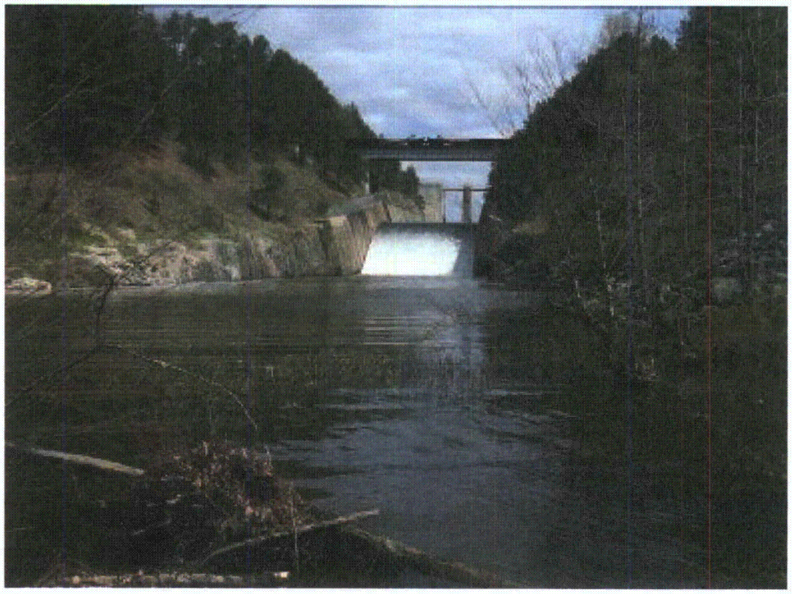
HARRIS ADVANCED REACTOR PROJECT

INSTREAM FLOW STUDY REPORT



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December 1, 2011

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Section 1
Introduction and Study Background

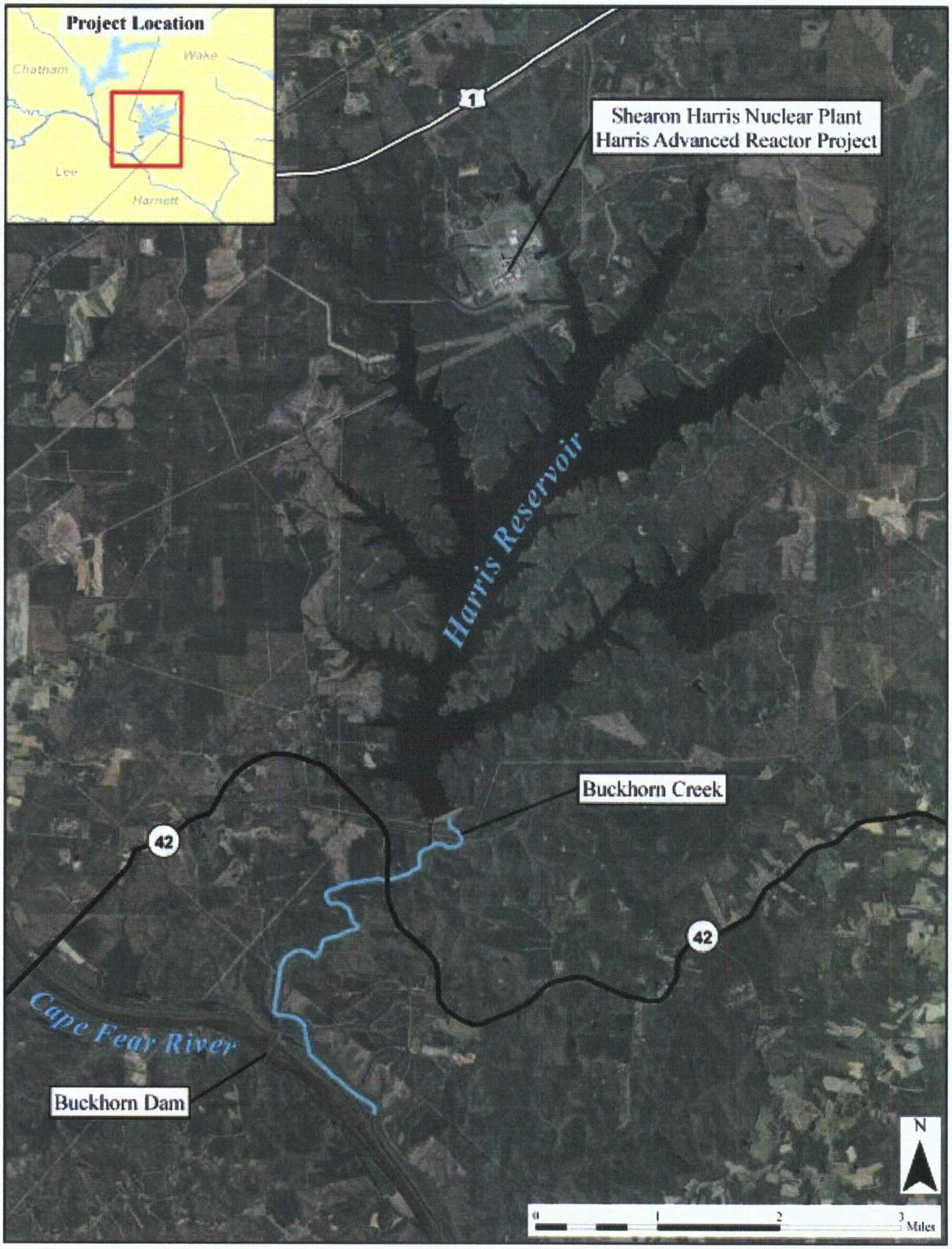
1.1 Introduction

The purpose of this report is to document the methodology, field data collection, and results of an instream flow study that was conducted for the 4.8-mile long section of Buckhorn Creek between Harris Dam and the Cape Fear River and a 2-mile reach of the Cape Fear River immediately downstream from Buckhorn Dam. This study was conducted to evaluate tradeoffs in habitat gains and losses in Buckhorn Creek through the introduction of regular releases from Harris Reservoir and potential habitat gains and losses in the Cape Fear River resulting from the transfer of water immediately upstream from Buckhorn Dam to Harris Reservoir to support reservoir operations and the releases to Buckhorn Creek.

1.2 Study Background

The proposed Harris Advanced Reactor (HAR Project) Units 2 and 3 will be co-located with the existing Shearon Harris Nuclear Plant Unit 1, currently owned by Progress Energy Carolinas, Inc. (PEC). The Project is the subject of a Combined Operating License (COL) Application submitted to the Nuclear Regulatory Commission (NRC) in February 2008. The HAR Project site will be located northwest of the existing facility and on the same peninsula that extends into Harris Reservoir (Figure 1), in Wake and Chatham counties of North Carolina, and within the Cape Fear River Basin.

FIGURE 1
HAR PROJECT LOCATION MAP



Harris Reservoir was created by impounding Buckhorn Creek, a tributary to the Cape Fear River (Figure 1). Construction of Harris Dam was completed in December 1980 and the existing Harris Nuclear Plant (HNP) was first operated in 1987. The primary purpose of Harris Reservoir is to provide cooling tower makeup water for the HNP. Harris Reservoir is also used for public recreation, primarily fishing and boating activities. The current full-pool elevation in Harris Reservoir is 220 feet mean sea level (ft msl), which is controlled by a reinforced concrete overflow spillway located adjacent to the main earthen dam. Harris Reservoir has a surface area of approximately 3,610 acres, a reservoir storage volume of approximately 73,000 acre-ft, a maximum depth of 59 feet (ft), and a mean depth of approximately 17.4 ft (Progress Energy 2008).

Operation of the proposed HAR Units 2 and 3 will require an additional 134 cubic ft per second (cfs) of makeup water from Harris Reservoir (Progress Energy 2008). As a result, the existing concrete overflow spillway elevation will be raised 20 ft to create a future full-pool elevation of 240 ft msl. With this increase in full-pool elevation, Harris Reservoir will have a surface area of approximately 7,616 acres and a reservoir volume of approximately 177,563 acre-ft (Progress Energy 2008). To provide makeup water to the reservoir, a new intake structure and pump-house will be located along the north bank of the Cape Fear River immediately upstream from Buckhorn Dam. Water will be withdrawn from the Cape Fear River via the new intake structure and pumped through a proposed 2.6-mile pipeline to a new outfall structure on Harris Reservoir.

PEC previously proposed a maximum withdrawal rate from the Cape Fear River above Buckhorn Dam of 137 cfs (Progress Energy 2008). The actual rate at which water is withdrawn will be based on a set of operational rules that will be developed to minimize impacts on downstream flow needs and hydrologic conditions. The results from this instream flow study will be used to help determine the withdrawal rate from the Cape Fear River.

The streams and rivers in the Harris Reservoir drainage area have North Carolina water quality designations of Class B and Class C. Class B applies to waters used for primary recreation on an organized basis. Class C waters are defined as those supporting aquatic life propagation and maintenance of biological integrity, wildlife, secondary recreation, and agriculture. The B and C classifications allow any type of National Pollutant Discharge Elimination System (NPDES) facility as long as the discharge will not violate water quality standards. Buckhorn Creek has a water quality designation of Class C between Harris Dam and the Cape Fear River. PEC's original approach, prior to conducting detailed habitat studies, was to maintain a minimum continuous flow of approximately 20 cfs in the Buckhorn Creek reach below Harris Dam (Progress Energy 2008). During periods of the year where more water is available, PEC proposed to release flows of 20 cfs or higher in Buckhorn Creek. The instream flow study evaluated this proposal along with many others to help revise and refine this initial instream flow recommendation.

During the HAR Project NRC consultation process, the North Carolina Department of Environment and Natural Resources (NCDENR) – Division of Water Resources (DWR), North Carolina Wildlife Resources Commission (NCWRC), and U.S. Army Corps of Engineers (COE) requested that an instream flow study be conducted to evaluate the impacts of the withdrawal of makeup water from the Cape Fear River. These agencies also requested a study to evaluate minimum instream flow requirements for Buckhorn Creek between Harris Dam and the Cape Fear River.

As a result, PEC assembled an instream flow study team to review and advise the overall study process. This included determining the areas to be studied and recommending appropriate methodologies for evaluating effects associated with withdrawing supplemental makeup cooling water from the Cape Fear River and determining an appropriate flow regime in Buckhorn Creek. This study team is comprised of individuals representing PEC and its consultants (HDR and Hydrologics, Inc.), as well as state and federal resource and regulatory agencies including the NCDENR, NCWRC, U.S. Fish and Wildlife Service (USFWS), COE, and NRC. A list of participants in the instream flow study process is provided in Table 1.

Planning for the instream flow study began in March 2009 and the first study team meeting was held at the Harris Nuclear Plant Visitor's Center on April 30, 2009. The first draft of the instream flow study plan was provided to the study team for comment on June 17, 2009. A second study team meeting and site visit to Buckhorn Creek was held on July 9, 2009, to select transects for the Buckhorn Creek study reach. A study team site visit to the Cape Fear River occurred on August 7, 2009, for the purposes of refining the overall extent of the study area and to determine study methodologies. The final study plan was provided to the study team in September 2009. Key components of the study plan have been incorporated into this report.

TABLE 1
INSTREAM FLOW STUDY TEAM MEMBERS

Name	Organization
Core agency participants	
Mr. Jim Mead	NCDENR-DWR
Mr. Vann Stancil	NCWRC
Mr. Chris Goudreau	NCWRC
Mr. Mark Bowers	USFWS
Mr. Monte Matthews	COE – Wilmington District
Other agency participants	
Mr. John Ellis	USFWS
Ms. Nancy Kuntzleman	NRC
Mr. Daniel Barnhurst	NRC
Mr. Fred Tarver	NCDENR-DWR
Consulting Team	
Mr. Ty Ziegler	HDR Engineering, Inc.
Mr. Jeff Smith	HDR Engineering, Inc.
Mr. Jarvis Caldwell	HDR Engineering, Inc.
Mr. Matt McKinney	HDR Engineering, Inc.
Mr. Brian McCrodden	Hydrologics, Inc.
Mr. Steve Nebiker	Hydrologics, Inc.
Progress Energy representatives	
Ms. Linda Hickok	Progress Energy Carolinas
Mr. Tom Thompson	Progress Energy Carolinas
Mr. Arun Kapur	Progress Energy Carolinas
Mr. Paul Snead	Progress Energy Carolinas
Mr. Jason Brown	Progress Energy Carolinas

In conjunction with this instream flow study, the study team also evaluated operating scenarios for the water withdrawals from the Cape Fear River using the Cape Fear River Basin Hydrologic Model (CFRBHM). Hydrologics, Inc. performed the CFRBHM modeling as a part of the overall study process. Flow scenarios were created based on the instream flow modeling and they were used as input data to the CFRBHM model which was in turn used to model effects on downstream users resulting from withdrawals from the Cape Fear River and water releases from Harris Reservoir into Buckhorn creek. The model was also used to evaluate reservoir elevations resulting from the various pumping scenarios and flow release regimes.

Section 2

Study Objectives and Study Area

2.1 Study Objectives

There are two primary objectives for this study. The first objective is to determine instream aquatic habitat flow needs for Buckhorn Creek between Harris Dam and the Cape Fear River. The second objective is to determine effects that Project operations may have on the aquatic habitat and recreation in the Cape Fear River study reach resulting from the proposed withdrawal of makeup water immediately upstream from Buckhorn Dam. These two study objectives are linked because minimum flow releases into Buckhorn Creek will result in removal of water from Harris Reservoir. This water volume will need to be replaced in part by pumping water from the Cape Fear River to Harris Reservoir. In addition, results of this study were used to provide hydrologic inputs to the CFRBHM.

2.2 Study Area

The study area for Buckhorn Creek extends from the confluence with the Cape Fear River (river mile [RM] 0.0) upstream to Harris Dam (RM 4.8) (Figure 2).

The study area for the Cape Fear River extends from just below the confluence with Buckhorn Creek (RM 190.3) upstream to Buckhorn Dam (RM 192.3) (Figure 3). This 2-mile section of the Cape Fear River contains numerous side channels (along both the north and south banks) that are sensitive to changes in river flow rates and depths. On August 7, 2009, the instream flow study team participated in a field reconnaissance trip to the Cape Fear River study area. During this trip, four study areas along three side channels in the 2-mile study area were selected for purposes of conducting the instream flow study. These four areas (Reach 0, Reach 1, Reach 2, and Reach 3) are outlined in Figure 3.

FIGURE 2
STUDY AREA FOR BUCKHORN CREEK

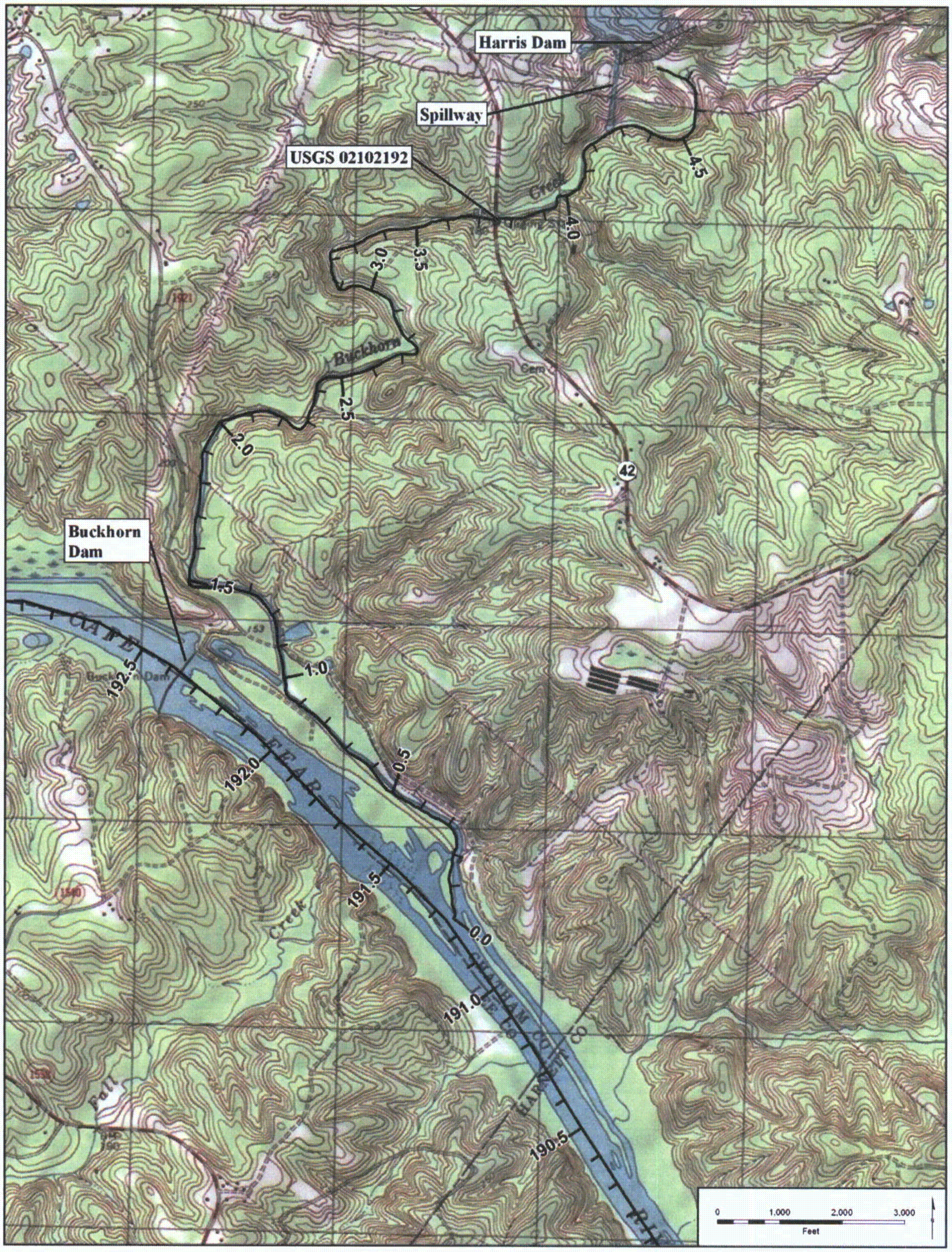
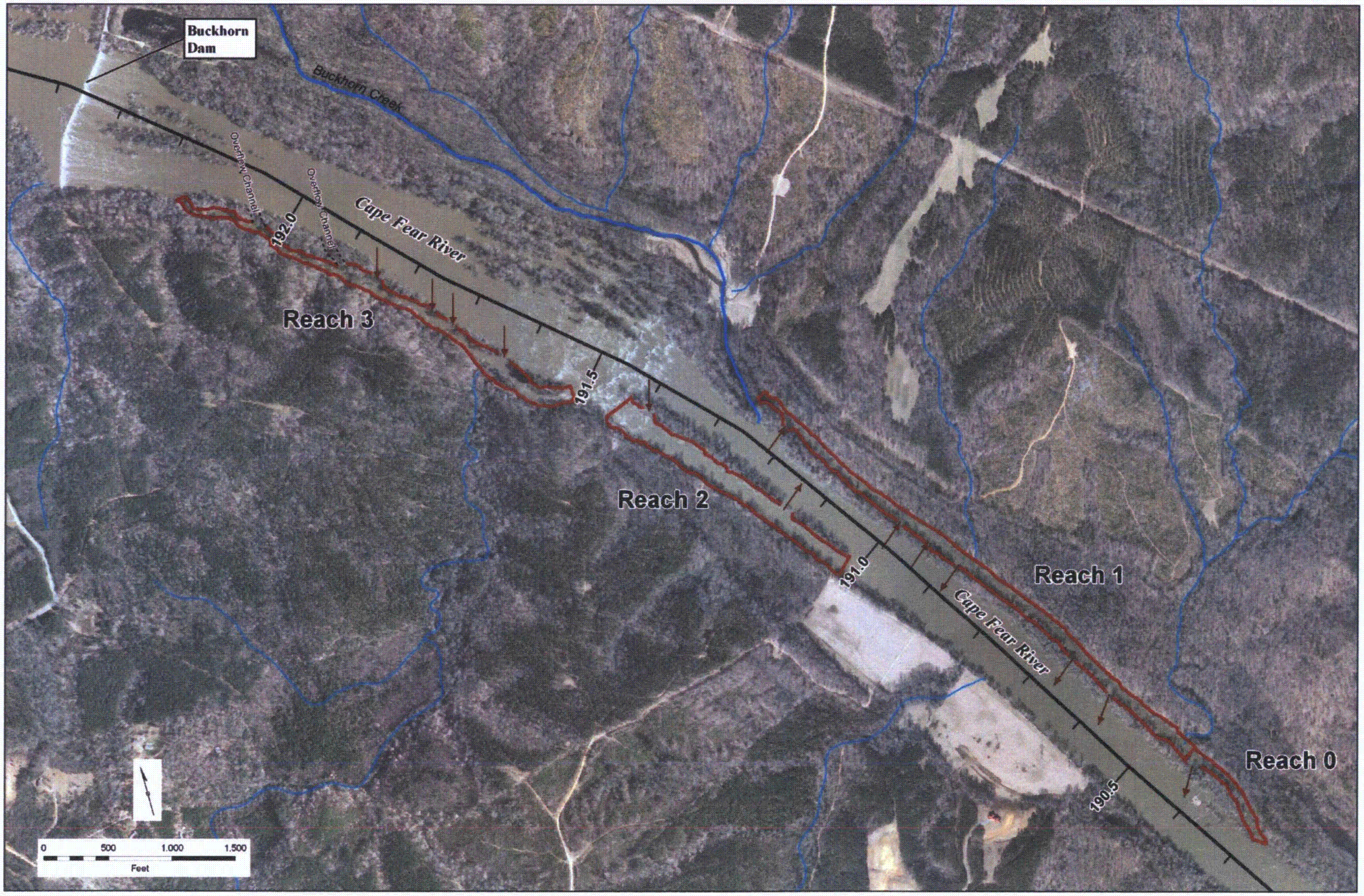


FIGURE 3
STUDY AREAS FOR THE CAPE FEAR RIVER



Section 3
Study Assumptions

PEC evaluated operating scenarios for the water withdrawals using the CFRBHM. When Cape Fear River flows are higher, it is assumed that larger volumes of water could be pumped, as needed, to maintain Harris Reservoir elevations. Conversely, when Cape Fear River flows are lower, less (or no) water would be pumped from the Cape Fear River. For purposes of this instream flow study, PEC anticipated that future water withdrawals from the Cape Fear River to support station operations would likely involve a multi-level or tiered approach based on Cape Fear River flow levels and Harris Reservoir elevations.

Jordan Reservoir is located on the Haw River, approximately 4.2 miles upstream from the confluence with the Deep River. The Cape Fear River begins at the confluence of the Deep and Haw Rivers, approximately 5.9 miles upstream from Buckhorn Dam. The Wilmington District of the COE operates Jordan Reservoir for regional flood control, recreation, and water supply needs. The normal year-round operating pool level for Jordan Reservoir is 216 ft msl. During low flow periods, the COE may declare drought conditions and enter into a Drought Contingency Plan (DCP) to help maintain Jordan Reservoir elevations and support downstream water supply and water quality needs.

The conservation pool level for Jordan Reservoir is 202 ft msl. There is 140,400 acre-ft of water stored in the conservation pool of Jordan Reservoir (i.e., between elevations 216 ft msl and 202 ft msl) for release during critically dry periods. A required minimum instantaneous flow of 40 cfs (7Q10 flow) is always maintained immediately below the dam except during brief periods such as periodic maintenance and inspections. However, a minimum service gate opening of 4 to 6 inches is typically maintained, which produces a flow of about 130 cfs to 200 cfs. Releases are made from the conservation pool storage as necessary to maintain a minimum flow of 600 cfs (+/- 50 cfs) as measured at the Cape Fear River near Lillington, North Carolina U.S. Geological Survey (USGS) streamflow gaging station (gage number 02102500) (COE 1992). This is to support municipal water supply needs for the city of Fayetteville, North Carolina, located approximately 51.6 miles downstream from Buckhorn Dam. Periodically, the flow at Lillington may drop below 600 cfs because of variations in river flows induced by small hydroelectric plants located on the Deep River (COE 1992).

A weekly update of the remaining water quality storage is required during extended drought conditions. The State of North Carolina is notified as the usable storage is depleted, in accordance with the DCP. This action identifies potential concerns with the remaining storage and allows conservation efforts to be established to minimize the impacts of drought operation. If the conservation pool is completely depleted of usable storage, flow releases from Jordan Reservoir are reduced to match inflow to the reservoir (minus evaporative and other losses) (COE 1992). In early 2011, the COE updated the DCP for Jordan Reservoir which resulted in modifications to the operating protocol during extended drought or low flow periods.

PEC does not intend for the HAR Project to impact the COE's management of Jordan Reservoir and the COE's obligation to maintain a minimum flow (currently 600 cfs [+/- 50 cfs]) at the Lillington USGS flow gauging station. Under normal operations, PEC plans to withdraw water from the Cape Fear River in accordance with its proposed pumping regime to maintain Harris Reservoir levels, support station operations, and provide releases to Buckhorn Creek. When minimum flows in the Cape Fear River are not present to meet the thresholds in the proposed pumping regime, PEC will reduce or cease pumping until those minimum river flows are again present. Under those conditions, station cooling water makeup needs would be met by using the water stored in Harris Reservoir.

The CFRBHM has been designed to evaluate the impact that discharges or releases into, and withdrawals from, the Cape Fear River will have on downstream water users and needs. Anticipated future water withdrawals to support HAR Project operations, maintain Harris Reservoir levels, and support flows in Buckhorn Creek were built into the CFRBHM. As stated above, the flow recommendations from this study were incorporated into the CFRBHM and Hydrologics, Inc. performed the modeling to assess their incremental impact on downstream water users under various hydrologic conditions. The recent modifications to the Jordan Reservoir DCP were incorporated into the CFRBHM model and the resulting simulated hydrology data sets used in this study.

Section 4
Study Methodology

4.1 Modeling Approach

In selecting a methodology to evaluate aquatic impacts resulting from HAR Project operations, PEC's goal was to develop a technical basis for systematically evaluating and balancing the needs and priorities of the various flow-related resources. To address the flow-related variables encompassed within the study objectives, PEC utilized the Physical Habitat Simulation (PHABSIM) Methodology developed by the USFWS. PHABSIM is a one-dimensional (1-D) modeling tool that simulates the relationship between river flow and aquatic habitat and is commonly used to conduct instream flow studies. Using this modeling tool, aquatic habitat is determined based on the physical parameters of depth, velocity, channel substrate, and cover type. PHABSIM is especially helpful when evaluating the effect of different flow release regimes from dams on downstream aquatic habitat. The PHABSIM study was conducted under the overall framework of the Instream Flow Incremental Methodology (IFIM) process (Bovee et al. 1998) to determine the incremental relationship between river flow and a standard index of habitat suitability for specific life stages of selected resident and migratory species and/or community guilds, as determined through study scoping and literature review.

PHABSIM models were developed for the 4.8-mile long Buckhorn Creek study reach and also for the three side channels in the 2-mile long Cape Fear River study reach. Individual models were developed for the three Cape Fear River side channels and results for each flow regime were analyzed and combined into an overall single reach.

For the Cape Fear River, a fourth study site was selected at the bottom end of the most downstream side channel (Reach 0). A gravel/cobble bar has formed at the mouth of a tributary creek approximately 1,000 ft above the downstream end of this side channel. At lower Cape Fear River flow rates, this obstruction limits or prevents flow from entering this 1,000 ft reach. Instead of a PHABSIM study, a methodology was selected to evaluate changes in wetted perimeter at different Cape Fear River flow rates. The objective of this study was to determine what flow rate was needed in the Cape Fear River to overtop the gravel/cobble bar and provide flow into this lower 1,000 ft reach.

4.2 Study Design and Planning

Before the fieldwork portion of the instream flow study was initiated, literature review and planning activities took place including:

- Selection of study sites and habitat mapping,
- Selection of species to model and habitat suitability indices,
- Selection of target flows for field data collection, and
- Consideration of other instream flow needs/uses.

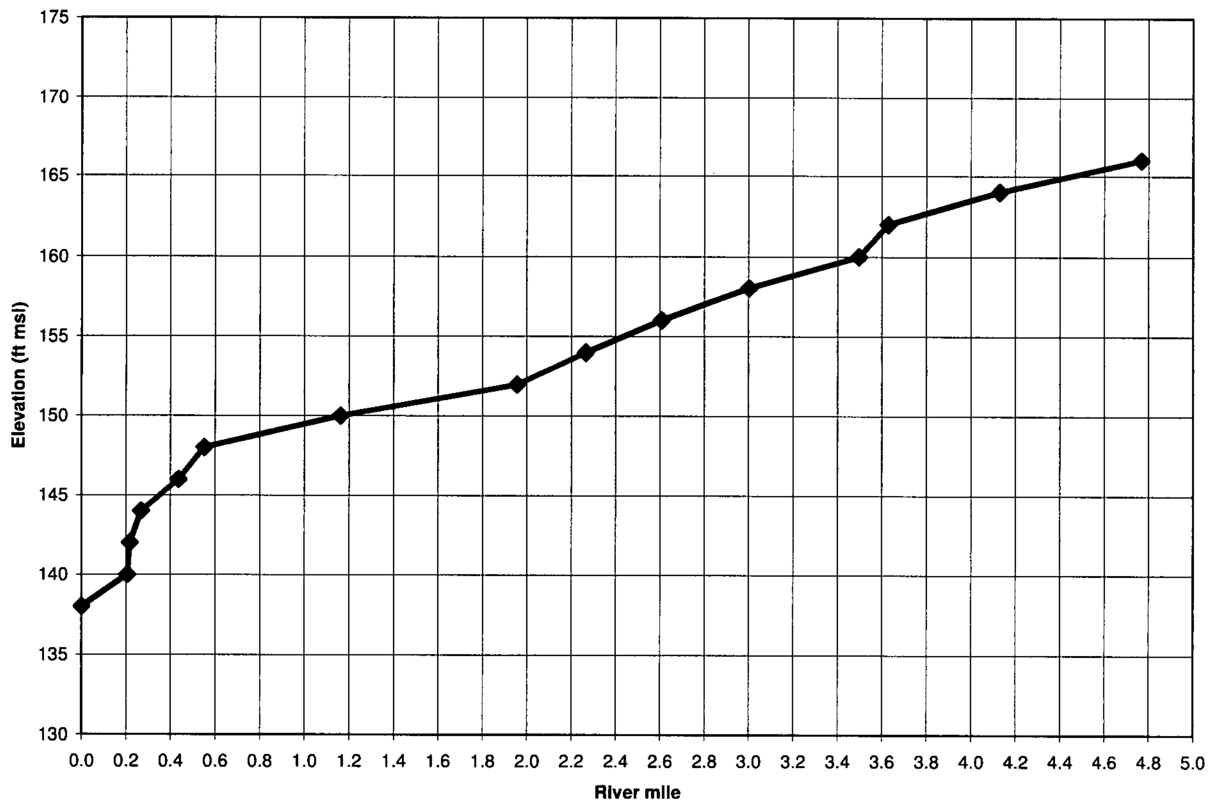
4.2.1 Habitat Mapping and Transect Selection

4.2.1.1 Buckhorn Creek

For Buckhorn Creek, selection of representative study sites occurred after a field reconnaissance trip was conducted to map channel habitat characteristics (i.e., habitat types) between Harris Dam and the confluence with the Cape Fear River. PEC conducted this reconnaissance trip on May 20 and 21, 2009, by walking/wading through the entire 4.8-mile reach from the mouth of Buckhorn Creek upstream to Harris Dam.

Channel habitat characteristics are often influenced by the longitudinal profile (i.e., slope) of the river reach. The longitudinal profile of Buckhorn Creek between the confluence with the Cape Fear River and Harris Dam is shown in Figure 4.

FIGURE 4
LONGITUDINAL PROFILE OF BUCKHORN CREEK BETWEEN THE CAPE FEAR RIVER (RM 0.0) AND HARRIS DAM (RM 4.8)



To clearly see the creek bottom, and for safety considerations, the habitat mapping effort was conducted during low flow conditions (1–2 cfs) where most of the channel bottom was visible. During the reconnaissance trip, aquatic habitat types were continuously recorded using a handheld Global Positioning System (GPS) unit. The habitat types were separated into pools (shallow and deep); runs (shallow and deep); glides (shallow and deep); and riffles. Habitat segments that were braided (i.e., multiple channels or small island complexes) were also noted. In addition to habitat types, segment lengths, widths, maximum depths, and dominant substrate types were also recorded. Substrate was measured visually and/or by tactile inspection as almost all of the depths were wadeable. Substrate size classification was in accordance with the coding system described in Table 2. This classification system has previously been approved by NCDENR for other instream flow studies conducted in North Carolina (Progress Energy 2006 and Duke Power 2005).

