Table 1. Species of mussels observed during survey of Susquehanna River completed near the proposed BBNPP site, October 2007.

Common name	Scientific name
Eastern Elliptio	*Elliptio complanata*
Eastern Floater	*Pyganodon cataracta*
Elktoe	*Alasmidonta marginata*
Triangle Floater	*Alasmidonta undulata*
Yellow Lampmussel	*Lampsilis cariosa*
[1]Green Floater	*Lasmigona subviridis*

[1] This species was not collected during the mussel survey. However, a single individual was identified in a macroinvertebrate sample collected by dome sampler upstream of the SSES intake.

VOLUME I – REPORT

POTENTIAL EFFECTS OF THE BELL BEND PROJECT ON AQUATIC RESOURCES AND DOWNSTREAM USERS

Proposed Bell Bend Nuclear Power Plant Site
Luzerne County, Pennsylvania

Report Number: 21665.001-LFHC4

Rev. 1, May 10, 2012

Prepared for

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Allentown, PA 18101

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ABBREVIATIONS

Abbreviation	Meaning
°F or °C	Degrees Fahrenheit or Celsius (water temperature)
ΔT	Change in temperature
7Q10	Seven-day, consecutive low flow with a ten-year return frequency.
ADCP	Acoustic Doppler Current Profiler, instrument to measure velocity at varying depths
ADF	Average Daily Flow computed on an annual basis
AMD	Acid Mine Drainage or Abandoned Mine Drainage
BBNPP	Bell Bend Nuclear Power Plant
BTA	Best Technology Available
cfs	Cubic feet per second; 1 cfs = 0.646 mgd
CORMIX	Cornell Mixing Zone Expert System, the USEPA mixing zone model
CU	Consumptive water use
DO	Dissolved oxygen
EPA	United States Environmental Protection Agency
HSC	Habitat Suitability Curve, index used to indicate fish preferences for microhabitat variables (e.g., water velocity, depth, substrate/cover);expressed on a scale of 0 (least suitable) to 1 (optimum)
IFIM	Instream Flow Incremental Methodology, habitat-based methodology to estimate available aquatic habitat under changing flow conditions; based on the premise that stream-dwelling organisms prefer a certain range of microhabitats (velocity,depth,and substrate/cover)
mgd	Million gallons per day; 1 mgd = 1.55 cfs
mg/L	Milligrams per liter
NRC	Nuclear Regulatory Commission
nWUA	Normalized WUA
PADEP	Pennsylvania Department of Environmental Protection
PFBC	Pennsylvania Fish & Boat Commission
PHABSIM	Physical Habitat Simulation, model integrates outputs of hydraulic model(s) and species micro-habitat preferences (depth, velocity, and substrate/cover)
PPL Bell Bend	PPL Bell Bend, LLC; sponsor of the BBNPP project
Sonde	Device that measures DO, temperature, pH and conductivity; French for "probe"
SRBC	Susquehanna River Basin Commission
SSES	Susquehanna Steam Electric Station
TRPA	Thomas R. Payne & Associates
TS	Time series
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WBAN	Weather Bureau-Army-Navy
WUA	Weighted Usable Area, an index of available habitat
WWF	Warm Water Fishery

1. SUMMARY

In October 2008, PPL Bell Bend, LLC (PPL Bell Bend) applied to the U.S. Nuclear Regulatory Commission (NRC) for a combined license to construct and operate the Bell Bend Nuclear Power Plant (BBNPP). The BBNPP will be a single-unit plant with an electrical output of approximately 1,600 megawatts, located adjacent to the Susquehanna Steam Electric Station (SSES) in Salem Township, Luzerne County, Pennsylvania.

On May 13, 2009, PPL Bell Bend applied to the Susquehanna River Basin Commission (SRBC or Commission) for approval of water use at the proposed BBNPP. In November 2009, PPL Bell Bend submitted a proposed study plan to the SRBC and cooperating agencies for review and comment. Subsequent discussions focused the study plan on five potential effects of consumptive water use. These potential effects have been studied and are addressed in this report in the form of responses to five questions. It should be noted that studies regarding the presence or absence of mussel species of concern, and associated impact analyses are the subject of separate studies to be undertaken in 2012. The results of these studies will be separately reported.

The study questions and a summary of the results of this study are presented below.

- ***What is the relationship between aquatic habitat and river flows for selected fish species and life stages with and without the BBNPP water withdrawal / consumptive use (BBNPP water use)?***

Physical Habitat Simulation (PHABSIM) analysis of aquatic habitat for eight fish species indicates that negative impacts on habitat due to the requested BBNPP water use are generally small and infrequent, and would not contribute to habitat-related population limitations.

- ***Is there a potential that BBNPP water use will cause an incremental impairment in water quality below Nescopeck Creek due to known abandoned mine drainage (AMD) in the Creek?***

Nescopeck Creek water quality is impaired due to AMD in the upper (eastern) part of the Creek's watershed. AMD from the Creek degrades water quality in the Susquehanna River. The potential for additional impairment of river water quality attributable to reduced dilutive capacity that could result from BBNPP water use was investigated by an extensive field program supplemented with mass balance calculations. It was determined that pH in the Susquehanna River recovered within a short distance of the Nescopeck Creek for all observed flow ranges. Flow from the Nescopeck Creek hugs the left shore of the river, effectively creating an AMD plume along the left shore. No surveys showed migration of the AMD plume into the main channel of the Susquehanna. Because the surveys were made over a large range of Susquehanna River flows and the behavior of the AMD plume was consistent from one survey to the next, it is concluded that a reduction in flow due to BBNPP water use would not affect either the extent of the AMD plume or the mixed pH in the Susquehanna River.

- ***What are the potential effects of BBNPP blowdown discharge on river water temperature and dissolved oxygen concentration?***

Because the BBNPP diffuser is nearly identical to the existing SSES diffuser, the latter's performance provides the best estimate of the anticipated performance of the BBNPP diffuser. The SSES blowdown discharge plume has been measured in three dimensions on five occasions covering a range of Susquehanna River flows. All five surveys showed small thermal plumes. The US Environmental Protection Agency's (EPA's) standard thermal plume model, the Cornell Mixing Zone Expert System (CORMIX), was shown to reproduce the observed dimensions of the SSES thermal plume. CORMIX replicated the BBNPP thermal plume under average and low flow conditions and indicated similar, small plumes for BBNPP. Potential reductions in dissolved oxygen concentrations due to the small rises in temperature adjacent to the BBNPP diffuser would be minimal and of limited extent.

- ***What is the impact of reduced river flow and stage due to BBNPP water use on dissolved oxygen and temperature in backwater areas habitable by smallmouth bass?***

There are few if any persistent backwater areas in this stretch of river and their extent varies seasonally. Smallmouth bass do spawn and develop through June. A "critical" period of SMB has generally been defined for this area of the Susquehanna River as May 1 through July 31 with additional consideration for habitat quality in August. Once water temperatures consistently exceed 84-85°F, juveniles migrate from the shoreline backwater habitat into deeper river water and this has generally occurred by the end of July. Collected water quality data confirm that during the summer low flow months similar to those recorded in 2005 and 2010, there are natural occurrences of water quality not meeting the Pennsylvania State criteria for a warm water fishery (WWF). These conditions were evaluated for the incremental effect of a 43 cfs consumptive use on shallow area temperatures in intensity, frequency and duration of events above the WWF standard and a potential critical threshold temperature of 84°F. Results suggest no significant change or increase in the stressors.

- ***Are there effects of BBNPP water use on downstream water withdrawers and dischargers?***

Users and dischargers of treated wastewater as far downstream as Danville were cataloged and phone interviewed with respect to anticipated impacts on either their water withdrawals or compliance with discharge limitations. One large water user expressed concern about the impact of BBNPP water use on its activities; several dischargers and one water user expressed interest in further evaluating impacts, but none voiced immediate objections. One large user anticipated little to no effect; two large dischargers anticipated no significant impact after running models and/or consulting with the Pennsylvania Department of Environmental Protection (PADEP). The smaller entities that responded did not anticipate any impacts from the proposed BBNPP water use, although one smaller discharger reserved the right of future comment. Based on discussion provided in Section 6 of this report the Bell Bend consumptive use is not expected to impact downstream users.

2. *AQUATIC HABITAT MODELING USING IFIM*

The Instream Flow Incremental Methodology (IFIM), developed by the U.S. Fish and Wildlife Service and supported by the U.S. Geological Survey, is commonly used to provide structure to the analysis of flow alteration effects on riverine aquatic habitat (Bovee et al. 1998). The IFIM is a modular decision-support system that includes elements for problem diagnosis, project scoping, legal-institutional analysis, baseline and study area designation, study method selection and implementation, linkage between scientific disciplines, alternatives analysis, and negotiation and resolution of project provisions (Figure 2-1). Different pathways through the IFIM schematic can be taken, depending on the level of participation by interested parties, the nature and timing of project evaluation needs, the type of potential aquatic impacts of the project, budgetary considerations, the regulatory environment, and the needs and policies of study participants. For BBNPP, the first step was development of 1-D and 2-D models to describe habitat per unit of river (left lower center of process flow chart) and the second step was application of river hydrology and operating flows to develop the time series analysis (center of process flow chart).

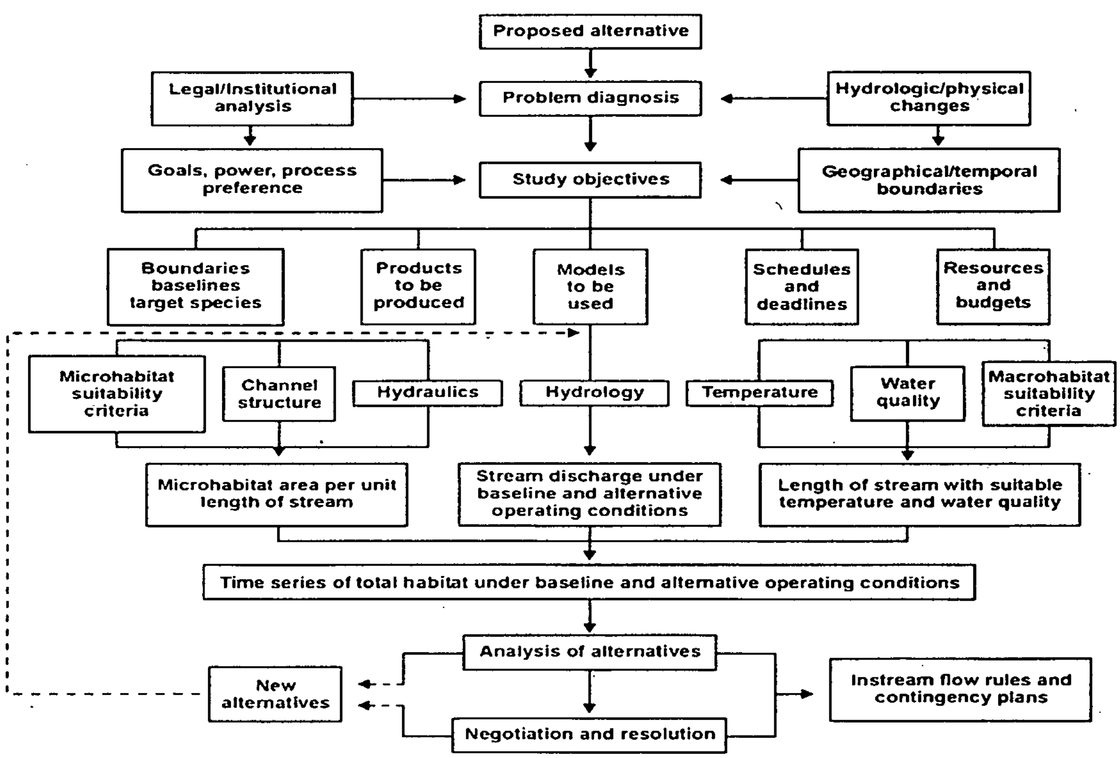
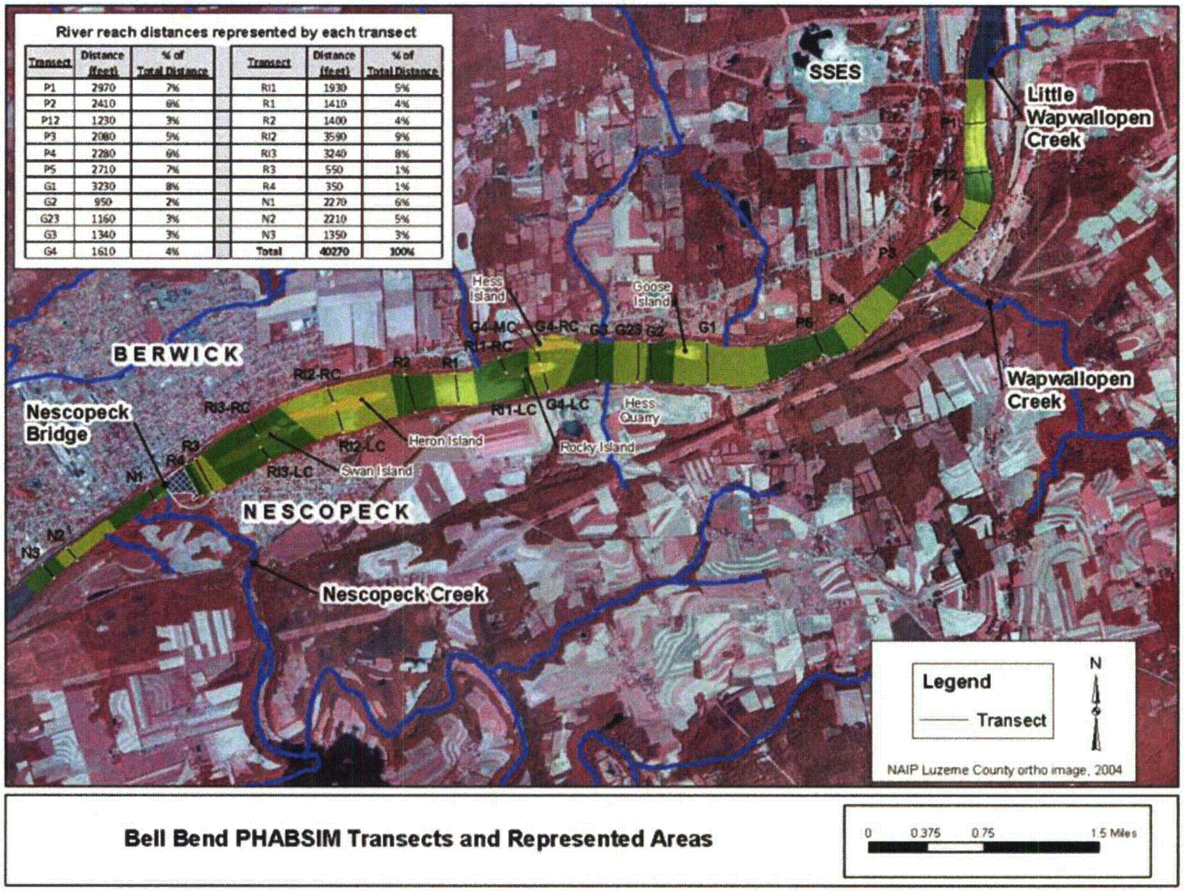


Figure 2-1 Schematic of the Instream Flow Incremental Methodology

2.1. *APPLICATION OF THE IFIM TO THE BELL BEND PROJECT AREA*

The proposed BBNPP would have a consumptive water use of up to 28 mgd (43 cfs), thereby potentially affecting the hydrology of the Susquehanna River and the habitat of aquatic species through changes to habitat suitability and water quality, including temperature. To assess the potential impacts of the BBNPP water use on aquatic habitat, a physical habitat simulation (PHABSIM) study was initiated. This type of study models stream channel hydraulics over a range of flows and links the hydraulic variables of depth and velocity (and a measure of substrate and/or cover) with microhabitat suitability criteria for target species to determine an index of suitable microhabitat area per unit length of stream (center left portion of Figure 2-1). Potential project impacts are then evaluated by the change in stream discharge under baseline and proposed project hydrology (center of Figure 2-1). The BBNPP PHABSIM study initially used a one-dimensional (1D) hydraulic model on 21 cross-sectional transects in the seven miles of river in the project area (Figure 2-2), and was subsequently supplemented with a two-dimensional (2D) hydrodynamic model in the complex shoal and island area around Rocky Island (Figure 2-3).



River reach distances represented by each transect

Transect	Distance (feet)	% of Total Distance	Transect	Distance (feet)	% of Total Distance
P1	2970	7%	RI1	1930	5%
P2	2410	6%	R1	1410	4%
P12	1230	3%	R2	1400	4%
P3	2080	5%	RI2	3590	9%
P4	2280	6%	RI3	3240	8%
P5	2710	7%	R3	550	1%
G1	3230	8%	R4	350	1%
G2	950	2%	N1	2270	6%
G23	1160	3%	N2	2210	5%
G3	1340	3%	N3	1350	3%
G4	1610	4%	Total	40270	100%

Figure 2-2 The BBNPP 1D PHABSIM study reach, showing the location of 21 study transects and represented river sections in light green/dark green bands

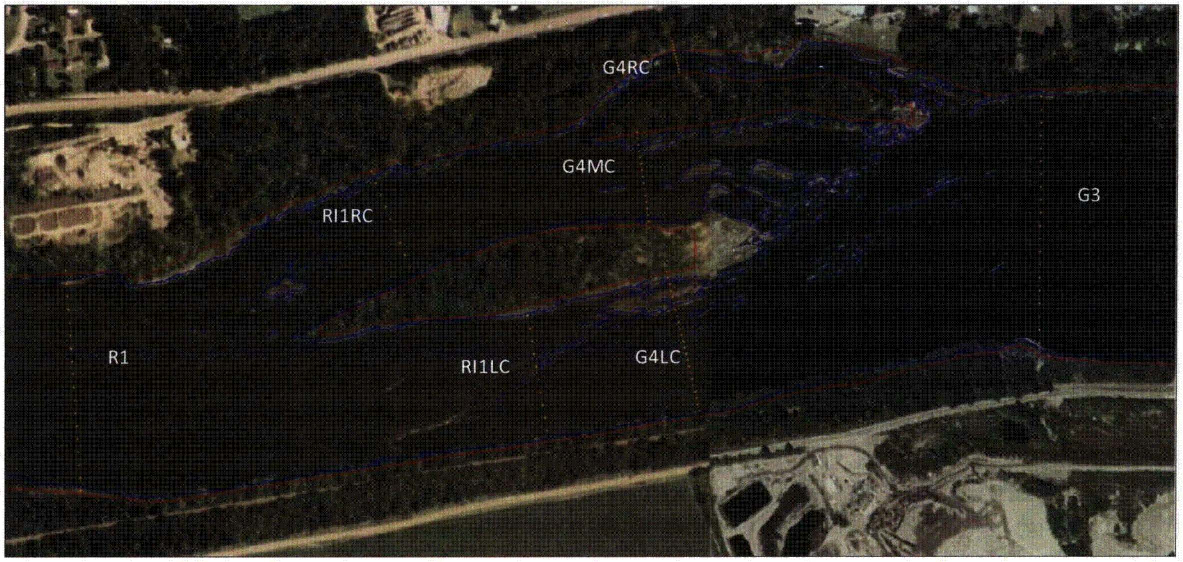


Figure 2-3 The BBNPP 2D study site between the R1 and G3 1D transects around Rocky Island

2.2. ECOLOGICAL CONCEPTS AND METHODS OF PHABSIM

Physical Habitat Simulation (PHABSIM) is based on the premise that stream-dwelling organisms occupy a specific range of depths, velocities, substrates, and cover types, and that their biomass (or abundance) will vary as the available habitat of these parameters changes with stream flow. The assessment method is designed to quantify potential physical habitat available for each species and life stage of interest at various levels of stream discharge, using a series of computer programs (Bovee 1982).

A natural stream contains a complex mosaic of physical features. One area, such as a riffle, may be shallow and fast-moving over a substrate of cobble and gravel and no cover, while another area, such as a pool, may be deep and slow-moving over a substrate of silt, with a large root wad along the shore. One species life stage may find the riffle suitable while another species may occupy the pool; a third species may utilize both. These different habitat types (e.g., pools, riffles, runs, and glides) are referred to as mesohabitats. (Macrohabitat refers to a larger segment of river composed of multiple mesohabitats, and microhabitat is the location within a mesohabitat occupied by organisms.) A fish species or life stage utilizes or avoids portions of a particular mesohabitat because the microhabitat characteristics of depth, velocity, substrate, and cover are either within or outside of its preferred range.

The suitability of velocity, depth, and substrate and cover for aquatic species and life stages are described with habitat suitability criteria (HSC) curves in which the optimum range of a particular microhabitat variable is assigned a value of 1.0, the unsuitable range a value of 0.0, and intermediate conditions values between the extremes. A PHABSIM habitat index is computed from the physical conditions at the measurement points of the hydraulic models, adjusted for the suitability of those conditions, and summed by area represented by the measurement points. This habitat index is commonly referred to as weighted usable area (WUA)

but more accurately as area-weighted suitability (AWS). The common term WUA is used in this report for convenience.

There are two basic approaches to sampling the hydraulic conditions of a river within a defined project area: habitat mapping or representative reach. Habitat mapping characterizes and categorizes the quantity and distribution of all mesohabitats in the project area, and transects are placed to sample and represent the microhabitat conditions of the mesohabitats. A representative reach focuses on a representative subsection (reach) of the project area and transects are placed to completely sample the subsection. One-dimensional hydraulic models are based on transects and can be used for either habitat mapping or representative reach sampling. Two-dimensional hydraulic models are based on contiguous sections of river and typically use representative reaches. Choosing between the two methods depends on the length of the project area and whether or not a representative reach (or reaches) can be identified with confidence.

There are several methods capable of using WUA habitat index results from either (or both) a 1D or 2D modeling approach. The principal IFIM method, habitat duration analysis (bottom-center of Figure 2-1), relies on analyzing the frequency and duration of flow under baseline and alternative project hydrology. For any given time step (e.g. hourly, weekly, monthly) in time periods appropriate for each species and life stage, flow values are converted to equivalent habitat index values from the WUA-flow relationships. These equivalent habitat index values are then treated in the same way as standard flow duration analysis to create habitat duration (or habitat time series) analysis, from which changes in habitat availability over time can be quantified (Bovee et al. 1998, Denslinger et al. 1988). Water managers or regulatory agencies can then use this analysis to determine the significance of the flow and habitat alteration and/or whether mitigation will be necessary.

2.3. 1D Model Methods Summary

The 1D hydraulic model was built with the data collected from 21 transects (Figure 2-2) placed in four habitat types. Data collection targeted flows of approximately 2,000 cfs, 5,000 cfs, and 10,000 cfs. These targets permitted data extrapolation to flows as low as the 7Q10 (820 cfs at the Wilkes-Barre river gaging station), and as high as approximately 25,000 cfs. The hydraulic data measurements followed the guidelines established in the PHABSIM field techniques manuals (Trihey and Wegner, 1981; Milhous et al., 1984; Bovee, 1997). Water surface elevations and bank profiles were surveyed relative to temporary benchmarks, which were later surveyed to true elevation with an RTK GPS. Velocities and depths were measured at high flow primarily with an acoustic Doppler current profiler (ADCP), except for the two transects that were added during an agency site visit after the high flow measurements. The substrate and cover were coded at low flow. The flow at the four split-channel transects was partitioned by measuring discharge at each calibration flow in each channel. All data were entered into RHABSIM software developed by Thomas R. Payne & Associates (TRPA) that implements the equivalent algorithms of PHABSIM.

The hydraulic model utilized an empirical log/log regression calculation based on the three measured calibration flows to determine the stage/discharge relationship. Each channel of the split-channel transects was modeled independently. The channel conveyance method was used

for quality control. Stations across each transect for depth and velocity measurements were incremented at four to six feet depending on channel width at individual transects. The single velocity method was used to simulate velocities at each station through the range of flows from 800 to 25,000 cfs. A complete description of the 1D hydraulic model methods and results is presented in Appendix 2-HYD.

After calibration according to established practice (Waddle 2001), the 1D model was used to simulate hydraulic conditions over the range of flow between 800 cfs (40% of 2,000 cfs low flow) to 25,000 cfs (250% of 10,000 cfs high flow). The limits of low and high flow extrapolation are initially set by the quality of the calibrated stage-discharge rating curves, supplemented by review of simulated velocities.

2.4. 2D MODEL METHODS SUMMARY

Data acquisition and calibration of the 2D hydraulic model used in the BBNPP project area for evaluation of aquatic habitat effects are presented in Appendix 2-A of this report. The topography of the study reach (Figure 2-3) was surveyed at high flow using depth sounding by boat with GPS and an ADCP, and at low flow using a robotic total station (equipment that can collect data with the user at a distance). All bathymetry data points (703,813) were entered into the bed topography module of River2D (Steffler and Blackburn 2002), a computational mesh of 225,982 nodes (density of 0.35 nodes/m^2) was created, and the resulting model was calibrated at a flow of 2,295 cfs against measured water surface elevation data by refining the mesh and adjusting bed roughness. After calibration, boundary conditions were set in replicate models for each of fifteen simulation flows between 500 and 2200 cfs. The fifteen models were run to steady state conditions where solution changes were all between 0.008 and 0.08 per iteration, showing good agreement.

2.5. HABITAT SUITABILITY CRITERIA FOR TARGET SPECIES

Habitat suitability criteria (HSC) curves for eight target fish species and two to four life stages per species (23 in all) were initially selected from literature sources, reviewed by participating resource agencies, amended in response to comments, and eventually agreed upon. The species, life stages, and seasonal periodicities are shown in Table 2-1. HSC coordinate points and graphs are contained in Appendix 2-HSC.

Table 2-1 Seasonal periodicity (blue shaded rectangles) of target species

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
American shad												
Spawning				■	■							
Fry				■	■	■						
Juvenile							■	■	■			
Adults					■	■						
River chub												
Adult/Juvenile	■	■	■	■	■	■	■	■	■	■	■	■
Northern hogsucker												
Spawning				■	■							
Fry					■							
Adults	■	■	■	■	■	■	■	■	■	■	■	■
Smallmouth bass												
Spawning					■	■						
Fry						■	■					
Juvenile								■	■	■	■	■
Adults	■	■	■	■	■	■	■	■	■	■	■	■
Tessellated darter												
Adult/Juvenile	■	■	■	■	■	■	■	■	■	■	■	■
Banded darter												
Spawning					■	■						
Juvenile	■	■	■	■	■	■	■	■	■	■	■	■
Adults	■	■	■	■	■	■	■	■	■	■	■	■
Walleye												
Spawning			■	■								
Fry				■	■	■	■					
Juvenile								■	■	■	■	■
Adults	■	■	■	■	■	■	■	■	■	■	■	■
Shorthead redhorse												
Spawning			■	■								
Juvenile									■	■	■	■
Adults	■	■	■	■	■	■	■	■	■	■	■	■

2.6. 1D MODEL HABITAT INDEX RESULTS

The hydraulic conditions simulated for the 21 study area transects by the 1D PHABSIM model were linked to habitat suitability criteria for the twenty-three target species and life-stage combinations to compute WUA versus flow habitat index relationships. An initial 1D analysis with the 1D model simulated flow increments between 800 cfs and 25,000 cfs, which is 40% of the low flow to 250% of the high flow. The standard approach of multiplying the suitability of each variable (velocity, depth, and substrate/cover) times the surface area represented by each data point, and summed for all data points at each flow, was used in the analysis. Numeric values for all species and life stages by flow in weighted square feet per 1000 feet of river are shown in Table 2-2 and in graphic form in Figure 2-4 and Figure 2-5.

Table 2-2 1D PHABSIM habitat index response (Sq. Ft./1,000 Ft. of River) to flow (CFS) for smallmouth bass, walleye, American shad, northern hogsucker, shorthead redhorse, river chub, banded darter, and tessellated darter in the Bell Bend study area (WUA v. flow).

FLOW	Smallmouth Bass Adult	Smallmouth Bass Juvenile	Smallmouth Bass Fry	Smallmouth Bass Spawning	Walleye Adult	Walleye Juvenile	Walleye Fry	Walleye Spawning	American Shad Adult	American Shad Juvenile	American Shad Fry	American Shad Spawning
800	227695	329249	384809	269989	174696	90131	66359	20507	205322	627568	561183	30442
900	243787	346228	383897	261324	171388	86890	58169	22707	213146	653004	587187	38285
1000	258797	361346	377875	251392	168321	83742	53840	25108	220648	670548	606486	46440
1100	272652	374883	369543	240819	165107	80623	51545	27553	227901	684586	622360	54825
1200	285588	387094	359785	230415	161472	77544	49424	29897	234953	696192	635757	63488
1300	297642	398028	349120	220222	157579	74574	47004	32162	241863	705902	647113	72391
1400	308744	407588	337625	210267	153202	71690	44447	34328	248624	714102	656809	81478
1600	327967	422850	312806	191621	142450	66424	39909	38334	261704	726453	672076	99733
1800	342903	433512	287215	175606	130674	61733	35670	41783	274395	734858	683185	117761
2000	353672	440755	264618	165070	118653	57508	32754	45114	286727	741957	692796	135548
2200	360254	444208	242773	154142	107214	53898	30934	49144	298542	746219	699365	152920
2400	363589	444971	222528	144343	96798	50827	28394	53800	310010	748437	703637	169824
2600	364598	443524	204843	135026	88275	48093	26274	59190	321234	748784	705876	186084
2800	363380	439962	189146	126268	81502	45737	24178	64984	332007	747666	706441	201644
3000	360707	434831	174912	118110	76107	43576	22096	71191	342416	745477	705717	216781
3200	356706	428670	161788	110629	71695	41654	20214	77694	352511	742494	704033	231598
3400	351699	421617	149955	103516	68002	39913	18624	84444	362326	738985	701826	246256
3600	345832	413893	139242	96629	64530	38306	17553	91511	371833	735266	699456	260673
3800	339151	405824	129589	90177	61450	36786	16104	98896	381091	731520	696990	274805
4000	331765	397382	120919	84020	58631	35377	14773	106554	390147	727806	694531	288669
4500	311199	374419	104999	71807	52814	32577	12886	126946	411306	717935	687697	321473
5000	291429	351517	91148	61283	47975	30461	11499	148499	431844	707232	679918	353000
6000	252154	308169	72687	48138	41289	26952	9751	189167	469722	681307	659329	409352
7000	218461	269226	56452	37601	37583	24436	9168	223105	504778	653964	636695	458538
8000	188214	233550	44886	31006	35408	22583	8607	249146	536097	626582	613496	498851
9000	160881	201408	37207	27141	34157	21226	8437	266002	563053	599989	590861	530437
10000	133965	170210	32141	24267	33201	19783	8105	276273	586858	572550	567428	555943
15000	69914	92453	22285	22049	30090	14243	8107	246836	636360	452091	461781	589611
20000	52192	63281	17991	20598	24785	12849	9313	177824	615929	354968	374101	549573
25000	44668	51234	16304	19712	20854	12721	8069	108715	559876	282669	308273	480921

Table 2-2 1D PHABSIM habitat index response (Sq. Ft./1,000 Ft. of River) to flow (CFS) for smallmouth bass, walleye, American shad, northern hogsucker, shorthead redhorse, river chub, banded darter, and tessellated darter in the Bell Bend study area (WUA v. flow).

FLOW	Northern Hogsucker Adult	Northern Hogsucker Fry	Northern Hogsucker Spawning	Shorthead Redhorse Adult	Shorthead Redhorse Juvenile	Shorthead Redhorse Spawning	River Chub Adult/Juv	Banded Darter Adult	Banded Darter Juvenile	Banded Darter Spawning	Tessellated Darter Adult/Juv
800	236671	173098	33682	143521	157745	1072	265507	48322	51134	18629	92009
900	271608	168330	41078	151334	166338	1314	277772	49681	52069	19045	96367
1000	306848	163687	49262	159036	174341	1543	287485	50892	52856	19368	99785
1100	340750	159139	57448	166618	181823	1763	293992	51938	53497	19618	102153
1200	372839	154766	65426	174048	188736	1981	297765	52878	54079	19820	103754
1300	403124	150146	73117	181339	195175	2208	299477	53734	54616	19984	104801
1400	431702	145099	80338	188518	201174	2457	299540	54517	55116	20101	105170
1600	483714	132999	93440	202496	211907	3028	297337	55900	56020	20219	104889
1800	528400	118574	105149	215939	221048	3720	293495	57039	56694	20228	103419
2000	565801	107088	115512	229104	229416	4550	289924	58438	57649	20281	101327
2200	597207	93592	124258	241465	235843	5524	284448	59131	57560	20170	98320
2400	624909	81982	131804	253367	241223	6611	277996	59607	57104	20001	94463
2600	650075	71767	138340	264965	245841	7789	270737	59911	56391	19801	90352
2800	672728	63443	143710	276090	249475	9033	262465	60056	55498	19566	85739
3000	693091	56771	148007	286673	252256	10366	253407	60086	54480	19310	80859
3200	711469	50964	151521	296756	254309	11742	243753	60024	53394	19023	75677
3400	728186	46263	154318	306318	255690	13127	234030	59873	52244	18714	70625
3600	743304	42114	156173	315541	256446	14537	224166	59631	50998	18396	65530
3800	757089	38530	157302	324463	256693	15936	214201	59337	49752	18065	60387
4000	769580	35634	157758	333205	256445	17307	204344	59015	48545	17721	55340
4500	794270	29694	156501	353089	253756	20564	182453	58174	45824	16887	44649
5000	814946	25022	152878	372052	249193	23234	163279	56949	42805	15978	35803
6000	841418	19631	140256	404516	236250	26142	129030	53227	36174	14056	23589
7000	851815	14484	125956	431721	220322	26597	100278	48678	30015	11980	15362
8000	849078	12620	110923	453917	202338	25616	77299	44133	25234	10094	10907
9000	837463	12636	94980	471568	183838	24120	59605	39895	21656	8604	8788
10000	819706	13410	78206	485473	165378	22743	46774	35975	18781	7420	7485
15000	687184	9900	29038	504706	100058	15124	20908	21575	10691	4378	5752
20000	546642	5784	13034	473202	62063	8553	12766	12941	5903	3620	2664
25000	424192	7630	8159	420676	39508	4151	9419	7667	3571	2620	2640

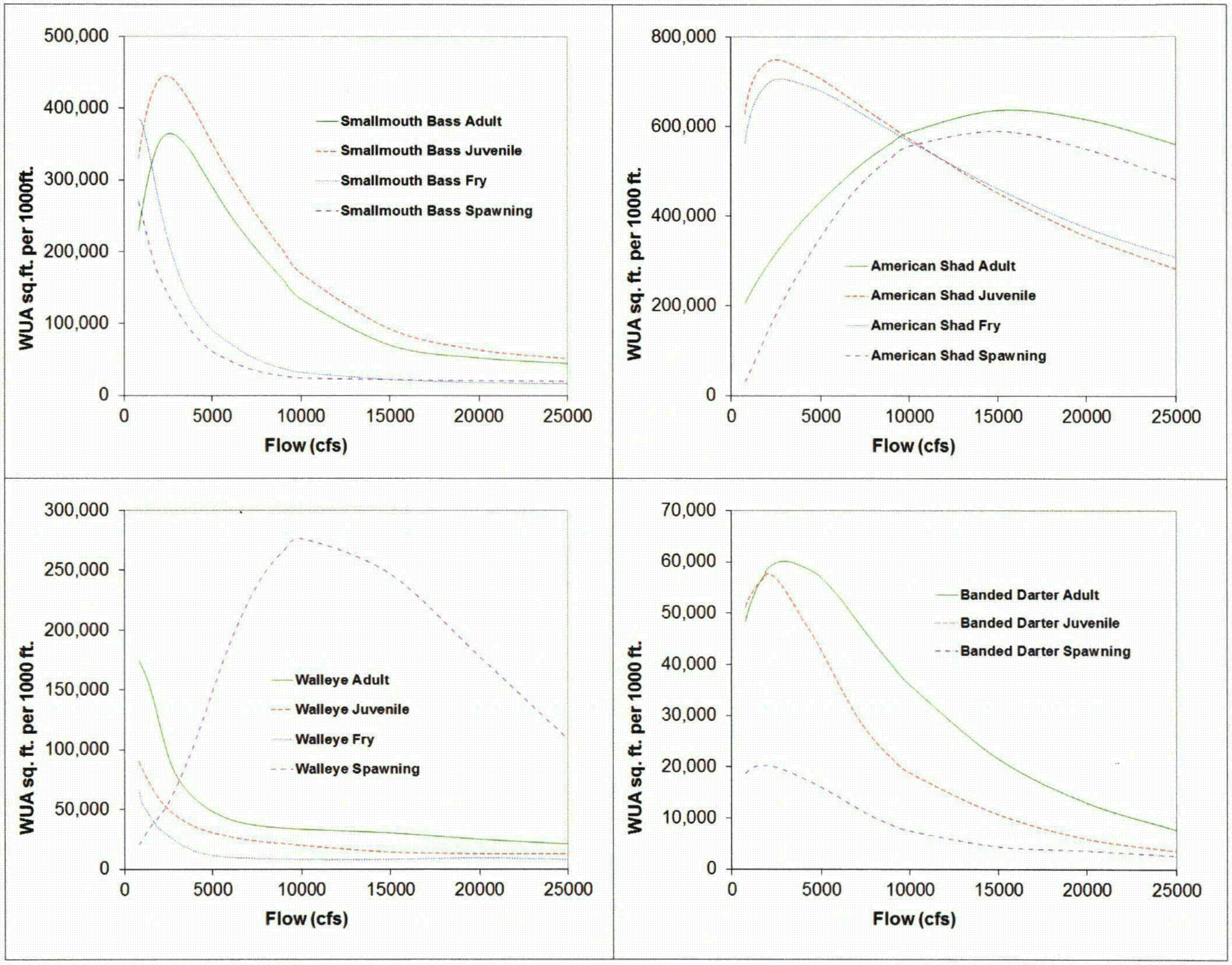


Figure 2-4 1D PHABSIM habitat index response of smallmouth bass, American shad, walleye, and banded darter to flow in the Bell Bend study area (WUA v. flow).

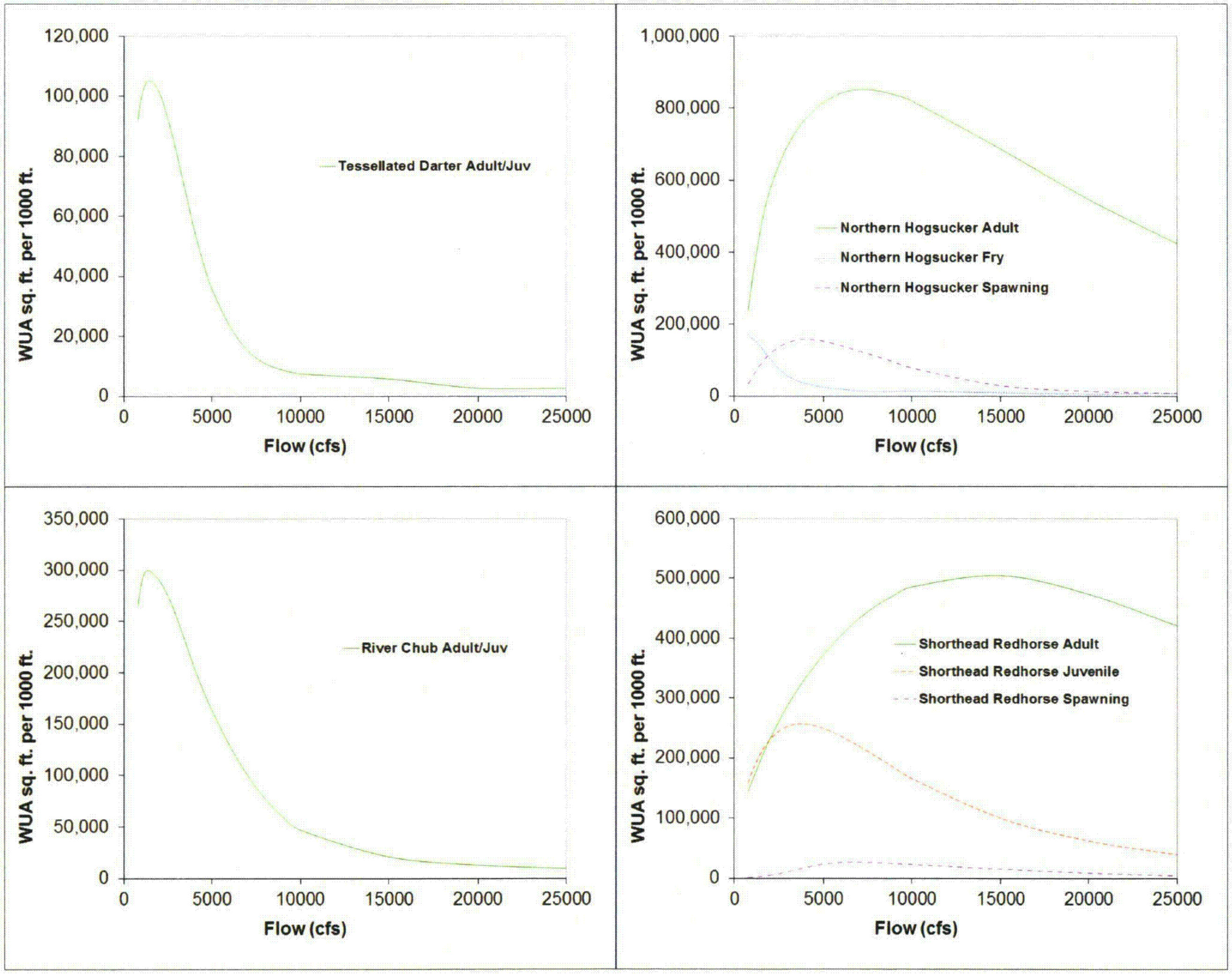


Figure 2-5 1D PHABSIM habitat index response of tessellated darter, northern hog sucker, river chub, and shorthead redhorse to flow in the Bell Bend study area (WUA v. flow).

2.7. 2D Model Habitat Index Results

The combined suitability of each flow and each species and life stages was calculated for each node in the River2D model by multiplying the simulated depth suitability, velocity suitability and substrate/cover (channel index) suitability, and expanded by the area represented by each node. This computation is done in River2D the same way as in 1D PHABSIM, but the resulting WUA habitat index is expressed in weighted square feet for the River2D study area. Numeric values for all species and life stages by flow in weighted square feet for the study site are shown in Table 2-3 and in graphic form in Figure 2-6 and Figure 2-7.

Table 2-3 River2D habitat index response (Weighted Sq. Ft.) to flow (CFS) for smallmouth bass, walleye, American shad, northern hog sucker, shorthead redhorse, river chub, banded darter, and tessellated darter in the Bell Bend River2D study area.

FLOW	Smallmouth Bass Adult	Smallmouth Bass Juvenile	Smallmouth Bass Fry	Smallmouth Bass Spawning	Walleye Adult	Walleye Juvenile	Walleye Fry	Walleye Spawning	American Shad Adult	American Shad Juvenile	American Shad Fry	American Shad Spawning
500	754443	1313548	2022464	1092892	69481	124203	470768	86814	333965	3024712	2594662	156585
600	827204	1429678	2070925	1092582	67021	119773	421558	103687	370403	3300607	2831156	197203
700	891845	1532290	2128298	1094190	62460	115951	370958	121989	407051	3554490	3050299	234368
800	948689	1625360	2192609	1096327	57329	111549	336681	141815	444539	3793790	3258823	269211
843	969568	1660446	2216213	1094193	55319	109654	325260	150370	460046	3884753	3338621	283503
900	997618	1708349	2250232	1093224	53009	107327	312748	162335	481504	4009630	3448569	303165
1000	1042624	1786213	2295118	1085616	49489	103634	290171	183817	518793	4203880	3620441	337695
1100	1082927	1856727	2321438	1072338	46292	100061	262541	205650	555066	4369963	3767847	372255
1200	1122569	1924173	2337023	1058480	43804	96456	230937	228144	591528	4518476	3900506	407509
1300	1161349	1988251	2343039	1042720	41885	92838	199024	251132	627583	4653692	4022589	443355
1400	1201270	2051785	2345179	1028589	40611	89635	166587	274930	664175	4780066	4138010	480201
1600	1275906	2157883	2315096	983989	39292	84388	120379	323121	735617	4970336	4313955	553972
1800	1348052	2250554	2258760	928043	38392	80509	92626	372944	805913	5118078	4454074	629172
2000	1414440	2329794	2174268	856612	37114	78108	75794	424583	875668	5229920	4563231	705703
2200	1473222	2394986	2064491	776413	35979	76754	63365	477977	944714	5308966	4642709	782980

FLOW	Northern Hogsucker Adult	Northern Hogsucker Fry	Northern Hogsucker Spawning	Shorthead Redhorse Adult	Shorthead Redhorse Juvenile	Shorthead Redhorse Spawning	River Chub Adult/Juv	Banded Darter Adult	Banded Darter Juvenile	Banded Darter Spawning	Tessellated Darter Adult/Juv
500	1219219	1391561	207351	570754	980186	18419	2134600	372275	420238	154439	672521
600	1420695	1388216	233565	640963	1079814	24177	2329431	403464	450696	168680	718513
700	1611837	1385945	258225	711030	1176000	30182	2513364	432990	479344	181947	758264
800	1802218	1382612	283141	782130	1271230	36415	2691399	461801	507088	194727	796507
843	1880649	1379777	293402	811222	1309046	39053	2759834	473172	518018	199728	811427
900	1987303	1375878	307122	851288	1360841	42687	2852632	488554	532708	206431	832402
1000	2170432	1359967	330524	919853	1446489	49100	2996983	513172	555656	217151	865499
1100	2347789	1337855	352845	985772	1525706	55548	3122237	535409	575691	226808	894766
1200	2522574	1311860	375483	1051010	1601697	62111	3235178	556141	593793	235690	921485
1300	2697688	1282832	400053	1115575	1675553	68905	3339179	576324	611076	244231	948203
1400	2873969	1251955	426647	1181182	1749766	76004	3434756	595849	627118	252462	974095
1600	3206686	1183418	482407	1306367	1882956	90633	3571960	629272	652575	266522	1012484
1800	3527846	1107044	543070	1429374	2007777	106141	3665180	658558	672512	278770	1041569
2000	3836515	1020810	607121	1550539	2124337	122578	3714970	683664	687028	289218	1057952
2200	4125145	929965	672108	1668983	2231387	139796	3726880	704842	696717	297867	1057914

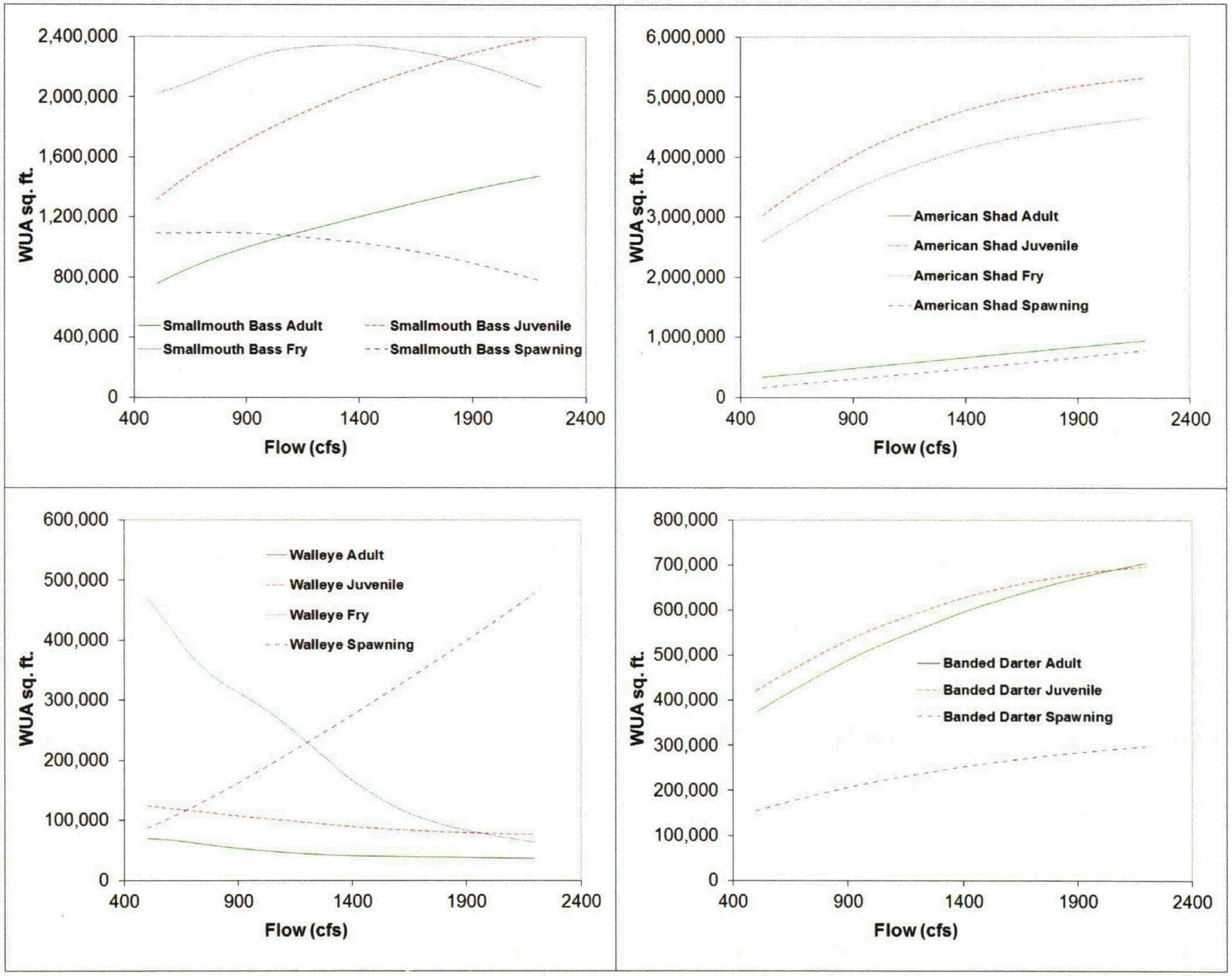


Figure 2-6 WUA habitat index response of smallmouth bass, American shad, walleye, and banded darter to flow in the Bell Bend River2D study area. Units are in weighted square feet.

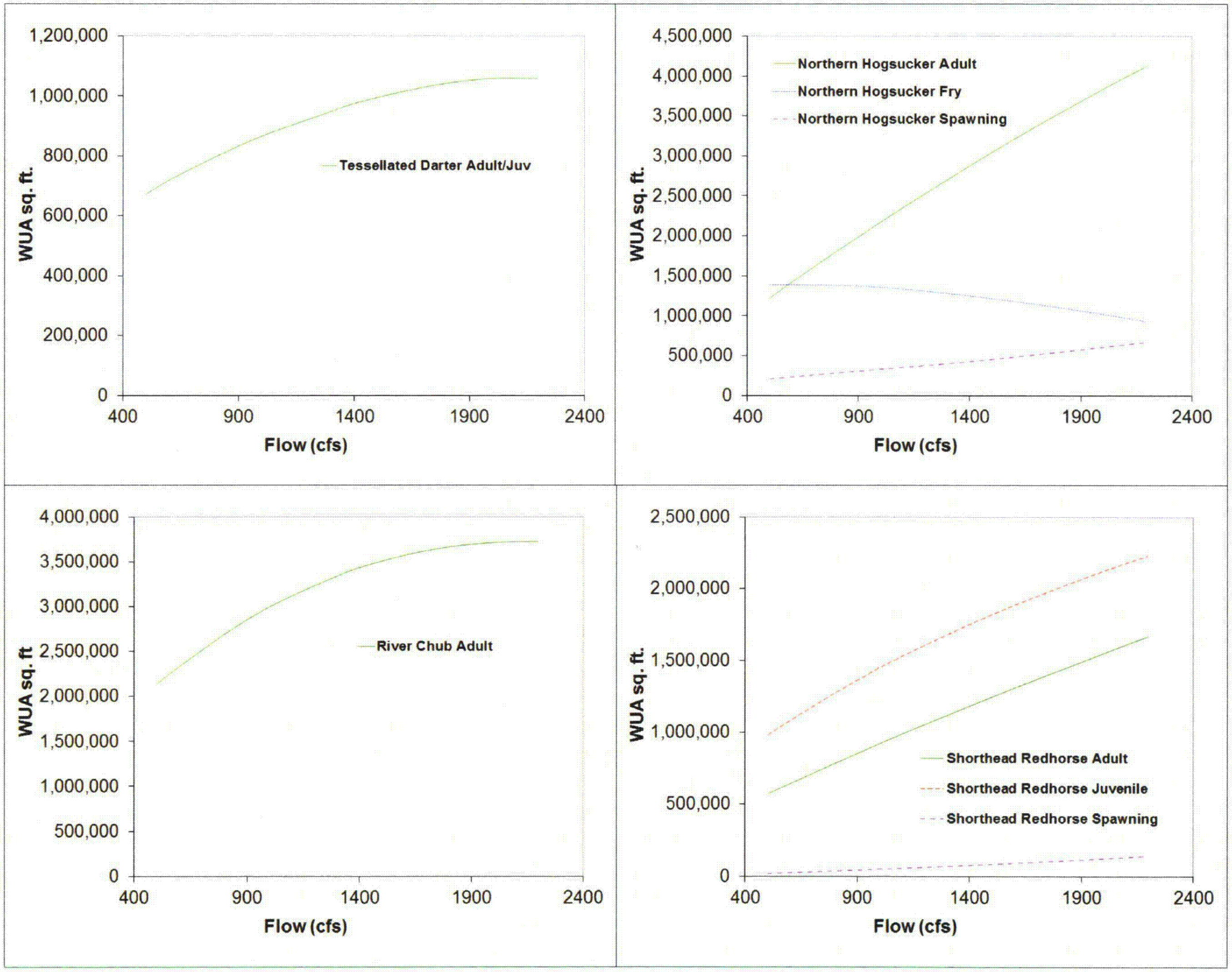


Figure 2-7 WUA habitat index response of tessellated darter, northern hog sucker, river chub, and shorthead redhorse to flow in the Bell Bend River2D study area. Units are in weighted square feet.

2.8. *COMBINED 1D AND 2D HABITAT INDEX RESULTS*

Two modifications were made to the original approach to aquatic habitat impact analysis for the BBNPP study area. First was the addition of a 2D model in the central portion of the study area, which is discussed above and in Appendix 2-A. This addition required combining the results from the two studies into a single WUA habitat index so that the net impact of the proposed flow change could be evaluated. Second was an agency request that the low flow extrapolation for both models be extended within the models down to 500 cfs. Previously, low flow extrapolation of the 1D model for the time series analysis was done by mathematically extending the trend line of each WUA habitat index relationship down from 800 cfs.

