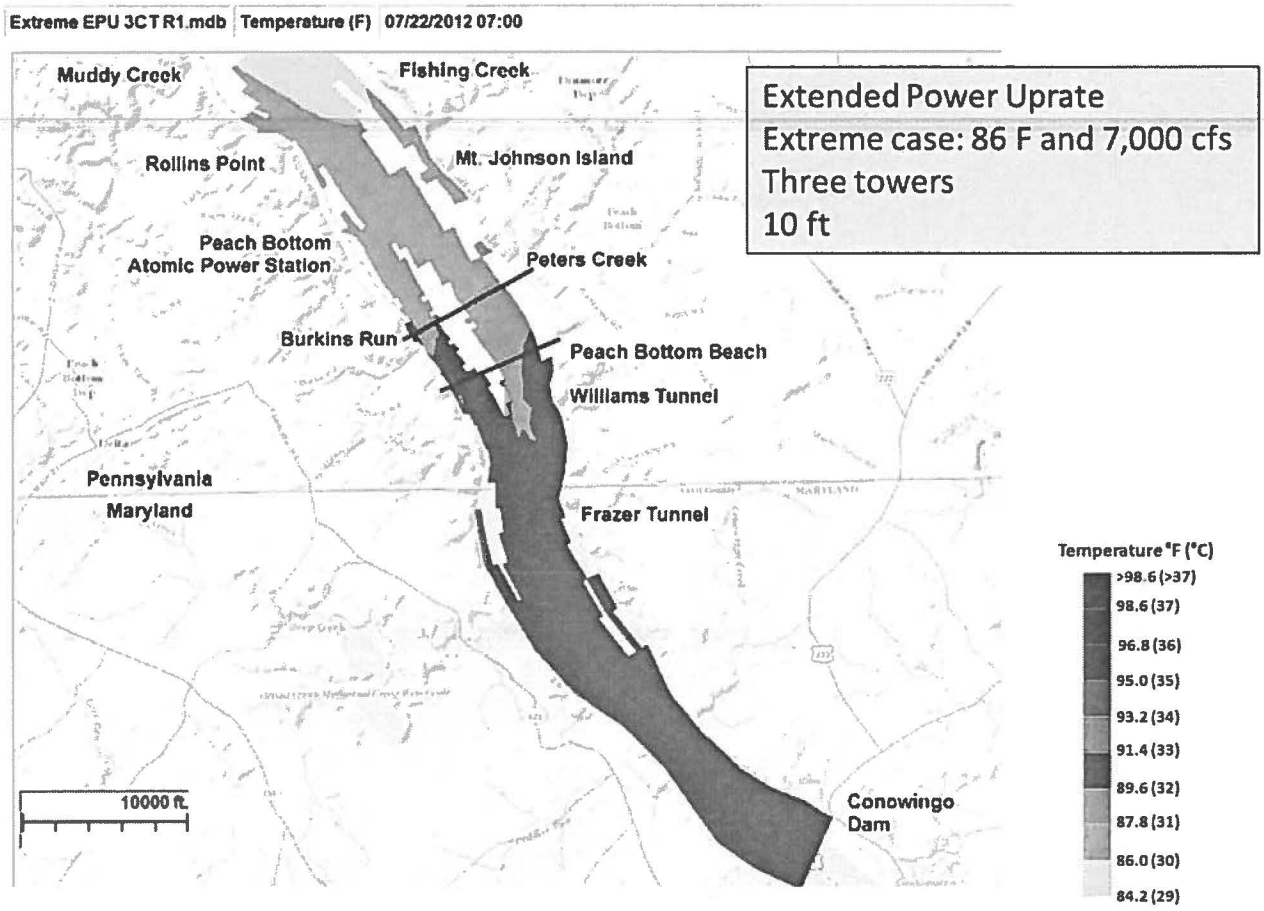
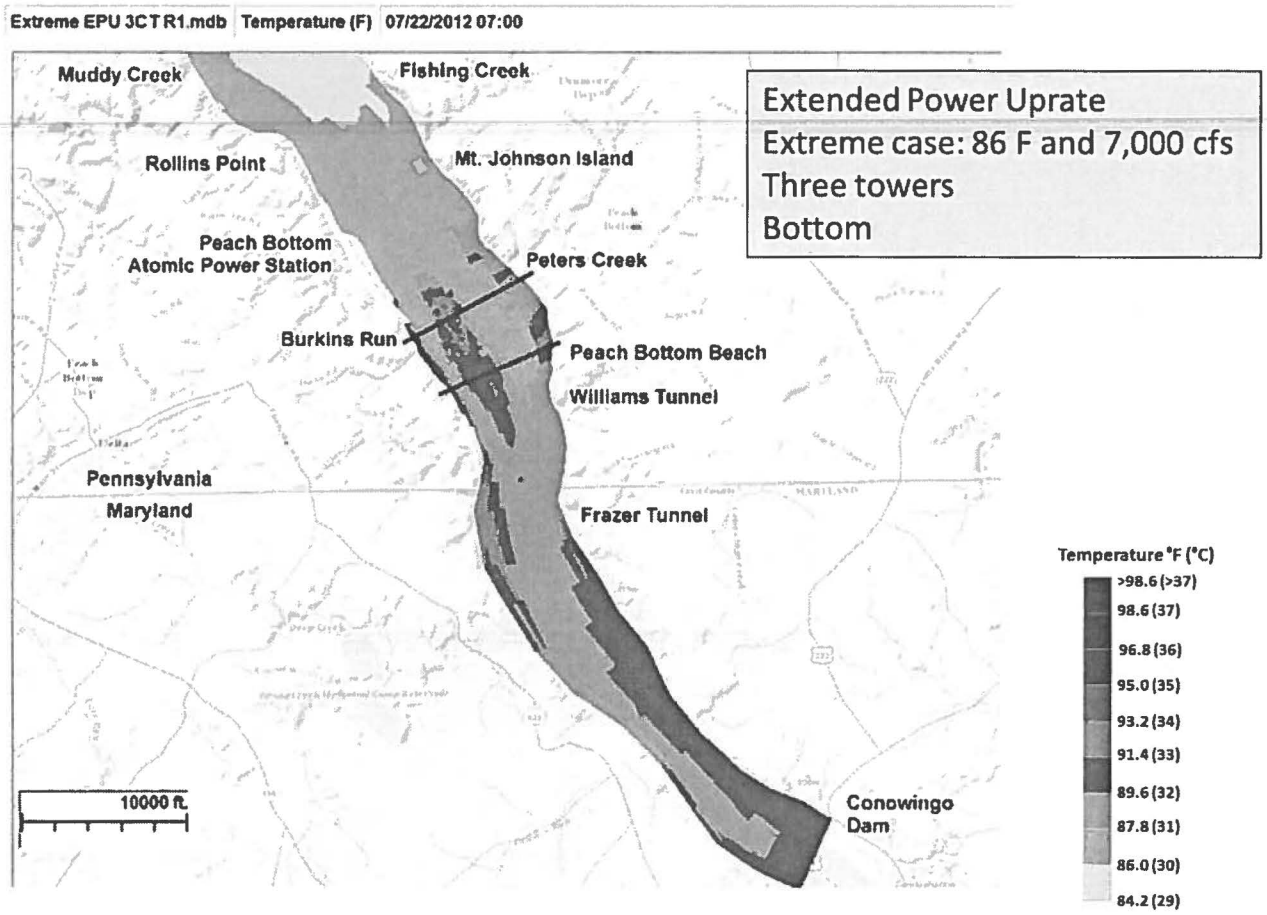
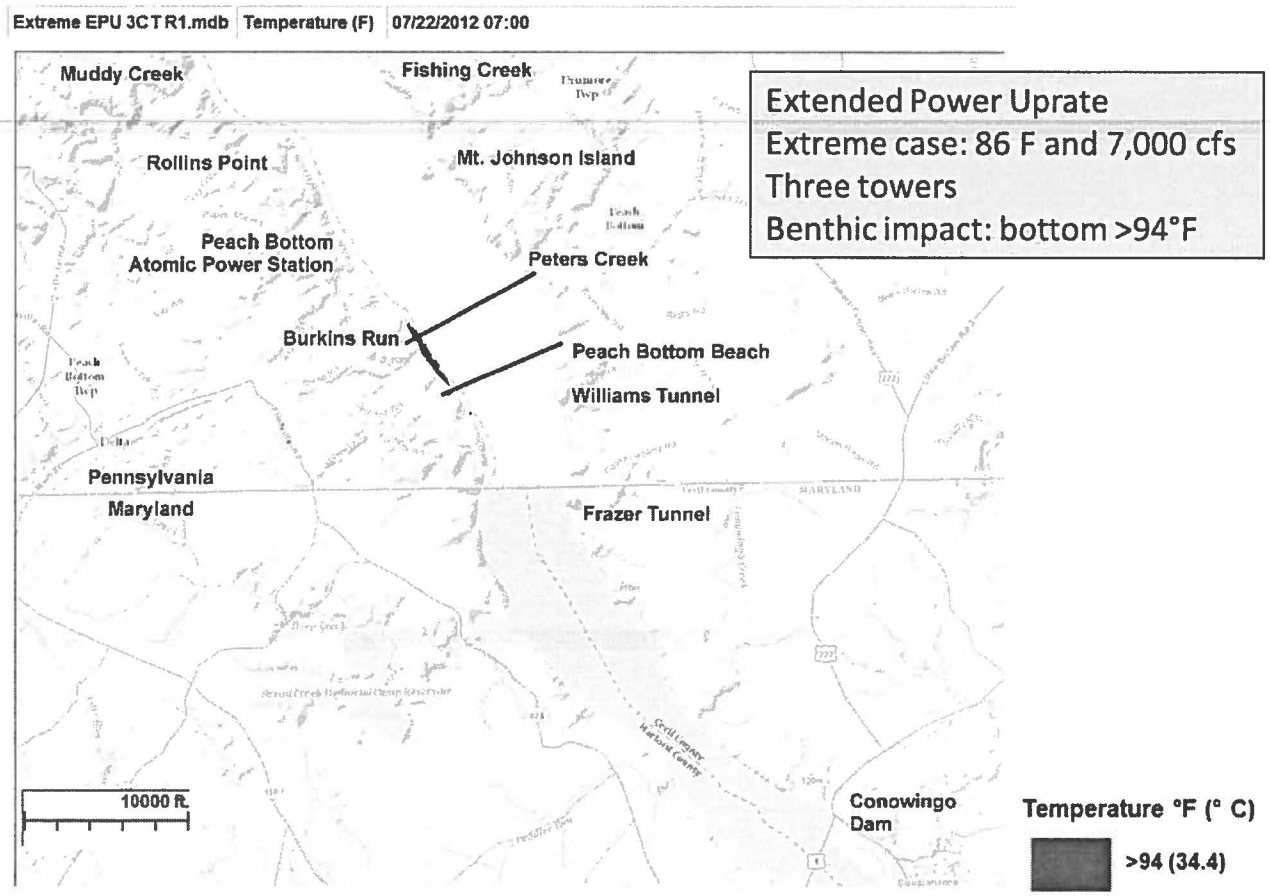
Extended Power Uprate
Extreme case: 86 F and 7,000 cfs
Three towers
5000 ft below discharge
Elevation, ft
109.9
107.9
105.9
103.9
101.9
99.9
97.9
95.9
93.9
91.9
89.9
87.9
85.9
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 6000
Distance along slice, ft
Western shoreline
Eastern shoreline
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)