TABLE 2
SUBSTRATE SIZE CLASSIFICATION AND CODES

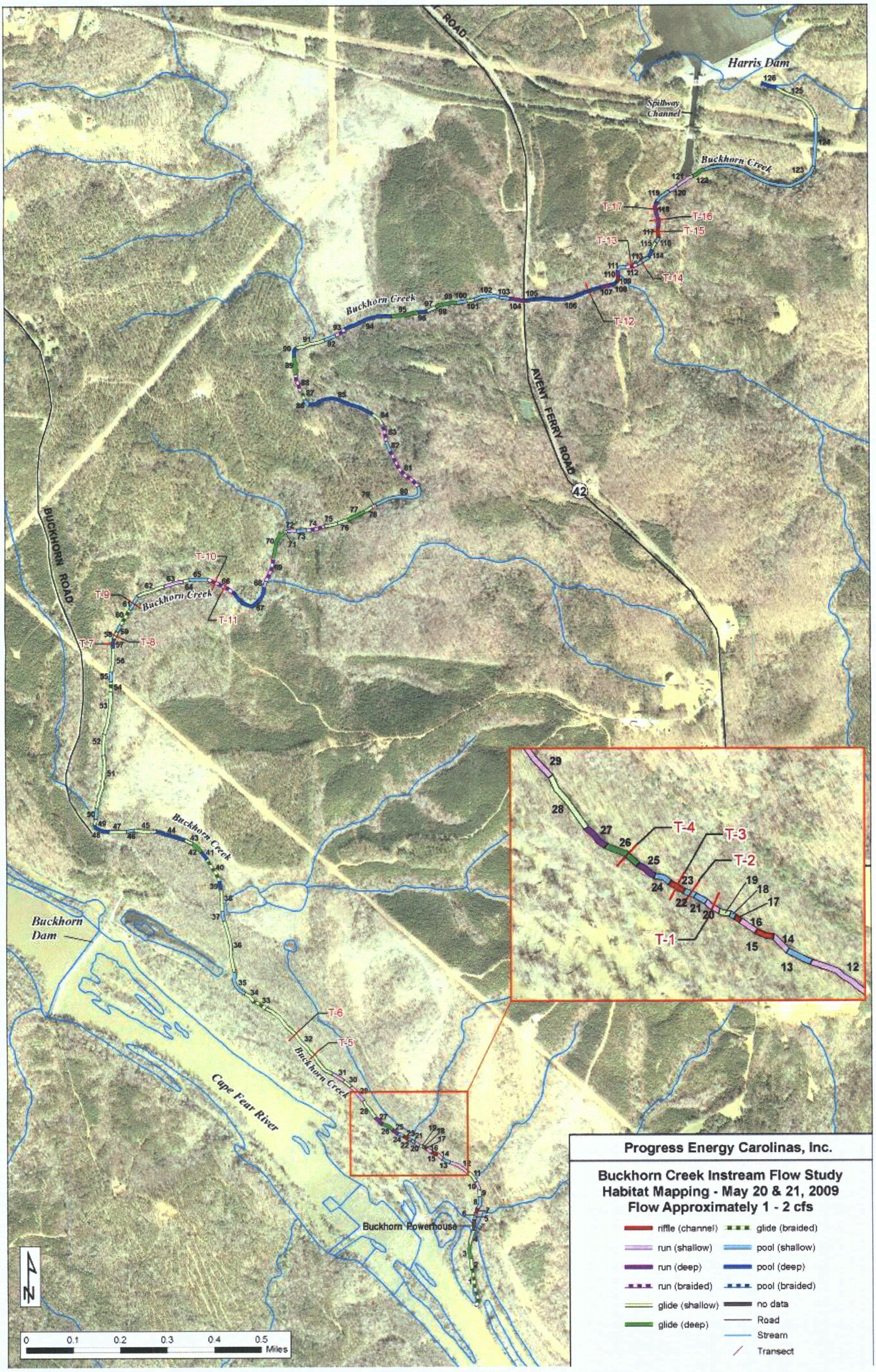
Code	Abbreviation	Description	Inches
0	ORG	Organic Detritus	N/A
1	SI	Silt, Clay	<0.1
2	SA	Sand	<0.1
3	SGR	Small Gravel	0.1–0.5
4	MGR	Medium Gravel	0.5–1.5
5	LGR	Large Gravel	1.5–3.0
6	SCOB	Small Cobble	3.0–6.0
7	LCOB	Large Cobble	6.0–12.0
8	SBOL	Small Boulder	12.0–36.0
9	LBOL	Large Boulder	>36.0
10	SBR	Smooth Bedrock	N/A
11	IBR	Irregular Bedrock	N/A

A summary of the data collected during the habitat mapping field trip is provided in Table 3. This data was also uploaded to Geographic Information System (GIS) software to create a map (Figure 5) showing the location of the different habitat types along Buckhorn Creek. The location of each transect is also shown in Figure 4-2 (labeled as T-1 through T-17).

TABLE 3
BUCKHORN CREEK HABITAT MAPPING FIELD DATA

Segment ID	Habitat Type	Width (ft)	Max Depth (ft)	Length (ft)	Substrate	Notes	Begin (mi)	End (mi)
1	glide	37.0	1.50	430	SA	braided; BR/SCOB subdom	0.000	0.082
2	glide	37.0	2.00	120	SBR		0.082	0.104
3	glide	36.0	3.00	157	SA		0.104	0.134
4	glide	32.0	1.50	166	LGR		0.134	0.165
--	N/A	N/A	N/A	116	N/A	Buckhorn Powerhouse	0.165	0.187
5	pool	21.0	1.50	56	SA		0.187	0.198
6	run	21.0	1.00	18	SA		0.198	0.201
7	riffle	20.0	1.00	59	LCOB		0.201	0.212
8	pool	24.0	2.50	140	SBOL	LBOL subdominant	0.212	0.239
9	glide	26.0	2.00	73	SA		0.239	0.253
10	run	23.0	1.50	100	LBOL		0.253	0.272
11	glide	17.0	2.00	134	SA		0.272	0.297
12	run	19.0	1.50	241	SBOL		0.297	0.343
13	riffle	30.0	1.00	97	LBOL	BR subdominant	0.360	0.378
14	run	30.0	1.00	75	SBOL		0.378	0.393
15	riffle	32.0	1.00	70	SBR		0.393	0.406
16	run	43.0	1.00	69	SBOL		0.406	0.419
17	riffle	41.0	2.00	26	SBR		0.419	0.424
18	pool	30.0	1.50	21	SBR		0.424	0.428
19	glide	28.0	2.00	42	LBOL		0.428	0.436
20	run	31.0	1.00	61	SBR		0.436	0.447
21	pool	32.0	2.00	47	SBR		0.447	0.456
22	pool	32.0	2.50	43	SBOL		0.456	0.464
23	riffle	35.0	1.00	63	LBOL		0.464	0.476
24	pool	36.0	2.50	64	SA		0.476	0.488
25	run	35.0	2.00	77	IBR		0.488	0.503
26	glide	29.0	2.50	137	IBR		0.503	0.529
27	run	30.0	2.00	103	IBR		0.529	0.549
28	glide	30.0	2.00	232	IBR	SA overlaying	0.549	0.593
29	run	29.0	1.50	214	SBOL	SA subdominant	0.593	0.633
30	glide	39.0	1.50	111	SA	chub redd	0.633	0.654
31	run	39.0	1.50	148	IBR	SA overlying; woody debris	0.654	0.682
32	glide	29.0	1.50	1,065	SA		0.682	0.884
33	glide	51.0	2.50	158	SA	braided	0.884	0.914
34	glide	35.0	2.00	131	SA		0.914	0.939
35	pool	29.0	3.50	291	SA		0.939	0.994
36	glide	37.0	1.50	592	SA		0.994	1.106
37	pool	40.0	3.50	111	SA	bridge ruins	1.106	1.127
38	glide	47.0	1.50	247	SA	tributary	1.127	1.174
39	pool	32.0	4.50	96	SA		1.174	1.192
40	glide	47.0	1.00	288	SA	braided	1.192	1.246
41	pool	42.0	4.00	101	SA		1.246	1.266
42	glide	49.0	2.50	132	SA	SGR subdominant	1.266	1.291
43	glide	42.0	1.50	106	SA		1.291	1.311
44	pool	42.0	6.00	331	SA		1.311	1.373
45	glide	28.0	2.00	249	SA		1.373	1.421
46	pool	29.0	3.50	87	SA	BR subdominant	1.421	1.437
47	glide	32.0	2.00	195	SA		1.437	1.474
48	pool	24.0	4.00	188	SBR	SA overlaying; large darters	1.474	1.510
49	glide	24.0	1.00	64	SA		1.510	1.522
50	pool	40.0	3.00	125	SA	tributary	1.522	1.545
51	glide	34.0	2.00	607	SA	SGR subdominant; juvenial mussels	1.545	1.660
52	glide	30.0	1.50	239	SA		1.660	1.706
53	glide	39.0	1.00	488	SA		1.706	1.798
54	glide	35.0	1.00	109	SA	braided	1.798	1.819
55	pool	35.0	3.00	113	SA		1.819	1.840
56	glide	28.0	1.50	272	SA		1.840	1.892
57	pool	32.0	4.50	103	IBR	SA overlaying	1.892	1.911
58	glide	37.0	2.00	88	SA		1.911	1.928
59	pool	28.0	2.50	94	SA		1.928	1.946
60	glide	50.0	2.00	198	SA	braided	3.892	3.929
61	pool	28.0	3.00	179	SA	SGR/BOL subdominant	1.946	1.980
62	glide	35.0	1.50	318	SA	tributary	1.980	2.040
63	run	43.0	0.50	222	SA	SGR subdominant	2.040	2.082
64	glide	35.0	1.00	64	SA		2.082	2.094
65	pool	37.0	3.00	211	SA		2.094	2.134
66	run	37.0	1.50	337	SA	braided	2.134	2.198
67	pool	31.0	4.00	513	SA	large woody debris	2.198	2.295
68	run	28.0	1.00	71	SA		2.295	2.308
69	run	41.0	1.00	280	SA	braided; SGR sub; lg woody debris	2.308	2.361
70	glide	32.0	2.50	315	SA	LBOL subdominant	2.361	2.421
71	pool	40.0	4.00	40	SA	braided; trib; lg woody debris	2.421	2.429
72	run	32.0	0.50	106	SA	SGR subdominant	2.429	2.449
73	pool	34.0	3.00	116	SA		2.449	2.471
74	run	35.0	1.50	205	SA	braided; short runs, pools, glides mixed in	2.471	2.509
75	glide	28.0	2.00	150	SA		2.509	2.538
76	glide	29.0	1.00	121	SA		2.538	2.561
77	glide	24.0	2.50	212	SA	lg woody debris; clay banks/mussels	2.561	2.601
78	glide	18.0	1.00	101	SA		2.601	2.620
79	run	35.0	0.80	50	SA	braided; SGR subdom	2.620	2.629
80	pool	30.0	3.50	605	SA	LBOL subdominant	2.629	2.744
81	run	30.0	1.00	509	SA	braided	2.744	2.840
82	pool	30.0	3.00	132	SA		2.840	2.865
83	run	30.0	1.00	191	SA	braided; SGR subdom	2.865	2.901
84	glide	30.0	1.50	170	SA		2.901	2.934
85	pool	30.0	6.00	766	SA	LBOL subdominant	2.934	3.079
86	pool	24.0	3.00	77	SA		3.079	3.093
87	glide	19.0	1.00	101	SA	braided	3.093	3.112
88	run	32.0	1.50	199	SA	braided	3.112	3.150
89	glide	47.0	3.00	199	SA		3.150	3.188
90	pool	34.0	5.00	110	SA	SA layer on top of bedrock	3.188	3.209
91	glide	37.0	2.00	331	SGR	SA subdominant	3.209	3.271
92	pool	34.0	3.00	135	SA		3.271	3.297
93	run	50.0	1.50	131	SA	braided; SGR subdom	3.297	3.322
94	pool	34.0	4.00	555	SA	beaver dam influence	3.322	3.427
95	glide	50.0	3.00	304	SA		3.427	3.484
96	pool	36.0	4.50	95	SI		3.484	3.502
97	glide	50.0	1.50	108	SA		3.502	3.523
98	glide	54.0	2.50	90	SA		0.343	0.360
99	glide	47.0	2.50	155	SA		3.523	3.552
100	pool	47.0	3.00	121	SA	large woody debris; downed trees	3.552	3.575
101	glide	53.0	1.50	86	SA		3.575	3.591
102	pool	47.0	4.00	288	SA		3.591	3.646
103	pool	36.0	2.00	119	SA		3.646	3.668
104	run	28.0	3.00	191	SA		3.668	3.705
105	pool	45.0	4.00	95	SA	large woody debris	3.705	3.723
106	pool	45.0	4.00	764	SA	beaver dam influence	3.723	3.867
107	run	28.0	2.00	129	MGR	mussels	3.867	3.892
108	pool	20.0	4.00	68	SGR	ledge pool	3.929	3.942
109	riffle	20.0	0.50	54	LGR	mussels	3.942	3.952
110	run	20.0	2.00	67	LGR	chub redd; mussel habitat	3.952	3.965
111	pool	30.0	2.00	116	MGR		3.965	3.987
112	run	30.0	1.00	134	LGR	braided; trib; mussels	3.987	4.012
113	pool	35.0	2.50	151	SBOL	LBOL / SA subdominant	4.012	4.041
114	pool	40.0	4.00	90	SGR		4.041	4.058
115	glide	35.0	2.00	96	LGR	sunfish nest	4.058	4.076
116	pool	35.0	3.00	62	LGR		4.076	4.088
117	riffle	30.0	1.00	117	LGR	mussels	4.088	4.110
118	run	30.0	2.00	300	SBOL	mussels	4.110	4.167
119	pool	35.0	2.00	185	SBOL		4.167	4.202
120	run	25.0	1.00	114	SCOB	BR subdominant	4.202	4.223
121	run	20.0	1.00	209	LGR	mussels; emergent vegetation	4.223	4.263
122	glide	30.0	2.50	149	SBOL		4.263	4.291
123	pool	25.0	2.00	1,373	SA		4.291	4.551
124	pool	20.0	1.50	531	SA	culvert under railroad	4.551	4.652
125	glide	45.0	1.00	589	SI	mussels	4.652	4.763
126	pool	50.0	5.00	179	SI	backwater to dam	4.763	4.797
				25,330	Total feet			

FIGURE 5
BUCKHORN CREEK HABITAT MAP



The habitat data that was collected was analyzed to determine the habitat weighting factors used in the PHABSIM model. This analysis was based on the habitat type and length of each segment. The different habitat percentages are provided in Table 4.

TABLE 4
BUCKHORN CREEK
SUMMARY OF HABITAT TYPES AND PERCENTAGE BASED ON LENGTH

Habitat Type / Description			Number of Occurrences	Total Length (ft)	Percent (%)	Transect Locations (Habitat Segment #)
Riffle	All	All	7	486	2	23 & 117
Run	Shallow	< 2 ft	13	1,648	7	20 & 118a
	Deep	>= 2 ft	6	867	3	118b
	Braided	All	9	2,035	8	66a, 66b, & 112
Glide	Shallow	< 2.5 ft	31	7,537	30	32a & 58
	Deep	>= 2.5 ft	10	1,849	7	26
	Braided	All	6	1,285	5	32b
Pool	Shallow	< 4 ft	28	5,303	21	22, 61 & 113
	Deep	>= 4 ft	15	4,164	16	57 & 106
	Braided	All	1	40	0	--
Total			126	25,214	100	17

Results of the habitat mapping effort were used to determine the location of representative study sites as well as the types of transects (and number of each) required to represent the different habitat types that are present. Each study site contained a representative and proportional number of individual transects based on the results of the habitat mapping effort. The individual transects were located near good river access points to facilitate efficient field data collection.

The instream flow study team participated in a transect selection and approval process during a site visit to Buckhorn Creek on July 9, 2009. During this visit, three study sites were chosen representing the lower, middle, and upper portions of Buckhorn Creek. A total of 17 transects were identified. Table 4 illustrates how these transects relate to overall habitat percentages and Table 5 demonstrates how the transects are distributed across the three study areas.

TABLE 5
BUCKHORN CREEK TRANSECT LOCATIONS BY STUDY SITE

Study Site	Habitat Type		Transect Locations (Habitat Segment #)
Lower	Riffle		23
	Run	Shallow	20
	Glide	Shallow	32b
		Deep	26
		Braided	32a
	Pool	Shallow	22
Middle	Run	Braided	66a & 66b
	Glide	Shallow	58
	Pool	Shallow	61
		Deep	57
Upper	Riffle		117
	Run	Shallow	118a
		Deep	118b
		Braided	112
	Pool	Shallow	113
		Deep	106
Total			17

4.2.1.2 Cape Fear River

For the Cape Fear River study area, selection of representative study sites occurred after a field trip was conducted to map channel habitat characteristics (i.e., habitat types) on the three side channels identified by the instream flow study team on the August 7, 2009, reconnaissance trip. PEC conducted this habitat mapping and initial transect selection trip on August 25 and 26, 2009, by wading through the entire length of all three side channels.

Similar to the habitat mapping effort in Buckhorn Creek, this habitat mapping effort was conducted during low flow conditions (400–500 cfs) where most of the channel bottom was visible. Also similar to the Buckhorn Creek effort, aquatic habitat types were continuously recorded using a handheld GPS unit. The habitat types were separated into pools (shallow and deep); runs (shallow and deep); glides (shallow and deep); and riffles. The same depth categories that were used to define shallow and deep for the Buckhorn Creek reach (described in Table 3) were used for the Cape Fear River side channel reaches. Habitat segments that were braided (i.e., multiple channels or small island complexes) were also noted. In addition to habitat types, segment lengths, widths, maximum depths, and dominant substrate types were also recorded. Substrate was measured visually and/or by tactile inspection as almost all of the depths were wadeable. Classification was in accordance with the substrate coding system described in Table 2.

A summary of the data collected during the habitat mapping field trip is provided in Table 6. This data was also uploaded to GIS software to create a map (Figure 6) showing the location of the different habitat types along the three side channels. Individual habitat maps for the three side channels are provided in Figures 7, 8, and 9, respectively.

During the first day of the habitat mapping field effort (August 25, 2009), it was discovered that a gravel bar had formed downstream of the mouth of a tributary creek approximately 1,000 ft upstream from the mouth of the most downstream side channel. This gravel bar deflects flow from the side channel out into the main channel and creates a bypass channel at lower Cape Fear River flow conditions. As a result, the area immediately downstream from the gravel bar is dewatered under low flow conditions. Isolated residual pools of water were present about half way between the gravel bar and the mouth of the side channel. A large pool had formed due to backwater, from the mainstem of the Cape Fear River toward the lower most portion of this side channel. This bypass channel is referred to as Reach 0 and is shown in Figure 6. During the habitat mapping effort, four potential transect locations were identified below the gravel bar and one transect was selected as a control point immediately above the gravel bar. The locations of these transects are shown in Figure 7 and a description of the associated habitat type and habitat segment number for each transect is provided in Table 7. No other similar bypass channels were observed during the two-day habitat mapping effort.

Reach 1 is located along the same side channel immediately upstream from Reach 0. During the habitat mapping trip on August 25, 2009, four potential transect locations were identified near the upstream end of this side channel. It is important to note that all three of the side channels contain cut-throughs, or connections, to the mainstem of the Cape Fear River. As a result, flow can enter or exit the side channels at multiple locations depending on overall flow levels in the Cape Fear River. To avoid difficulties in hydraulically modeling the side channels, it was desirable to locate study transects near the upper ends of each side channel (i.e., upstream from the first channel cut-through). The locations and descriptions of the Reach 1 transects are provided in Table 7 and Figure 7, respectively.

Reach 2 is located along the south bank of the Cape Fear River across from the mouth of Buckhorn Creek (Figure 6). Habitat mapping and transect identification occurred on August 26, 2009. Four transects were identified near the upstream end of Reach 2 and are shown on Figure 8. The habitat descriptions associated with these transects are provided in Table 7.

Reach 3 is also along the south bank of the Cape Fear River and it is located between Reach 2 and Buckhorn Dam (Figure 6). On August 26, 2009, four transects were selected near the upper end of Reach 3 and are shown on Figure 9. Habitat types and segment numbers associated with each transect location are provided in Table 7.

The instream flow study team met at Buckhorn Dam on November 2, 2009, and visited each of the three side channels (via canoes) to review the potential transects that were selected during the August 2009 habitat mapping effort. After several minor adjustments were made to the proposed transect locations, the study team approved all 17 transects in the four study reaches.

TABLE 6
CAPE FEAR RIVER HABITAT MAPPING FIELD DATA

Reach	Segment ID	Habitat Type	Width (ft)	Depth (ft)	Length (ft)	Substrate	Notes	Begin (ft)	End (ft)
1	1	other (shallow)	50	1.0	993	SCOB	dewatered channel	0	993
1	2	glide (shallow)	185	0.8	156	SCOB		993	1,149
1	3	complex (braided)	170	1.0	129	SCOB		1,149	1,278
1	4	glide (shallow)	170	1.5	434	SCOB		1,278	1,712
1	5	pool (shallow)	170	2.5	328	IBR		1,712	2,040
1	6	pool (deep)	170	4.0	157	IBR		2,040	2,197
1	7	glide (shallow)	170	2.0	222	IBR		2,197	2,419
1	8	pool (deep)	170	3.0	216	IBR		2,419	2,634
1	9	run (deep)	170	2.0	328	IBR		2,634	2,962
1	10	run (shallow)	170	1.5	140	IBR		2,962	3,102
1	11	pool (shallow)	150	3.5	176	IBR		3,102	3,278
1	12	run (shallow)	150	1.5	279	IBR		3,278	3,556
1	13	run (shallow)	120	1.5	183	IBR		3,556	3,739
1	14	glide (shallow)	120	1.5	123	IBR		3,739	3,862
1	15	pool (shallow)	120	3.6	195	IBR		3,862	4,056
1	16	glide (shallow)	120	2.0	104	IBR		4,056	4,160
1	17	glide (shallow)	120	2.0	142	LCOB		4,160	4,302
1	18	pool (shallow)	120	2.0	49	IBR		4,302	4,351
1	19	pool (shallow)	120	3.5	165	IBR		4,351	4,516
1	20	pool (shallow)	100	2.5	101	LBOL		4,516	4,617
1	21	pool (shallow)	75	2.0	55	IBR		4,617	4,673
1	22	run (shallow)	75	1.5	142	IBR		4,673	4,814
1	23	run (shallow)	60	1.5	300	LCOB		4,814	5,114
1	24	pool (shallow)	25	1.5	199	SA		5,114	5,313
2	25	glide (shallow)	150	2.0	153	IBR		5,313	5,466
2	26	pool (shallow)	150	3.5	173	IBR		5,466	5,639
2	27	glide (deep)	150	2.5	304	IBR		5,639	5,943

Reach	Segment ID	Habitat Type	Width (ft)	Depth (ft)	Length (ft)	Substrate	Notes	Begin (ft)	End (ft)
2	28	glide (deep)	150	2.5	317	IBR		5,943	6,260
2	29	pool (shallow)	150	3.0	130	IBR		6,260	6,390
2	30	glide (deep)	150	2.5	111	IBR		6,390	6,501
2	31	run (deep)	200	3.0	166	LGR		6,501	6,667
2	32	riffle (channel)	200	1.0	108	LCOB	possible manmade weir	6,667	6,775
2	33	glide (shallow)	200	2.0	105	SCOB		6,775	6,880
2	34	riffle (channel)	200	1.0	294	LCOB		6,880	7,174
2	35	shoal (shallow)	400	1.0	141	IBR		7,174	7,315
2	36	pool (deep)	300	4.0	83	IBR		7,315	7,398
2	37	shoal (shallow)	300	2.0	82	IBR		7,398	7,480
3	38	run (braided)	100	2.0	290	IBR		7,480	7,770
3	39	run (deep)	120	2.0	177	IBR		7,770	7,947
3	40	glide (braided)	250	3.0	351	IBR		7,947	8,298
3	41	glide (deep)	100	2.5	263	IBR		8,298	8,561
3	42	pool (deep)	80	4.0	150	IBR		8,561	8,711
3	43	pool (shallow)	100	3.0	341	IBR		8,711	9,052
3	44	pool (shallow)	100	3.5	293	IBR		9,052	9,345
3	45	pool (shallow)	80	3.5	247	IBR		9,345	9,592
3	46	glide (deep)	75	3.0	674	SA		9,592	10,266
3	47	glide (braided)	75	2.0	172	SA		10,266	10,438
3	48	pool (shallow)	50	3.5	185	SA		10,438	10,623
3	49	glide (shallow)	50	1.0	123	LGR		10,623	10,746
3	50	pool (shallow)	50	3.0	195	LGR		10,746	10,941
3	51	glide (shallow)	30	1.0	100	LGR		10,941	11,041