Use of the models for low flow extrapolation is typically constrained by the quality of the stage-discharge relationships and a normal limit of 40% of the low flow. The low flows when data were collected in 2010 for the 1D PHABSIM ranged between 1,898 and 2,296 cfs. Forty percent of this flow range is about 800 cfs, while 500 cfs would be 25%. Table 3-4 of Appendix 2-HYD shows that the errors of stage-discharge regression for almost all 1D transects are 1% or less (5% is the normal standard), meaning that extension of the model down to 500 cfs would have a low likelihood of error. The regression errors for transects R1 and G3, which establish the boundary conditions for the 2D study site, are only 0.68% and 0.82%, respectively, so the extension to 500 cfs is reasonable for the River2D model as well.

These two changes resulted in creation of a complex spreadsheet combining the main channel 1D transect WUA habitat index results with the split channel transect 1D results for flows between 500 cfs and 25,000 cfs, and replacing the river section between transects R1 and G3 with the River2D results for flows between 500 cfs and 2200 cfs. Transects R1 and G3 remained in the combined model for the lower flows but their respective weights were reduced due to the insertion of the 2D data.

It was also necessary to normalize the magnitude of WUA habitat index values for flows above 2200 cfs (which used only the 1D model) to make them continuous with the habitat values below 2,200 cfs for each species and life stage and to match the magnitude of the combined 1D and 2D models. The magnitudes of the WUA from the two models at the flow of overlap were different for three reasons: 1) the output from the 1D has to be converted to match the format of the 2D–so there will be some disconnect when they are reweighted; 2) the 2D reach contained greater areas of shallow complex shoals than sampled by the 1D transects in the same location; and 3) the substrate/cover coding approaches in the two models were different (2D by polygons and 1D by point observations), and substrate/cover codes strongly affect WUA magnitude (but rarely trend). Adjusted results are presented in the combined table (Table 2-4) and graphic plots (Figure 2-8 and Figure 2-9).

Table 2-4 Merged and smoothed habitat index response data for River2D and 1D PHABSIM (Sq. Ft./1,000 Ft. of River) to flow (CFS) for smallmouth bass, walleye, American shad, northern hog sucker, shorthead redhorse, river chub, banded darter, and tessellated darter in the Bell Bend project area.

FLOW	Smallmouth Bass Adult	Smallmouth Bass Juvenile	Smallmouth Bass Fry	Smallmouth Bass Spawning	Walleye Adult	Walleye Juvenile	Walleye Fry	Walleye Spawning	American Shad Adult	American Shad Juvenile	American Shad Fry	American Shad Spawning
500	162559	258404	341266	285385	190005	102564	95445	14712	172729	498762	442093	10922
600	182068	281176	349157	281840	184171	98620	85980	16476	181372	539096	481906	16303
700	199312	303539	359115	277615	178048	95000	80235	18360	189725	583898	525554	22467
800	215855	323634	366038	272192	173713	91539	73249	20500	197861	622725	563813	29060
900	231414	340441	365877	264568	170546	88353	64685	22892	205683	650269	592000	35968
1000	245878	355340	360932	255647	167605	85225	59804	25502	213228	669835	613306	43214
1100	259222	368670	353846	245987	164490	82087	56894	28149	220513	685683	630910	50785
1200	271739	380787	345528	236376	160948	78948	54167	30693	227607	699009	645917	58706
1300	283446	391652	336407	226701	157146	75901	50992	33150	234561	710381	658818	66950
1400	294449	401278	326644	217165	152859	72940	47683	35502	241389	720268	670097	75486
1600	313980	416799	305043	198816	142232	67528	42152	39823	254579	735271	687861	93008
1800	329814	428238	282515	182615	130506	62696	37392	43537	267388	745934	701118	110722
2000	341931	436207	260495	168506	118502	58375	33115	47104	279859	753599	711210	128412
2200	350431	440898	239896	155970	107067	54716	30333	51402	291938	758547	718456	145890
2400	354122	441971	219750	142048	96651	51639	27792	56098	303536	760829	722797	162867
2600	355142	440498	201870	132557	88128	48909	25672	61493	314773	761183	725035	179157
2800	353907	436880	185979	123751	81356	46547	23582	67289	325545	760011	725544	194739
3000	351232	431682	171487	115546	75961	44383	21501	73496	335965	757789	720794	209897
3200	347223	425489	158112	108024	71549	42462	19594	80001	346066	754803	719113	224737
3400	342179	418404	146042	100888	67857	40740	18016	86753	355886	751303	716919	239423
3600	336270	410650	135197	97961	64384	39143	16927	93822	365403	743568	714533	253869
3800	329564	402544	125354	91458	61305	37621	15458	101213	374681	739815	712062	268038
4000	322131	394033	116624	85348	58485	36210	14175	108878	383741	736084	709582	281927
4500	302224	371377	98742	72558	52679	33414	12387	129445	405380	726222	702780	315349
5000	282106	348114	84937	62301	47842	31273	10938	151042	425927	715417	694893	346976
6000	242089	303672	64777	48751	41181	27769	9174	192202	464533	689090	673990	404337
7000	206099	263213	50543	38836	37491	25285	8562	226404	499505	661387	651067	453276
8000	174267	227005	40386	32545	35318	23423	7994	252701	530732	633761	627657	493311
9000	147208	194794	33411	28792	34077	22050	7811	269902	557616	607000	604860	524733
10000	123743	166504	28998	26137	33055	20596	7510	278488	580118	580776	582395	548848
15000	59692	88747	19141	23919	29943	15056	7512	249051	629621	460317	476748	582515
20000	41971	59575	14848	22468	24638	13662	8718	180039	609190	367192	389068	542478
25000	34447	47528	13161	21582	20707	13534	7475	110925	553137	294894	327238	473826

Table 2-4 Merged and smoothed habitat index response data for River2D and 1D PHABSIM (Sq. Ft./1,000 Ft. of River) to flow (CFS) for smallmouth bass, walleye, American shad, northern hog sucker, shorthead redhorse, river chub, banded darter, and tessellated darter in the Bell Bend project area.

FLOW	Northern Hogsucker Adult	Northern Hogsucker Fry	Northern Hogsucker Spawning	Shorthead Redhorse Adult	Shorthead Redhorse Juvenile	Shorthead Redhorse Spawning	River Chub Adult/Juv	Banded Darter Adult	Banded Darter Juvenile	Banded Darter Spawning	Tessellated Darter Adult/Juv
500	147396	199291	17035	118962	134068	884	232415	45634	50317	17940	80781
600	182439	195650	23417	128061	145947	1192	253556	48025	52273	18903	86789
700	214358	190504	30404	136640	156652	1537	272977	50190	54070	19709	93280
800	246007	184979	37577	145098	166789	1919	289576	52120	55610	20428	98554
900	279389	180205	44813	153405	176126	2299	303208	53855	56941	21015	102792
1000	313264	175472	52820	161611	184857	2666	314487	55412	58094	21490	106112
1100	345964	170812	60802	169652	192983	3021	322642	56781	59068	21879	108461
1200	377138	166391	68586	177543	200530	3375	328148	58038	59973	22215	110138
1300	406862	161665	76149	185290	207593	3741	331633	59216	60835	22512	111344
1400	435215	156539	83325	192965	214283	4137	333481	60330	61652	22767	111974
1600	487060	144207	96501	207819	226191	5008	333852	62270	63062	23136	112216
1800	532233	129303	108528	222123	236494	6016	331931	63925	64163	23381	111433
2000	570816	114286	119401	235963	245393	7179	328539	65296	64834	23525	109766
2200	604300	99833	128937	249288	252955	8498	323470	66373	65015	23594	107205
2400	632571	88079	136623	261356	258528	9587	316997	66836	64528	23415	103305
2600	657771	77777	143183	272953	263117	10767	309542	67135	63812	23212	99094
2800	680416	69397	148558	284061	266696	12011	301203	67281	62926	22975	94466
3000	700754	62669	152852	294627	269442	13344	292059	67311	61915	22717	89578
3200	719124	56854	156352	304703	271456	14721	282343	67246	60828	22429	84367
3400	735824	52185	159130	314258	272793	16106	272577	67096	59680	22121	79268
3600	750888	48067	160975	323467	273515	17516	262678	66856	58439	21802	74154
3800	764637	44491	162087	332383	273740	18915	252719	66563	57198	21472	68992
4000	777058	41699	162524	341119	273458	20286	242864	66240	55990	21128	63955
4500	802889	35795	161507	361460	270847	23555	220349	65363	53205	20260	52886
5000	822998	31216	157793	380384	266143	26225	201008	64146	50197	19356	44228
6000	849855	25833	145272	413485	252955	29166	165815	60378	43481	17400	32027
7000	859264	20520	130617	440554	236728	29643	137566	55842	37354	15345	24095
8000	856023	18739	115183	462622	218561	28692	114868	51313	32609	13475	19661
9000	844192	18846	98935	480153	199983	27214	97377	47087	29042	12001	17531
10000	822165	19721	82752	493050	182248	25715	85664	43228	26270	10853	16350
15000	693641	16211	33583	512342	116929	18096	59799	28828	18179	7811	14616
20000	553100	12095	17579	480946	78934	11525	51656	20193	13391	7053	11528
25000	430649	13942	12705	428683	56379	7123	48309	14920	11287	6053	11504

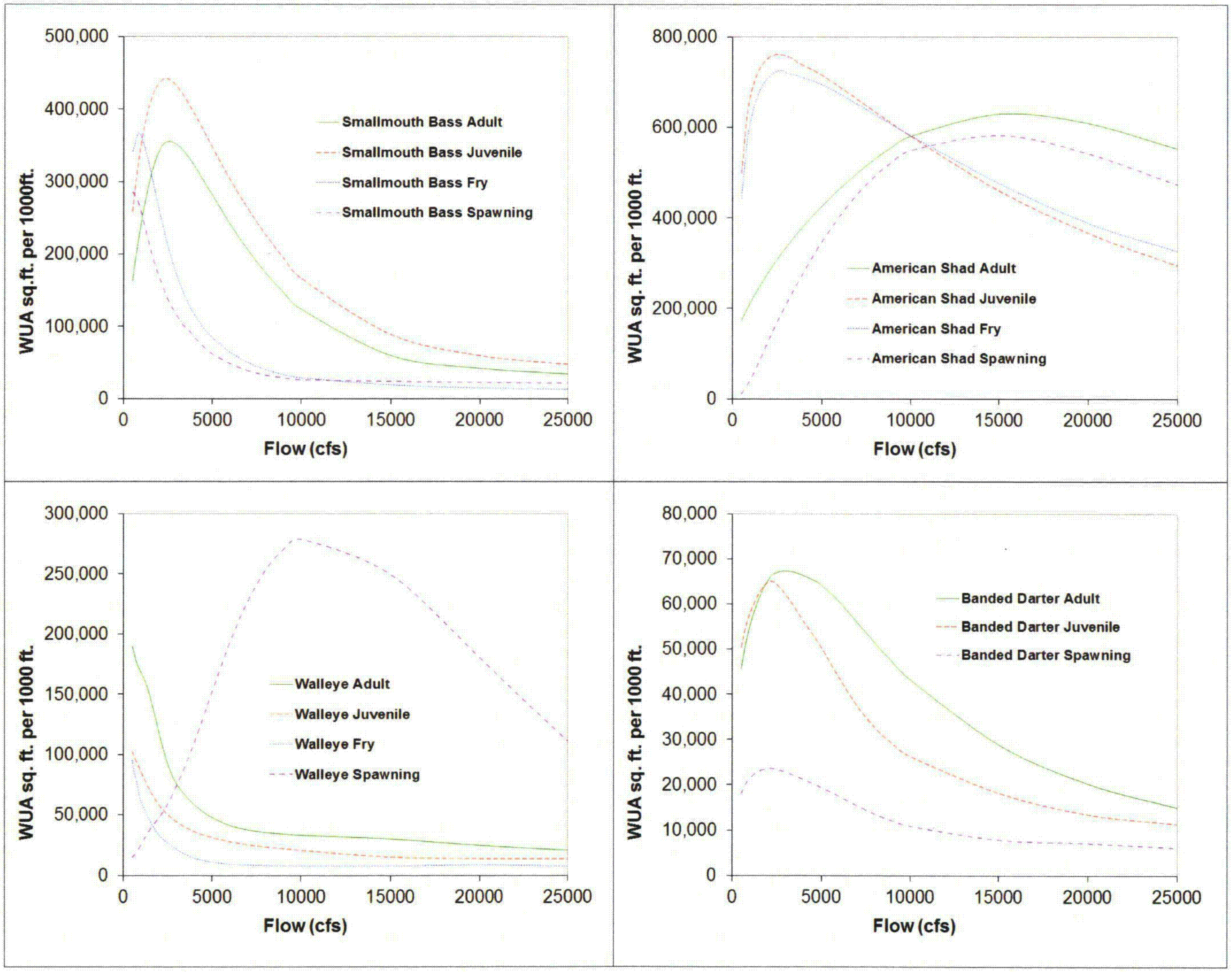


Figure 2-8 Merged and smoothed habitat index response curves for River2D and 1D PHABSIM for smallmouth bass, American shad, walleye, and banded darter in the Bell Bend project area.

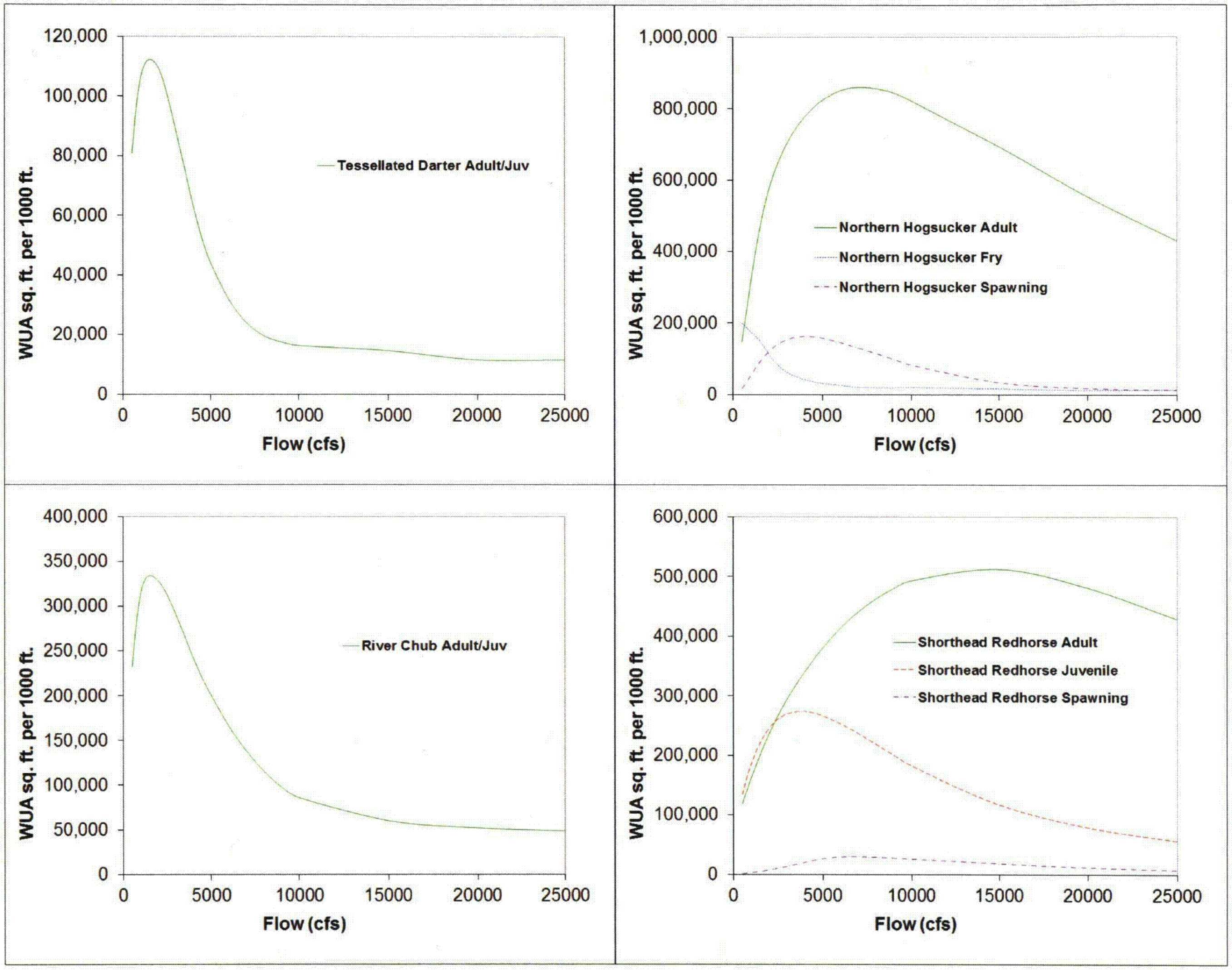


Figure 2-9 Merged and smoothed habitat index response curves for River2D and 1D PHABSIM for tessellated darter, northern hog sucker, river chub, and shorthead redhorse in the Bell Bend project area.

In some instream flow studies, the objective is to determine a river flow (or at least a minimum flow) that yields the best response in WUA (i.e. - the most suitable habitat) for the species and life stages of concern. However, this study was intended only to quantify and assess the impact of the requested consumptive use on suitable habitat availability, and particularly at natural low flows in order for the SRBC to evaluate whether a BBNPP consumptive water use would have an unacceptable negative impact on habitat availability, and hence population density. As such, the magnitude of the WUA response curve is not so important; rather, the slope (positive or negative, and steepness) of the curve is critical to determining how WUA will change in response to small changes in flow, over the entire range of flows experienced in this river reach.

In general for this river reach, suitable aquatic habitat, quantified as WUA over the entire study reach, decreases as the river flow increases. This section of the Susquehanna River is generally wide and shallow, and the higher water velocities associated with higher river flows become less suitable for fish habitat. For five of the twenty-three species and life stage combinations in this study (smallmouth bass spawning; walleye adult, juvenile, and fry; and northern hog sucker fry), the WUA response to flow is monotonically decreasing. That means that a decrease in flow always yields an increase in WUA, such that any flow reduction due to consumptive use of river water can never have a negative effect on the available suitable habitat. These five species-life stage combinations were not considered further in the habitat analysis, since they are not impacted by consumptive use at any level.

For the remaining eighteen species/life stage combinations in this study, the peak of the WUA response curve occurs at different flows, but is most often at lower flows (less than 5000 cfs on twelve curves), and the ascending limbs of the curves (where the slope is positive) are short. These are the ranges of river flow where a reduction in flow could have some negative impact on WUA. It is the slope of the ascending limb in the WUA response curve that is directly related to the magnitude of negative impact on WUA associated with a given flow reduction.

For several of the species and life stages in this study, the ascending slope of the WUA response curve at very low flows is fairly steep; however, it is also noted that this potential for negative impact also occurs near the peak of the curve. That is, for some portion of the year, when flows are higher, the available WUA is naturally much less than that available at low flows, with or without consumptive use reductions.

This general pattern in WUA response is not seen for American shad spawning and fry, walleye spawning, shorthead redhorse adult and spawning, and northern hog sucker adult. For these six species and life stages, the peak WUA response occurs at higher flows, but the ascending slopes (except for northern hog sucker) are less steep, indicating smaller negative impacts on WUA resulting from consumptive use flow reductions.

2.9. COMPARISON OF THE RIVER2D AND PHABSIM 1D MODEL RESULTS

The River2D site is represented by the PHABSIM 1D transects R1, RI1, G4 and G3 in the 1D study. R1 and G3 are the downstream and upstream boundaries of the River2D study site. The River2D field data represent this study site with sufficient measured data points to characterize

every change in bed elevation within the study area. The full PHABSIM 1D study utilized 21 cross-sectional transects distributed over a larger study area representing additional habitat types as well as additional locations of riffle island habitats. The PHABSIM 1D transect data from the four transects within the River2D study area (the riffle area) represents a subsample of the full PHABSIM data. The number of data nodes representing the study site from the River2D model is 225,982, whereas the riffle-only PHABSIM 1D model uses 1290 data points, or 0.57% of the River2D data points. In this discussion we compare the River2D results to the PHABSIM 1D results for the four transects located within the River2D site. The two models represent different approaches to simulate the relationship of microhabitat to flow and provide insight into the validity of the results.

The WUA curves determined by the PHABSIM 1D model were originally modeled for a flow range of 800 cfs to 25,000 cfs, but the hydraulic simulation was subsequently extended down to 500 cfs. Flows from 500 cfs to 2200 cfs were simulated in the River2D study. In this discussion we compare the model results for the flow range of 500 cfs to 2200 cfs. The River2D WUA has been adjusted to WUA per 1000 ft^2 of river in order to provide comparative output units for PHABSIM 1D. Differences in magnitude of the WUA were expected due to the different methods of calculation between the two models. With a few exceptions, the WUA/flow curves from both models are very similar. The shape of the curve determines the habitat impact of the consumptive use of water. Plots in Appendix 2-F depict the comparison for all species/life-stages of interest, and only within the 2D study area.

Most of the PHABSIM 1D and River2D curves were similar but there were a few differences. Several PHABSIM 1D WUA/flow curves (e.g. smallmouth bass spawning, walleye fry, and northern hog sucker fry) have unusual bends in the curves at 1800 cfs. These are a result of the model flow in the small northern channel dropping to zero and becoming dry in the PHABSIM 1D model at flows below 1800 cfs. River2D has a ground water component in the model which provides water in the channel with no velocity, avoiding the abrupt change in available habitat from 1800 cfs to 2000 cfs that was depicted by the PHABSIM 1D curve. The River 2D model is more realistic in this scenario since the side channel is unlikely to completely dry at 1800 cfs.

The shape of both the walleye fry and shorthead redhorse spawning WUA/flow curves differ between models. Walleye fry suitable habitat is characterized by deep, slow water (1 to 6 feet deep and less than 0.2 fps). At the lower flows the PHABSIM 1D transects simulate higher velocities in the deeper water than River2D and thus less suitable habitat. This occurs due to the ability of theRiver2D model to account for topographic velocity shelters upstream of data nodes, whereas PHABSIM 1D cannot account for topographic variation upstream of a data point. The River2D model captured additional deep, slow areas of suitable habitat at the lower flows. For walleye fry, both models indicate increasing habitat with decreasing flow, resulting in positive habitat impacts associated with the consumptive use. When the small northern side channel becomes inundated at flows in excess of 1,800 cfs, the PHABSIM 1D transect G4RC captures suitable habitat in that channel. Since the walleye fry habitat is very scarce within the study site, the small quantity in the side channel modeled by the PHABSIM 1D side channel transect creates a "kink" in the WUA/flow curve at 1800 cfs. Shorthead redhorse spawning habitat is also scarce at low flows (Appendix 2-B) which is similar to the walleye fry. The PHABSIM 1D transects did not recognize as much of the limited suitable area as the River2D model because it

is such a small subset of the River2D model. The shorthead redhorse spawning WUA curves of both models decrease with decreasing flow resulting in negative habitat impacts at lower flows; however, they do not spawn during the season of the low flows.

Interestingly, low-flow habitat impacts (Table 2-4, Figure 2-8, and Figure 2-9) predicted by the River2D model in the riffle section only compare much more closely to the combined 1D/2D model for the full study reach, than they do to the PHABSIM riffle-only model. This suggests that the WUA differences described here may be largely the result of limiting the PHABSIM riffle- only model to only 4 transects.

2.10. BBNPP PROJECT AREA HYDROLOGY

A time series of daily river flow at BBNPP was developed from the record of daily discharge as measured and recorded by the USGS at gaging station No. 01536500, Susquehanna River at Wilkes-Barre, PA ("Wilkes-Barre gage"). The Wilkes-Barre gage record extends from April 1899 to the present. For purposes of this study, daily discharge data from the period January 1900 through March 2010 were used. The Wilkes-Barre gage daily discharges were not adjusted for upstream usage or flow regulation, insofar as usage and flow regulation were judged to be relatively insignificant and in any case not possible to determine.

The drainage area of the Susquehanna River at the Wilkes-Barre gage is 9,960 square miles. The drainage area of the river at the site of the proposed BBNPP intake is approximately 10,240 square miles. To represent flow at BBNPP as augmented by flow from the 280 square miles of drainage area between the Wilkes-Barre gage and BBNPP, the daily discharges measured and recorded at the Wilkes-Barre gage were increased by 2.8 percent.

Thus, daily river flow at BBNPP unaffected by BBNPP consumptive use is represented by the recorded daily discharge at the Wilkes-Barre gage from January 1900 through March 2010 (111 years), with each daily discharge multiplied by 1.028.

To evaluate potential impact on aquatic habitat, two alternative "levels" of BBNPP consumptive use ("A" and "B") were considered. Alternative level "A" is based on the maximum (peak-day) net consumptive use of 28 mgd (43 cfs) for which PPL Bell Bend has applied to SRBC. Alternative level "B" is based on the expected maximum monthly average BBNPP net consumptive use simulated from long-term Wilkes-Barre meteorological data as 24.8 mgd (38.4 cfs, July 1955). The potential impact of the total BBNPP water withdrawal of 42 mgd (65 cfs) on the river area between the BBNPP intake and discharge point approximately 600 ft. downstream of the intake has been considered and is discussed in Section 5 of this report.

Each alternative will vary during the year. For purposes of this study, the alternatives were considered to vary, by month, in proportion to the variation of the maximum monthly averages experienced at SSES determined from records since 1987. Table 2-5 shows the resulting monthly average values of BBNPP consumptive use assumed in the study.

Table 2-5 Projected monthly consumptive use

Month	Experienced maximum consumptive use at SSES as percentage of peak month (1987-2009)[1]	A - Maximum daily consumptive use applied for with SRBC, adjusted (cfs)[2]	B - Representative expected maximum average BBNPP consumptive use (cfs)[3]
January	73%	31	28
February	74%	32	28
March	67%	29	26
April	76%	33	29
May	85%	37	33
June	86%	37	33
July	100%	43	38
August	100%	43	38
September	96%	41	37
October	89%	38	34
November	75%	32	29
December	73%	31	28

Five different project operating scenarios were considered in developing time series for this study. The first two considered BBNPP consumptive use ("A" and "B", respectively) without mitigation. The third, fourth and fifth considered consumptive use alternative "A" with the following alternative operating scenarios:

- Consumptive use is prohibited whenever river flow is below the 7Q10; the at-site 7Q10 is 843 cfs, derived as the 7Q10 at Wilkes-Barre (820 cfs) adjusted for the 2.8 percent additional drainage area at BBNPP.

- Consumptive use is prohibited whenever river flow is below the 20% of average daily flow (ADF); the at-site 20%ADF is 2,817 cfs, derived as the 20%ADF at Wilkes-Barre (2,740 cfs) adjusted for the 2.8 percent additional drainage area at BBNPP.

- 50 percent of consumptive use is replaced by upstream flow augmentation ("make up" water) whenever the river flow is less than the 20%ADF flow.

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[1] Percentages rounded to nearest percent. Maximum monthly monitored consumptive use at SSES 1987-2009 occurred July 2000.

[2] The amounts in this column are the product of the maximum (peak day) consumptive use applied for with SRBC (28 mgd, equivalent to 43 cfs) and the respective SSES percentages in the column to the left, rounded to nearest cfs. These amounts are extremely conservative and include sufficient allowance for in-river evaporation due to the thermal discharge.

[3] The amounts in this column are the product of the maximum monthly consumptive use at BBNPP simulated from long-term Wilkes-Barre meteorological data (24.8 mgd, equivalent to 38.4 cfs, in July 1955) and the respective SSES percentages in the second column to the left, rounded to nearest cfs. These amounts are conservative and include sufficient allowance for in-river evaporation due to the thermal discharge.

Duration curves of daily consumptive use rates for these five project scenarios are shown in Figure 2-10. Note that with a 20% ADF passby flow, the daily consumptive use is zero (BBNPP cannot operate) about 79% of the time. With a 7Q10 passby flow, consumptive use is zero less than 1% of the time. The "50% make up" scenario represents a net consumptive use; BBNPP would consume water per alternative "A", but make up water would be added to the river, augmenting flows both above and below the BBNPP site.

Duration curves of natural river flow and project alternative flow "A" are shown in Figure 2-11. The 20% ADF is exceeded about 79% of the time; the 7Q10 flow of 843 cfs is exceeded more than 99% of the time.

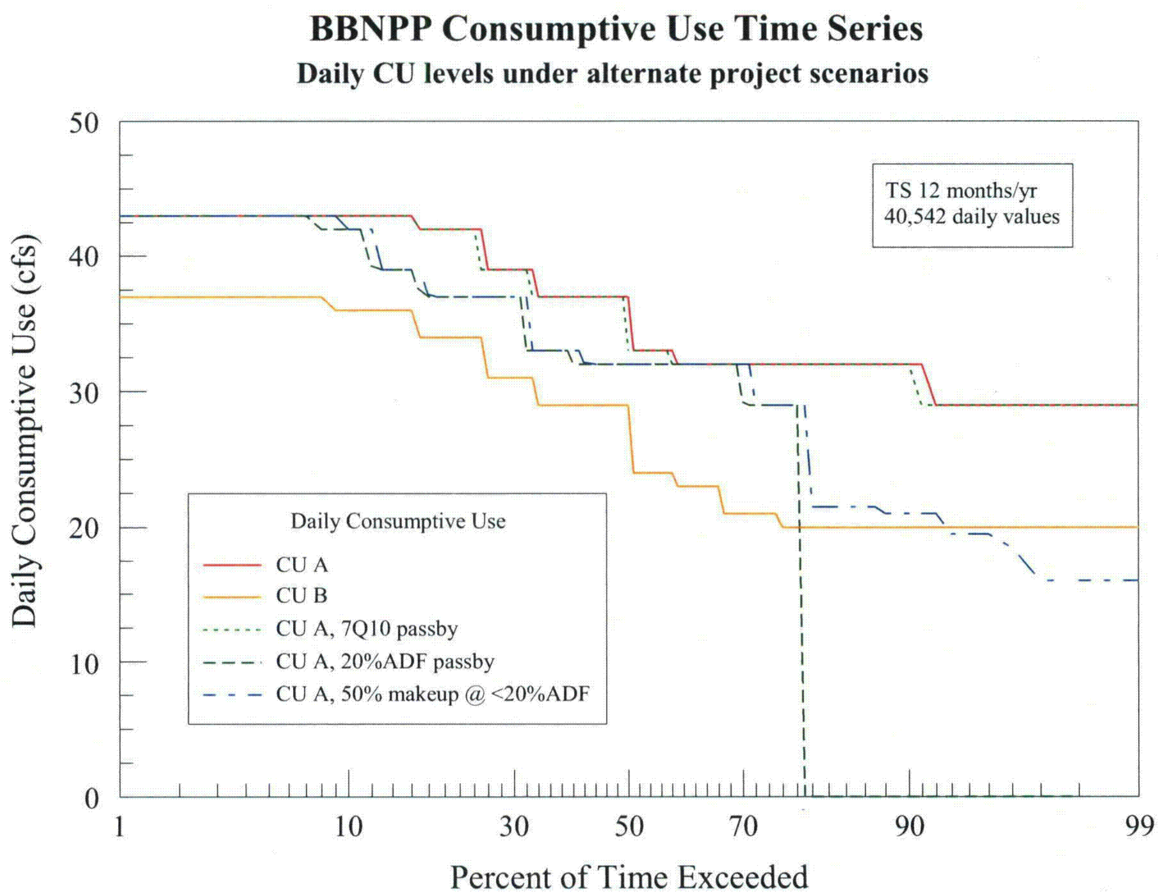


Figure 2-10 Duration curves for daily consumptive use rates

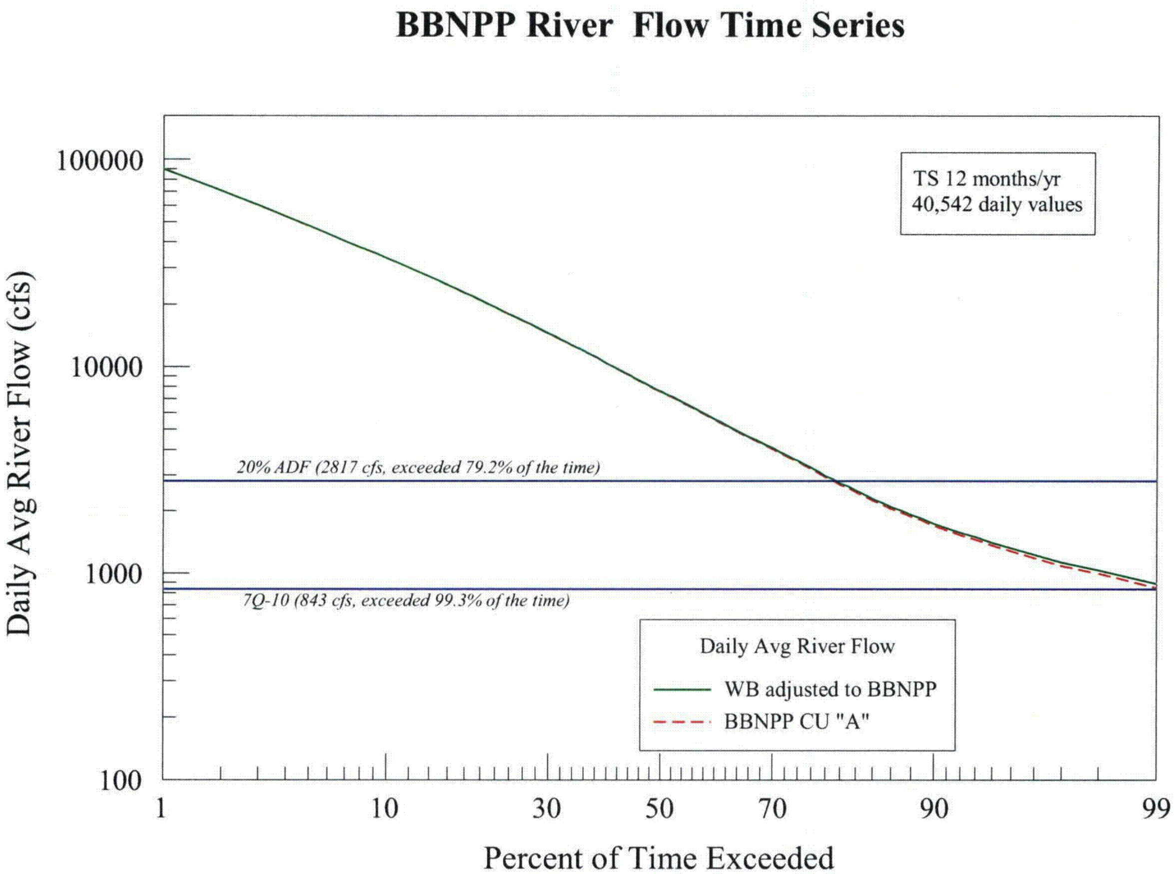


Figure 2-11 Duration curves for river flow at BBNPP

Section 2.11 below provides results for flow scenario "A".

2.11. TIME SERIES AND HABITAT IMPACT ANALYSIS

The combined-model WUA vs. flow relationships and the long-term daily hydrologic record for the Susquehanna River at the BBNPP site were used to generate daily habitat time-series (the WUA available in the study reach for each day of the historical record), for each of the eighteen species and life stage combinations with some potential for negative impact. Habitat time series were limited to the relevant months of seasonal occurrence for each species and life stage (

Table 2-1). The distributions of WUA values in these time-series were used to estimate, in a manner similar to flow duration curves, the probability, or proportion of time, that a given level of WUA will be equaled or exceeded, with natural river flows. Similar habitat distributions were developed for the five alternative project flow scenarios, based on the historical natural river flows adjusted to reflect:

- the requested consumptive use of 43 cfs, adjusted monthly ("A")
- the expected maximum monthly consumptive use ("B")
- scenario "A" with a 7Q10 passby flow (no withdrawal below 843 cfs at BBNPP)
- scenario "A" with a 20% ADF passby flow (no withdrawal below 2817 cfs at BBNPP)
- scenario "A" with 50% make-up additions below 20% ADF

Comparison of habitat duration for natural flows and adjusted flows demonstrate the overall impact of the project on habitat availability.

In discussing habitat impact analysis, SRBC Publication 191 (Denslinger, *et al.* 1998) defines "impact" as "the percentage difference between habitat available without the withdrawal and habitat available with the withdrawal in place." This approach speaks more directly to the question of how BBNPP consumptive use will affect available habitat at a range of river flows, and will allow consideration of whether the level of impact is acceptable or not. In this analysis, the change in habitat (WUA) resulting from the consumptive use is expressed both as an area and as a percentage of the habitat available at natural river flows.

"Change in habitat" for a given species and life stage is essentially the difference, on the habitat axis, between two identical WUA vs. flow curves which are offset on the flow axis by an amount equal to the consumptive use. That is, for any given river flow entering the study reach, the habitat available in the presence of a consumptive use would be the same as the habitat provided by a lower un-impacted river flow. The absolute change in WUA due to the consumptive use is compared, as a percentage, to the level of WUA that would be provided at the natural river flow (Figure 2-12).

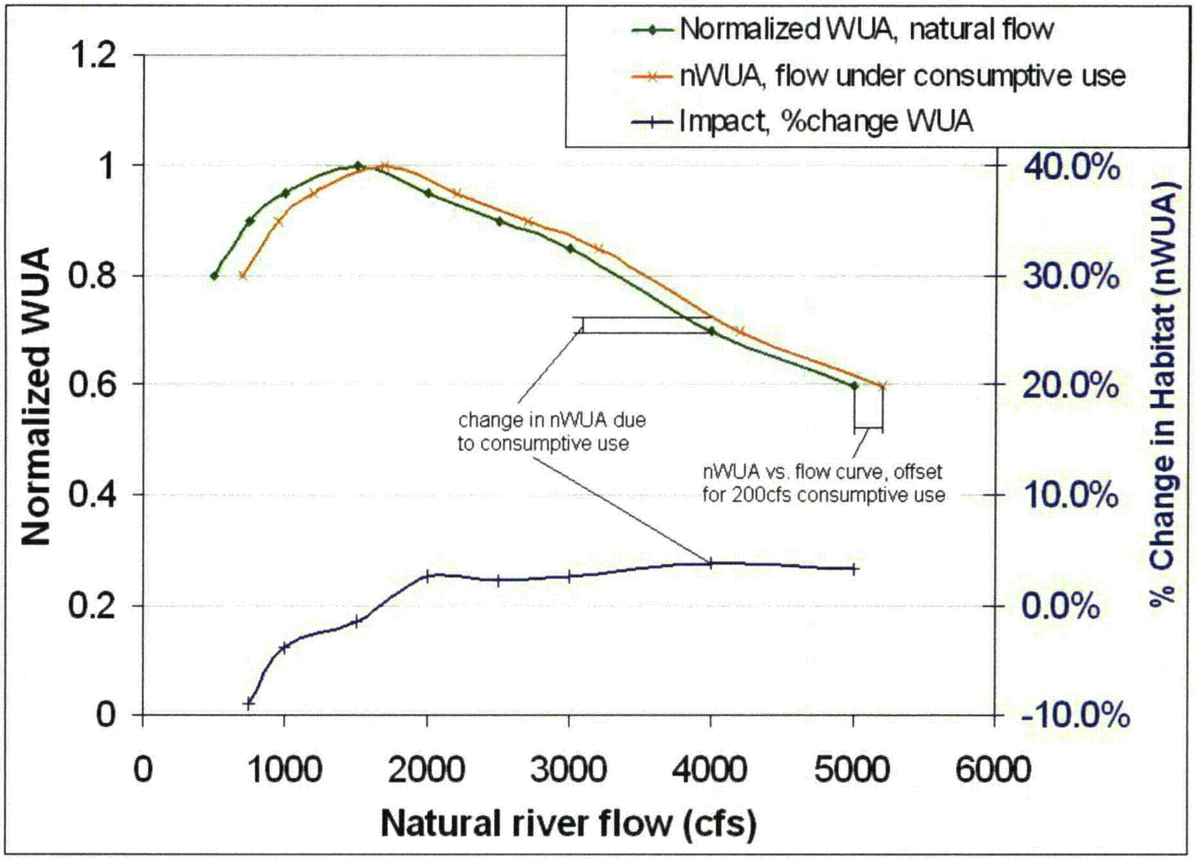


Figure 2-12 An example of habitat impact analysis, based on a hypothetical normalized WUA vs. river flow curve and a 200 cfs consumptive use

The WUA response curve at natural river flow is offset to the right to simulate a 200 cfs consumptive use; that is, the available habitat at a given natural flow under a consumptive use is the same as the available habitat at a natural flow 200 cfs lower. The vertical distance between the curves represents the change in habitat (positive or negative) due to the consumptive use at a given natural flow. This change is then expressed as either an area or a percent of the habitat available at the natural flow, resulting in the relationship of habitat impact to flow.

This calculation can also be expressed in equation form. Given:

WUA(q) = relationship of usable habitat to flow (per species and life stage)

I = impact: % difference between habitat with flow alteration and habitat without flow alteration

CU = consumptive use

CU(q) = flow-related consumptive use (e.g., with passby limit in effect)

then the habitat impact % at a given (natural) flow q is:

I(q) = (WUA(q-CU(q)) - WUA(q)) / WUA (q)

The resulting relationship of "percent change in habitat" vs. flow can be examined directly to evaluate the habitat impacts, positive or negative, of a given, level consumptive use at different river flows. For this analysis, the WUA vs. flow relationships were "normalized," or scaled as a proportion of the maximum WUA value from each curve, so that habitat responses for all species and life stages are expressed on a comparable zero-to-one scale of normalized WUA (nWUA). The calculation of percent change is not affected by this normalization.

The impact vs. flow relationships can also be converted, with a natural flow time-series, into "habitat impact duration curves" for a given level consumptive use. However, since the project flow scenarios considered in this study represent a consumptive use that is not level, but varies by month and with passby restrictions, the habitat impact time series were generated by calculating the daily difference, or percent change, in WUA between the natural flow habitat time series and each of the alternate project flow habitat time-series. These daily impacts were then summarized in a duration analysis showing what percent of time (based on the historical flow record) a given percent change in usable habitat area can be expected to be equaled or exceeded in the positive (improvement) direction. This analysis allows the various project flow alternatives to be compared for both magnitude and duration of impact.

The results of these habitat impact analyses for sixteen species and life stage combinations are shown in figures in Appendix 2-TS. The Appendix contains a series of four plots for each species and life stage. These plots are based on the habitat index response curves from the initial 1D PHABSIM analysis. Differences between this analysis and the combined 1D and 2D analysis are small, and are primarily found at extremely low flows, which are examined in more detail later in this report.

The first two plots, side by side, share the same vertical axis of WUA area (sq. ft./1000 ft. of stream). The "WUA vs. Flow Response" plot shows the WUA vs. flow relationship over an 800 to 25,000 cfs range of simulation. A region of "low flows," defined as less than 20% of the ADF (2,817 cfs at BBNPP) and greater than the minimum flow observed in the time series for the species and life stage, is marked on the flow axis. Typically in this study, this is also the range of flows where a positive slope of the WUA response curve indicates the potential for negative impacts on habitat due to BBNPP consumptive water use. The corresponding range of WUA at these flow values is marked on the vertical axis, and carried across to the second plot, the "Habitat Time Series."

The seasonality and size of the time series (TS) are labeled on this plot. Lines labeled Natural Flow and CU A represent the frequency of occurrence, or duration, of WUA over the entire study reach for both the natural river flow and the requested BBNPP consumptive water use. Because the habitat impacts related to the requested BBNPP consumptive water use are so small, these two lines are generally indistinguishable, so the other alternative project flows are not shown (they all have lower water use levels, and would be even more similar). The conclusion of this time-series analysis for all BBNPP water use scenarios evaluated is that, overall (for the entire study reach, and over time), there is no substantial difference in aquatic habitat availability

between natural river flows and flows reduced by the requested BBNPP consumptive water use whether or not any form of mitigation is imposed.

The habitat duration curves also show that, for most species and life stages, the WUA available during times of low flow, typically when any potential negative habitat impacts occur, is not the lowest WUA available over the entire seasonal time-series. There are substantial periods of seasonally relevant time over the year when naturally available WUA, not impacted by BBNPP consumptive water use, is much lower. To the extent that fish populations are limited by available habitat (as represented by WUA) over time, any negative impacts due to the requested BBNPP consumptive water use would not be expected to be habitat limiting as BBNPP impacts at low flows do not produce the lowest levels of WUA over time.

The third line on the Habitat Time Series plot, "Daily Difference," represents the frequency of occurrence of daily differences in WUA (impact) between the natural flow and requested BBNPP consumptive water use time series. It is plotted on the same scale as the habitat time series to show the size and frequency of negative impacts, in particular, as compared to the total available WUA. As these are duration (frequency of occurrence) curves, the lines are not linked in the horizontal axis: The most-negative daily difference values do not necessarily occur at the same time as the smallest daily WUA values.

The third and fourth plots for each species and life stage, side-by-side, share the same vertical axis of Habitat Impact (% Change due to CU). The "Habitat Impact – Level 43 cfs CU" plot shows the calculation of habitat impact vs. flow for a given level of BBNPP consumptive water use, in this case the maximum requested 43 cfs consumptive use. The WUA vs. flow response curve is normalized on a 0 to 1 scale, and then shifted right by 43 cfs. Again, since the requested consumptive use is so small in comparison to the observed range of river flows, the two curves are nearly indistinguishable. However, the vertical difference between them can be calculated, and is plotted as a percent of the natural flow WUA by the line labeled "Habitat % Impact." As expected, negative impacts occur where the WUA response curve has a positive slope, which is typically at lower flows in this study. Where the WUA response curve slopes down, there are positive changes in WUA when flows are reduced. The size of the % impact at a given flow depends on both the slope and the magnitude of the WUA response curve, but in general, negative impacts in this study are not large.

The fourth plot, "Habitat Impact Time Series," takes into account both the possible seasonal variation in consumptive use (often less than the requested maximum 43 cfs), and the seasonal limits of the time series some life stages are not present year-round, and will not be affected by the full annual range of observed river flows. The five lines on this plot represent the frequency of occurrence, or duration, of daily habitat impact (% change in WUA) over the entire study reach for the five alternate project flow scenarios as compared to the natural river flow. The requested consumptive use (scenario A) typically results in the largest negative impacts. However, in general, the largest negative impacts are still small (less than 5% of natural WUA), and they occur infrequently (20% of the time, or less) within the seasonally relevant time series for each species and life stage.

The same habitat impact analysis was also conducted using the habitat index response curves from the combined 1D and 2D analysis. Those results were not plotted as in Appendix 2-TS, but are presented here in tabular form. Table 2-6 shows, for each flow scenario evaluated in this study, the statistical distribution, by percentiles, of the daily habitat impact time series for the eighteen species and life stages that show any degree of negative impact from consumptive use during the months they are present in the river. As a result of combining the River 2D analysis with the original PHABSIM analysis, two additional life stages – smallmouth bass fry, and banded darter spawning show some minor negative impacts at very low river flows.

This table is based on the WUA vs. flow response curves from the combined PHABSIM and River 2D model for the entire study reach, and the full daily river flow time series for 1900 to 2010. For each species and life stage, it shows the number of seasonally relevant days in the time series, the minimum to median percentile distribution of daily river flows, and the minimum to 99th percentile distribution of habitat impacts (as WUA change in square feet, and WUA change as a percent of WUA at natural flow) that would have been experienced under BBNPP consumptive use scenarios "A" and "B", and three additional mitigation scenarios (as described previously). Note that these represent a single extreme point in the entire time series. The table also shows the percentile of "zero impact" for each of the consumptive use scenarios, which represents the percent of the time series in which consumptive use impacts are negative. Resulting from the shape of the WUA vs. flow curves, consumptive use actually increases WUA over a wide range of river flows.