Extreme EPU 3CT R1.mdb
Temperature (F)
07/22/2012 07:00
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
Conowingo
Dam
10000 ft.
Extended Power Uprate
Extreme case: 86 F and 7,000 cfs
Three towers
Surface
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)


Extreme EPU 3CT R1.mdb
Temperature (F)
07/22/2012 07:00
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
Conowingo
Dam
10000 ft
Extended Power Uprate
Extreme case: 86 F and 7,000 cfs
Three towers
10 ft
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)


Extreme EPU 3CT R1.mdb
Temperature (F)
07/22/2012 07:00
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
Conowingo
Dam
10000 ft.
Extended Power Uprate
Extreme case: 86 F and 7,000 cfs
Three towers
Bottom
Temperature °F (°C)
>98.6 (>37)
98.6 (37)
96.8 (36)
95.0 (35)
93.2 (34)
91.4 (33)
89.6 (32)
87.8 (31)
86.0 (30)
84.2 (29)


Extreme EPU 3CTR1.mdb
Temperature (F)
07/22/2012 07:00
Muddy Creek
Fishing Creek
Rollins Point
Mt. Johnson Island
Peach Bottom
Atomic Power Station
Peters Creek
Burkins Run
Peach Bottom Beach
Williams Tunnel
Pennsylvania
Maryland
Frazer Tunnel
10000 ft.
Conowingo
Dam
Extended Power Uprate
Extreme case: 86 F and 7,000 cfs
Three towers
Benthic impact: bottom >94°F
Temperature °F (° C)
>94 (34.4)

7.2 Biological Assessment of Potential RIS Avoidance and Benthos Impact Areas

The previous section discussed the model development and output. This section describes the two modeled scenarios after implementation of the EPU relative to the RIS of fish and benthos community. Potential avoidance areas for CLTP is not evaluated because this as well as prior studies have demonstrated the presence of a BIC in Conowingo Pond.

The potential for RIS habitat to be reduced or impaired in the Pond by elevated water temperatures is a primary focus of this study. The PADEP has expressed interest in the potential extent of fish exclusion from habitats affected by the thermal plume, in particular, during July and August, when the warmest temperatures occur in the Pond. In concept, large areas of avoidance or exclusion for extended periods may harm the RIS. Potential harm could result from unavailability of necessary habitats used for feeding, protective cover, or reproduction. For example, avoidance may preclude organisms from completion of portions of their life cycle. Large areas of exclusion from spawning habitats could result in low recruitment and long-term decline in relative abundance of a species. New data presented in this report and previous studies indicate the Conowingo Pool has no such impairments. Most fish species in the Pond complete spawning prior to July and August, which are the warmest months of the year. Although avoidance of portions of the thermal plume does occur, particularly during July at the near-field stations, the collection data shows that fish return to previously avoided areas in subsequent collection months. Nonetheless, avoidance is a predictive tool for evaluating the potential thermal impact of the PBAPS on the fish community in the Pond.

Avoidance is the active movement of fish to evade undesirable and potentially lethal temperatures through selective habitat use and by utilization of available escape routes. Coutant (1977) describes upper avoidance temperature as a sharply defined upper temperature at which an organism at a given acclimation temperature will avoid. The upper avoidance temperature is the temperature below which active avoidance will not occur as long as fish are acclimated to the elevated temperatures. This is a typical "endpoint" derived in laboratory tests of fish response to thermal gradients (Peterson and Schutsky 1977). Exposures to temperatures at or above the upper avoidance temperature, but less than the upper incipient lethal temperature, for short periods (i.e., 7 or fewer days) will not cause direct mortality, but longer exposures may induce chronic effects, such as lowered body condition or increased susceptibility to disease and predation. However, we have not observed fish in poor condition or high rates of disease at thermally affected locations in Conowingo Pond.