FIGURE 6
CAPE FEAR RIVER HABITAT MAP AND TRANSECT LOCATIONS

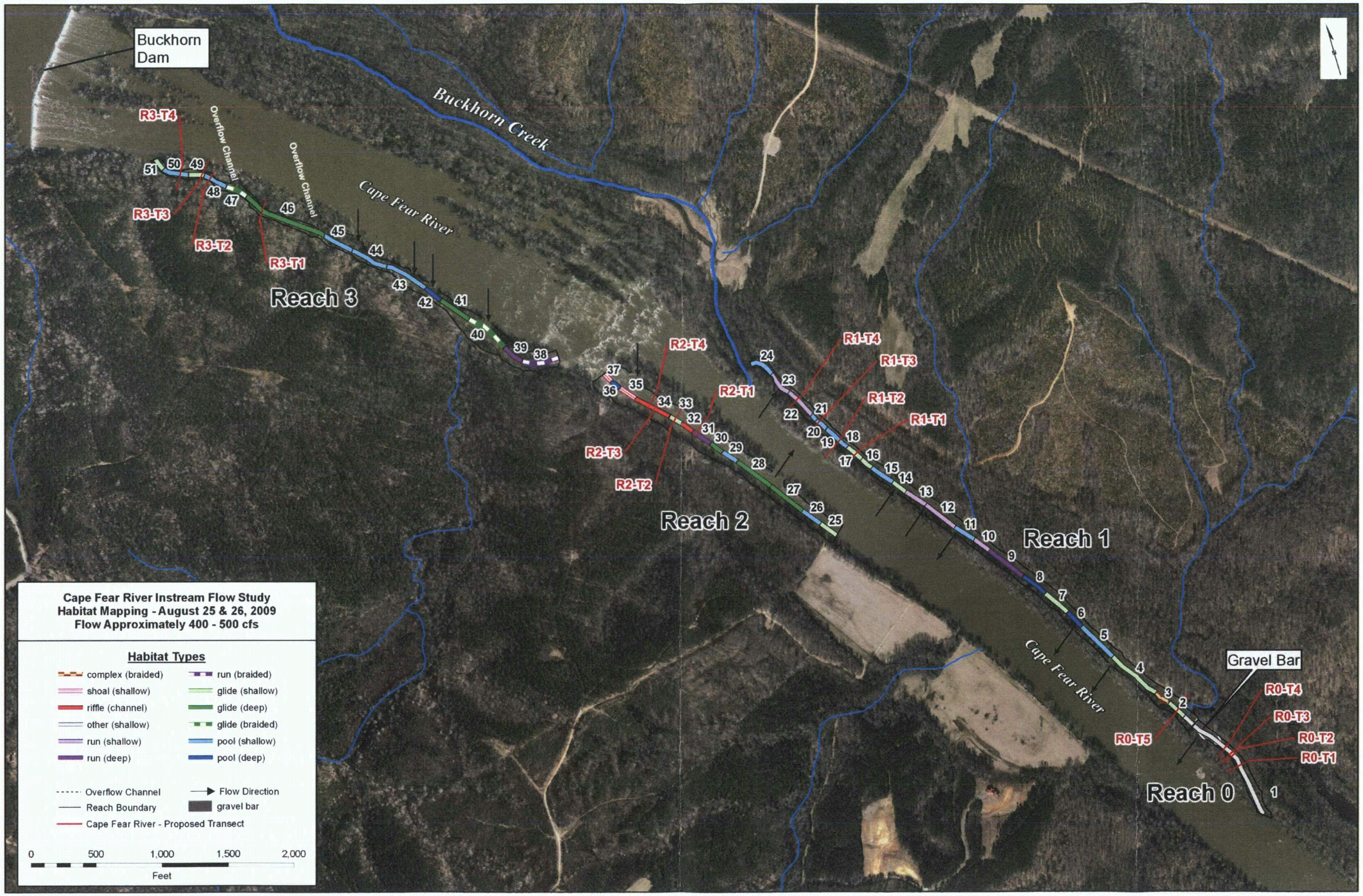


FIGURE 7
CAPE FEAR RIVER – STUDY REACHS 0 AND 1

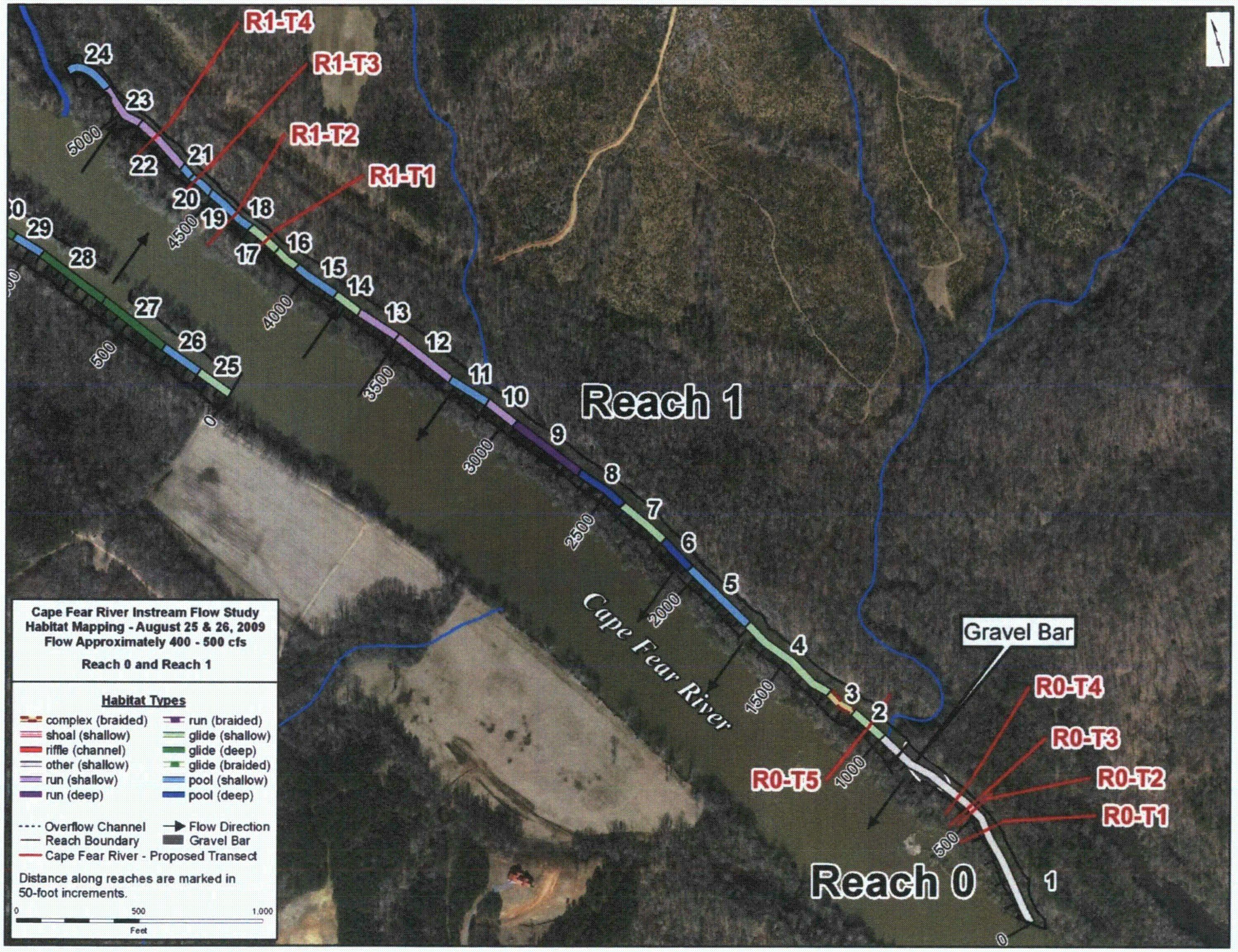


FIGURE 8
CAPE FEAR RIVER – STUDY REACHS 1 AND 2

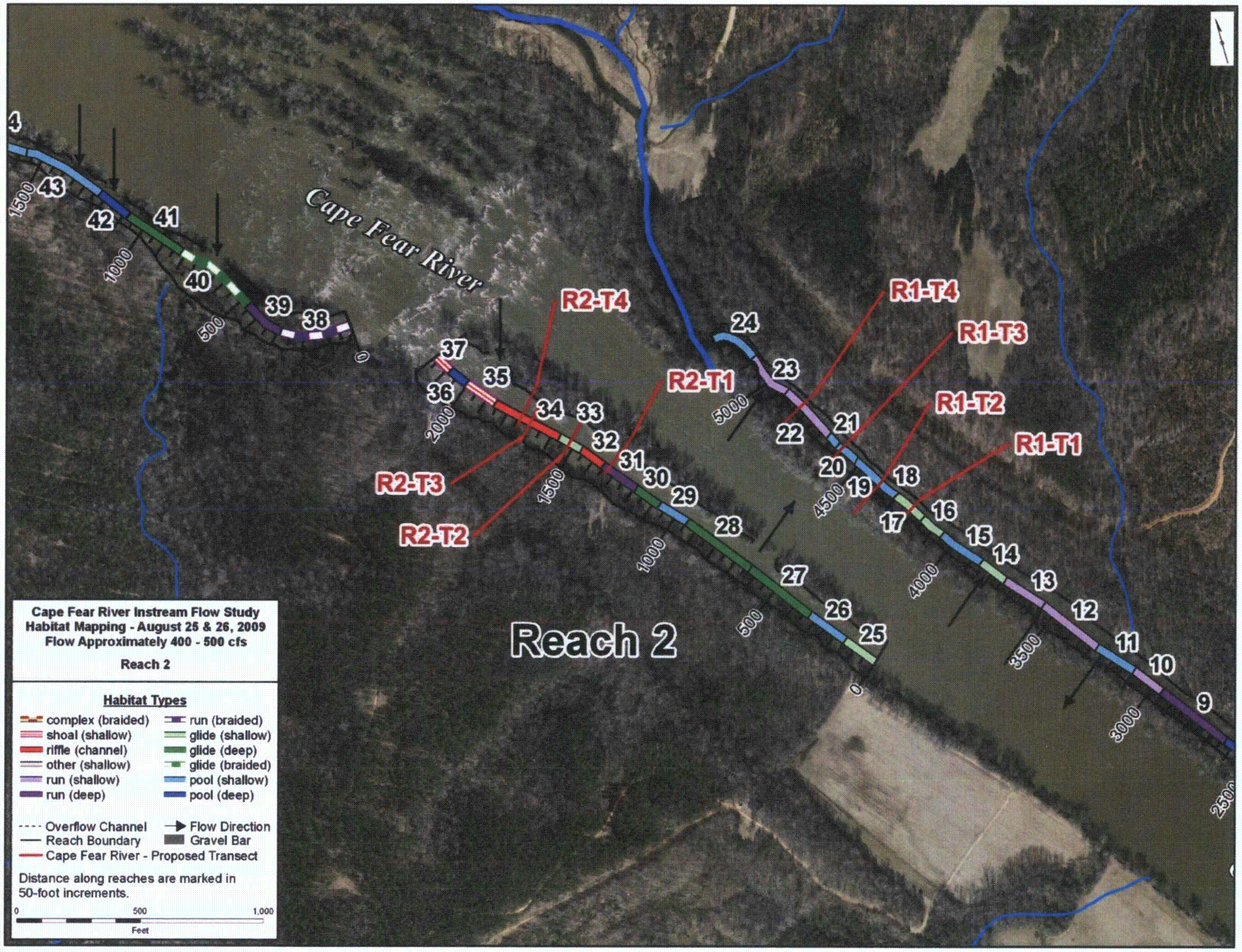


FIGURE 9
CAPE FEAR RIVER – STUDY REACH 3

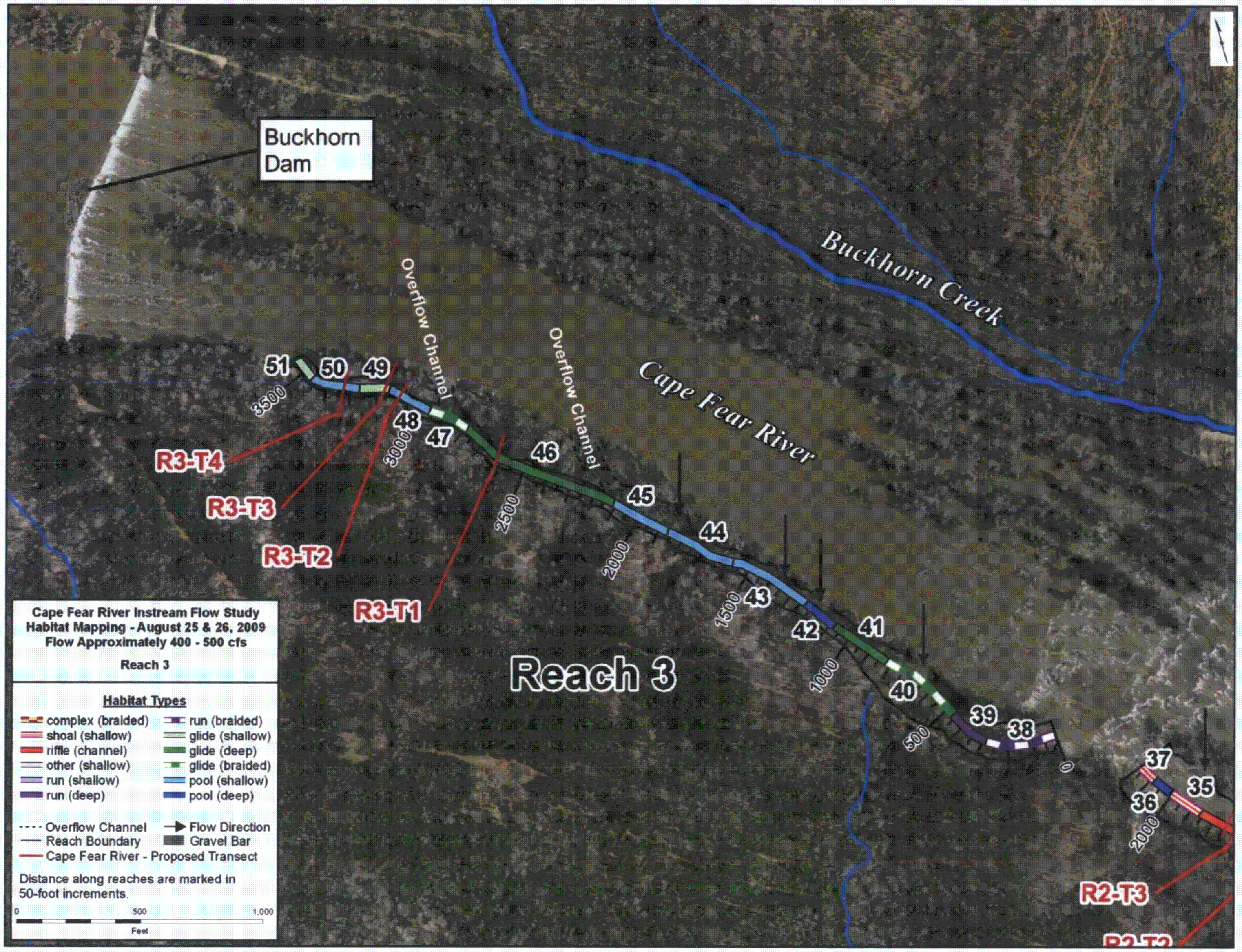


TABLE 7
CAPE FEAR RIVER TRANSECT LOCATIONS BY STUDY REACH

Study Site	Transect Number	Habitat Type		Transect Locations (Habitat Segment #)
Reach 0	R0-T1	Pool	Shallow	1
	R0-T2	Pool	Shallow	
	R0-T3	Pool	Shallow	
	R0-T4	Riffle	Shallow	
	R0-T5	Pool	Shallow	
Reach 1	R1-T1	Glide	Shallow	17
	R1-T2	Pool	Deep	18
	R1-T3	Pool	Shallow	20
	R1-T4	Run	Shallow	22
Reach 2	R2-T1	Run	Deep	31
	R2-T2	Glide	Deep	33
	R2-T3	Riffle	Deep	34
	R2-T4	Riffle	Shallow	34
Reach 3	R3-T1	Glide	Braided	46
	R3-T2	Pool	Shallow	48
	R3-T3	Glide	Shallow	49
	R3-T4	Pool	Shallow	50

4.2.2 Selection of Species to Model

Habitat suitability criteria (HSC) curves describe the relationship between depth, velocity, and substrate/cover and the degree to which these physical parameters provide suitable habitat for each aquatic species/life stage of concern. HSC values range from 0 to 1.0, which describe habitat conditions that are unsuitable to optimal, respectively, for a species/life stage. HSC provides biological criteria input into the hydraulic model that converts physical simulation data into weighted usable area (WUA) for evaluation of various flow scenarios on the particular species and life stage(s) of interest. WUA is usually expressed on an areal basis (square feet) or linear basis (WUA per 1,000 ft of stream).

HSC curves were obtained for target fish species and/or a surrogate species/life stage using available regional information in the scientific literature and instream flow studies. Appendix A provides a technical memo (dated September 15, 2010) and a complete set of HSC curves that were reviewed and approved by the instream flow study team at the two meetings referenced above. The technical memo also includes background documentation, source material references, and relevant rationale for using the HSC curves to model aquatic habitat in both the Buckhorn Creek and Cape Fear River study reaches. Selected HSC became the basis for evaluation of the effects of HAR Project flow management scenarios on the aquatic habitat of Buckhorn Creek and the Cape Fear River study areas. The habitats use guilds and several of the stand-alone species HSC used in this analysis were derived directly from previous instream flow studies that involved stakeholder consultation and approval of appropriate curves.

A combination of target species and guilds to be modeled in PHABSIM were selected from a list of species known to be present in the study area and habitat-use guilds utilized in other regional instream flow studies. A complete fish species list for the upper Cape Fear River basin was developed from scientific literature, results of fish sampling conducted by PEC in 2009 and 2010, and through consultation with the HAR Instream Flow Study Team (Table 4 in Appendix A). Selection of individual target species/life stages were chosen from this list based on their management importance and consultation with the study team. Target species consisted primarily of diadromous fish species; rare, threatened, and endangered (RTE) fish and mussel species; or fish species of recreational importance. The individual target species and life stages selected with available HSC are listed in Table 8. Table 9 includes spawning and early life stage periodicities for the proposed target stand-alone species.

For guilds, species/life stages were grouped according to generally similar habitat preferences. Guilds are typically used to represent native stream fish communities such as shiners, minnows, suckers, darters, and sunfish, of which individual HSC curves may not be available. Both a target species and guild approach were deemed necessary due to the diverse assemblage of species and habitat types encountered in the study area. Additionally, by grouping species into guilds, the number of required HSC curves and resulting model output could be reduced to a manageable level relative to data management and interpretation. Table 10 includes the habitat-use guilds that were modeled for the HAR Instream Flow Study, as well as species/life stages that represent each guild with substrate and cover criteria. Fish species that were requested to be modeled without stand-alone HSC were incorporated into a guild using these criteria or criteria recommended by the stakeholder group. During consultation with the study group, it was suggested that the USFWS bluebook HSC for black bullhead (*Ictalurus melas*) (Stuber 1982) be used for the three native bullhead species found in Buckhorn Creek, which do not have individual HSC. After review of the guilds, it was determined that the shallow-slow guild type represented by redbreast sunfish (*Lepomis auritis*) spawning was adequate in addressing habitat suitability requirements for adult black bullhead. It should be noted that HSC for only black bullhead adults (velocity parameter only) and spawning/embryo (substrate parameter only) life stages was provided in Stuber (1982).

Most of the HSC curves used for Buckhorn Creek and Cape Fear River target species were taken directly from the Pee Dee River Instream Flow Study (FERC No. 2206) in North and South Carolina (PEC 2006). This includes all of the guilds and most of the stand-alone target species, excluding channel catfish (*Ictalurus punctatus*), Cape Fear shiner (*Notropis mekistocholas*), and composite chub (*Nocomis* and *Semotilus* species). Channel catfish and composite chub HSC were taken from the Smith Mountain Instream Flow Needs Study (Thomas R. Payne and Associates, Inc. 2007) on the Roanoke River in Virginia, while Cape Fear shiner HSC was obtained from a published scientific paper on the species' population dynamics and instream habitat suitability in the Deep and Rocky rivers just upstream from Buckhorn Dam (Howard 2003).

The Cape Fear shiner is a federally endangered fish that is endemic to the Cape Fear River basin in the Piedmont physiographic province. The species has primarily been found upstream of Buckhorn Dam in the Rocky, Haw, and Deep rivers; however, in 2009-2010 sampling in the study area by PEC, one individual was collected in the Cape Fear River side channels. Because of its potential occurrence in the study area, the species was added to the target species list prior to this collection. Two federal fish species of concern are also known to occur in the Cape Fear River drainage in Chatham County: Carolina darter (*Etheostoma collis lepidinion*) and Carolina redhorse (*Moxostoma* sp.). One Carolina redhorse was collected by PEC just upstream of

Buckhorn Dam on the mainstem of the Cape Fear River in 2010 and five individuals were collected below the dam during 2011. Similar to the Cape Fear shiner, this species had already been added to the species list prior to this collection due to its rare status and potential to occur in the project vicinity. Although no individual HSC curves were available for Carolina redhorse, the golden redhorse (*Moxostoma erythrurum*) HSC was determined to be an appropriate surrogate during the Pee Dee River Instream Flow Study, therefore it was used for the HAR Instream Flow Study.

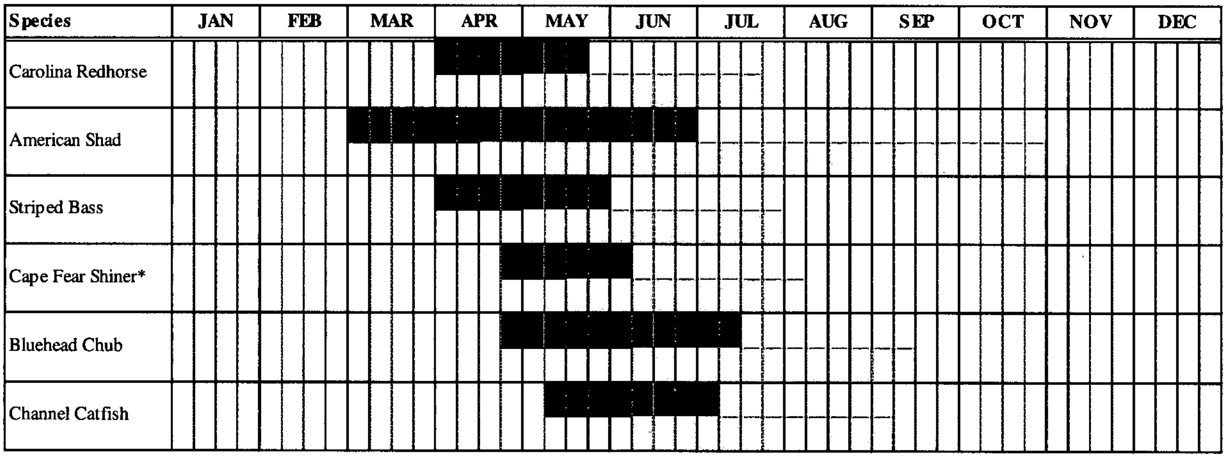
Because of the Pee Dee River and Cape Fear River basins' geographic and physiographic similarities, transferability of the HSC was considered reasonable. Several of the HSC utilized in the Pee Dee River Instream Flow Study represent modified versions of the original source HSC data, particularly as they relate to substrate and cover parameters. Selection of the target species/life stages and approval of their transferability to Buckhorn Creek and the Cape Fear River side channels was performed in consultation with the study group. This included two stakeholder meetings held on May 20, 2010, and August 24, 2010. No modifications to the Pee Dee or Roanoke rivers' HSC curves were performed during these consultations.

TABLE 8
STAND-ALONE TARGET GAME SPECIES/LIFE STAGES AND HSC SOURCES FOR THE SHEARON-HARRIS INSTREAM FLOW STUDY

Species	Available HSC/ Life Stage*	Target Life Stage*	Applicable Water Body (BHC=Buckhorn Creek; CFR=Cape Fear River)	References
Carolina Redhorse	J,A (golden redhorse used as surrogate)	J,A	BHC and CFR	[1,2]MN DNR (2004). [3]Adult developed by Pee Dee Instream Flow Relicensing Subgroup, June 2004; juvenile by MN DNR (2004); [4]Adult developed by MN DNR (2004); juvenile by Pee Dee Instream Flow Relicensing Subgroup, June 2004
American Shad	L,J,O,S,I	L,J,O,S,I	CFR	[1,2,3,4]Modification of Stier and Crance (1985); developed for Swift Creek – 10/11/03 memo from P. Leonard). Spawning HSC used based on 10/1/10 email from J. Hightower to T. Thompson.
		J	BHC	
Striped Bass	L,I,J,S	L,I,S	CFR	[1,2]Larval, incubation, and spawning (EA 1994); [3]Larval and incubation (EA 1994 and Pee Dee Instream Flow Relicensing Subgroup, July 2004). No cover curve available.
		J	CFR	[2]Crance (1984); Velocity, substrate, and cover curves not available.
Cape Fear Shiner	A,S	A,S	BHC and CFR	[1,2,3,4]Howard 2003
Composite Chub	A,S	A,S	BHC and CFR	[1,2,3,4]Thomas R. Payne and Associates (2007)
Channel Catfish	J,A,S	J,A,S	CFR	[1,2,3,4]Herricks et al. 1980; Thomas R. Payne and Associates (2007)
Native Mussels	N/A	A	BHC and CFR	N/A - will use wetted perimeter as a measure of habitat availability
Insects	L (EPT)	L	BHC and CFR	[1,2,3]Developed by Jim Gore, provided by Jim Mead, NCDWR in 6/11/04 e-mail. No cover curve available.

[1] Velocity HSC
[2] Depth HSC
[3] Substrate HSC
[4] Cover HSC
* A=adult; J=juvenile; Y=young of year; F=fry; L=larval; D=drift; I=incubation; S=spawning; O=outmigration

TABLE 9
SPAWNING AND EARLY LIFE STAGE PERIODICITIES FOR TARGET FISH SPECIES



■ Spawning
□ Early Life Stage (estimated to begin two-thirds of the way through the spawning period and lasting 60 days post spawn; except for Cape Fear Shiner)
Source: Jenkins and Burkhead (1993)
* Cape Fear Shiner Source: Hewitt et al. (2009)

TABLE 10
HABITAT-USE GUILDS AND SPECIES REPRESENTATIVES FOR BUCKHORN CREEK AND CAPE FEAR RIVER

Substrate/Cover Type	Representative Species/Lifestage	Comments
SHALLOW-SLOW GUILD (Depth < 2 ft, Velocity < 1 ft/s)		
Fine substrate without cover	Redbreast sunfish spawning	Representative of centrarchid spawning requirements
Woody debris cover	Silver redhorse young-of-year (YOY)	Representative of catostomid and cyprinid YOY requirements
Aquatic vegetation cover	Silver redhorse YOY	Representative of catostomid and cyprinid YOY requirements
Coarse substrate	Generic shallow-slow guild	Representative of the habitat requirements of adult cyprinids and the YOY of species that may use the predominant susbtrate type found in the Elk River study area
None	Generic shallow-slow guild; bluehed chub fry	Representative of the habitat requirements of many adult cyprinids and the YOY of many species since there are no substrate or cover requirements
SHALLOW-FAST GUILD (Depth < 2 ft, Velocity > 1 ft/s)		
Lower velocity with coarse substrate and no cover	Margined madtom adult	Representative of many spawning cyprinids and adult darters
Moderate velocity with coarse susbtrate and no cover	Generic shallow-fast guild	Representative of all species inhabiting shallow-fast habitats since there is no substrate and cover
High velocity with coarse susbtrate and cover	Fantail darter adult	Representative of species inhabiting shallow-fast habitats with coarse substrate and cover requirements
DEEP-SLOW GUILD (Depth > 2 ft, Velocity < 1 ft/s)		
Cover	Redbreast sunfish adult	Representative of many adult centrarchids and other cover dependent species reliant on primarily woody debris and boulder cover types which are predomiant in the Elk River study area
No cover	Generic deep-slow guild	Representative of many speices inhabiting deep, slow habitats since there are no susbtrate or cover criteria
Cover	Generic deep-slow guild	Representative of many speices inhabiting deep, slow habitats that are cover dependent
DEEP-FAST GUILD (Depth > 2 ft, Velocity > 1 ft/s)		
Fine substrate	Silver redhorse adult	Representative of many adult catostomids and cyprinids
Gravel/small cobble substrate	White bass spawning	Representative of those species requiring deep-fast habitats for spawning on coarse substrate
Coarse-mixed susbtrate	Shorthead rehorse adult	Representative of those species requiring deep-fast habitats for foraging on coarse-mixed substrate

NOTE: All guilds (depth and velocity criteria) were modeled regardless of additional substrate and/or cover types identified by the stakeholder group. Guild depth and velocity criteria were originally developed by Aadland (1991) and modified by ENTRIX (2002, 2003) for use in the Savannah River and Swift Creek Instream Flow Studies, respectively. Comments on guild types and proposed species representatives were derived from the Swift Creek Instream Flow Study (ENTRIX 2003) and Pee Dee River Instream Flow Study (Progress Energy 2006).

4.2.3 Selection of Target Flows for Field Data Collection

4.2.3.1 Buckhorn Creek

Target flows are necessary in order to collect field data under several different flows used to calibrate the PHABSIM model. Generally, it is required that field data be collected under at least three different flow regimes based on the hydrologic period of record. For Buckhorn Creek, two different hydrologic periods of record were analyzed: one that reflects the current regulated flow regime below Harris Dam and one that reflects the unregulated period of record (pre-Harris Dam). Regulated and unregulated flow regimes are often used to evaluate differences in aquatic habitat between these two flow regimes. USGS gage number 02102192 provides a hydrology record from 1972 to present. Based on a comparison of the Buckhorn Creek streamflow data to flow data recorded at the nearby Middle Creek USGS stream gaging station near Clayton, North Carolina (gage number 02088000), it appears that Harris Reservoir was undergoing fill operations from October 1980 through January 1983. As a result, streamflow data recorded at the Buckhorn Creek USGS gage was not able to be used during this period.

Therefore, the period from 1972 through September 1980 is considered representative of unregulated flow conditions and the period from February 1983 through August 2009 is considered representative of regulated flow conditions. Figure 10 provides cumulative flow frequency curves for Buckhorn Creek for the unregulated and regulated periods of record. For the Buckhorn Creek study reach, the instream flow study team recommended that the PHABSIM model be able to simulate flows representing approximately 90 percent (%) of the historic flow range (for unregulated and regulated periods). Based on Figure 10, 90% of the historic flow range is captured by flows ranging from 0.1 to approximately 150 cfs.

To simulate between 0.1 and 150 cfs, three target flows were selected to calibrate the PHABSIM model. Generally, target flows are selected such that each target flow, when multiplied or divided by a factor of 2.5, will extend up to or down to the next target flow simulation range. Following these generally accepted guidelines, proposed target flows for the Buckhorn Creek study reach were 5 cfs, 30 cfs, and 60 cfs. A target flow of 5 cfs allows a simulation range between 2 cfs and 12.5 cfs. A target flow of 30 cfs allows a simulation range between 12 cfs and 75 cfs. Finally, a target flow of 60 cfs allows a simulation range between 24 cfs and 150 cfs.

Since there was no way to deliver controlled releases at Harris Dam or the adjacent spillway, it was necessary to perform field data collection activities under flows that are naturally available. For this reason, some flexibility in the target flows was necessary and is described in more detail in Section 5.4.1.

4.2.3.2 Cape Fear River

Similar to the Buckhorn Creek instream flow study reach, target flows were also determined for the Cape Fear River instream flow study reaches. One difference between the two study areas is that while 90% of the historic flow regime was recommended for Buckhorn Creek, having a model capable of accurately simulating the lower end of the Cape Fear River flow regime was desirable. The study team recognized that potential impacts to aquatic habitat in the Cape Fear River associated with future water withdrawals would be more likely to occur under lower flow conditions.

Based on the cumulative flow frequency curve shown below in Figure 11, the lower two-thirds (approximately 67%) of the daily average flow values are below 2,500 cfs at the Lillington, North Carolina USGS flow gauging station (gage number 02102500). It was proposed that target flows be selected such that the instream flow model would be capable of simulating full channel flows up to 2,500 cfs. Using similar target flow setting guidance as described above in Section 4.2.3.1, the proposed target flows for the Cape Fear River instream flow study were 450 cfs, 850 cfs, and 1250 cfs. Like Buckhorn Creek, there was no way to deliver controlled releases to the Cape Fear River study area. As a result, some flexibility in the target flow was also necessary and is described in more detail in Section 5.4.2.

FIGURE 10
FLOW EXCEEDANCE CURVES
BUCKHORN CREEK NEAR CORINTH, NC (USGS 02102192)

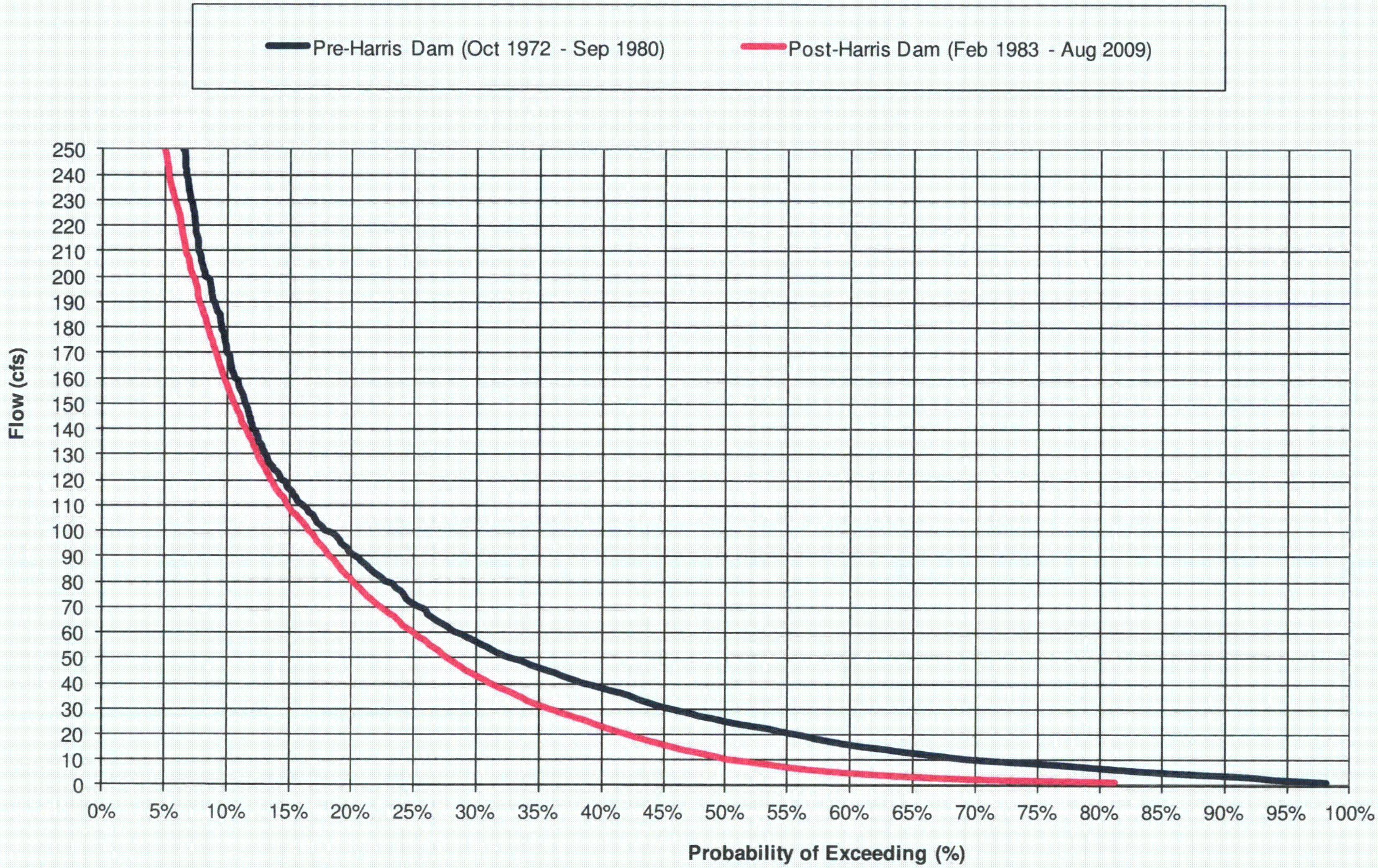
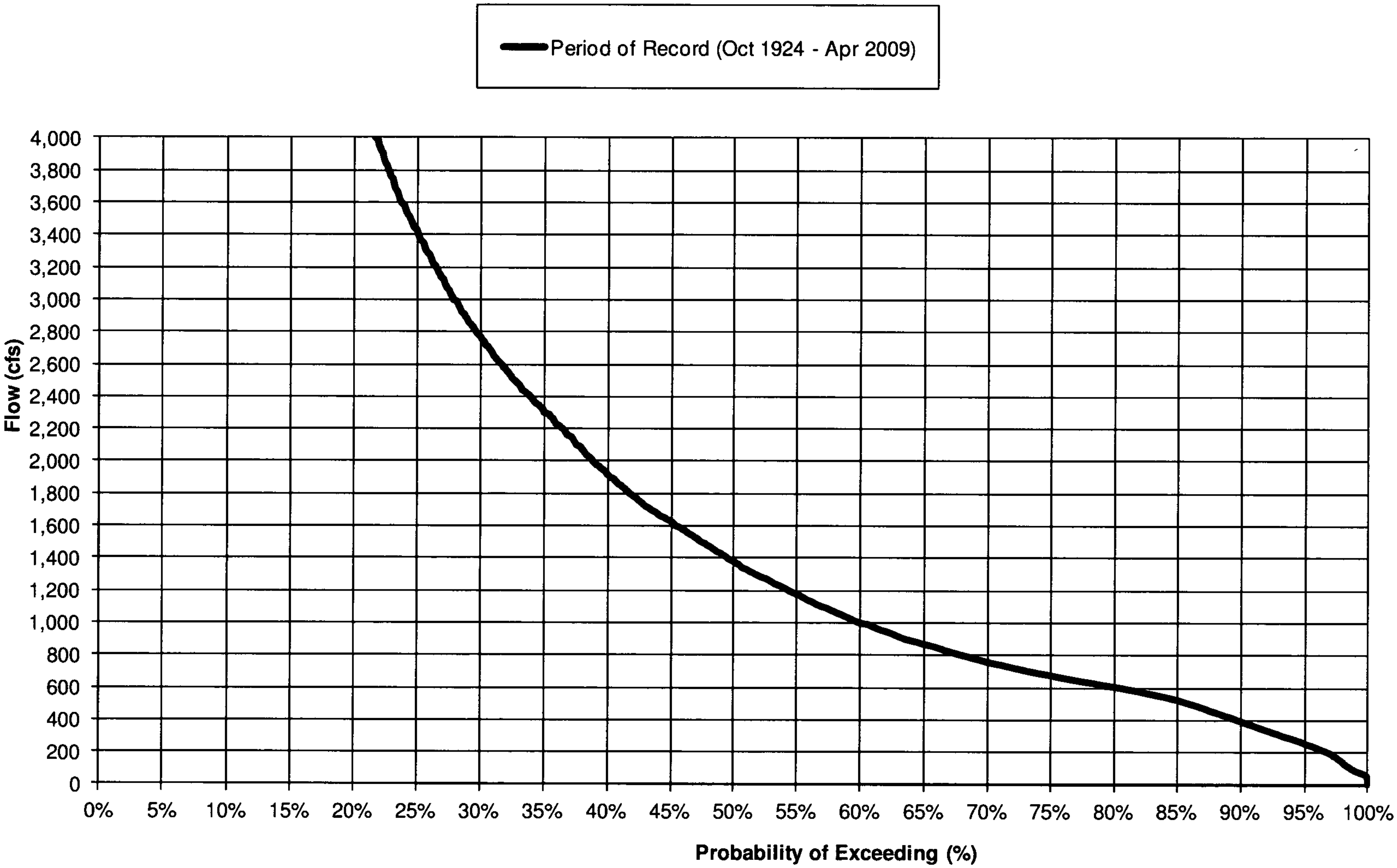


FIGURE 11
FLOW EXCEEDANCE CURVE
CAPE FEAR RIVER AT LILLINGTON, NC (USGS 02102500)



4.2.4 Consideration of Other Instream Needs/Uses

In addition to the instream flow studies in Buckhorn Creek and the Cape Fear River side channels, a recreation study is planned in the mainstem of the Cape Fear River between RM 191.3 and 191.8 (see Figure 3). This study will focus on paddling activities in the high gradient shoal area of the Cape Fear River immediately upstream from the confluence with Buckhorn Creek. This study is scheduled to be conducted in 2012.

Section 5
Field Data Collection

5.1 General Methods

For both the Buckhorn Creek and Cape Fear River instream flow study reaches, physical habitat and hydraulic parameters were measured using a combination of standard techniques of the USFWS IFIM process (Trihey and Wegner 1981; Bovee 1982; Bovee et al. 1998), the USGS (Rantz 1982), and techniques established in consultation with the instream flow study team. PHABSIM data collection procedures were the same for both the Buckhorn Creek and Cape Fear River study reaches. A detailed description of steps involved in PHABSIM data collection is provided below.

5.2 Transect Setup

After the study sites and transect locations in Buckhorn Creek and the Cape Fear River were selected and approved by the instream flow study team (as described in Sections 4.2.1.1 and 4.2.1.2), the individual transects in each study reach were set up to establish a semi-permanent location using headpins and tailpins on the creek bank. In all, there are 17 transects along the Buckhorn Creek study reach and 17 transects along the four Cape Fear River side channel study reaches. The channel cross sections for each transect were surveyed to top-of-bank, and substrate and cover type were recorded along the entire length of each transect using approved NCDENR methods. Substrate classification and codes are provided above in Section 4.2.1.1 (Table 2) and cover types and codes are provided below in Table 11. A GPS point was also taken to locate each transect on a USGS quadrangle map.