Table 2-6 BBNPP habitat impact time series analysis

BBNPP Habitat Impact Time-series analysis

Daily flow record (1900-2010) converted to daily WUA, using
WUA vs. flow response for all transects, PHABSIM and River2D combined
Daily % Impact is change in WUA from natural flow to project flow,
as a percent of WUA at natural flow

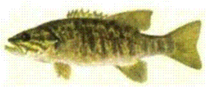
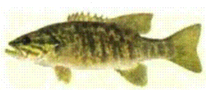
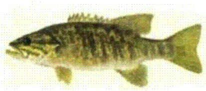
					Flow Datasets for PHABSIM Time-series Analyses						
					[1]	[2]	[2]	[3]	[4]	[5]	[6]
					W-B flows adjusted to BBNPP	[1] with BBNPP "A" CU removed	[1] with BBNPP "A" CU removed	[1] with BBNPP "B" CU removed	[2] with Q7-10 passby	[2] with 20% ADF passby	[2] plus 50% makeup at flow <20% ADF
				% Exceed-ance	cfs	WUA change sq.ft./1000ft	WUA %Impact	WUA %Impact	WUA %Impact	WUA %Impact	WUA %Impact
Smallmouth Bass Adult 12 months	Days:	40,542	Minimum	100	547	-8423	-4.90	-3.95	-2.88	0.00	-2.42
			1st %tile	99	890	-6320	-2.73	-2.21	-2.31	0.00	-1.35
			5th %tile	95	1,326	-4645	-1.61	-1.29	-1.49	0.00	-0.80
			10th %tile	90	1,738	-3061	-0.95	-0.73	-0.85	0.00	-0.47
			25th %tile	75	3,393	34	0.06	0.05	0.06	0.00	0.04
			Median:	50	7,608	252	0.33	0.23	0.33	0.33	0.33
			75th %tile	25		1548	0.53	0.36	0.53	0.53	0.53
			95th %tile	5		1733	0.67	0.55	0.67	0.67	0.67
			99th %tile	1		1722	0.80	0.64	0.80	0.80	0.80
			%tile for 0 impact				19	19	18	0	19
Smallmouth Bass Juvenile Aug-Dec only	Days:	16,983	Minimum	100	547	-9606	-3.57	-2.89	-2.07	0.00	-1.78
			1st %tile	99	782	-7800	-2.45	-1.92	-1.82	0.00	-1.21
			5th %tile	95	1,080	-5512	-1.49	-1.22	-1.33	0.00	-0.74
			10th %tile	90	1,285	-4223	-1.09	-0.85	-0.95	0.00	-0.54
			25th %tile	75	2,005	-1319	-0.30	-0.24	-0.23	0.00	-0.15
			Median:	50	4,380	350	0.28	0.20	0.28	0.28	0.28
			75th %tile	25		1293	0.46	0.33	0.46	0.46	0.46
			95th %tile	5		1814	0.61	0.49	0.61	0.61	0.61
			99th %tile	1		1966	0.67	0.55	0.67	0.67	0.67
			%tile for 0 impact				31	31	30	0	31
Smallmouth Bass Fry Jun-Jul only	Days:	6,771	Minimum	100	809	-1998	-0.55	-0.45	0.00	0.00	-0.22
			1st %tile	99	1,131	8	0.06	0.05	0.06	0.00	0.06
			5th %tile	95	1,480	15	0.14	0.12	0.14	0.00	0.14
			10th %tile	90	1,871	35	0.21	0.17	0.21	0.00	0.21
			25th %tile	75	2,796	279	0.74	0.62	0.74	0.00	0.61
			Median:	50	4,565	1196	1.20	1.02	1.20	0.74	0.89
			75th %tile	25		3022	1.55	1.31	1.55	1.25	1.25
			95th %tile	5		4685	1.79	1.54	1.79	1.71	1.71
			99th %tile	1		4850	1.91	1.64	1.91	1.76	1.76
			%tile for 0 impact				0	0	0	0	0

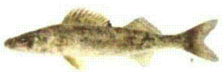
Table 2-6 (cont.) BBNPP habitat impact time series analysis

BBNPP Habitat Impact Time-series analysis

Daily flow record (1900-2010) converted to daily WUA, using
WUA vs. flow response for all transects, PHABSIM and River2D combined
Daily % Impact is change in WUA from natural flow to project flow,
as a percent of WUA at natural flow

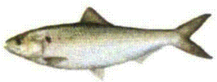
Flow Datasets for PHABSIM Time-series Analyses

Walleye Spawning
Mar-Apr only



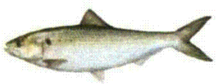
			% Exceed-ance	[1] W-B flows adjusted to BBNPP	[2] [1] with BBNPP "A" CU removed	[2] [1] with BBNPP "A" CU removed	[3] [1] with BBNPP "B" CU removed	[4] [2] with Q7-10 passby	[5] [2] with 20% ADF passby	[6] [2] plus 50% makeup at flow <20% ADF
				cfs	WUA change sq.ft./1000ft	WUA %Impact	WUA %Impact	WUA %Impact	WUA %Impact	WUA %Impact
Days:	6,771	Minimum	100	2,159	-1386	-1.32	-0.91	-1.32	-1.28	-1.28
		1st %tile	99	3,998	-1222	-1.04	-0.72	-1.04	-1.03	-1.03
		5th %tile	95	6,901	-909	-0.43	-0.30	-0.43	-0.40	-0.43
		10th %tile	90	8,897	-407	-0.15	-0.11	-0.15	-0.14	-0.15
		25th %tile	75	14,496	0	0.00	0.00	0.00	0.00	0.00
		Median:	50	23,749	88	0.03	0.02	0.03	0.03	0.03
		75th %tile	25		409	0.26	0.18	0.26	0.26	0.26
		95th %tile	5		456	1.03	0.71	1.03	1.03	1.03
		99th %tile	1		497	5.16	3.73	5.16	5.16	5.16
		%tile for 0 impact				15	15	15	15	15

American Shad Adult
May-Jun only



			% Exceed-ance	cfs	WUA change sq.ft./1000ft	WUA %Impact	WUA %Impact	WUA %Impact	WUA %Impact	WUA %Impact
Days:	6,771	Minimum	100	1,388	-2517	-1.05	-0.88	-1.05	-0.59	-0.60
		1st %tile	99	1,889	-2317	-0.85	-0.71	-0.85	-0.57	-0.57
		5th %tile	95	2,663	-2006	-0.63	-0.53	-0.63	-0.49	-0.49
		10th %tile	90	3,311	-1805	-0.51	-0.42	-0.51	-0.43	-0.44
		25th %tile	75	5,038	-1482	-0.35	-0.28	-0.35	-0.30	-0.33
		Median:	50	8,883	-900	-0.16	-0.13	-0.16	-0.11	-0.16
		75th %tile	25		63	0.01	0.01	0.01	0.01	0.01
		95th %tile	5		415	0.10	0.08	0.10	0.10	0.10
		99th %tile	1		496	0.21	0.17	0.21	0.21	0.21
		%tile for 0 impact				72	72	72	66	72

American Shad Juvenile
Jul-Sep only



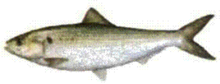
			% Exceed-ance	cfs	WUA change sq.ft./1000ft	WUA %Impact	WUA %Impact	WUA %Impact	WUA %Impact	WUA %Impact
Days:	10,212	Minimum	100	547	-18977	-3.38	-2.74	-1.71	0.00	-1.70
		1st %tile	99	802	-15208	-2.44	-1.99	-1.45	0.00	-1.18
		5th %tile	95	1,010	-7475	-1.11	-0.91	-0.92	0.00	-0.55
		10th %tile	90	1,213	-5344	-0.76	-0.63	-0.69	0.00	-0.37
		25th %tile	75	1,696	-2340	-0.32	-0.26	-0.29	0.00	-0.15
		Median:	50	2,745	260	0.03	0.03	0.03	0.00	0.02
		75th %tile	25		943	0.16	0.13	0.16	0.16	0.16
		95th %tile	5		1192	0.20	0.17	0.20	0.20	0.20
		99th %tile	1		1654	0.25	0.21	0.25	0.25	0.25
		%tile for 0 impact				46	46	45	0	46

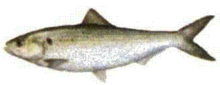
Table 2-6 (cont.) BBNPP habitat impact time series analysis

BBNPP Habitat Impact Time-series analysis

Daily flow record (1900-2010) converted to daily WUA, using
WUA vs. flow response for all transects, PHABSIM and River2D combined
Daily % Impact is change in WUA from natural flow to project flow,
as a percent of WUA at natural flow

					Flow Datasets for PHABSIM Time-series Analyses						
					[1]	[2]	[2]	[3]	[4]	[5]	[6]
					W-B flows adjusted to BBNPP	[1] with BBNPP "A" CU removed	[1] with BBNPP "A" CU removed	[1] with BBNPP "B" CU removed	[2] with Q7-10 passby	[2] with 20% ADF passby	[2] plus 50% makeup at flow <20% ADF
				% Exceed-ance	cfs	WUA change sq.ft./1000ft	WUA %Impact	WUA %Impact	WUA %Impact	WUA %Impact	WUA %Impact
American Shad Fry Apr-Jun only	Days:	10,101	Minimum	100	1,388	-4057	-0.61	-0.51	-0.61	0.00	-0.30
			1st %tile	99	2,026	-1583	-0.22	-0.19	-0.22	0.00	-0.11
			5th %tile	95	2,982	0	0.00	0.00	0.00	0.00	0.00
			10th %tile	90	3,886	0	0.00	0.00	0.00	0.00	0.00
			25th %tile	75	6,703	408	0.11	0.08	0.11	0.11	0.11
			Median:	50	13,365	581	0.13	0.10	0.13	0.13	0.13
			75th %tile	25		783	0.15	0.12	0.15	0.15	0.15
			95th %tile	5		864	0.28	0.21	0.28	0.28	0.28
			99th %tile	1		868	1.16	0.88	1.16	1.16	1.16
			%tile for 0 impact				4	4	4	0	4
American Shad Spawning Apr-May only	Days:	6,771	Minimum	100	2,056	-3254	-2.44	-1.91	-2.44	-1.37	-1.37
			1st %tile	99	3,640	-2641	-1.03	-0.81	-1.03	-0.97	-1.01
			5th %tile	95	5,295	-2190	-0.60	-0.47	-0.60	-0.58	-0.60
			10th %tile	90	6,703	-1731	-0.39	-0.31	-0.39	-0.39	-0.39
			25th %tile	75	10,487	-622	-0.11	-0.08	-0.11	-0.11	-0.11
			Median:	50	17,889	173	0.03	0.02	0.03	0.03	0.03
			75th %tile	25		453	0.11	0.08	0.11	0.11	0.11
			95th %tile	5		508	0.26	0.19	0.26	0.26	0.26
			99th %tile	1		551	0.85	0.62	0.85	0.85	0.85
			%tile for 0 impact				37	37	37	36	37
Northern Hog Sucker Adult 12 months	Days:	40,542	Minimum	100	547	-15033	-9.15	-7.38	-5.24	-0.65	-4.53
			1st %tile	99	890	-14095	-4.99	-4.02	-4.31	-0.56	-2.50
			5th %tile	95	1,326	-11877	-2.87	-2.29	-2.63	-0.40	-1.43
			10th %tile	90	1,738	-8822	-1.71	-1.35	-1.57	-0.26	-0.85
			25th %tile	75	3,393	-3070	-0.42	-0.32	-0.40	-0.03	-0.36
			Median:	50	7,608	0	0.00	0.00	0.00	0.00	0.00
			75th %tile	25		799	0.13	0.09	0.13	0.13	0.13
			95th %tile	5		1004	0.28	0.20	0.28	0.28	0.28
			99th %tile	1		1107	1.06	0.75	1.06	1.06	1.06
			%tile for 0 impact				48	48	48	28	48





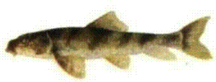


Table 2-6 (cont.) BBNPP habitat impact time series analysis

BBNPP Habitat Impact Time-series analysis

Daily flow record (1900-2010) converted to daily WUA, using
WUA vs. flow response for all transects, PHABSIM and River2D combined
Daily % Impact is change in WUA from natural flow to project flow,
as a percent of WUA at natural flow

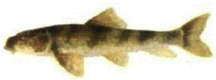
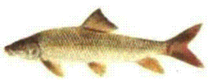
					Flow Datasets for PHABSIM Time-series Analyses						
					[1]	[2]	[2]	[3]	[4]	[5]	[6]
					W-B flows adjusted to BBNPP	[1] with BBNPP "A" CU removed	[1] with BBNPP "A" CU removed	[1] with BBNPP "B" CU removed	[2] with Q7-10 passby	[2] with 20% ADF passby	[2] plus 50% makeup at flow <20% ADF
				% Exceed-ance	cfs	WUA change sq.ft./1000ft	WUA %Impact	WUA %Impact	WUA %Impact	WUA %Impact	WUA %Impact
Northern Hog Sucker Spawning April-May only	Days:	6,771	Minimum	100	2,056	-1855	-1.52	-1.19	-1.52	-0.52	-0.75
			1st %tile	99	3,640	-258	-0.16	-0.12	-0.16	-0.09	-0.16
			5th %tile	95	5,295	0	0.00	0.00	0.00	0.00	0.00
			10th %tile	90	6,703	0	0.00	0.00	0.00	0.00	0.00
			25th %tile	75	10,487	32	0.22	0.16	0.22	0.22	0.22
			Median:	50	17,889	77	0.41	0.31	0.41	0.41	0.41
			75th %tile	25		394	0.60	0.44	0.60	0.60	0.60
			95th %tile	5		593	0.71	0.55	0.71	0.71	0.71
			99th %tile	1		605	3.29	2.58	3.29	3.29	3.29
			%tile for 0 impact				2	2	2	2	2
Shorthead Redhorse Adult 12 months	Days:	40,542	Minimum	100	547	-3874	-3.14	-2.54	-2.34	-0.80	-1.56
			1st %tile	99	890	-3483	-2.25	-1.82	-2.06	-0.72	-1.12
			5th %tile	95	1,326	-3194	-1.69	-1.37	-1.61	-0.56	-0.85
			10th %tile	90	1,738	-2918	-1.32	-1.05	-1.27	-0.44	-0.70
			25th %tile	75	3,393	-1833	-0.58	-0.45	-0.56	-0.21	-0.47
			Median:	50	7,608	-752	-0.17	-0.12	-0.16	0.00	-0.17
			75th %tile	25		131	0.03	0.02	0.03	0.03	0.03
			95th %tile	5		355	0.12	0.09	0.12	0.12	0.12
			99th %tile	1		410	0.36	0.25	0.36	0.36	0.36
			%tile for 0 impact				69	69	68	48	69
Shorthead Redhorse Juvenile Sep-Dec only	Days:	13,542	Minimum	100	547	-5108	-3.65	-2.95	-2.22	-0.23	-1.81
			1st %tile	99	769	-4026	-2.44	-1.89	-1.95	-0.18	-1.21
			5th %tile	95	1,110	-3213	-1.64	-1.29	-1.47	-0.07	-0.82
			10th %tile	90	1,738	-2597	-1.24	-0.93	-1.11	0.00	-0.62
			25th %tile	75	2,241	-1208	-0.47	-0.35	-0.39	0.00	-0.24
			Median:	50	5,295	144	0.12	0.08	0.12	0.12	0.12
			75th %tile	25		453	0.27	0.19	0.27	0.27	0.27
			95th %tile	5		643	0.36	0.27	0.36	0.36	0.36
			99th %tile	1		755	0.95	0.67	0.95	0.95	0.95
			%tile for 0 impact				40	40	38	8	40

Table 2-6 (cont.) BBNPP habitat impact time series analysis

BBNPP Habitat Impact Time-series analysis

Daily flow record (1900-2010) converted to daily WUA, using
WUA vs. flow response for all transects, PHABSIM and River2D combined
Daily % Impact is change in WUA from natural flow to project flow,
as a percent of WUA at natural flow

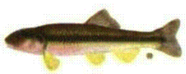
					Flow Datasets for PHABSIM Time-series Analyses						
					[1]	[2]	[2]	[3]	[4]	[5]	[6]
					W-B flows adjusted to BBNPP	[1] with BBNPP "A" CU removed	[1] with BBNPP "A" CU removed	[1] with BBNPP "B" CU removed	[2] with Q7-10 passby	[2] with 20% ADF passby	[2] plus 50% makeup at flow <20% ADF
				% Exceed-ance	cfs	WUA change sq.ft./1000ft	WUA %Impact	WUA %Impact	WUA %Impact	WUA %Impact	WUA %Impact
Shorthead Redhorse Spawning Mar-Apr only	Days:	6,771	Minimum	100	2,159	-205	-2.32	-1.60	-2.32	-1.53	-1.53
			1st %tile	99	3,998	-196	-0.97	-0.67	-0.97	-0.93	-0.93
			5th %tile	95	6,901	0	0.00	0.00	0.00	0.00	0.00
			10th %tile	90	8,897	0	0.00	0.00	0.00	0.00	0.00
			25th %tile	75	14,496	0	0.00	0.00	0.00	0.00	0.00
			Median:	50	23,749	26	0.20	0.14	0.20	0.20	0.20
			75th %tile	25		42	0.30	0.22	0.30	0.30	0.30
			95th %tile	5		50	1.01	0.70	1.01	1.01	1.01
			99th %tile	1		51	4.68	3.32	4.68	4.68	4.68
			%tile for 0 impact				5	5	5	4	5
River Chub Adult/Juv 12 months	Days:	40,542	Minimum	100	547	-9053	-3.73	-3.01	-1.87	0.00	-1.85
			1st %tile	99	890	-5339	-1.77	-1.43	-1.31	0.00	-0.87
			5th %tile	95	1,326	-1016	-0.31	-0.24	-0.19	0.00	-0.14
			10th %tile	90	1,738	18	0.03	0.02	0.03	0.00	0.03
			25th %tile	75	3,393	25	0.06	0.05	0.06	0.04	0.06
			Median:	50	7,608	323	0.29	0.21	0.29	0.15	0.21
			75th %tile	25		1184	0.60	0.42	0.60	0.60	0.60
			95th %tile	5		1907	0.79	0.66	0.79	0.79	0.79
			99th %tile	1		2121	0.84	0.72	0.84	0.84	0.84
			%tile for 0 impact				7	7	7	0	7
Tessellated Darter Adult/Juv 12 months	Days:	40,542	Minimum	100	547	-2767	-3.09	-2.50	-1.71	-0.11	-1.55
			1st %tile	99	890	-1639	-1.61	-1.28	-1.12	-0.05	-0.78
			5th %tile	95	1,326	-349	-0.31	-0.24	-0.19	0.00	-0.14
			10th %tile	90	1,738	-1	0.00	0.00	0.00	0.00	0.00
			25th %tile	75	3,393	0	0.00	0.00	0.00	0.00	0.00
			Median:	50	7,608	34	0.18	0.14	0.18	0.11	0.17
			75th %tile	25		463	0.97	0.69	0.97	0.93	0.93
			95th %tile	5		996	1.42	1.17	1.42	1.42	1.42
			99th %tile	1		1102	1.63	1.38	1.63	1.63	1.63
			%tile for 0 impact				10	10	10	2	10

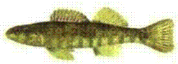
Table 2-6 (cont.) BBNPP habitat impact time series analysis

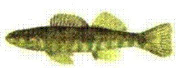
BBNPP Habitat Impact Time-series analysis

Daily flow record (1900-2010) converted to daily WUA, using
WUA vs. flow response for all transects, PHABSIM and River2D combined
Daily % Impact is change in WUA from natural flow to project flow,
as a percent of WUA at natural flow

Flow Datasets for PHABSIM Time-series Analyses

Species / period	Days		Statistic	% Exceed-ance	[1] W-B flows adjusted to BBNPP: cfs	[2] [1] with BBNPP "A" CU removed: WUA change sq.ft./1000ft	[2] [1] with BBNPP "A" CU removed: WUA %Impact	[3] [1] with BBNPP "B" CU removed: WUA %Impact	[4] [2] with Q7-10 passby: WUA %Impact	[5] [2] with 20% ADF passby: WUA %Impact	[6] [2] plus 50% makeup at flow <20% ADF: WUA %Impact
Banded Darter Adult 12 months	Days:	40,542	Minimum	100	547	-1027	-2.20	-1.77	-1.36	-0.02	-1.09
			1st %tile	99	890	-696	-1.30	-1.04	-1.07	-0.01	-0.64
			5th %tile	95	1,326	-469	-0.78	-0.63	-0.73	0.00	-0.39
			10th %tile	90	1,738	-323	-0.51	-0.40	-0.48	0.00	-0.25
			25th %tile	75	3,393	0	0.00	0.00	0.00	0.00	0.00
			Median:	50	7,608	51	0.21	0.14	0.21	0.21	0.21
			75th %tile	25		111	0.27	0.20	0.27	0.27	0.27
			95th %tile	5		168	0.37	0.31	0.37	0.37	0.37
			99th %tile	1		194	1.31	0.94	1.31	1.31	1.31
			%tile for 0 impact				22	22	21	1	22
Banded Darter Juvenile 12 months	Days:	40,542	Minimum	100	547	-838	-1.63	-1.32	-0.98	0.00	-0.81
			1st %tile	99	890	-529	-0.93	-0.75	-0.74	0.00	-0.46
			5th %tile	95	1,326	-344	-0.56	-0.45	-0.52	0.00	-0.28
			10th %tile	90	1,738	-210	-0.33	-0.25	-0.28	0.00	-0.16
			25th %tile	75	3,393	13	0.13	0.09	0.13	0.05	0.11
			Median:	50	7,608	54	0.25	0.19	0.25	0.24	0.24
			75th %tile	25		185	0.40	0.30	0.40	0.40	0.40
			95th %tile	5		252	0.57	0.45	0.57	0.57	0.57
			99th %tile	1		283	0.68	0.57	0.68	0.68	0.68
			%tile for 0 impact				15	15	14	0	15
Banded Darter Spawning May-Jun only	Days:	6,771	Minimum	100	1,388	-91	-0.40	-0.33	-0.40	0.00	-0.20
			1st %tile	99	1,889	-29	-0.12	-0.10	-0.12	0.00	-0.06
			5th %tile	95	2,663	3	0.05	0.04	0.05	0.00	0.05
			10th %tile	90	3,311	6	0.08	0.06	0.08	0.05	0.07
			25th %tile	75	5,038	7	0.14	0.11	0.14	0.13	0.13
			Median:	50	8,883	39	0.28	0.23	0.28	0.28	0.28
			75th %tile	25		65	0.39	0.31	0.39	0.39	0.39
			95th %tile	5		76	0.48	0.39	0.48	0.48	0.48
			99th %tile	1		77	0.49	0.41	0.49	0.49	0.49
			%tile for 0 impact				2	2	2	0	2





The percentile distributions of habitat impact under the consumptive use "A" project scenario from Table 2-6 are graphically summarized for all species and life stages in Figure 2-13. Of the 23 species and life stages considered in this study, 5 experience no negative habitat impact from this "worst case" consumptive use scenario. Fifth percentile negative impacts (pink bars; more negative than this 5% of the time) are less than 2% of natural flow WUA, and first percentile negative impacts (red bars) are less than 3% of natural flow WUA, for all but one life stage, northern hog sucker adults. Negative impacts are even smaller for the other four project flow scenarios.

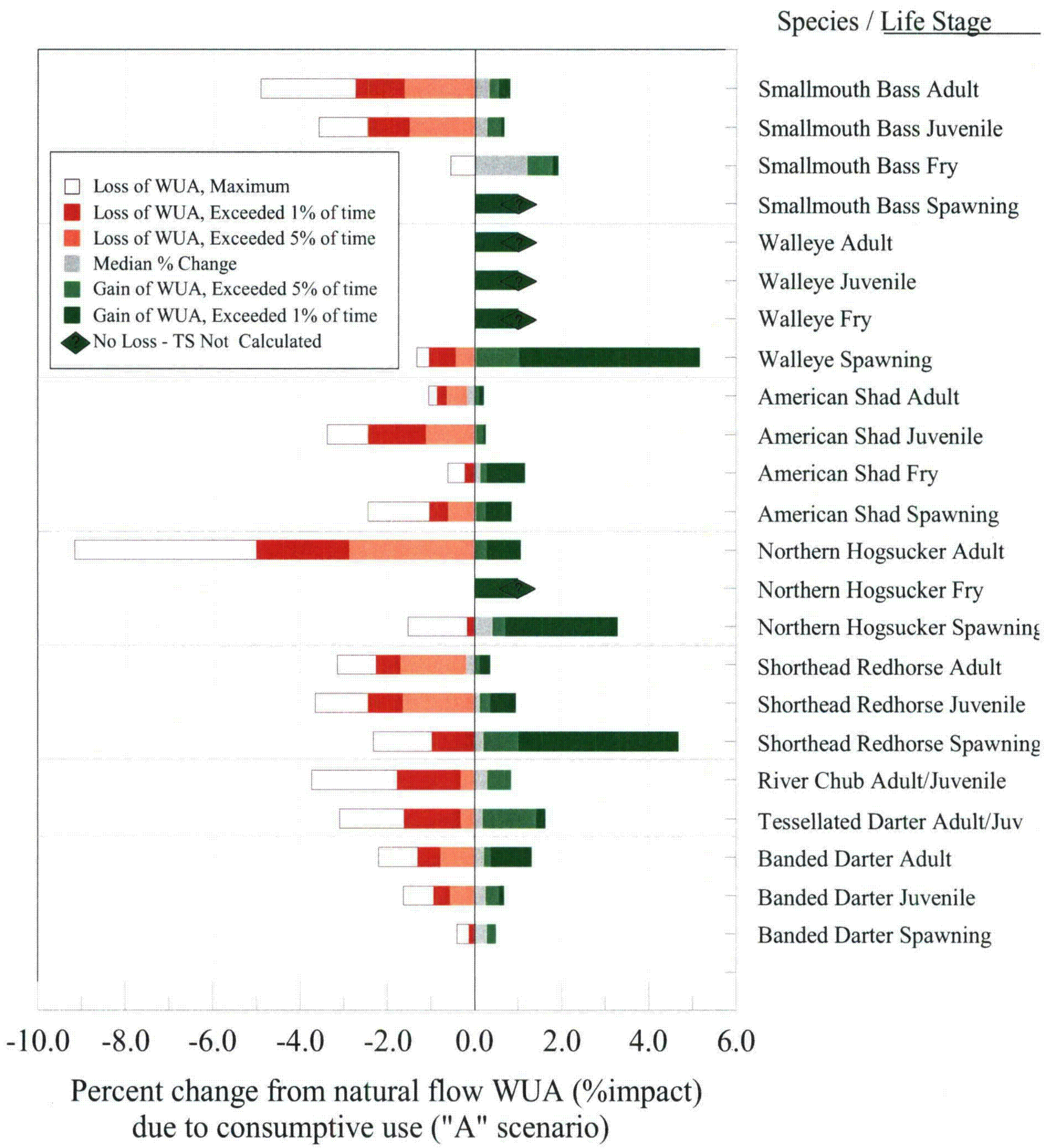


Figure 2-13 Habitat impact time series summary. Habitat impact from the BBNPP consumptive use scenario "A", based on a seasonally relevant 111 year flow time series

The habitat and impact time series analysis was also completed using shorter time frames from the historical flow record: 1960 to 2008, and 1999 to 2002. Those results are tabulated in

Appendix 2-D. The results are generally not different from the analysis using the full 111 year time series.

Time series analysis is also presented on a seasonal basis, showing the range of suitable habitat and consumptive use impacts that might be expected at different times of the year. To do that, the habitat and impact time series were grouped by "week of the year." Figure 2-14 is an example of this analysis for the smallmouth bass juvenile life stage. Similar graphs for all eighteen species and life stages that may experience negative impacts from consumptive use are included in Appendix 2-E.

For each week of the year (when a given species and life stage is present), the distribution of the habitat impacts from the consumptive use "A" scenario is represented by a green "box and whisker" diagram, each based on approximately 777 daily values (7 days per week, 111 years). Following the axis scale on the left side, the central box represents the interquartile range of daily impact values from the time series, the 25th to the 75th percentiles, or the middle 50% of the data. The median value is indicated by a darker horizontal line within the box. The minimum (most negative) single value within each weekly time series is at the "T" at the end of the lower line, while the maximum value is at the upper "T", or often off the graph.

The time series of habitat (WUA, square feet/1000 feet) for each week and flow scenario also contain about 777 daily values, but for clarity only the median value is plotted on these graphs, following the axis scale on the right side. The blue line represents the median weekly habitat (WUA square feet) from the natural flow time series; the red line (where it can be seen) represents the median weekly habitat from the consumptive use "A" scenario flow time series. The two lines are nearly the same, because the reduction in habitat is small given the size of the consumptive use. As expected, the two lines diverge the most in weeks where the habitat impacts range the farthest from zero.

These graphs provide a description of the seasonal variation in both habitat and habitat impact from the time series analysis. In general, negative habitat impacts due to consumptive use are largest in the late summer months, when river flows are generally lowest. However, for many species and life stages, the available habitat is also greatest during these same months. For smallmouth bass juveniles, for example, the reduction in habitat due to consumptive use (represented by the difference between the two median habitat lines) is much less than the reduction in habitat experienced by the fish population throughout the fall due to increasing natural river flows.

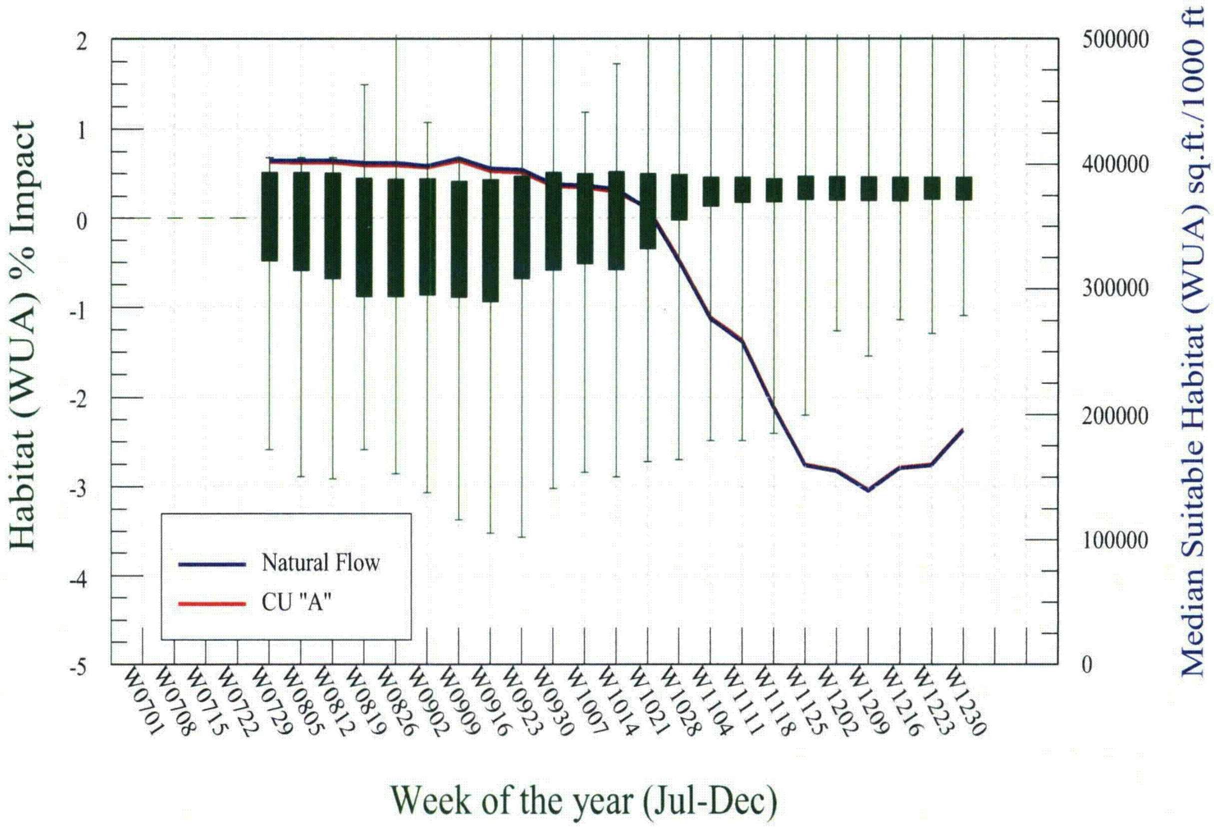


Figure 2-14 Smallmouth bass juvenile habitat and consumptive use (scenario "A") impact by week, based on a 111 year flow time series (1900-2010) and WUA vs. flow responses, PHABSIM and River2D combined, for the entire study reach

2.12. TIMING, DURATION, AND HABITAT IMPACT OF EXTREME LOW-FLOW EVENTS

The SRBC has indicated a concern with the timing and duration of extreme low-flow events in the Susquehanna River in the vicinity of the BBNPP site, and particularly in the riffle section. The limited range of flow simulation in the 2D habitat model (500 to 2200 cfs) precludes a traditional habitat time-series analysis of those results based on the historic river flows, as daily flows are often much higher than 2200 cfs, even during the summer months of July through September. However, the 1900 to 2010 record of daily flows at the Bell Bend site (augmented from the daily flow the Wilkes-Barre, PA, gage) was analyzed to characterize the timing (start date) and duration (number of consecutive days) of river flows below 1000 cfs, and lower thresholds (900, 800, 700, and 600 cfs). This, combined with the analysis of maximum habitat impact levels at these low flow levels presented later in this report, demonstrate how severe, how often, when (seasonally), and for how long habitat impacts resulting from the maximum consumptive use might be expected in the future.

Table 2-7 shows individual low-flow events during the period of record, by start date and duration. "Nested" events occurred as daily flows dropped below consecutive 100 cfs thresholds, and these are shaded together in the table. In some cases, several individual events of flows less than 1000 cfs occurred within a relatively short time frame, notably in 1908, 1909, 1910, 1962, and 1999. There were several extended periods of continual low flows, notably in 1900, 1908, 1939, 1940,1955, 1962, 1963, and especially August through November of 1964. However, since 1964 there has been only one instance, for 3 consecutive days, of river flows below 800 cfs.

Figure 2-15 shows frequency charts of the duration of low flow events at each of the low flow thresholds. Between 1900 and 2011, there were 75 individual instances of river flows dropping below 1000 cfs, and 30 of these were of 1 or 2 day duration; there were 11 events lasting 15 days or more. In that same time period, there were 20 individual instances of flows dropping below 800 cfs. Of these, 11 were of 1 to 3 day duration; 4 events lasting 15 days or more all occurred in 1962-1964. There were only 5 instances of flows below 700 cfs, 2 to 22 days duration, in 1939, 1941, and 1964. Flows dropped below 600 cfs only one time, for 13 consecutive days in 1964 (not plotted).

The seasonal timing of extreme low-flow events is shown in Figure 2-16, with the number of events below various flow thresholds plotted by the month of the event start-date. Consecutive-day flow events below 1000 cfs and 900 cfs mostly occurred in August and September. Nested events at lower flow thresholds centered on September, or even October.

This analysis indicates that extreme low-flow events are rare (based on a 111 year historical record), but have, in a few cases, persisted for two weeks or more. Given the low levels of habitat (WUA) impacts expected at these low flows (less than 5% for most species and life stages of concern), the overall impact of the requested consumptive use at Bell Bend is minimal.

Table 2-7 Daily flows at the BBNPP site (augmented from Wilkes-Barre PA), 1900 to 2010. Start date and duration (consecutive days) of events with flow less than a given cfs. Nested events are shaded together.

	Consecutive days with flow less than:							Consecutive days with flow less than:				
Start date	1000 cfs	900 cfs	800 cfs	700 cfs	600 cfs		Start date	1000 cfs	900 cfs	800 cfs	700 cfs	600 cfs
9/18/1900	29						9/26/1910	2				
9/19/1900		8					9/29/1910	1				
9/21/1900			1				10/16/1910	20				
9/28/1900		2					10/20/1910		1			
10/6/1900		10					10/24/1910		12			
10/7/1900			2				8/12/1911	8				
8/23/1907	1						8/17/1911		3			
8/29/1907	6						8/24/1911	2				
9/3/1908	26						7/31/1912	3				
9/8/1908		21					8/5/1913	4				
9/17/1908			12				8/11/1913	42				
9/30/1908	14						8/19/1913		34			
10/9/1908		3					8/27/1918	2				
10/15/1908	12						8/20/1930	4				
10/22/1908		5					10/23/1930	2				
12/10/1908	1	1					10/26/1930	2				
12/24/1908	1						9/20/1932	8				
9/7/1909	4						7/21/1939	3				
9/13/1909	2						7/25/1939	3				
9/25/1909	1						8/18/1939	7				
9/28/1909	1						8/23/1939		2			
9/30/1909	1						8/26/1939	35	13			
10/5/1909	2						8/30/1939			3		
10/8/1909	1						9/3/1939			3		
10/10/1909	2						9/9/1939		18			
8/7/1910	3						9/12/1939			1		
8/16/1910	3						9/14/1939			13		
8/18/1910		1					9/17/1939				9	
8/20/1910	1						9/20/1941	31				
8/23/1910	14						9/23/1941		18			
8/24/1910		12					9/27/1941			11		
9/18/1910	7						10/2/1941				2	
9/23/1910		2					10/17/1941		2			

Table 2-7 (cont.) Daily flows at the BBNPP site (augmented from Wilkes-Barre PA), 1900 to 2010. Start date and duration (consecutive days) of events with flow less than a given cfs. Nested events are shaded together.

	Consecutive days with flow less than:							Consecutive days with flow less than:				
Start_date	1000 cfs	900 cfs	800 cfs	700 cfs	600 cfs		Start_date	1000 cfs	900 cfs	800 cfs	700 cfs	600 cfs
8/27/1953	10						8/4/1964	8				
8/31/1953		5					8/6/1964		6			
9/28/1953	10						8/9/1964			3		
10/1/1953		6					8/13/1964	106				
10/24/1953	1						8/14/1964		104			
10/26/1953	2						8/18/1964			1		
8/22/1954	4						9/4/1964			29		
8/27/1954	2						9/7/1964				22	
7/22/1955	2						9/16/1964					13
7/25/1955	1						10/4/1964			53		
7/27/1955	15						10/12/1964				5	
7/29/1955		13					11/2/1964				18	
8/4/1955			1				7/27/1965	6				
8/6/1955			2				7/29/1965		3			
8/9/1955			2				8/10/1965	4				
8/4/1959	2						8/12/1965		1			
8/22/1959	5						8/13/1966	2				
8/23/1959		2					8/26/1966	9				
9/17/1959	14						9/3/1966		1			
9/21/1959		10					9/24/1985	3				
7/14/1962	4						8/7/1991	2				
7/17/1962		1					9/6/1991	13				
7/21/1962	2						9/11/1991		7			
7/28/1962	12						8/26/1995	17				
8/1/1962		8					8/29/1995		7			
8/23/1962	5						9/8/1995		2			
8/24/1962		4					8/8/1999	6				
8/29/1962	30						8/10/1999		4			
8/30/1962		18					8/15/1999	6				
9/1/1962			15				8/16/1999		1			
9/18/1962		10					8/29/1999	9				
9/21/1962			7				8/30/1999		8			
9/18/1963	12						9/4/1999			3		
9/27/1963		2					9/10/1999	1				
10/1/1963	37						9/14/1999	2				
10/10/1963		9					9/13/2002	2				
10/14/1963			4				9/19/2002	1				
10/20/1963		18	18									

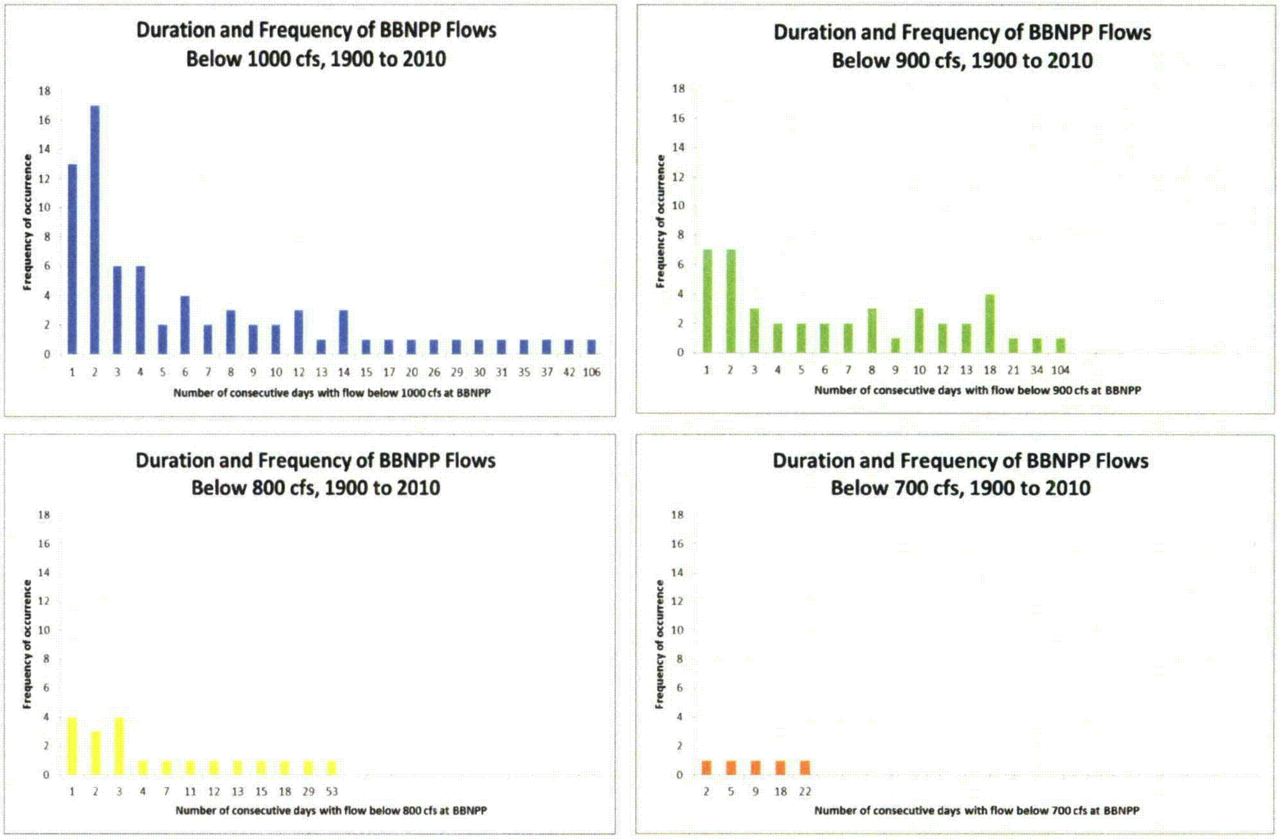
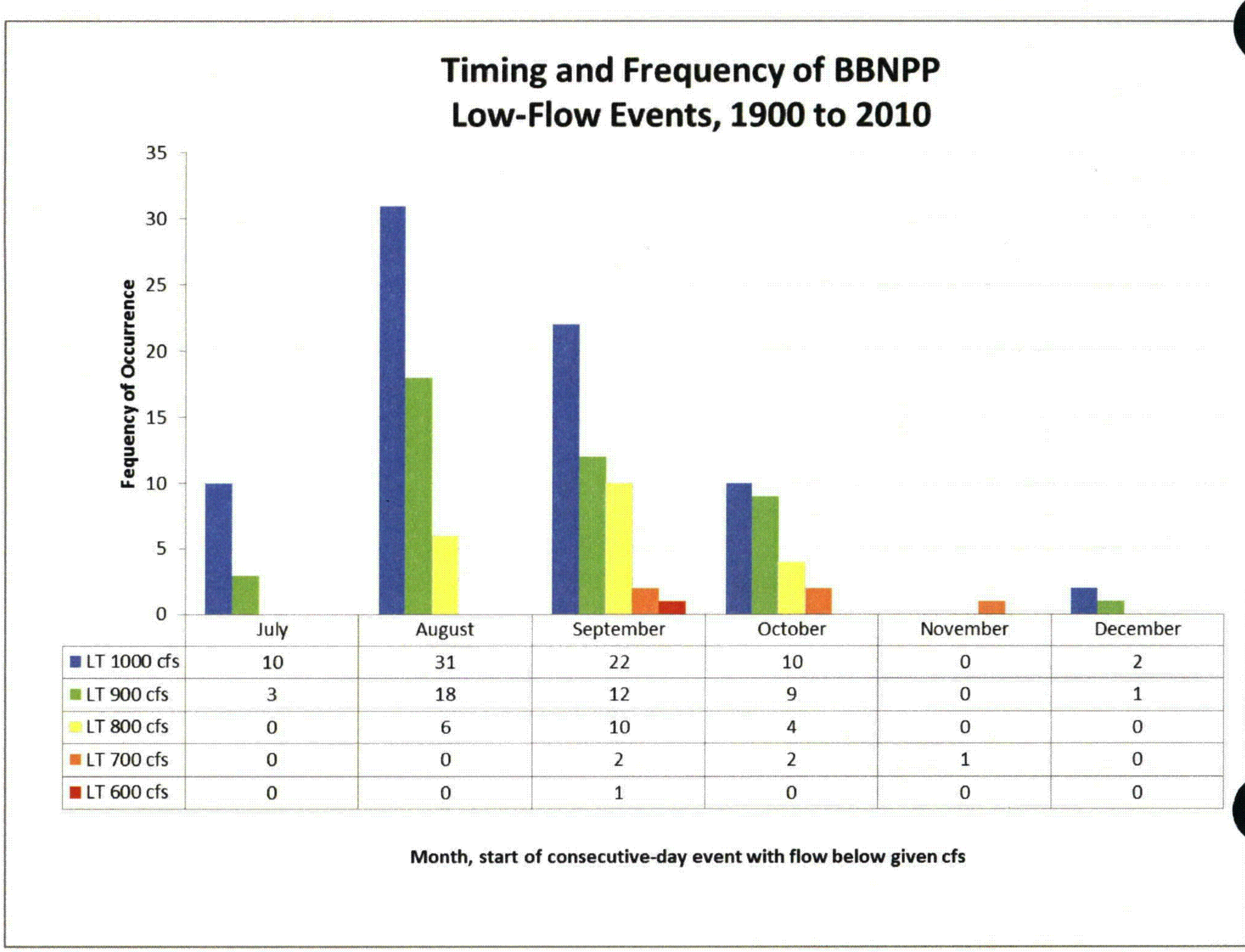


Figure 2-15 Duration (number of consecutive days with flow below a given cfs) and frequency of low-flow events at the BBNPP site, 1900-2010



	July	August	September	October	November	December
LT 1000 cfs	10	31	22	10	0	2
LT 900 cfs	3	18	12	9	0	1
LT 800 cfs	0	6	10	4	0	0
LT 700 cfs	0	0	2	2	1	0
LT 600 cfs	0	0	1	0	0	0

Figure 2-16 Timing (start date of consecutive days with flow below a given cfs) and frequency of low-flow events at the BBNPP site, 1900-2010

Habitat impacts at these extremely low river flows were examined for eleven of the eighteen species and life stages with some potential for negative impact, those which are present in the river when flows may go below 1000 cfs. For the other seven species and life stages, historic river flows never went below 1000 cfs during the months they are present. The relationship between habitat impact (percent change in WUA when the given natural river flow is reduced by 43 cfs) and river flow at the BBNPP site was calculated and plotted for flows between 500 and 1000 cfs. These values represent what negative impacts might result from a 43 cfs consumptive use; negative impacts would mostly be smaller (sometimes the same) with the actual or net consumptive use expected under any of the plant operation or mitigation flow scenarios.

Figure 2-17, Figure 2-18 and Figure 2-19 depict the expected negative habitat impacts from the BBNPP potential maximum 43 cfs consumptive use at extremely low natural river flow. Impacts were calculated using both the PHABSIM 1D and River2D habitat models in the River2D study area (riffle section) only, in addition to the combined habitat model for the entire BBNPP study site. In general, the models produced similar results, particularly between the combined model

full reach and the River2D model. The PHABSIM model limited to the riffle section, based on only 4 transects, varied from the other models for a few life stages. Along with the habitat impacts, the figures show the probabilities of experiencing river flows at or below these levels, based on the 1900 to 2010 daily flow record at the BBNPP site (augmented from the Wilkes-Barre, PA USGS gage), and two shorter time spans: 1960 to 2008, and 1999 to 2002. The minimum daily flow observed in the full time period was 547 cfs (probability of lower flow is 0). The full time period probability of observing flows at or less than the 7Q10 flow (843 cfs) is 0.6%.

This combination of flow frequency and habitat impacts indicates that during extremely low flows in the riffle and island section of the study area, only about half of the species and life stages of interest in this study are negatively impacted by the requested consumptive use at BBNPP, and for those that are negatively impacted, the habitat impacts are both small (even for northern hogsucker adults, less than 7% loss of WUA at the lowest flow observed in 111 years, according to the River2D model), and infrequent (flows below 1000 cfs occur only about 1.7% of the time).

It is important to reiterate that extreme low-flow events are rare and given the low levels of habitat (WUA) impacts expected at these low flows (less than 5% for most species and life stages of concern), the overall impact of the requested consumptive use at Bell Bend is minimal.

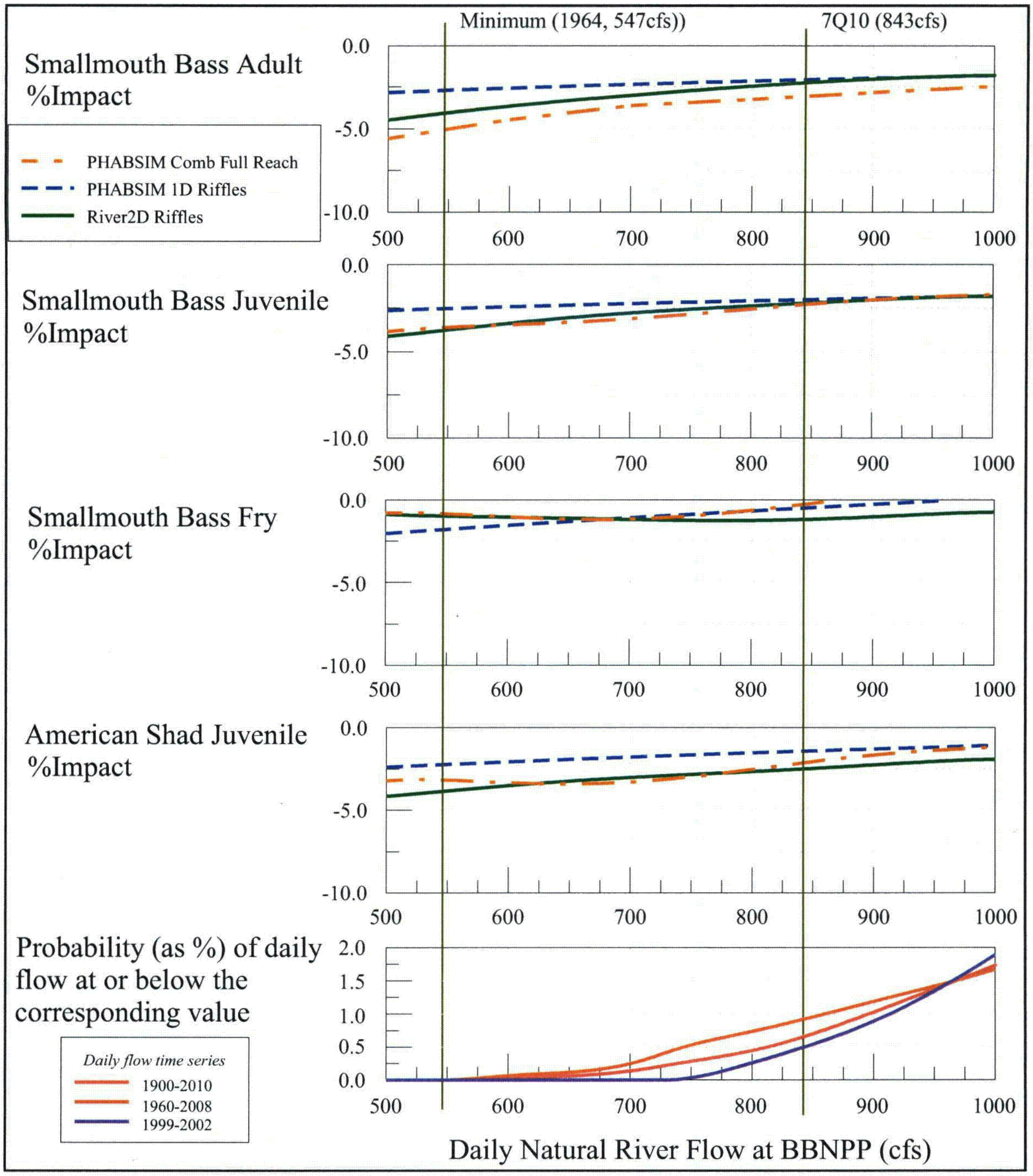


Figure 2-17 Comparison of habitat impacts (% change in WUA) associated with a 43 cfs reduction in flow in the riffle section and the full BBNPP study site, as calculated with different habitat models.

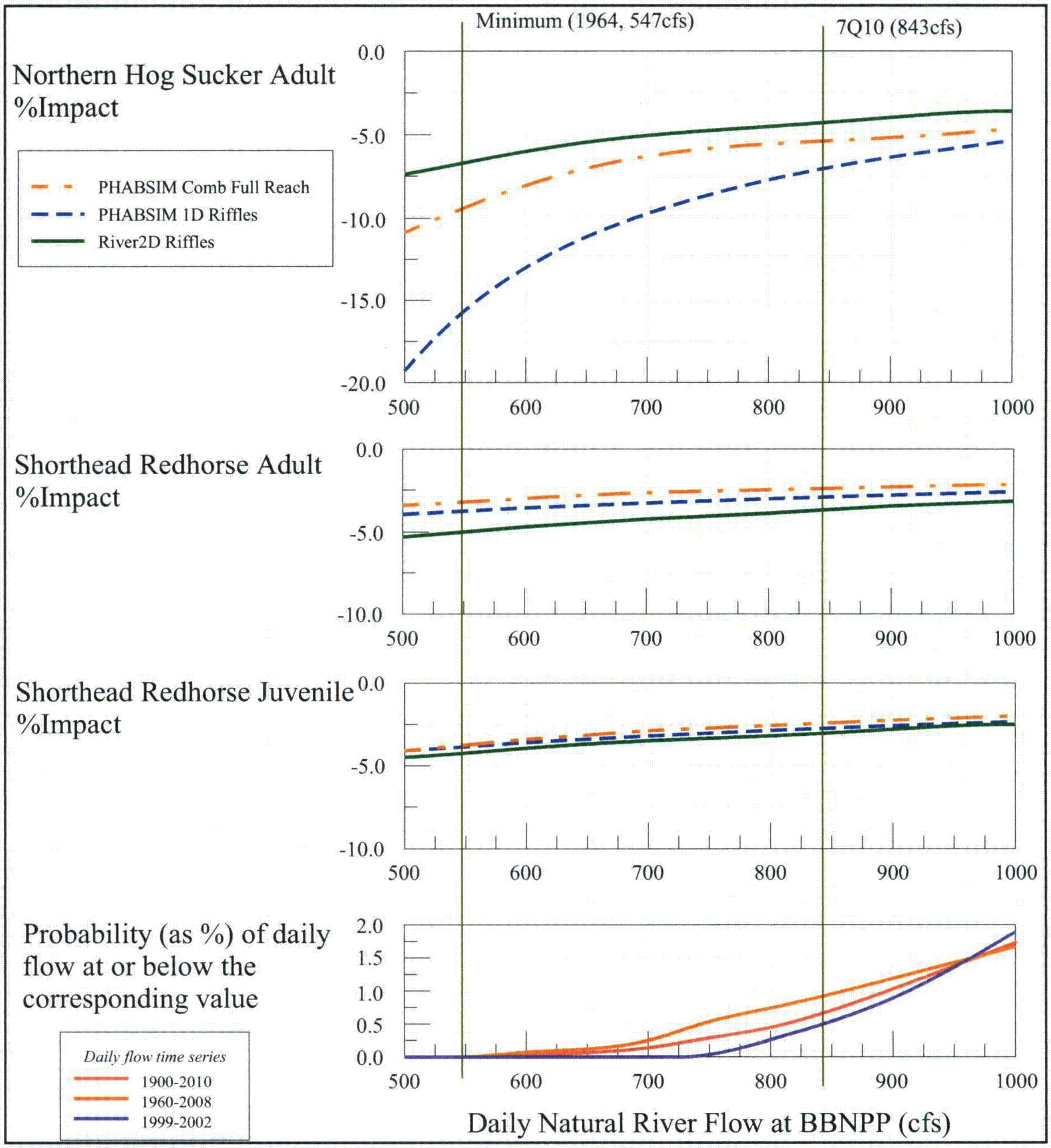


Figure 2-18 Comparison of habitat impacts (% change in WUA) associated with a 43 cfs reduction in flow in the riffle section and the full BBNPP study site, as calculated with different habitat models.

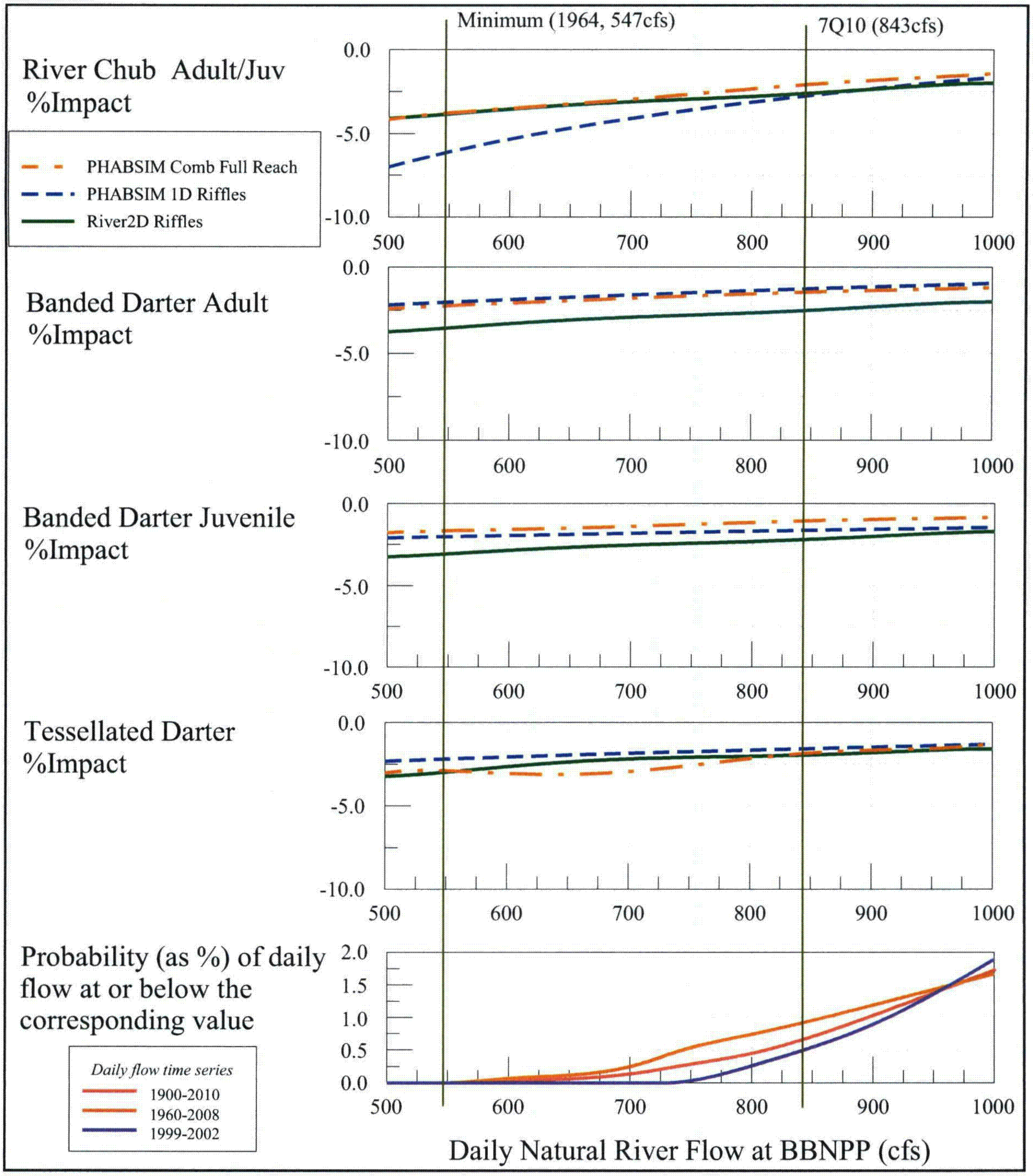
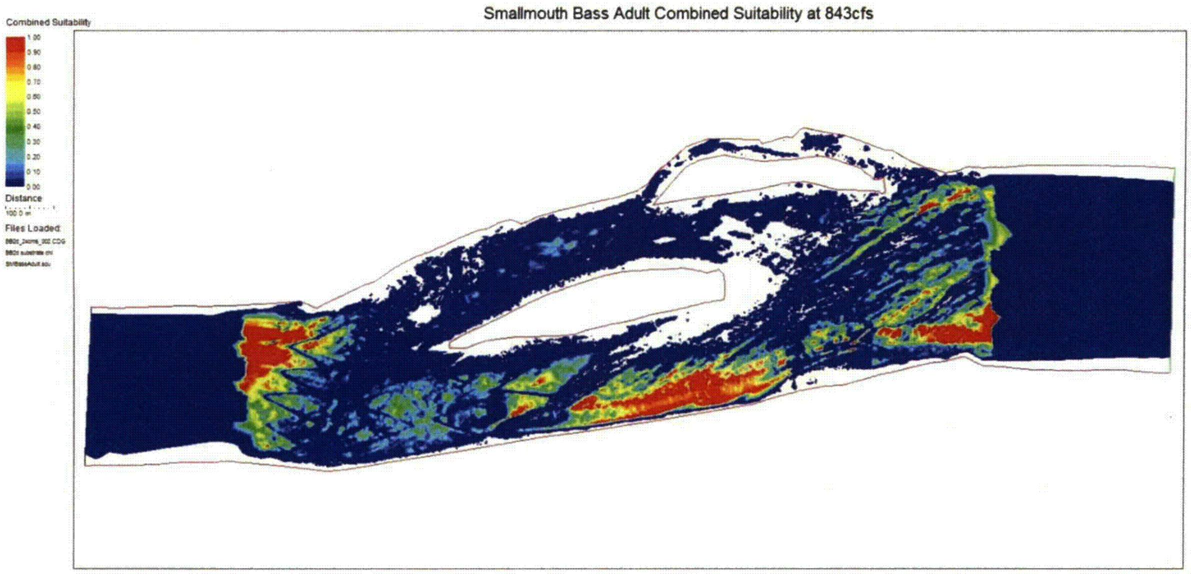


Figure 2-19 Comparison of habitat impacts (% change in WUA) associated with a 43 cfs reduction in flow in the riffle section and the full BBNPP study site, as calculated with different habitat models.