For fish, the avoidance concept is particularly applicable because they can sense small differences in temperature, and will move away from temperatures they will not tolerate. Fish are highly mobile and can move within waterbodies based on species-specific habitat preference, which includes water temperatures. Fish are also known to move toward a particular temperature which they may prefer. This is termed final preferendum and is the temperature at which a fish population will ultimately congregate regardless of previous thermal experience (Fry 1947). Also important in understanding the avoidance concept is acclimation temperature. This is the temperature that an organism has been exposed to and involves physiological adjustment. Fish can acclimate to rising temperatures, resulting in an increase in the avoidance temperature. Responses of fish to temperature may be affected by multiple factors including

habitat (cover, depth), life stage, water quality, time of year, predators, food availability, competitors, etc.

Of particular importance to this analysis is the distribution and abundance of the 11 RIS in relation to the PBAPS thermal plume. For each RIS a theoretical avoidance temperature was selected based on upstream ambient (acclimation) water temperature (Table 7-12 and Table 7-13). This theoretical avoidance temperature is the water temperature at which a species would not be expected to occur based on various literature sources. The avoidance temperatures used in this evaluation were based on review of relevant literature and through discussions with PADEP. Avoidance temperatures were selected for two acclimation temperatures, 26.7°C (80°F) and 30°C (86°F). These two acclimation or ambient temperatures represent both a typical case (26.7°C) and a more extreme case (30°C) for summertime ambient temperatures within Conowingo Pond. Section 6 provided additional detail on temperature selection and data sources.

Table 7-12 provides avoidance temperatures for the RIS at an acclimation temperature of 30°C. This table provides three columns of avoidance temperatures for each RIS. The "Agreed-upon" column provides the avoidance temperatures that were determined based on discussion with PADEP and utilized available literature and professional judgment. Both PADEP and Exelon consultants reviewed relevant literature sources pertaining to avoidance temperatures and agreed to these temperatures as a basis for analysis of avoidance areas within the Pond. Also included are additional avoidance temperatures for each RIS from Mathur *et al.* (1983) and Yoder (2006). These provide examples of published avoidance temperature values that form the basis for the "Agreed-upon" values. These values are also provided to show some of the range of potential avoidance temperatures reported in the literature for a given species. Table 7-13 provides avoidance temperatures for each RIS based on acclimation temperature of 26.7°C (80°F). These avoidance temperatures are based on species-specific avoidance equations given in Mathur *et al.* (1983).

Thermally affected shoreline benthic habitats are also a component of this analysis. The amount of potential reduction in the composition of the benthic community has been determined based on analysis and observations of the data collected over the course of this study. The temperature-benthic impact metric used in this analysis is the amount of River bottom that exceeds 94°F. The development of the 94°F water temperature threshold for evaluating thermal effects to the benthic community was discussed previously in Section 5.5.

Derivation and discussion of development of the two modeling scenarios was completed in Sections 7.1 and 7.2. Although the output provided in Section 7.1 is based on theoretical conditions, ambient temperature and River flow conditions similar to both scenarios were observed during the study. The probability of occurrence of the typical scenario is equivalent to 35 days per year. During 2010-2013 non-consecutive combinations of flow-temperature values similar to or more extreme than the typical scenario occurred from June to September (44 days in 2010, 25 days in 2011, 60 days in 2012, and 3 days in 2013). The probability for the extreme scenario equates to a few days each year. The extreme scenario or similar conditions were also observed infrequently during the study period.

Avoidance Modeling Results

The EPU modeled temperatures for the cross-sections at 1,000 and 5,000 ft downstream from PBAPS discharge indicate suitable areas of the water column available for fish movement (Table 7-1; thermal plume diagrams). Both scenarios indicated similar proportion of elevated water temperature regardless of the number of cooling towers in operation. The proportion of the cross-section exceeded by the selected temperatures was higher at the 5000 ft transect than the 1000 ft transect for most temperatures and cooling tower cases. The typical scenario output showed that much of the water column is available for fish movement regardless of avoidance temperature and that the highest temperatures are restricted to west shoreline. Similarly, the extreme scenario cross-section model output indicated that the highest temperatures occurred along the west shoreline. For the extreme case sufficient areas of lower temperature water adjacent to areas of elevated water temperature are available to provide pathways for fish to move through or around the thermal plume.

For both modeling scenarios the largest areas of elevated water temperatures were calculated to occur at the water surface regardless of the number of cooling towers in operation. The smallest areas of elevated water temperatures occurred at the mid-depth and bottom portions of the water column. Operation of cooling towers typically resulted in smaller areas of elevated water temperatures at all depths (Table 7-2; thermal plume diagrams). Table 7-6 and Table 7-7 to Table 7-11 provide species-specific avoidance areas and percent reduction in avoidance areas for the typical and extreme summer scenarios based on the four cooling tower cases.

In general, most of the RIS are unlikely to frequent the water surface where the highest water temperatures will occur. The only two exceptions are Bluegill and Gizzard Shad. Gizzard Shad utilize various habitats, depending on life stage, and can be found throughout the water column including in open water at the surface. Similarly, Bluegill also can occur throughout the water column and are known to inhabit open water and near surface areas as well as shoreline habitats (Paukert and Willis 2002). Bluegill primary habitat occurs in association with structure (e.g. SAV, snags, woody debris, etc.), which typically occurs nearshore or toward the bottom of the water column. However, the other nine RIS are typically associated with and oriented to shoreline or toward the bottom of the water column. Therefore, the avoidance areas for the bottom and mid-depth portions of the water column are more applicable in determining avoidance and potential displacement of species from their preferred habitat. RIS descriptions in Section 4 discuss habitat requirements and preference.

Bluegill

Bluegill is one of the more thermally tolerant species that occur in the Pond. As stated previously, Bluegill is known to inhabit open water and near surface areas as well as shoreline habitats. Bluegill can occur throughout the entire water column but primarily live in association with structure (e.g. SAV, snags, woody debris), which typically occurs nearshore or toward bottom of the water column. For this species' habitat preference, the bottom and mid-depth areas are likely more useful in determining the potential for avoidance. However, this species will also frequent the upper portions of water column and thus surface avoidance areas may also be important. Observations of collection location during the current field study indicated

most Bluegill were collected by electrofishing along the shoreline and the few were collected by trawl in open water areas.

For the typical scenario at an acclimation temperature of 26.7°C (80°F), Bluegill potentially avoid water temperature of approximately 34°C (93.2°F) (Table 7-13). Table 7-6 provides model output for bluegill avoidance at surface, mid-depth, and bottom of the water column and also provides percent reduction in avoidance based on cooling tower operation. The avoidance temperature model for the typical case indicates avoidance areas for Bluegill are highest at no cooling tower operation for the surface (110 acres) and lowest for three cooling tower operation at the surface and mid- depth (1 acre) (Table 7-6; thermal plume diagrams). One cooling tower would potentially reduce surface avoidance areas by 53% and three cooling towers would reduce surface avoidance areas by 99%. Overall, predicted avoidance areas for Bluegill are extremely small in comparison to the entire Pond and restricted mostly to surface areas. The primary areas of habitat use by Bluegill are predicted to have extremely small avoidance zones for mid-depth and bottom areas. Cooling tower operation for these areas would only result in a small decrease in avoidance area for this species. These predicted areas of avoidance are restricted to the near-field along the western shoreline directly downstream from the PBAPS discharge.

The avoidance temperature for the extreme scenario is 35°C (95°F) at an acclimation of 30°C (86°F). Table 7-9 provides model output for Bluegill at surface, mid-depth, and bottom areas of the water column. The modeled areas for potential avoidance are small for mid-depth and bottom and nearly identical for no cooling towers or three cooling towers. The model predicts no reduction in avoidance for mid-depth regions with one, two, or three cooling towers operating and only a marginal decrease for the bottom region with one or two additional cooling towers. The largest predicted avoidance areas for Bluegill would occur at the surface (1,058 acres) and would be reduced by 50% with operation of three cooling towers.