TABLE 11
COVER TYPE CLASSIFICATION AND CODES

Overhead Cover		Description	Proximal Cover	
Code	Abbreviation		Abbreviation	Code
0.0	NC	No Cover	N/A	N/A
0.1	UCB	Undercut Bank	PUCB	0.14
0.2	OHV	Overhanging Vegetation Touching Water	POHV	0.24
0.3	ROOT	Root Wad (greatest width 1.5 ft)	PROOT	0.34
0.5	SNAG	Snags and Stream Wood	PSNAG	0.54
0.6	WEED	Submerged Aquatic Vegetation	PWEED	0.64
0.7	DEB	Fine Organic Substrate	PDEB	0.74
0.8	TV	Terrestrial Grass and Bushes	N/A	N/A
0.9	ISC	Instream Cover	PISC	0.94

Note: Proximal cover is a cover object not at a vertical, but within 4.0 ft in any direction.

5.3 Surveying and Controls

All elevations were surveyed by standard differential survey techniques using an auto level or total station instrument. Headpin and tailpin elevations, Water Surface Elevations (WSEs), hydraulic controls, and above-water bed and bank elevations were referenced to a temporary benchmark serving a single transect or multiple transects, depending on their proximity to one another. For each of the four Cape Fear River study reaches, benchmarks within each reach were tied together.

5.4 Flow Measurements

Hydraulic data was collected at all transects in a manner suitable for one-dimensional PHABSIM modeling (Bovee 1997). Stream depths and velocities were measured on a cell-by-cell basis at each transect and WSEs across each transect were measured at each of the target flows.

Velocities were collected at most of the Buckhorn Creek transects and all of the Cape Fear River transects using handheld, propeller-type velocity meters (Swoffer® brand) mounted on standard USGS top-set wading rods. Vertical cells were placed to define substrate, bed elevation, and hydraulic boundaries. The number of verticals across each transect was expanded as necessary at higher flows to define these boundaries and to limit discharge in one cell to no more than 10% of the total discharge. Since velocity data collection was conducted under naturally occurring flows (versus controlled flow releases), it was important to record any changes in stage during data collection activities. This was accomplished by installing temporary staff gages during field measurements.

For Buckhorn Creek transects T-7 and T-12, depths and velocities were measured using an acoustic Doppler current profiler (ADCP) mounted on a portable flotation device that could be pulled across each transect. ADCP technology uses acoustic pulses to measure water velocities at multiple points in the water column while simultaneously measuring depths across the channel. The ADCP was used at these two pool transects because they were too deep to manually wade across, even at the lower target flows.

5.4.1 Buckhorn Creek Flow Measurements

The Buckhorn Creek USGS 02102192 flow gaging station was used to track flow rates in the Buckhorn Creek study reach and identify opportunities to measure target flows. During the study plan development phase, the instream flow study team had recommended target flows of 60 cfs, 30 cfs, and 5 cfs.

During transect setup activities, WSEs at each of the 17 transects were measured at a flow of 0.6 cfs. While this was not one of the recommended flow targets, it was determined that this would be a useful data set for PHABSIM model calibration purposes. On November 16, 2009, a complete hydraulic data set (WSEs, depths, and velocities) was collected at a high target flow of 68 cfs. On January 10, 2010, an attempt to measure a flow near the middle target flow of 30 cfs resulted in a complete hydraulic data set at 49 cfs instead. At the time, the USGS gage had been relaying flow in the 30 cfs range so the USGS field office in Raleigh, North Carolina was contacted and a crew was sent to investigate. It was determined that recent beaver dam building activity immediately downstream from the USGS gaging station had altered the readings from the gage, so the gage was subsequently re-calibrated.

On April 12, 2010, a complete hydraulic data set was collected at 37 cfs. Since this flow was slightly higher than the 30 cfs target, the instream flow study team was consulted. Since a set of data had previously been collected at 0.6 cfs, and with a slightly higher than anticipated middle target flow, the study team recommended that the low flow target be revised from 5 cfs to 8 cfs. On April 27, 2010, a complete set of data was collected at 8 cfs.

Overall, five hydraulic data sets were collected on the Buckhorn Creek instream flow study reach. Table 12 provides the dates and flows measured, along with the expected model simulation range for each flow based on the standard 0.4 (low end) and 2.5 (high end) multipliers. As shown in Table 12, with the exception of the lowest measured flow (0.6 cfs), the simulation range associated with each measured flow overlaps the simulation range of the adjacent higher and lower measured flows. This is the ideal situation for model calibration purposes as there are no simulation "gaps" between measured flows.

TABLE 12
BUCKHORN CREEK FLOW MEASUREMENTS

Date	Min Simulation Range (cfs)	Measured Flow (cfs)	Max Simulation Range (cfs)
11/16/2009	27	68	170
1/10/2010	20	49	123
4/12/2010	15	37	93
4/27/2010	3	8	20
8/10-12/2009	0.24	0.6	1.5

5.4.2 Cape Fear River Flow Measurements

The Cape Fear River three USGS gages were used to estimate flows in the study reach immediately below Buckhorn Dam:

- USGS gage number 02098198, Haw River below B. Everett Jordan Dam near Moncure, North Carolina;
- USGS gage number 02102000, Deep River at Moncure, North Carolina; and
- USGS gage number 02102500, Cape Fear River near Lillington, North Carolina.

The first two gages are on the Haw and Deep Rivers which combine to form the Cape Fear River approximately 6.0 miles upstream from Buckhorn Dam and the gage near Lillington is approximately 14.4 miles downstream from Buckhorn Dam. In addition, operators at the COE's B. Everett Jordan Dam were consulted to determine expected flow releases from the reservoir and how those flow releases might impact overall flows below Buckhorn Dam. During the study plan development phase, the instream flow study team had recommended Cape Fear River target flows of 450 cfs, 850 cfs, and 1,250 cfs.

On November 4, 2009, immediately after the Cape Fear River side channel transects were setup, a complete hydraulic data set was measured at 680 cfs. Subsequent data sets were measured at 396 cfs and 882 cfs on May 11, 2010, and June 8, 2010, respectively. Table 13 provides the dates and flows measured along with the expected model simulation range for each flow based on the standard 0.4 (low end) and 2.5 (high end) multipliers. As shown in Table 13, the overall expected simulation range is 158 cfs to 2,205 cfs with adequate overlap in individual simulation ranges for each measured flow. While the low, middle, and high flow measurements were lower than the recommended target flows, the expected simulation range of these flows captures the lower 64% of the cumulative flow frequency curve, which is very close to the objective of being able to simulate flows over the lower 2/3 of the Cape Fear River flow regime (see Section 4.2.3.2 for details).

TABLE 13
CAPE FEAR RIVER FLOW MEASUREMENTS

Date	Min Simulation Range (cfs)	Measured Flow (cfs)	Max Simulation Range (cfs)
6/8/2010	353	882	2,205
11/4/2009	272	680	1,700
5/11/2010	158	396	990

The instream flow study team agreed to use the measured flows for PHABSIM calibration purposes as the data collected provided strong coverage of the flow range likely to be of most interest during the evaluation and decision making process.

Section 6
PHABSIM Modeling Process

6.1 Model Calibration

The hydraulic model for the Buckhorn Creek and Cape Fear River PHABSIM studies was calibrated by HDR using Riverine Habitat Simulation (RHABSIM) 3.0, a commercial software program written by Thomas R. Payne and Associates of Arcata, California. RHABSIM is a commercial version of the PHABSIM computer model (Milhous et al. 1984).

The first step in model calibration was to enter all field data into Microsoft Excel spreadsheets and perform a rigorous quality control review. When this process was complete, input data decks were created and run through the PHABSIM model calibration process. The calibration process is based on the model's ability to match observed (i.e., measured) WSEs and velocities for each transect on an incremental (i.e., cell-by-cell) basis.

For WSEs, these procedures included the development of stage-discharge rating curves using Log/Log regression (IFG4) and Manning's formula (MANSQ), direct comparison of results, and selection of the most appropriate and accurate method. To determine whether the model was accurately predicting measured values, a set of modeling guidelines was established. The guidelines are as follows:

1. The beta value (a measure of the change in channel roughness with changes in streamflow) must be between 2.0 and 4.5;
2. The mean error in calculated versus given discharges must be less than 10%;
3. There must be no more than a 25% difference for any calculated versus given discharge;
4. There must be no more than a 0.1-ft difference between measured and simulated WSEs.

To determine whether the MANSQ model accurately predicts measured values, the second through fourth of the above criteria must be met, and the beta value parameter used by MANSQ must be within the range of 0.0 to 0.5. The first IFG4 criterion is not applicable to MANSQ.

Velocity calibration in the hydraulic model utilized the "one-velocity set" method. This method uses measured velocities across a given transect and estimates a Manning's N value for each cell. Calibration techniques include adjustments to the Manning's N value to obtain accurate predictions of measured velocities as well as reasonable predictions of velocities at simulated flows. The purpose of the velocity calibration is to accurately simulate the measured velocities and WSEs at the observed flows while at the same time, provide reasonable velocities and WSEs over the full range of simulated flows. Changes to velocities were kept to a minimum and the input data decks were revised only when specific changes improved model performance.

The study team held its first of nine model-related workshops on February 23, 2011 to discuss the model calibration results for Buckhorn Creek and the Cape Fear River.

6.1.1 Buckhorn Creek Model Calibration

One PHABSIM model comprised of three individual hydraulic models was developed for the 17 transects on Buckhorn Creek. Each model was associated with a velocity calibration set: 68 cfs, 37 cfs, and 8 cfs. Stage/discharge regressions were also developed using four calibration discharges: 68 cfs, 49 cfs, 37 cfs, and 8 cfs. During the calibration process, 15 of the 17 transects had mean errors of less than 5%. The other two transects, T-8 and T-12, had mean errors of 8.6% and 7.3%, respectively; which are still within the established modeling guidelines of 10%. Complete details on the calibration process are provided in Appendix B. Photographs of each transect, transect details (cross-section profiles, velocity profiles, and substrate mapping), and transect weighting factors are also provided in Appendix B.

6.1.2 Cape Fear River Model Calibration

Three PHABSIM models were developed for the Cape Fear River study area; one for each of the three side channels. In order to develop the hydraulic models for each side channel, it was first necessary to determine the percentage of the overall Cape Fear River flow that entered each of the side channels. This flow percentage varies based on overall magnitude of flow in the Cape Fear River.

Table 14 provides Reach 1 versus Cape Fear River main channel calibration flow measurement data and resulting flow proportion calculations. During the model calibration process, it was determined that the mid-high flow measurement did not fit in with the best-fit trendline flow relationship for the other 3 flow measurements. The 680 cfs hydraulic calibration data set was collected on November 4, 2009. Several large flow events occurred on the Cape Fear River between November 2009 and the spring and early summer of 2010; when subsequent hydraulic calibration data sets were collected. The large flow events resulted in minor cross-sectional profile differences at a couple of the Reach 1 transects due to natural scour and deposition of sediments in the side channel. When this initial data set was removed from the process, the resulting model calibration improved somewhat. However, it was only based on a two point rating curve. The study team was consulted and the recommendation was to attempt to measure a higher calibration flow in Reach 1. This opportunity presented itself on March 2, 2011, when a main channel flow of 1,239 cfs was measured (the Reach 1 portion of this flow was 92 cfs). The resulting 3-point flow relationship curve between Reach 1 and the Cape Fear River main channel is provided in Figure 12.

Table 15 provides the Reach 2 versus Cape Fear River main channel calibration flow measurement data and resulting flow proportion calculations. No cross-sectional profile changes were noted in Reach 2 during the data collection period, so all three of the target flow data sets were used. Note that unlike Reach 1 where the percentage of flow in the side channel increases with increasing main channel flows, the reverse trend was observed in Reach 2. The percentage of flow in Reach 2 decreased with increasing main channel flows, as shown in Figure 13.

Table 16 provides the Reach 3 versus Cape Fear River main channel calibration flow measurement data and resulting flow proportion calculations. Similar to Reach 1, there were minor changes to a couple of the cross-sectional profiles in Reach 3 over the course of the field data collection period. Replacing the mid-high flow data set with an additional (mid-flow) data set that was collected at a main channel flow of 483 cfs (Reach 3 flow of 23.7 cfs) improved the overall main channel versus Reach 3 flow relationship as shown in Figure 14.

TABLE 14
CAPE FEAR RIVER REACH 1 FLOW PROPORTION

Target Calibration Flow	Reach 1 Flow (cfs)	Main Channel Flow (cfs)	Flow Proportion (%)
Additional High Flow	92	1239	7.43%
High Flow	61	882	6.92%
Mid-High Flow*	32	680	4.71%
Low Flow	19	396	4.80%

*Note: mid-high flow measurement was dropped from the flow proportion analysis.

FIGURE 12
CAPE FEAR RIVER REACH 1 FLOW RELATIONSHIP

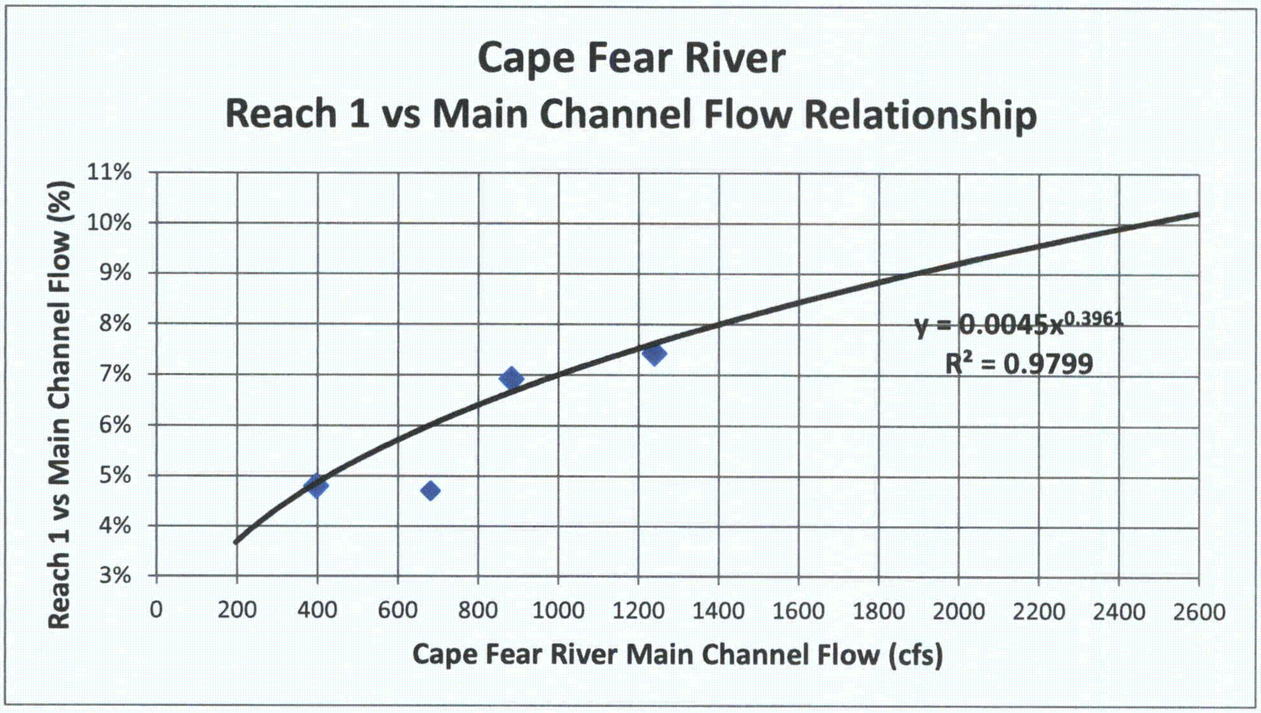


TABLE 15
CAPE FEAR RIVER REACH 2 FLOW PROPORTION

Target Calibration Flow	Reach 2 Flow (cfs)	Main Channel Flow (cfs)	Flow Proportion (%)
High Flow	350	882	39.68%
Mid-High Flow	305	680	44.85%
Low Flow	217	396	54.80%

FIGURE 13
CAPE FEAR RIVER REACH 2 FLOW RELATIONSHIP

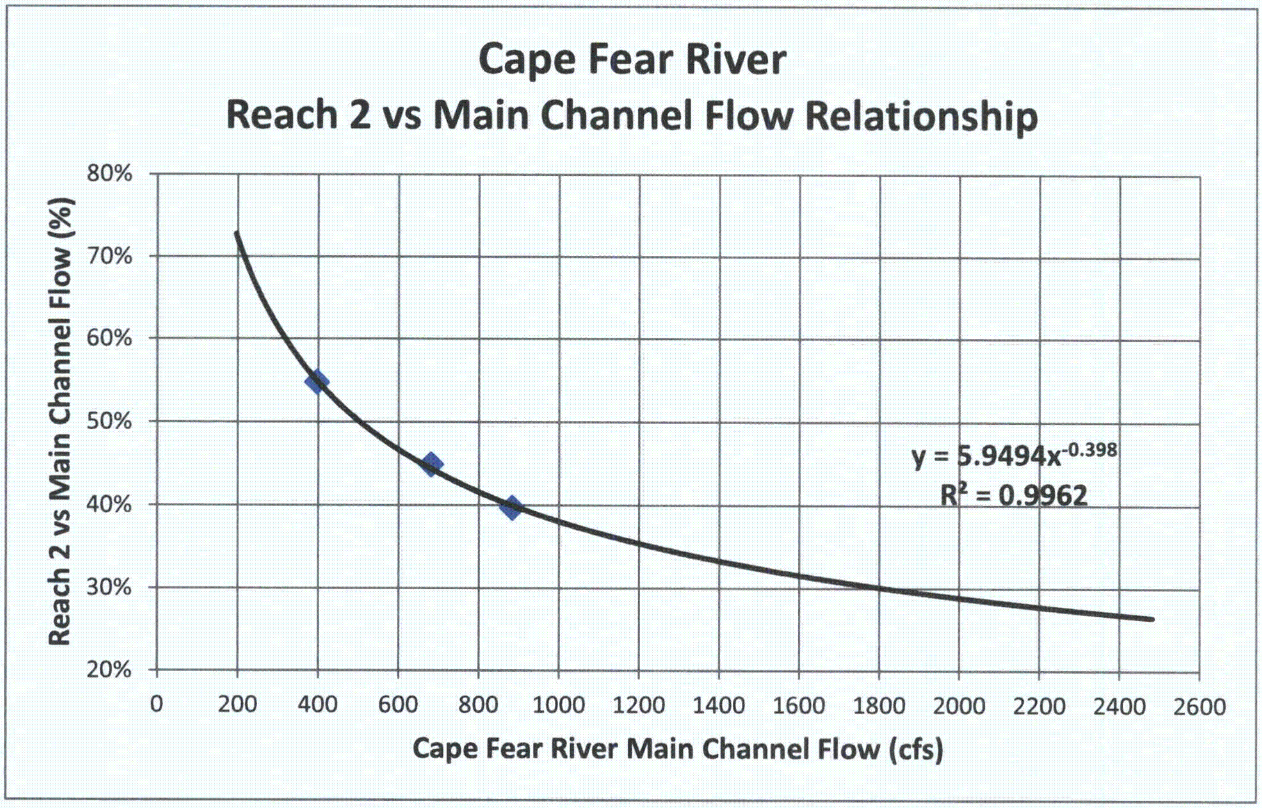
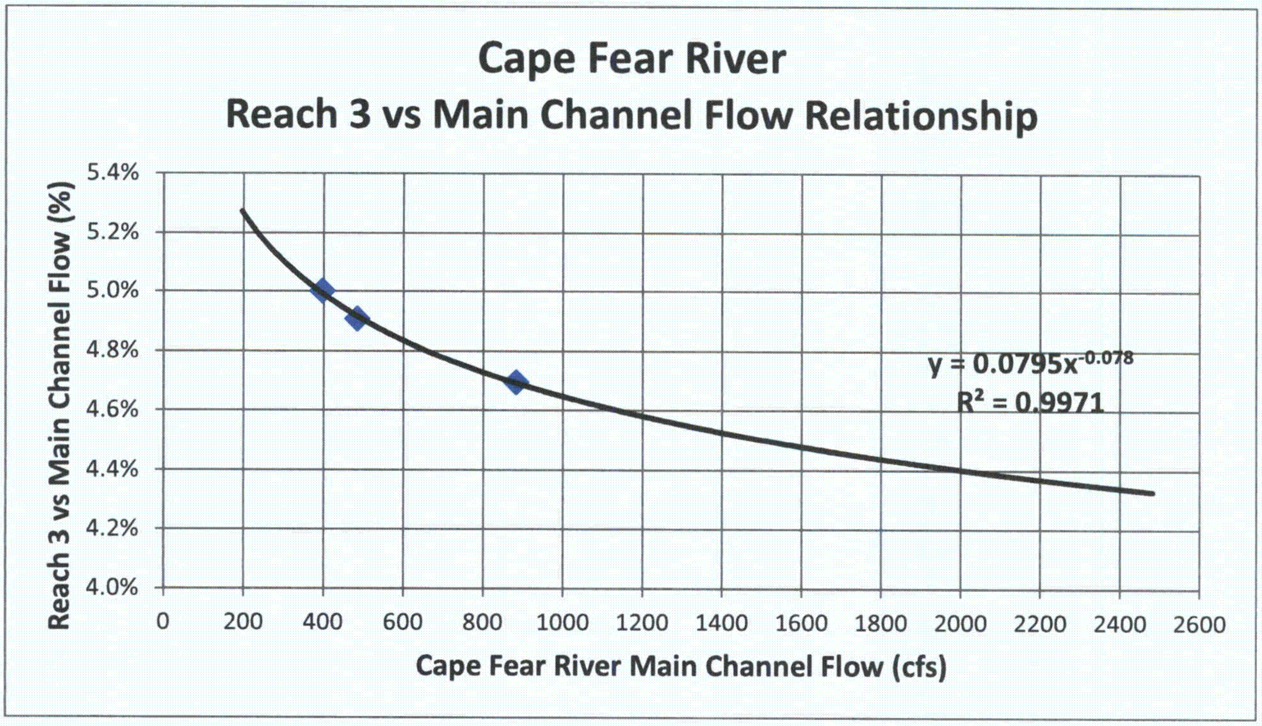


TABLE 16
CAPE FEAR RIVER REACH 3 FLOW PROPORTION

Target Calibration Flow	Reach 3 Flow (cfs)	Main Channel Flow (cfs)	Flow Proportion (%)
High Flow	41.4	882	4.69%
Mid-High Flow	30	680	4.41%
Mid Flow	23.7	483	4.91%
Low Flow	19.8	396	4.99%

*Note: mid-high flow measurement was dropped from the flow proportion analysis.

FIGURE 14
CAPE FEAR RIVER REACH 3 FLOW RELATIONSHIP



Three hydraulic calibration models were developed for the four transects on the Reach 1 side channel. Each model was associated with a velocity calibration set based on the measured flows of 61 cfs, 32 cfs, and 19 cfs. A Log/Log regression was selected as the preferred calibration method for Transects T-2 and T-3 and MANSQ was selected as the preferred calibration method for Transects T-1 and T-4. Mean errors for all four transects were less than 5%.

Three hydraulic calibration models were developed for the four transects on the Reach 2 side channel. The velocity calibration sets were associated measured flows of 350 cfs, 305 cfs, and 217 cfs. A Log/Log regression was selected as the preferred calibration method for Transect T-1 and MANSQ was selected as the preferred calibration method for Transects T-2, T-3, and T-4. The Log/Log mean error was less than 10% and the MANSQ mean errors were less than 2%.

The four transects in Reach 3 exhibited a non-linear stage-discharge relationship over the range of field data collected. Several causes of this non-linear relationship were explored and the most plausible explanation was that a transitory change in the upstream hydraulic control between data collection events may have been the cause. The middle-high flow (24.1 cfs) was the first flow collected on November 4, 2009. Subsequent calibration flows were collected at least seven months later (May, June, and September 2010). Several high flow events occurred on the Cape Fear River during this seven month period which could have modified the hydraulic control for flows entering the top end of Reach 3. As a result, the middle-high flow velocity data set was excluded and the hydraulic model was calibrated using the remaining two velocity data sets associated with measured flows of 41.4 cfs and 19.8 cfs. Log/Log was selected as the primary calibration method over MANSQ for all four transects since it resulted in mean errors of less than 5%.

Complete details on the calibration process are provided in Appendix C. Photographs of each transect, transect details (cross-section profiles, velocity profiles, and substrate mapping), and transect weighting factors are also provided in Appendix C.

After the PHABSIM models were calibrated from a hydraulic standpoint, the HSC curves were entered into the model to calculate WUA for each species/life stage over the model simulation flow range. WUA describes the amount of habitat a given flow provides (based on depth, velocity, and substrate/cover) for each species/life stage modeled.

WUA is determined in a three-step process. First, the 1-D PHABSIM model provides habitat results on a cell-by-cell basis across each transect for each species/life stage and for each flow simulated. These incremental amounts of habitat are determined based on the product of the habitat suitability variables (depth, velocity, and substrate/cover), which each vary from 0.0 to 1.0. Next, the results are converted to square ft of habitat by factoring in the weighting factor for each transect and the overall reach length. This result is then normalized into square feet per 1,000 linear ft. WUA does not directly translate to actual area of suitable habitat, but instead, it is the relative suitability of the available habitat.

The maximum WUA for each species/life stage is the flow at which the relative suitability of the available habitat is the highest for each target species/life stage. It does not define the optimum flow regime for the particular species/life stage. Rather, WUA is considered a building block for the Habitat Duration Analysis (HDA) (described in Section 6.3) which is used to evaluate the relative habitat suitability of different flow regimes.

6.2. Buckhorn Creek WUA

The Buckhorn Creek PHABSIM model output yielded a series of curves representing the modeled WUA between 2 cfs and 165 cfs for each of the 24 species/life stages of fish and macroinvertebrates modeled. These 24 species/life stages were grouped by individuals and guilds for the purpose of displaying results for like species and guilds. Buckhorn Creek WUA figures for individual species/life stages, the four habitat guilds (i.e., shallow slow, shallow fast, deep slow, and deep fast), and macroinvertebrates are provided in Appendix D. Table 1 in Appendix D is a list of individual species and guild acronyms used for modeling and graphing purposes.

Based on field data collection, 51% of the Buckhorn Creek study reach is comprised of shallow-slow habitat types (Table 4). For the target fish species and guilds, the shallow-slow guild (redbreast sunfish spawning and silver redhorse YOY) had the highest WUA at flows between 10 and 30 cfs. WUA for the shallow-fast guild also peaked in this flow range, but the amount of habitat was much smaller as only 9% of the reach is comprised of shallow-fast habitat types (e.g., [riffles and shallow runs]). Deep-slow guild species (redbreast sunfish adult) had similar peaks in WUA around 30 cfs. The deep-fast guild generally reached maximum WUA at flows greater than 80 cfs, but was still within 30-60% of maximum WUA at lower flows. By contrast, the higher flows preferred by the deep-fast guild resulted in a 65% reduction of WUA for shallow-slow guild species.

For the stand-alone species/life stages modeled, American shad juvenile, which prefer deep-fast habitat types, had the largest amount of WUA at the highest modeled flow of 165 cfs. At 30 cfs, American shad juvenile WUA is only reduced by half. Cape Fear shiner had the lowest WUA, possibly as a result of their preference for gravel and cobble substrates, which are not prevalent in Buckhorn Creek. Macroinvertebrate WUAs are relatively high across a wide range of flows.

6.2.1 Cape Fear River WUA

The Cape Fear River PHABSIM model output yielded a series of WUA curves for the 33 species/life stages modeled for each of the three side channel study reaches. Similar to Buckhorn Creek, these 33 species/life stages were grouped by individuals and guilds for the purpose of displaying results for like species and guilds. Cape Fear River WUA figures for individual species/life stages, the four habitat guilds (i.e., shallow slow, shallow fast, deep slow, and deep fast), and macroinvertebrates are provided in Appendix E. Table 1 in Appendix E is a list of individual species and guild acronyms used for modeling and graphing purposes.

<u>Reach 1</u>

Reach 1 is a moderately wide side channel at the lower end of the study area containing primarily bedrock, cobble, and sand substrates with some woody debris along the margins. Shallow-slow and shallow-fast habitat types make up 56% and 24% of the reach, respectively (Appendix C—Reach 1, Table 1). For the target fish species and guilds investigated, the shallow-slow guild (coarse substrate) had the largest amount of WUA at very low flows (10 cfs in Reach 1 which corresponds to a main channel flow of approximately 250 cfs). The shallow-fast guild preferred higher flows (40 cfs in Reach 1 which corresponds to a main channel flow of approximately 650 cfs). WUA for these two guilds decreases as flows increase above their preferred range. The opposite trend occurs for the deep-slow and deep-fast guilds as their habitat increases with increasing flows. This is also the case for several individual species including

American shad and striped bass spawning life stages. Macroinvertebrates had relatively high WUAs across the full range of flows modeled in Reach 1.

Reach 2

Reach 2 is the widest of the three side channels and at lower flows, carries a slightly higher percentage of the overall flow than the main channel does. Little to no woody debris cover exists on the channel margins, and substrates primarily include bedrock with smaller percentages of gravel and cobble. Reach 2 is comprised of 38% deep-slow, 26% shallow-slow, and 10% shoal habitat types; which is unique among the three side channels (Appendix C—Reach 2, Table 1). The diversity of habitat types in Reach 2 results in relatively high WUAs for all of the guilds at the flows modeled. For the individual species modeled, American shad spawning had the highest WUA and Channel catfish spawning had the lowest. Channel catfish prefer deep-slow habitat which is available, but also sandy substrate which is not. Macroinvertebrate WUAs were high across the full range of flows modeled.

Reach 3

Reach 3 is the narrowest of the three side channels and has more woody debris and gravel/sand substrates than the other two side channels. The dominant habitat types in Reach 3 are shallow-slow (41%), deep-slow (26%), and run habitats (23%) with gravel and sand substrates (Appendix C—Reach 3, Table 1). The shallow-slow and deep-slow guilds had the highest overall WUAs. Of the individual species modeled, the golden redhorse adult (surrogate for the Carolina redhorse) had the highest amount of WUA while Striped bass spawning had the lowest; possibly a result of deeper depth preferences. Macroinvertebrate WUAs were relatively high across the full range of flows modeled.

Overall, the three side channel study reaches provide a diverse array of habitat. While shallow-slow and deep-slow habitats are the most prevalent, there is also a fairly large amount of shallow-fast habitat – particularly in Reach 1 and the shoal area of Reach 2. While there is some deep-fast habitat in the side channels, it is a smaller percentage when compared to the other habitat types available. These habitat types are likely more prevalent in the main channel of the Cape Fear River.

6.3 Habitat Duration (Time Series) Model

The WUA function is a static relationship between discharge and habitat that does not represent how often a specific flow/habitat relationship occurs. For this reason, WUA is usually not considered the final result of an instream flow study. A more complete analysis is the HDA, also referred to as a time-series analysis. An HDA integrates WUA with hydrology and project operations to provide a dynamic analysis of flow versus habitat. The time-series analysis tool provides habitat information specific to the stream reach being modeled over a long period of record and various flow release scenarios. In the case of the Buckhorn Creek and Cape Fear River models, daily hydrology was used to determine the amount of daily habitat present in each reach. A habitat duration curve was then constructed in exactly the same way as a flow duration curve, but used habitat values instead of stream discharges as the ordered data. As a result, the time-series product is a more realistic measure of available habitat in a regulated stream over time than WUA curve analysis alone.

6.3.1 Development of Hydrology Records

During the study plan development phase of this project, the study team recommended that regulated and unregulated hydrology databases be developed and used as baselines, or benchmarks, to which other proposed flow regimes could be compared. Further, the study team recommended that the Cape Fear River Basin Model (CFRBM) (developed by Hydrologics, Inc.), be used to develop the hydrology databases. The CFRBM is a hydrology and operations model that is being used to study the Cape Fear River Basin as a comprehensive water resources system. The area studied by the model includes the drainage area from the top of the basin downstream to Lock and Dam #1. This drainage area encompasses all of the upper basin and much of the lower basin. The model uses the full period of record of 80 years of stream flow data (1930 through 2009) to simulate the system under any water use scenario the user defines. A detailed description of the CFRBM model, including model logic and hydrology calibration, has been documented in the Hydrologics, Inc. report titled "Modeling Harris Lake Proposed Operations Using OASIS" (Hydrologics, Inc. 2011).

For the Buckhorn Creek HDA, the CFRBM was used to create 80-year regulated and unregulated hydrology databases at two flow nodes: Harris Dam and the Buckhorn Creek near Corinth, North Carolina USGS flow gaging station. For the Cape Fear River HDA, the CFRBM was used to create similar hydrology databases at three locations:

1. The Cape Fear River immediately upstream from the proposed location of the pumping station that will be used to transfer water from the Cape Fear River to Harris Reservoir;
2. The Cape Fear River immediately downstream from Buckhorn Dam, but upstream from the proposed Western Wake Partners wastewater discharge location; and
3. The Cape Fear River immediately downstream from the proposed Western Wake Partners wastewater discharge location, but upstream from the mouth of Buckhorn Creek.