A plan view depiction of the River2D aquatic habitat for the species of interest at the 7Q10 flow (843 cfs) and the 7Q10 flow minus the maximum potential consumptive use (800 cfs) for smallmouth bass adults is presented in Figure 2-20. The plan view depictions of the remaining species and life-stages habitat are presented in Appendix 2-B. Sharp delineation of areas of suitable habitat such as depicted for the shad fry, are caused by substrate changes and the substrate suitability criteria. High resolution images (in order to zoom in to specific areas) for all species/life-stages are available in electronic format (Appendix 2-B - electronic images).

Since changes in habitat are small and locations are difficult to determine, additional views depicting only the *change* in habitat suitability associated with a 43 cfs consumptive use at the 7Q10 flow were generated for smallmouth bass and northern hog sucker (Figure 2-21 through Figure 2-24), as species of particular concern, or subject to greatest impact. The plan view depictions of change in habitat suitability for the eleven species and life-stages impacted at flows below 1000 cfs are presented in Appendix 2-C. In these images, white indicates no suitability (e.g. dry areas), dark blue indicates positive or no change in suitability, and other colors are incremental negative changes in suitability. For both species and all life-stages, the negative changes to the habitat suitability are small (mostly less than 0.1 on a scale of 0.0 to 1.0) and distributed throughout the study site. The response scale of the plots is set at 0 to 0.29 because a few isolated nodes do have changes in suitability that high, but they are so small and scattered that they are not discernible on the plots. High resolution images (in order to zoom in to specific areas) for eleven species/life-stages are available in electronic format (Appendix 2-C - electronic images). In addition, high resolution images describing the water's edge in the 2D hydraulic analysis for both the 7Q10 flow and 7Q10 minus consumptive use are provided as well in Appendix 2-G.



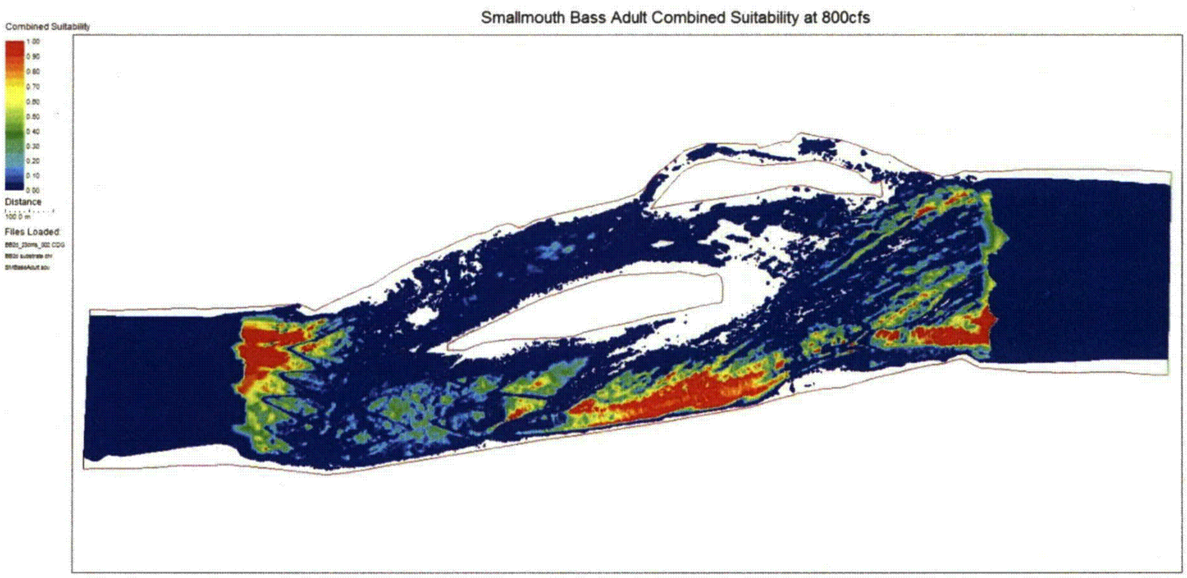


Figure 2-20 Comparison of the smallmouth bass combined suitability at 843 cfs and at 800 cfs

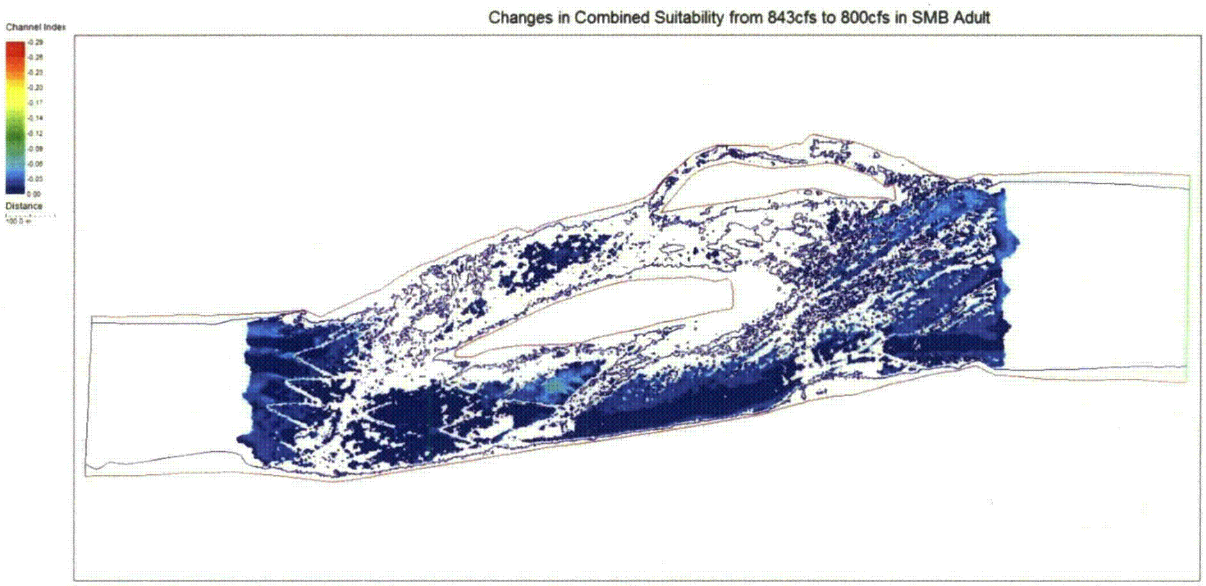


Figure 2-21 Change in habitat combined suitability due to a CU of 43 cfs at the 7Q10 flow of 843 cfs for smallmouth bass adult in the Bell Bend River2D study site

Figure 2-22 Change in habitat combined suitability due to a CU of 43 cfs at the 7Q10 flow of 843 cfs for smallmouth bass juvenile in the Bell Bend River2D study site

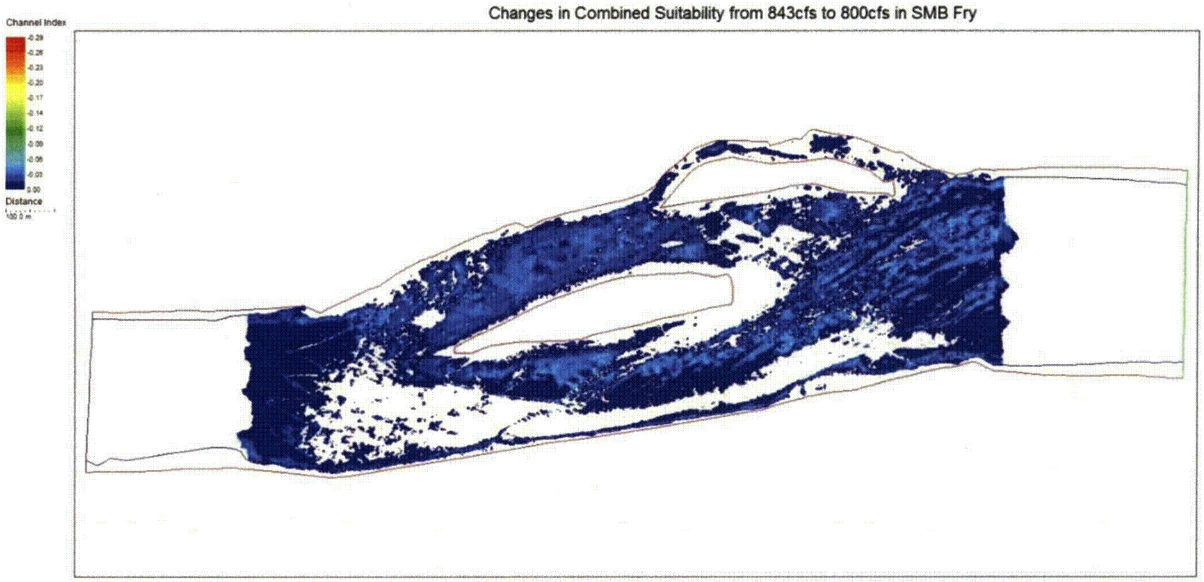


Figure 2-23 Change in habitat combined suitability due to a CU of 43 cfs at the 7Q10 flow of 843 cfs for smallmouth bass fry in the Bell Bend River2D study site

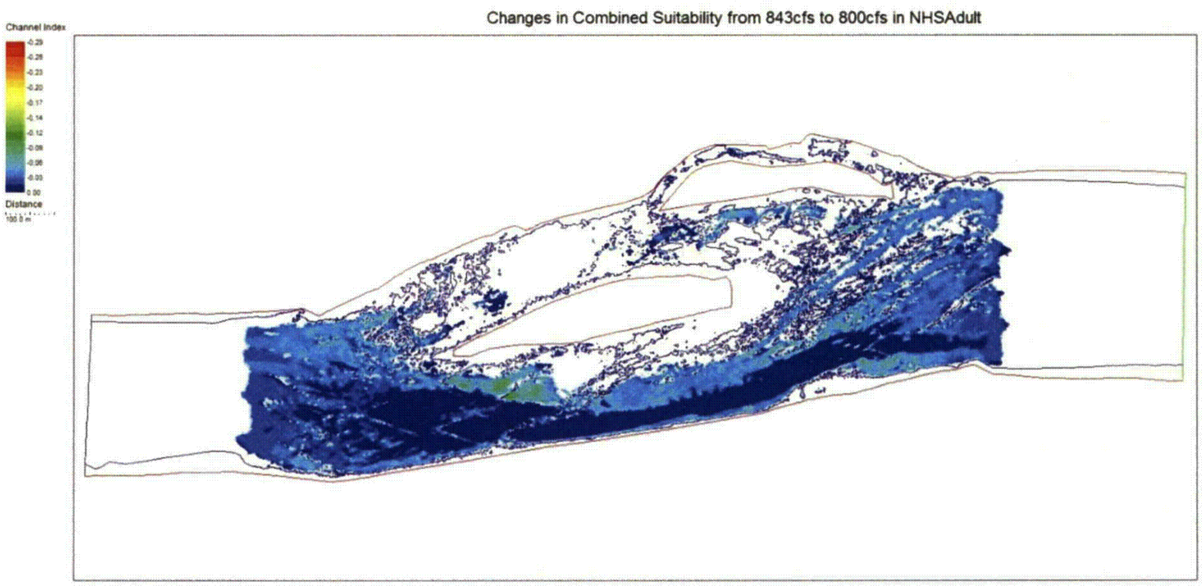


Figure 2-24 Change in habitat combined suitability due to a CU of 43 cfs at the 7Q10 flow of 843 cfs for northern hog sucker adult in the Bell Bend River2D study site

2.13. CONCLUSIONS AND DISCUSSION

The potential for negative impacts on aquatic habitat due to reduction in flow in the Susquehanna River was investigated using both the PHABSIM 1D model and the River 2D model of the Instream Flow Incremental Methodology. For PHABSIM, stream hydraulics were modeled on three sets of field data from 21 transects in the seven mile study reach, and were simulated for river flows ranging from 500 cfs to 25,000 cfs. For River 2D, stream hydraulics were modeled on detailed bathymetric data from a 0.9 mile reach of riffle and island complex, and were simulated for river flows ranging from 500 cfs to 2,200 cfs. Habitat Suitability Criteria were prepared for multiple life stages of eight fish species, and from these, the response of Weighted Useable Area vs. river flow was determined using combined hydraulic data from both models.

Habitat time-series were prepared based on the daily river flow record at Wilkes-Barre, PA from 1900 to 2010 (as well as for shorter time periods), for both natural flows and flows adjusted to reflect various BBNPP water use scenarios. In this study the net impact of BBNPP water use, i.e. the consumptive water use (CU) of up to 28 mgd (43 cfs), was evaluated.

Habitat impact analysis was conducted to determine percent change in WUA over the range of flows due to the requested consumptive water use. There is no negative impact from any level of consumptive BBNPP water use at any flow for five of 23 species and life stage combinations. For the remaining 18 species and life stage combinations, potential negative impacts due to the requested BBNPP consumptive water use are generally small (less than 5% of naturally available WUA) and infrequent (less than 20% of the time). For most species and life stages, negative habitat impacts occur at low river flows and at times of the year (late summer) when available WUA is well above annual minima, so they do not contribute to habitat-related population limitations. For much of the year, consumptive use of water actually increases habitat suitability.

For 11 species and life stages that are present in the river when flows may be expected to drop below 1000 cfs, the potential habitat impacts of a maximum 43 cfs consumptive use were examined in detail at extremely low (and infrequent) river flows. Results were similar for both the full study reach, and the smaller riffle-only (River 2D) reach: potential negative impacts are generally less than 5% in the extreme, and less than 2% to 3% at 7Q10 river flows, which have an occurrence rate of less than 1%. At the expected BBNPP consumptive use rates of less than 43 cfs, negative impacts on habitat will be even smaller.

Predictions of habitat and habitat impacts are very similar from the limited-area River2D study, the original full reach PHABSIM 1D study, and the revised full reach 1D/2D combined study.

Detailed habitat suitability maps from the 2D study indicate that suitable habitat is dispersed throughout the riffle/island study reach, and of course varies by species and life stage. Negative changes in suitability (habitat impact) from a 43 cfs reduction of flow at the 7Q10 flow are small, and also distributed throughout the riffle section.

3. *WATER QUALITY ASSESSMENT OF NESCOPECK AMD DISCHARGES*

3.1. BACKGROUND

The Jeddo Tunnel system drains deep anthracite mines in watersheds adjacent to the Little Nescopeck and discharges AMD to the Little Nescopeck Creek. The Little Nescopeck Creek flows into the Nescopeck Creek and ultimately into the Susquehanna River just below the Nescopeck-Berwick Bridge.

Although the mines are no longer active, the Jeddo Tunnel system continues to drain the abandoned mine workings. Daily outflow from the tunnel as gaged by the USGS during 1974-79 and 1995-98 ranged from 20 to 435 cfs. Ballaron (1999) reports measured pH values at the tunnel portal in the range of 3.6 to 5, with an average pH value of approximately 4.3. The AMD-impaired Little Nescopeck reduces pH values in the Nescopeck Creek, and low pH waters are detectable in the Susquehanna River 6.5 miles downstream of the BBNPP site.

Flow reduction in the Susquehanna River has two potential consequences relative to low-pH water entering the river from the Nescopeck Creek. These are

> (1) that a decrease in Susquehanna River flow will reduce dilution of AMD from Nescopeck Creek and thus decrease pH in the river to a level that will impact downstream users; and
>
> (2) that a decrease in Susquehanna River flow will allow Nescopeck Creek AMD-impaired waters to extend farther into the Susquehanna River and potentially decrease habitat because aquatic organisms will be excluded from or reduced in the extended low-pH area.

These two concerns have been assessed using a combination of a field program and a mass-balance calculation. The mass-balance calculation uses observed values of hydronium ion (H^+) concentrations in the Susquehanna River and the Nescopeck Creek and incorporates the buffering capacity of the Susquehanna River. The mass balance calculation requires that Nescopeck Creek flows be estimated (see Section 3-3), since these flows are not routinely measured.

The Study Plan suggested that the study reach for this assessment extend as far downstream as the Fishing Creek in Bloomsburg, approximately 13 miles from the BBNPP site. The field study presented here indicates the downstream extent of low pH waters is significantly shorter than was supposed when the Study Plan was prepared.

An important objective of this study was to obtain field values of pH for a range of Nescopeck Creek and Susquehanna River flows. Having observations at a range of flows provides direct estimates of the distribution of Nescopeck Creek AMD-impacted water in the Susquehanna River if flows are reduced by BBNPP water use. For example, field observations of pH values

when Susquehanna River flows are 1,460 cfs are equivalent to values that would be observed when Susquehanna River flows are 1,503 cfs and BBNPP consumptive water use is the maximum anticipated 43 cfs.

3.2. FIELD PROGRAM

Ecology III implemented the field program and provided geo-referenced datasets. The field program consisted of measurements of pH, temperature, conductivity, and dissolved oxygen recorded using a YSI 650 MDS equipped with a 600 XL Multi-Parameter Water Quality Monitor. The YSI instrument was calibrated before each use in the field according to the manufacturer's procedure. The location of each sample point was recorded with a Magellan Meridian Platinum model GPS.

The sampling protocol consisted of taking measurements along transects across the river. Each transect consisted of four points across the river: one starting in the low-pH waters (the "AMD plume") near the south (left) bank of the river, one on the outside edge of the plume, one mid-river, and one on the west bank. Transects were extended downstream until low-pH waters could no longer be detected. The downstream-most transect was located approximately 2.5 miles from the mouth of Nescopeck Creek.

Ten surveys over a range of flows were conducted in 2010 (Table 3-1); four of the surveys were at flows less than 2,000 cfs.

Table 3-1 Field Survey data of Susquehanna River downstream of Nescopeck Creek

Survey date	Number of samples	Downstream-most transect distance from the Nescopeck Creek (mi)	Susquehanna River at Wilkes-Barre (cfs)	Estimated Nescopeck Creek flow (cfs)	Susquehanna River pH[4]	Nescopeck Creek pH
5/21/2010	28	2.5	10,700	180	8.4	5.7
6/25/2010	15	2.1	3,910	118	8.1	6.7
8/6/2010	36	1.8	1,810	102	8.1	5.2
8/13/2010	42	2.1	2,180	108	7.9	4.9
9/21/2010	32	1.7	1,650	107	8.5	5.8
9/24/2010	27	1.7	1,580	121	8.4	5.9
9/29/2010	31	1.9	1,460	142	8.0	5.8
10/6/2010	37	1.9	30,600	644	7.3	6.9
10/20/2010	37	1.8	14,200	173	7.6	5.2
10/29/2010	32	1.8	22,400	173	7.6	5.3

The field data were examined graphically to determine the point at which Susquehanna River pH values recovered, and to determine the spatial extent of the low pH plume in the Susquehanna

[4] Measured immediately upstream of the Nescopeck Creek confluence.

River. Examples of the data displays are shown in Figure 3-1, Figure 3-2, and Figure 3-3. These figures show, respectively, low flow, low pH, and high flow events. The remaining surveys are presented in Appendix 3-SRWQS. The scale on the figures represents the PA Chapter 93 criterion for pH, which designates values between 6 and 9 as acceptable. On the figures, orange and red dots indicate values below standard.

It can be seen that pH values in the Susquehanna River quickly return to values well in excess of the minimum pH value of 6. It is also clear how little of the Susquehanna River is affected in the downstream and lateral directions by low pH waters entering from the Nescopeck Creek.

Figure 3-1 Measurements of pH in the Susquehanna downstream of the Nescopeck-Berwick Bridge at low Susquehanna River flow

Survey of 29 September 2010: Susquehanna River flow at Wilkes-Barre was 1,460 cfs, and the pH upstream of the Nescopeck Creek was 8.0. Estimated Nescopeck Creek flow was 142 cfs, and pH measured at the Creek mouth was 5.8.

Figure 3-2 Measurements of pH in the Susquehanna downstream of the Nescopeck-Berwick Bridge at showing minimum observed pH

Survey of 13 August 2010: Susquehanna River flow at Wilkes-Barre was 2,180 cfs, and the pH upstream of the Nescopeck Creek was 7.9. Estimated Nescopeck Creek flow was 108 cfs, and pH measured at the Creek mouth was 4.9.

Figure 3-3 Measurements of pH in the Susquehanna downstream of the Nescopeck-Berwick Bridge at high Susquehanna River flow

Survey of 6 October 2010: Susquehanna River flow at Wilkes-Barre was 30,600 cfs, and the pH upstream of the Nescopeck Creek was 7.3. Estimated Nescopeck Creek flow was 644 cfs, and pH measured at the Creek mouth was 6.9.

The downstream extent of low pH waters can be estimated by developing a metric that allows a quantitative definition of recovery to acceptable pH values. The metric selected is the distance from the Nescopeck Creek confluence with the Susquehanna River to the first transect in which all values exceed a pH of 7 – a value exceeding water quality standards by one pH unit. These distances are shown in Table 3-2. The maximum distance (0.6 mi) occurs on the survey of 13 August (characterized as the minimum observed pH survey). The average distance to recovery is 0.2 mi.

Table 3-2 Distance to pH recovery in Susquehanna River downstream of Nescopeck Creek by survey

Survey date	Closest transect with all pH measurements >7 (ft)	Closest transect with all pH measurements >7 (mi)	Average pH at the transect
5/21/2010	513	0.1	7.1
6/25/2010	647	0.1	7.6
8/6/2010	2,090	0.4	7.9
8/13/2010	3,127	0.6	7.6
9/21/2010	1,168	0.2	8.4
9/24/2010	1,119	0.2	8.1
9/29/2010	2,113	0.4	7.9
10/6/2010	528	0.1	7.4
10/20/2010	513	0.1	7.6
10/29/2010	676	0.1	7.6

3.3. ESTIMATES OF NESCOPECK CREEK FLOW RATES

Although there are no currently active stream gages recording daily flows in the Nescopeck Creek watershed, the USGS maintains a partial-record gaging station in Nescopeck Creek at the Rt. 339 Bridge in Nescopeck (USGS gaging station No. 01538600, Nescopeck Creek at Nescopeck, PA). The USGS has taken approximately 140 flow measurements between 1949 and the present. The drainage area at the gage is 171 square miles, and the gage site is sufficiently close to the mouth of the stream so that it is not necessary to add "local" inflow to represent the total flow entering the Susquehanna River.

For this study, daily Nescopeck flows have been estimated assuming a linear relationship to the daily flow of Wapwallopen Creek. The USGS has recorded daily flow at the Wapwallopen gage since 1919. The drainage area of the stream at the gaging site is 43.8 square miles.

A Nescopeck-Wapwallopen flow relationship was first derived as the sum of two components, namely flow from the Jeddo Tunnel ("Jeddo flow") and flow from the remainder of the Nescopeck drainage. However, that relationship was not better than a direct relationship of Nescopeck flow to Wapwallopen flow. The resulting relationship is:

Nescopeck flow (cfs) = (3.46 x Wapwallopen flow (cfs)) + 76.5 cfs

The relationship was determined by linear regression as depicted in Figure 3-4. The plotted points (diamonds) are Nescopeck Creek flows measured by the USGS since 1982 (approximately 120 measured flows) plotted against the daily flow in Wapwallopen Creek gaged on the same day[5]. The R-squared value of the resulting regression is approximately 0.85, indicating a very good correlation and a strong relationship between the two sites.

[5] No flow measurements were taken between 1971 and 1982, when the gaging station was re-established. The flow measurements taken in 1971 and earlier were disregarded due to the length of the hiatus in measurements,

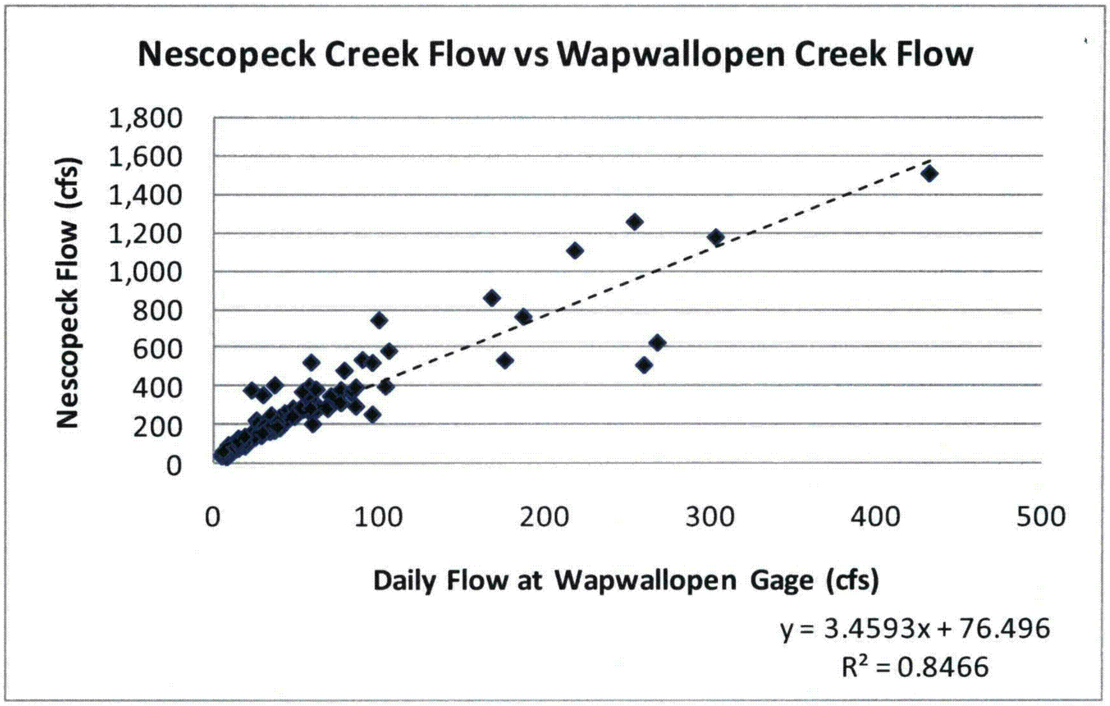


Figure 3-4 Relationship between Nescopeck Creek and Wapwallopen flows

3.4. Mass Balance Calculations

Table 3-3 shows the results of a mass balance modified by an alkalinity buffering calculation for each of the stream pH survey dates and the average observed pH at the farthest downstream transect. Table 3-3 also includes the impacts on pH due to the maximum consumptive use of 43 cfs at BBNPP. In this sequence of calculations, the H^+ ion flux is developed from Susquehanna River and Nescopeck Creek flows and pH values. Downstream pH is then calculated from the change in pH and observed alkalinities for the Susquehanna River[6].

Agreement between calculated and observed pH is good and indicates that the downstream pH is predictable from upstream pH, alkalinity, and flow data. Reduced flow due to consumptive use at BBNPP showed no significant effect on calculated pH.

the possibility that the earlier gaging records were less reliable, and the adequate number of measurements available since 1982.

[6] Alkalinity values for the Susquehanna River were not available for the first four surveys; these values were estimated from seasonal data.

Table 3-3 Calculated and observed pH downstream of the Nescopeck Creek confluence

Date	Susquehanna River upstream pH	Nescopeck pH	Susquehanna River calculated pH	Susquehanna River calculated pH with BBNPP consumptive water use	Susquehanna River pH observed at the farthest downstream transect
5/21/2010	8.4	5.7	8.3	8.1	8.4
6/25/2010	8.1	6.7	8.1	8.1	8.3
8/6/2010	8.1	5.2	8.1	8.1	8.1
8/13/2010	7.9	4.9	7.9	7.9	7.8
9/21/2010	8.5	5.8	8.5	8.5	8.6
9/24/2010	8.4	5.9	8.4	8.4	8.1
9/29/2010	8.0	5.8	8.0	8.0	7.8
10/6/2010	7.3	6.9	7.3	7.3	7.4
10/20/2010	7.6	5.2	7.6	7.6	7.7
10/29/2010	7.6	5.3	7.6	7.6	7.7

3.5. CONCLUSIONS

The potential for additional impairment of the Susquehanna River due to reduced dilutive capacity was investigated with an extensive field program supplemented with mass balance calculations. It was determined that pH in the Susquehanna River recovered within a short distance (the maximum observed is 0.6 mi; the average distance is 0.2 mi) of the Nescopeck Creek's entry point for all observed flows. The ten surveys conducted during the spring, summer and fall seasons of 2010 covered a range of flows from 1,460 to 30,600 cfs as measured at Wilkes-Barre with few pH values less than 6 in the Susquehanna. In addition, all surveys showed that the AMD plume remained attached to the south shoreline of the Susquehanna River. The anticipated reduction in flow from BBNPP consumptive water use would not change this observed behavior.

4. *ASSESSMENT OF COOLING TOWER BLOWDOWN IMPACTS*

This section describes the analyses that were performed to assess potential increases in river water temperature (the "thermal plume") due to the BBNPP cooling tower blowdown discharge and related, potential reductions in dissolved oxygen (DO) concentrations. The analyses include two elements: (1) an assessment of surveyed thermal plume sizes and configurations for the nearly-identical SSES blowdown release system and (2) modeling for two periods when the largest thermal plumes are likely to occur. These periods are (1) a winter period when the maximum difference between the BBNPP blowdown temperature and Susquehanna River temperature occurs and (2) a late summer period when river flows are lowest. The SSES thermal plume surveys presented here correspond to these winter and late summer periods. For each of these two periods, average and worst-case conditions were modeled using EPA's Cornell Mixing Zone Model (CORMIX), a total of four scenarios. Potential changes in DO due to temperature increases in the thermal plume were computed by calculating changes in DO saturation concentrations for each of the four scenarios.

An examination of the observed SSES thermal plumes and an assessment of the model results show that the BBNPP thermal plume is small and that temperature increases are limited to the immediate vicinity of the diffusers. Temperature increases from the combined SSES and BBNPP cooling blowdown releases will be virtually undetectable at the end of the pool in which the SSES and BBNPP discharge structures are located. Reductions in DO concentrations due to the small temperature rises that occur adjacent to the BBNPP diffuser would be minimal.

4.1. COOLING TOWER OPERATION AND DIFFUSER SYSTEMS

Cooling towers are designated Best Technology Available (BTA) for condenser cooling. The BBNPP and SSES diffusers are virtually identical engineered structures designed to rapidly mix cooling tower blowdown with the waters of the Susquehanna River. The diffusers are located on the bottom of the Susquehanna River approximately 80 ft from the shoreline, and separated by 350 ft (Figure 4-1). Each diffuser consists of a 120-ft long, 42-in. diameter manifold with 72 ports. Each port is four inches in diameter, spaced 18 inches apart, and angled upward at 45° to the horizontal oriented downstream.

A significant difference between the SSES and BBNPP cooling towers is that the BBNPP towers are designed to limit discharge blowdown temperatures to less than 90°F, whereas the SSES blowdown temperatures can exceed 90°F under certain conditions.

An important feature of cooling tower blowdown temperatures is that they are functions of wet bulb temperature and the cooling tower approach temperature. The approach temperature indicates how closely the blowdown temperatures (referred to as the "cold side" temperature by cooling tower design engineers) will approach the wet bulb temperature. The wet bulb temperature is the limiting temperature for evaporative cooling. Winter wet bulb temperatures can be high relative to river water temperatures because the latter respond slowly to meteorological changes and can be near freezing for long periods whereas winter air and wet

bulb temperatures can be relatively high when warm air masses are present. This phenomenon means that the largest differences between blowdown temperatures and river water temperatures (the "ΔT") occur during the winter.

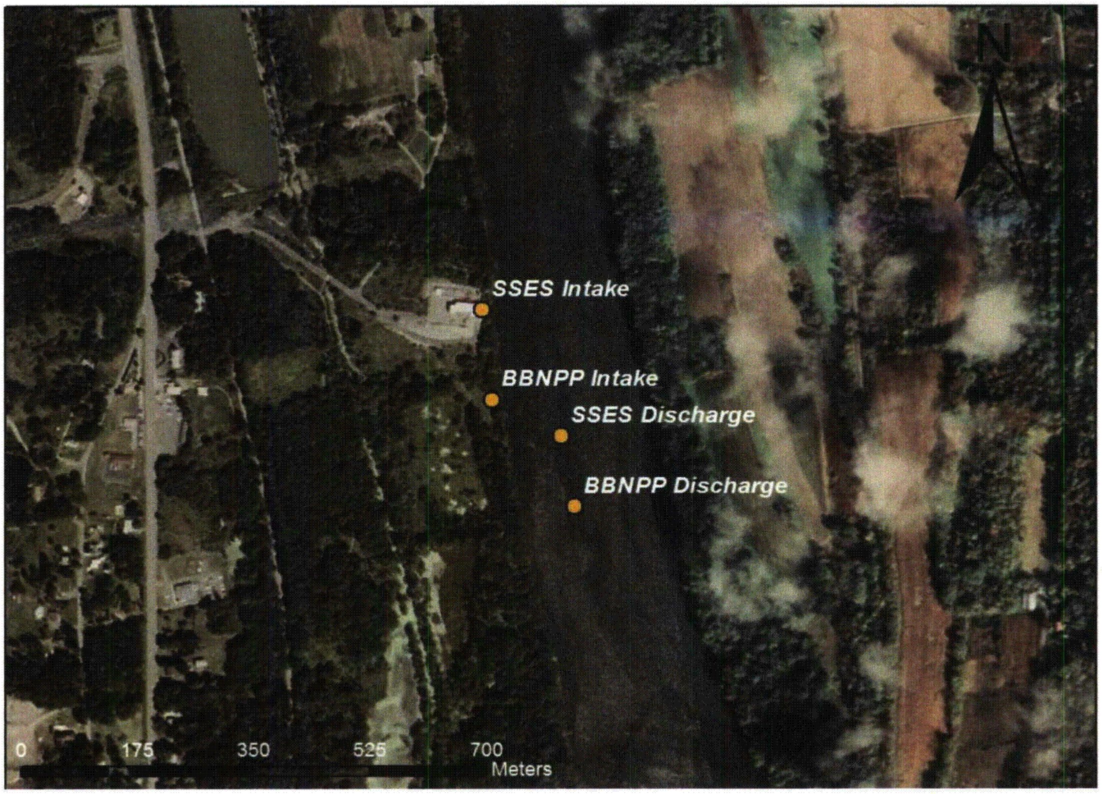


Figure 4-1 Arrangement of the SSES and BBNPP intake and discharge structures

4.2. THE SSES THERMAL PLUME SURVEYS

Ecology III measured the SSES cooling tower blowdown discharge plume on five occasions covering the winter, spring, summer, and fall seasons. The surveys were performed for a range of Susquehanna River flows from 2,140 to 9,250 cfs. All surveys were made when SSES was fully operational. Each survey measured temperatures at a minimum of 20 stations. At each station, temperatures were measured at 1-ft intervals in the vertical (a total of 10 to 15 measurements at each station). Overall, about 300 temperatures were obtained for each survey. The surveys are documented in two Ecology III reports (1987 and 2009).

Susquehanna River and SSES conditions for each of the surveys are summarized in Table 4-1. The ΔT is the difference between the discharge temperature as measured in the cooling tower basins (the cold side temperature) and the upstream Susquehanna River temperature as measured during the survey. Because the surveys took one to two hours to complete and were generally done later in the morning (a period of rapidly rising natural temperatures), the upstream temperature increased from the start to the end of the survey. For the analysis, the upstream

temperature at the start of the survey was used as the ambient temperature. Choosing the lower temperature as the ambient value tends to overestimate the size of the thermal plume.

The five surveys show that the largest ΔT occurred in the winter and the smallest ΔT in the summer. The maximum observed surface temperature rise was 1°F, which occurred during the low flow survey of 3 September 2008. The length of the 1°F temperature rise isotherm at the surface for this survey was 16 ft. For the other surveys, no 1°F temperature rise isotherm was detectable at the surface, and the maximum temperature rise isotherm rise for these surveys was 0.5°F. The average length of the 0.5°F isotherm (maximum distance from the diffuser to the isotherm in the downstream direction) over all surveys was 130 ft.

Table 4-1 Susquehanna River and SSES parameters for the five thermal plume surveys

	11/5/1986	1/9/1987	5/14/1987	8/21/2008	9/3/2008
Susquehanna River flow (reported), cfs	4,840	9,250	5,120	3,230	2,140
Water surface elevation, ft	487.8	489.0	487.9	487.0	486.5
Susquehanna River water temperature, °F	47.0	33.5	65.5	74.5	74.3
SSES blowdown flow rate, gpm	8,000	8,000	8,000	12,000	12,000
SSES blowdown temperature, °F	62.0	61.0	75.0	81.1	84.3
ΔT, °F	15.0	27.5	9.5	6.6	10.0

4.2.1. SSES Thermal Plume for Winter and Late Summer Conditions

Of interest in the context of low summer flow and high winter conditions are the January and September surveys. Results of these surveys are summarized in the plots shown in Figure 4-2 and Figure 4-3. These plots show the small surface temperature rises and the limited length of the thermal plumes. Also plotted in Figure 4-3 is the shape of the plume at depth.

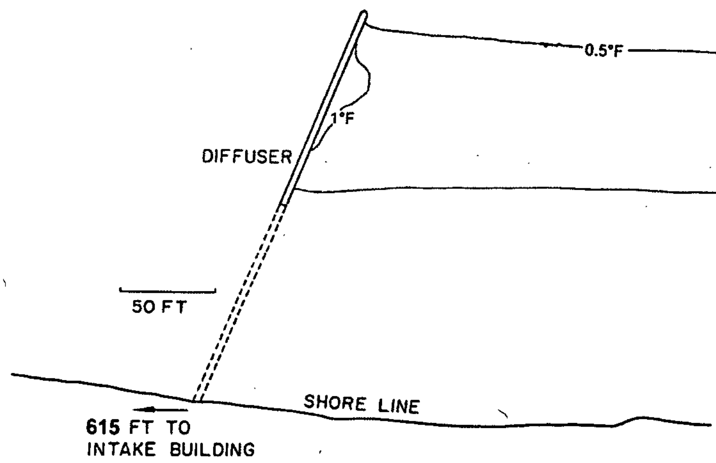


Figure 4-2 Observed surface temperature rises for the low-flow survey (3 September 2008)

The measured upstream temperature at the beginning of the survey was 74.3°F

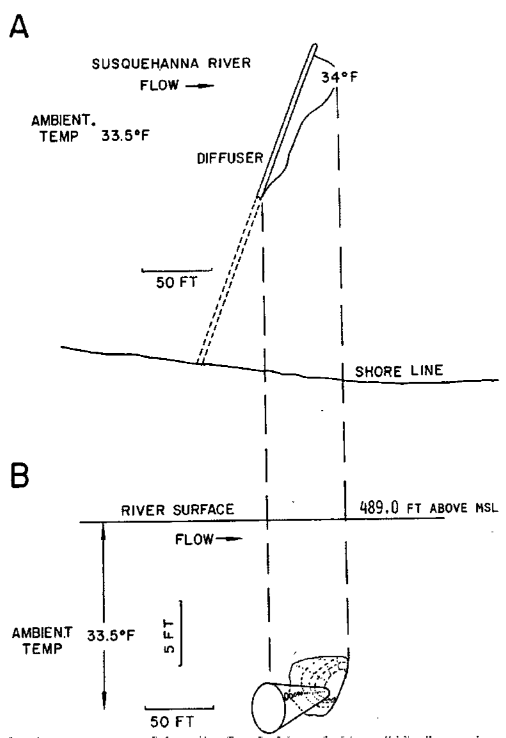


Figure 4-3 Plume configuration for the high-ΔT survey (9 January 1987)

A temperature of 34°F corresponds to a rise above ambient of 0.5°F; the isotherms indicated at the bottom adjacent to the diffuser ("B") are projected onto the water surface in "A".

4.2.2. Sources of Uncertainty in the Surveys

The fall, winter and spring surveys were conducted in 1986 and 1987 and used instrumentation accurate to 0.5°F (p. 3, Ecology III, 1987). This level of measurement accuracy essentially forecloses a precise measure of the length of the 0.5°F isotherm for these three surveys. The two summer surveys, conducted in August and September 2008, used instrumentation accurate to 0.1°F (p. 2, Ecology III, 2009).

Each of the five surveys lasted on average 1.5 hours and all surveys except the January survey were performed during periods of rising ambient temperature. The thermal plume diagrams drawn by Ecology III rely on subtracting an upstream ambient temperature from the temperature observed downstream of the diffuser to calculate the temperature rise. Ecology III noted the difficulty of assessing temperature rises given the changing ambient temperature (p. 6, Ecology III, 1987 and pp. 3 and 4, Ecology III, 2009).

The distances to the 0.5°F isotherm were based on a visual interpolation of observed values at discrete stations. An examination of the Ecology III data showed that for the August 2008 survey the length of the 0.5°F isotherm is dependent on a single data point (Station 23; see p. 10, Ecology III, 2009). An underestimate of 0.1°F in the observation or an overestimate of 0.1°F in the ambient temperature would shorten the isotherm length to 40 ft from 120 ft. Similarly for the September survey, an overestimate of 0.1°F in the observation or an underestimate of 0.1°F in the ambient temperature at Station 14 (see p. 11, Ecology III, 2009) would lengthen the observed isotherm to 420.

The small extent of the SSES plume can be confirmed by overlaying the largest observed plume (September 2003) onto the full width of the Susquehanna River – see Figure 4-4 below.

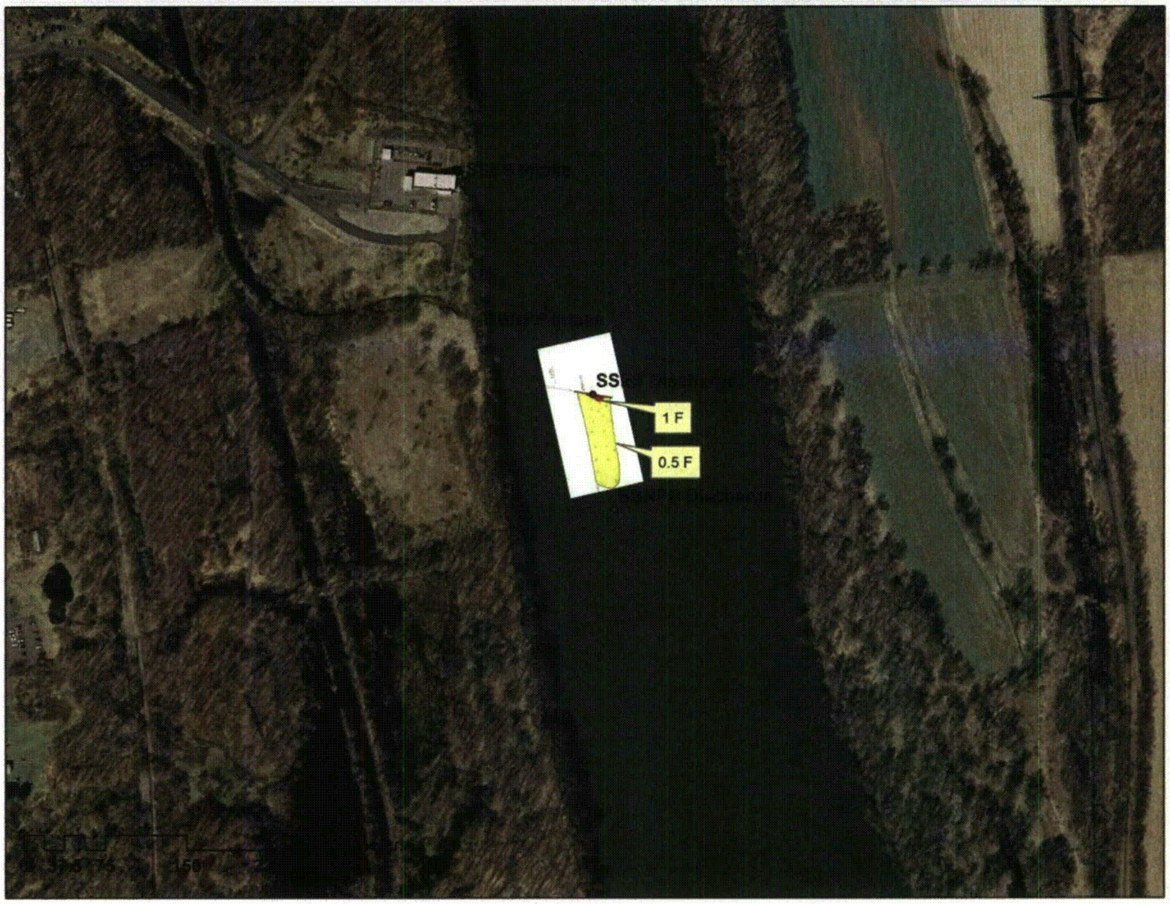


Figure 4-4 Observed thermal plume for the low-flow survey (3 September 2008) mapped onto the Susquehanna River

4.3. MODELING THE BBNPP THERMAL PLUME

Because the SSES blowdown system is similar to the system to be built for BBNPP, the SSES thermal plume observations constitute a useful "model" of the BBNPP thermal plume: SSES and BBNP have similar blowdown rates and temperatures and have nearly-identical diffusers located in the same reach of the Susquehanna River. However, because the scenarios evaluated are combinations of infrequent events, the conditions under which the observations were obtained do not match the scenario conditions. Modeling was therefore used to estimate thermal plume sizes for these scenarios.

4.3.1. Model Selection

EPA developed the CORMIX model specifically for the analysis of the wastewater plumes from surface discharges, submerged multi-port diffusers, and submerged single-port discharges. CORMIX is a rule-based expert system and is used both for design studies and analysis of existing discharges. Because the model is based on analytical solutions to the dynamic plume equations and on extensive experimental and field data, there are no calibration parameters.

Example CORMIX applications can be found on the MixZon Inc. website (http://www.cormix.info/index.php), which also lists references, validations, and benchmarks. Regionally, CORMIX has been adopted by the Delaware River Basin Commission as its standard mixing zone model.

To quote the CORMIX User Manual (p. 17, Jirka, et al. 1996):

> The CORMIX system represents a robust and versatile computerized methodology for predicting both the qualitative features (e.g. flow classification) and the quantitative aspects (e.g. dilution ratio, plume trajectory) of the hydrodynamic mixing processes resulting from different discharge configurations and in all types of ambient water bodies, including small streams, large rivers, lakes, reservoirs, estuaries, and coastal waters. The methodology: (a) has been extensively verified by the developers through comparison of simulation results to available field and laboratory data on mixing processes (Doneker and Jirka 1990; Akar and Jirka 1991; Jones et al.1996a; Jirka et al. 1996), (b) has undergone independent peer review in journal proceedings (Doneker, and Jirka 1991; Jirka and Doneker 1991; Jirka and Akar 1991; Akar and Jirka 1994; Akar and Jirka 1995; Mendéz Díaz and Jirka, 1996; Jones et al. 1996b; Jones and Jirka, 1996; Nash and Jirka 1996) and (c) is equally applicable to a wide range of problems from a simple single submerged pipe discharge into a small stream with rapid cross-sectional mixing to a complicated multiport diffuser installation in a deeply stratified coastal water.

CORMIX divides the plume calculations into near- and far-field regions. In the near-field, the size, configuration, and mixing characteristics of the plume are dominated by the diffuser exit velocity and buoyancy of the discharge. Beyond the near-field is the far-field, in which the plume is passive and its trajectory and mixing are dominated by the ambient velocity and temperature fields. The near-field algorithms for CORMIX are very detailed; the far-field algorithms less so.

CORMIX calculates the location of the plume centerline in three dimensions and, at each location, the temperature rise, the thickness and width of the plume, and the time of travel to that location. Temperature rises along the centerline are often presented as a way of summarizing results, but it should be noted that the temperature rises decrease rapidly with distance from the centerline as a Gaussian distribution. The plume edges are defined by CORMIX as occurring one standard deviation on each side of the centerline.

CORMIX also identifies the flow class for each location along the centerline. As an example, the initial flow class for the BBNPP diffuser is "acceleration zone of unidirectional co-flowing diffuser," which applies immediately adjacent to the diffuser. The flow classification system also indicates at what point the near-field ends and the far-field begins.

CORMIX has a number of limitations. It is a steady-state model[7] and assumes unidirectional ambient flow and a prismatic channel for the receiving waterbody. Neither of these limitations disqualifies its use for computing the size and configuration of the BBNPP blowdown plume. Its suitability can be demonstrated by comparing the computed CORMIX plume sizes with the observed plume sizes for each of the five surveys of the SSES thermal plume.

4.3.2. Comparison to SSES Thermal Plume Dimensions

Table 4-2 shows computed and observed distances from the SSES diffuser to the 1°F and 0.5°F temperature rise isotherms. Computed distances to the 1°F isotherm show good agreement with those observed. CORMIX both over- and under predicts distances relative to the 0.5°F isotherm, notably over predicting the distance for the low-flow case. An important discussion of uncertainty in the observation is presented in Section 4.2.2.

Table 4-2 Observed and computed isotherm distances (SSES)

	11/5/1986	1/9/1987	5/14/1987	8/21/2008	9/3/2008
Observed distance to the 0.5°F isotherm, ft	125	25	80	120	300
Computed distance to the 0.5°F isotherm, ft	27	26	9	21	498
Observed distance to the 1.0°F isotherm, ft	0	0	0	0	16
Computed distance to the 1.0°F isotherm, ft	6	6	2	4	21

CORMIX (Version 7) input and output files for these five surveys are provided on DVD (Appendix 4-CTB).

4.4. Scenarios

Susquehanna River, BBNPP and SSES parameters were derived from daily data for the three-year period August 2004 to July 2007. These data consisted of available observations, including monitored flows and temperatures at SSES and simulated BBNP flows and temperatures. A three-year period was judged to be of sufficient length to represent the range of parameter values. The data used to develop Susquehanna River temperatures used in the scenarios were measured by Ecology III upstream of the SSES intake.

To obtain the parameters for the summer low flow scenario (shown in Table 4-3), the daily differences (ΔTs) between calculated BBNPP discharge temperatures and observed Susquehanna River temperatures were examined for the period when the 7Q10 is most likely to occur (September). The maximum ΔT in the three-year record (16.9°F) occurred on 9/23/2004 when the observed Susquehanna River temperature was 62.3 F. All other parameters were selected

[7] An implication of the steady-state nature of CORMIX is that the results are not indicative of changes in temperature over any particular period, instead they show temperature rises over background. Because SSES operates at a steady rate and BBNPP is expected to operate similarly, temperature changes are expected to be small.

from September values to be consistent with the seasonal behavior of the cooling tower performance, e.g., blowdown rates corresponding to the date of maximum ΔT were selected for this analysis instead of the overall maximum temperature values. Also selected were the minimum Susquehanna River temperature, the average SSES withdrawal rate, blowdown rate, and blowdown temperature for all Septembers in the three-year analysis period. At the Commission's request, the Susquehanna River annual 7Q10 for the period of record adjusted to the BBNPP site was used. The worst case scenarios therefore represent infrequent events of short duration.

For the winter scenario ("high ΔT"), parameters were selected by choosing the day of the maximum BBNPP ΔT from the three-year analysis period (12/23/2004) and the withdrawal rate, blowdown rate, and blowdown temperature for that day. For Susquehanna River parameters, the period-of-record 7Q10 flow for December and the minimum observed temperature for the three-year analysis period were selected. For SSES the average withdrawal rate, blowdown rate, and blowdown temperature over all Decembers in the three-year analysis period were used.

Two similar scenarios were developed using average values of the Susquehanna River, BBNPP and SSES parameters. Parameters for these and the worst case scenarios are summarized in Table 4-3. The four scenarios are similar to those selected for analysis for the 1972 SSES Environmental Report and to conditions observed for the five plume surveys.

Table 4-3 Scenario parameters

Parameter	Winter low flow	Winter average	Summer low flow	Summer average
Nominal Susquehanna River flow, cfs	December 7Q10	December mean	Annual 7Q10	September mean
	2,220	14,906	843	4,729
Net Susquehanna River flow[8], cfs	2,146	14,836	755	4,641
Water surface elevation, ft	486.5	490.4	485.7	487.6
Susquehanna River water temperature, °F	12/23/2004	December mean	9/23/2004	September mean
	33.2	37.8	62.3	69.1
BBNPP blowdown flow rate, gpm	12/23/2004	December mean	9/23/2004	September mean
	6,867	5,967	7,664	7,620
BBNPP blowdown temperature, °F	12/23/2004	December mean	9/23/2004	September mean
	68.4	58.2	79.2	77.6
BBNPP ΔT, °F	35.2	20.4	16.9	8.5
SSES blowdown flow rate, gpm	December mean	September mean	December mean	September mean
	8,119	8,119	8,119	8,119
SSES blowdown temperature, °F	December mean	December mean	September mean	September mean
	62.4	62.4	79.5	79.5
SSES ΔT, °F	29.2	24.6	17.2	10.4

The selected parameters can be used to estimate fully-mixed temperature rises using a mass-balance approach. The fully-mixed temperatures for each of the scenarios are shown in Table 4-4. The fully-mixed calculation uses the net Susquehanna River flow shown in Table 4-3 as follows:

$$\Delta T_{FM} = \frac{\Delta T_{SSES} B_{SSES} + \Delta T_{BBNPP} B_{BBNPP}}{Q_{SRnet}}$$

[8] The net Susquehanna River flow is the nominal flow show minus the consumptive use at SSES and BBNPP.

where

ΔT_{FM}	Fully-mixed temperature rise, °F
$\Delta T_{SSES}, B_{SSES}$	SSES blowdown ΔT and flow rate, °F and cfs, respectively
$\Delta T_{BBNPP}, B_{BBNPP}$	BBNPP blowdown ΔT and flow rate, °F and cfs, respectively
Q_{SRnet}	Net Susquehanna River flow, cfs

These temperatures represent the temperature increases downstream after the blowdown discharges are mixed entirely with the Susquehanna River but do not account for surface heat loss, an important heat transfer process in the far-field. The temperatures in Table 4-4 are therefore overestimates of actual temperature increases.