Field collections at water temperatures similar to the extreme scenario show that Bluegill was present in water temperatures up to 36.5°C (97.7°F). A total of 23 Bluegill were collected at temperatures greater than 35°C (95°F) (Table 7-14). The data indicate that at least some individual Bluegill do not avoid temperatures up to 36.5°C (97.7°F) and that the avoidance model predictions are conservatively high, that is, the model overestimates potential avoidance areas for this species.

Chesapeake Logperch

No avoidance temperature data is available for this species (*Percina bimaculata*); however, Logperch (*Percina caprodes*) is thought to be particularly sensitive to elevated water temperatures. These are nearly identical species and some limited avoidance information is available for Logperch. Yoder (2006) calculated the Logperch upper avoidance temperature of 23°C (73.4°F) for use in developing temperature criteria for ORSANCO. This value is well below the maximum temperature of 33.9°C (93°F) in which four Chesapeake Logperch were collected in Conowingo Pond and are lower than the ambient water temperatures observed in Conowingo Pond which can reach or exceed 30°C (86°F) during the summer months. The lack

of sufficient avoidance temperature data for this species precludes the utility of completing avoidance temperature analysis for this species.

Although temperature tolerance information is not available for this species, the preferred habitat for this benthic species is at the bottom of the water column in nearshore areas and at the mouth of tributaries. Since Chesapeake Logperch is a benthic species, elevated water temperature at the surface and in open-water areas are unlikely to affect its distribution in the Pond.

White Sucker

White Sucker, one of the more thermally sensitive species, occur in low abundance in the Pond, primarily due to the nature of the habitat (impounded waterbody), which this species does not prefer. Literature values for White Sucker avoidance temperatures are limited. Yoder (2006) calculated White Sucker upper avoidance temperature of 29°C (84.2°F). Ambient water temperatures in Conowingo Pond can reach or exceed 30°C (86°F) during the summer months. Based on the available literature, the ambient conditions in Conowingo Pond preclude the utility of completing avoidance temperature analysis for this species.

Similar to Chesapeake Logperch, the White Sucker is a benthic species that inhabits areas near the bottom of the water column. Its distribution is limited within the Pond and is much more abundant in and near the mouth of tributary streams and potentially in the upper portion of the Pond. The elevated water temperatures at the surface are unlikely to affect its distribution.

Gizzard Shad

Gizzard Shad is one of the more thermally tolerant species to occur in the Pond. This species lives throughout the water column including open water, at or near the surface, and at the bottom. Occurrence and distribution within a waterbody depends on life stage. As such, potential avoidance areas occur throughout the water column and span the entire Pond for this species.

The model for the typical summer scenario utilizes an avoidance water temperature of 33°C (91.4°F) at an acclimation temperature of 26.7°C (80°F). The avoidance temperature model for this species indicates avoidance areas are highest at no cooling tower operation for the surface (315 acres) and lowest for three cooling tower operation at mid-depth (3 acres) (Table 7-5). Cooling towers operation would result in substantial decrease in avoidance areas at the surface ranging from 33% with one to 86% with three cooling towers. Reductions in avoidance areas would be minimal for mid-depth and bottom regions with operation of cooling towers. Predicted avoidance areas for Gizzard Shad are extremely small in comparison to the entire Pond. These areas of avoidance are restricted to the surface and near-field along the western shoreline directly downstream from the PBAPS discharge.

The avoidance temperature for the extreme scenario is 35°C (95°F) at an acclimation of 30°C (86°F). The avoidance model for Gizzard Shad indicates avoidance acreages would be highest at no cooling tower operation for surface (1,058 acres) and lowest for three cooling towers operating at the mid-depth and bottom (combined 24 acres) (Table 7-9). Cooling towers would

reduce surface avoidance areas from 18 to 50%. Cooling tower operation would not decrease the small areas of avoidance predicted to occur at the mid-depth regions and only marginally decrease avoidance areas at the bottom.

Field observations during conditions similar to the extreme scenario show that Gizzard Shad were collected at water temperatures between 36.0-36.9°C (96.8-98.4°F) (Table 7-14). A total of 20 Gizzard Shad were collected at temperatures greater than 35°C. For this species, habitat preference includes most of the Pond and avoidance areas were mostly restricted to surface areas.

Largemouth Bass

Largemouth Bass is one of the more thermally tolerant species present in the Pond. Similar to Bluegill, this species prefers shoreline habitat in association with structural features. This species tends not to frequent open-water habitats toward the surface of the water column. For this species, the bottom and mid-depth areas are more useful in determining the potential for avoidance. Catch data for the current study confirm general habitat preference for this species, with most Largemouth Bass collected along the shoreline while electrofishing and few collected by trawl in open water areas.

The model for the typical summer scenario utilizes avoidance water temperature of approximately 34°C (93.2°F) at acclimation of 26.7°C (80°F). Avoidance areas for Largemouth Bass are extremely small in comparison to the entire Pond and restricted to surface areas that are less likely to be used by this species (Table 7-6). The primary areas of habitat use by Largemouth Bass show extremely small avoidance zones with zero to three cooling towers operating, ranging from 6-11 acres combined for mid-depth and bottom areas. These areas of predicted avoidance are restricted to the near-field along the western shoreline directly downstream from the PBAPS discharge.

The avoidance temperature for the extreme scenario is 36°C (96.8°F) at an acclimation of 30°C (86°F). The avoidance temperature model for Largemouth Bass indicates preferred habitat avoidance acreages are low for this species (Table 7-10). The modeled areas for potential avoidance are small and nearly identical for no cooling towers and three cooling towers (13-14 acres bottom, 3-4 acres mid-depth). Operation of cooling towers is predicted to result in a marginal reduction in avoidance areas for preferred habitat of this species. One cooling tower would not reduce the already low avoidance areas for mid-depth or bottom regions. Three cooling towers would reduce mid-depth avoidance by 13% and bottom avoidance areas by 4%. Field observations during conditions similar to the extreme scenario indicate few Largemouth Bass were collected at water temperatures exceeding 34.0°C (93.2°F).

Smallmouth Bass

Smallmouth Bass is of intermediate tolerance to elevated water temperatures. Smallmouth Bass prefers cover and uses all forms of submerged cover; such as boulders, rocks, stumps, root-masses, trees, and crevices; without apparent preference for any one type. These types of habitat typically occur along shoreline and at the bottom of the Pond. This species typically

does not frequent the surface in open water. Catch data for the current study confirm general habitat preference for this species with most Smallmouth Bass collected along shoreline while electrofishing or seining and few collected by trawl in open water areas.

The model for the typical summer scenario utilizes avoidance water temperature of approximately 33°C (91.4°F) at acclimation of 26.7°C (80°F). The primary areas of habitat use by Smallmouth Bass show extremely small avoidance zones of 13 to 14 acres combined for mid-depth and bottom areas depending on the number of cooling towers operating (Table 7-5). Avoidance area reduction for these regions with three cooling tower operation would result in a maximum of 1-acre decrease in avoidance areas. These areas of avoidance are restricted to the near-field along the western shoreline directly downstream from the PBAPS discharge. At the specified avoidance temperatures, the avoidance areas for Smallmouth Bass are extremely small in comparison to the entire Pond and mostly restricted to surface areas that are less likely to be used by Smallmouth Bass.