The location of all flow nodes used for the Buckhorn Creek and Cape Fear River instream flow studies is shown on Figure 15. In addition, a flow node was established at the mouth of Buckhorn Creek. Flows at this node were calculated by adding incremental drainage area accretion flows between the Buckhorn Creek USGS gage node and the mouth of Buckhorn Creek. This additional drainage area was determined to be 3.86 square miles and is depicted in Figure 16.

FIGURE 15
FLOW NODE LOCATIONS

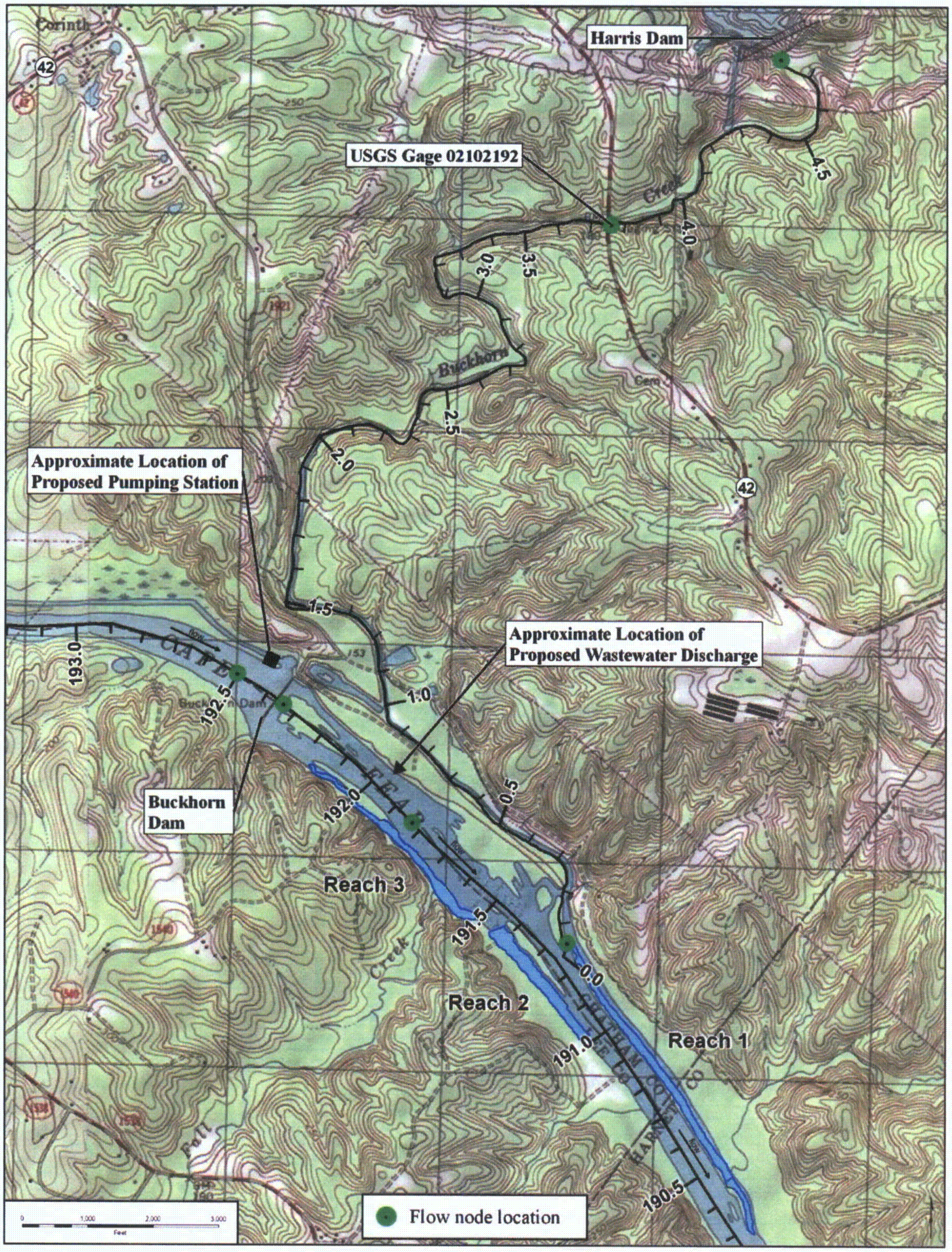
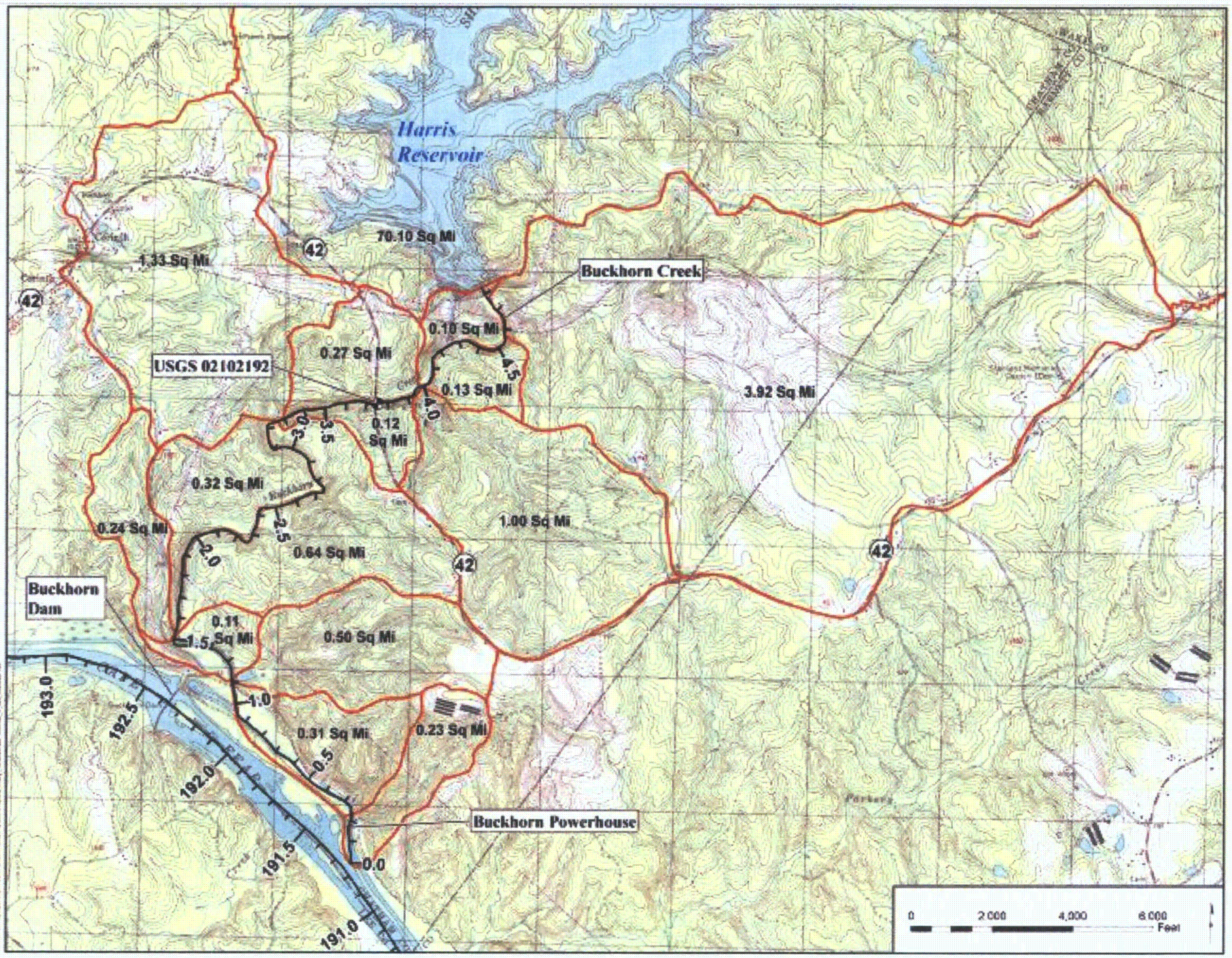


FIGURE 16
BUCKHORN CREEK DRAINAGE AREA MAP



6.3.2 HDA Interactive Analytical Tool

While habitat duration curves are one of the best means of comparing habitat availability over time between one flow scenario and another, the number of graphs required can become overwhelming (often in the thousands) as study variables become more numerous. For example, there is one habitat duration curve generated for each species/life stage for each flow modeled. To overcome the problems of data overload, the study team used a proprietary software program developed by HDR called Flow Time Series (written in Power Basic®). Flow Time Series relies on the computer to store, calculate, and visually organize habitat duration results. The program calculates the area under each habitat duration curve, commonly referred to as the Area Under the Curve (AUC), and stores that information as a single value. These values can then be analyzed in the form of various habitat "indices" or "metrics." These habitat metrics are defined as:

- **Median** – if all daily habitat values for the period of record for a given month are rank ordered, the median value is that habitat level at which half of the values are greater and half are lesser. This is also referred to as the 50% exceedance level.
- **Index A** is defined as the average WUA value of all habitat events in a given month that fall between the 50% and 90% exceedance levels.
- **Index B** is defined as the average WUA value of all habitat events in a given month that fall between the 10% and 90% exceedance levels and is sometimes referred to as a "trimmed mean."
- **Index C** is defined as the average WUA value of all habitat events in a given month that fall between the 50% and 100% exceedance levels which represent the lower half of the WUA values (the 100% exceedance level is the minimum value for the month). The lower half of the WUA values can be the result of flows that are either too high or too low depending on the species and life stage being evaluated. Index C is often used as a metric because it is associated with the lower, or more critical, end of the habitat scale and as such is a conservative means of evaluating aquatic habitat gains.
- **AUC** is very similar to Index C with the exception that it is the total area under the habitat duration curve between 50% and 100% exceedance instead of the mean value between 50% and 100% exceedance.

The study team primarily used three habitat metrics to compare habitat availability over time between one flow scenario and another. The first two were slightly modified versions of Index B. Instead of evaluating the 10% - 90% portion of the exceedance curve, the first metric evaluated the entire exceedance curve (i.e., 0% - 100%) and the second metric evaluated a trimmed mean from 5% - 95%. The third habitat metric used was Index C as described above.

Flow Time Series calculated the chosen metric by species/life stage, month, and flow scenario. The program creates individual files of all model runs, which provides an efficient means of data analysis with a large number of species/guilds and life stages and flow scenarios.

For Buckhorn Creek, the 17 transects were modeled as a single study reach. As a result, the HDA results were developed for the reach as a whole. For the Cape Fear River, HDA results were generated for each of the three side channel study reaches individually and then combined into a composite set of HDA results.

Section 7
Model Results and Discussion

7.1 Initial Model Results

Once the Buckhorn Creek and Cape Fear River PHABSIM models were calibrated hydraulically, and the 80-year period of record unregulated and regulated hydrology databases were available and approved for use, an initial set of model results was prepared. For Buckhorn Creek, the initial model runs used unregulated and regulated hydrology datasets that were created assuming that the full pond elevation at Harris Reservoir remained at the current 220 ft msl with no withdrawals from the Cape Fear River to support water needs in Harris Reservoir or minimum flows in Buckhorn Creek. The rationale behind this study team recommendation was that until more was known about the potential range of suitable minimum flows in Buckhorn Creek, there were too many unknowns to develop a pumping scheme that would support the proposed future full pond elevation at Harris Reservoir of 240 ft msl. For the Cape Fear River, the initial model runs assumed either 135 cfs or 200 cfs was removed from the Cape Fear River to support Harris Reservoir levels and Buckhorn Creek minimum flows regardless of what the daily flows were in the Cape Fear River.

The study team held four workshops on March 22, April 25, May 20, and June 17, 2011 to review the initial habitat modeling results for Buckhorn Creek and the Cape Fear River.

7.1.1 Buckhorn Creek Initial Model Results

For the initial set of Buckhorn Creek model results, the regulated hydrology habitat results were compared to the unregulated hydrology habitat results for each month. The study team established a criterion of trying to achieve 80% of the unregulated habitat results (i.e., the habitat that would have been available if Harris Dam had never been built). While achieving 80% of the unregulated habitat is not a rule or standard, it is often used by natural resource agencies as a goal when evaluating instream flow habitat results. The monthly minimum flows in Buckhorn Creek were increased, in 1 cfs increments, until the regulated habitat results met (or came very close to meeting) the 80% unregulated habitat criteria. The resulting monthly flows are provided in Table 17. Note that the 80% unregulated habitat criteria is often met by a flow range instead of a single flow. Habitat for many species/life stages may be low at the low end of the flow regime and also low at the high end of the flow regime (refer to the WUA discussion in Section 6.2 and figures provided in Appendix D and Appendix E). As a result, a low and high minimum flow was determined for each month based on meeting the 80% unregulated habitat criteria. For comparison purposes, the monthly median unregulated flows are also provided in Table 17.

TABLE 17
BUCKHORN CREEK INITIAL HABITAT MODEL RESULTS

Buckhorn Creek Initial Monthly Minimum Baseflow Range based on Full AUC (1% - 100%) Habitat Metric					Monthly Median Unregulated Flow (cfs)
Month	Baseflow Range (cfs)		Individual Species/Life Stages with < 80% Unregulated Habitat		
	Low	High	Low Baseflow Range	High Baseflow Range	
Jan	14	30	DF-Coarse (74%); DF-Gravel Cobble (71%)	DF-Coarse (79%)	92
Feb	4	30	All species/life stages > 80%	All species/life stages > 80%	79
Mar	4	30	All species/life stages > 80%	All species/life stages > 80%	93
Apr	4	25	CCHUBS (79%)	All species/life stages > 80%	53
May	8	17	All species/life stages > 80%	SS-Early (79%)	20
Jun	8	17	DF-Coarse (70%); DF- Gravel Cobble (78%)	SS-Early (71%); DF-Coarse (79%)	12
Jul	8	17	All species/life stages > 80%	SS-Early (67%)	10
Aug	4	17	All species/life stages > 80%	SS-Early (70%)	10
Sep	4	17	DF-Coarse (72%)	SS-Early (66%)	7
Oct	4	17	All species/life stages > 80%	SS-Early (70%)	9
Nov	14	25	DF- Gravel Cobble (70%)	SS-Early (74%); SS-Coarse (74%)	17
Dec	14	30	DF- Gravel Cobble (64%)	All species/life stages > 80%	38

7.1.2 Cape Fear River Initial Model Results

Two scenarios were evaluated for the initial set of Cape Fear River model runs: removing 135 cfs on a daily basis and removing 200 cfs on a daily basis. The 135 cfs withdrawal scenario was based on the initial maximum pumping capacity identified in the Combined Operating License

Application for the HAR Project. The 200 cfs withdrawal scenario was based on an arbitrary cap used in the model for the initial set of model runs. Initial model results are provided in Table 18.

TABLE 18
CAPE FEAR RIVER INITIAL HABITAT MODEL RESULTS

Cape Fear River Habitat Initial Habitat Model Results
All Water Year Types with Trimmed AUC (5% - 95%)

Habitat at 0 cfs Withdrawal (% of Unregulated)

No.	Species/Lifestage	Guild* / Stand Alone	Abbreviation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	American Shad Incubation	Stand Alone	AMSHI				104	92	92						
2	American Shad Juvenile and Larval	Stand Alone	AMSHJL				104	92	90	88					
3	American Shad Outmigration	Stand Alone	AMSHO				104	90	87	83	83	90	90		
4	American Shad Spawning	Stand Alone	AMSHS			105	103	95	95						
5	Composite Chub Adult	Stand Alone	CCHUBA	102	99	99	112	120	120	117	114	110	108	110	120
6	Composite Chub Spawning	Stand Alone	CCHUBS			99	108	117	123	123					
7	Cape Fear Shiner Adult	Stand Alone	CFSHA	104	101	102	110	120	111	114	118	112	116	117	133
8	Cape Fear Shiner Spawning	Stand Alone	CFSHS				100	106	102						
9	Channel Catfish Adult	Stand Alone	CHCFA	104	105	107	104	89	86	83	82	89	89	86	89
10	Channel Catfish Juvenile	Stand Alone	CHCFJ	103	104	106	103	93	93	92	91	98	97	91	92
11	Channel Catfish Spawning	Stand Alone	CHCFS					89	84	81					
12	Shorthead Redhorse Adult	DF - Coarse Mix Sub	DF-Coarse	103	103	105	103	94	94	95	95	100	100	94	93
13	Silver Redhorse Adult	DF - Fine Sub	DF-Fine	103	104	106	103	92	91	89	88	95	94	89	90
14	White Bass Spawning	DF - Grav Sm Cob Sub	DF-GrCob	105	105	108	105	90	88	83	81	89	87	85	89
15	Redbreast Sunfish Adult	DS - Cover Redbreast	DS-C	99	99	99	100	102	103	104	103	104	104	102	101
16	Deep Slow Generic - Cover	DS - Generic Cover	DS-GenC	102	102	103	101	94	93	94	94	99	100	94	93
17	Deep Slow Generic - No Cover	DS - Generic No Cover	DS-GenNC	103	104	105	103	94	94	93	90	97	94	90	92
18	Ephemeroptera - Mayfly	EPT	EPHEM	99	99	98	101	104	106	107	106	107	106	103	103
19	Golden Redhorse Adult - Carolina Surrogate	Stand Alone	GORHA	101	102	103	101	96	97	98	98	101	102	96	95
20	Golden Redhorse Juvenile - Carolina Surrogate	Stand Alone	GORHJ					95	95	97					
21	Plecoptera - Stonefly	EPT	PLECO	99	99	98	100	104	108	111	109	112	110	102	100
22	Fantail Darter Adult	SF - High Velocity	SF-HV	103	104	106	103	94	92	93	94	101	103	95	94
23	Margined Madtom Adult	SF - Lower Velocity	SF-LV	101	99	99	107	112	112	111	111	108	108	109	116
24	Shallow Fast Guild	SF - Moderate Velocity	SF-MV	99	99	98	100	102	104	107	108	110	110	103	100
25	Shallow Slow Guild	SS - Coarse Sub	SS-Coarse	105	99	98	117	123	114	108	107	100	100	109	133
26	Bluehead Chub YOY	SS - Early Life Stage	SS-Early	103	100	100	109	112	105	102	100	90	85	101	120
27	Redbreast Sunfish Spawning	SS - Fine Sub No Cover	SS-FineNC	100	99	99	101	103	103	104	105	104	105	104	105
28	Silver Redhorse YOY - Surrogate for Notchlip	SS - Veg Cover	SS-Veg	100	99	99	102	104	104	104	105	104	104	104	107
29	Silver Redhorse YOY - Surrogate for Notchlip	SS - Wood Cover	SS-Wood	100	99	99	103	105	104	104	105	103	103	105	108
30	Striped Bass Incubation	Stand Alone	STBAI					91	87	84					
31	Striped Bass Juvenile	Stand Alone	STBAJ	105	105	108	105	90	87	83	82	91	90	86	90
32	Striped Bass Spawning	Stand Alone	STBAS				105	91							
33	Trichoptera 1 - Caddisfly	EPT	TRIC1	99	100	100	100	100	101	103	102	104	104	99	98

Habitat at 135 cfs Withdrawal (% of Unregulated)

No.	Species/Lifestage	Guild* / Stand Alone	Abbreviation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	American Shad Incubation	Stand Alone	AMSHI				101	86	81						
2	American Shad Juvenile and Larval	Stand Alone	AMSHJL				101	85	80	78					
3	American Shad Outmigration	Stand Alone	AMSHO				101	83	76	73	73	79	79		
4	American Shad Spawning	Stand Alone	AMSHS			103	101	89	87						
5	Composite Chub Adult	Stand Alone	CCHUBA	114	112	111	125	122	114	114	115	110	110	114	129
6	Composite Chub Spawning	Stand Alone	CCHUBS			109	113	107	99	102					
7	Cape Fear Shiner Adult	Stand Alone	CFSHA	113	104	104	125	148	141	136	133	122	124	121	145
8	Cape Fear Shiner Spawning	Stand Alone	CFSHS				101	107	98						
9	Channel Catfish Adult	Stand Alone	CHCFA	101	102	104	100	83	77	74	74	80	80	79	84
10	Channel Catfish Juvenile	Stand Alone	CHCFJ	101	102	104	100	87	83	82	82	86	86	83	87
11	Channel Catfish Spawning	Stand Alone	CHCFS					82	76	72					
12	Shorthead Redhorse Adult	DF - Coarse Mix Sub	DF-Coarse	101	102	103	100	90	88	87	87	91	91	86	89
13	Silver Redhorse Adult	DF - Fine Sub	DF-Fine	101	102	104	100	85	79	77	77	83	82	81	86
14	White Bass Spawning	DF - Grav Sm Cob Sub	DF-GrCob	101	103	105	101	82	73	69	69	76	76	77	84
15	Redbreast Sunfish Adult	DS - Cover Redbreast	DS-C	100	100	100	101	101	100	101	101	101	101	100	101
16	Deep Slow Generic - Cover	DS - Generic Cover	DS-GenC	100	101	102	99	89	86	87	87	90	90	85	89
17	Deep Slow Generic - No Cover	DS - Generic No Cover	DS-GenNC	100	102	104	101	85	77	75	77	82	82	83	87
18	Ephemeroptera - Mayfly	EPT	EPHEM	101	101	101	103	102	101	103	103	102	102	100	102
19	Golden Redhorse Adult - Carolina Surrogate	Stand Alone	GORHA	100	101	102	100	93	92	93	92	95	95	91	92
20	Golden Redhorse Juvenile - Carolina Surrogate	Stand Alone	GORHJ					90	88	88					
21	Plecoptera - Stonefly	EPT	PLECO	99	101	100	101	99	97	99	99	99	99	94	97
22	Fantail Darter Adult	SF - High Velocity	SF-HV	101	102	104	101	91	92	91	89	94	94	87	90
23	Margined Madtom Adult	SF - Lower Velocity	SF-LV	110	108	108	118	119	115	115	115	111	111	112	123
24	Shallow Fast Guild	SF - Moderate Velocity	SF-MV	99	100	100	101	100	101	103	102	102	102	96	97
25	Shallow Slow Guild	SS - Coarse Sub	SS-Coarse	124	117	115	142	140	126	120	120	112	112	124	155
26	Bluehead Chub YOY	SS - Early Life Stage	SS-Early	112	109	109	120	125	119	114	112	102	98	118	134
27	Redbreast Sunfish Spawning	SS - Fine Sub No Cover	SS-FineNC	102	102	101	104	107	107	108	107	105	105	104	107
28	Silver Redhorse YOY - Surrogate for Notchlip	SS - Veg Cover	SS-Veg	104	103	103	106	107	106	106	107	105	105	105	109
29	Silver Redhorse YOY - Surrogate for Notchlip	SS - Wood Cover	SS-Wood	104	103	103	107	108	107	107	108	106	106	107	112
30	Striped Bass Incubation	Stand Alone	STBAI					84	79	76					
31	Striped Bass Juvenile	Stand Alone	STBAJ	102	103	105	102	83	77	73	73	81	80	78	85
32	Striped Bass Spawning	Stand Alone	STBAS				102	84							
33	Trichoptera 1 - Caddisfly	EPT	TRIC1	99	100	100	99	97	95	97	97	97	97	94	96

Habitat at 200 cfs Withdrawal (% of Unregulated)

No.	Species/Lifestage	Guild* / Stand Alone	Abbreviation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	American Shad Incubation	Stand Alone	AMSHI				99	83	78						
2	American Shad Juvenile and Larval	Stand Alone	AMSHJL				99	82	76	73					
3	American Shad Outmigration	Stand Alone	AMSHO				99	80	72	69	69	75	75		
4	American Shad Spawning	Stand Alone	AMSHS			103	99	87	83						
5	Composite Chub Adult	Stand Alone	CCHUBA	119	119	117	132	128	118	118	118	112	112	116	133
6	Composite Chub Spawning	Stand Alone	CCHUBS			114	116	108	99	102					
7	Cape Fear Shiner Adult	Stand Alone	CFSHA	117	107	106	134	158	149	141	137	126	128	128	152
8	Cape Fear Shiner Spawning	Stand Alone	CFSHS				102	111	111						
9	Channel Catfish Adult	Stand Alone	CHCFA	99	101	103	99	80	73	70	70	76	76	75	82
10	Channel Catfish Juvenile	Stand Alone	CHCFJ	99	101	103	99	84	79	78	78	81	81	79	85
11	Channel Catfish Spawning	Stand Alone	CHCFS					79	72	68					
12	Shorthead Redhorse Adult	DF - Coarse Mix Sub	DF-Coarse	100	101	103	99	87	84	83	83	86	86	82	87
13	Silver Redhorse Adult	DF - Fine Sub	DF-Fine	99	101	103	99	82	75	73	73	77	78	77	84
14	White Bass Spawning	DF - Grav Sm Cob Sub	DF-GrCob	100	101	104	100	78	69	65	66	72	72	73	82
15	Redbreast Sunfish Adult	DS - Cover Redbreast	DS-C	101	101	101	101	101	100	100	100	100	100	98	101
16	Deep Slow Generic - Cover	DS - Generic Cover	DS-GenC	99	100	102	98	86	82	82	82	84	84	81	87
17	Deep Slow Generic - No Cover	DS - Generic No Cover	DS-GenNC	99	101	103	99	82	73	72	75	77	78	79	86
18	Ephemeroptera - Mayfly	EPT	EPHEM	101	102	102	103	102	100	101	101	100	100	98	102
19	Golden Redhorse Adult - Carolina Surrogate	Stand Alone	GORHA	99	100	101	99	91	90	90	89	91	91	87	91
20	Golden Redhorse Juvenile - Carolina Surrogate	Stand Alone	GORHJ					88	84	84					
21	Plecoptera - Stonefly	EPT	PLECO	99	101	102	101	97	94	95	94	94	93	90	95
22	Fantail Darter Adult	SF - High Velocity	SF-HV	100	101	103	100	88	87	86	85	88	88	82	87
23	Margined Madtom Adult	SF - Lower Velocity	SF-LV	114	113	113	122	123	119	118	117	112	112	113	126
24	Shallow Fast Guild	SF - Moderate Velocity	SF-MV	99	101	100	101	99	99	99	98	98	97	92	96
25	Shallow Slow Guild	SS - Coarse Sub	SS-Coarse	134	128	126	154	151	135	129	129	119	119	131	165
26	Bluehead Chub YOY	SS - Early Life Stage	SS-Early	117	114	113	126	130	123	117	118	113	109	134	146
27	Redbreast Sunfish Spawning	SS - Fine Sub No Cover	SS-FineNC	103	103	103	106	107	108	108	107	105	104	103	107
28	Silver Redhorse YOY - Surrogate for Notchlip	SS - Veg Cover	SS-Veg	105	105	105	108	108	107	107	107	105	105	105	110
29	Silver Redhorse YOY - Surrogate for Notchlip	SS - Wood Cover	SS-Wood	106	105	106	109	110	109	109	109	106	106	107	113
30	Striped Bass Incubation	Stand Alone	STBAI					81	76	72					
31	Striped Bass Juvenile	Stand Alone	STBAJ	100	102	104	100	80	74	70	69	76	76	75	82
32	Striped Bass Spawning	Stand Alone	STBAS				100	81							
33	Trichoptera 1 - Caddisfly	EPT	TRIC1	99	100	100	99	95	93	94	94	94	94	92	95

Legend: =>100% | =>80% | =>70% | =>60% | <60%

Guild Descriptions:

*SS = Shallow Slow; <= 2 ft deep and < 1ft/s velocity

*SF = Shallow Fast; <= 2 ft deep and > 1 ft/s velocity

*DS = Deep Slow; >= 2 ft deep and < 1 ft/s velocity

*DF = Deep Fast; >= 2 ft deep and > 1 ft/s velocity

Initial model results are provided for three scenarios in Table 18. The first set of model output assumes no withdrawals from the Cape Fear River. The second and third sets of model output provide results for daily withdrawals of 135 cfs and 200 cfs, respectively. Results are provided for each species/life stage on a monthly basis. The numbers in each cell refer to the amount of habitat that is provided compared to the unregulated model results. For example, in row 13 of Table 18, the Silver redhorse, adult life stage is being used as a surrogate for the deep fast fine substrate guild. Under regulated hydrologic conditions with no water withdrawals, the amount of available habitat in June is 91% of the unregulated habitat. If 135 cfs is removed on a daily basis, the amount of available habit decreases to 79% of the unregulated habitat. If 200 cfs is removed on a daily basis, the available habitat drops to 75% of the unregulated habitat. The color-coding system is based on percent of habitat compared to the unregulated habitat. Equal to or greater than 100% of unregulated is blue; equal to or greater than 80% of unregulated is green, etc. The grayed out cells are based on the periodicity associated with some of the individual species/life stages that are not present during parts of the year. Any species/life stage that represents a guild is assumed to be present year-round. Overall, the habitat results for the two initial withdrawal scenarios mostly met, or exceeded, the 80% unregulated habitat criteria.

7.2 Intermediate Model Results

The initial model results for Buckhorn Creek and the Cape Fear River study reaches provided the foundation from which additional Buckhorn Creek minimum flow regimes and Cape Fear River pumping schemes were developed. The CFRBM unregulated and regulated hydrology databases were updated assuming the future 240 ft msl full pond elevation at Harris Reservoir. With the updated hydrology incorporated into the PHABSIM models, habitat tradeoffs between Buckhorn Creek and the Cape Fear River could be evaluated. The study team held three workshops on July 12, August 17, and September 14, 2011, during which a wide range of alternatives were considered as agency and stakeholder interests were vetted.

During this process, it quickly became apparent that Harris Reservoir elevations were going to be a key component of any minimum flow and pumping scheme determination. As a result, the study team decided to establish Harris Reservoir elevation criteria based on wetland and recreation concerns. The reservoir elevation thresholds that were evaluated included the amount of time above/below 238 ft msl (potential wetland impacts) and the amount of time above/below 234 ft msl (potential impacts to recreation). These criteria were used as part of the overall evaluation process to compare and contrast different flow scenarios.

For Buckhorn Creek, the initial habitat modeling resulted in potential low and high baseflow ranges that met the 80% unregulated habitat criteria. To better match the unregulated monthly median flow pattern, adjustments were made to the low baseflow range for June (from 8 cfs to 6 cfs), July (from 8 cfs to 4 cfs), and November (from 14 cfs to 8 cfs) (see Table 19). No adjustments were made to the high baseflow range.

TABLE 19
BUCKHORN CREEK ADJUSTED MINIMUM BASEFLOWS

Month	Low Baseflow Range (cfs)	High Baseflow Range (cfs)	Unregulated Median-of-Medians All Water Yrs 1930 - 2009 (cfs)
January	14	30	86
February	8	30	75
March	8	30	86
April	8	25	47
May	8	17	18
June	6	17	11
July	4	17	8
August	4	17	7
September	4	17	5
October	4	17	7
November	8	25	15
December	14	30	32

The study team then decided to evaluate the low and high baseflow scenarios under three different Cape Fear River pumping regimes. The pumping regimes assumed that either three or four 45 cfs pumps were available, which resulted in total pumping capacities of 135 cfs and 180 cfs, respectively. Cape Fear River flow thresholds were also established that dictated when the first pump, and subsequent pumps, could be turned on to transfer water from the Cape Fear River to Harris Reservoir. Details for the three pumping regimes are provided in Table 20.

TABLE 20
CAPE FEAR RIVER PUMPING REGIMES

Pumping Regime #1	1 Pump = 45 cfs	when	645 cfs	< Q_{CFR} <=	690 cfs
	2 Pumps = 90 cfs	when	690 cfs	< Q_{CFR} <=	735 cfs
	3 Pumps = 135 cfs	when	735 cfs	< Q_{CFR}	
Pumping Regime #2	1 Pump = 45 cfs	when	645 cfs	< Q_{CFR} <=	690 cfs
	2 Pumps = 90 cfs	when	690 cfs	< Q_{CFR} <=	735 cfs
	3 Pumps = 135 cfs	when	735 cfs	< Q_{CFR} <=	780 cfs
	4 Pumps = 180 cfs	when	780 cfs	< Q_{CFR}	
Pumping Regime #3	1 Pump = 45 cfs	when	700 cfs	< Q_{CFR} <=	800 cfs
	2 Pumps = 90 cfs	when	800 cfs	< Q_{CFR} <=	1000 cfs
	3 Pumps = 135 cfs	when	1000 cfs	< Q_{CFR} <=	1200 cfs
	4 Pumps = 180 cfs	when	1200 cfs	< Q_{CFR}	

The study team also wanted to evaluate scenarios that were based in part on trying to mimic the natural flow regime. To accomplish this, a "Variable" Buckhorn Creek flow release pattern was created in the CFRBM model. The Variable flow release logic was set to release a percentage of the inflow to Harris Reservoir based on lake elevation (see Table 21). The logic incorporated limits on the minimum flow release to Buckhorn Creek (4 cfs) and the maximum Harris Reservoir drawdown (226 ft msl). The Variable flow release logic also set several different caps on the maximum, non-spill releases to Buckhorn Creek. Initially, these caps were set at 40 cfs, 180 cfs, and 320 cfs. The caps were based on assumed capacities of three Howell Bunger-type flow release valves planned to be installed at the Harris Dam spillway. Two 36-inch Howell Bunger valves were assumed to have an operating range of 40 – 140 cfs each and one 12-inch Howell Bunger valve was assumed to have an operating range of 4 – 40 cfs. The caps assumed either single or multiple valves could be used to deliver the required flows to Buckhorn Creek.