Table 4-4 Fully-mixed temperature rises for BBNPP and SSES for the four scenarios

	Winter low flow	Winter average	Summer low flow	Summer average
BBNPP fully-mixed rise, °F	0.24	0.02	0.34	0.03
SSES fully-mixed rise, °F	0.24	0.03	0.49	0.05
Combined fully-mixed rise, °F	0.48	0.05	0.83	0.08

4.5. Thermal Plume Size and Configuration Estimates

For each of the four scenarios, CORMIX shows a short near-field region for the BBNPP plume consistent with the behavior observed in the surveys of the SSES plume. For the two worst-case scenarios (winter high ΔT and summer low flow) and the summer average scenario, the plume beyond the near-field becomes stratified, reflecting the buoyancy of the discharge. For the winter average scenario (higher Susquehanna River flow and somewhat lower ΔT), the plume is mixed vertically in the far-field.

The near-field and stratified behaviors can be understood by studying side views of the plumes (Figure 4-5, Figure 4-6, Figure 4-7, and Figure 4-8). For all scenarios, the overall behavior is intense mixing at the diffuser (the near-field) followed by stratification in the far-field for the two low-flow and summer average scenarios or by vertical mixing for the winter average scenario. Although not shown, the CORMIX results indicate that the SSES plumes behave in a manner similar to that shown by the BBNPP plumes for each of the four scenarios.

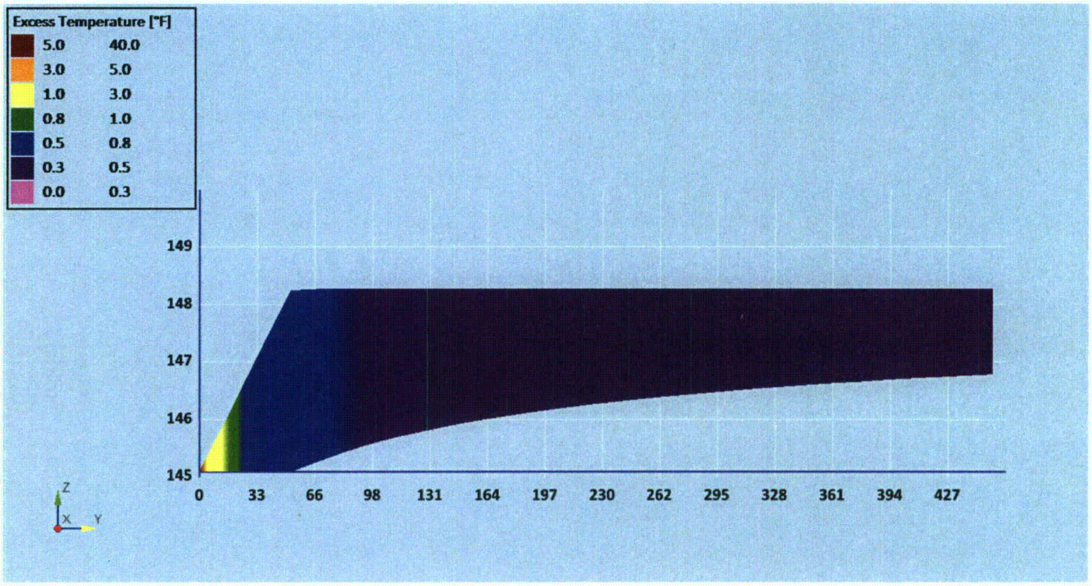


Figure 4-5 BBNPP winter low-flow scenario - plume side view

Vertical axis is mMSL; horizontal axis is ft downstream of the BBNPP diffuser.

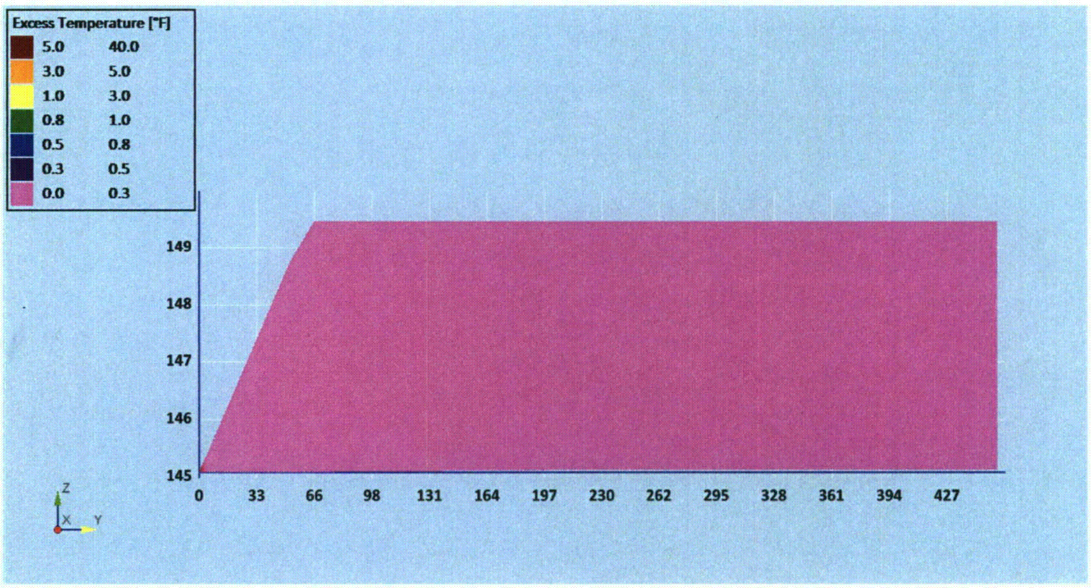


Figure 4-6 BBNPP winter average-flow scenario - plume side view

Vertical axis is mMSL; horizontal axis is ft downstream of the BBNPP diffuser.

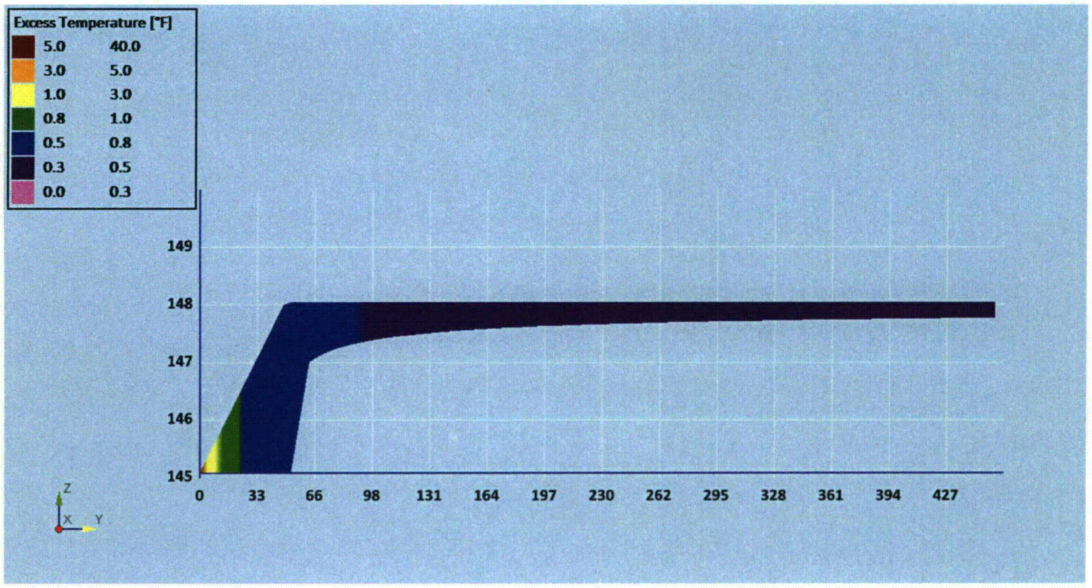


Figure 4-7 BBNPP summer low-flow scenario - plume side view

Vertical axis is mMSL; horizontal axis is ft downstream of the BBNPP diffuser.

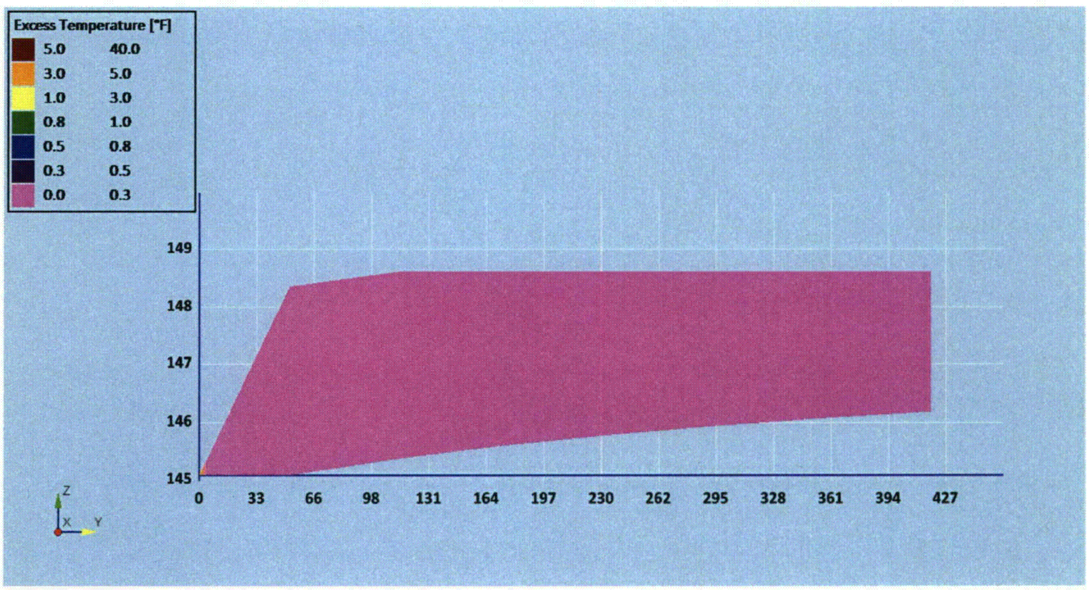


Figure 4-8 BBNPP summer average-flow scenario - plume side view

Vertical axis is mMSL; horizontal axis is ft downstream of the BBNPP diffuser.

Although separated by 350 ft, the SSES discharge plume can overlap the BBNPP plume at low temperature rise values. An estimate of the extent of overlapping can be made by studying the temperature rise from SSES at the BBNPP discharge. Table 4-5 shows the temperature rise within the SSES thermal plume at a downstream distance of 350 ft. Only the low-flow scenarios (winter low flow and summer low flow) show an SSES plume that overlaps the BBNPP plume at

a temperature rise above 1°F at the centerline. The temperature rise within the plume drops rapidly to less than 0.5°F at the plume edges. The temperature rise within the BBNPP plumes shown earlier can be expected to increase by the amount shown in Table 4-5 at the centerline and plume edges.

Table 4-5 Temperature rise from the SSES thermal plume at the BBNPP discharge

Scenario	Temperature rise at centerline, °F	Temperature rise at plume edge, °F
Winter low flow	1.09	0.40
Winter average	0.18	0.07
Summer low flow	1.29	0.48
Summer average	0.28	0.10

The overlapping of the plumes will result in an increase in the size of the combined plume. The worst-case scenario of summer low flow was used to study the implications of overlapped plumes. To illustrate the spatial relationship of the SSES and BBNPP thermal plumes, the plume can be shown as an isosurface (i.e., a three-dimensional surface defined by a constant temperature rise). Figure 4-9 shows the 1°F temperature rise isosurface due to the BBNPP discharge alone. In the presence of the SSES discharge, the 1°F isosurface will expand and is shown in Figure 4-10. The downstream extent of the 1°F isosurface does not increase as much as the lateral extent, because the temperature rise drops quickly with downstream distance. The lateral extent of the overlapping plume as shown by the 1°F isosurface does not extend over the entire width of the Susquehanna River under the summer extreme low flow scenario.

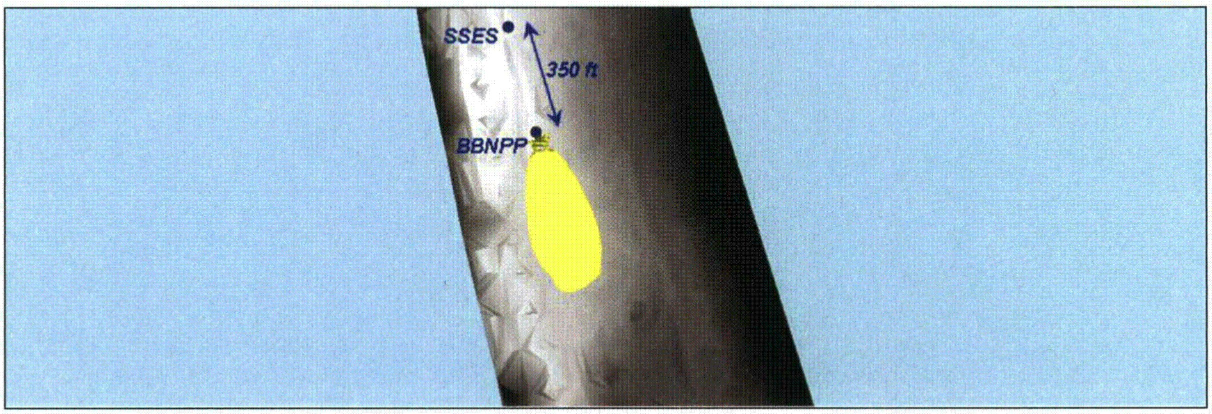


Figure 4-9 The 1°F temperature rise isosurface emerging from BBNPP discharge alone for the summer low-flow scenario

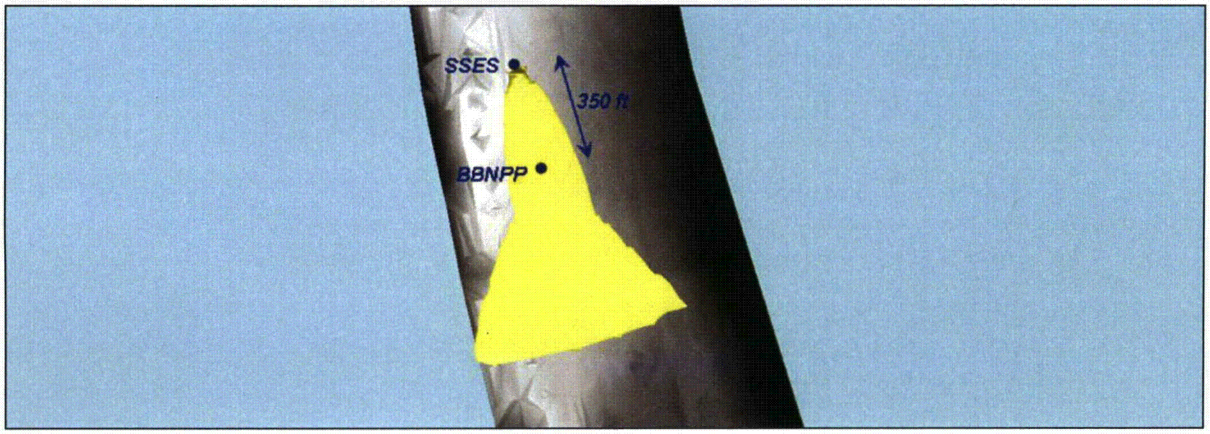


Figure 4-10 The 1°F temperature rise isosurface emerging from combined BBNPP and SSES discharge for the summer low-flow scenario

Besides the lateral extent of the plumes, the vertical extent is of interest in evaluating the potential for thermal blockage. As noted, all plumes calculated for the scenarios are stratified except for the winter average scenario. For this scenario, the temperature rise is so small (less than 0.25°F) as to make the plume nearly indistinguishable from ambient water. For the other three scenarios, the average temperature rise in the stratified layers of the BBNPP can be calculated from the CORMIX results. These values are shown in Table 4-6 at a representative distance of 100 ft from the BBNPP discharge and indicate that the plume does not extend over the entire water column. There is a thin bottom layer unaffected by the plume that occurs with the summer average flow scenario, but the temperature rise in the surface layer is only 0.19°F. The summer low-flow scenario that shows the highest temperature rise (1.35°F) has the thickest bottom layer at 7.6 ft.

Table 4-6 Surface and bottom layer temperature rises for the four scenarios

Location: 100 ft downstream of BBNPP discharge	Winter low flow	Winter average	Summer low flow	Summer average
Surface layer rise at the centerline, °F	1.32	0.12	1.35	0.19
Surface layer rise at plume edge, °F	0.49	0.04	0.50	0.07
Surface layer thickness, ft	7.9	14.4	2.1	10.6
Surface layer width, ft	150.9	110.3	193.6	124.7
Bottom layer rise, °F	0.00	(not stratified)	0.00	0.00
Bottom layer thickness, ft	2.0	(not stratified)	7.6	1.0

Plume overlapping and its implications in the vertical direction can be studied in a similar fashion to that in the horizontal plane. The summer low-flow scenario was used for this analysis. Figure 4-11 shows the 1°F temperature rise isosurface from the BBNPP discharge alone. Figure 4-12 shows the 1°F temperature rise isosurface from the combined SSES and BBNPP discharges. Due to the overlapping of the plumes, the BBNPP plume has increased in the vertical direction and in its downstream extent. However, the increase in size is small relative to the river water column depth. The side view of the plume shows that the bottom ambient temperature layer occupies most of the water column and provides a large zone for fish passage.

Similar diagrams are included for the 0.5°F temperature rise isotherm in Figure 4-13 and Figure 4-14

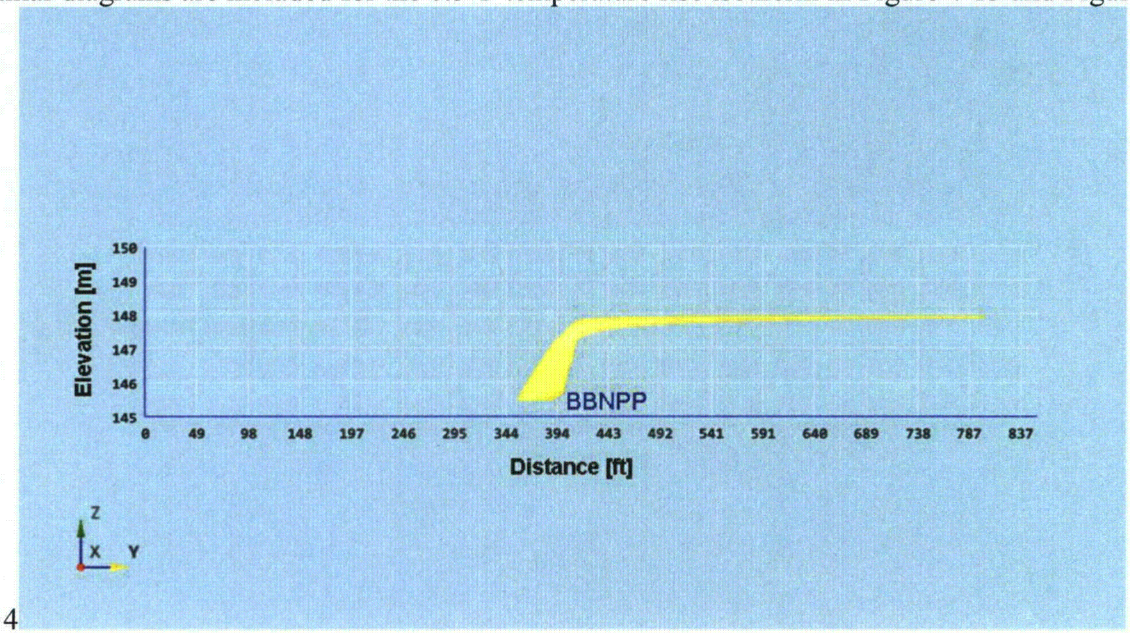


Figure 4-11 The 1°F temperature rise isosurface emerging from BBNPP discharge alone for the summer low-flow scenario

Distances are from the SSES discharge.

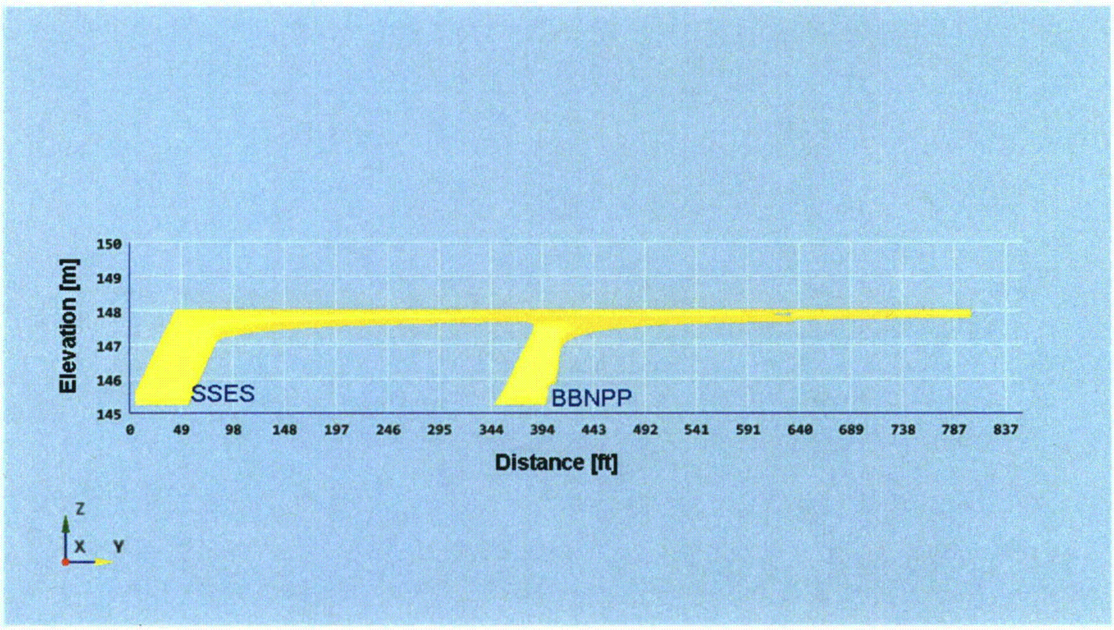


Figure 4-12 The 1°F temperature rise isosurface emerging from combined BBNPP and SSES discharge for the summer low-flow scenario

Distances are from the SSES discharge.

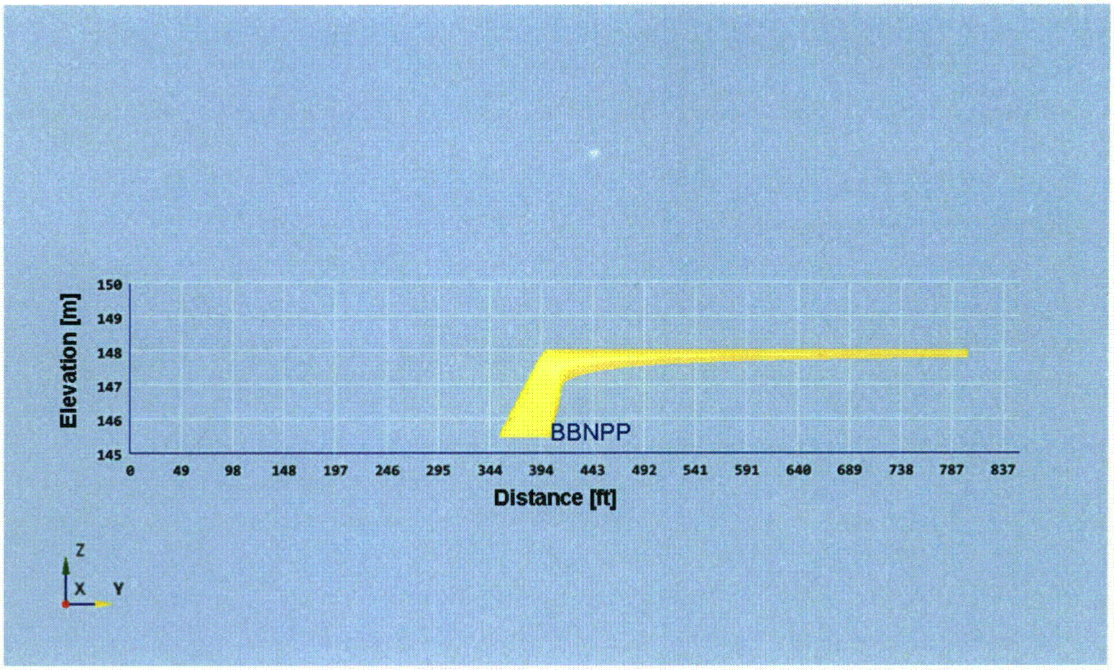


Figure 4-13 The 0.5°F temperature rise isosurface emerging from BBNPP discharge alone for the summer low-flow scenario

Distances are from the SSES discharge.

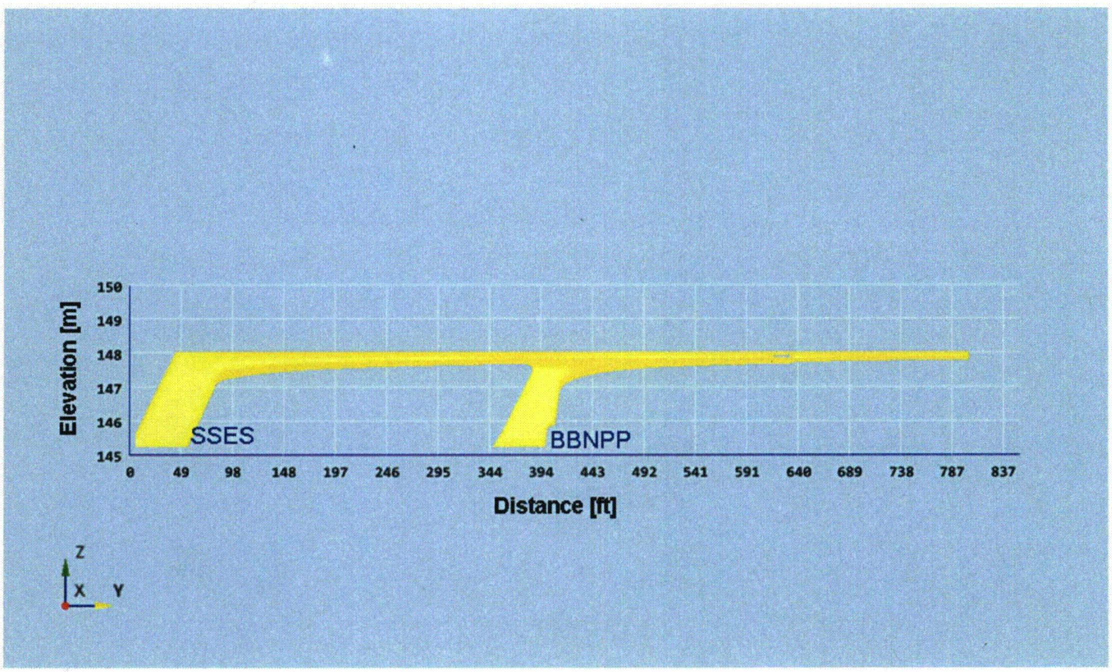


Figure 4-14 The 0.5°F temperature rise isosurface emerging from combined BBNPP and SSES discharge for the summer low-flow scenario

Distances are from the SSES discharge.

4.6. Sensitivity Analysis

An analysis was performed to quantify the sensitivity of the CORMIX model to two key input parameters, water depth and river velocity. For this analysis, these parameters were varied by 5% (plus and minus) from the base case values for the BBNPP summer low flow scenario. Temperature rises for the base and sensitivity cases are compared at a distance 100 feet downstream of the discharge structure. At distances further than 100 feet, the differences between the base and sensitivity cases are too small to be illustrative of the model's sensitivity.

Results of the sensitivity analysis are presented in Table 4-7, which shows temperature rise and plume width at 100 ft from the BBNPP diffuser. A 5% reduction in depth caused a 1.6% increase in temperature rise at 100 ft, and the 5% decrease in velocity caused a 2.1% increase in temperature rise. Plume widths did not change with depth, but the 5% increase in velocity widened the plume by 3.3%. The changes in temperature rise and plume width are smaller than the changes in the values of the depth and velocity input parameters indicating limited model sensitivity to changes in input parameters.

Table 4-7 CORMIX sensitivity analysis results

Case	Temperature rise (°F) at 100 ft	Plume width (feet) at 100 feet distance
Base, i.e., summer low flow	2.43	196.8
+ 5% depth	2.39	196.8
- 5% depth	2.47	196.8
+ 5% velocity	2.38	203.4
- 5% velocity	2.48	196.8

4.7. Dissolved Oxygen Effects

Increases in temperature in the BBNPP cooling tower blowdown plume may cause a decrease in dissolved oxygen (DO) concentration. This potential reduction can be estimated by comparing the saturation concentration at the ambient temperature to the saturation concentration at the ambient temperature plus temperature rise for each of the four scenarios. The saturation concentration can be calculated using Mortimer's (1981) formulation as shown below:

$$DO_{sat} = \exp(7.7117 - 1.31403\ln[T + 45.93])$$

where T is the water temperature in °C.

Susquehanna River temperatures for the four scenarios were used to calculate the saturation DO values without the BBNPP thermal plume. The temperature rise obtained from CORMIX at a distance of 54 ft was added to the ambient value to recalculate the DO. The difference is the reduction in DO due to the presence of the thermal plume. The value of 54 ft corresponds to the end of the near-field for all scenarios except for the summer low-flow scenario. As noted earlier, CORMIX does not report a near-field termination distance for the summer low-flow scenario; for consistency the DO calculation for this scenario is also reported for the 54 ft distance. Use of

the 54 ft distance for the DO calculation is conservative, because centerline temperature rises are used.

The calculated values of DO saturation concentration at the end of the near-field (54 ft) are shown in Table 4-8. The temperature rise is largest for the two low-flow scenarios; these scenarios show the largest reduction in saturation DO. However, the relative temperature rise is largest for the winter low-flow scenario; consequently, the largest DO saturation reduction (0.31 mg/L) is obtained for this scenario. For the summer low flow case the reduction (0.16 mg/L) is much smaller and likely to fall below detection by standard field instrumentation. None of the reductions in saturation DO would cause DO to fall below water quality standards. In addition, as noted in the thermal plume discussions, the plumes themselves are limited in extent so the volume of water in which saturation DO is reduced is similarly limited in extent.

Table 4-8 DO values at the plume centerline at the end of the near-field with and without the influence of the BBNPP thermal plume

Scenario	Winter low flow	Winter average flow	Summer low flow	Summer average flow
Susquehanna River temperature (°F)	33.2	37.8	62.3	69.1
Susquehanna River saturation DO (mg/L)	14.35	13.38	9.70	8.99
Temperature rise (°F)	1.41	0.12	1.40	0.19
Temperature (°F)	34.61	37.92	63.70	69.29
Saturation DO (mg/L)	14.04	13.35	9.55	8.97
Reduction in DO saturation (mg/L)	0.31	0.02	0.16	0.02

4.8. CONCLUSIONS

Because the BBNPP diffuser is nearly identical to the existing SSES diffuser, the latter's performance provides the best estimate of the anticipated performance of the BBNPP diffuser. The SSES blowdown discharge plume has been measured on five occasions covering a range of flows, including a September survey when the Susquehanna River flow rate was 2,140 cfs. All five surveys showed small thermal plumes.

To provide estimates of the BBNPP thermal plume at lower flows, EPA's standard thermal plume model, CORMIX, was used. To confirm its applicability, the model was first used to reproduce the observed dimensions of the SSES thermal plume. EPA's model similarly calculates small sizes for the BBNPP thermal plume for average and worst case conditions.

Potential reductions in dissolved oxygen concentrations were estimated by comparing the saturation DO concentration at ambient temperature to the saturation DO at the plume temperatures. Potential reductions in dissolved oxygen concentrations due to the small rises in temperature adjacent to the BBNPP diffuser would be minimal and of limited extent.

5. *WATER QUALITY ASSESSMENT OF SHALLOW AREAS USED BY FRY AND YOUNG-OF-THE-YEAR (YOY) SMALLMOUTH BASS (SMB)*

5.1. OBJECTIVE

The Bell Bend water quality study was designed to identify whether stressful water-quality conditions occurred in 2010 in microhabitats and main-channel habitats during the critical period for fry (≤25 mm) and young-of-the-year (YOY) smallmouth bass (*Micropterus dolomieui*) (SMB). A report by Chaplin *et al.* (2009) postulated that sub-optimal dissolved oxygen (DO), particularly during the nighttime and in combination with relatively warm temperatures in habitats of YOY SMB, may play a role in predisposing the fish to bacterial infections. The bacterium (*Flavobacterium columnare*) is common in soil and water and causes secondary infections in stressed fish (PFBC 2005, cited in Chaplin *et al.* 2010).

Microhabitats in which such sub-optimal DO and warm temperatures occur are typically in side channels or shallow areas that are characterized by relatively low velocities (<0.1 ft/sec) and shallow depths (<2 ft) compared to the main river channel. These microhabitats, occupied by YOY SMB for the first 2-3 months of their lives, can be subject to wide fluctuations in DO and are susceptible to heating by solar radiation (Chaplin *et al.* 2009). YOY SMB utilizing these habitats during a sustained, extreme low river flow may be subject to potentially stressful, low DO concentrations (<5.0 mg/L) at night and elevated water temperatures exceeding both the PA WQ Standard and/or other biological threshold during the day. It is important to note that state water quality standards for Warm Water Fisheries (WWF) streams do not always coincide with the 84°F described as a possible biological threshold temperature for YOY SMB. For example, the WWF regulatory standard upper limit for temperature is 87°F from 1 July through 31 August. In addition, a 5.0 mg/L biological measure needs to be considered in light of the state regulatory standard for dissolved oxygen in a WWF which is an instantaneous lower limit of 4.0 mg/L or greater and a daily average equal to 5.0 mg/L or greater. As a result both temperature thresholds and both DO levels are evaluated in this report.

Relative to the proposed Bell Bend Project, an agency concern arose that its consumptive water use of the Susquehanna River water may exacerbate the summer water quality conditions in the SMB microhabitats concomitant with depth changes. Figure 5-1 shows SMB fry usage of shallow, low velocity areas in the study reach for the proposed Bell Bend Project.

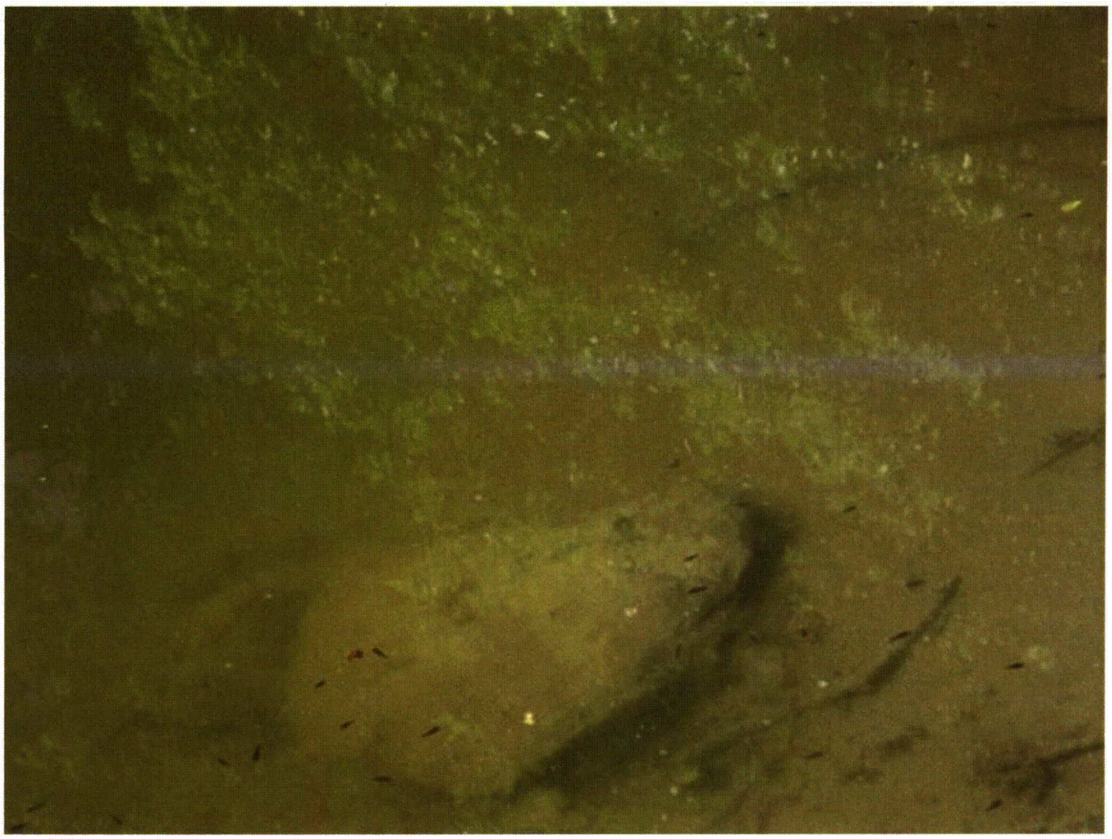


Figure 5-1 Smallmouth usage of shallow with negligible velocity microhabitat

There was no attempt as a part of this study effort to quantitatively identify "backwater areas" in absolute terms based on the stated characteristics described above for such microhabitats. It may generally be assumed that these areas are typically floodplain aquatic habitats that are seasonally or periodically connected to the main channel and for the purpose of this study, support early life stage maturation habitat for fry and YOY SMB. In the project area, these microhabitats are typically found during the summer months on the shallow side of island outcrops and/or naturally formed shallow coves sheltered from higher river velocities. It is important to note that there are few if any proper or persistent backwater areas in this stretch of river and that these intermittent backwater characteristics are subject to seasonal variation. This assessment instead uses the three shallow areas where data sondes were deployed to assess shallow water conditions, which may or may not be "backwaters" in the strict meaning of the term.

According to Chaplin, *et al.* (2009), SMB typically spawn from late April to early June when temperatures reach 15°C (59°F). Eggs hatch in 2 to 9 days and they are ready to leave the nest and disperse in 5 to 6 days. Since fry are susceptible to predation and cannot withstand higher mid-channel velocities, they typically spend the first 2 to 3 months after swim up (roughly May through July) in the same microhabitat where they were born.

5.2. *PENNSYLVANIA WATER QUALITY CRITERIA*

The Susquehanna River adjacent to the proposed Bell Bend Project is designated as a WWF. The Pennsylvania Water Quality Standards, (PA Code, Chapter 93, §93.7) applicable to a WWF are as follows: For DO a minimum daily average of 5.0 mg/L and a minimum instantaneous 4.0 mg/L. The pH range is between 6.0 and 9.0 inclusive. Pennsylvania provides the following criteria (Table 5-1) for temperature. Maximum temperatures in the receiving water body resulting from heated waste sources are regulated under Chapters 92, 96 and other sources where temperature limits are necessary to protect designated and existing uses. The temperature values shown are considered to be instantaneous limits based on cross-sectional average temperatures.

Table 5-1 Temperature limits applicable to Warm Water Fishery streams. Highlighted areas denote sampling period of the 2010 water quality study

Critical Use Period:	Temperature (°F)
January1-31	40
February1-29	40
March1-31	46
April1-15	52
April16-30	58
May1-15	64*
May16-31	72*
June1-15	80*
June16-30	84*
July1-31	87*
August1-15	87**
August16-30	87**
September1-15	84
September16-30	78
October1-15	72
October16-31	66
November1-15	58
November16-30	50
December1-31	42

* Critical Period for Fry per Chaplin *et al.* (2009)
**Additional Period Evaluated by this Study

5.3. *FIELD MEASUREMENTS AND OBSERVATIONS*

The assessment of shallow areas in the vicinity of the Bell Bend Project was conducted during the summer of 2010 to identify water quality-related conditions that may be stressful to YOY (fry and juvenile) SMB. The assessment was also to determine if the proposed consumptive water use associated with the Bell Bend Project could potentially intensify those conditions.

Water temperature, DO, pH, and conductivity[9] were continuously monitored using Hydro Lab data sonde recorders at three paired locations (inshore (shallow) and main channel habitats). The three monitored locations were the Susquehanna SES Environmental Laboratory (Environmental

[9] Conductivity data is available but not reported herein.

Lab) boat ramp, Goose Island, and Berwick Test Track ramp. The former location is upstream of the proposed Bell Bend Project and the latter two are downstream of the project with the Goose Island location 2.8 mi and the Berwick Test Track Ramp 8.4 mi downstream of the proposed discharge structure, respectively.

Continuous monitoring of DO and water temperature in representative shallow areas (upstream and downstream of the proposed Bell Bend Project intake) was conducted from 22 June to 3 September 2010, a potential period of high water temperature and low nighttime DO values in shallow areas. This monitoring program was implemented to identify whether stressful water quality conditions occur during the critical nursery and rearing times of fry and YOY SMB and to define the magnitude and frequency of occurrence of these conditions. The "critical period" according to Chaplin *et al.* (2009) for survival and development of SMB is 1 May through 31 July.[10] This study extended that evaluation through the end of August.

As in the Chaplin *et al.* (2009) study, paired sondes were deployed (one each in a shallow microhabitat and a corresponding main channel location to monitor DO) water temperature, and pH (Figure 5-2). This pairing was intended to document the extent of differences in water quality between main channel and shallow microhabitats. Table 5-2 provides descriptions of sampled locations.

[10] Jeffery J. Chaplin, et al., Water Quality Monitoring in 2008 in Response to Young-of-the-Year Smallmouth Bass Mortality in the Susquehanna River and Major Tributaries, Pennsylvania, 2009, p. 11.

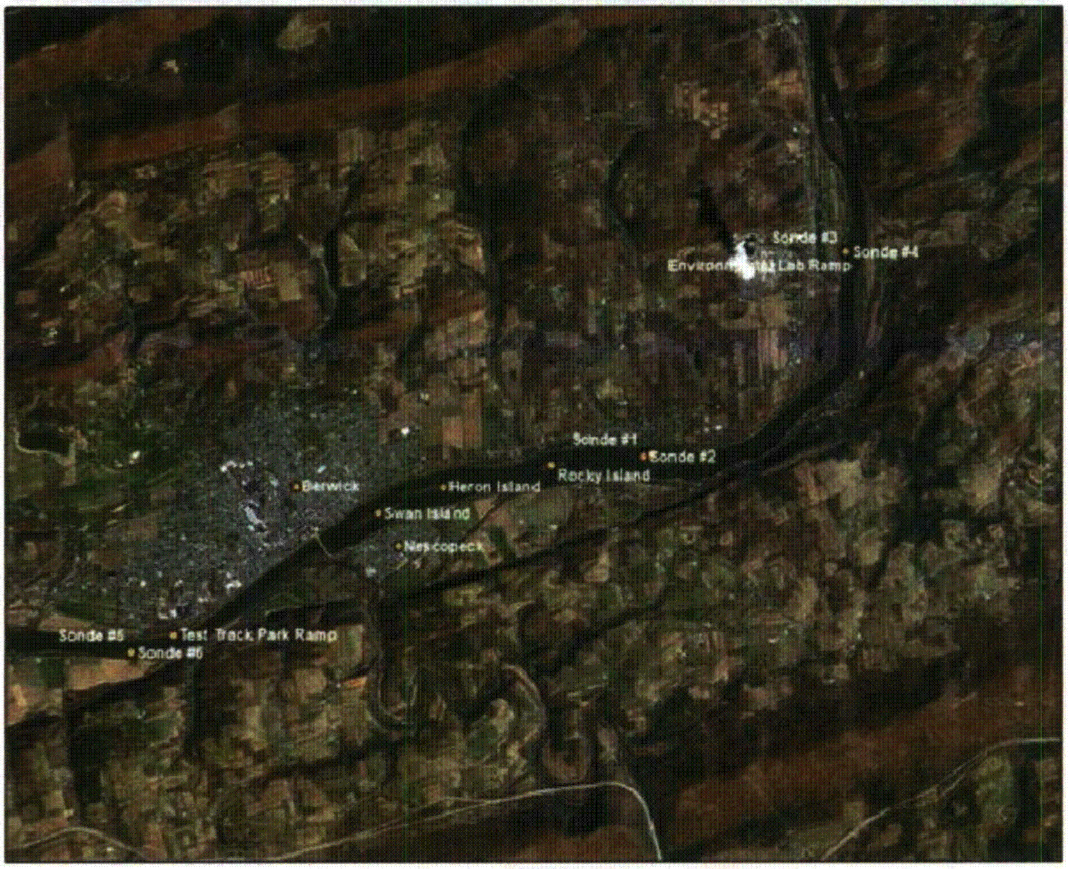


Figure 5-2 Water quality data sonde locations with habitat characteristics

Table 5-2 Sonde locations

Location	Sonde Number	Latitude/Longitude
Near southern tip of Goose Island - near east bank shoreline. Water depth <1.5 feet with very little current. Area contained abundant submerged aquatic vegetation. River width 1430 feet.	1	41°03.901N/076°10.151W
Near southern tip of Goose Island - approximately 100 feet from east bank. Water depth 3 feet with notably more current than Sonde 1 location. River width 1430 feet.	2	41°03.884N/076°10.160W
Near Environmental Lab boat ramp - near west bank. Water depth <1.5 feet located in an eddy situation. River width 870 feet.	3	41°05.580N/076°07.827W
Near Environmental Lab boat ramp - approximately 100 feet from west bank in main river channel. Water depth 3 feet. River width 870 feet.	4	41°05.588N/076°07.803W
Approximately ½-mile downriver from Berwick Test Track boat ramp - 100 feet from east bank in main river channel. Water depth 4 feet with a cobble substrate. River width 660 feet.	5	41°02.271N/076°16.126W
Approximately ½-mile downriver from Berwick Test Track boat ramp - near east bank. Water depth 2.5 feet near shoreline. Similar flow conditions as Sonde 5 location. River width 660 feet.	6	41°02.260N/076°16.126W

Figure 5-3, Figure 5-4, and Figure 5-5 show the sampling locations and their habitats for this monitoring study. These locations were selected for accessibility, ease of servicing, and representativeness of potential shallow habitat for assessing SMB spawning, fry emergence, juvenile nursery, and rearing. An upstream location (Data Sondes 3 and 4 at the Environmental Lab boat ramp) was selected to determine whether a relationship exists in water temperature and DO between upstream and downstream locations within the aquatic habitat study reach.[11]

[11] No meaningful correlation between upstream and downstream 2010 water quality data was found. Therefore this is not discussed further in this report.

Figure 5-3 Southeast shore of Goose Island on the Susquehanna River with abundant aquatic vegetation, July 2010 (data sonde locations 1, inshore, and 2, main channel)

Figure 5-4 Environmental Lab boat ramp on west bank of Susquehanna River, July 2010 (data sonde locations 3, inshore, and 4, main channel)

Figure 5-5 Southeast shore of Susquehanna River across from Berwick Test Track boat ramp, July 2010 (data sonde locations 5, main channel, and 6, inshore)

As specified in the study plan, the continuous monitoring data were analyzed for detection of deviations from the Pennsylvania State Water Quality Criteria. Temperature data was also evaluated with respect to the possible threshold level of 84°F regardless of whether this temperature was within state water quality standards.

Mean daily temperature data by month for 2010 as recorded at the Environmental Lab shown in Figure 5-6 indicates that 2010 water temperatures in the Susquehanna River for the area of interest were higher than the average monthly historical temperature data (1974-2009). Figure 5-6 also shows the +1 and +2 standard deviation for the 1974 – 2009 period of record to further demonstrate that the 2010 water temperatures were not only higher than average, but exceeded +1 standard deviation for the May 1 through August 31 period of interest and were nearly 2 standard deviations higher in July which is the most stressed month. Figure 5-7 shows the 2010 flows relative to a historical flow period (1974 – 2011) demonstrating that 2010 was not only a high temperature year, but also a low flow year for the period of interest.

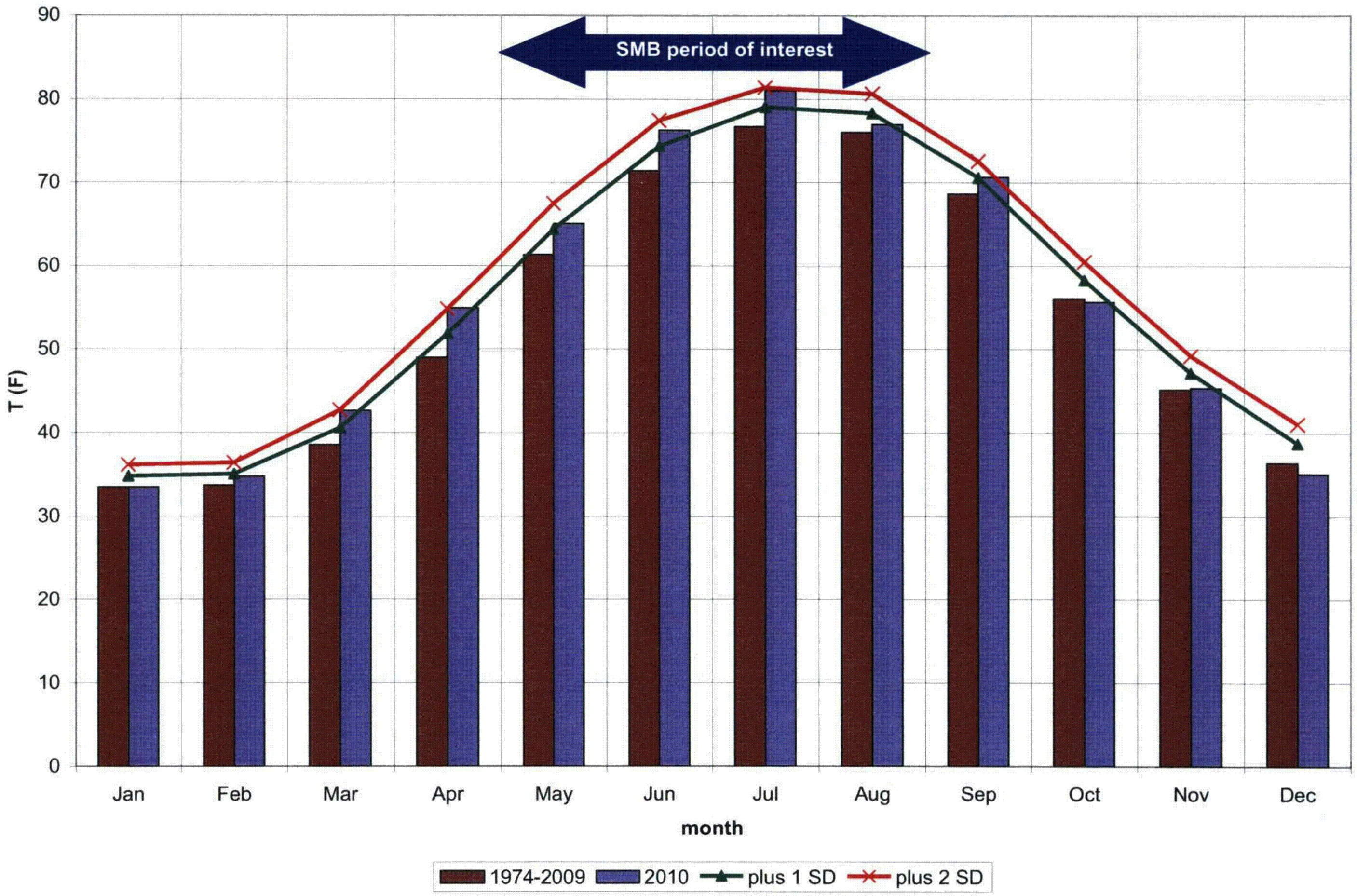


Figure 5-6 Average monthly temperatures compared with 2010 temperatures and showing 1 and 2 standard deviations above mean long term (1974 – 2009) averages

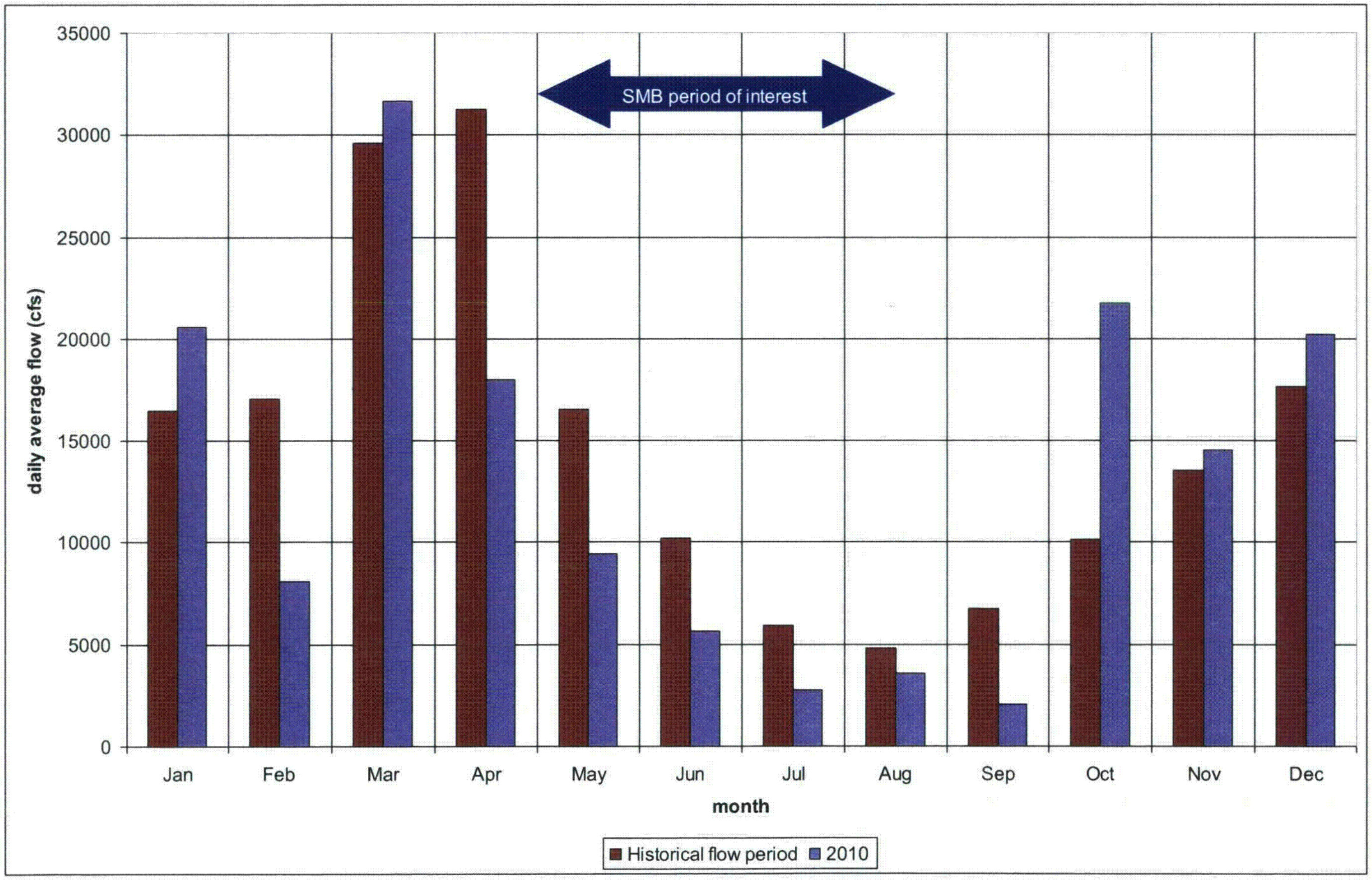


Figure 5-7 Average daily flow by month (1974 – 2011) compared with 2010 Average daily flows by month

5.4. *RESULTS OF CONTINUOUS MONITORING OF WATER QUALITY PARAMETERS*

Table 5-3 presents overall summary statistics for water temperature, dissolved oxygen, and pH hourly measurements recorded at the three paired continuous monitors within the study reach between 22 June and 3 September 2010.