The modeled avoidance temperature for the extreme scenario is 33°C at an acclimation of 30°C (86°F). For this species' habitat preference, the bottom and mid-depth areas are more useful in determining the potential for avoidance. The modeled areas for potential avoidance areas for Smallmouth Bass are sizable for no cooling towers (864 acres bottom, 1,902 acres mid-depth) and greatly reduced for three cooling towers (302 acres bottom, 32 acres mid-depth) (Table 7-8). Reduction in avoidance areas would be substantial with three cooling tower operation, with avoidance areas reduced 98% at mid-depth and 65% at the bottom.

Field sampling during conditions similar to the extreme scenario collected Smallmouth Bass at water temperatures exceeding 35°C (95F) (Table 7-14). A total of 50 Smallmouth Bass were collected at temperatures greater than or equal to 33°C. The data indicate that at least some Smallmouth Bass do not avoid temperatures of 33°C and that the selected avoidance temperature may be conservatively low for this species. This observation is supported by research performed by Mathur *et al.* (1983) that showed avoidance by this species occurred at temperatures exceeding 35°C.

Walleye

Walleye is one of the more thermally sensitive species to occur in the Pond. Similar to the basses, Walleye is typically found on the bottom of the Pond in both deep and shallow water habitats. This species does not typically occur toward the surface of the water column in open water areas, thus areas of elevated temperatures at the surface are not important to this species. Catch data for the current study confirm general habitat preference for this species with most Walleye collected along the shoreline while electrofishing and few collected with the trawl in off-shore bottom areas.

Walleye potentially avoid water temperature of approximately 32°C (89.6°F) at acclimation of 26.7°C (80°F). Modeled avoidance areas for the typical scenario are small in comparison to the entire Pond and mostly restricted to surface areas that are less likely to be used by this species. The primary areas of habitat use by Walleye show extremely small avoidance zones of 17-18 acres combined for mid-depth and bottom areas, depending on the number of cooling towers in

operation (Table 7-4). Operation of three cooling towers would result in less than a 2-acre decrease in avoidance areas for combined mid-depth and bottom areas. These areas of avoidance are restricted to the near-field along the western shoreline directly downstream from the PBAPS discharge.

The avoidance output for the extreme scenario is based on an avoidance temperature of approximately 32°C at an acclimation of 30°C (86 F). The modeled areas for Walleye are sizable for no cooling towers (3,048 acres bottom, 3,572 acres mid-depth) and smaller for three cooling towers (2,004 acres bottom, 3,433 acres mid-depth) (Table 7-7). Operation of three cooling towers would result in 34% decrease in bottom avoidance. Mid-depth regions would benefit marginally from operation of up to three cooling towers.

Field observations during conditions similar to the extreme scenario indicate Walleye were collected at water temperatures up to 30°C (86°F) (Table 7-14). Based on this species' habitat preference, the bottom and mid-depth areas are most useful in determining the potential for avoidance.

White Crappie

White Crappie is one of the more thermally sensitive species to occur in the Pond. It occupies both pelagic and shoreline habitats. Catch data for the current study confirm general habitat preference for this species with most White Crappie collected along the shoreline while electrofishing and few collected with the trawl in open water areas. For this species, the bottom and mid-depth areas are more useful in determining the potential for avoidance.

White Crappie potentially avoid water temperature of approximately 32°C (89.6°F) at acclimation of 26.7°C (80°F). The modeled output for the typical scenario indicates that the primary areas of habitat used by White Crappie would have extremely small avoidance zones of 17-18 acres combined for mid-depth and bottom areas, depending on the number of cooling towers in operation (Table 7-4). Operation of three cooling towers would result in less than 2 acre decrease in avoidance areas for combined mid-depth and bottom areas. These areas of avoidance are restricted to the near-field along the western shoreline directly downstream from the PBAPS discharge. Avoidance areas for White Crappie are a small percentage of the entire Pond and mostly restricted to surface areas that are less likely to be used by this species.

Table 7-7 provides modeled output for White Crappie for the extreme summer scenario based on an avoidance temperature of 32°C at an acclimation of 30°C (86°F). The modeled areas for potential avoidance by White Crappie are substantial for no cooling towers (3,048 acres bottom, 3,572 acres mid-depth) and smaller for three cooling towers (2,004 acres bottom, 3,433 acres mid-depth). Operation of three cooling towers would result in a 34% decrease in bottom avoidance. Mid-depth regions would benefit marginally from operation of up to three cooling towers. Cooling towers would have little effect on reducing avoidance areas at mid-depth regions.

Field sampling during conditions similar to the extreme scenario collected White Crappie at water temperatures between 32.0-32.9°C (89.6-91.2°F) (Table 7-14). However, it should be noted that few White Crappie were collected in Conowingo Pond over the course of this study.

Channel Catfish

Channel Catfish is the most thermally tolerant RIS in the Pond. This species occurs at various water depths, is typically oriented toward the bottom of the water column, and prefers structural features that provide cover. In the current field study similar numbers of Channel Catfish were collected by electrofishing along shoreline as were collected by trawl in deeper, open-water areas.

The model for the typical summer scenario utilizes avoidance water temperature of 34°C (93.2°F) at acclimation of 26.7°C (80°F). Table 7-6 provides the model output for this scenario. The primary areas of habitat use by Channel Catfish show extremely small avoidance zones regardless of cooling tower operation, ranging from 6-11 acres combined for mid-depth and bottom areas. These areas of avoidance would be restricted to the near-field along the western shoreline directly downstream from the PBAPS discharge. Potential avoidance areas for Channel Catfish would be extremely small in comparison to the entire Pond and restricted to surface areas that are less likely to be used by Channel Catfish. Cooling towers are predicted to marginally decrease avoidance areas for mid-depth and bottom regions.

The modeled avoidance temperature for the extreme scenario is 37°C (98.6°F) at an acclimation of 30°C (86°F), and output is provided in Table 7-11. The modeled bottom and mid-depth areas of potential avoidance for Channel Catfish would be small and nearly identical for no cooling towers (11 acres bottom, 3 acres mid-depth) and three cooling towers (10 acres bottom, 2 acres mid-depth). Cooling tower operation would result in a marginal decrease in avoidance areas at both mid-depth and bottom regions.

During conditions similar to the extreme scenario, Channel Catfish were collected at water temperatures between 35-35.9°C (95-96.6°F) in this study (Table 7-14). A total of 57 Channel Catfish was collected within this temperature range.

Bluntnose Minnow

Bluntnose Minnow have intermediate tolerance to elevated water temperatures. Its preferred habitat includes shallow areas of clear water with sand and gravel bottoms, but they are also found over mud and silt and/or aquatic vegetation. This species does not typically occur in open water toward the surface. Catch data for the current study show that most Bluntnose Minnow were collected along the shoreline while electrofishing or seining; few were collected by trawl in offshore areas. This species is commonly collected near the mouths of tributaries within Conowingo Pond. Due to the types of habitat preferred by this species, the bottom and mid-depth areas are more useful in determining the potential for avoidance.

The typical summer scenario used an avoidance water temperature of 33°C (91.4°F) at an acclimation of 26.7°C (80°F). Table 7-5 provides the typical summer scenario model output for Bluntnose Minnow. The primary areas of habitat use by Bluntnose Minnow show extremely

small avoidance zones depending on cooling tower operation ranging from 13-14 acres combined for mid-depth and bottom areas (Table 7-5). Cooling towers would be of little utility in reducing avoidance areas for mid-depth and bottom regions with 1 acre or less reduction with three cooling towers operating. These areas of avoidance would be restricted to the near-field along the western shoreline directly downstream from the PBAPS discharge. Potential avoidance areas for Bluntnose Minnow represent extremely small areas of the Pond and are restricted to surface areas that are less likely to be frequented by this species.