TABLE 21
BUCKHORN CREEK VARIABLE FLOW RELEASE SCENARIOS

Buckhorn Creek 'Variable' flow release logic:
100% of inflow down to Harris level 235 ft msl
70% of inflow down to Harris level 230 ft msl
30% of inflow below Harris level 230 ft msl
Buckhorn Creek 'Variable A' flow release logic:
90% of inflow down to Harris level 238 ft msl
60% of inflow down to Harris level 234 ft msl
30% of inflow below Harris level 234 ft msl
Buckhorn Creek 'Variable B' flow release logic:
90% of inflow down to Harris level 239 ft msl
60% of inflow down to Harris level 236 ft msl
30% of inflow below Harris level 236 ft msl

All Buckhorn Creek flow release scenarios have a minimum of 4 cfs
Harris Reservoir maximum drawdown = 226 ft msl

Taking into account the low and high baseflow scenarios, the three Cape Fear River pumping regimes, and the Variable release flow pattern, 15 new Buckhorn Creek minimum flow scenarios were created. These scenarios are designated numerically from 1 to 15 with no additional letters following the scenario number (Table 22). A hydrology dataset for each of these flow scenarios was created using the CFRBM model and incorporated into the Buckhorn Creek PHABSIM model.

A review of the PHABSIM habitat modeling results for these 15 scenarios led to elimination of several scenarios based on the following reasons:

- All three low baseflow scenarios (Scenarios 1, 6, and 11) were eliminated because they provided relatively low overall habitat when compared to the other scenarios. Scenario 2 (high baseflow, pumping regime #1) was eliminated for the same reason.
- Scenario 7 (high baseflow, pumping regime #2) had more habitat than the low baseflow scenarios, but lacked flow variability when compared to the unregulated hydrology.
- Scenarios 4, 5, and 15 were not eliminated for habitat reasons, but did result in Harris Reservoir elevations that were below the recreation criteria of maintaining the lake at or above 234 ft msl at least 95% of the time from March through November.

TABLE 22
INTERMEDIATE MODEL SCENARIOS

Scenario	Cape Fear River Pumping Regime	Buckhorn Creek Release Scenario	Reason for Elimination
1	Pumping Regime #1	Low Baseflow	Low Relative Habitat
2	Pumping Regime #1	High Baseflow	Low Relative Habitat
2e	Pumping Regime #1	High Baseflow with Pulse	Low Reservoir Elevation
3	Pumping Regime #1	40 cfs cap / Variable	Revised Valve Flow Range
3a	Pumping Regime #1	30 cfs cap / Variable A	Low Reservoir Elevation
3b	Pumping Regime #1	30 cfs cap / Variable B	Low Reservoir Elevation
4	Pumping Regime #1	180 cfs cap / Variable	Low Reservoir Elevation
4a	Pumping Regime #1	150 cfs cap Jan-Apr 30 cfs cap May-Dec Variable A	Low Reservoir Elevation
5	Pumping Regime #1	320 cfs cap / Variable	Low Reservoir Elevation
6	Pumping Regime #2	Low Baseflow	Low Relative Habitat
6-7e	Pumping Regime #2	See Table 23	Finalist
7	Pumping Regime #2	High Baseflow	Low Habitat Variability
7e	Pumping Regime #2	High Baseflow with Pulse	Finalist
8	Pumping Regime #2	40 cfs cap / Variable	Revised Valve Flow Range
8a	Pumping Regime #2	30 cfs cap / Variable A	Low Habitat Variability
8b	Pumping Regime #2	30 cfs cap / Variable B	Low Habitat Variability
9	Pumping Regime #2	180 cfs cap / Variable	Low Reservoir Elevation
9a	Pumping Regime #2	180 cfs cap / Variable A	Finalist
9b	Pumping Regime #2	150 cfs cap Jan-Apr 30 cfs cap May-Dec Variable A	Replaced by 9bd
9bd	Pumping Regime #2	150 cfs cap Jan-Apr 30 cfs cap May-Dec Variable A	Finalist
10	Pumping Regime #2	320 cfs cap / Variable	Low Reservoir Elevation
11	Pumping Regime #3	Low Baseflow	Low Relative Habitat
12	Pumping Regime #3	High Baseflow	Low Reservoir Elevation
12e	Pumping Regime #3	High Baseflow	Low Reservoir Elevation
13	Pumping Regime #3	40 cfs cap / Variable	Revised Valve Flow Range
14	Pumping Regime #3	180 cfs cap / Variable	Low Reservoir Elevation
14b	Pumping Regime #3	150 cfs cap Jan-Apr 30 cfs cap May-Dec Variable A	Replaced by 14bd
14bd	Pumping Regime #3	150 cfs cap Jan-Apr 30 cfs cap May-Dec Variable A	Finalist
15	Pumping Regime #3	320 cfs cap / Variable	Low Reservoir Elevation

First set of eliminated scenarios
Second set of eliminated scenarios

Upon further evaluation of the Howell Bunger flow release valve design specifications, PEC recommended revising the operating range of the smaller (12-inch diameter) valve from (4 cfs – 40 cfs) to (4cfs – 30 cfs). As a result, Scenarios 3, 8, and 13 were no longer applicable and were eliminated from further consideration.

Only four of the original fifteen scenarios survived the initial rounds of elimination (Scenarios 9, 10, 12, and 14). However, thirteen new scenarios (excluding Scenario 6-7e) were created based on what the study team learned from the first set of Buckhorn Creek habitat results and the CFRBM Harris Reservoir elevation results. These thirteen additional scenarios are described below and are shown with a letter designation after the scenario base number in Table 22.

To maintain higher elevations in Harris Reservoir, the study team devised two more Variable flow release options: "Variable A" and "Variable B." When compared to the original Variable flow release logic, these new options reduced the percentage of inflow released to Buckhorn Creek and also raised the reservoir thresholds to which those flow release percentages applied (see Table 21). The original concept of a maximum flow cap was also modified to better match seasonal unregulated hydrology. The original 180 cfs cap was reduced to a 150 cfs cap from January through April. A 30 cfs cap was then applied from May through December. These recommendations added eight Scenarios: 3a, 3b, 4a, 8a, 8b, 9a, 9b, and 14b.

At this point, all of the model scenarios that incorporated one of the three Variable flow release options were based on an inherent assumption that the flow released to Buckhorn Creek could be changed every day. From an operations standpoint, this was not practical, so two scenarios (9b and 14b) were modified with an assumption that the flow release could be changed twice per week. These modified Scenarios were named 9bd and 14bd.

Throughout the model results review process, the study team was keenly interested in how closely each scenario provided flow releases to Buckhorn Creek that mimicked patterns seen in the unregulated hydrology dataset. It was desired that in addition to a minimum baseflow, a pulse flow similar to a rainfall runoff event, be incorporated into the model logic. Hydrologics, Inc. investigated the frequency that pulse events occurred over the full period of record (1930 –

2009) and determined that on average, a pulse event occurred approximately once every 30 days. As a result, Scenarios 2e, 7e, and 12e were created where the "e" indicated "enhanced" with a pulse once per month.

During the September 14, 2011, modeling workshop, the study team focused on narrowing down the field of potential Buckhorn Creek flow release options. Nine of the remaining seventeen scenarios were eliminated based on Harris Reservoir elevations. Scenarios 2e, 3a, 3b, 4a, 9, 10, 12, 12e, and 14 were eliminated because they resulted in a relatively high percentage of time (i.e., greater than 25%) Harris Reservoir would be below 238 ft msl on a year-round basis. Scenarios 9b and 14b were eliminated in favor of 9bd and 14bd that had more realistic operating assumptions. From a habitat perspective, Scenarios 8a and 8b did not provide the natural variability in flow releases to Buckhorn Creek that the study team was striving for. After this round of elimination, four scenarios remained: 7e, 9a, 9bd, and 14bd. All scenarios associated with pumping regime #1 had been eliminated and only one scenario associated with pumping regime #3 was still under consideration (14bd). The rest of the scenarios used pumping regime #2 assumptions.

Again, based on what the study team learned through the modeling results workshops, one final new scenario was created in an attempt to combine the best features from several other scenarios. The new scenario was designated Scenario 6-7e (which stands for Scenario 6-7 enhanced). Scenario 6-7e is a hybrid that uses both the pump regime #2 low and high baseflow scenarios as bookends, and also includes the monthly pulse enhancement. In addition, a mid-baseflow range was also determined. The baseflow range for a given month is determined by comparing the previous month's hydrology to the historic hydrology range. If the previous month's hydrology is in the lowest quartile, the low baseflow range is used. Likewise, if the previous month's hydrology is in the highest quartile, the high baseflow range is used. Also, if the previous month's hydrology is in the middle two quartiles, the mid-baseflow range is used.

The pulsing feature for Scenario 6-7e works as follows:

- A determination is made approximately mid-month as to whether or not a spill event has occurred during the previous 30-day period;
- If a spill event has occurred, no pulse flow is required;
- If a spill event has not occurred, a pulse flow is required;
- For the lower flow months of May through October, the duration of the pulse is two days;
- For the higher flow months of November through April, the duration of the pulse is three days;
- For all months, the magnitude of the pulse on Day 1 is five times the current baseflow, with a minimum of 30 cfs;
- For all months, the magnitude of the pulse on Day 2 is 50% of the Day 1 pulse;
- For the lower flow months of May through October, the flow would return to the current baseflow on Day 3;
- For the higher flow months of November through April, the Day 3 pulse is 50% of the Day 2 pulse and would return to current baseflow on Day 4.

Details outlining Scenario 6-7e are provided in Table 23.

TABLE 23
BUCKHORN CREEK SCENARIO 6-7 ENHANCED

Month	Unregulated Median-of-Medians All Water Yrs 1930 - 2009 (cfs)	Low[1] Baseflow Range (cfs)	Mid[2] Baseflow Range (cfs)	High[3] Baseflow Range (cfs)	Monthly[4] Pulse (# of Days)	Day 1 Pulse Magnitude (30 cfs minimum)	Day 2 Pulse Magnitude (Baseflow minimum)	Day 3 Pulse Magnitude (Baseflow minimum)
January	86	14	30	30	3	5 x Baseflow	50% Day 1	50% Day 2
February	75	8	30	30	3	5 x Baseflow	50% Day 1	50% Day 2
March	86	8	30	30	3	5 x Baseflow	50% Day 1	50% Day 2
April	47	8	20	25	3	5 x Baseflow	50% Day 1	50% Day 2
May	18	8	15	17	2	5 x Baseflow	50% Day 1	Baseflow
June	11	6	10	17	2	5 x Baseflow	50% Day 1	Baseflow
July	8	4	6	17	2	5 x Baseflow	50% Day 1	Baseflow
August	7	4	6	17	2	5 x Baseflow	50% Day 1	Baseflow
September	5	4	6	17	2	5 x Baseflow	50% Day 1	Baseflow
October	7	4	6	17	2	5 x Baseflow	50% Day 1	Baseflow
November	15	8	15	25	3	5 x Baseflow	50% Day 1	50% Day 2
December	32	14	20	30	3	5 x Baseflow	50% Day 1	50% Day 2

Notes:

Baseflow Range is determined by comparing previous month hydrology to historic hydrology range

[1] Low Baseflow if previous month hydrology falls into the lowest historic quartile

[2] Mid Baseflow if previous month hydrology falls into the middle two historic quartiles

[3] High Baseflow if previous month hydrology falls into the highest historic quartile

[4] Monthly pulse required approximately mid-month only if a spill event has not occurred during the previous 30 days

7.3 Final Model Results

The five scenarios that made it through the study team's final selection process are summarized in Table 24.

TABLE 24
FINAL MODEL SCENARIOS

Scenario	Cape Fear River Pumping Regime	Buckhorn Creek Release Scenario
6-7e	Pumping Regime #2	See Table 23
7e	Pumping Regime #2	High Baseflow with Pulse
9a	Pumping Regime #2	180 cfs cap / Variable A
9bd	Pumping Regime #2	150 cfs cap Jan-Apr 30 cfs cap May-Dec Variable A
14bd	Pumping Regime #3	150 cfs cap Jan-Apr 30 cfs cap May-Dec Variable A

The study team met for the 9th and final workshop on October 13, 2011, to review the final five PHABSIM habitat model runs for Buckhorn Creek and the Cape Fear River. Individual results and discussion are provided in Sections 7.3.1 and 7.3.2 for Buckhorn Creek and the Cape Fear River study reaches, respectively.

7.3.1 Buckhorn Creek Final Habitat Modeling Results

All five of the final scenarios provide very good habitat results when compared to the unregulated habitat (see Tables 25 and 26). The majority of the species/life stages modeled had habitat values greater than the 80% of unregulated habitat criteria established by the study team. Only the shallow-fast and deep-fast guilds had any species below the 80% unregulated criteria and most of those were still above 70%. The deep-fast gravel/cobble guild representative (white bass spawning) was the only species/life stage that had relatively poor habitat when compared to unregulated habitat (with a low of 51%). While white bass spawning has a relatively large HSC preference range for depths (2 – 5 ft) and velocities (0.3 – 4.3 feet per second [fps]), the preference range for substrate is very small. Small gravel, large gravel, and small cobbles are the only substrate types that have a non-zero HSC value. In Buckhorn Creek, there are relatively few habitat segments where one of these three substrate types is dominant. This narrow substrate preference range results in zero WUA for the majority of the Buckhorn Creek study reach, no matter how much flow is present. Other deep-fast guild representatives (shorthead redhorse adult and silver redhorse adult) have a wider substrate preference range and provide more representative flow versus habitat results. As a result, the study team largely discounted the deep-fast gravel/cobble (white bass spawning) results and instead relied on results from the other two deep-fast guild representatives.

Since all five of the final scenarios largely met the 80% unregulated habitat criteria, the study team narrowed the list based on four other objectives, namely:

- Seasonal flow ranges would be incorporated;
- Normal, wet, and dry hydrologic cycles would be recognized;
- Natural variability would be included by ensuring either a spill event or man-made pulse event every month; and
- Operational logistics regarding changes in flow releases could be planned in advance, to the extent possible.

The study team moved away from the Variable flow release scenarios (9a, 9bd, and 14bd) when CFRBM modeling results demonstrated the enhanced options (6-7e and 7e) provided flow release patterns to Buckhorn Creek that were very similar to the natural flow regime and represented a simpler, more-predictable operating approach.

Unlike Scenario 7e which was based on the high baseflow range, Scenario 6-7e incorporates the effects of normal, wet, and dry hydrologic cycles on flow releases to Buckhorn Creek. As a result, Scenario 6-7e became the preferred option.

TABLE 25
BUCKHORN CREEK HABITAT RESULTS (SCENARIOS 6-7E, 7E, AND 9A)

Buckhorn Creek - Final Habitat Results
All Water Year Types - Sum of Area Under the Curve (AUC) 5% to 95%

Scenario 6-7 Enhanced: (as % of Unimpaired) PR#2; Low/High Baseflow + Variable Inflow logic; monthly pulse

No	Species/Lifestage	Guild* / Stand Alone	Abbreviation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	American Shad Juvenile and Larval	Stand Alone	AMSHJL				86	96	101	93					
2	Bluehead Chub YOY	SS - Early Life Stage	SS-Early	129	122	127	117	91	93	107	112	104	109	84	105
3	Composite Chub Adult	Stand Alone	CCHUBA	219	155	168	129	119	128	123	134	138	120	136	135
4	Composite Chub Spawning	Stand Alone	CCHUBS			138	107	115	124	115					
5	Cape Fear Shiner Adult	Stand Alone	CFSHA	228	164	192	162	112	118	119	129	124	118	121	142
6	Cape Fear Shiner Spawning	Stand Alone	CFSHS				161	108	118						
7	Deep Slow Generic - Cover	DS - Generic Cover	DS-GenC	111	104	105	100	106	113	106	108	115	102	119	105
8	Deep Slow Generic - No Cover	DS - Generic No Cover	DS-GenNC	164	131	135	111	107	117	112	118	123	108	126	118
9	Ephemeroptera - Mayfly	EPT	EPHEM	125	113	114	103	106	111	108	113	117	106	113	107
10	Fantail Darter Adult	SF - High Velocity	SF-HV	84	87	89	82	84	88	85	74	97	76	90	74
11	Golden Redhorse Adult - Carolina Surrogate	Stand Alone	GORHA	93	95	95	94	100	103	101	100	110	100	105	95
12	Golden Redhorse Juvenile - Carolina Surrogate	Stand Alone	GORHJ					99	103	100					
13	Margined Madtom Adult	SF - Lower Velocity	SF-LV	195	150	161	126	114	123	122	133	135	122	124	127
14	Plecoptera - Stonefly	EPT	PLECO	133	116	117	103	110	121	113	117	127	108	126	112
15	Redbreast Sunfish Adult	DS - Cover Redbreast	DS-C	125	114	115	105	105	108	107	112	113	106	110	108
16	Redbreast Sunfish Spawning	SS - Fine Sub No Cover	SS-FineNC	150	129	132	119	109	112	112	119	117	111	115	119
17	Shallow Fast Guild	SF - Moderate Velocity	SF-MV	118	108	108	95	102	112	108	109	121	103	115	100
18	Shorthead Redhorse Adult	DF - Coarse Mix Sub	DF-Coarse	66	76	76	83	92	93	90	84	103	93	93	79
19	Shallow Slow Guild	SS - Coarse Sub	SS-Coarse	213	171	193	148	106	105	114	122	112	115	99	125
20	Silver Redhorse Adult	DF - Fine Sub	DF-Fine	86	89	90	87	95	99	95	91	111	93	103	85
21	Silver Redhorse YOY - Surrogate for Notchlip	SS - Veg Cover	SS-Veg	139	123	127	114	106	109	110	116	114	110	109	114
22	Silver Redhorse YOY - Surrogate for Notchlip	SS - Wood Cover	SS-Wood	147	128	132	116	106	109	111	118	115	111	109	115
23	Trichoptera 1 - Caddisfly	EPT	TRIC1	107	102	103	98	103	109	106	108	114	103	111	101
24	White Bass Spawning	DF - Grav Sm Cob Sub	DF-GrCob	59	70	72	73	72	60	62	51	84	63	69	59

Scenario 7 Enhanced: (as % of Unimpaired) PR#2; High Baseflow; monthly pulse

No	Species/Lifestage	Guild* / Stand Alone	Abbreviation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	American Shad Juvenile and Larval	Stand Alone	AMSHJL				89	99	119	130					
2	Bluehead Chub YOY	SS - Early Life Stage	SS-Early	128	117	120	112	86	74	70	74	67	70	75	96
3	Composite Chub Adult	Stand Alone	CCHUBA	219	158	175	131	124	148	167	180	193	164	147	132
4	Composite Chub Spawning	Stand Alone	CCHUBS			159	117	127	173	205					
5	Cape Fear Shiner Adult	Stand Alone	CFSHA	222	149	167	147	113	118	125	135	131	124	117	97
6	Cape Fear Shiner Spawning	Stand Alone	CFSHS				133	96	92						
7	Deep Slow Generic - Cover	DS - Generic Cover	DS-GenC	112	107	109	103	111	132	144	147	161	143	135	112
8	Deep Slow Generic - No Cover	DS - Generic No Cover	DS-GenNC	166	137	147	117	114	136	150	158	168	147	153	133
9	Ephemeroptera - Mayfly	EPT	EPHEM	125	115	118	105	109	121	130	135	142	129	121	112
10	Fantail Darter Adult	SF - High Velocity	SF-HV	83	89	92	86	88	107	115	106	131	113	120	96
11	Golden Redhorse Adult - Carolina Surrogate	Stand Alone	GORHA	93	96	96	96	102	114	120	120	132	122	115	101
12	Golden Redhorse Juvenile - Carolina Surrogate	Stand Alone	GORHJ					103	120	129					
13	Margined Madtom Adult	SF - Lower Velocity	SF-LV	193	147	160	124	116	129	142	152	159	141	123	118
14	Plecoptera - Stonefly	EPT	PLECO	134	120	124	108	116	143	162	169	192	161	142	121
15	Redbreast Sunfish Adult	DS - Cover Redbreast	DS-C	126	115	118	107	107	115	120	125	128	119	117	112
16	Redbreast Sunfish Spawning	SS - Fine Sub No Cover	SS-FineNC	149	127	132	117	110	117	122	129	128	121	115	113
17	Shallow Fast Guild	SF - Moderate Velocity	SF-MV	119	113	116	100	107	132	144	147	166	142	137	117
18	Shorthead Redhorse Adult	DF - Coarse Mix Sub	DF-Coarse	66	77	76	85	94	103	108	101	122	114	102	86
19	Shallow Slow Guild	SS - Coarse Sub	SS-Coarse	209	153	166	133	102	93	91	97	89	92	78	91
20	Silver Redhorse Adult	DF - Fine Sub	DF-Fine	86	91	92	91	99	120	131	127	153	134	124	98
21	Silver Redhorse YOY - Surrogate for Notchlip	SS - Veg Cover	SS-Veg	138	122	125	112	106	109	113	119	118	112	106	108
22	Silver Redhorse YOY - Surrogate for Notchlip	SS - Wood Cover	SS-Wood	146	126	131	114	106	109	113	119	117	112	106	109
23	Trichoptera 1 - Caddisfly	EPT	TRIC1	107	105	106	100	106	120	127	131	140	127	119	107
24	White Bass Spawning	DF - Grav Sm Cob Sub	DF-GrCob	59	72	73	77	77	81	85	73	105	95	95	75

Scenario 9a: (as % of Unimpaired) PR#2 Variable A; 180 cfs Cap Year Round

No	Species/Lifestage	Guild* / Stand Alone	Abbreviation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	American Shad Juvenile and Larval	Stand Alone	AMSHJL				97	97	97	101					
2	Bluehead Chub YOY	SS - Early Life Stage	SS-Early	112	106	106	103	104	107	108	114	113	112	112	115
3	Composite Chub Adult	Stand Alone	CCHUBA	131	112	113	106	99	103	105	110	114	104	98	103
4	Composite Chub Spawning	Stand Alone	CCHUBS			105	100	94	95	95					
5	Cape Fear Shiner Adult	Stand Alone	CFSHA	155	125	121	110	102	106	108	113	117	110	105	113
6	Cape Fear Shiner Spawning	Stand Alone	CFSHS				113	107	111						
7	Deep Slow Generic - Cover	DS - Generic Cover	DS-GenC	104	101	102	100	97	98	99	101	98	95	93	95
8	Deep Slow Generic - No Cover	DS - Generic No Cover	DS-GenNC	112	102	104	101	97	100	102	104	104	98	95	97
9	Ephemeroptera - Mayfly	EPT	EPHEM	106	102	103	100	98	101	103	106	107	101	97	98
10	Fantail Darter Adult	SF - High Velocity	SF-HV	97	97	100	97	94	98	106	103	95	96	90	87
11	Golden Redhorse Adult - Carolina Surrogate	Stand Alone	GORHA	99	99	100	99	98	99	102	102	104	100	95	95
12	Golden Redhorse Juvenile - Carolina Surrogate	Stand Alone	GORHJ					97	99	103					
13	Margined Madtom Adult	SF - Lower Velocity	SF-LV	126	112	111	105	101	106	109	114	118	109	101	105
14	Plecoptera - Stonefly	EPT	PLECO	107	102	103	100	97	99	101	103	104	97	93	95
15	Redbreast Sunfish Adult	DS - Cover Redbreast	DS-C	107	102	103	101	99	101	103	106	107	102	99	99
16	Redbreast Sunfish Spawning	SS - Fine Sub No Cover	SS-FineNC	115	108	107	103	101	103	105	108	110	105	102	104
17	Shallow Fast Guild	SF - Moderate Velocity	SF-MV	102	99	101	97	95	99	102	104	104	97	93	92
18	Shorthead Redhorse Adult	DF - Coarse Mix Sub	DF-Coarse	88	93	93	96	98	98	101	99	104	102	92	90
19	Shallow Slow Guild	SS - Coarse Sub	SS-Coarse	141	123	117	111	105	108	109	115	116	113	112	120
20	Silver Redhorse Adult	DF - Fine Sub	DF-Fine	98	98	100	98	96	98	104	103	102	99	91	90
21	Silver Redhorse YOY - Surrogate for Notchlip	SS - Veg Cover	SS-Veg	111	106	106	103	101	103	105	108	110	105	102	104
22	Silver Redhorse YOY - Surrogate for Notchlip	SS - Wood Cover	SS-Wood	114	107	107	103	101	104	105	109	110	106	103	105
23	Trichoptera 1 - Caddisfly	EPT	TRIC1	102	100	101	99	98	100	102	104	105	100	96	96
24	White Bass Spawning	DF - Grav Sm Cob Sub	DF-GrCob	89	93	95	94	94	93	101	96	98	101	85	83

=>100%   =>80%   =>70%   =>60%   <60%

Guild Descriptions:

*SS = Shallow Slow; <= 2 ft deep and < 1ft/s velocity

*SF = Shallow Fast; <= 2 ft deep and > 1 ft/s velocity

*DS = Deep Slow; >= 2 ft deep and < 1 ft/s velocity

*DF = Deep Fast; >= 2 ft deep and > 1 ft/s velocity

TABLE 26
BUCKHORN CREEK HABITAT RESULTS (SCENARIOS 9BD AND 14BD)

Buckhorn Creek - Final Habitat Results
All Water Year Types - Sum of Area Under the Curve (AUC) 5% to 95%

Scenario 9bd: (as % of Unimpaired) PR#2 Var A; 150 cfs Cap Jan-Apr; 30 cfs Cap May-Dec; Adjust 2/wk

No	Species/Lifestage	Guild* / Stand Alone	Abbreviation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	American Shad Juvenile and Larval	Stand Alone	AMSHJL				105	96	101	99					
2	Bluehead Chub YOY	SS - Early Life Stage	SS-Early	112	104	105	97	98	99	104	108	110	109	113	119
3	Composite Chub Adult	Stand Alone	CCHUBA	125	98	99	90	114	117	121	129	123	113	110	124
4	Composite Chub Spawning	Stand Alone	CCHUBS			94	93	121	128	124					
5	Cape Fear Shiner Adult	Stand Alone	CFSHA	143	103	103	86	105	107	113	118	117	111	110	127
6	Cape Fear Shiner Spawning	Stand Alone	CFSHS				86	97	103						
7	Deep Slow Generic - Cover	DS - Generic Cover	DS-GenC	104	101	102	101	106	110	109	112	106	101	97	98
8	Deep Slow Generic - No Cover	DS - Generic No Cover	DS-GenNC	112	100	99	95	112	117	117	125	116	108	105	111
9	Ephemeroptera - Mayfly	EPT	EPHEM	105	100	101	98	105	109	110	115	112	105	101	103
10	Fantail Darter Adult	SF - High Velocity	SF-HV	99	104	105	110	93	108	105	104	107	97	79	71
11	Golden Redhorse Adult - Carolina Surrogate	Stand Alone	GORHA	99	101	101	103	100	104	104	105	107	102	93	91
12	Golden Redhorse Juvenile - Carolina Surrogate	Stand Alone	GORHJ					101	106	106					
13	Margined Madtom Adult	SF - Lower Velocity	SF-LV	119	99	98	90	110	113	119	125	124	114	109	121
14	Plecoptera - Stonefly	EPT	PLECO	106	99	100	97	110	116	116	123	116	107	101	105
15	Redbreast Sunfish Adult	DS - Cover Redbreast	DS-C	105	100	100	97	105	107	107	112	110	105	102	105
16	Redbreast Sunfish Spawning	SS - Fine Sub No Cover	SS-FineNC	112	100	100	94	106	107	110	115	113	108	107	116
17	Shallow Fast Guild	SF - Moderate Velocity	SF-MV	101	99	99	99	107	116	115	121	116	107	98	96
18	Shorthead Redhorse Adult	DF - Coarse Mix Sub	DF-Coarse	90	98	97	106	91	96	94	91	101	97	82	75
19	Shallow Slow Guild	SS - Coarse Sub	SS-Coarse	135	104	103	88	100	102	107	112	113	111	115	132
20	Silver Redhorse Adult	DF - Fine Sub	DF-Fine	99	102	103	106	98	106	105	106	109	101	85	80
21	Silver Redhorse YOY - Surrogate for Notchlip	SS - Veg Cover	SS-Veg	109	100	100	95	105	105	108	113	111	107	106	113
22	Silver Redhorse YOY - Surrogate for Notchlip	SS - Wood Cover	SS-Wood	111	100	100	94	105	106	109	114	112	108	107	115
23	Trichoptera 1 - Caddisfly	EPT	TRIC1	102	101	101	100	103	107	108	111	110	104	98	98
24	White Bass Spawning	DF - Grav Sm Cob Sub	DF-GrCob	92	101	101	110	77	82	78	74	93	85	58	54

Scenario 14bd: (as % of Unimpaired) PR#3 Var A; 150 cfs Cap Jan-Apr; 30 cfs Cap May-Dec; Adjust 2/wk

No	Species/Lifestage	Guild* / Stand Alone	Abbreviation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	American Shad Juvenile and Larval	Stand Alone	AMSHJL				104	95	101	99					
2	Bluehead Chub YOY	SS - Early Life Stage	SS-Early	112	105	105	97	98	99	104	108	110	110	113	120
3	Composite Chub Adult	Stand Alone	CCHUBA	127	101	100	90	114	117	121	130	125	113	110	124
4	Composite Chub Spawning	Stand Alone	CCHUBS			95	93	121	128	125					
5	Cape Fear Shiner Adult	Stand Alone	CFSHA	147	107	104	87	105	108	113	119	118	111	111	128
6	Cape Fear Shiner Spawning	Stand Alone	CFSHS				86	97	104						
7	Deep Slow Generic - Cover	DS - Generic Cover	DS-GenC	104	101	102	101	106	110	109	112	106	101	97	98
8	Deep Slow Generic - No Cover	DS - Generic No Cover	DS-GenNC	113	101	100	96	112	117	117	126	117	108	105	111
9	Ephemeroptera - Mayfly	EPT	EPHEM	105	101	101	98	105	109	110	115	112	105	101	103
10	Fantail Darter Adult	SF - High Velocity	SF-HV	99	103	105	110	92	107	104	103	102	96	77	70
11	Golden Redhorse Adult - Carolina Surrogate	Stand Alone	GORHA	99	101	101	103	100	103	104	104	107	101	93	91
12	Golden Redhorse Juvenile - Carolina Surrogate	Stand Alone	GORHJ					101	106	106					
13	Margined Madtom Adult	SF - Lower Velocity	SF-LV	121	101	99	90	110	113	119	126	125	114	110	122
14	Plecoptera - Stonefly	EPT	PLECO	106	99	100	97	110	116	116	123	117	106	100	105
15	Redbreast Sunfish Adult	DS - Cover Redbreast	DS-C	106	100	101	97	105	107	108	113	111	105	102	105
16	Redbreast Sunfish Spawning	SS - Fine Sub No Cover	SS-FineNC	113	101	101	94	106	107	110	115	113	108	108	116
17	Shallow Fast Guild	SF - Moderate Velocity	SF-MV	101	99	100	99	107	116	115	121	116	107	97	96
18	Shorthead Redhorse Adult	DF - Coarse Mix Sub	DF-Coarse	90	97	97	105	91	95	94	90	99	96	81	75
19	Shallow Slow Guild	SS - Coarse Sub	SS-Coarse	137	109	104	88	101	103	107	113	114	112	116	133
20	Silver Redhorse Adult	DF - Fine Sub	DF-Fine	99	102	103	106	98	106	105	105	107	100	84	79
21	Silver Redhorse YOY - Surrogate for Notchlip	SS - Veg Cover	SS-Veg	110	101	101	95	105	106	108	113	112	107	107	113
22	Silver Redhorse YOY - Surrogate for Notchlip	SS - Wood Cover	SS-Wood	111	102	101	94	105	106	109	114	113	108	108	115
23	Trichoptera 1 - Caddisfly	EPT	TRIC1	102	101	102	101	103	107	108	111	110	103	98	97
24	White Bass Spawning	DF - Grav Sm Cob Sub	DF-GrCob	91	99	101	110	76	81	78	72	87	82	56	53

Legend: =>100% | =>80% | =>70% | =>60% | <60%

Guild Descriptions:

*SS = Shallow Slow; <= 2 ft deep and < 1ft/s velocity

*SF = Shallow Fast; <= 2 ft deep and > 1 ft/s velocity

*DS = Deep Slow; >= 2 ft deep and < 1 ft/s velocity

*DF = Deep Fast; >= 2 ft deep and > 1 ft/s velocity

7.3.2 Cape Fear River Final Habitat Modeling Results

Final habitat model results for the Cape Fear River study reaches are provided in Tables 27 through 31. Each table includes habitat results for one of the five final scenarios. Within each table, separate results are provided for each side channel and all three side channels combined.