The average water temperature for the monitoring period was highest (80.0°F) in the main channel location near the Goose Island site (Sonde 2) with similarity in average temperatures (77.9 °F to 78.8 °F) at other locations (Table 5-3). The widest range (21.8°F) in water temperature was measured at the inshore location near the Goose Island site (Sonde 1).

The average DO values were lowest at inshore locations near the Goose Island (Sonde 1) and Environmental Lab boat ramp (Sonde 3). The widest range in DO values (≥11.0 mg/L) also occurred at these locations.

Average pH values were lower at Goose Island and the Environmental Lab boat ramp locations (Table 5-3).

Table 5-3 Summary statistics of hourly measurements of water temperature (°F), dissolved oxygen (DO), and pH recorded on Data Sondes 1-6, June 23 – September 3, 2010

	Data Sondes					
	1	2	3	4	5	6
Temp (°F)						
Range	70.0-91.8	70.3-85.8	69.7-89.0	70.5-87.1	69.4-87.1	68.7-89.6
Mean	78.8	80.0	78.3	78.6	77.9	78.3
Number of observations	1,595	1,718	1,733	1,336	1,339	1,518
DO (mg/L)						
Range	2.5-14.7	5.9-13.2	3.3-17.8	5.5-13.2	5.5-12.2	5.5-15.9
Mean	7.8	8.5	7.8	8.4	8.4	8.9
Number of observations	1,534	1,720	1,264	1,334	1,339	1,507
pH						
Range	6.7-9.0	7.1-9.0	6.9-8.9	7.2-9.1	7.3-9.2	7.2-9.0
Median	7.7	7.8	7.5	7.9	8.0	7.8
Number of observations	1,683	1,717	1,734	1,336	1,339	1,518

5.5. *WATER TEMPERATURE*

Hourly temperature data from all sonde locations is shown in Figure 5-8 through Figure 5-13. As noted above, that state water quality standards for WWF streams do not always coincide with the 84°F described as a possible biological threshold temperature for YOY SMB. For example, the

WWF standard upper limit for temperature is 87°F from 1 July through 31 August. As a result, both temperatures are evaluated in this report.

Although daily fluctuations in temperature occurred at all locations, the amplitude of these fluctuations was higher at the inshore Goose Island site, particularly in July and August. See Figure 5-8. The frequency of temperatures exceeding either 84°F or 87°F was highest at the Goose Island inshore location; with most exceedances occurring in July. This location is characterized by shallow depth and negligible current and subject to elevated temperature during the daytime. Some values exceeded either 84°F or 87°F at other inshore locations though at much lower frequencies. See Figure 5-9. Analyses provided in Section 4.7 illustrate that small thermal and DO changes will occur due to reduced depth. The approximate impact on depth based on the BBNPP consumptive use of 43 cfs throughout the study area for flows <1,000 cfs is 0.5 inches (Figure 5-35). According to the analysis, depths characteristic of spawning areas (<2 feet) produce a thermal change of approximately < 0.5°F based on a reduction in water depth of 0.5 inches under worst case summer conditions. These potential changes are small in comparison to natural diurnal T and DO changes.

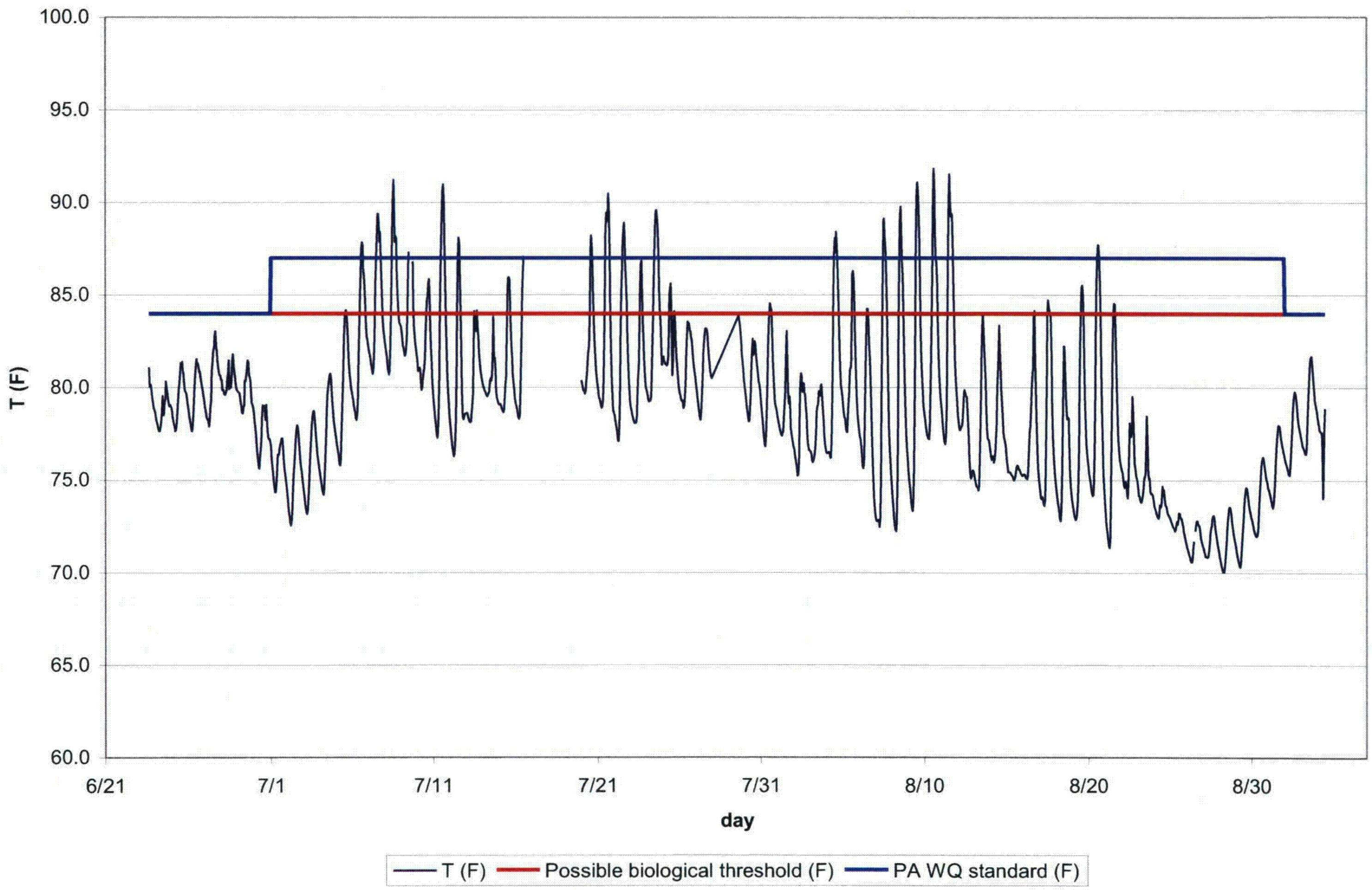


Figure 5-8 Sonde 1 (Goose Island shallow) hourly temperature data (F)

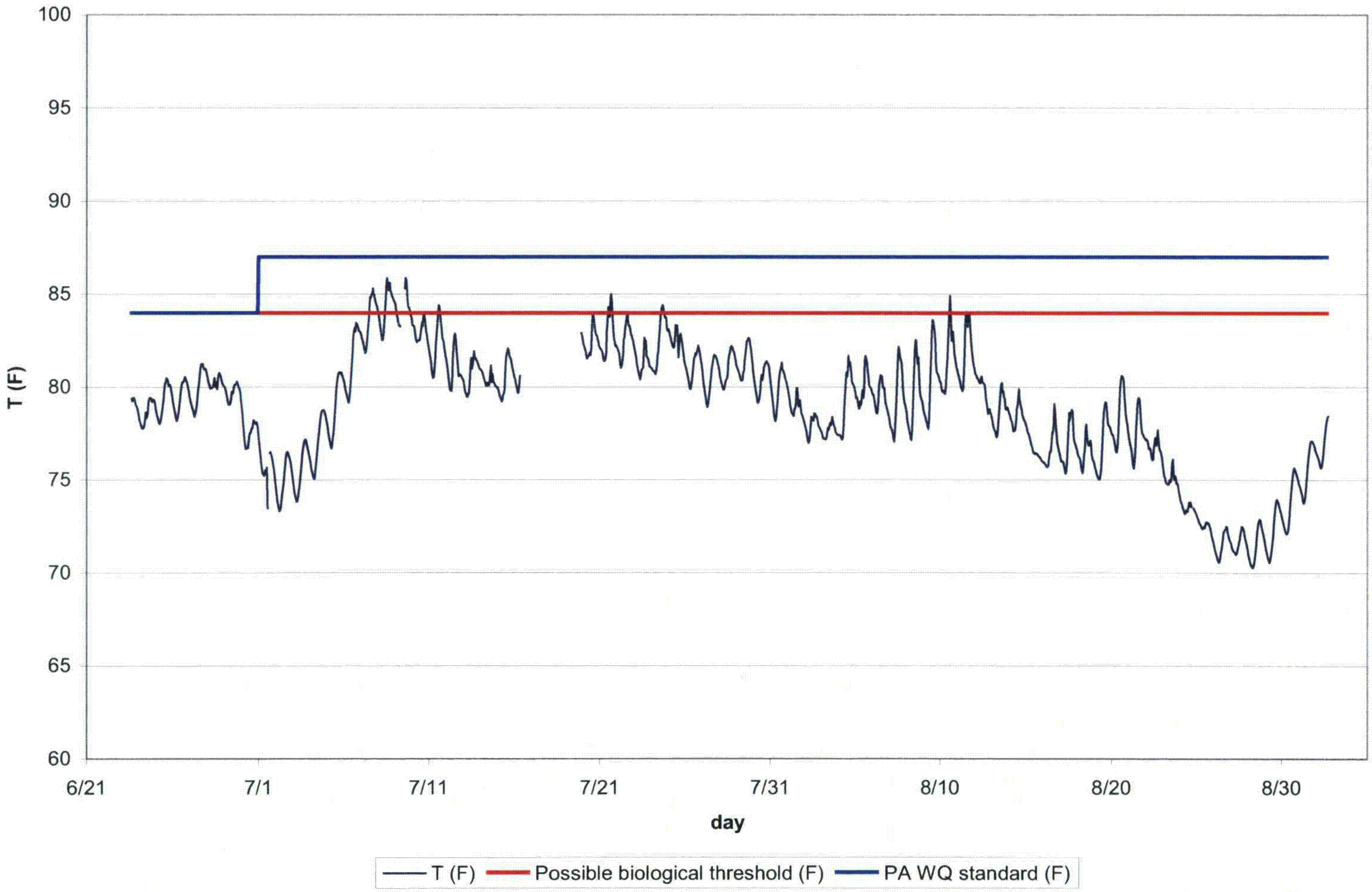


Figure 5-9 Sonde 2 (Goose Island main channel) hourly temperature data (F)

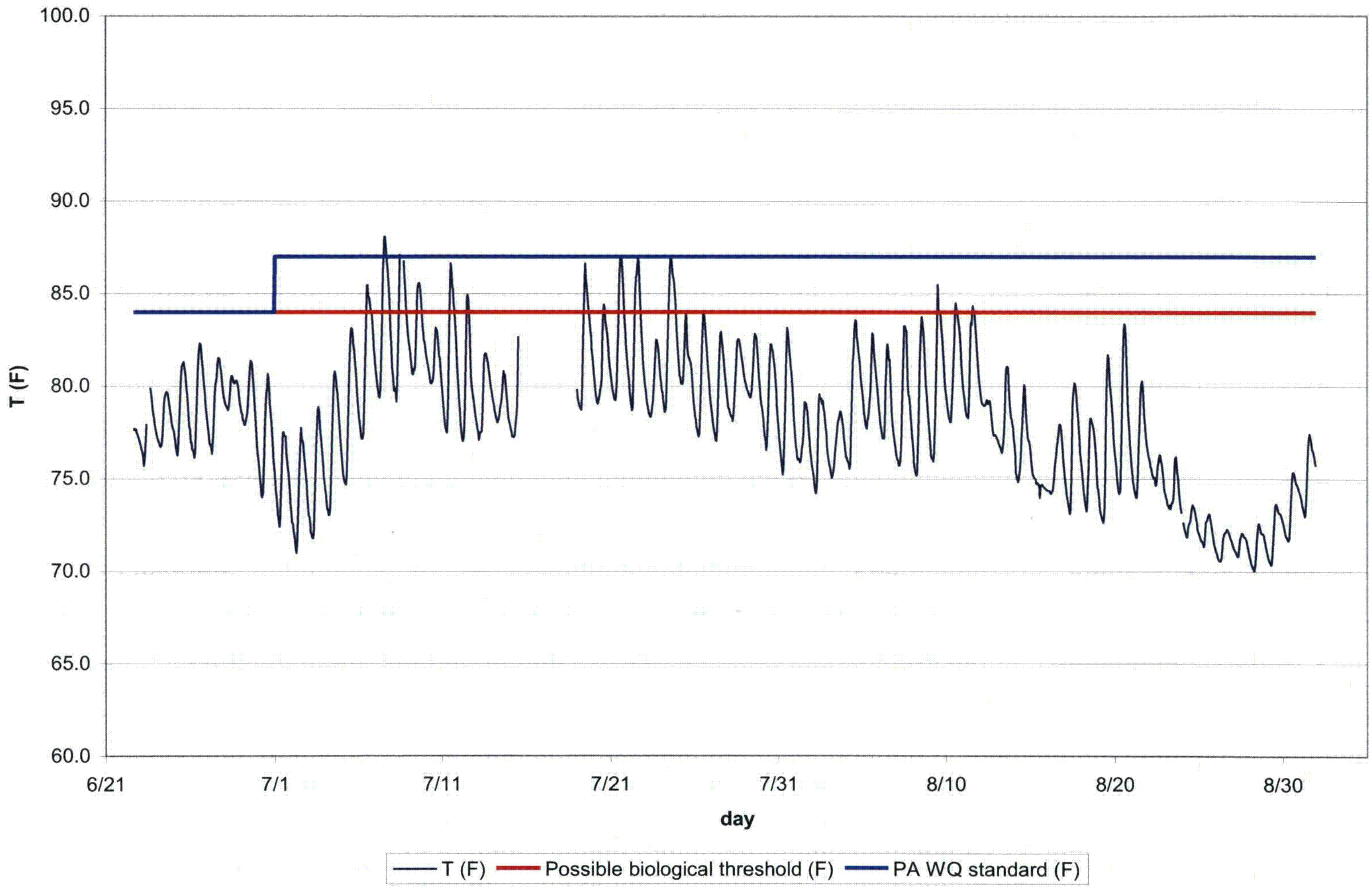


Figure 5-10 Sonde 3 (Environmental lab shallow) hourly temperature data (F)

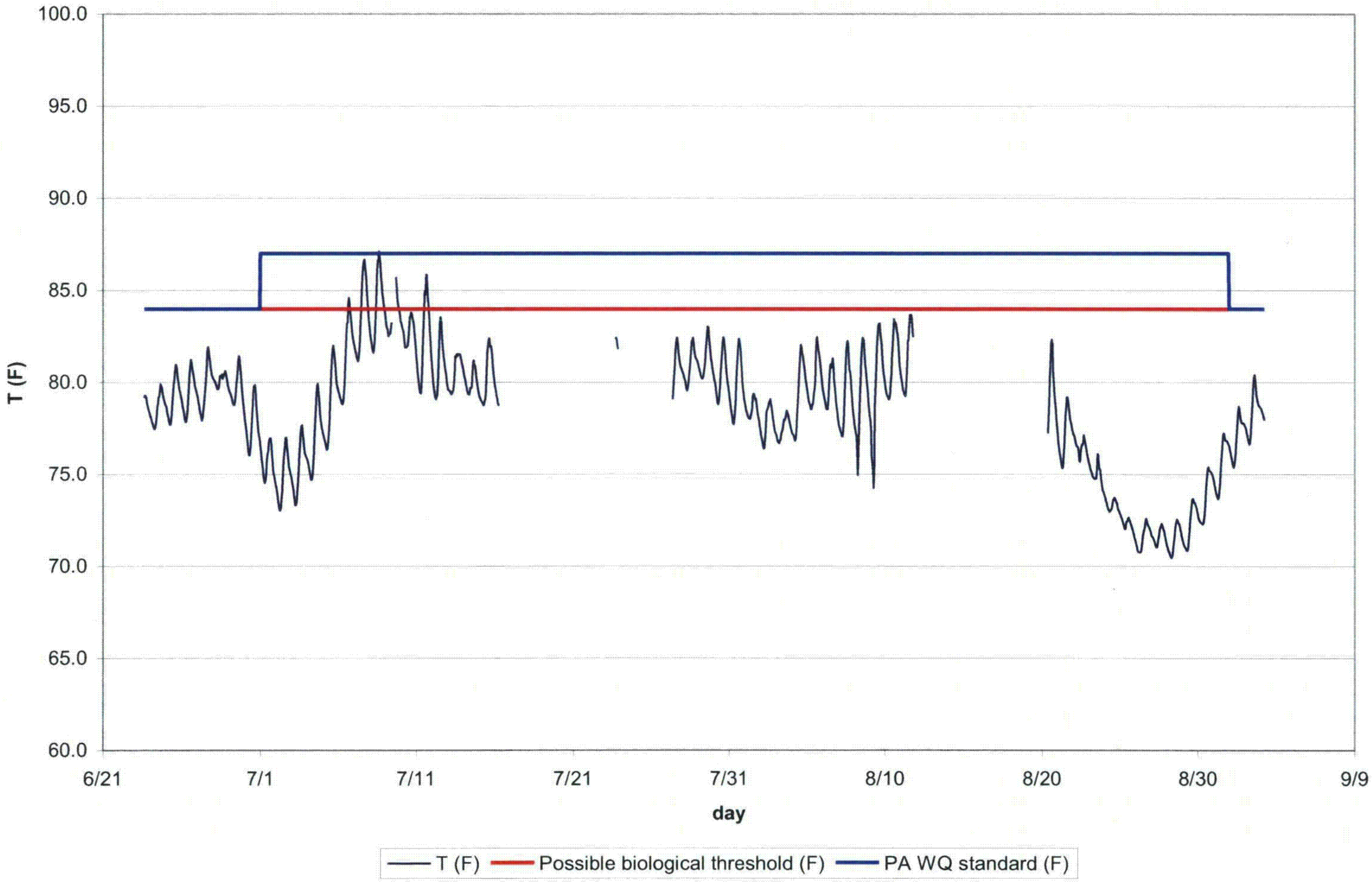


Figure 5-11 Sonde 4 (Environmental lab main channel) hourly temperature data (F)

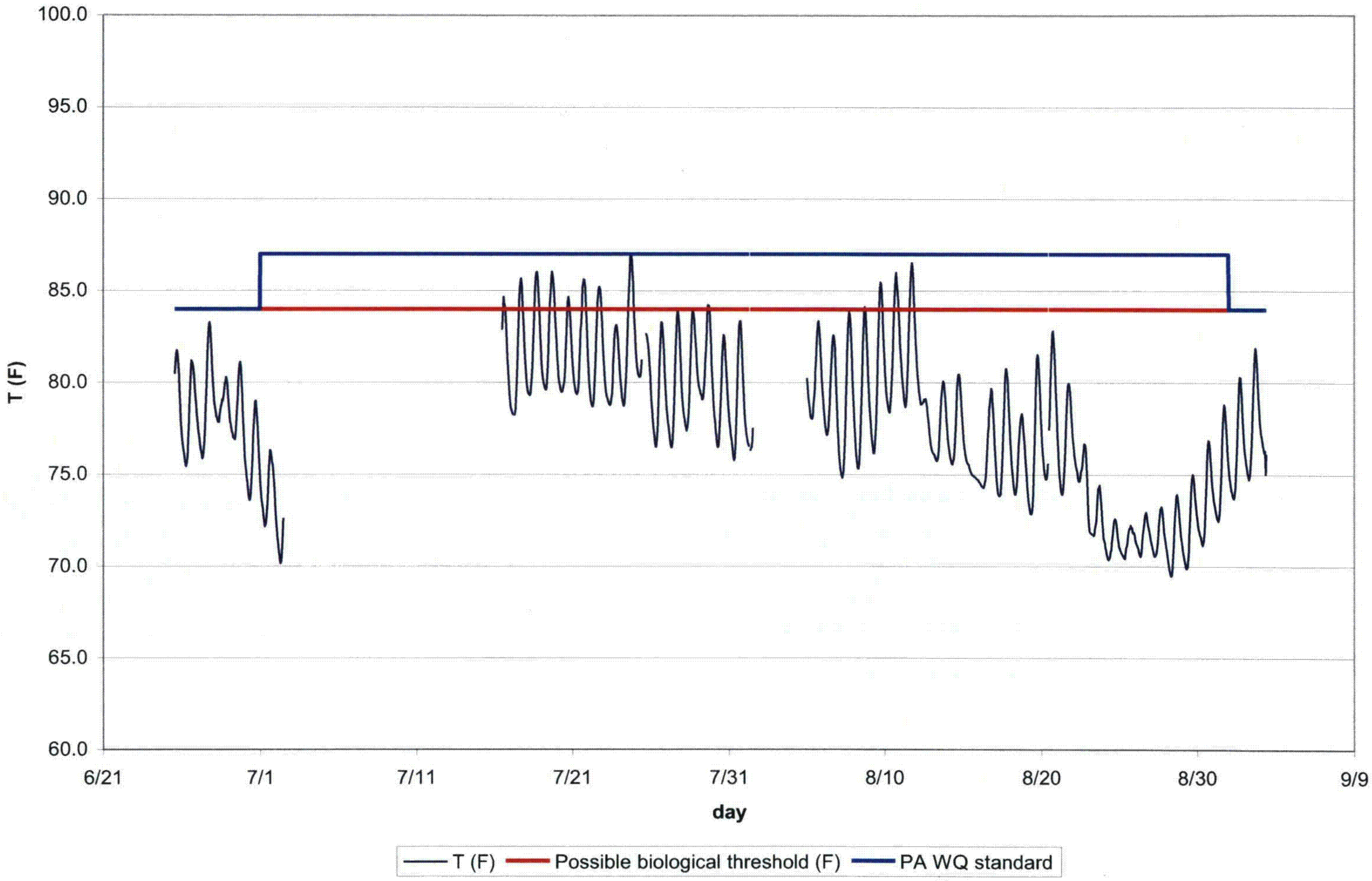


Figure 5-12 Sonde 5 (Downstream from Test Track, main channel) hourly temperature data (F)

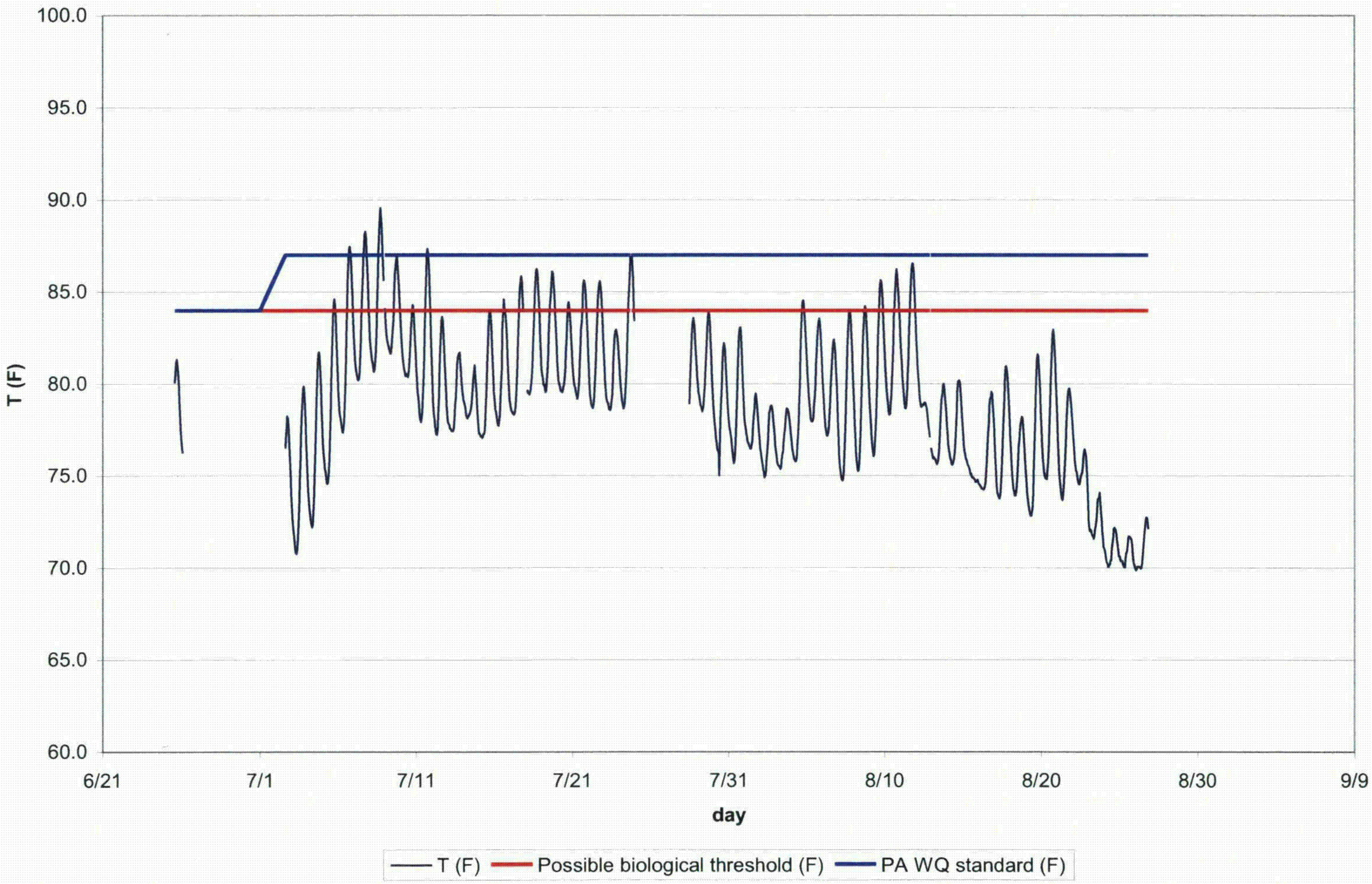


Figure 5-13 Sonde 6 (Downstream from Test Track, shallow) hourly temperature data (F)

Figure 5-14 shows a summary of the hours at each sonde above the 84°F SMB possible biological threshold for July and August data as well as the PA 87 °F water quality standard for July and August.

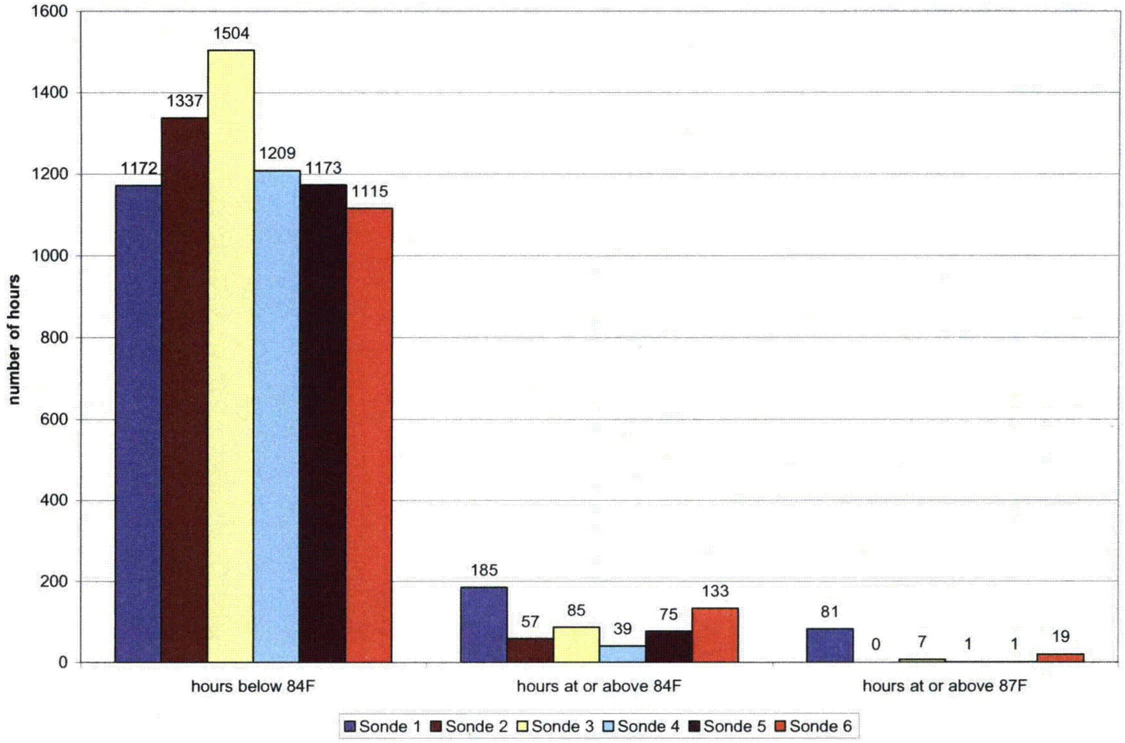


Figure 5-14 Hours below 84F, above or at 84F and above or at 87F for all sondes

5.6. DISSOLVED OXYGEN

Hourly dissolved oxygen data from all sonde locations is shown in Figure 5-15 through Figure 5-20. Daily average dissolved oxygen levels are illustrated in Figure 5-21 through Figure 5-26. Daily diurnal fluctuations of ≥11 mg/L were observed between the three monitored locations (Environmental Lab boat ramp, Goose Island, and Berwick Test Track ramp). The largest fluctuations were at the inshore (Sonde 1) Goose Island site (Figure 5-15).

Most hourly DO values <4.0 mg/L (instantaneous standard) occurred at the inshore Goose Island location and in July (Figure 5-15). The Environmental Lab boat ramp inshore location (Sonde 3) ranked second in exhibiting < 4.0 mg/L DO. Other locations did not show DO < 4.0 mg/L. Although more hourly low DO values were observed at the Goose Island location (Sonde 1), the average daily DO was ≥ 5.0 mg/L (daily average standard, see Figure 5-21).