The modeled avoidance temperature for the extreme scenario is 33°C (91.4°F) at an acclimation of 30°C (86°F) as shown in Table 7-8. The modeled areas for potential avoidance by Bluntnose Minnow would be substantial for no cooling towers (864 acres bottom, 1,902 mid-depth) and much smaller with three cooling towers (302 acres bottom, 32 acres mid-depth). Cooling towers would be highly effective in reducing avoidance areas of the primary Bluntnose Minnow habitat. Three cooling towers would reduce mid-depth avoidance areas by 98% and bottom areas by 65%. Operation of one or two cooling towers would also provide significant reductions in avoidance areas for this species.

In this study, at temperature conditions similar to the extreme scenario, Bluntnose Minnow were collected at water temperatures exceeding 35.0°C (95°F), with 45individuals collected at temperatures exceeding 33°C (Table 7-14). The data indicate that some individuals do not avoid temperatures of 33°C.

Spotfin Shiner

Spotfin Shiner has intermediate tolerance to elevated water temperatures. This species is commonly collected near the mouths of tributaries or along shallow shoreline areas within Conowingo Pond and not in the more open-water areas. During the current study most Spotfin Shiner were collected from shallow shoreline habitat while electrofishing and seining; few were collected by trawl in off-shore bottom habitat.

The typical scenario used an avoidance temperature of 31°C (87.8°F) at an acclimation of 26.7°C (80°F). The primary habitats used by Spotfin Shiner show extremely small avoidance zones depending on cooling tower operation, ranging from 23-27 acres combined for mid-depth and bottom areas. Cooling towers would not be effective in reducing avoidance areas for mid-depths and only marginally decrease avoidance areas for bottom regions with one or two cooling towers. These areas of avoidance would be restricted to the near-field along the western shoreline directly downstream from the PBAPS discharge. The potential avoidance areas for Spotfin Shiner would be extremely small portion of the entire Pond and restricted to surface areas that are less likely to be used by this species.

The modeled avoidance temperature for the extreme scenario is 35°C (95°F) at an acclimation of 30°C (86°F), and model output is provided in Table 7-9. The modeled avoidance areas for Spotfin Shiner are small for no cooling towers (22 acres bottom, 4 mid-depth) and similar with three cooling towers (20 acres bottom, 4 acres mid-depth). Cooling towers would have little utility in reducing avoidance areas for the primary habitat of this species.

During conditions similar to the extreme scenario, Spotfin Shiner was collected at water temperatures exceeding 36.0°C (96.8°F) (Table 7-14). A total of 217 Spotfin Shiner was collected at temperatures exceeding 35°C indicating that the selected avoidance temperature may be conservatively low for this species.

Benthic Macroinvertebrate Community

Potential impacts to the benthos community are illustrated in a series of thermal plume diagrams for both the typical and extreme summer scenarios at various cooling tower operations. The potential areas of benthos impact are estimated based on the River bottom that would exceed 94°F. In general, potential impacts areas would be quite small for the typical scenario. Bottom areas greater than 94 °F would be confined to a narrow band along the western shoreline immediately downstream of PBAPS. Cooling tower operation would only marginally reduce the small areas of benthos impact.

For the extreme scenario, areas of potential benthos impact would be larger and extend farther downstream into Maryland. The extreme scenario without cooling towers shows that considerable amounts of bottom area would be >94°F extending along the western shoreline from the end of the PBAPS discharge canal downstream below the Pennsylvania-Maryland border along the western shoreline. Operation of cooling towers would substantially reduce areas >94°F and the associated theoretical impacts to the benthic community. However, it should be noted that the duration of the extreme scenario may not be sufficiently long to result in actual impact to the benthos community in all these areas.

Discussion

The Temperature Avoidance Model provided species-specific potential avoidance areas that varied widely depending on the avoidance temperature selected for evaluation, location in the water column, and the number of cooling towers in operation. For all species, the areas with potentially avoided temperatures were greatest at the water surface and smallest toward the bottom of the water column. The cross-sectional area output indicates that temperatures do not prohibit movement of fishes laterally around or through the PBAPS thermal plume. For the extreme case, sufficient areas of lower temperature water adjacent to areas of elevated water temperature are available to provide pathways for fish to move through or around the thermal plume. Fish can move vertically toward the bottom of the water column or laterally downstream or toward the east shoreline into areas with water temperatures at or near ambient.

Preferred habitat for a given species is important in interpreting the modeled temperature isotherms and potential avoidance areas. Open-water surface areas are not a primary or preferred habitat for most RIS in Conowingo Pond. Preferred habitats for most of the RIS are bottom and mid-depth areas of the water column typically associated with various types of structure.

The theoretical avoidance areas derived from the Temperature Avoidance Model are useful in characterizing the potential for fish exclusion from areas of the Pond. However, the Model assumptions and inputs for both scenarios were developed in a conservative fashion. These

conservatisms result in modeled avoidance areas that are much larger than indicated by actual field sampling data. The avoidance model also shows avoidance in locations where fish were collected in excess of the agreed-upon avoidance temperatures.

The available literature related to temperature avoidance utilizes two approaches for determining avoidance for a given species. There are laboratory based avoidance values that are determined by exposing a particular species to a range of elevated temperatures for several different acclimation temperatures. Other, often more conservative, avoidance temperatures are based on field observations which document the highest temperature at which a species was collected and then assign that temperature as the species-specific avoidance temperature.

Inherent in the various thermal studies is the variable thermal tolerance or plasticity observed among members of a species as well as for closely related species. The concept of thermal tolerance plasticity also aids in explaining the differences between laboratory and field based temperature tolerances. Thermal plasticity refers to the theory that a given ectothermic species does not have an inherent, invariable fixed tolerance to external temperature. Several studies have shown a wide range of thermal tolerance comparability for a given species between laboratory and field-based thermal sensitivity determinations.

Previous studies in Conowingo Pond documented field collection of individuals at temperatures greater than their expected laboratory-based avoidance and in some cases in excess of the species' reported upper incipient lethal temperature (UILT) (Normandeau Associates 1997-1999). In a study of brook and brown trout both species were observed to have natural short-term exposure (≤7 days) to maximum temperatures that were higher than laboratory-based 7-day ultimate upper incipient lethal temperature (UUILT) values (Essig 1998). This study also determined that field derived thermal tolerances for both trout species were very similar, in contrast to interspecific differences in thermal tolerance documented in previous laboratory and field studies. Similarly, a study of Bonneville cutthroat trout documented no adverse effect to trout in field conditions exposed to temperatures nearly 3°C above the laboratory determined 7-day UUILT (Shrank *et al.* 2003). These and other studies document the variability between field and laboratory based thermal sensitivity determination.

Differences in thermal histories may play an important role in the observed differences in thermal sensitivity among populations of a given species. In the present study, individuals of six of the RIS (Bluegill, Bluntnose Minnow, Gizzard Shad, Smallmouth Bass, Spotfin Shiner, and Walleye) were collected at water temperatures equal to or exceeding their theoretical avoidance temperatures. These field observations confirm the conservatively low nature of the species-specific avoidance temperatures provided in the literature. One potential reason for disagreement between literature avoidance temperatures and what was observed during the current study is the selection of acclimation temperature. The temperature avoidance model used ambient upriver temperature as the acclimation temperature. This is a conservative approach and does not reflect the actual temperatures that fishes are exposed and acclimated to by living within the thermal plume. These fishes are acclimated to temperatures that are likely several degrees higher than ambient which would result in higher avoidance temperatures. This is another conservative component of this model.