The habitat results are almost identical among the five scenarios. Differences between scenarios in the unregulated habitat comparisons are usually within one percentage point. More pronounced differences in unregulated habitat percentages are seen when comparing the side channel reaches to each other for a given scenario. Three examples illustrate how different species/life stages prefer different side channel reaches:

- The Cape Fear shiner adult has the highest percentage of habitat in Reach 1 with decreasing percentages in Reaches 2 and 3;
- Conversely, the shallow-slow early life stage guild (bluehead chub young-of-year) has the lowest percentage of habitat in Reach 1 with higher percentages in Reaches 2 and 3; and
- Striped bass juvenile has the highest percentage of habitat in Reach 2 with lower percentages in Reaches 1 and 3.

Clearly, the side channel reaches offer different types of habitat for a given flow regime which is important considering the wide array of fish species/life stages present (or potentially present) in the Cape Fear River system. The three side channel reaches, when combined, also provide well over 80% of the unregulated habitat with the exception of channel catfish spawning (79% in July) and deep-fast gravel cobble (i.e., white bass spawning) (78% in August).

Based on the Cape Fear River habitat modeling results, the preferred scenario for Buckhorn Creek (Scenario 6-7e) with Pumping Regime #2 (withdrawals of up to 180 cfs at appropriate flow thresholds in the river) is also protective of aquatic habitat in the Cape Fear River.

TABLE 27
CAPE FEAR RIVER SCENARIO 6-7E HABITAT RESULTS

Cape Fear River - Final Habitat Results
Scenario 6-7 Enhanced (Pump Regime #2; Low/High Baseflow Hybrid + Variable Inflow Logic; Monthly Pulse)
All Water Year Types - Sum of Area Under the Curve (AUC) 5% to 95%

No	Species/Lifestage	Guild* / Stand Alone	Abbreviation	Scenario 6-7 Enhanced (as % of Unimpaired) Reach 1												Scenario 6-7 Enhanced (as % of Unimpaired) Reach 2											
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	American Shad Incubation	Stand Alone	AMSHI				107	88	81										101	95	98						
2	American Shad Juvenile and Larval	Stand Alone	AMSHJL				106	89	86	82									101	94	97	96					
3	American Shad Outmigration	Stand Alone	AMSHO				106	87	79	73	73	83	82						102	93	95	93	91	98	96		
4	American Shad Spawning	Stand Alone	AMSHS			108	105	91	90									102	101	97	100						
5	Composite Chub Adult	Stand Alone	CCHUBA	108	108	103	115	124	127	134	132	133	132	119	122	114	108	105	120	128	122	116	113	107	104	112	131
6	Composite Chub Spawning	Stand Alone	CCHUBS			97	96	90	87	90								106	119	132	135	131					
7	Cape Fear Shiner Adult	Stand Alone	CFSHA	126	133	122	161	149	143	151	152	150	160	138	157	106	103	103	106	92	70	76	89	84	94	111	130
8	Cape Fear Shiner Spawning	Stand Alone	CFSHS				130	131	111										97	92	89						
9	Channel Catfish Adult	Stand Alone	CHCFA	104	106	109	106	90	87	83	83	93	92	86	88	101	102	104	101	92	95	92	88	95	91	86	88
10	Channel Catfish Juvenile	Stand Alone	CHCFJ	104	106	109	106	90	85	81	80	91	89	84	88	99	100	101	100	96	99	100	98	104	102	94	92
11	Channel Catfish Spawning	Stand Alone	CHCFS					89	84	80										88	87	79					
12	Shorthead Redhorse Adult	DF - Coarse Mix Sub	DF-Coarse	103	104	107	104	93	92	92	92	100	99	91	91	101	102	104	101	94	96	96	96	101	101	93	92
13	Silver Redhorse Adult	DF - Fine Sub	DF-Fine	104	106	109	106	90	86	82	82	92	91	85	88	99	100	101	99	96	102	101	96	102	97	91	90
14	White Bass Spawning	DF - Grav Sm Cob Sub	DF-GrCob	106	107	111	109	88	80	72	70	84	82	80	86	102	103	106	103	89	89	85	82	90	87	83	86
15	Redbreast Sunfish Adult	DS - Cover Redbreast	DS-C	99	99	97	99	102	104	107	107	109	109	104	101	102	100	99	102	106	106	105	104	103	102	104	107
16	Deep Slow Generic - Cover	DS - Generic Cover	DS-GenC	102	103	105	102	94	95	97	98	106	106	94	92	98	100	100	98	86	79	77	79	83	83	85	88
17	Deep Slow Generic - No Cover	DS - Generic No Cover	DS-GenNC	103	104	107	104	87	81	78	79	87	87	84	87	100	101	100	104	117	126	124	111	119	107	100	99
18	Ephemeroptera - Mayfly	EPT	EPHEM	100	99	98	100	104	108	112	111	114	113	105	103	101	100	99	102	105	106	107	106	105	104	104	106
19	Golden Redhorse Adult - Carolina Surrogate	Stand Alone	GORHA	102	103	104	102	96	97	98	98	103	104	96	94	100	101	102	101	98	99	100	100	102	103	98	96
20	Golden Redhorse Juvenile - Carolina Surrogate	Stand Alone	GORHJ					93	93	93										96	99	100					
21	Plecoptera - Stonefly	EPT	PLECO	99	99	97	99	104	111	119	116	124	121	103	98	101	100	99	101	106	108	108	107	107	105	104	105
22	Fantail Darter Adult	SF - High Velocity	SF-HV	105	106	110	107	87	79	71	71	82	82	80	86	101	103	105	102	93	92	94	94	100	103	94	92
23	Margined Madtom Adult	SF - Lower Velocity	SF-LV	110	108	103	118	124	124	128	127	126	128	120	128	108	104	102	109	112	109	108	108	104	104	109	119
24	Shallow Fast Guild	SF - Moderate Velocity	SF-MV	101	100	98	101	104	109	115	116	120	121	108	104	99	99	98	99	101	104	107	107	109	110	102	100
25	Shallow Slow Guild	SS - Coarse Sub	SS-Coarse	121	132	122	143	133	120	118	116	109	108	114	144	116	106	103	120	121	110	102	102	95	95	110	139
26	Bluehead Chub YOY	SS - Early Life Stage	SS-Early	102	99	98	104	115	103	84	74	60	49	77	112	114	106	103	116	117	105	114	123	111	118	116	136
27	Redbreast Sunfish Spawning	SS - Fine Sub No Cover	SS-FineNC	102	100	99	103	108	110	112	112	112	112	108	110	102	100	98	101	102	98	99	102	99	101	105	110
28	Silver Redhorse YOY - Surrogate for Notchlip	SS - Veg Cover	SS-Veg	102	100	98	104	108	107	106	105	103	102	105	110	102	100	99	102	104	102	104	105	103	105	105	108
29	Silver Redhorse YOY - Surrogate for Notchlip	SS - Wood Cover	SS-Wood	103	101	99	105	110	108	106	105	103	102	106	114	102	100	99	102	104	102	104	105	103	105	105	108
30	Striped Bass Incubation	Stand Alone	STBAI					88	80	72										90	88	87					
31	Striped Bass Juvenile	Stand Alone	STBAJ	105	107	111	108	88	79	71	70	83	82	80	86	101	103	105	102	92	93	91	90	97	95	88	88
32	Striped Bass Spawning	Stand Alone	STBAS				109	88											103	90							
33	Trichoptera 1 - Caddisfly	EPT	TRIC1	99	100	100	99	98	100	103	103	107	106	98	96	100	100	98	101	104	106	106	105	106	104	103	103

No	Species/Lifestage	Guild* / Stand Alone	Abbreviation	Scenario 6-7 Enhanced (as % of Unimpaired) Reach 3												Scenario 6-7 Enhanced (as % of Unimpaired) Combined Reaches											
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	American Shad Incubation	Stand Alone	AMSHI				103	85	80										104	91	91						
2	American Shad Juvenile and Larval	Stand Alone	AMSHJL				102	89	88	86									104	91	90	87					
3	American Shad Outmigration	Stand Alone	AMSHO				103	86	82	78	77	86	85						104	89	86	82	81	90	88		
4	American Shad Spawning	Stand Alone	AMSHS			103	100	91	91									106	103	94	95						
5	Composite Chub Adult	Stand Alone	CCHUBA	111	110	108	116	119	119	121	120	117	118	113	122	112	109	105	118	125	122	119	116	112	110	113	128
6	Composite Chub Spawning	Stand Alone	CCHUBS			105	107	113	120	128								103	111	122	127	127					
7	Cape Fear Shiner Adult	Stand Alone	CFSHA	131	141	142	144	101	70	58	68	61	36	101	184	111	104	103	116	121	109	112	117	111	116	120	142
8	Cape Fear Shiner Spawning	Stand Alone	CFSHS				108	96	93										101	105	98						
9	Channel Catfish Adult	Stand Alone	CHCFA	101	103	106	102	86	82	78	77	86	85	82	85	102	104	107	103	88	85	81	80	89	88	83	86
10	Channel Catfish Juvenile	Stand Alone	CHCFJ	101	103	105	102	88	85	83	82	90	89	84	86	102	103	106	103	92	92	91	90	97	96	89	89
11	Channel Catfish Spawning	Stand Alone	CHCFS					86	82	79										87	83	79					
12	Shorthead Redhorse Adult	DF - Coarse Mix Sub	DF-Coarse	101	102	104	101	92	92	92	91	96	96	90	90	101	103	105	102	94	94	94	94	100	100	92	91
13	Silver Redhorse Adult	DF - Fine Sub	DF-Fine	101	103	105	102	89	88	86	85	92	92	86	87	102	104	106	103	91	91	88	87	94	93	87	88
14	White Bass Spawning	DF - Grav Sm Cob Sub	DF-GrCob	102	104	107	104	84	75	69	67	79	77	76	83	103	104	108	105	89	87	81	78	88	85	81	86
15	Redbreast Sunfish Adult	DS - Cover Redbreast	DS-C	99	100	100	99	97	97	98	98	100	101	97	96	100	99	99	100	102	104	104	104	104	104	102	102
16	Deep Slow Generic - Cover	DS - Generic Cover	DS-GenC	100	101	102	100	92	92	91	91	96	96	92	92	101	102	103	101	93	93	93	93	100	100	93	91
17	Deep Slow Generic - No Cover	DS - Generic No Cover	DS-GenNC	98	98	98	98	96	100	100	98	102	100	95	94	102	104	106	103	93	95	93	90	97	94	89	90
18	Ephemeroptera - Mayfly	EPT	EPHEM	99	99	99	99	100	102	104	103	105	105	101	100	101	100	99	101	104	106	108	107	108	107	104	104
19	Golden Redhorse Adult - Carolina Surrogate	Stand Alone	GORHA	100	101	102	100	95	95	96	95	99	99	94	93	101	102	103	101	96	97	97	97	101	102	96	94
20	Golden Redhorse Juvenile - Carolina Surrogate	Stand Alone	GORHJ					95	97	99										94	95	97					
21	Plecoptera - Stonefly	EPT	PLECO	99	100	99	100	102	104	107	106	109	110	101	99	100	99	98	100	105	109	113	111	113	111	103	101
22	Fantail Darter Adult	SF - High Velocity	SF-HV	108	103	102	109	115	116	122	128	125	136	120	122	102	103	106	103	92	91	92	93	99	102	93	91
23	Margined Madtom Adult	SF - Lower Velocity	SF-LV	112	110	107	116	119	113	111	111	105	105	111	127	108	105	103	111	115	113	112	112	109	109	111	121
24	Shallow Fast Guild	SF - Moderate Velocity	SF-MV	113	114	112	120	121	119	123	124	118	120	114	125	100	99	98	100	101	104	108	108	110	110	103	101
25	Shallow Slow Guild	SS - Coarse Sub	SS-Coarse	149	149	137	169	147	114	104	106	96	95	118	174	118	112	107	128	127	115	109	108	101	100	112	142
26	Bluehead Chub YOY	SS - Early Life Stage	SS-Early	114	122	119	121	114	108	106	104	103	100	109	124	110	107	104	113	114	105	102	101	91	86	102	125
27	Redbreast Sunfish Spawning	SS - Fine Sub No Cover	SS-FineNC	101	100	99	101	102	102	103	104	104	104	103	103	101	100	99	102	104	103	105	106	104	105	105	107
28	Silver Redhorse YOY - Surrogate for Notchlip	SS - Veg Cover	SS-Veg	104	104	103	105	103	103	105	106	106	105	104	107	102	101	100	103	105	104	104	105	104	104	105	108
29	Silver Redhorse YOY - Surrogate for Notchlip	SS - Wood Cover	SS-Wood	105	104	104	106	105	104	104	105	104	104	105	110	103	101	100	104	106	104	105	105	103	104	105	110
30	Striped Bass Incubation	Stand Alone	STBAI					85	77	69										89	86	83					
31	Striped Bass Juvenile	Stand Alone	STBAJ	102	104	107	104	83	75	68	66	79	77	76	83	103	105	108	105	89	86	82	80	90	89	83	87
32	Striped Bass Spawning	Stand Alone	STBAS				106	85											105	90							
33	Trichoptera 1 - Caddisfly	EPT	TRIC1	100	101	102	100	96	97	98	98	101	101	95	94	99	100	100	100	100	102	104	103	105	104	99	98

=>100% =>80% =>70% =>60% <60%

Guild Descriptions:

*SS = Shallow Slow; <= 2 ft deep and < 1ft/s velocity

*SF = Shallow Fast; <= 2 ft deep and > 1 ft/s velocity

*DS = Deep Slow; >= 2 ft deep and < 1 ft/s velocity

*DF = Deep Fast; >= 2 ft deep and > 1 ft/s velocity

TABLE 28
CAPE FEAR RIVER SCENARIO 7E HABITAT RESULTS

Cape Fear River - Final Habitat Results
Scenario 7 Enhanced (Pump Regime #2; High Baseflow; Monthly Pulse)
All Water Year Types - Sum of Area Under the Curve (AUC) 5% to 95%

Scenario 7 Enhanced (as % of Unimpaired) – Reach 1

No	Species/Lifestage	Guild* / Stand Alone	Abbreviation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	American Shad Incubation	Stand Alone	AMSHI				107	88	81						
2	American Shad Juvenile and Larval	Stand Alone	AMSHJL				106	89	86	82					
3	American Shad Outmigration	Stand Alone	AMSHO				106	87	79	73	73	83	82		
4	American Shad Spawning	Stand Alone	AMSHS			108	105	91	90						
5	Composite Chub Adult	Stand Alone	CCHUBA	107	108	104	116	124	128	134	132	133	133	119	122
6	Composite Chub Spawning	Stand Alone	CCHUBS			98	97	90	87	90					
7	Cape Fear Shiner Adult	Stand Alone	CFSHA	122	130	123	161	149	143	151	152	151	160	138	157
8	Cape Fear Shiner Spawning	Stand Alone	CFSHS				131	131	110						
9	Channel Catfish Adult	Stand Alone	CHCFA	104	106	109	106	90	87	83	83	93	93	86	88
10	Channel Catfish Juvenile	Stand Alone	CHCFJ	104	106	109	106	90	85	81	80	91	90	85	88
11	Channel Catfish Spawning	Stand Alone	CHCFS					89	84	80					
12	Shorthead Redhorse Adult	DF - Coarse Mix Sub	DF-Coarse	103	104	107	104	93	92	92	92	100	100	92	91
13	Silver Redhorse Adult	DF - Fine Sub	DF-Fine	104	105	109	106	90	86	82	82	92	91	85	88
14	White Bass Spawning	DF - Grav Sm Cob Sub	DF-GrCob	105	107	111	109	88	80	72	70	84	83	80	86
15	Redbreast Sunfish Adult	DS - Cover Redbreast	DS-C	99	99	97	99	102	104	107	107	109	110	104	101
16	Deep Slow Generic - Cover	DS - Generic Cover	DS-GenC	102	103	105	102	94	95	98	98	106	107	95	92
17	Deep Slow Generic - No Cover	DS - Generic No Cover	DS-GenNC	103	104	107	104	87	81	78	79	88	87	84	87
18	Ephemeroptera - Mayfly	EPT	EPHEM	100	99	98	100	104	108	112	112	114	114	106	103
19	Golden Redhorse Adult - Carolina Surrogate	Stand Alone	GORHA	102	103	104	102	96	97	98	98	104	104	97	94
20	Golden Redhorse Juvenile - Carolina Surrogate	Stand Alone	GORHJ					93	93	94					
21	Plecoptera - Stonefly	EPT	PLECO	99	99	98	99	104	111	120	117	125	121	104	98
22	Fantail Darter Adult	SF - High Velocity	SF-HV	105	106	110	107	87	79	71	71	82	82	80	86
23	Margined Madtom Adult	SF - Lower Velocity	SF-LV	109	108	104	118	125	124	127	126	126	128	120	128
24	Shallow Fast Guild	SF - Moderate Velocity	SF-MV	101	100	99	101	104	109	116	116	120	121	109	105
25	Shallow Slow Guild	SS - Coarse Sub	SS-Coarse	120	130	123	144	133	120	118	115	109	108	113	143
26	Bluehead Chub YOY	SS - Early Life Stage	SS-Early	102	99	98	104	116	103	84	74	59	49	76	112
27	Redbreast Sunfish Spawning	SS - Fine Sub No Cover	SS-FineNC	102	100	99	104	108	110	112	112	112	112	108	110
28	Silver Redhorse YOY - Surrogate for Notchlip	SS - Veg Cover	SS-Veg	102	100	99	104	108	107	106	105	103	102	105	110
29	Silver Redhorse YOY - Surrogate for Notchlip	SS - Wood Cover	SS-Wood	103	101	99	106	110	108	106	105	102	101	106	113
30	Striped Bass Incubation	Stand Alone	STBAI					88	80	72					
31	Striped Bass Juvenile	Stand Alone	STBAJ	105	107	110	108	88	79	71	70	83	82	80	86
32	Striped Bass Spawning	Stand Alone	STBAS				108	88							
33	Trichoptera 1 - Caddisfly	EPT	TRIC1	100	100	100	99	97	100	103	103	107	106	99	96

Scenario 7 Enhanced (as % of Unimpaired) – Reach 2

No	Abbreviation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	AMSHI				101	95	98						
2	AMSHJL				101	94	97	96					
3	AMSHO				102	93	95	93	91	98	96		
4	AMSHS			102	101	97	100						
5	CCHUBA	114	109	106	121	128	123	116	112	107	105	112	130
6	CCHUBS			107	119	132	135	131					
7	CFSHA	105	103	103	107	93	71	78	90	85	95	112	130
8	CFSHS				97	92	88						
9	CHCFA	101	102	104	101	92	94	91	87	95	90	86	87
10	CHCFJ	99	100	101	99	95	98	99	98	103	102	94	92
11	CHCFS					88	86	79					
12	DF-Coarse	101	102	104	101	94	95	96	95	101	101	93	92
13	DF-Fine	99	100	101	99	96	102	100	96	102	97	91	90
14	DF-GrCob	102	103	106	103	89	89	84	81	90	86	82	86
15	DS-C	102	100	99	102	106	106	105	104	103	102	104	107
16	DS-GenC	98	99	100	98	86	79	77	79	84	83	85	88
17	DS-GenNC	101	102	100	104	117	125	123	110	119	106	99	99
18	EPHEM	101	100	99	102	105	106	106	106	105	104	104	106
19	GORHA	100	101	102	100	98	99	100	99	102	102	98	96
20	GORHJ					96	99	100					
21	PLECO	101	100	99	102	106	108	108	107	107	105	104	105
22	SF-HV	101	103	105	102	93	92	93	94	101	103	94	92
23	SF-LV	108	105	103	110	112	109	108	108	104	104	109	119
24	SF-MV	99	99	98	99	101	104	107	107	109	109	102	100
25	SS-Coarse	115	107	104	120	121	110	102	103	95	96	110	139
26	SS-Early	111	106	103	117	118	106	116	123	110	117	115	137
27	SS-FineNC	102	100	99	101	103	98	100	102	99	101	106	110
28	SS-Veg	102	100	99	102	104	102	104	105	103	105	105	108
29	SS-Wood	102	100	99	102	104	102	104	105	103	105	105	108
30	STBAI					90	88	87					
31	STBAJ	101	103	105	102	92	92	91	89	97	95	88	88
32	STBAS				103	90							
33	TRIC1	100	100	99	101	104	106	106	105	106	104	103	103

Scenario 7 Enhanced (as % of Unimpaired) – Reach 3

No	Abbreviation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	AMSHI				103	85	80						
2	AMSHJL				102	89	87	86					
3	AMSHO				103	86	82	78	76	86	85		
4	AMSHS			103	100	91	91						
5	CCHUBA	110	111	109	116	119	119	121	120	117	118	113	122
6	CCHUBS			105	108	113	119	127					
7	CFSHA	131	142	148	146	104	71	58	68	59	37	100	175
8	CFSHS				108	97	94						
9	CHCFA	101	103	106	102	86	81	77	77	85	85	82	85
10	CHCFJ	101	103	105	102	88	85	83	82	90	89	84	86
11	CHCFS					86	82	79					
12	DF-Coarse	101	102	104	101	92	92	91	91	96	96	90	90
13	DF-Fine	101	102	105	102	89	87	86	85	92	91	86	87
14	DF-GrCob	102	104	107	104	83	75	69	67	79	77	76	83
15	DS-C	99	100	100	99	97	97	98	98	100	100	97	96
16	DS-GenC	100	101	102	100	92	91	91	91	96	96	92	92
17	DS-GenNC	98	98	98	97	96	100	100	97	101	99	95	94
18	EPHEM	99	99	99	99	100	102	103	103	105	105	101	100
19	GORHA	100	101	102	100	94	95	95	95	99	99	94	93
20	GORHJ					95	96	98					
21	PLECO	99	100	99	100	102	104	107	106	109	110	101	99
22	SF-HV	107	103	103	109	115	117	122	129	126	137	120	123
23	SF-LV	112	111	108	117	119	113	111	111	105	105	111	127
24	SF-MV	112	115	113	121	121	120	123	124	118	120	114	125
25	SS-Coarse	148	151	142	172	149	116	106	107	97	96	118	173
26	SS-Early	114	123	121	122	114	108	106	103	102	99	109	123
27	SS-FineNC	101	100	100	101	102	102	103	104	104	104	103	104
28	SS-Veg	104	104	104	105	103	103	104	106	105	105	104	107
29	SS-Wood	105	105	104	106	105	104	104	105	104	104	105	110
30	STBAI					85	77	69					
31	STBAJ	102	104	107	104	83	75	68	66	79	77	76	83
32	STBAS				106	85							
33	TRIC1	100	101	102	100	96	97	98	97	101	101	95	94

Scenario 7 Enhanced (as % of Unimpaired) – Combined Reaches

No	Abbreviation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	AMSHI				104	91	91						
2	AMSHJL				104	90	89	87					
3	AMSHO				104	89	86	82	81	90	88		
4	AMSHS			105	103	94	95						
5	CCHUBA	112	109	106	119	125	122	119	116	112	110	113	127
6	CCHUBS			104	112	122	127	126					
7	CFSHA	110	103	103	116	121	109	113	118	112	117	122	142
8	CFSHS				101	105	98						
9	CHCFA	102	104	106	103	88	85	81	80	89	88	83	86
10	CHCFJ	102	103	106	103	92	92	91	90	97	96	89	89
11	CHCFS					87	83	79					
12	DF-Coarse	102	103	105	102	93	94	94	94	100	100	92	91
13	DF-Fine	102	103	106	103	91	90	88	87	94	93	87	88
14	DF-GrCob	103	104	107	105	89	86	81	78	88	85	81	86
15	DS-C	100	100	99	100	102	104	104	104	104	104	102	102
16	DS-GenC	101	102	103	101	93	92	93	94	100	100	93	92
17	DS-GenNC	102	104	106	103	93	95	93	90	97	93	89	90
18	EPHEM	101	100	99	101	104	106	108	107	108	107	104	104
19	GORHA	101	102	103	101	96	96	97	97	101	102	96	94
20	GORHJ					94	95	97					
21	PLECO	100	99	98	100	105	109	113	111	113	112	104	101
22	SF-HV	102	103	105	103	92	91	92	93	99	102	93	91
23	SF-LV	108	105	103	112	115	113	112	112	109	109	111	121
24	SF-MV	99	99	98	100	101	104	107	108	110	110	103	101
25	SS-Coarse	118	112	108	129	127	115	109	108	101	100	112	142
26	SS-Early	110	107	105	113	114	105	103	101	90	85	101	125
27	SS-FineNC	101	100	99	102	104	103	105	106	105	105	105	107
28	SS-Veg	102	101	100	103	105	104	105	105	104	104	105	108
29	SS-Wood	103	102	100	104	106	104	105	105	103	104	105	110
30	STBAI					89	86	82					
31	STBAJ	103	105	108	105	89	86	81	80	90	88	83	87
32	STBAS				105	89							
33	TRIC1	100	100	100	100	100	102	103	103	105	104	99	98

Legend: =>100% | =>80% | =>70% | =>60% | <60%

Guild Descriptions:

*SS = Shallow Slow; <= 2 ft deep and < 1ft/s velocity

*SF = Shallow Fast; <= 2 ft deep and > 1 ft/s velocity

*DS = Deep Slow; >= 2 ft deep and < 1 ft/s velocity

*DF = Deep Fast; >= 2 ft deep and > 1 ft/s velocity

TABLE 29
CAPE FEAR RIVER SCENARIO 9A HABITAT RESULTS

Cape Fear River - Final Habitat Results

Scenario 9a (Pump Regime #2; Variable A; 180 cfs Cap Year Round)

All Water Year Types - Sum of Area Under the Curve (AUC) 5% to 95%

Scenario 9a (as % of Unimpaired) Reach 1

No	Species/Lifestage	Guild* / Stand Alone	Abbreviation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	American Shad Incubation	Stand Alone	AMSHI				107	87	81						
2	American Shad Juvenile and Larval	Stand Alone	AMSHJL				105	89	85	82					
3	American Shad Outmigration	Stand Alone	AMSHO				106	86	79	73	74	83	82		
4	American Shad Spawning	Stand Alone	AMSHS			108	104	91	89						
5	Composite Chub Adult	Stand Alone	CCHUBA	108	111	107	119	125	128	134	131	133	133	119	123
6	Composite Chub Spawning	Stand Alone	CCHUBS			98	97	89	86	89					
7	Cape Fear Shiner Adult	Stand Alone	CFSHA	127	142	133	172	152	144	151	151	151	160	138	158
8	Cape Fear Shiner Spawning	Stand Alone	CFSHS				138	134	111						
9	Channel Catfish Adult	Stand Alone	CHCFA	105	106	109	106	90	86	83	84	93	92	86	88
10	Channel Catfish Juvenile	Stand Alone	CHCFJ	105	106	109	106	89	85	81	81	91	89	84	87
11	Channel Catfish Spawning	Stand Alone	CHCFS					88	84	80					
12	Shorthead Redhorse Adult	DF - Coarse Mix Sub	DF-Coarse	103	104	107	104	92	92	92	92	100	99	91	90
13	Silver Redhorse Adult	DF - Fine Sub	DF-Fine	104	106	109	106	89	85	82	82	92	91	85	88
14	White Bass Spawning	DF - Grav Sm Cob Sub	DF-GrCob	106	107	111	108	88	80	72	71	85	83	80	86
15	Redbreast Sunfish Adult	DS - Cover Redbreast	DS-C	99	99	98	99	102	104	107	107	109	109	104	101
16	Deep Slow Generic - Cover	DS - Generic Cover	DS-GenC	102	103	105	102	94	95	97	98	105	106	94	92
17	Deep Slow Generic - No Cover	DS - Generic No Cover	DS-GenNC	103	104	107	103	86	81	78	80	87	87	84	87
18	Ephemeroptera - Mayfly	EPT	EPHEM	100	99	98	101	104	108	112	111	114	113	105	103
19	Golden Redhorse Adult - Carolina Surrogate	Stand Alone	GORHA	102	103	104	102	96	97	98	98	103	104	96	94
20	Golden Redhorse Juvenile - Carolina Surrogate	Stand Alone	GORHJ					92	93	93					
21	Plecoptera - Stonefly	EPT	PLECO	98	99	98	99	104	111	119	116	124	120	102	97
22	Fantail Darter Adult	SF - High Velocity	SF-HV	105	106	110	107	87	79	71	72	83	82	80	86
23	Margined Madtom Adult	SF - Lower Velocity	SF-LV	111	111	107	122	126	125	128	126	126	128	120	129
24	Shallow Fast Guild	SF - Moderate Velocity	SF-MV	100	101	99	102	104	109	115	116	120	121	108	104
25	Shallow Slow Guild	SS - Coarse Sub	SS-Coarse	122	138	132	153	136	121	118	115	109	108	115	146
26	Bluehead Chub YOY	SS - Early Life Stage	SS-Early	102	100	98	105	116	104	84	74	60	49	78	113
27	Redbreast Sunfish Spawning	SS - Fine Sub No Cover	SS-FineNC	102	101	100	105	108	110	112	112	112	112	108	110
28	Silver Redhorse YOY - Surrogate for Notchlip	SS - Veg Cover	SS-Veg	102	101	99	105	109	107	106	105	103	102	105	111
29	Silver Redhorse YOY - Surrogate for Notchlip	SS - Wood Cover	SS-Wood	104	102	100	107	111	108	106	105	103	102	106	114
30	Striped Bass Incubation	Stand Alone	STBAI					88	80	72					
31	Striped Bass Juvenile	Stand Alone	STBAJ	106	107	110	108	87	79	71	71	84	82	80	86
32	Striped Bass Spawning	Stand Alone	STBAS				108	88							
33	Trichoptera 1 - Caddisfly	EPT	TRIC1	99	100	100	99	97	100	103	103	107	106	98	96

Scenario 9a (as % of Unimpaired) Reach 2

No	Species/Lifestage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	American Shad Incubation				100	95	98						
2	American Shad Juvenile and Larval				101	94	97	96					
3	American Shad Outmigration				102	92	95	93	91	99	96		
4	American Shad Spawning			102	100	97	100						
5	Composite Chub Adult	116	110	108	124	130	123	116	113	108	105	112	132
6	Composite Chub Spawning			110	124	135	136	132					
7	Cape Fear Shiner Adult	106	102	103	107	91	70	77	89	83	93	108	129
8	Cape Fear Shiner Spawning				97	92	89						
9	Channel Catfish Adult	100	102	104	101	91	94	91	88	95	90	86	87
10	Channel Catfish Juvenile	99	100	101	99	95	99	99	98	104	102	94	92
11	Channel Catfish Spawning					87	86	78					
12	Shorthead Redhorse Adult	101	102	103	101	94	95	96	95	101	101	93	92
13	Silver Redhorse Adult	99	100	101	99	96	102	101	96	103	97	91	90
14	White Bass Spawning	101	103	106	102	89	89	84	81	90	86	82	85
15	Redbreast Sunfish Adult	102	101	100	103	107	107	106	104	103	102	104	108
16	Deep Slow Generic - Cover	97	100	100	98	85	79	77	78	83	82	84	87
17	Deep Slow Generic - No Cover	101	102	101	105	118	127	124	111	121	108	101	100
18	Ephemeroptera - Mayfly	102	101	100	103	106	107	107	106	105	104	104	106
19	Golden Redhorse Adult - Carolina Surrogate	100	101	102	100	98	99	100	99	102	103	98	96
20	Golden Redhorse Juvenile - Carolina Surrogate					96	99	100					
21	Plecoptera - Stonefly	101	100	99	102	106	108	108	107	107	106	104	105
22	Fantail Darter Adult	101	102	104	102	92	92	93	94	100	103	94	92
23	Margined Madtom Adult	109	106	105	112	113	109	108	109	105	104	109	120
24	Shallow Fast Guild	100	99	98	100	101	104	107	107	109	110	103	100
25	Shallow Slow Guild	118	108	106	124	122	110	103	103	95	95	110	139
26	Bluehead Chub YOY	116	107	105	119	118	105	115	123	111	119	117	137
27	Redbreast Sunfish Spawning	102	100	99	102	102	98	99	102	98	101	105	110
28	Silver Redhorse YOY - Surrogate for Notchlip	102	100	99	102	104	102	104	105	103	105	105	108
29	Silver Redhorse YOY - Surrogate for Notchlip	102	101	100	103	104	102	104	105	103	105	105	108
30	Striped Bass Incubation					89	88	86					
31	Striped Bass Juvenile	101	102	105	102	91	92	91	89	98	95	88	88
32	Striped Bass Spawning				102	90							
33	Trichoptera 1 - Caddisfly	101	100	99	101	104	106	107	106	106	105	103	103