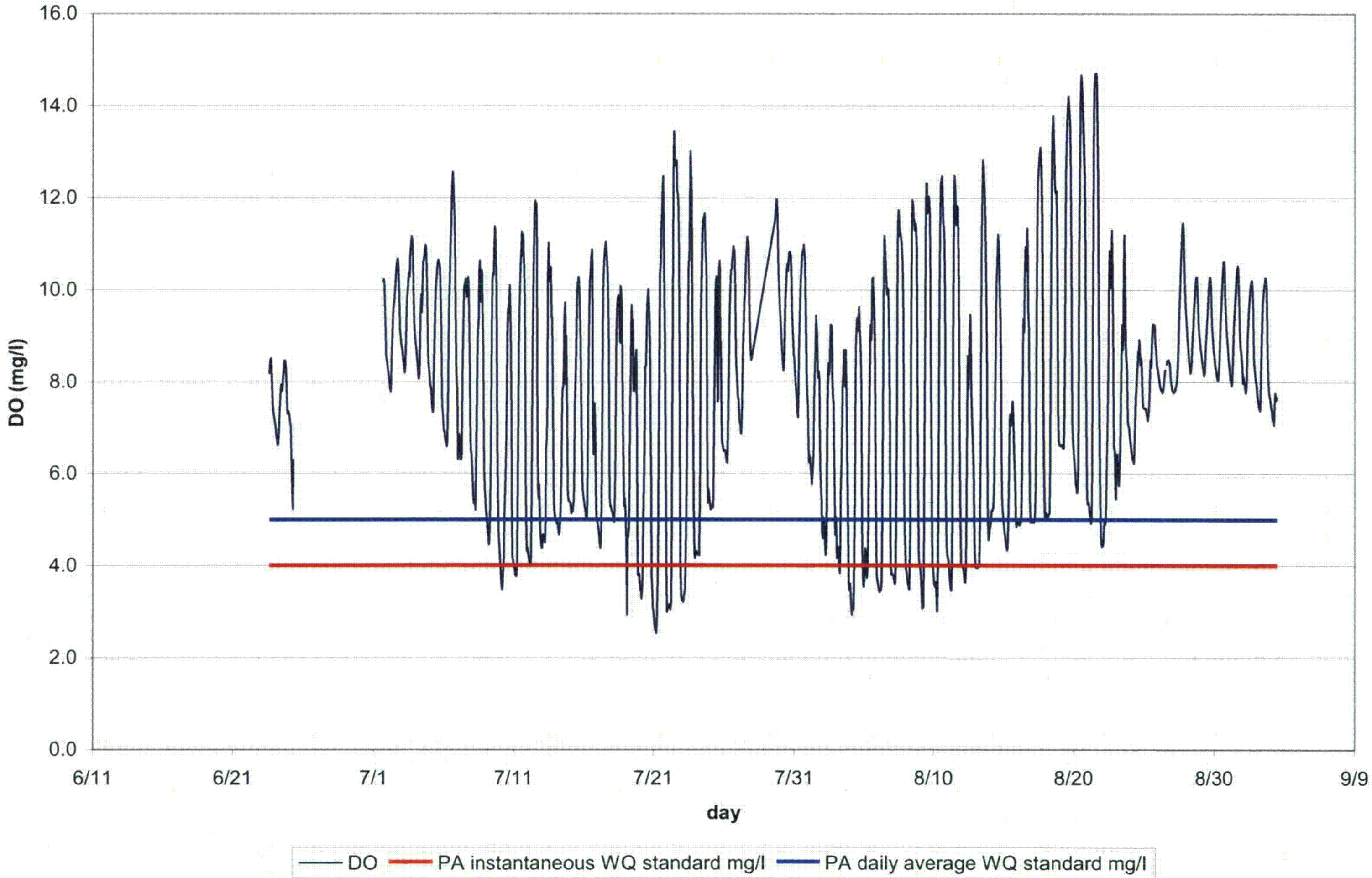


Figure 5-15 Sonde 1 (Goose Island, shallow) dissolved oxygen

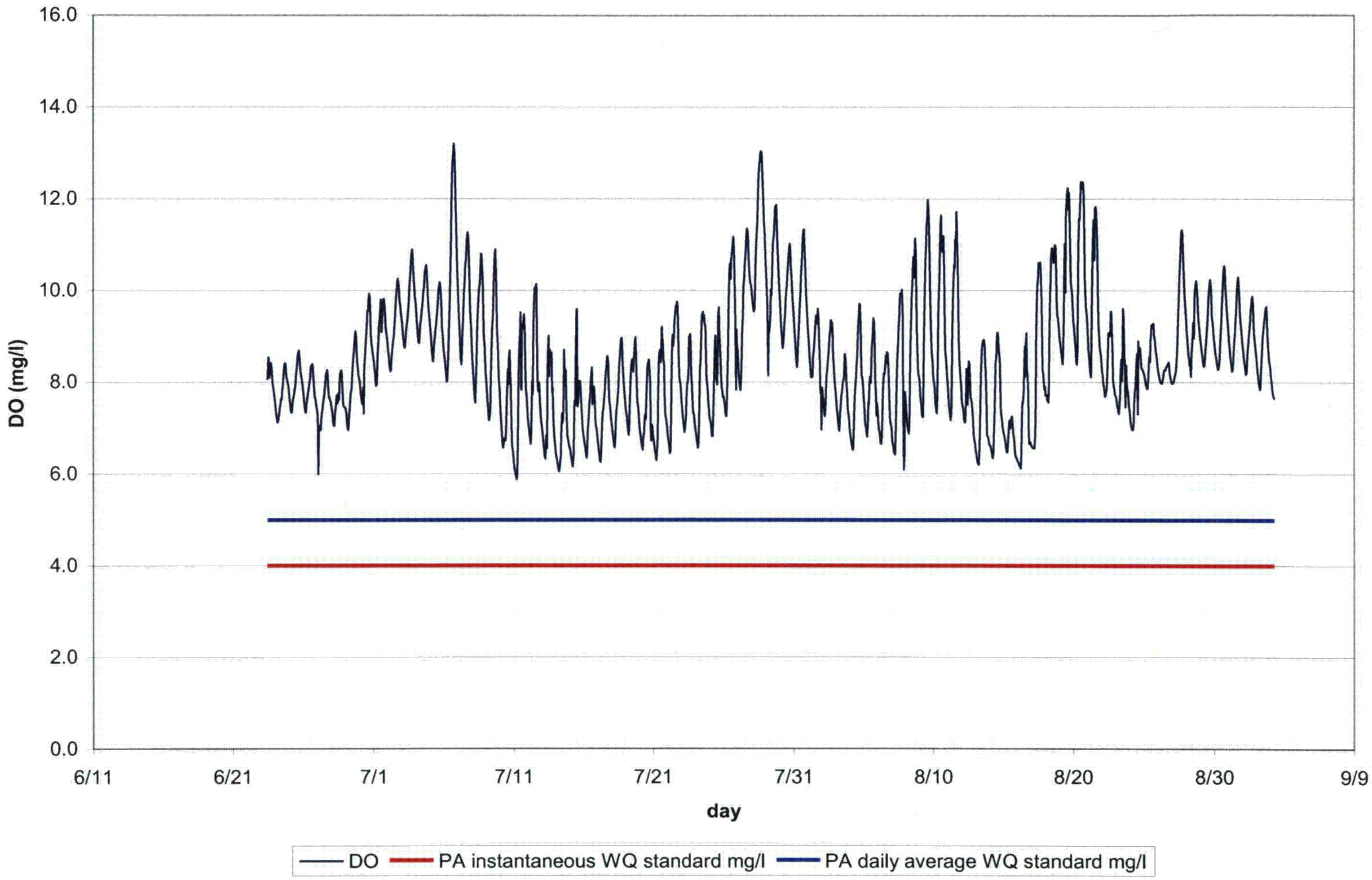


Figure 5-16 Sonde 2 (Goose Island, main channel) dissolved oxygen

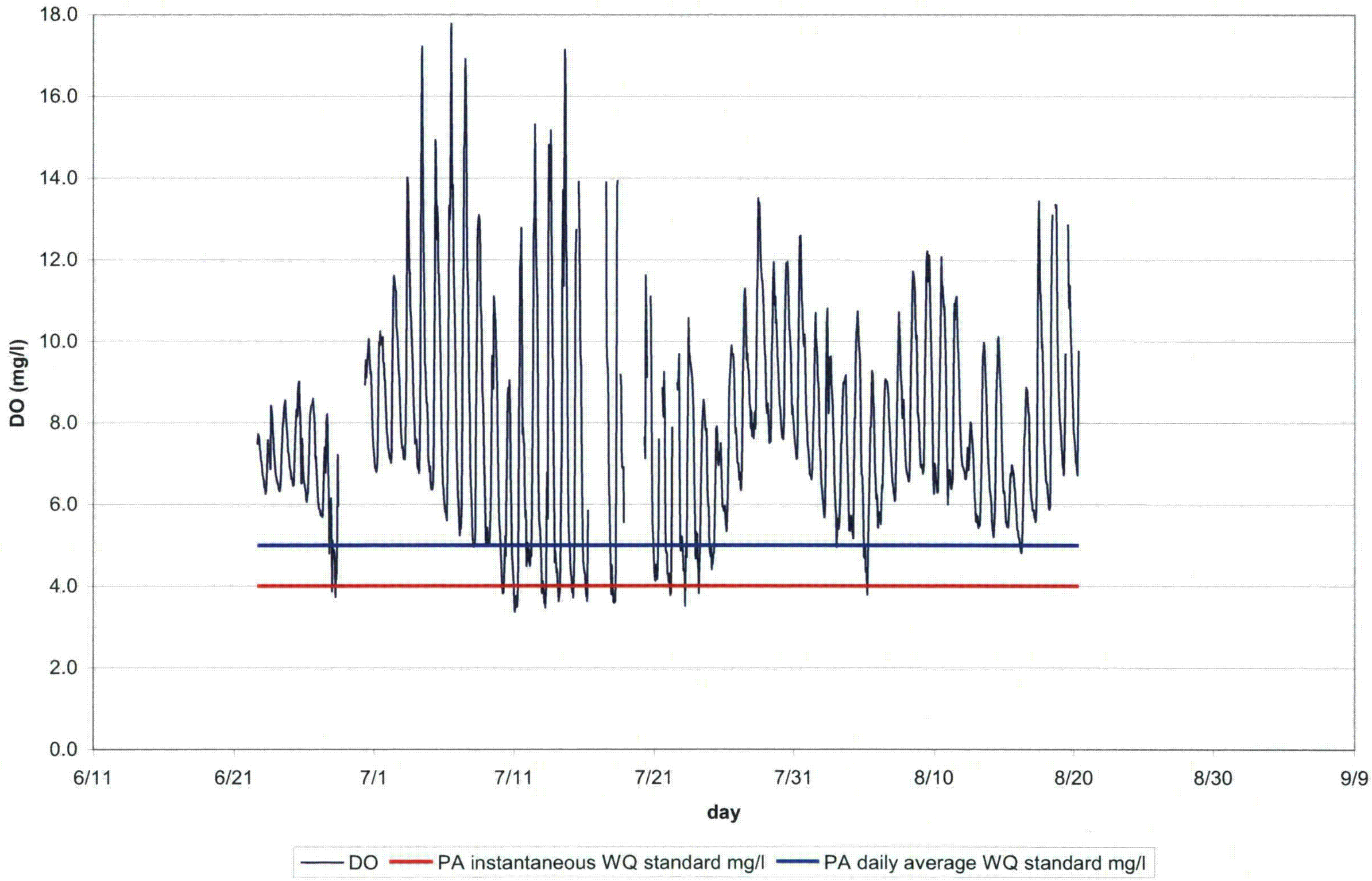


Figure 5-17 Sonde 3 (Environmental lab, shallow) dissolved oxygen

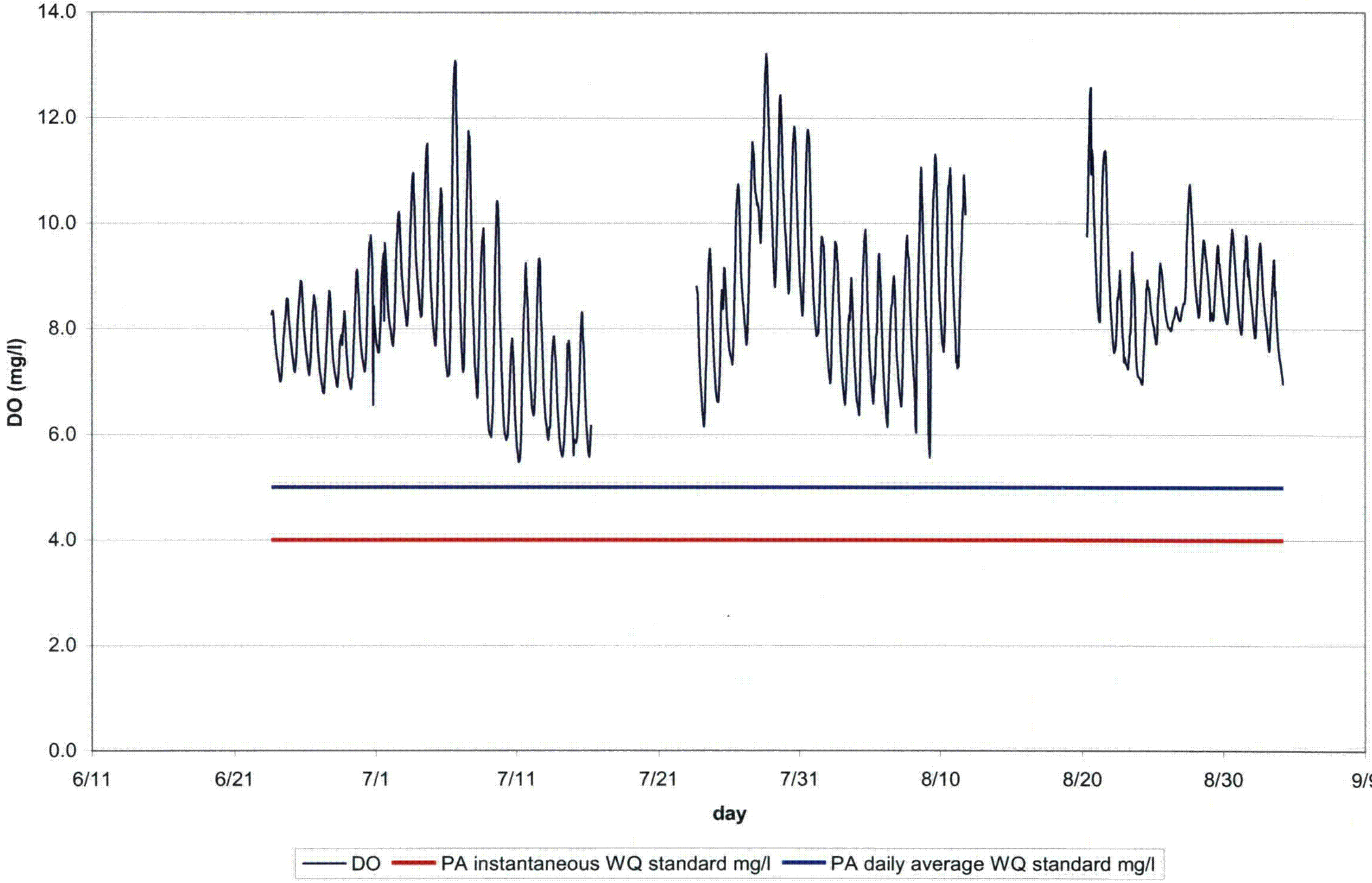


Figure 5-18 Sonde 4 (Environmental lab, main channel) dissolved oxygen

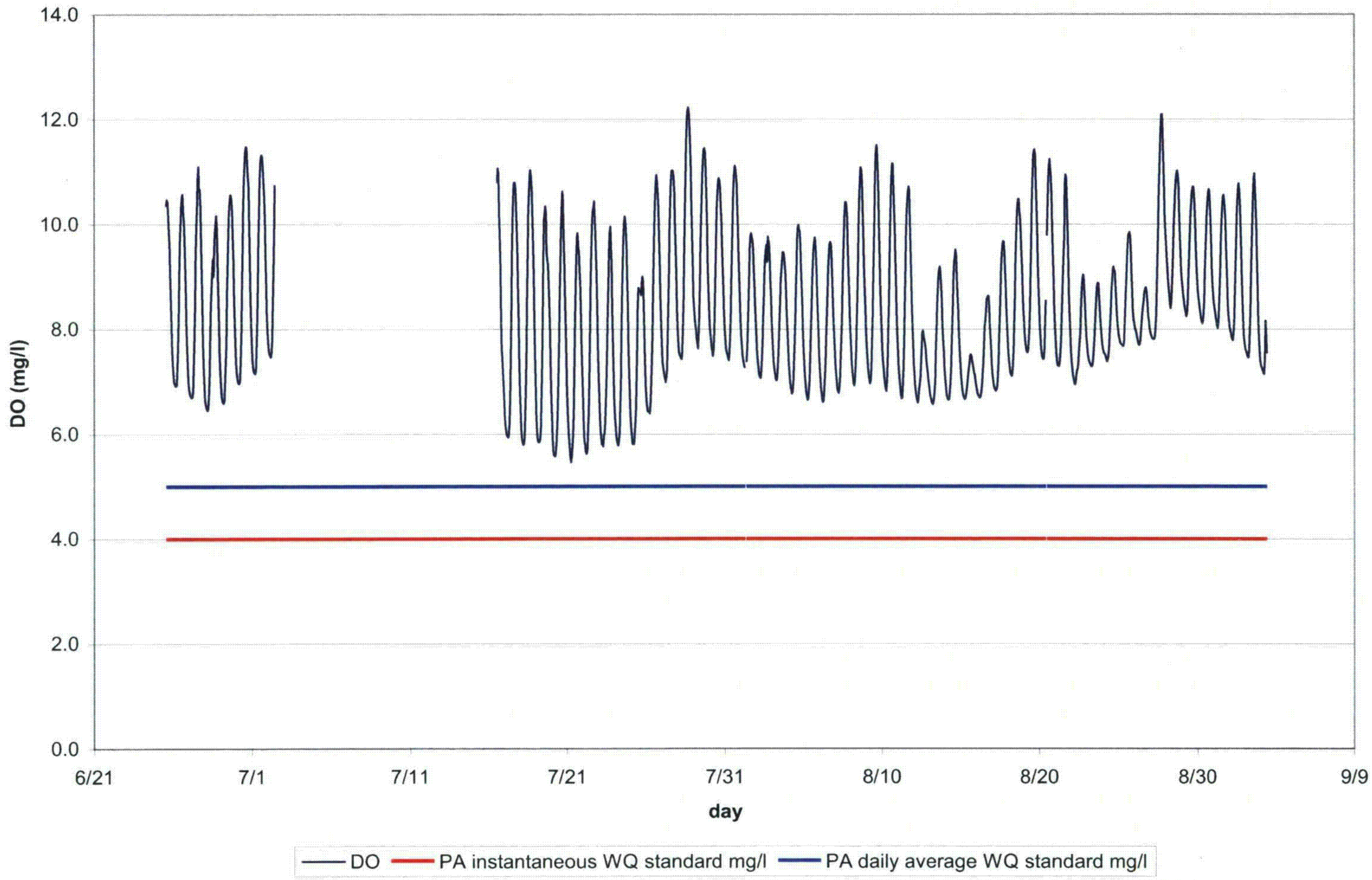


Figure 5-19 Sonde 5 (Downstream from Test Track, main channel) dissolved oxygen

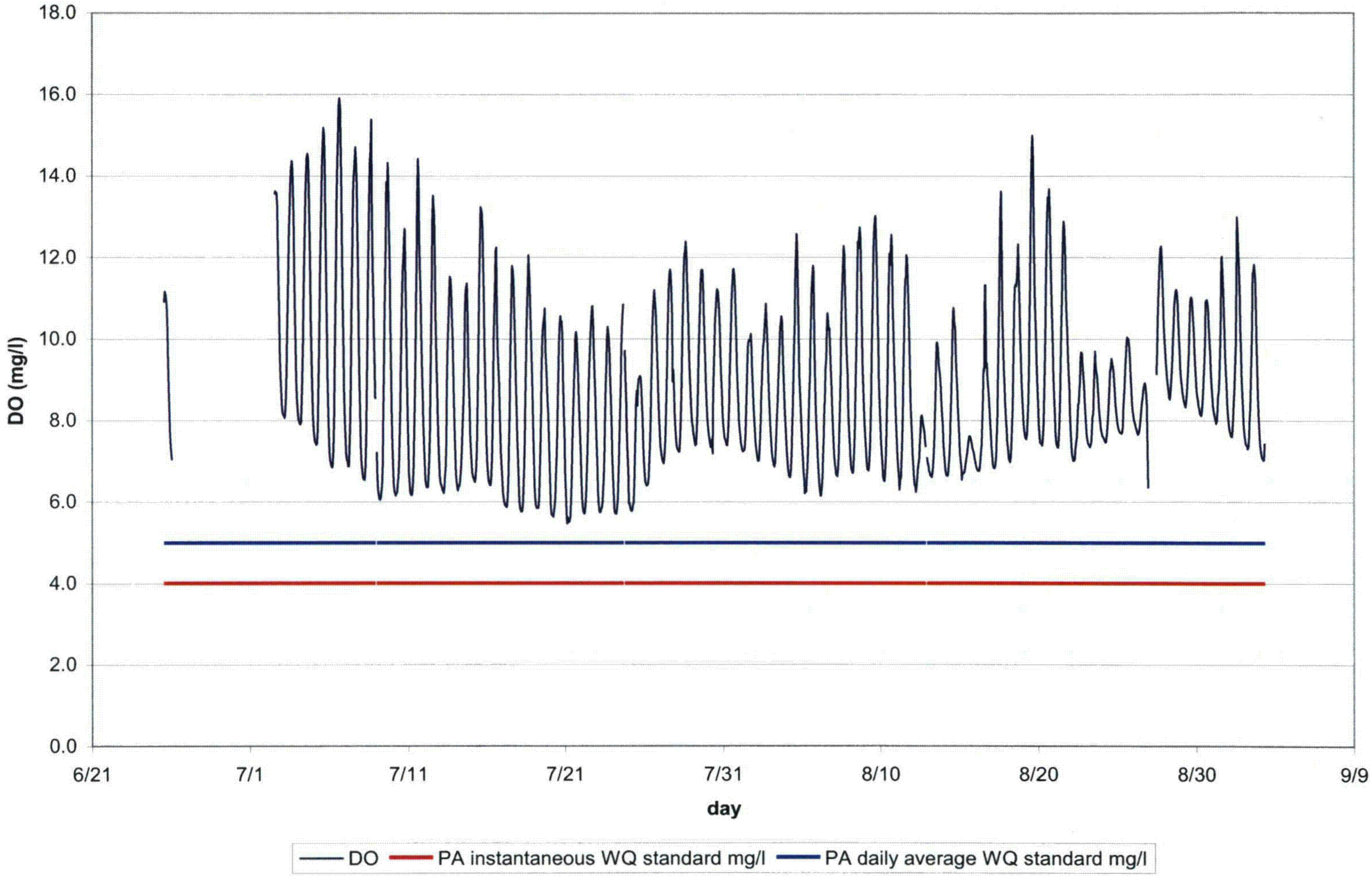


Figure 5-20 Sonde 6 (Downstream from Test Track, shallow) dissolved oxygen

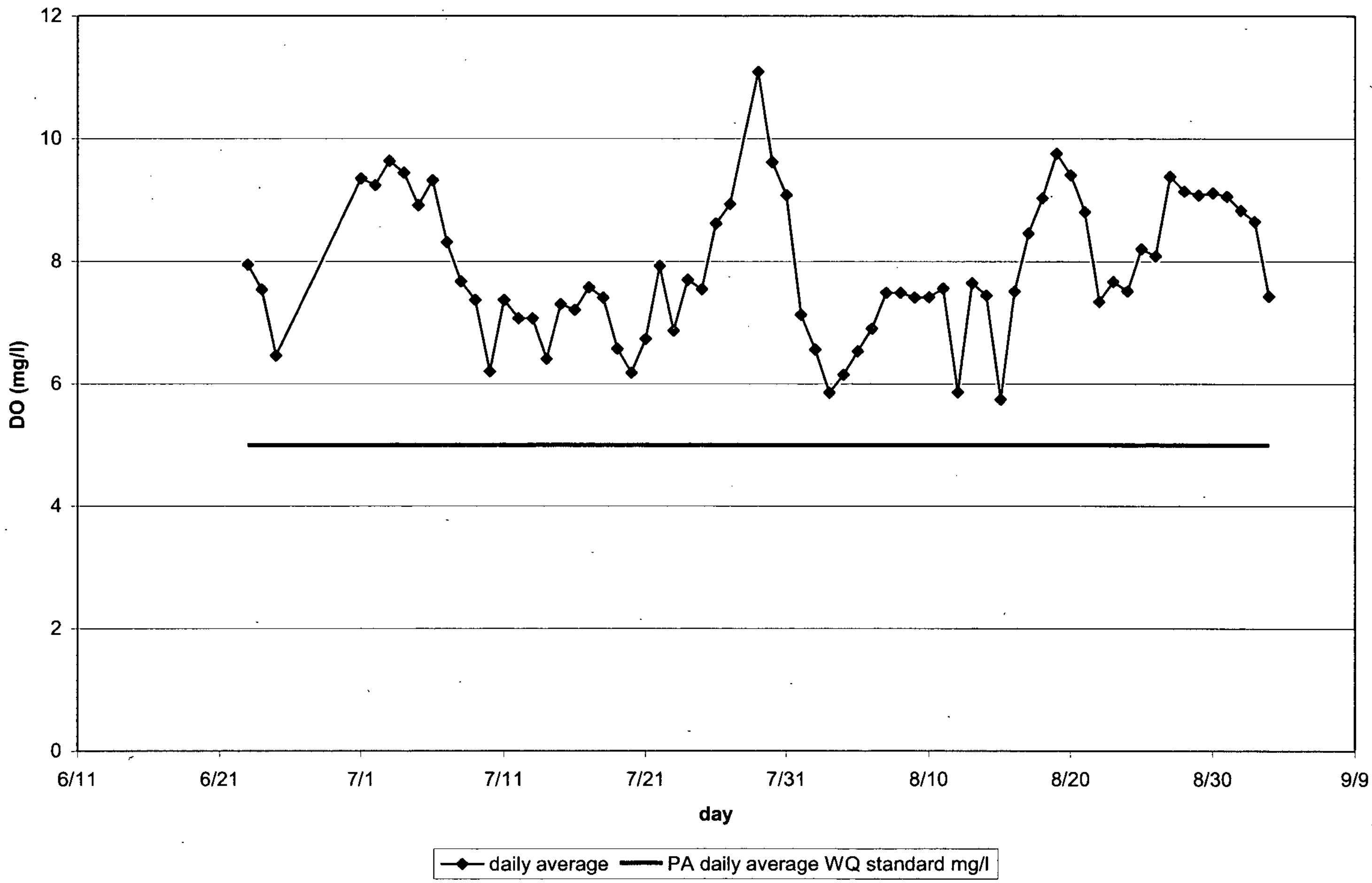


Figure 5-21 Sonde 1 (Goose Island, shallow) DO daily average

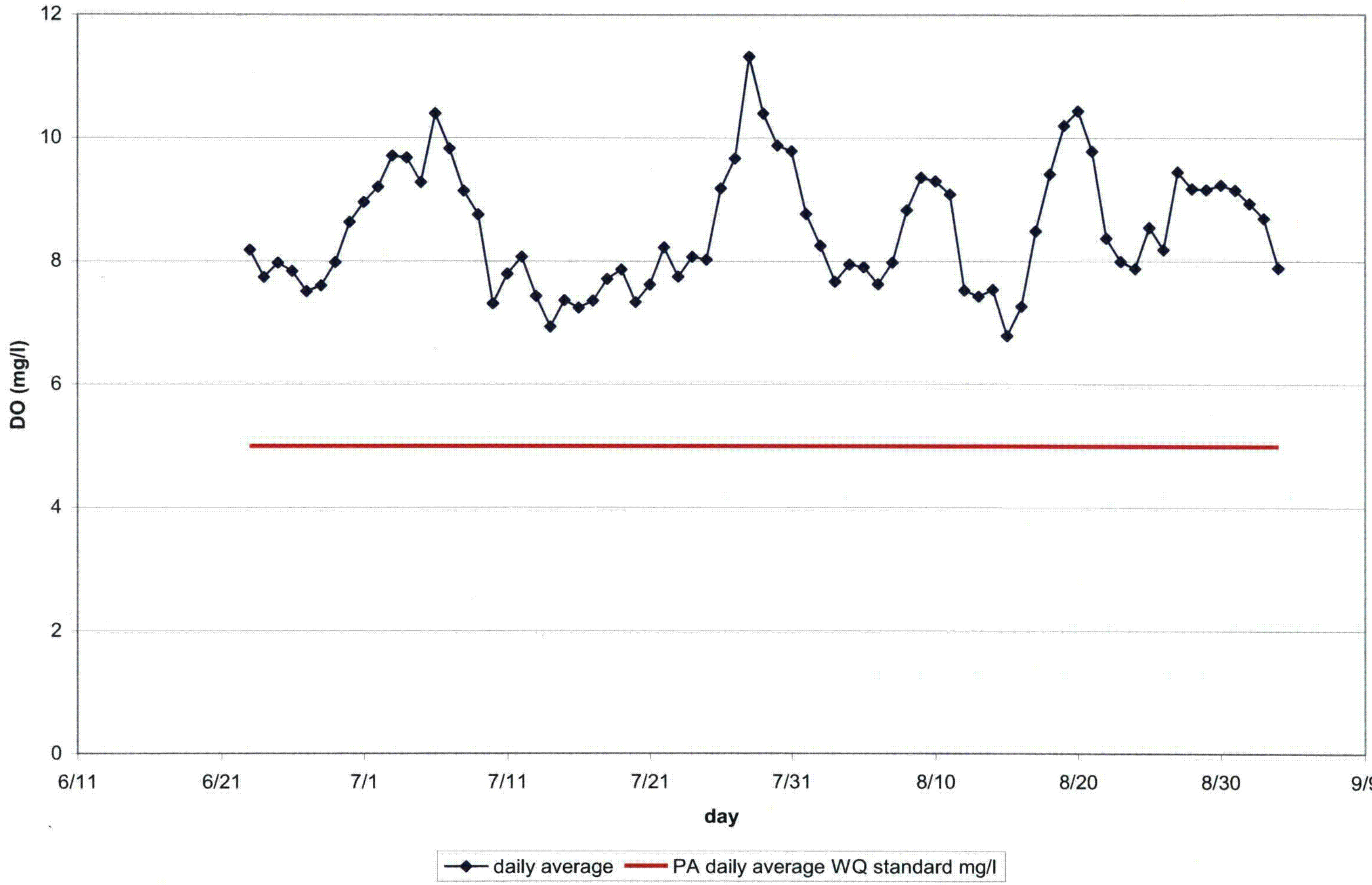


Figure 5-22 Sonde 2 (Goose Island, main channel) DO daily average

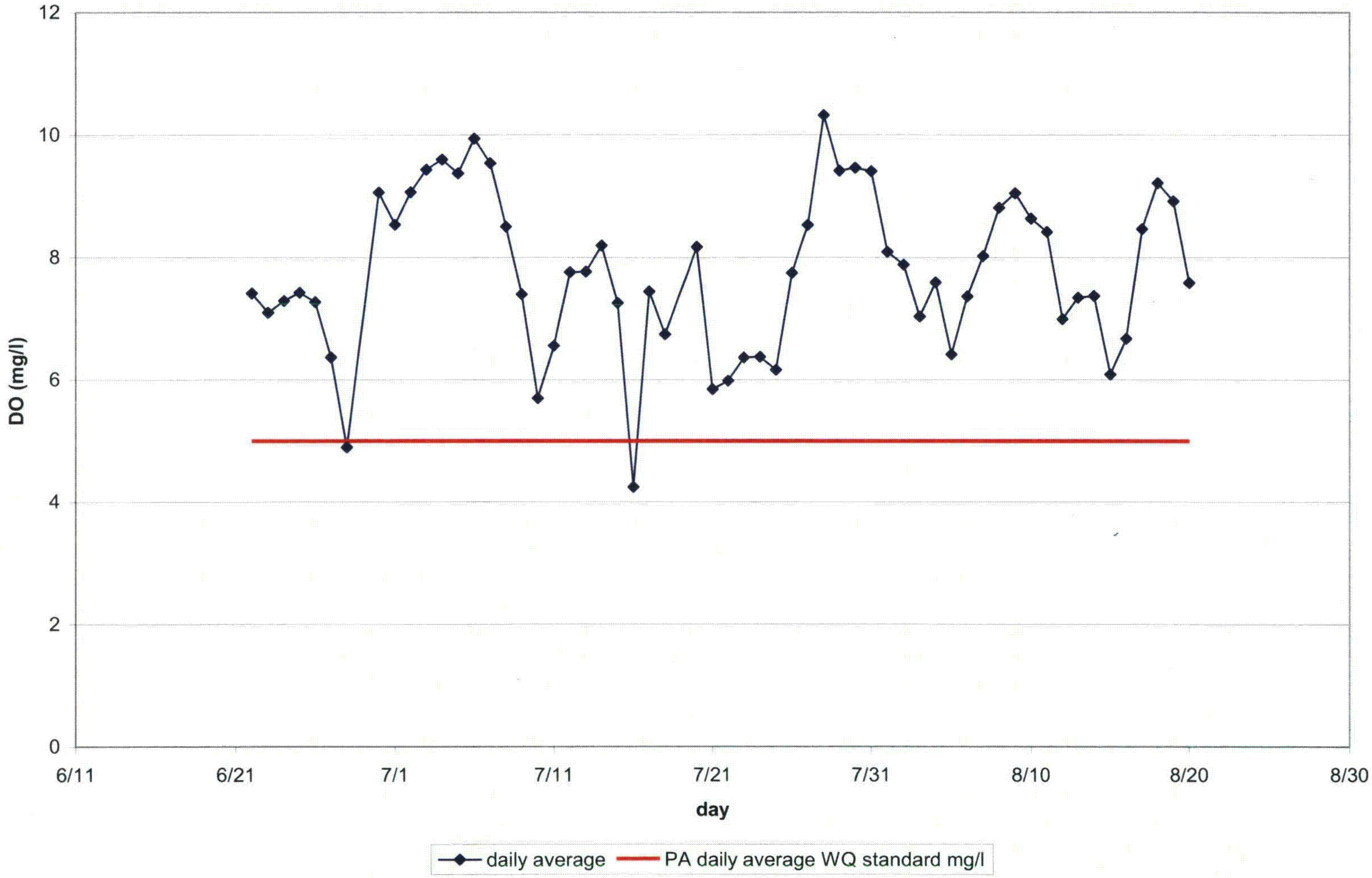


Figure 5-23 Sonde 3 (Environmental lab, shallow) DO daily average

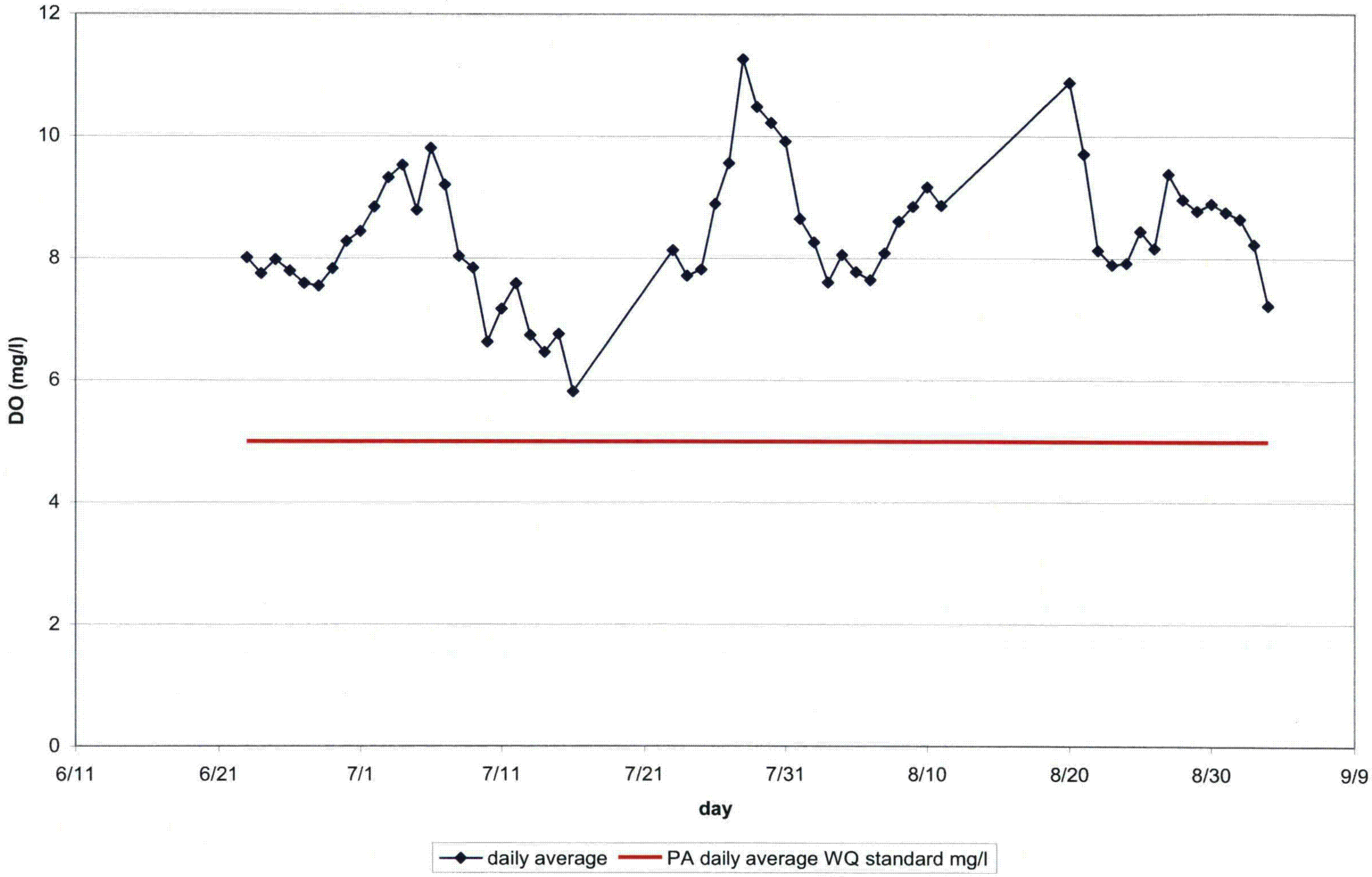


Figure 5-24 Sonde 4 (Environmental lab, main channel) DO daily average

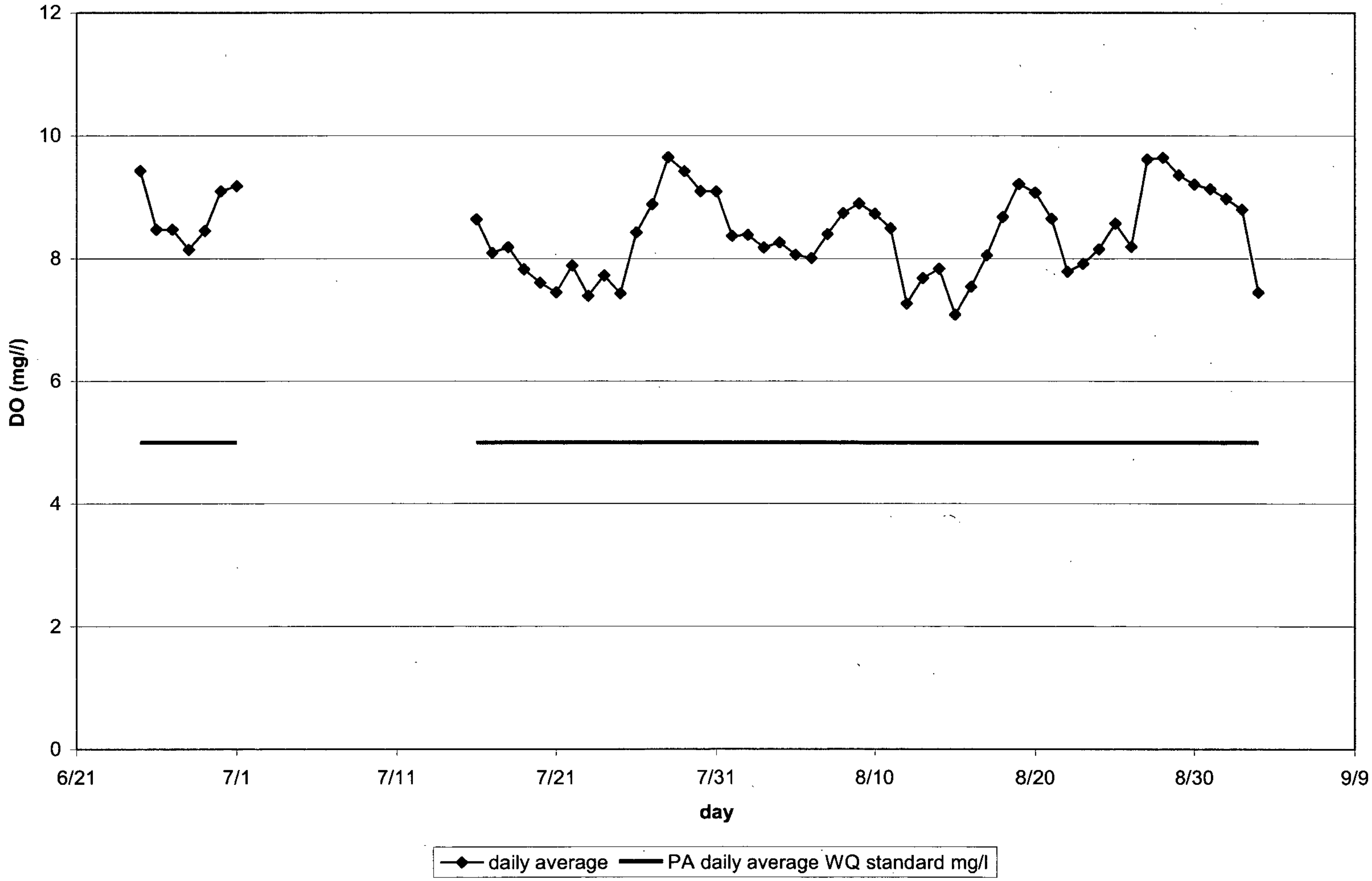


Figure 5-25 Sonde 5 (Downstream from Test Track, main channel) DO daily average

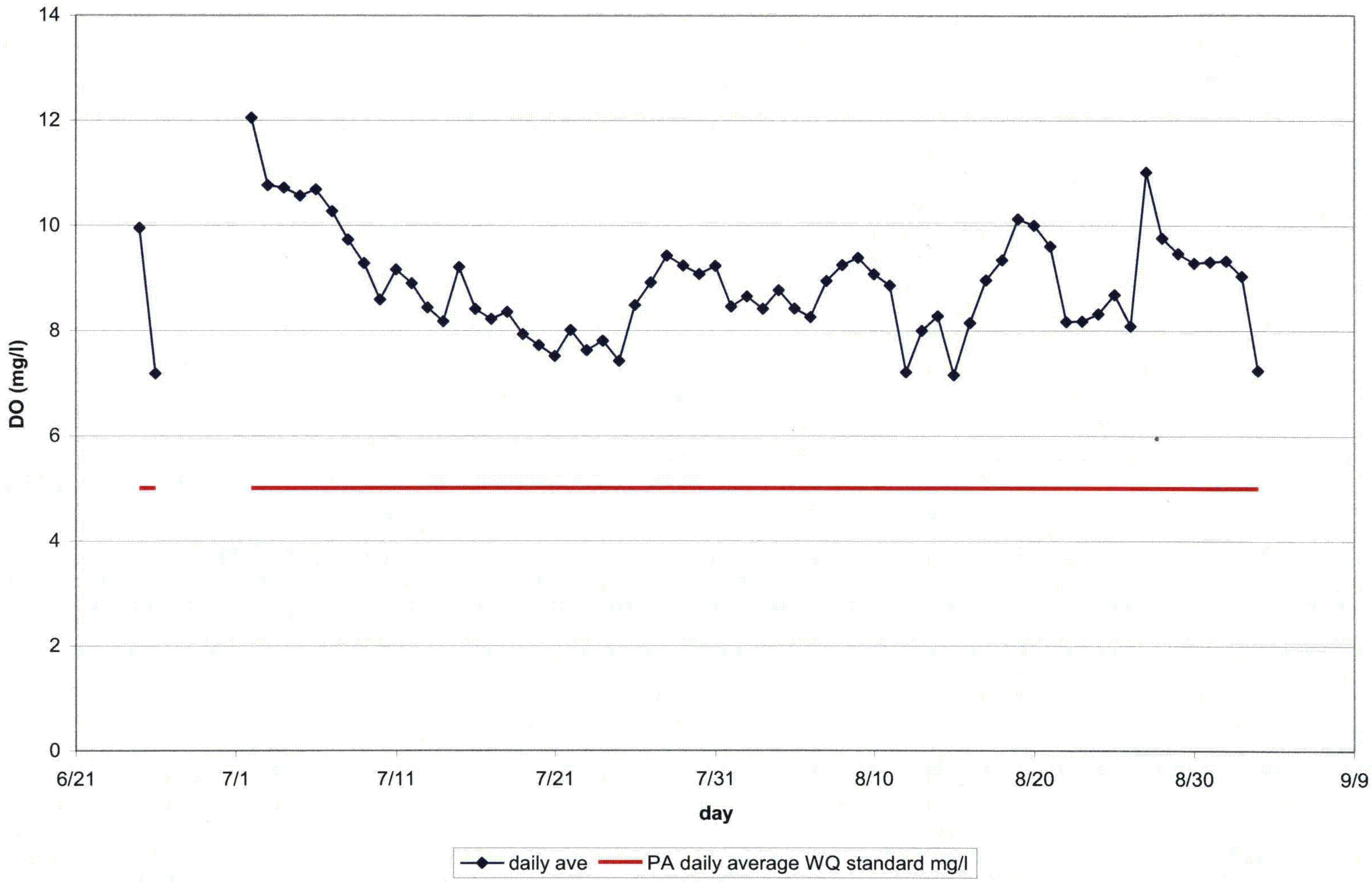


Figure 5-26 Sonde 5 (Downstream from Test Track, main channel) DO daily average

Figure 5-27 shows a summary of the hours at each sonde below 4 and 5 mg/l DO and hours above 4 mg/l.

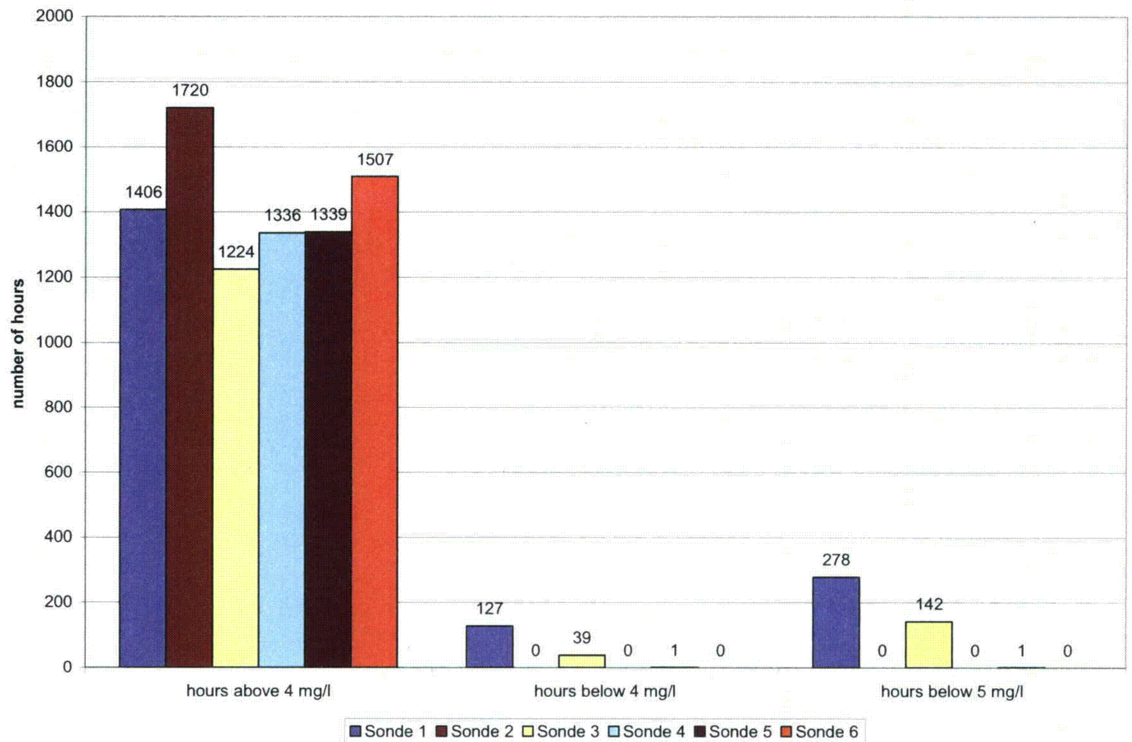


Figure 5-27 Hours below 4 and 5 mg/l DO and above 4 mg/l for all sondes

5.7. PH

Figure 5-28 through Figure 5-33 present the temporal pattern of pH recorded at the six data sondes. Although pH varied between dates, the fluctuations were generally within 1.0 pH unit and followed a similar pattern at all sites.

Approximately 30 (2.2%) pH values out of 1,339 slightly exceeded the upper range of PA State criteria of 9.0 at the main channel habitat of Berwick Test Track; five (0.3%) out of 1,336 at main channel habitat at the Environmental Lab boat ramp. All were naturally occurring events in July, and the longest consecutive period was 9 hours.

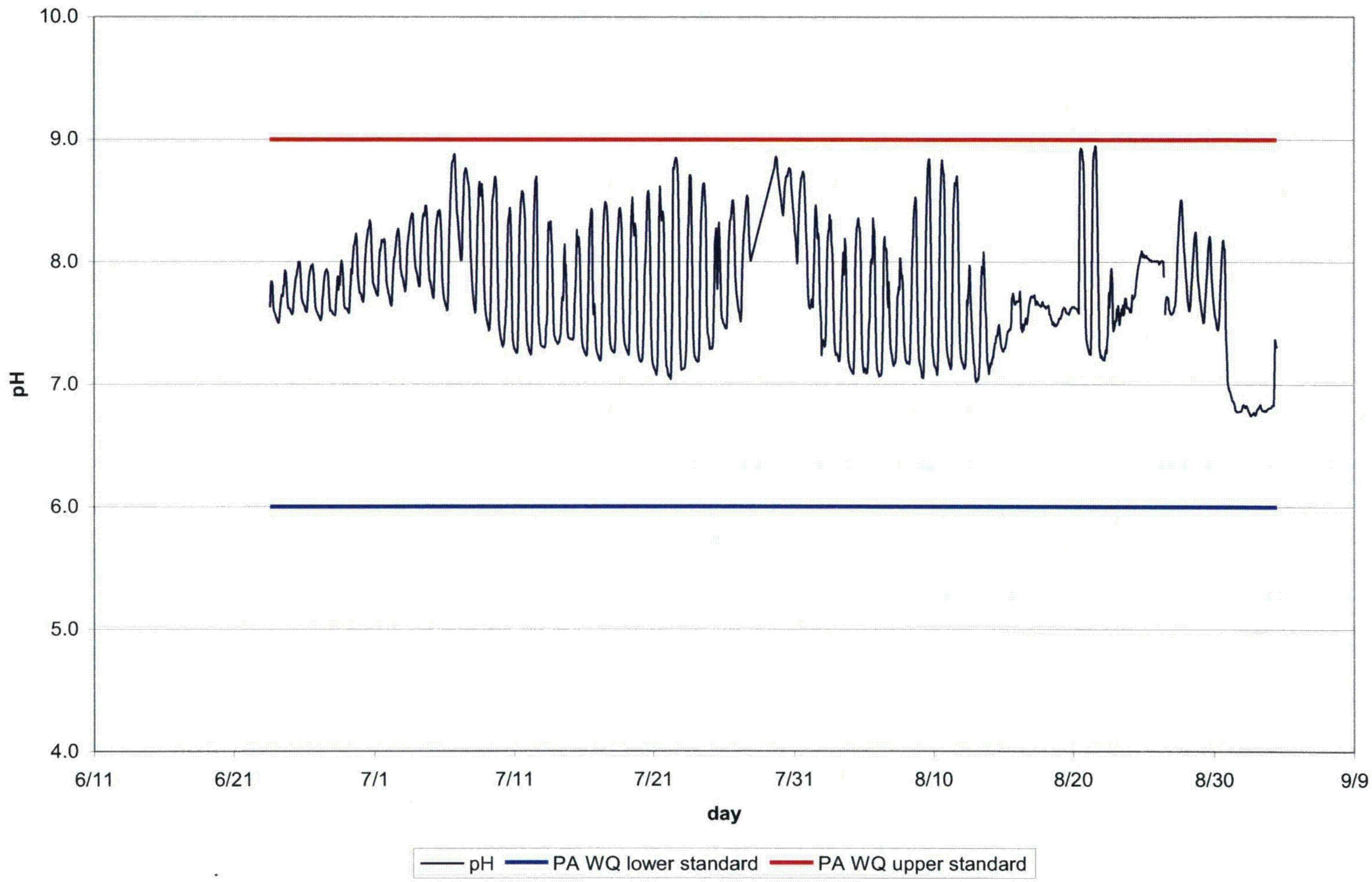


Figure 5-28 Sonde 1 (Goose Island, shallow) pH

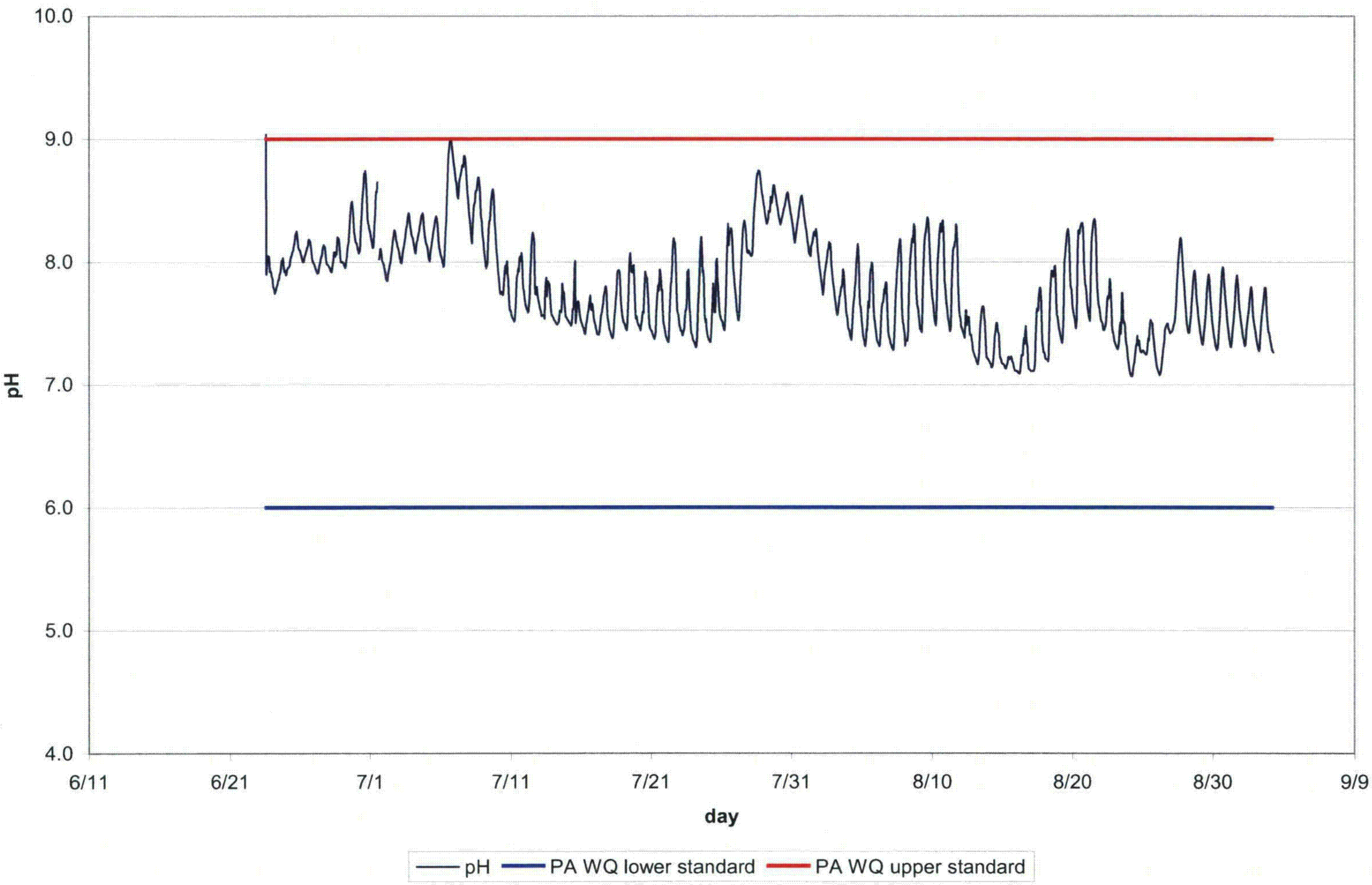


Figure 5-29 Sonde 2 (Goose Island, main channel) pH

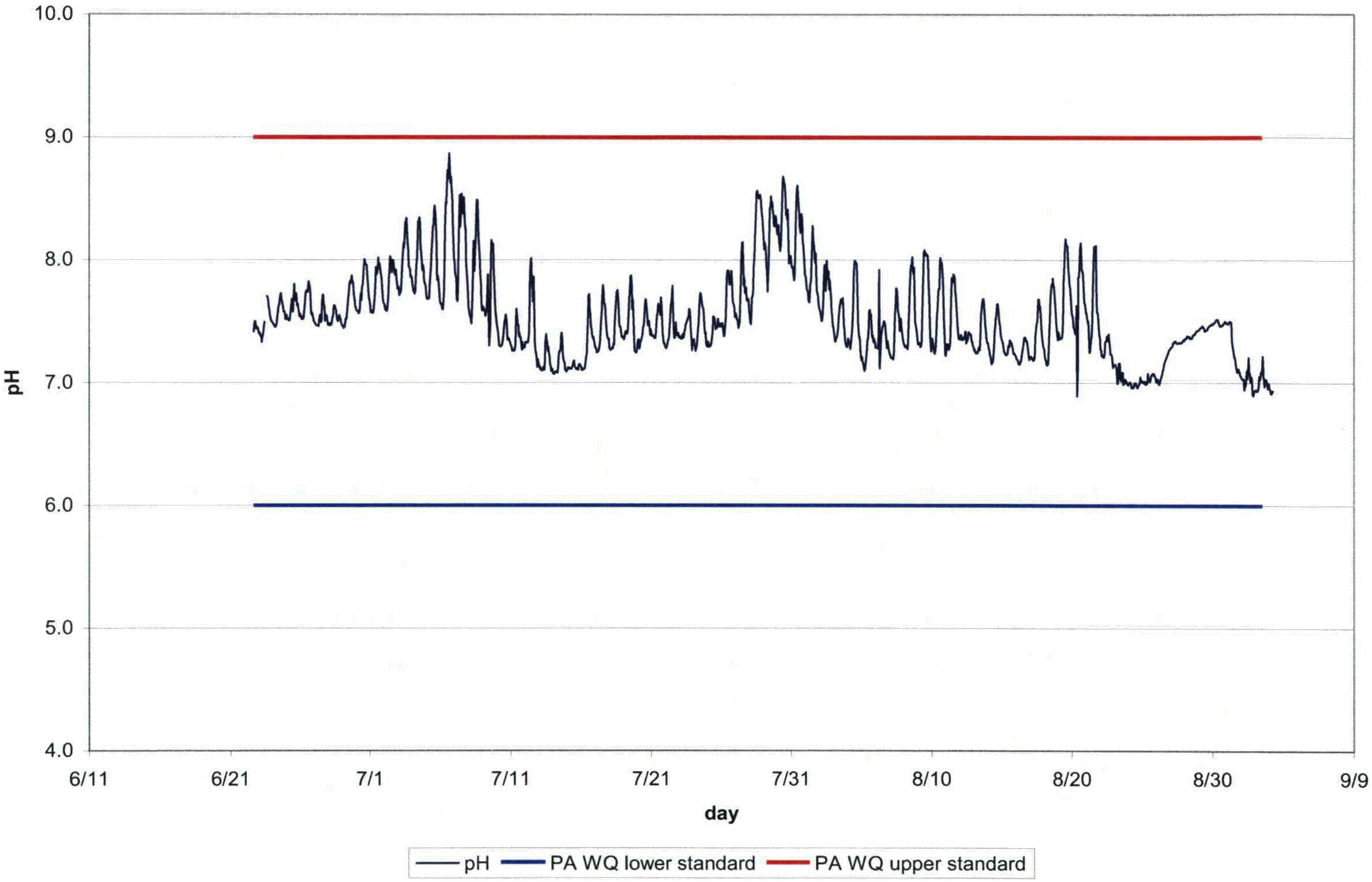


Figure 5-30 Sonde 3 (Environmental lab, shallow) pH

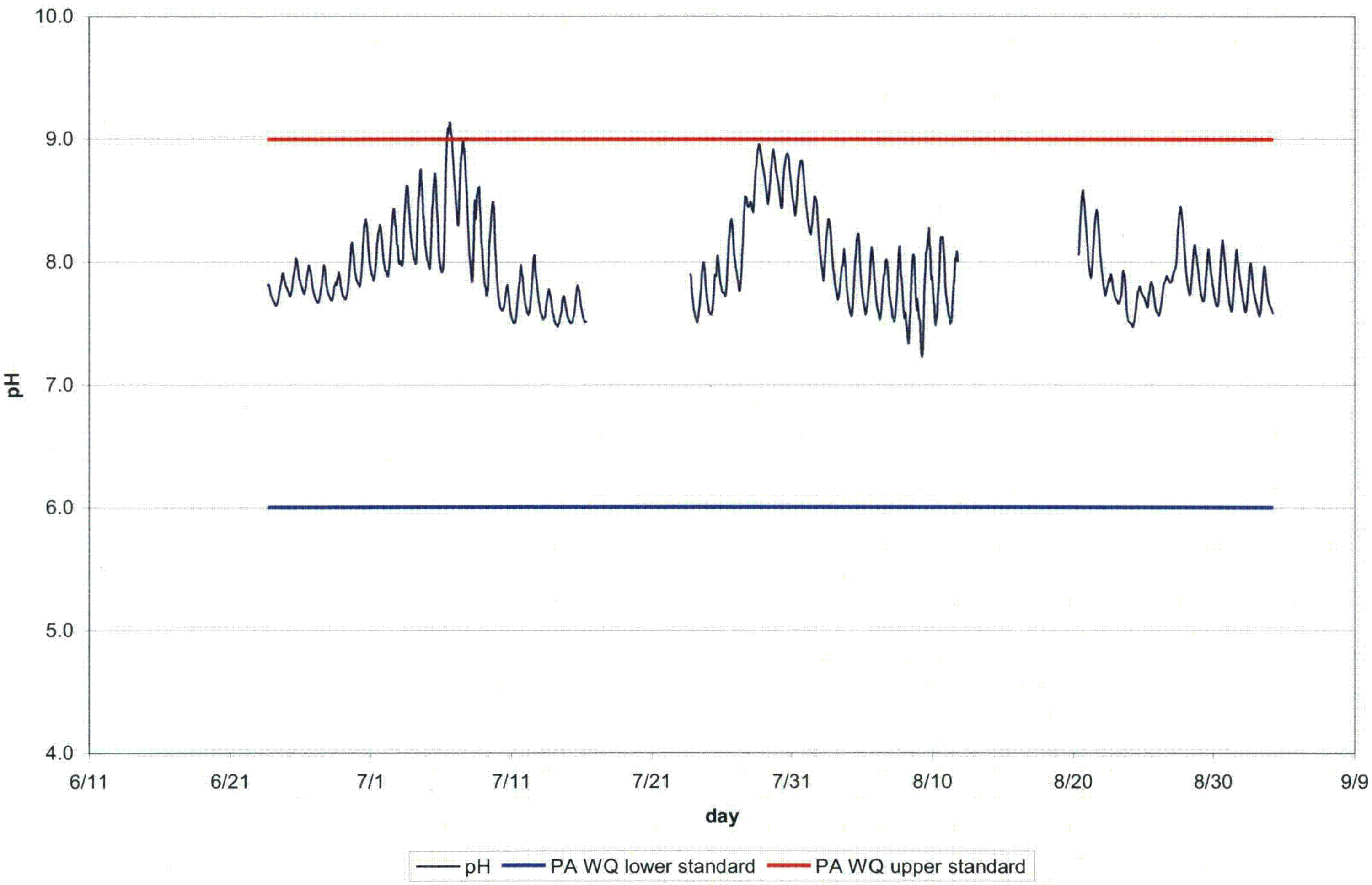


Figure 5-31 Sonde 4 (Environmental lab, main channel) pH

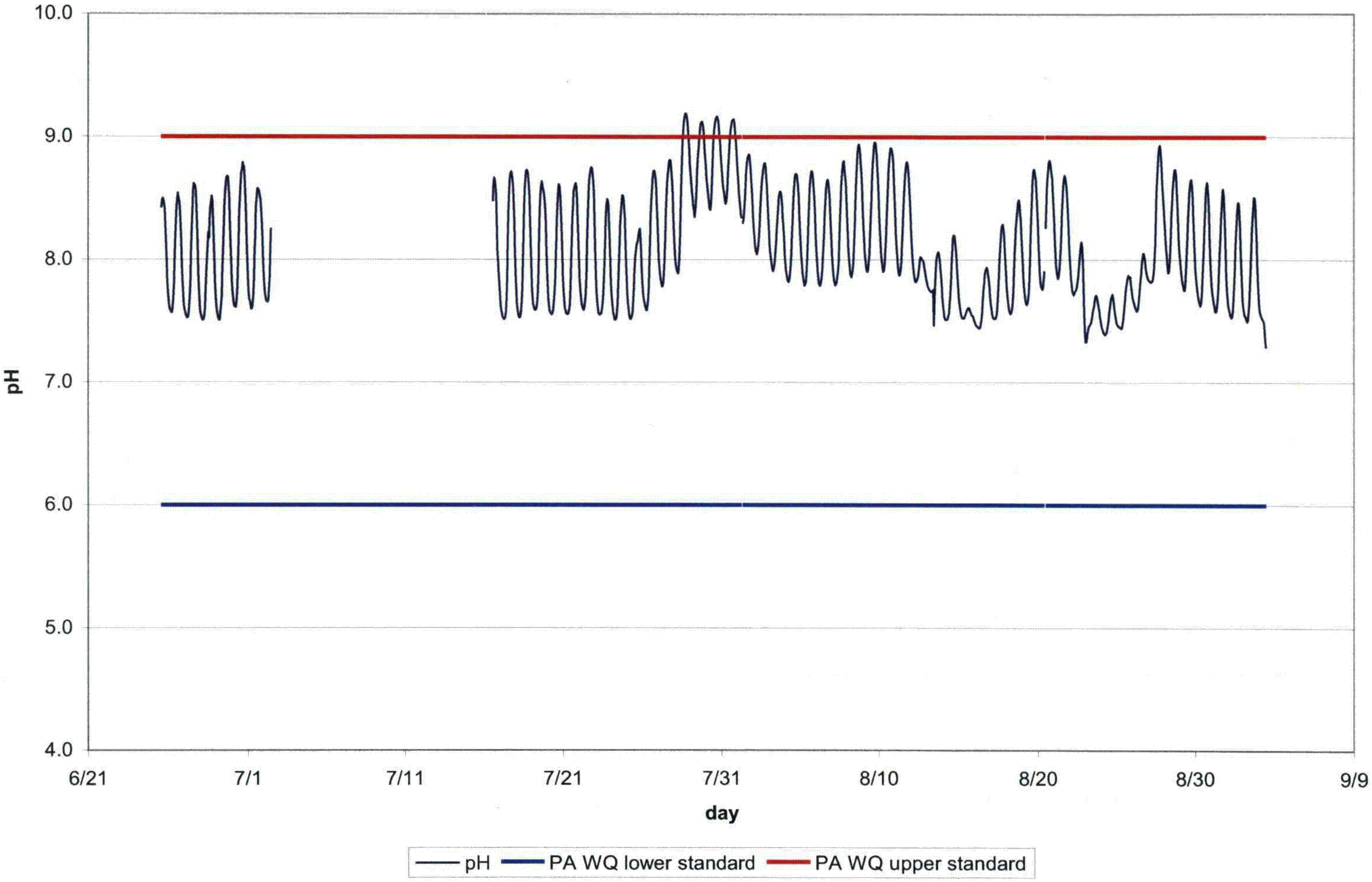


Figure 5-32 Sonde 5 (Downstream from Test Track, main channel) pH

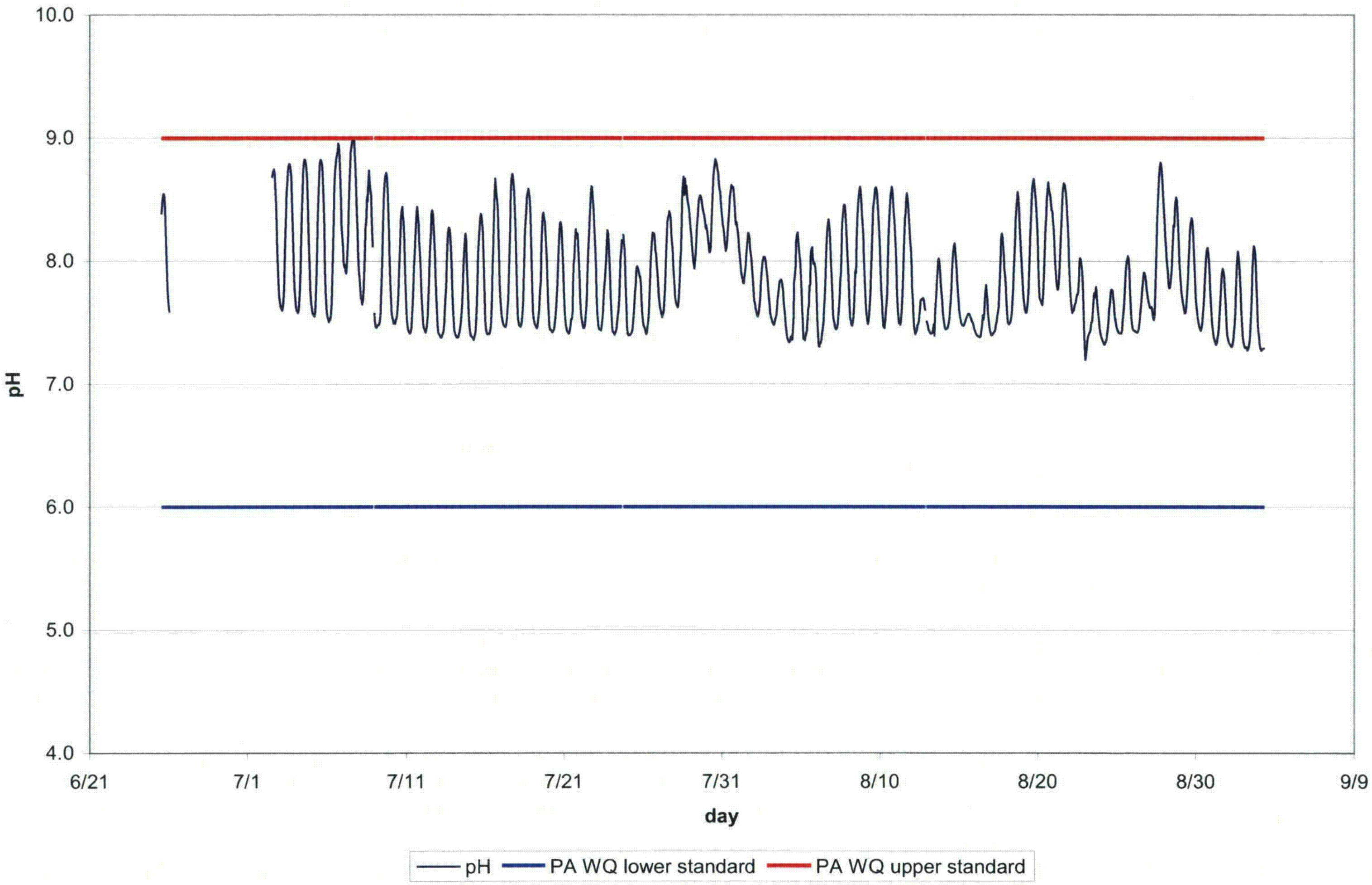


Figure 5-33 Sonde 6 (Downstream from Test Track, shallow) pH

5.8. *OBSERVATIONS ON SMB SPAWNING, REARING, AND NURSERY AREAS*

Ten surveys of SMB spawning activity, fry behavior, and subsequent survival were conducted from May through July 2010. A narrative of survey activities is provided in Appendix 5-A. Most observations were made in the upriver section of the study area which afforded the most spawning sites. A motorized kayak was used to gain easy access to the shoreline in shallow water.

Most spawning, fry emergence, and YOY SMB were observed at Rocky Island, Goose Island, Environmental Lab boat ramp, and upriver of the mouth of Little Wapwallopen Creek. Spawning occurred in shallow areas (<2 ft deep) with little or no current, mostly on gravel substrate. Fry and juveniles utilized near-shore shallow (<1 ft deep) and low velocity areas. Occasionally in July and more often in August, naturally occurring water temperature exceeded 87°F (PA state standard for temperature in WWF stream from 1 July to 30 August) in SMB nursery areas but field observations noted that juveniles vacated those locales prior to the occurrence of temperatures.

YOY SMB, apparently infected by the bacterium *Flavobacterium columnare*, were observed in July; these infected juvenile bass appeared vulnerable to Blue Heron predation. These fish appeared stressed to the extent that they could be hand-dipped. A detailed description of observations is included in Appendix 5-A.

5.9. *IMPACT ANALYSIS*

The 2010 sonde data cover a period from late June through 3 September. These data partially overlap the 1 May through 31 July SMB fry period of interest, as well as the potential juvenile SMB activity period through August. Three of the sondes were set in shallow areas that provide habitat to fry and juvenile SMB. To assess the potential effects of the 43 cfs withdrawal on the quality of these representative backwater habitats, the number of hours was calculated that the water temperature was equal to or greater than 1) the possible biological threshold of 84°F and 2) was equal to or greater than the PA WQ Standard of 87°F in July and August and 84°F in June. As discussed in Section 5.1, 84°F is considered a "possible biological threshold" temperature condition that prior studies suggest may be associated with increased *Flavobacterium columnare* virulence in fish fry.

For the impact assessment, the change in temperature due to the maximum expected reduction in depth of 0.5 inch was estimated with a thermal response calculation that uses meteorological data to assess heat transfer rates and the overall heat balance. The estimated changes in temperature were then applied to the observed sonde temperatures to obtain a modified sonde record. The observed sonde temperatures and the modified sonde temperatures were compared to both the PA WQ standard and the "possible biological threshold" to determine how often the number of exceedances increased for the reduced depth case.

5.10. THERMAL RESPONSE ANALYSIS

Changes in water temperature due to changes in water depth can be estimated by calculating the response temperature[12,13,14,15]. Response temperature is defined as the temperature a column of fully-mixed water would have if surface heat exchange were the only active heat transfer process (i.e., the water temperature "responds" only to surface heat exchange). This calculation is useful because it isolates temperature changes due to depth variations, which is the intent of the impact assessment. The calculation does not consider temperature changes in shallow areas due to overtopping during high flows or replenishment due to inflow and outflows through sands and gravels. These two processes would mitigate increases in temperature due to depth reduction.

The rate of change of response temperature can be written in terms of the net rate of surface heat exchange as

$$D\frac{dT}{dt} = \frac{R_n}{\rho c_p}$$

where

D	=	mean depth of the water column, m
dT	=	change water column temperature, °C
dt	=	change in time, s
R_n	=	net rate of surface heat exchange, W/m^2
ρ	=	density of water, 1000 kg/m^3
c_p	=	specific heat of water, 4186 J /kg/°C

[12] Joy, J., R. Noll and E. Snouwaert. 2009. Hangman (Latah) Creek Watershed Fecal Coliform, Temperature, and Turbidity Total Maximum Daily Load, Water Quality Improvement Report. Publication No. 09-10-030. Washington State Department of Ecology, Olympia, Washington 98504-7710. June.