The Temperature Avoidance Model provided results similar to the previous study by Normandeau Associates (2000) which indicated that minimal portions of the Pond are in excess of avoidance temperatures. The areas of the PBAPS thermal plume with the highest water temperatures and potential avoidance of primary habitat are relatively small compared to the size of Conowingo Pond. Fish are free to move about and avoid the areas with temperatures not in their preferred range. Based on the coincident low-flow and high temperature conditions it can be inferred that little or no habitat exclusion occurs during spring and early summer, a peak spawning period for most fishes in Conowingo Pond. The largest potential avoidance areas occurred at near-field surface and mid-depth areas in July and August when the RIS have mostly completed their spawning activity or have left the area. These near-field surface and mid-depth regions are not vital to population maintenance. This is evidenced by the previously discussed similarity in composition and relative abundance of RIS in the Pond regardless of the operation of cooling towers.

Conclusions

- Modeling results for the typical scenario show that areas of fish avoidance would be small, localized, and temporary in nature.
- Most of the potential avoidance areas for the typical scenario would occur at the water surface in close proximity to the west shoreline immediately downstream from the discharge canal.
- Modeling results for the extreme scenario show that sizable potential avoidance areas would exist for several species with most of the elevated water temperatures and avoidance areas at the surface or in the immediate vicinity of the discharge canal.
- The modeled avoidance areas are conservatively large because fish were collected in locations where water temperatures exceeded their modeled avoidance temperatures.
- No habitat critical to the maintenance of the BIC would be avoided within the thermal plume, thus diminished maintenance of RIS is not expected.
- Cross-sections of the thermal plume for both modeling scenarios indicate that sufficient areas of the channel would be available at water temperature below the avoidance temperatures for the RIS to allow for their movement within the Pond

An increase in heat load from PBAPS will occur after the EPU is implemented. Based on the hydrothermal model results, it is likely that a BIC of aquatic biota will be maintained after the EPU. However, consideration should be given to thermal and biological monitoring after the power uprates are implemented. Monitoring and evaluation of actual thermal conditions post-EPU could be used to determine whether modification from operating under the previous variance is required to maintain a BIC.

Table 7-3. Modeled and percent reduction in avoidance area at various water depths for Spotfin Shiner (avoidance temperature = 31°C) based on typical summer scenario (80 °F ambient water temperature and discharge of 13,000 cfs) at EPU for the four cooling tower (CT) cases.

	Total Avoidance Area (acres)				Percent Reduction in Avoidance Area		
	0 CT	1 CT	2 CT	3 CT	1 CT	2 CT	3 CT
Surface area	1071	938	794	629	12	26	41
Area at 10-ft	4	4	4	4	0	0	0
Bottom area	23	21	19	19	10	19	19

Table 7-4. Modeled and percent reduction in avoidance area at various water depths for Walleye and White Crappie (avoidance temperature = 32°C) based on typical summer scenario (80 °F ambient water temperature and discharge of 13,000 cfs) at EPU for the four cooling tower (CT) cases.

	Total Avoidance Area (acres)				Percent Reduction in Avoidance Area		
	0 CT	1 CT	2 CT	3 CT	1 CT	2 CT	3 CT
Surface area	661	517	371	240	22	44	64
Area at 10-ft	4	3	3	3	11	10	11
Bottom area	14	14	14	14	0	3	2

Table 7-5. Modeled and percent reduction in avoidance area at various water depths for Smallmouth Bass, Bluntnose Minnow and Gizzard Shad (avoidance temperature = 33°C) based on typical summer scenario (80 °F ambient water temperature and discharge of 13,000 cfs) at EPU for the four cooling tower (CT) cases.

	Total Avoidance Area (acres)				Percent Reduction in Avoidance Area		
	0 CT	1 CT	2 CT	3 CT	1 CT	2 CT	3 CT
Surface area	315	210	118	45	33	62	86
Area at 10-ft	3	3	3	3	0	0	4
Bottom area	11	11	11	10	1	5	8

Table 7-6. Modeled and percent reduction in avoidance area at various water depths for Bluegill, Channel Catfish, and Largemouth Bass (avoidance temperature = 34°C) based on typical summer scenario (80 °F ambient water temperature and discharge of 13,000 cfs) at EPU for the four cooling tower (CT) cases.

	Total Avoidance Area (acres)				Percent Reduction in Avoidance Area		
	0 CT	1 CT	2 CT	3 CT	1 CT	2 CT	3 CT
Surface area	110	51	15	1	53	87	99
Area at 10-ft	2	2	2	1	4	14	41
Bottom area	9	9	8	5	4	17	41

Table 7-7. Modeled and percent reduction in avoidance area at various water depths for Walleye, White Crappie, and White Sucker (avoidance temperature = 32°C) based on extreme summer scenario (86°F ambient water temperature and discharge of 7,000 cfs) at EPU for the four cooling tower (CT) cases.

	Total Avoidance Area (acres)				Percent Reduction in Avoidance Area		
	0 CT	1 CT	2 CT	3 CT	1 CT	2 CT	3 CT
Surface area	5681	5577	5452	5318	2	4	6
Area at 10-ft	3572	3554	3512	3433	1	2	4
Bottom area	3048	2777	2504	2004	9	18	34

Table 7-8. Modeled and percent reduction in avoidance area at various water depths for Smallmouth Bass and Bluntnose Minnow (avoidance temperature = 33°C) based on extreme summer scenario (86°F ambient water temperature and discharge of 7,000 cfs) at EPU for the four cooling tower (CT) cases.

	Total Avoidance Area (acres)				Percent Reduction in Avoidance Area		
	0 CT	1 CT	2 CT	3 CT	1 CT	2 CT	3 CT
Surface area	4762	4290	3795	3280	10	20	31
Area at 10-ft	1902	1117	246	32	41	87	98
Bottom area	864	660	437	302	24	49	65

Table 7-9. Modeled and percent reduction in avoidance area at various water depths for Spotfin Shiner, Gizzard Shad, and Bluegill (avoidance temperature = 35°C) based on extreme summer scenario (86°F ambient water temperature and discharge of 7,000 cfs) at EPU for the four cooling tower (CT) cases.

	Total Avoidance Area (acres)				Percent Reduction in Avoidance Area		
Depth	0 CT	1 CT	2 CT	3 CT	1 CT	2 CT	3 CT
Surface area	1058	873	702	525	18	34	50
Area at 10-ft	4	4	4	4	0	0	0
Bottom area	22	21	20	20	6	10	10

Table 7-10. Modeled and percent reduction in avoidance area at various water depths for Largemouth Bass (avoidance temperature = 36°C) based on extreme summer scenario (86°F ambient water temperature and discharge of 7,000 cfs) at EPU for the four cooling tower (CT) cases.

	Total Avoidance Area (acres)				Percent Reduction in Avoidance Area		
	0 CT	1 CT	2 CT	3 CT	1 CT	2 CT	3 CT
Surface area	649	491	337	195	24	48	70
Area at 10-ft	4	4	3	3	0	11	13
Bottom area	14	14	14	13	0	2	4

Table 7-11. Modeled and percent reduction in avoidance area at various water depths for Channel Catfish (avoidance temperature = 37°C) based on extreme summer scenario (86°F ambient water temperature and discharge of 7,000 cfs) at EPU for the four cooling tower (CT) cases.

	Total Avoidance Area (acres)				Percent Reduction in Avoidance Area		
	0 CT	1 CT	2 CT	3 CT	1 CT	2 CT	3 CT
Surface area	333	206	105	34	38	68	90
Area at 10-ft	3	3	3	2	0	2	8
Bottom area	11	11	10	10	0	1	7

Table 7-12. Upper avoidance temperatures for RIS based on 30°C (86°F) acclimation temperature. Avoidance temperatures were evaluated based on review of relevant literature.