Scenario 9a (as % of Unimpaired) Reach 3

No	Species/Lifestage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	American Shad Incubation				102	84	79						
2	American Shad Juvenile and Larval				102	88	87	86					
3	American Shad Outmigration				102	85	81	78	76	86	85		
4	American Shad Spawning			103	100	91	91						
5	Composite Chub Adult	113	112	111	119	120	119	121	120	117	118	114	123
6	Composite Chub Spawning			107	109	114	121	128					
7	Cape Fear Shiner Adult	136	146	152	153	101	71	59	69	61	36	100	185
8	Cape Fear Shiner Spawning				109	96	93						
9	Channel Catfish Adult	101	102	105	102	85	81	77	76	85	85	81	84
10	Channel Catfish Juvenile	100	102	105	101	87	85	82	82	90	89	84	86
11	Channel Catfish Spawning					85	81	79					
12	Shorthead Redhorse Adult	100	102	104	101	92	91	91	91	96	96	90	90
13	Silver Redhorse Adult	100	102	104	101	88	87	86	85	92	91	86	87
14	White Bass Spawning	102	103	107	103	82	75	68	66	79	77	75	82
15	Redbreast Sunfish Adult	99	100	100	99	96	97	98	98	100	101	97	96
16	Deep Slow Generic - Cover	99	101	102	100	92	91	91	91	96	96	92	92
17	Deep Slow Generic - No Cover	98	98	98	97	96	100	100	98	102	100	95	94
18	Ephemeroptera - Mayfly	100	100	99	100	100	102	104	103	105	105	101	100
19	Golden Redhorse Adult - Carolina Surrogate	100	101	102	100	94	95	95	95	99	99	94	93
20	Golden Redhorse Juvenile - Carolina Surrogate					95	97	98					
21	Plecoptera - Stonefly	99	100	99	100	102	104	107	106	109	110	101	99
22	Fantail Darter Adult	109	104	104	111	116	117	122	128	125	136	120	122
23	Margined Madtom Adult	114	112	110	120	120	114	111	111	106	105	112	128
24	Shallow Fast Guild	115	117	116	124	122	120	124	124	118	121	114	126
25	Shallow Slow Guild	152	157	148	180	149	114	105	106	96	95	118	176
26	Bluehead Chub YOY	117	125	125	126	115	109	106	104	103	100	109	125
27	Redbreast Sunfish Spawning	101	101	100	102	102	102	104	104	104	104	103	104
28	Silver Redhorse YOY - Surrogate for Notchlip	105	105	105	106	104	104	105	106	106	105	105	108
29	Silver Redhorse YOY - Surrogate for Notchlip	106	106	106	108	105	104	104	105	105	104	105	110
30	Striped Bass Incubation					84	76	69					
31	Striped Bass Juvenile	102	103	107	103	82	74	67	66	79	77	75	82
32	Striped Bass Spawning				105	83							
33	Trichoptera 1 - Caddisfly	100	101	102	100	96	97	98	98	101	101	95	94

Scenario 9a (as % of Unimpaired) Combined Reaches

No	Species/Lifestage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	American Shad Incubation				103	91	91						
2	American Shad Juvenile and Larval				103	90	89	87					
3	American Shad Outmigration				104	88	85	82	81	90	88		
4	American Shad Spawning			105	103	94	95						
5	Composite Chub Adult	114	111	108	122	127	123	119	116	112	110	113	128
6	Composite Chub Spawning			106	115	124	128	127					
7	Cape Fear Shiner Adult	111	104	104	119	122	109	113	117	111	116	120	142
8	Cape Fear Shiner Spawning				101	105	98						
9	Channel Catfish Adult	102	103	106	103	87	84	81	80	89	87	83	86
10	Channel Catfish Juvenile	102	103	105	102	92	92	91	90	98	96	89	89
11	Channel Catfish Spawning					86	82	79					
12	Shorthead Redhorse Adult	101	103	105	102	93	94	94	94	100	100	92	91
13	Silver Redhorse Adult	102	103	106	103	90	90	88	87	95	93	86	88
14	White Bass Spawning	103	104	107	104	88	86	80	78	89	85	81	85
15	Redbreast Sunfish Adult	100	100	99	100	102	104	104	104	104	104	102	102
16	Deep Slow Generic - Cover	100	102	103	101	92	92	93	93	99	100	92	91
17	Deep Slow Generic - No Cover	102	104	106	103	93	95	93	91	98	94	89	90
18	Ephemeroptera - Mayfly	101	100	99	102	104	106	108	107	108	107	104	104
19	Golden Redhorse Adult - Carolina Surrogate	101	102	103	101	95	96	97	97	101	102	96	94
20	Golden Redhorse Juvenile - Carolina Surrogate					94	95	97					
21	Plecoptera - Stonefly	100	100	99	101	105	109	113	111	113	111	103	101
22	Fantail Darter Adult	102	103	105	102	92	91	92	92	99	101	93	91
23	Margined Madtom Adult	109	107	105	114	116	113	113	113	109	109	111	122
24	Shallow Fast Guild	100	100	99	100	102	104	108	108	110	111	103	101
25	Shallow Slow Guild	120	115	110	134	129	115	109	108	101	100	112	143
26	Bluehead Chub YOY	111	108	106	116	115	105	103	101	91	87	103	126
27	Redbreast Sunfish Spawning	102	101	100	102	104	103	105	106	104	105	105	107
28	Silver Redhorse YOY - Surrogate for Notchlip	103	102	101	104	105	104	105	105	104	104	105	109
29	Silver Redhorse YOY - Surrogate for Notchlip	104	102	101	105	106	105	105	105	103	104	106	110
30	Striped Bass Incubation					88	85	82					
31	Striped Bass Juvenile	103	105	108	105	89	86	81	80	91	88	83	86
32	Striped Bass Spawning				104	89							
33	Trichoptera 1 - Caddisfly	100	100	100	100	100	102	103	103	105	104	99	98

Legend: =>100% | =>80% | =>70% | =>60% | <60%

Guild Descriptions:

*SS = Shallow Slow; <= 2 ft deep and < 1ft/s velocity

*SF = Shallow Fast; <= 2 ft deep and > 1 ft/s velocity

*DS = Deep Slow; >= 2 ft deep and < 1 ft/s velocity

*DF = Deep Fast; >= 2 ft deep and > 1 ft/s velocity

TABLE 30
CAPE FEAR RIVER SCENARIO 9BD HABITAT RESULTS

Cape Fear River - Final Habitat Results

Scenario 9bd (Pump Regime #2; Variable A; 150 cfs Cap Jan - Apr; 30 cfs Cap May - Dec; Adjust twice/week)

All Water Year Types - Sum of Area Under the Curve (AUC) 5% to 95%

Scenario 9bd (as % of Unimpaired) – Reach 1

No	Species/Lifestage	Guild* / Stand Alone	Abbreviation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	American Shad Incubation	Stand Alone	AMSHI				107	87	81						
2	American Shad Juvenile and Larval	Stand Alone	AMSHJL				105	89	85	82					
3	American Shad Outmigration	Stand Alone	AMSHO				106	86	79	73	73	83	82		
4	American Shad Spawning	Stand Alone	AMSHS			108	105	91	90						
5	Composite Chub Adult	Stand Alone	CCHUBA	107	110	106	119	125	128	134	132	133	132	118	122
6	Composite Chub Spawning	Stand Alone	CCHUBS			98	97	89	87	90					
7	Cape Fear Shiner Adult	Stand Alone	CFSHA	126	139	130	172	151	143	151	152	150	160	137	158
8	Cape Fear Shiner Spawning	Stand Alone	CFSHS				137	134	111						
9	Channel Catfish Adult	Stand Alone	CHCFA	105	106	109	106	89	86	83	83	93	92	86	88
10	Channel Catfish Juvenile	Stand Alone	CHCFJ	105	106	109	106	89	85	81	80	91	89	84	87
11	Channel Catfish Spawning	Stand Alone	CHCFS					88	84	80					
12	Shorthead Redhorse Adult	DF - Coarse Mix Sub	DF-Coarse	104	105	107	104	92	92	92	92	100	99	91	90
13	Silver Redhorse Adult	DF - Fine Sub	DF-Fine	105	106	109	106	89	85	82	82	92	91	85	87
14	White Bass Spawning	DF - Grav Sm Cob Sub	DF-GrCob	106	107	111	108	88	80	72	70	84	83	80	86
15	Redbreast Sunfish Adult	DS - Cover Redbreast	DS-C	99	99	97	99	102	104	107	107	109	109	104	101
16	Deep Slow Generic - Cover	DS - Generic Cover	DS-GenC	102	103	105	102	94	95	97	98	106	106	94	92
17	Deep Slow Generic - No Cover	DS - Generic No Cover	DS-GenNC	103	104	107	103	86	81	78	79	87	87	84	87
18	Ephemeroptera - Mayfly	EPT	EPHEM	99	99	98	101	104	108	112	111	114	113	105	103
19	Golden Redhorse Adult - Carolina Surrogate	Stand Alone	GORHA	102	103	104	102	96	97	98	98	103	104	96	94
20	Golden Redhorse Juvenile - Carolina Surrogate	Stand Alone	GORHJ					92	93	93					
21	Plecoptera - Stonefly	EPT	PLECO	98	99	98	99	104	111	119	116	124	120	102	97
22	Fantail Darter Adult	SF - High Velocity	SF-HV	106	106	110	107	86	79	71	71	82	82	80	86
23	Margined Madtom Adult	SF - Lower Velocity	SF-LV	110	110	106	122	126	125	128	126	126	128	120	129
24	Shallow Fast Guild	SF - Moderate Velocity	SF-MV	100	100	99	102	104	109	115	116	120	121	108	104
25	Shallow Slow Guild	SS - Coarse Sub	SS-Coarse	121	136	129	152	135	121	118	116	109	108	114	145
26	Bluehead Chub YOY	SS - Early Life Stage	SS-Early	102	100	98	105	116	104	85	74	60	49	78	113
27	Redbreast Sunfish Spawning	SS - Fine Sub No Cover	SS-FineNC	102	101	99	105	108	110	112	112	112	112	108	110
28	Silver Redhorse YOY - Surrogate for Notchlip	SS - Veg Cover	SS-Veg	102	100	99	105	109	107	106	105	103	102	105	111
29	Silver Redhorse YOY - Surrogate for Notchlip	SS - Wood Cover	SS-Wood	103	102	100	107	111	108	106	105	103	102	106	114
30	Striped Bass Incubation	Stand Alone	STBAI					88	80	72					
31	Striped Bass Juvenile	Stand Alone	STBAJ	106	107	111	108	87	79	71	70	83	82	79	86
32	Striped Bass Spawning	Stand Alone	STBAS				108	87							
33	Trichoptera 1 - Caddisfly	EPT	TRIC1	99	100	100	99	97	100	103	103	107	106	98	96

Scenario 9bd (as % of Unimpaired) – Reach 2

No	Abbreviation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	AMSHI				100	95	98						
2	AMSHJL				101	94	97	96					
3	AMSHO				101	92	95	93	91	99	96		
4	AMSHS			102	100	97	100						
5	CCHUBA	115	111	108	125	130	123	116	113	107	105	112	131
6	CCHUBS			110	125	133	136	131					
7	CFSHA	105	102	103	107	92	70	77	89	84	93	108	128
8	CFSHS				96	92	89						
9	CHCFA	100	102	104	100	91	94	91	88	95	90	86	88
10	CHCFJ	99	100	101	99	95	99	100	98	104	102	94	92
11	CHCFS					88	87	79					
12	DF-Coarse	101	102	103	101	94	95	96	95	101	101	94	92
13	DF-Fine	99	100	101	99	96	102	101	96	103	97	91	90
14	DF-GrCob	101	103	106	102	89	89	84	81	91	86	83	86
15	DS-C	102	101	100	103	107	107	105	104	103	102	104	107
16	DS-GenC	97	99	100	98	85	79	77	79	83	82	84	87
17	DS-GenNC	101	102	101	106	117	126	124	111	120	107	100	100
18	EPHEM	102	101	100	103	106	107	107	106	105	104	104	106
19	GORHA	100	101	102	100	98	99	100	100	102	103	98	96
20	GORHJ					96	99	100					
21	PLECO	101	100	100	102	106	108	108	107	107	106	104	105
22	SF-HV	101	102	104	101	93	92	93	94	100	103	94	92
23	SF-LV	109	106	105	113	113	109	108	108	104	104	109	120
24	SF-MV	100	99	99	100	101	104	107	107	109	110	103	100
25	SS-Coarse	117	109	106	125	122	110	102	102	95	95	109	139
26	SS-Early	115	107	105	120	118	105	115	123	112	119	117	136
27	SS-FineNC	102	100	99	102	102	98	99	102	99	101	105	110
28	SS-Veg	102	100	100	103	104	102	104	105	103	105	105	108
29	SS-Wood	102	101	100	103	104	102	104	105	103	105	105	108
30	STBAI					89	88	87					
31	STBAJ	101	102	105	101	91	93	91	90	98	95	88	88
32	STBAS				102	90							
33	TRIC1	101	100	99	101	104	106	106	105	106	104	103	103

Scenario 9bd (as % of Unimpaired) – Reach 3

No	Abbreviation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	AMSHI				102	84	79						
2	AMSHJL				101	89	87	86					
3	AMSHO				102	85	82	78	76	86	85		
4	AMSHS			103	100	91	91						
5	CCHUBA	112	112	111	120	120	119	121	120	117	118	114	122
6	CCHUBS			107	110	113	120	128					
7	CFSHA	133	146	158	158	104	71	58	68	61	36	100	185
8	CFSHS				109	97	93						
9	CHCFA	101	102	105	101	85	81	77	77	86	85	82	85
10	CHCFJ	101	102	105	101	87	85	83	82	90	89	84	86
11	CHCFS					85	82	79					
12	DF-Coarse	100	102	104	101	92	92	91	91	96	96	91	90
13	DF-Fine	101	102	104	101	89	87	86	85	92	92	86	87
14	DF-GrCob	102	103	106	103	83	75	68	67	79	77	76	83
15	DS-C	99	100	100	99	96	97	98	98	100	101	97	96
16	DS-GenC	99	101	102	99	92	91	91	91	96	96	92	92
17	DS-GenNC	98	98	98	97	96	100	100	98	102	100	95	94
18	EPHEM	100	100	99	100	100	102	104	103	105	105	101	100
19	GORHA	100	101	102	100	94	95	96	95	99	99	94	93
20	GORHJ					95	97	99					
21	PLECO	99	100	99	100	102	104	107	106	109	110	101	99
22	SF-HV	109	104	104	111	116	116	122	128	125	136	120	122
23	SF-LV	114	112	110	121	120	113	111	111	105	105	111	127
24	SF-MV	114	117	116	125	122	120	124	124	118	120	114	126
25	SS-Coarse	151	157	148	183	149	114	105	106	96	95	117	174
26	SS-Early	116	126	126	128	115	109	106	104	103	100	109	125
27	SS-FineNC	101	101	100	102	102	102	103	104	104	104	103	104
28	SS-Veg	105	105	105	107	104	103	105	106	106	105	104	108
29	SS-Wood	106	106	106	108	105	104	104	105	104	104	105	110
30	STBAI					84	76	69					
31	STBAJ	102	103	106	103	83	75	68	66	79	77	76	83
32	STBAS				105	84							
33	TRIC1	100	101	102	100	96	97	98	98	101	101	95	94

Scenario 9bd (as % of Unimpaired) – Combined Reaches

No	Abbreviation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	AMSHI				103	91	91						
2	AMSHJL				103	90	89	87					
3	AMSHO				104	88	86	82	81	90	88		
4	AMSHS			105	103	94	95						
5	CCHUBA	113	111	108	123	127	123	119	116	112	110	113	128
6	CCHUBS			106	115	123	128	127					
7	CFSHA	111	104	104	119	122	109	112	117	111	116	119	141
8	CFSHS				101	105	98						
9	CHCFA	102	103	106	103	87	84	81	80	89	88	83	86
10	CHCFJ	102	103	106	102	92	92	91	90	98	96	89	89
11	CHCFS					86	83	79					
12	DF-Coarse	102	103	105	102	93	94	94	94	100	100	92	91
13	DF-Fine	102	103	106	103	90	90	88	87	95	93	87	88
14	DF-GrCob	103	104	107	104	88	86	81	78	89	85	81	86
15	DS-C	100	100	99	100	102	104	104	104	104	104	102	102
16	DS-GenC	101	102	103	101	92	92	93	93	100	100	93	91
17	DS-GenNC	103	104	106	103	93	95	93	90	98	94	89	90
18	EPHEM	101	100	99	102	104	106	108	107	108	107	104	104
19	GORHA	101	102	103	101	96	96	97	97	101	102	96	94
20	GORHJ					94	95	97					
21	PLECO	100	100	99	101	105	109	113	111	113	111	103	101
22	SF-HV	102	103	105	102	92	91	92	93	99	101	93	91
23	SF-LV	109	107	105	114	116	113	112	112	109	109	111	122
24	SF-MV	100	100	99	100	102	104	108	108	110	111	103	101
25	SS-Coarse	119	115	110	135	128	115	109	108	101	100	112	143
26	SS-Early	111	108	106	116	115	105	102	101	91	86	103	125
27	SS-FineNC	102	101	100	102	104	103	105	106	104	105	105	107
28	SS-Veg	103	102	101	104	105	104	105	105	104	104	105	108
29	SS-Wood	103	102	101	105	106	104	105	105	103	104	106	110
30	STBAI					88	86	82					
31	STBAJ	104	105	108	105	89	86	81	80	90	88	83	87
32	STBAS				104	89							
33	TRIC1	100	100	100	100	100	102	103	103	105	104	99	98

=>100% =>80% =>70% =>60% <60%

Guild Descriptions:

*SS = Shallow Slow; <= 2 ft deep and < 1ft/s velocity

*SF = Shallow Fast; <= 2 ft deep and > 1 ft/s velocity

*DS = Deep Slow; >= 2 ft deep and < 1 ft/s velocity

*DF = Deep Fast; >= 2 ft deep and > 1 ft/s velocity

TABLE 31
CAPE FEAR RIVER SCENARIO 14BD HABITAT RESULTS

Cape Fear River - Final Habitat Results

Scenario 14bd (Pump Regime #3; Variable A; 150 cfs Cap Jan - Apr; 30 cfs Cap May - Dec; Adjust twice/week)

All Water Year Types - Sum of Area Under the Curve (AUC) 5% to 95%

No	Species/Lifestage	Guild* / Stand Alone	Abbreviation	Scenario 14bd (as % of Unimpaired) Reach 1											
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	American Shad Incubation	Stand Alone	AMSHI				107	87	81						
2	American Shad Juvenile and Larval	Stand Alone	AMSHJL				105	89	85	83					
3	American Shad Outmigration	Stand Alone	AMSHO				106	86	79	73	73	83	82		
4	American Shad Spawning	Stand Alone	AMSHS			108	105	91	90						
5	Composite Chub Adult	Stand Alone	CCHUBA	107	111	107	119	125	128	134	132	133	132	119	122
6	Composite Chub Spawning	Stand Alone	CCHUBS			98	98	91	88	91					
7	Cape Fear Shiner Adult	Stand Alone	CFSHA	122	137	135	166	150	143	151	151	150	159	136	155
8	Cape Fear Shiner Spawning	Stand Alone	CFSHS				129	131	110						
9	Channel Catfish Adult	Stand Alone	CHCFA	105	106	109	106	89	86	83	83	93	92	86	88
10	Channel Catfish Juvenile	Stand Alone	CHCFJ	105	106	109	106	89	85	81	80	91	89	84	87
11	Channel Catfish Spawning	Stand Alone	CHCFS					88	84	80					
12	Shorthead Redhorse Adult	DF - Coarse Mix Sub	DF-Coarse	103	105	107	104	92	92	92	92	100	99	91	91
13	Silver Redhorse Adult	DF - Fine Sub	DF-Fine	105	106	109	106	89	86	82	82	92	91	85	88
14	White Bass Spawning	DF - Grav Sm Cob Sub	DF-GrCob	106	107	111	108	87	80	72	70	84	82	80	86
15	Redbreast Sunfish Adult	DS - Cover Redbreast	DS-C	99	99	98	100	102	104	107	107	109	109	104	101
16	Deep Slow Generic - Cover	DS - Generic Cover	DS-GenC	102	103	105	102	94	95	98	98	106	106	94	92
17	Deep Slow Generic - No Cover	DS - Generic No Cover	DS-GenNC	103	104	107	103	86	81	78	80	88	87	84	87
18	Ephemeroptera - Mayfly	EPT	EPHEM	100	99	98	101	105	108	112	112	114	113	105	103
19	Golden Redhorse Adult - Carolina Surrogate	Stand Alone	GORHA	102	103	104	102	96	97	98	98	103	104	96	94
20	Golden Redhorse Juvenile - Carolina Surrogate	Stand Alone	GORHJ					93	93	94					
21	Plecoptera - Stonefly	EPT	PLECO	99	99	98	100	104	111	120	117	125	121	103	98
22	Fantail Darter Adult	SF - High Velocity	SF-HV	105	106	110	107	86	78	71	71	82	82	80	86
23	Margined Madtom Adult	SF - Lower Velocity	SF-LV	109	110	107	121	125	124	127	126	125	128	119	128
24	Shallow Fast Guild	SF - Moderate Velocity	SF-MV	100	101	99	102	105	109	116	116	120	121	108	105
25	Shallow Slow Guild	SS - Coarse Sub	SS-Coarse	119	135	134	149	134	121	118	115	109	108	113	143
26	Bluehead Chub YOY	SS - Early Life Stage	SS-Early	101	100	98	105	116	103	84	74	60	49	78	112
27	Redbreast Sunfish Spawning	SS - Fine Sub No Cover	SS-FineNC	102	101	100	105	108	110	112	112	112	112	108	110
28	Silver Redhorse YOY - Surrogate for Notchlip	SS - Veg Cover	SS-Veg	102	101	99	105	109	107	106	105	103	102	105	111
29	Silver Redhorse YOY - Surrogate for Notchlip	SS - Wood Cover	SS-Wood	103	102	100	107	111	108	106	105	103	102	106	114
30	Striped Bass Incubation	Stand Alone	STBAI					88	80	72					
31	Striped Bass Juvenile	Stand Alone	STBAJ	106	107	110	108	87	79	71	70	84	82	79	86
32	Striped Bass Spawning	Stand Alone	STBAS				108	87							
33	Trichoptera 1 - Caddisfly	EPT	TRIC1	100	100	100	99	98	100	103	103	107	106	98	96

No	Abbreviation	Scenario 14bd (as % of Unimpaired) Reach 2											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	AMSHI				100	95	98						
2	AMSHJL				101	94	97	96					
3	AMSHO				101	93	95	94	91	99	96		
4	AMSHS			102	100	97	100						
5	CCHUBA	114	111	108	124	129	123	116	112	107	105	111	130
6	CCHUBS			111	125	134	136	131					
7	CFSHA	105	102	103	105	90	69	76	88	83	93	107	126
8	CFSHS				97	92	89						
9	CHCFA	100	102	104	100	92	95	92	88	96	91	87	88
10	CHCFJ	99	100	101	99	95	99	100	98	104	103	95	93
11	CHCFS					88	87	79					
12	DF-Coarse	101	102	103	101	94	96	96	96	101	101	94	92
13	DF-Fine	99	100	101	99	96	102	101	97	103	97	92	91
14	DF-GrCob	101	103	105	102	89	89	85	82	91	87	83	86
15	DS-C	102	101	100	103	107	106	105	104	103	102	104	107
16	DS-GenC	98	99	100	98	86	80	78	80	84	83	85	88
17	DS-GenNC	101	102	101	106	118	126	125	112	121	108	101	101
18	EPHEM	102	101	100	103	106	107	107	106	105	104	104	106
19	GORHA	100	101	101	100	98	99	100	100	102	103	98	97
20	GORHJ					96	99	100					
21	PLECO	101	101	100	103	106	108	108	107	107	106	104	105
22	SF-HV	101	102	104	101	93	92	94	94	100	103	94	92
23	SF-LV	108	106	105	112	113	109	108	108	104	104	108	119
24	SF-MV	100	100	99	100	101	104	107	107	109	110	103	100
25	SS-Coarse	115	108	107	123	121	109	102	102	94	94	108	137
26	SS-Early	113	107	106	119	117	105	114	122	111	118	116	134
27	SS-FineNC	102	100	99	102	102	97	99	102	98	101	105	109
28	SS-Veg	102	101	100	103	104	102	104	105	103	105	105	108
29	SS-Wood	102	101	100	103	104	102	104	105	103	105	105	108
30	STBAI					89	88	87					
31	STBAJ	101	102	105	101	91	93	92	90	98	96	88	89
32	STBAS				102	90							
33	TRIC1	101	100	99	102	104	106	107	106	106	105	103	103

No	Abbreviation	Scenario 14bd (as % of Unimpaired) Reach 3											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	AMSHI				102	84	80						
2	AMSHJL				101	89	88	86					
3	AMSHO				102	85	82	78	77	87	85		
4	AMSHS			103	100	91	91						
5	CCHUBA	112	112	112	120	120	119	121	120	117	118	113	122
6	CCHUBS			108	111	114	120	129					
7	CFSHA	134	148	161	153	104	71	58	68	60	36	100	183
8	CFSHS				109	96	93						
9	CHCFA	101	102	105	101	85	81	78	77	86	85	82	85
10	CHCFJ	101	102	105	101	87	85	83	82	90	89	84	86
11	CHCFS					85	82	79					
12	DF-Coarse	100	102	103	101	92	92	92	91	96	96	91	90
13	DF-Fine	101	102	104	101	89	87	86	85	92	92	86	87
14	DF-GrCob	102	103	106	103	83	75	69	67	79	77	76	83
15	DS-C	99	100	100	99	97	97	98	98	100	101	97	96
16	DS-GenC	99	101	102	99	92	92	91	92	97	96	93	92
17	DS-GenNC	98	98	98	97	96	100	100	98	102	100	95	94
18	EPHEM	100	100	99	100	100	102	104	103	105	105	101	100
19	GORHA	100	101	102	100	94	95	96	95	99	99	94	93
20	GORHJ					95	97	99					
21	PLECO	99	100	99	100	102	104	107	106	109	110	101	99
22	SF-HV	108	105	105	110	115	116	122	128	125	136	119	121
23	SF-LV	113	112	111	120	120	113	111	110	105	105	111	126
24	SF-MV	114	117	117	125	122	120	123	124	118	120	114	125
25	SS-Coarse	147	158	151	175	146	114	104	105	95	95	116	170
26	SS-Early	116	126	127	128	115	109	106	104	103	100	109	125
27	SS-FineNC	101	101	100	102	102	102	103	104	104	104	103	104
28	SS-Veg	105	106	106	107	104	104	105	106	106	105	105	108
29	SS-Wood	106	106	106	108	105	104	104	105	105	104	105	110
30	STBAI					84	76	69					
31	STBAJ	102	103	106	103	83	75	68	66	79	77	76	83
32	STBAS				105	84							
33	TRIC1	100	101	101	100	96	97	99	98	101	101	95	94

No	Abbreviation	Scenario 14bd (as % of Unimpaired) Combined Reaches											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	AMSHI				103	91	91						
2	AMSHJL				103	90	89	88					
3	AMSHO				104	88	86	82	81	90	88		
4	AMSHS			105	103	94	95						
5	CCHUBA	112	111	109	122	126	122	119	116	112	110	113	127
6	CCHUBS			107	116	124	128	127					
7	CFSHA	110	104	104	117	121	108	112	116	110	115	118	138
8	CFSHS				100	105	98						
9	CHCFA	102	103	106	103	87	85	81	80	89	88	83	86
10	CHCFJ	102	103	105	102	92	92	91	90	98	97	90	89
11	CHCFS					86	83	80					
12	DF-Coarse	102	103	105	102	93	94	94	94	100	100	93	91
13	DF-Fine	102	103	106	102	90	90	89	87	95	93	87	88
14	DF-GrCob	103	104	107	104	88	86	81	79	89	85	82	86
15	DS-C	100	100	99	101	102	104	104	104	104	104	102	102
16	DS-GenC	101	102	103	101	93	93	93	94	100	100	93	92
17	DS-GenNC	103	104	106	103	93	95	93	91	98	94	89	90
18	EPHEM	101	100	99	102	105	106	108	107	108	107	104	104
19	GORHA	101	102	103	101	96	97	98	97	101	102	96	94
20	GORHJ					94	95	97					
21	PLECO	100	100	99	101	105	109	113	111	113	112	104	101
22	SF-HV	102	103	105	102	92	91	92	93	99	101	93	91
23	SF-LV	108	107	106	114	116	113	112	112	109	109	111	121
24	SF-MV	100	100	99	100	102	104	108	108	110	111	103	101
25	SS-Coarse	117	115	112	132	127	115	109	107	100	100	111	141
26	SS-Early	110	108	107	116	114	105	102	101	90	86	102	124
27	SS-FineNC	102	101	100	102	104	103	105	106	104	105	105	107
28	SS-Veg	103	102	101	104	105	104	104	105	104	104	105	108
29	SS-Wood	103	102	102	105	106	104	105	105	103	104	105	110
30	STBAI					89	86	83					
31	STBAJ	104	105	108	105	89	86	82	80	91	89	84	87
32	STBAS				104	89							
33	TRIC1	100	100	100	100	100	102	104	103	105	104	100	98

Legend: =>100% | =>80% | =>70% | =>60% | <60%

Guild Descriptions:

*SS = Shallow Slow; <= 2 ft deep and < 1ft/s velocity

*SF = Shallow Fast; <= 2 ft deep and > 1 ft/s velocity

*DS = Deep Slow; >= 2 ft deep and < 1 ft/s velocity

*DF = Deep Fast; >= 2 ft deep and > 1 ft/s velocity

7.3.3 Cape Fear River Reach 0 Wetted Perimeter Study

A wetted perimeter analysis was developed for the Cape Fear River Reach 0 study area to determine what flow rate is needed in the Cape Fear River to overtop the gravel/cobble bar (located at the top end of the reach) and provide flow into this 1,000 ft long reach. Reach 0 represents approximately 9% of the combined side channel total based on length (1,000 ft / 10,900 ft). The study methodology, transect details, and results are provided in Appendix F.

In summary, a flow rate of approximately 626 cfs is needed to overtop the gravel/cobble bar. Under the current regulated hydrology conditions, flows are at or above 626 cfs approximately 79% of the time March through June which represents the spawning period for most of the migratory species analyzed in the instream flow study, as well as most of the resident fish species occurring in the area. Depths and velocities in Reach 0 resulting from mainstem flows just over 626 cfs (i.e., overtopping flows) may not be suitable for spawning requirements of larger fish species (e.g., striped bass and American shad); however, smaller stream fish like native minnow and darter species could potentially utilize these habitats.

At river flows less than 626 cfs, fish utilization of Reach 0 likely occurs only in the lower section of the reach where water backs up from the mainstem of the Cape Fear River. Habitats available during these lower flow conditions would primarily be low- or no-flow, stagnant backwater conditions. The percent of time flows are at or above 626 cfs during the summer/fall low-flow periods is much lower than the spring, but is at least 32% of the time.

Section 8
Recommendation

The recommended flow regime for Buckhorn Creek is Scenario 6-7e. To support this flow release pattern and also maintain Harris Reservoir elevations, water must periodically be withdrawn from the Cape Fear River. Originally, Scenario 6-7e was based on Pumping Regime #2 (Table 20). At the October 13, 2011, workshop, the study team discussed a couple of modifications (Pumping Regime A and Pumping Regime B) to Pumping Regime #2 that would further limit withdrawals from the Cape Fear River. Both of these options are described in more detail below and also in Table 32.

The first modification (Pumping Regime A) would limit withdrawals during the March through May period when anadromous fish spawning is likely to occur in the Cape Fear River. Pumping Regime A, like Pumping Regime #2, still has a built-in 600 cfs withdrawal floor. From June through February, the pumping thresholds are also the same as Pumping Regime #2. However, from March through May, pumping would be limited to 10% of the total Cape Fear River flow.

The second modification (Pumping Regime B) would raise the year-round withdrawal floor from 600 cfs to 700 cfs. As a result, the pumping thresholds set to control start-up of additional pumps would be higher than Pumping Regime #2 and Pumping Regime A (June through February). Raising the overall withdrawal threshold from 600 cfs to 700 cfs provides an extra 100 cfs buffer that would support aquatic habitat in the Cape Fear River and also support downstream water users by withdrawing less during low flow conditions.

Neither of these pumping regime options would alter the Scenario 6-7e Buckhorn Creek flow releases. The effect on Cape Fear River aquatic habitat would either be neutral or positive as a higher percentage of flow would remain in the river during lower flow conditions. Effects on Harris Reservoir elevations would likely be minimal for either pumping option when compared to the original Pumping Regime #2. As a result, the recommended flow regime is Scenario 6-7e with either Pumping Regime A or Pumping Regime B.

TABLE 32
CAPE FEAR RIVER PUMPING REGIME OPTIONS

Withdrawal Capacity (cfs)	Cape Fear River Flow Threshold June – February[1] (cfs)	Percent of Flow Withdrawn June – February[1] (%)	Remaining Flow in River June – February[1] (cfs)	Cape Fear River Flow Threshold March - May (cfs)	Percent of Flow Withdrawn March - May (%)	Remaining Flow in River March - May (cfs)
Pumping Regime A – 600 cfs floor						
45	645	7	600	645	7	600
90	690	13	600	900	10	810
135	735	18	600	1,350	10	1,215
180	780	23	600	1,800	10	1,620
Pumping Regime B – 700 cfs floor						
45	745	6	700	N/A	N/A	N/A
90	845	11	755	N/A	N/A	N/A
135	945	14	810	N/A	N/A	N/A
180	1,000	18	820	N/A	N/A	N/A

Notes:

1. For Pumping Regime B, the withdrawal thresholds are year-round.

Section 9
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APPENDICES