[13] Edinger, J. E., D. K. Brady and J. C. Geyer. 1974. Heat Exchange and Transport in the Environment. Cooling Water Studies for the Electric Power Research Institute, Research Project RP-49, Report 14. Palo Alto, California. EPRI Publication Number 74-049-00-3. November.

[14] Baldwin, K. and A. J. Whiley. 2011. Pend Oreille River, Temperature Total Maximum Daily Load, Water Quality Improvement Report, Revised. Publication No. 10-10-065. Washington State Department of Ecology, Olympia, Washington 98504-7710. November

[15] Chapra, S.C. and G.J. Pelletier 2003. QUAL2K: A Modeling Framework for Simulating River and Stream Water Quality: Documentation and Users Manual. Civil and Environmental Engineering Dept., Tufts University, Medford, MA.

The rate of surface heat exchange can be computed from air and dew point temperature, windspeed, cloud cover, solar radiation, and atmospheric pressure. These meteorological variables are used to compute the seven individual terms that make up the net rate of surface heat exchange. These terms include shortwave solar radiation; reflected shortwave solar radiation; longwave atmospheric radiation; reflected longwave atmospheric radiation; back radiation; evaporative heat loss; and conduction.

For the present calculation, hourly meteorological data from the NOAA station at Avoca, PA (WBAN 14777), six miles southwest of Scranton and 27 miles northeast of the site, were used to calculate the hourly response temperature for the sonde data period. Solar radiation is not observed at Avoca and was instead calculated using cloud cover observations. However, to emphasize maximum water temperature changes for this assessment and to show more warming than actually would have occurred, clear sky solar radiation rates were used instead of the reduced values due to cloud cover.

When hourly or more frequent meteorological data are used to compute the response temperature, the characteristic diurnal pattern of warm afternoon temperatures and cool overnight temperatures emerges. Daytime heating is due primarily to incident solar radiation; nighttime cooling is due primarily to nighttime longwave back radiation. Furthermore, the diurnal pattern is more pronounced for waterbodies with shallow depths than for very deep waterbodies. Damping of the diurnal amplitude as depths increase is due to the increased mass of water on which the heating and cooling processes operate.

As noted, observed meteorological data were used for this impact assessment, except that clear sky solar radiation was used instead of a reduced value due to cloud cover. Use of observed meteorological data resulted in a variable pattern of heating and cooling from day to day as various processes become more or less important to the heat balance. For example, evaporation is an important heat loss process which increases with wind speed which varies during the day and from day-to-day. Inclusion of observed meteorological data results in an irregular diurnal temperature pattern, as shown in Figure 5-34.

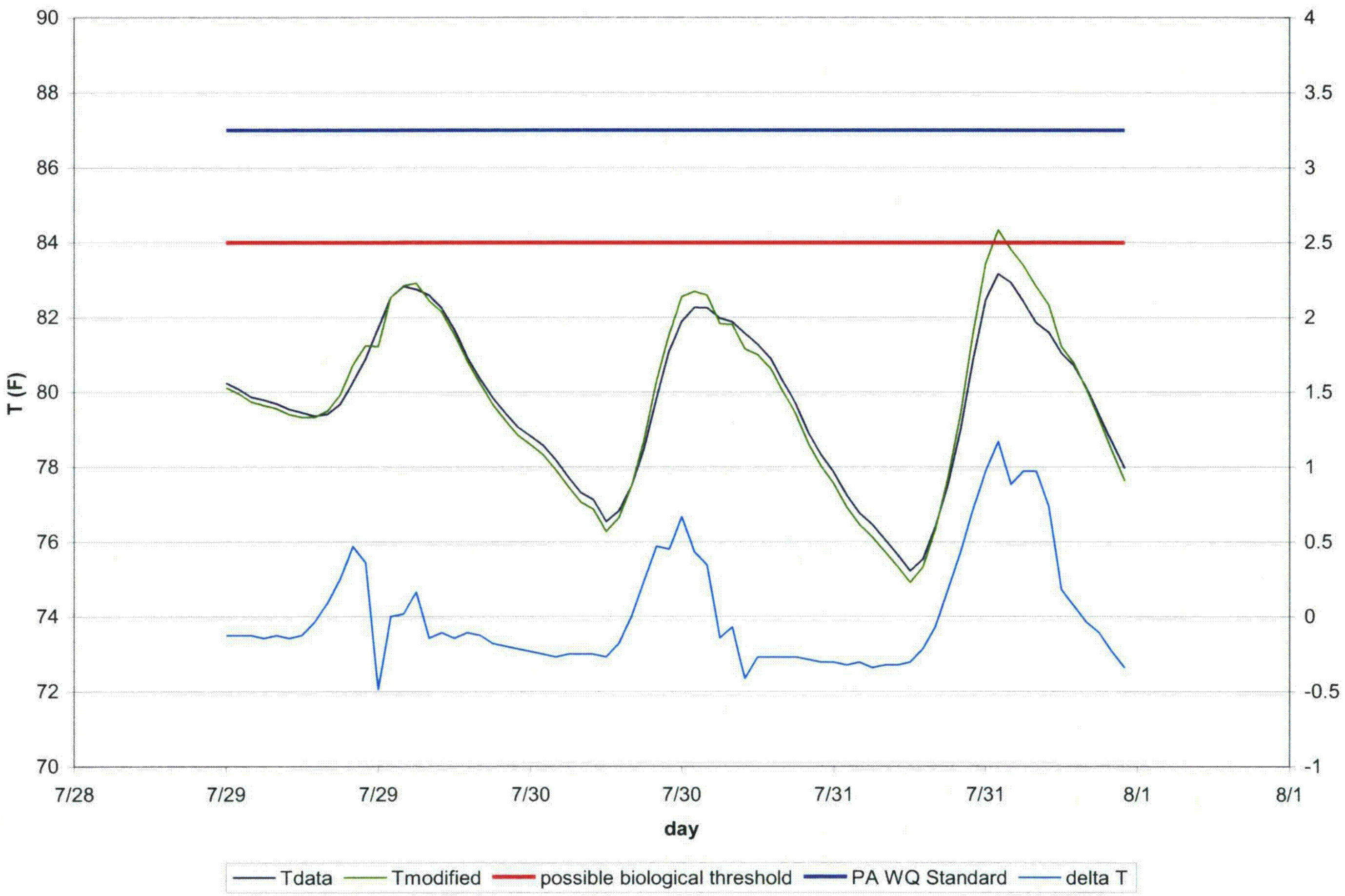


Figure 5-34 Sample sonde observed and modified temperature series and computed change in temperature from depth effect (ΔT) shown in light blue below on right hand y-axis (Sonde 3 Environmental Lab July 29 – 31 2010)

The calculation was run for six cases: once for each of the three shallow sondes (1, 3 and 6) at their nominal depths and once for these sondes at their nominal depth minus 0.5 inches. The hourly change in temperature (ΔT) was then applied to the hourly sonde observations to create a reduced-depth temperature record, referred to as the "modified record."

Drawdown values as a function of river flow from the stage-discharge curves developed for each PHABSIM transect are shown in Figure 5-35 for representative transects within the study reach. The 0.5 inch reduction in depth that was used in the thermal response analysis is the maximum drawdown value which occurs at 7Q10 at Transect RI1-RC regardless of location, time of year, or river flow.

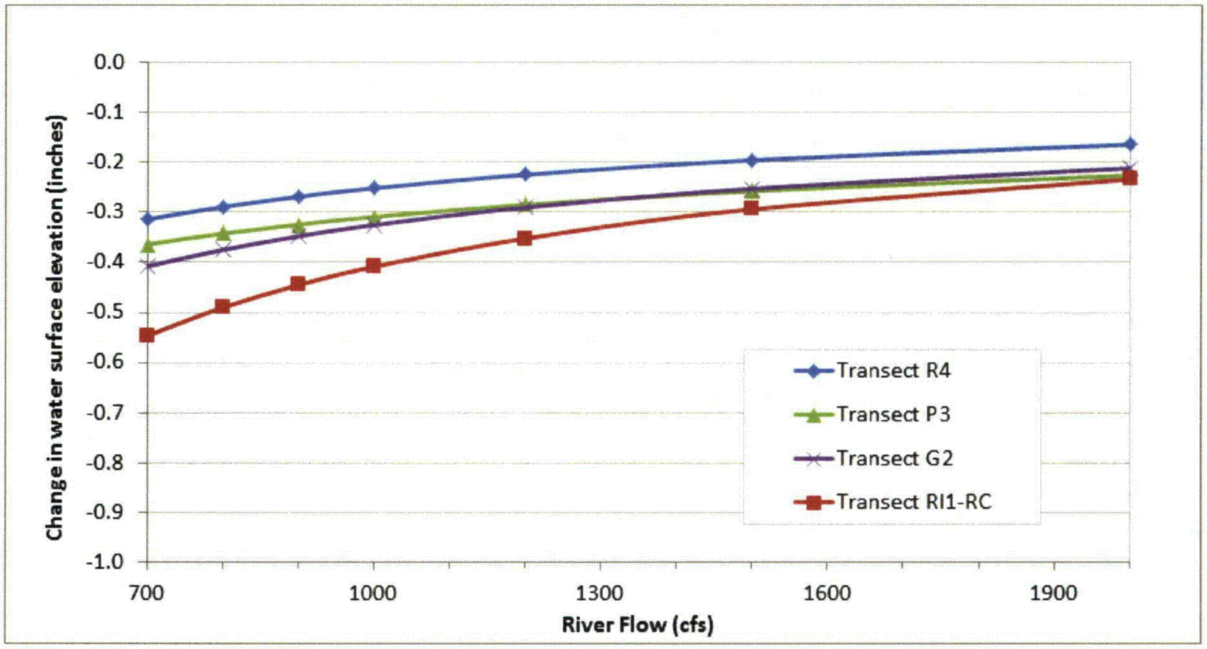


Figure 5-35 Depth reduction at four transects as a function of river flow

For illustration purposes, Figure 5-36 shows the observed Sonde 3 temperature, the calculated ΔT, and the modified Sonde 3 record obtained by adding the observed temperature and the ΔT. The period selected for this example includes the highest calculated ΔT (1.12°F) which results in the modified record exceeding one of the threshold values, in this case 84°F.

Both the observed temperatures and the calculated ΔT show daytime heating and nighttime cooling characteristic of heat balances controlled by surface heat exchange. The same positive, net heat flux that causes high temperatures in the early afternoon results in high ΔT values because the net heat flux is acting on a smaller mass.

The distribution of positive ΔT's for Sonde 3 for those occasions when the 0.5 inch depth reduction increases temperature is shown in Figure 5-36. This figure shows that the majority of increases are less than 0.5°F and that the example shown earlier is in fact the maximum change.

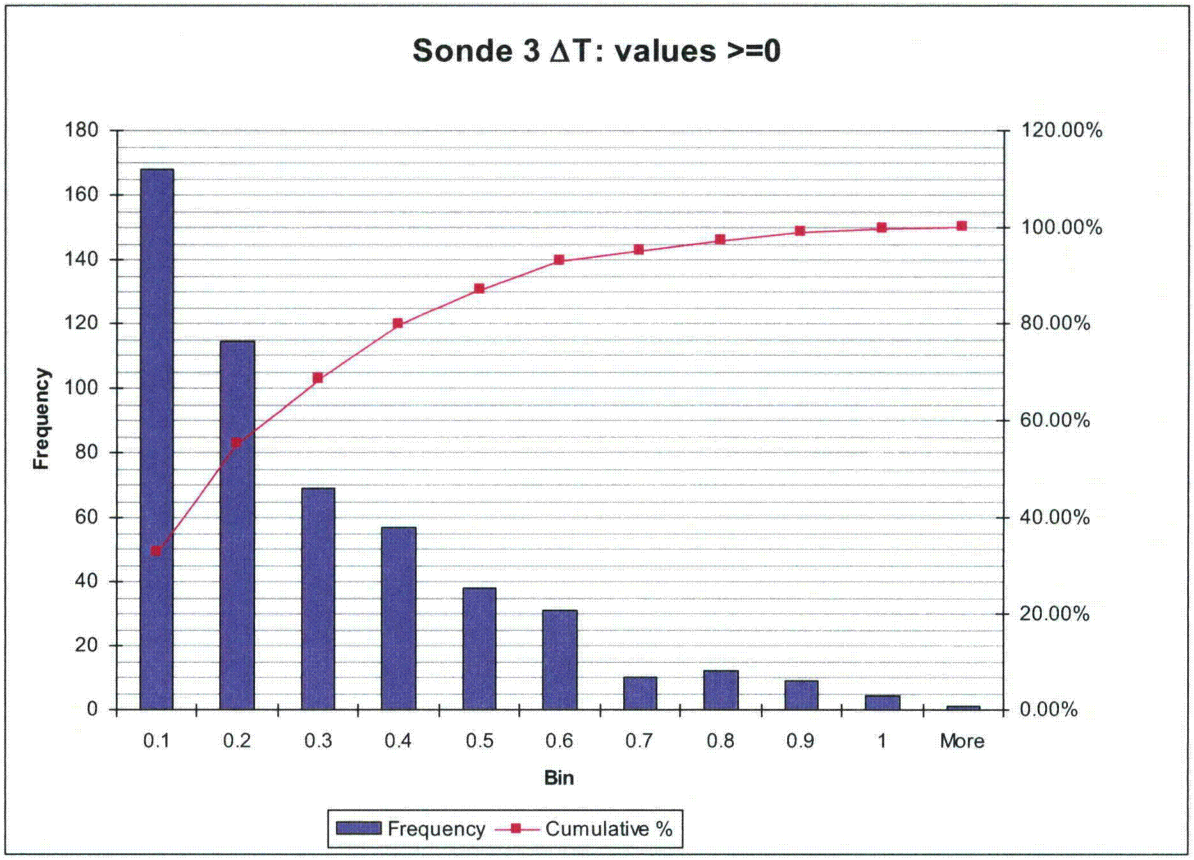


Figure 5-36 Frequency of occurrence of positive ΔTs for Sonde 3

The foregoing approach to calculating maximum temperatures is conservative, i.e., the calculation is an overestimate of the temperature increases that are likely to occur, for the following reasons:

- The calculation assumes a fully-insulated cylinder open only to heat gain or loss at the surface and assumes no replenishment due to mixing with groundwater in the hyporheic zone or due to flows that overtop the microhabitat boundary.
- The drawdown is a constant 0.5 inch for all Susquehanna River flows for all locations and times.
- The calculation assumes no cloud cover and therefore maximizes solar radiation and temperature change.

5.11. RESULTS

The computed response temperatures show the expected daytime heating and nighttime cooling cycle. When the predicted 0.5 inch maximum depth reduction associated with the 43 cfs is applied, the daytime maximum temperature is increased and the nighttime minimum temperature is decreased.

Figure 5-37, Figure 5-38, and Figure 5-39 show the diurnal hourly change in temperature (ΔT), averaged over the sonde data period for Sondes 1, 3, and 6, respectively. The average shown in these figures summarizes the overall effects of the 0.5 inch depth reduction: small increases in afternoon temperature and small decreases in nighttime temperature. This result is expected given the decreased water mass undergoing the same amount of daytime heating and nighttime cooling. The maximum and minimums in the figures illustrate the largest and smallest changes for each hour of the day over the period of analysis.

The calculated hourly changes in temperature were applied to the sonde data hour-by-hour. Figure 5-40, Figure 5-41, and Figure 5-42 show the sonde temperature record as observed and as modified for Sondes 1, 3 and 6, respectively. Also shown is the hourly change in temperature (ΔT). The changes in temperature due to the anticipated reduction in depth of 0.5 inch are so slight as to make the observed and modified temperature curves overlay closely and show no appreciable difference. However an analysis of the observed and modified record presented in both tabular and graphic format (Appendix 5-B and 5-C) shows that there are occasions when the daytime temperature increases cause the temperature to exceed the 84°F possible biological threshold and to exceed the PA WQ standard.

Table 5-4 provides a summary of the threshold analysis that shows the frequency and duration of exceedance of the PA WQ standard and the 84°F for the observed and modified sonde record.

Quantifying frequency and duration consists of counting the number of hours exceeding these values for the observed and the modified sonde temperature records. Two metrics can be derived from this procedure: the number of additional hours exceeded and the number of additional events. An event is a set of consecutive exceedances, that is, the duration of the exceedance. An event therefore is representative of potential recurring stress. It is important to note with regard to recurring (or cyclic) stress that Chaplin *et al.* (2009) indicated that the effect is poorly understood and that little is known about it over a period of days or weeks in YOY SMB microhabitats. Since additional recurring stress events associated with consumptive use as identified by the analysis in this report are extremely infrequent and are certainly not on the order of either days or weeks, no adverse effect is considered for this particular effect.

Because the temperature changes are small with increases confined to the afternoon, Table 5-4 shows that the 0.5 inch reduction in depth has no appreciable effect on the magnitude, the duration or the frequency of events greater than the possible biological threshold of 84°F. Similarly, the table shows that the reduction in depth due to consumptive use has no appreciable effect on the magnitude, the duration or the frequency of events greater than the PA WQ Standard.

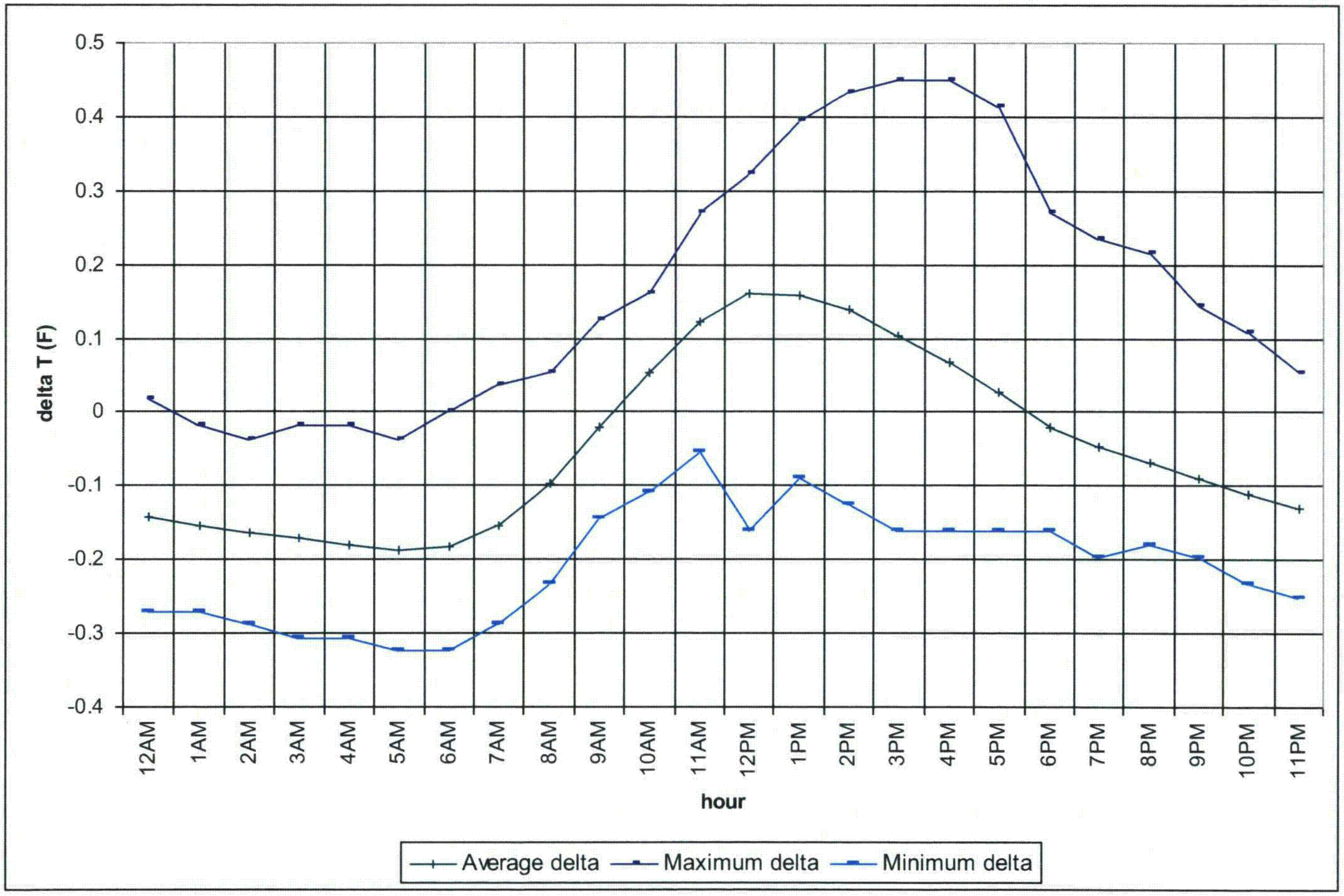


Figure 5-37 Overall change in temperature from reduced depth for Sonde 1 (Goose Island, shallow)

The ΔT is positive for increases and negative for decreases when applied to sonde data; nominal depth for Sonde 1 is 15 in.

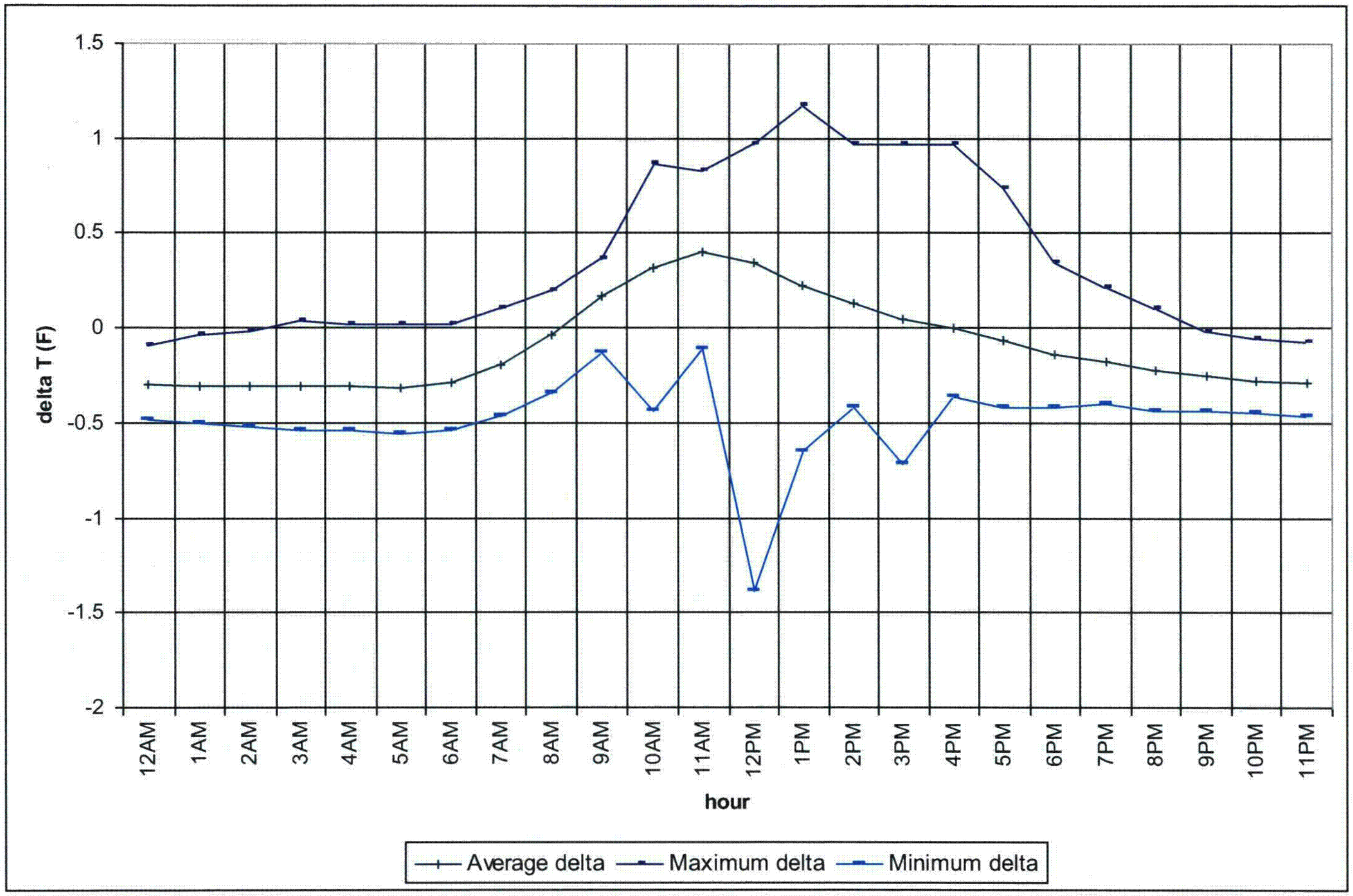


Figure 5-38 Overall change in temperature from reduced depth for Sonde 3 (Environmental lab, shallow)

The ΔT is positive for increases and negative for decreases when applied to sonde data; nominal depth for Sonde 3 is 9 in.

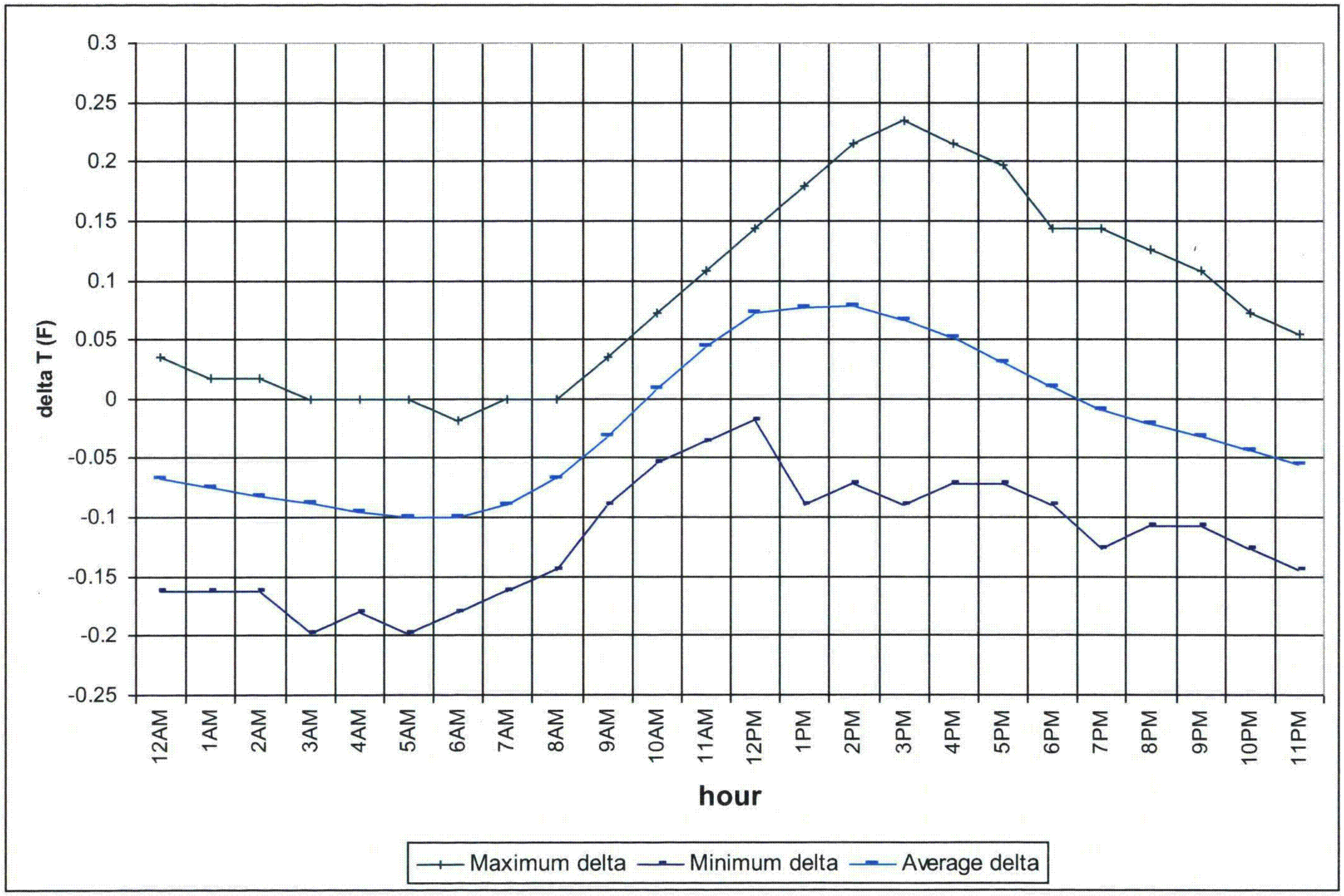


Figure 5-39 Overall change in temperature from reduced depth for Sonde 6 (downstream from Test Track, shallow)

The ΔT is positive for increases and negative for decreases when applied to sonde data; nominal depth for Sonde 6 is 21 in.

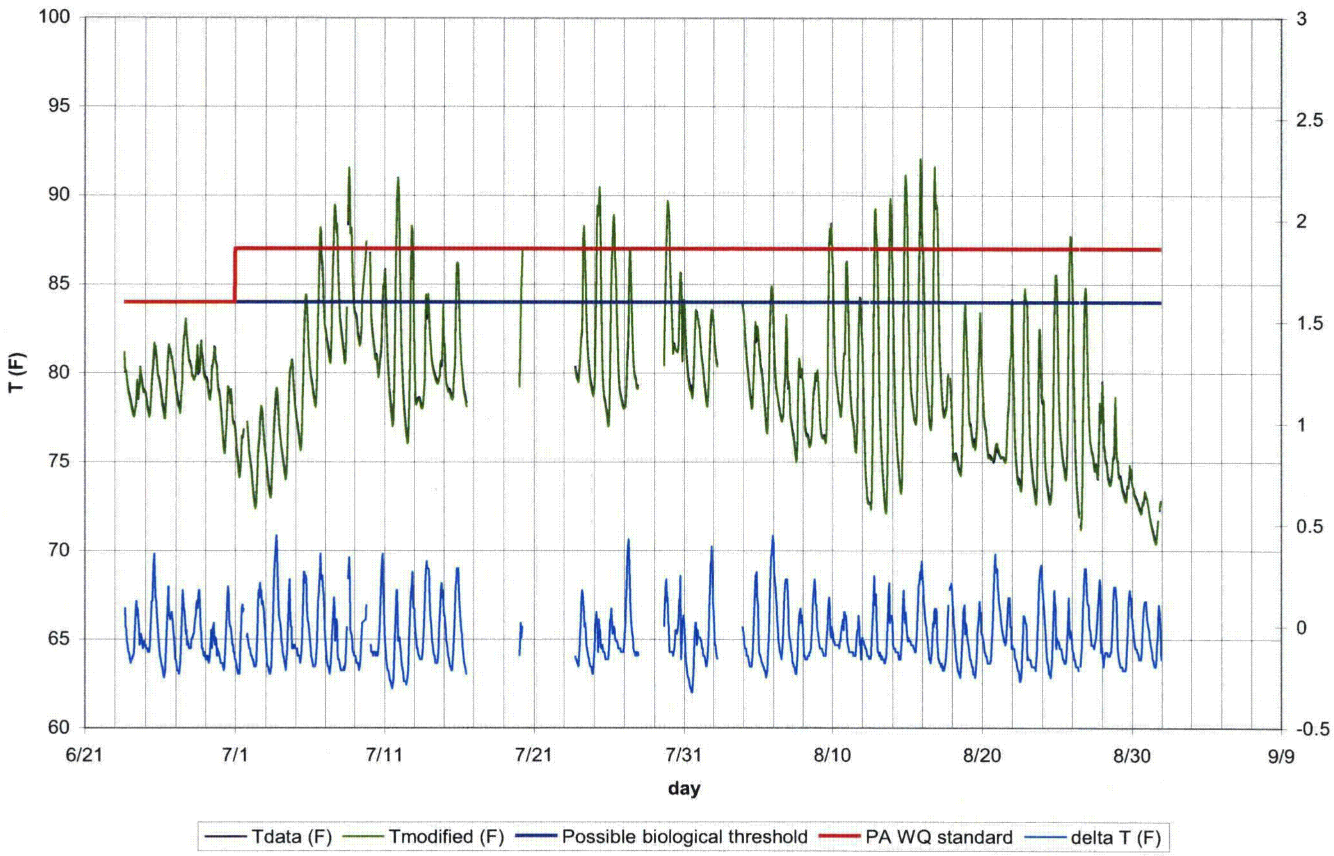


Figure 5-40 Sonde 1 (Goose Island, shallow) observed and modified temperatures series and computed change in temperature from depth effect (ΔT) shown in light blue below on right hand y-axis

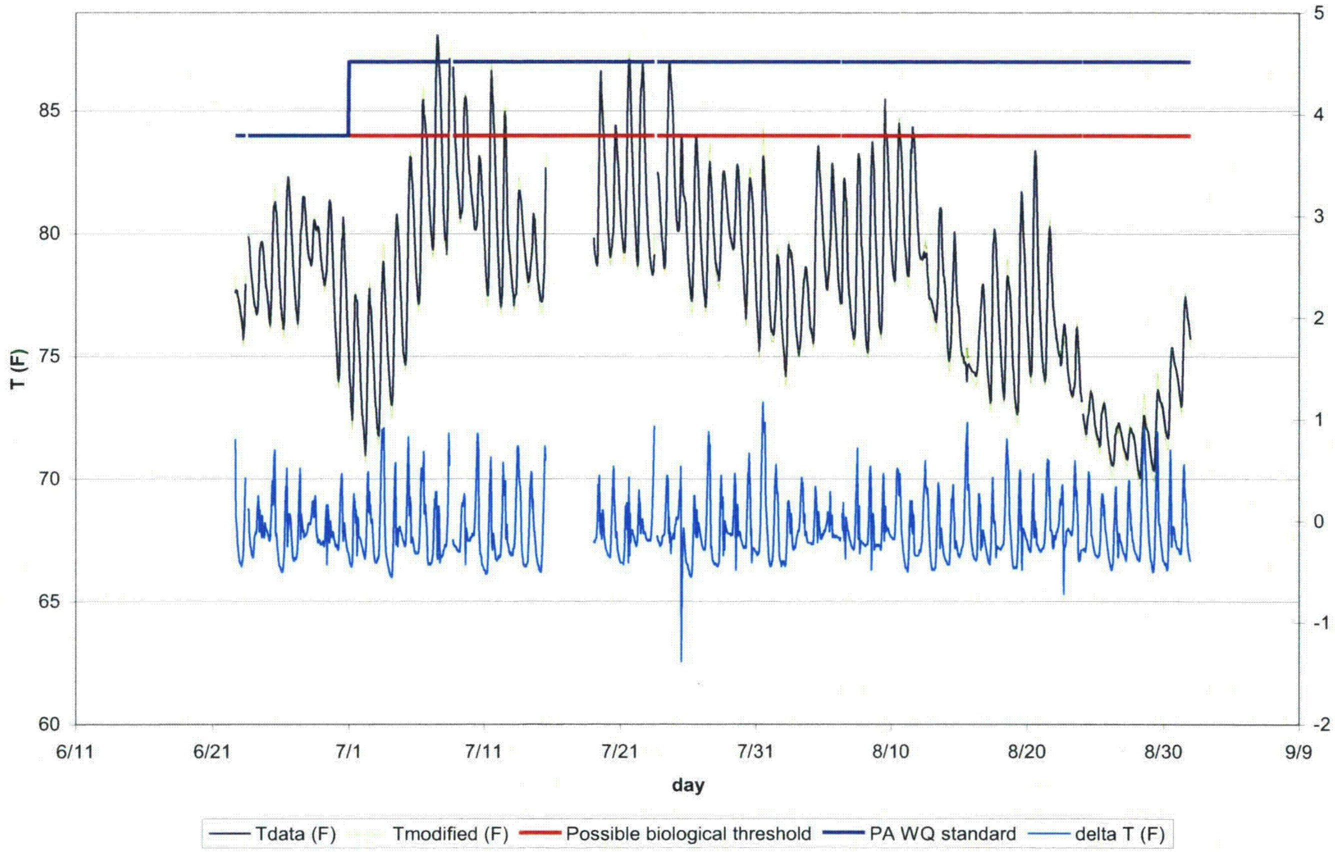


Figure 5-41 Sonde 3 (Environmental lab, shallow) observed and modified temperatures series and computed change in temperature from depth effect (ΔT) shown in light blue below on right hand y-axis

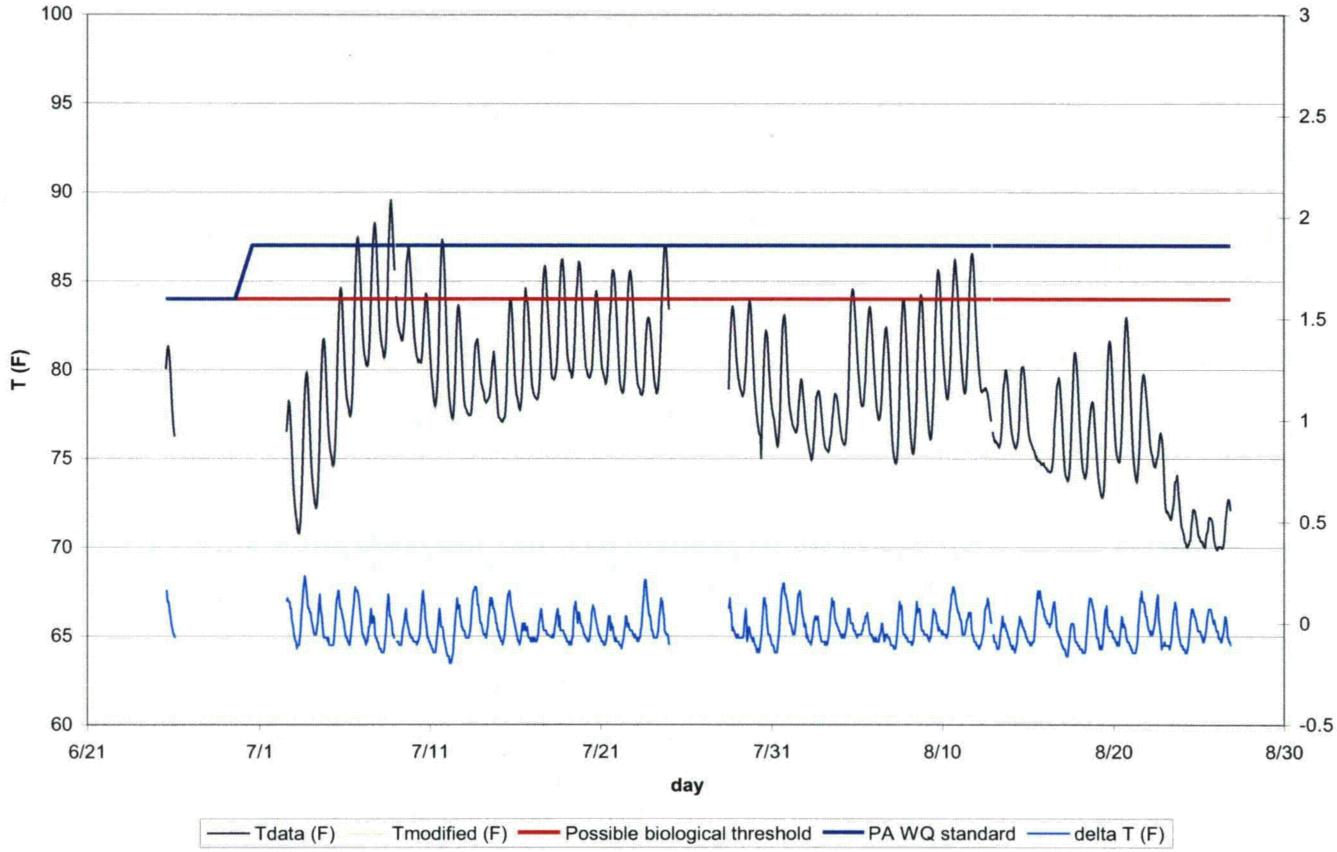


Figure 5-42 Sonde 6 (Downstream of Test Track, shallow) observed and modified temperatures series and computed change in temperature from depth effect (ΔT) shown in light blue below on right hand y-axis

Table 5-4 Thermal analysis summary

	Sonde 1 (Goose Island)	Sonde 3 (Environmental lab)	Sonde 6 (Test Track)
Sonde data period (2010)	23 June – 3 September	22 June – 3 September	25 June – 3 September
Depth used for thermal response calculation (inches)	15	9	21
Comparison to PA WQ Standard			
2010 data: hours above PA WQ standard	81	7	19
With ΔT applied: hours above PA WQ standard	81	8	19
Added hours	0	1	0
2010 data: number of events above PA WQ standard	18	3	6
With ΔT applied: number of events above PA WQ standard	18	4	6
New events	0	1	0
2010 data: average event duration (hours)	4.50	2.33	3.17
With ΔT applied: average event duration (hours)	4.50	2.33	4.25
Comparison to possible biological threshold			
2010 data: hours above 84°F	185	85	133
With ΔT applied: hours above 84°F	185	90	133
Added hours	0	5	0
2010 data: number of events above 84°F	34	16	22
With ΔT applied: number of events above 84°F	34	17	22
New events	0	1	0
2010 data: average event duration (hours)	5.44	5.31	6.05
With ΔT applied: average event duration (hours)	5.44	5.31	6.05

5.12. CONCLUSIONS

Based on field observations, SMB successfully spawned throughout the study area in late May and early June 2010. As the fry developed throughout June, they tended to disperse from the schools, but remained along the shoreline in aquatic vegetation at the river banks and the islands. However, by the time water temperature consistently exceeded 84-85° F these fry had grown to juvenile size and migrated from the shoreline habitat into deeper river water. In early July, shoreline water temperatures were approaching 90° F. At this time, YOY SMB were not observed in these areas.

Based on field observations and during naturally occurring flow events, some smallmouth bass juveniles appeared to suffer in 2010 from the same bacterial disease (*Flavobacterium*) experienced in 2005.

Collected water quality data indicates that during the summer low flow months there are natural occurrences of water quality not meeting the Pennsylvania State criteria for warm water fisheries, primarily for water temperature and DO and to a much lesser extent pH. These naturally occurring variations from the Pennsylvania Water Quality Criteria in water temperature and dissolved oxygen, independent of consumptive use, were of short duration and were limited to the shallow, inshore areas both upstream and downstream of the proposed BBNNP discharge location.

The thermal response analysis shows that the 0.5 inch reduction in depth has no appreciable effect on the magnitude, the duration or the frequency of events greater than or equal to a possible biological threshold of 84°F nor on the magnitude, the duration or the frequency of events greater than the PA WQ Standard.

Therefore, we conclude that the proposed consumptive use of the Bell Bend Project will have no appreciable effect on the condition for SMB spawning, fry emergence, rearing, and nursery.

6. ASSESSMENT OF POTENTIAL IMPACTS ON DOWNSTREAM USERS

Users of the waters of the Susquehanna River downstream of BBNPP can be classified as either direct withdrawers of water or dischargers that depend on the dilution and assimilative capacities of the Susquehanna. For direct withdrawers (e.g., municipal water utilities) the primary issue is availability of water and the functionality of intake structures at low water surface elevations. For dischargers, end-of-pipe concentration limits may depend on a specific flow rate used in calculations and models (e.g., PENTOXSD).

6.1. METHODS

The following evaluation of potential impacts on downstream water intakes and treated wastewater dischargers covers the area downstream of the BBNPP site as far as Danville and Riverside, PA (just over 30 miles distance from BBNPP), as stated in the Study Plan. For each group (withdrawers, dischargers), we sought to understand the scope of impacts (physical, chemical, and regulatory) that might occur for the group, divided into large (1 mgd or more) and small (less than 1 mgd) withdrawal or discharge rates. Inquiries were made by telephone and email, with repeated calls to facilities that did not respond, to attempt to ensure that each known withdrawer and discharger had the opportunity to respond. Contacts with water withdrawers focused on defining impacts on their ability to serve their customer base and/or their ability to maintain suitable intake velocities because of potential reduced water availability, decreased river stage, or changed water quality. Other concerns included potentially increased chemical usage due to reduced river flow. Discussions with treated wastewater dischargers focused on potential reductions of effluent limits driven by decreased dilution based upon a seven-day, ten-year low flow in the Susquehanna River reduced by a maximum of 48 cfs of added consumptive water use arising from the installation of a new generating unit at the BBNPP. The 48 cfs value was used for the interviews because the downstream user survey was begun prior to the change to 43 cfs in PPL Bell Bend's application to the SRBC. The 7Q10 at Bell Bend is 843 cfs; at Bloomsburg, it is estimated at 942 cfs; at Danville, it is estimated to be 1,010 cfs per http://paapps.er.usgs.gov/flowstats.

The list in Table 6-1of water withdrawers in excess of 0.1 mgd is based on internet research on local water suppliers and telephone contacts with the withdrawers. While three of the withdrawers are extracting from wells, rather than directly from the Susquehanna River, these withdrawers were included because of their wells' proximity to the river.

Table 6-1 Downstream water withdrawals

Facility/Location	Type	Design flow (mgd)	Distance downstream of the BBNPP intake (mi)	Expected Impact
PA-American Water Company (serves Berwick and Nescopeck)	Water supply - wells	4.6	6.5	No impact, reserves the right to reassess in the future (e-mail R. Schnitzler, 5/15/2011)
Mifflin Township Water Authority	Water supply - wells[16]	0.223 (typ.) 0.432 (max.)	11	No impact (e-mail P. Hartzell, 5/11/2011)
Catawissa Borough Municipal Authority	Water supply - wells[17]	0.12 (avg.) 0.2 (max.)	22	None expected (telecon C. Bachman, 5/3/11)
Danville Municipal Authority	Water supply	2 (avg.)	30	Potential impact on treatability (including chemical usage) of Authority's raw water and quantity of treatment residuals requiring disposal (e-mail D. Marks, Gannett-Fleming, 5/11/2011)
Cherokee Pharmaceuticals, Riverside	Process water supply	34.392	31.2	Could potentially impact the facility, but still under evaluation (e-mail J. Brenchley, 5/9/2011)

The list in Table 6-2 of downstream sanitary and industrial wastewater dischargers to the Susquehanna is based on a USEPA Envirofacts search (last updated in 2006) of all dischargers to the Susquehanna River having greater than 0.1 mgd flow. This flow cutoff was based on our assumption that flows smaller than this would not be impacted by the 43 cfs maximum BBNPP consumptive use, given that an 0.1 mgd discharge is less than 0.1% of the 7Q10 for the Susquehanna River at the point of discharge.

[16] within ¼ mi of river

[17] wells ½ mi upstream along Catawissa Creek; the surface intake (not usually used) on Catawissa Creek

Table 6-2 Downstream treated wastewater dischargers

Facility/Location	Type	Design flow (mgd)	Distance downstream of the SSES intake (mi)	Expected Impact
Nescopeck Borough	POTW	0.11	6.5	None (e-mail from J. Hendricks, Herbert, Rowland, & Grubic, Inc. for Nescopeck Borough, 4/28/2011)
Berwick Area Joint Sewer Authority	POTW	3.7	6.5	Little to no effect on BAJSA's effluent limits and their ability to meet them (e-mail and letter from E. Threet, Herbert Rowland & Grubic Inc., 5/16/2011)
Bloomsburg Municipal Authority	POTW	4.29	18	Based upon a check of PENTOX and a discussion with PADEP, no significant impact on Bloomsburg's WWTP discharge is anticipated (voice mail T. Jones, Gannett-Fleming, 5/22/2011)
Danville Municipal Authority	POTW	3.62	30	Authority suggests that PADEP be asked to rerun its models for effluent limit development based upon reduced Q7,10 (e-mail R. Jager, Gannett-Fleming, 5/10/2011)
Wise Foods, Berwick	Indust.	0.59	7.3	NPDES permit undergoing renewal at present; therefore, comment at this time would be premature. Wise Foods reserves the right to comment in the future on this matter (e-mail R. Wolfe, 5/6/2011).
DelMonte Corp., Bloomsburg	Indust.	0.671	12.9	No response after multiple calls
Cherokee Pharmaceuticals, Riverside	Indust.	12.2	31.7	Could potentially impact the facility, but still under evaluation (e-mail J. Brenchley, 5/9/2011)

6.2. Evaluation of Potential Impacts

Downstream Water Withdrawals

As provided in Table 6-1 three downstream withdrawal facilities (PA American Water, Mifflin Township Water Authority, and Catawissa Borough Municipal Authority) indicated no expected impact on their well water withdrawals as a result of the project consumptive water use. The Danville Municipal Authority indicated a potential impact on raw water treatability and the quantity of treatment residuals requiring disposal. Cherokee Pharmaceuticals, Riverside indicated a general concern for potential impacts.

Generally, the BBNPP consumptive use will only result in a very small change in water level (less than 0.5 inch at the BBNPP intake) which is unlikely to have any impact on either the

Danville Municipal Authority or Cherokee Pharmaceuticals' ability to withdraw water from the river 30 miles downstream from BBNPP. Small water level changes are also unlikely to have any impacts on nearby municipal well water levels, confirming the no expected impact response from PA American Water, Mifflin Township and Catawissa Borough.

In terms of raw water treatability the discharge from BBNPP is typically about 1% of the average river flow increasing to about 5% at 7Q10 conditions. The BBNPP discharge must meet PADEP NPDES permit discharge standards. In addition, this ratio illustrates only minimal potential changes to stream water quality (T, DO, pH) in areas immediately below the BBNPP discharge. These small changes are unlikely to even be detectable at the location of these downstream facilities. As a result, no treatability impacts would be expected.

Downstream Treated Wastewater Discharges

The principal issue with respect to regulated downstream wastewater discharges is the owner's ability to meet effluent limits under an assumption that the BBNPP consumptive use will alter (reduce) the rate of flow used by PADEP for calculating the discharge limits that treatment standards imposed in their NPDES permits are based on.

Three of the seven wastewater treatment dischargers as listed in

Table 6-2 indicated little or no expected impact due to the proposed BBNPP consumptive water use. One discharger did not respond to phone inquiries, while three dischargers indicated either that they could be potentially impacted or that additional analysis is required.

Normally, when effluent limitations in an NPDES discharge permit are set by the PADEP, the PADEP performs modeling using PENTOXSD[18]. PENTOXSD uses a mass-balance water quality analysis model that includes consideration for mixing, first-order decay and other factors to determine recommended water quality-based effluent limits. The primary purpose of the model is to assist PADEP permit engineers in determining appropriate NPDES permit limits for toxics and certain other substances. For each parameter evaluated, the program:

- Computes a Wasteload Allocation (WLA) on a single discharge basis (i.e., without the consideration of multiple source interactions) for each applicable criterion.
- Determines a recommended maximum water quality-based effluent limitation (WQBEL) for each parameter.
- Compares the recommended WQBEL with the entered discharge concentration to determine which is more stringent.
- Recommends average monthly and maximum daily effluent limitations.

PENTOXSD uses two different design stream flows to compute the Wasteload Allocations (WLAs). They are the 7Q10 and Qh (harmonic mean flow). The 7Q10 stream flow is specified in the Water Quality Standards, Pa. Code Title 25 Section 96.4(g) Table 1. This stream flow is used in the application of three of the four water quality criteria:

- Acute Fish Criteria (AFC), also referred to as Criteria Maximum Concentration
- Chronic Fish Criteria (CFC), also referred to as Criteria Continuous Concentration
- Threshold Human Health (THH)

The Qh flow is specified by regulation in the Water Quality Standards, Pa. Code Title 25 Section 96.4(g) Table 1. Section 93.8a(e) specifies that "*...for carcinogens, the design conditions result in a lifetime – 70 years – average exposure...*" DEP has determined that Qh meets this requirement.

Consumptive water use at BBNPP is less than one percent of harmonic mean flow and is unlikely to impact any effluent limitations for carcinogens. Flow analyses separately performed by PPL[19] suggest that existing operation of the Cowanesque and Whitney Point Reservoirs during low flow periods (flows equal to or less than 7Q10) would be expected to offset any flow reduction associated with the BBNPP consumptive use. These reservoir operations are not currently reflected in the historical flow record used in this analysis and as a result are not

[18] Technical Reference Guide (TRG) PENTOXSD for Windows PA Single Discharge Wasteload Allocation Program for Toxics, Version 2.0, Commonwealth of Pennsylvania, Department of Environmental Protection.

[19] "Modification And Use Of the Oasis Model to Evaluate Sources of Flow Augmentation For PPL Consumptive Water Use Mitigation in the Susquehanna River Basin, Document JCP-BB-1, Rev. 0, March 7, 2012"

reflected in the statistical derivation of the 7Q10 flow or any PENTOXSD modeling that has been performed in setting downstream discharge effluent limitations. In this section of the Susquehanna River down to and including the location of the

Table 6-2 listed treated wastewater discharges, these reservoir operations result in enhanced streamflow conditions during low flow periods that appear to effectively offset any potential flow reductions due to BBNPP consumptive use. As a result, no net change to the statistically derived 7Q10 is expected, and no impacts to downstream effluent limitations would be expected to occur once these flows enhancements are accounted for. Since the 7Q10 will be maintained there is no need to recalculate effluent limitations with PENTOXSD.

6.3. Conclusions

One large downstream water user expressed concern about consumptive use impact on its activities; several downstream dischargers and one water user expressed interest in further evaluation of quantitative impacts, but none voiced immediate objections. One large discharger anticipated little to no effect; two large dischargers anticipated no significant impact after running models and/or consulting with PADEP. The smaller entities that responded do not anticipate any impacts from the proposed consumptive use, although one smaller discharger reserves the right of future comment. Separate analysis suggests that a BBNPP consumptive use will not alter water chemistry at any downstream withdrawal or discharge point and is therefore unlikely to have any impact on water treatability. When the BBNPP consumptive water use is considered in combination with existing flow enhancements in this section of the river due to operation of the Cowanesque and Whitney Point reservoirs, no impact on downstream effluent limitations would be expected.

7. STUDY CONCLUSIONS

Potential effects of the requested level of the BBNPP consumptive water use were investigated using the procedures and methods identified in the Study Plan. These procedures and methods relied as much as possible on field programs in which data directly useful in addressing the study questions were obtained. Analysis of the data was supplemented with calculations and models as appropriate.

This study benefited from the opportunity to measure the characteristics and behavior of the Susquehanna River over the range of flows that occurred in 2010 including a period of sustained low flows.

For all five study questions, either minimal or no impacts due to 43 cfs of BBNPP consumptive water use were found. This result is largely due to the small fraction of the 7Q10 that consumptive water use represents (5%) and the consequent small reduction in water surface elevation (<0.5 in.) that is expected to occur.

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