	Avoidance Temperature (°C)		
Species	Agreed-Upon[4]	Mathur[3]	Yoder[5]
spotfin shiner	35	33	34
channel catfish	37	37	35
largemouth bass	36	36	32
smallmouth bass	33	35	32
walleye	32	33	30[c]
white crappie	32	34	31
bluegill	35	35	34
bluntnose minnow	33	35[a]	31
Chesapeake logperch[2]	NA[d]	NA	22.7[c]
white sucker	32	NA	28.7[c]
gizzard shad	35	35	34

NA no data available for species

[a]Used the equation developed for falling water temperatures because it was more conservative

[2] Note that value for *Percina caprodes* (logperch)

[5] Upper avoidance temperature calculated for use in Fish Temperature Model (Appendix Table Z-3) used in developing temperature criteria for ORSANCO

[3] Values calculated from regression equations given in Mathur et al. 1983

[c] Ambient summer temperatures in Conowingo Pond exceed value

[d] Collected at 33.9°C in Conowingo Pond during 2011

[4] Values based on discussion with PADEP

Table 7-13 Upper avoidance temperatures for RIS based on 26.7°C (80°F) acclimation temperature.

	Avoidance Temperature (°C)
Species	Mathur[1]
spotfin shiner	31
channel catfish	34
largemouth bass	34
smallmouth bass	34
walleye	32
white crappie	32
bluegill	34
bluntnose minnow[2]	33
Chesapeake logperch	NA
white sucker	NA
gizzard shad	33

NA no data available for species

[1] Values calculated from regression equations given in Mathur et al. 1983

[2]Used the equation developed for falling water temperatures because it was more conservative

Table 7-14. Total number of RIS collected at elevated water temperatures, 2010-2013.

	Water Temperature °C				
Taxon	32 - 32.9	33 - 33.9	34 - 34.9	35 - 35.9	36 - 36.9
Gizzard shad	1,025	1,354	4	17	3
Spotfin shiner	128	146	270	121	96
Bluntnose minnow	10	16	16	13	
White sucker	1				
Channel catfish	89	119	10	57	
Bluegill	150	30	92	16	7
Smallmouth bass	39	21	6	22	1
Largemouth bass	2	5	3		
White crappie	2				
Chesapeake logperch		4			
Walleye					
Total number	1,446	1,695	401	246	107
Total Species	9	8	7	6	4

8 Summary of Conclusions

The three main components of this study are temperature monitoring, biological monitoring and hydrothermal modeling. Each component can be used independently to make a meaningful assessment of the PBAPS thermal discharge and to make decisions related to the applicability of a thermal variance. In combination, the three components provide a robust framework for evaluating whether a 316(a) thermal variance is appropriate for PBAPS.

The main findings and conclusions for each component of the study are provided below.

Temperature Monitoring

- The towers performed as designed; each tower cooled the discharge by about an additional 1.6°F, measured from the head to the end of the discharge canal.
- Operation of the towers reduced water temperatures in Conowingo Pond by consistent and measurable amounts within 1.2 miles of the discharge and near the western shoreline and by smaller amounts beyond 1.2 miles where reductions were variable and related to ambient temperatures and Susquehanna River flows.

Benthic Macroinvertebrate Community

- The composition and relative abundance of the benthic community was similar during all 4 years of the study.
- Temporary impact, in terms of lower IBI scores, was observed at Stations 214 and 215 in July and August after a sustained period of high water temperatures, but was followed by recovery.
- Benthic community changes resulting from the thermal plume are localized and temporary and limited to a small proportion of the available shallow shoreline habitat within Conowingo Pond.
- There was no observed impact to the benthic community at the three thermally-influenced Stations (189, 216 and 217) that are 1.3 miles or more downstream from the discharge canal.
- There is a balanced indigenous benthic community within Conowingo Pond.

Fish Community

- Inter-annual variation in relative abundance of the RIS and other species did not appear to be related to differences in water temperature resulting from cooling tower operation.
- Relative abundance of most RIS from 2010 through 2013 was within the range of values observed previously in Conowingo Pond.
- Metrics used to describe fish community structure show no clear differences in the fish community between thermally influenced and non-thermally influenced locations.
- Limited avoidance by selected species was observed at Stations 161, 214, and 215 which are closest to the end of the discharge canal, during the periods of highest water temperature in July and/or August.

- Little or no habitat avoidance occurs in May and early June, the peak spawning period for most fishes in Conowingo Pond.
- The observed fish avoidance for select species occurred mostly in July and August when either the species move out of the area or for most RIS, have completed spawning activity.
- Observations of the aquatic community during the current study support the thermal variance that PBAPS has operated under since 2000.

Hydrothermal Model

- The model accurately reproduces the hydrodynamics and thermal structure of the Pond relative to the PBAPS thermal plume and other dynamic input parameters.
- The agreement of computed and observed temperatures over the range of conditions that occurred in 2010, 2011 and 2012 allows the model to predict the thermal structure in the pond for other-than-observed conditions.
- The model provides detailed information for the PBAPS thermal plume that can be used to quantify temperature zones that are potentially avoided by fish in Conowingo Pond.
- EPU modeling results for the *typical summer condition* show that areas of potential fish avoidance would be small, localized, and temporary in nature.
- Most of the potential avoidance areas for the *typical summer condition* modeling scenario would occur at the water surface proximate to the west shoreline immediately downstream from the discharge canal.
- EPU modeling results for the *extreme summer condition* show that areas of potential fish avoidance would be sizable for several species with most of the elevated water temperatures and avoidance areas at the surface or in the immediate vicinity of the discharge canal.
- No habitat critical to the maintenance of the BIC would be avoided within the thermal plume, thus diminished maintenance of RIS would not be expected.
- Cross-sections of the thermal plume for both modeling scenarios indicated that sufficient areas of the channel would be available at water temperatures less than the avoidance temperatures for the RIS and will allow for their movement within the Pond.

The findings and conclusions from the three main components provide for an overarching set of conclusions.

- The previous thermal variance that allows for operation of PBAPS without cooling towers sustains, and protects, the integrity of the BIC of Conowingo Pond.
- The previous variance is appropriate and supported by the fish and benthic community monitoring and analyses.
- No appreciable harm to the aquatic community has occurred as a result of the thermal discharge.

This demonstration study concludes that under current operation of PBAPS, there is a BIC in Conowingo Pond. The conditions of a thermal variance are satisfied and confirmed with the

present study. The previous 316(a) thermal variance is appropriate and achieves the goal of protecting and maintaining the BIC. Continuation of the previous thermal variance is appropriate and warranted based on the results of this study. A similar conclusion was reached after the completion of the most recent historic thermal effects study.

An increase in the heat load from PBAPS to Conowingo Pond will occur after the EPU. Based on the hydrothermal model, it is likely that a BIC will be maintained after the EPU. However, consideration should be given to thermal and biological monitoring after the power uprates are implemented. Monitoring and evaluation of actual thermal conditions post-EPU could be used to determine whether modification from operating under the previous variance is required to maintain a BIC.

9 Glossary

BIC	Balanced indigenous community
BTU	British thermal unit
cfs	Cubic feet per second
CLTP	Current Licensed Thermal Power
CPUE	Catch per unit effort
Delta-T	Temperature rise, typically between the intake and the discharge
EPU	Extended Power Uprate
GEMSS	Generalized Environmental Modeling System for Surface waters
MRPSF	Muddy Run Pump Storage Facility
MWe	Megawatts electric
MWt	Megawatts thermal
PBAPS	Peach Bottom Atomic Power Station
RIS	Representative important species
SAV	Submerged aquatic vegetation

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10.2 GEMSS

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11 Appendices

11.1 Study Plan

11.2 Supplemental Data

11.3 DVD with Model and Results